MONITORING OF LAND USE IN THE MAJOR GRAIN CROP PRODUCTION AREA USING TEMPORAL CHARACTERISTICS OF NDVI OBTAINED FROM COARSE RESOLUTION SATELLITE DATA

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ABSTRACT:

NDVI obtained from satellite at the pixel over the area of crop cultivation would represent a specific temporal profile, which could be discriminated from that of other land use. In this study, the author attempted to estimate the acreage of winter wheat sown area using multitemporal NDVI obtained from NOAA-AVHRR data. The study site was selected in the Huang-Huai-Hai plain in China, where the most popular cropping pattern was double cropping of winter wheat and maize. First, the author examined a linear unmixing method, of which the value of NDVI at pixel was assumed as a composition of end-member values of NDVI in proportion to land use components. This method could be adopted if there was a high spatial resolution data taken in the appropriate period to estimate end-member values, and could be applied to the area where cropping season was almost resonant in the wide area. Secondly, he examined a relation of the ratio of winter wheat sown area in a pixel from the values of 2-temporal NDVI, which could show the relation with the components of land use. Estimated acreage by the either method showed a compatible spatial distribution with the acreage obtained from LANDSAT-ETM+ data. The advantageous point of the second method was that it would not require a high spatial resolution data for each year, supposed that the consistent parameters were adopted. By applying this method, the author could characterize the recent changes of winter wheat sown area in the northern part of the Huang-Huai-Hai plain.

1. INTRODUCTION

1.1 Background

Satellite remote sensing has been expected as an efficient technology to monitor of agricultural land use, which could be changed depending on the various factors, for a wide area. Especially it should be useful for the area where the accurate statistics data was hardly obtained. Multi-spectral and adequately high spatial resolution sensor data showed enough capability to discriminate the sown area of major crops, however, the timing of obtaining good quality data for this sensor was not optimized to detect the coverage of a specific crop. On the other hand, the spatial resolution of high temporal resolution sensor data was coarse compared with the unit of lot size and the pixel-based classification of it might cause false estimation of acreage of each land use type.

Many researches were implemented to resolve the components within a pixel. They often employed the assumption that the spectral characteristics of pixel were represented by a linear combination of end-member spectral values of each pure component. This unmixing technique could be effective for the case when each end-member values showed physically distinctive characteristics. But for the case of agricultural land use discrimination, the category defined by the crop type might be confused with other categories containing vegetation cover. From this context, the analysis of temporal pattern of the specific index such as NDVI, which shows the distinctive characteristics by land use types, may have a kind of possibility to estimate the percentage of sown area of the specific crop in a pixel.

1.2 Objectives

The objectives were firstly to develop a method to estimate the percentage of sown area of the major crop in a pixel of coarse resolution satellite data, and secondly to characterize the spatial and temporal features of cultivation of the major crop estimated by the method developed in this study. The author examined the temporal profile of NDVI to develop a method and applied it to estimate the winter wheat sown area in the major crop production area of China.

2. MATERIALS AND METHOD

2.1 Data

The author obtained the 10-day maximum composite NDVI of NOAA-AVHRR for the period from 1994 to 2003 provided by SIDaB (Satellite Image Database System), which is operated by the Research Information Center, Ministry of Agriculture, Forestry and Fisheries of the government of Japan. He also collected 3 scenes of LANDSAT-ETM+ data (Path: 123, Row: 32-34) taken on 19 May, 2001.

2.2 Study Site

The Huang-Huai-Hai plain is located in the eastern part of China and selected as the study site (Figure 1). The dominant cropping pattern in this area is winter wheat and maize in summer, so that winter wheat is popularly cultivated except in the urban areas as well the mountainous areas. Winter wheat is generally seeded in October, flowered in May and harvested in June. Although the distance from the south to the north of plain reaches about 1,000 km, the time difference of harvest would be as small as 3 weeks.

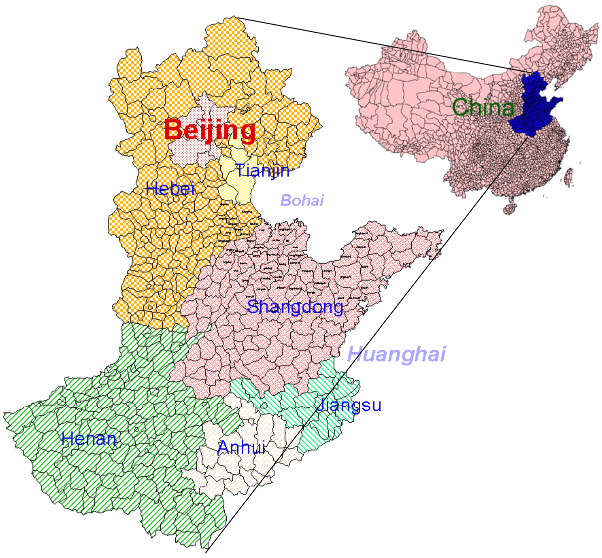

Figure 1. Location of Huang-Huai-Hai plain in China

2.3 Method

2.3.1 Linear Unmixing: The basic assumption of the method lies on linear mixture modelling of NDVI as a function of time *t* expressed in the followings (Uchida, 2001).

$$NDVI(t) = \sum_{i=1}^{n} \rho_i NDVI_i(t) \quad (1)$$

where ρ_i = probability density of land use item *i* in the pixel in the condition of $\sum_{i=1}^{n} \rho_i = 1$

This formula can be solved if (n-1) temporal data are given. This method is supposed to be applied to NOAA/AVHRR data. From the theoretical point of view, temporal changes of NDVI for each land use cannot be uniquely defined due to not only atmospheric effects on radiometric characteristics but also growing conditions affected by various environmental factors. The end-member of $NDVI_i(t)$, which is the value at the pixel wholly occupied by land use item *i* when time is *t*, can be estimated by combining with land use information extracted from LANDSAT-ETM+ data. In this study it is assumed that the end-member value, which is obtained at specific site, can be used for other sites where physical and land use conditions are similar.

In order to obtain end-member value of NDVI for each land use, first LANDSAT-ETM+ data was classified by maximum likelihood method and converted to probability density value of objective land use within 33 by 33 pixels window. The author drew a linear regression line in the figure of probability density against NDVI of NOAA/AVHRR at the same location, and extrapolated it to the value of one of probability density. When a linear mixture modeling formula is solved, negative value of probability density may come to appear. This is treated by addition of values so as to be zero for the minimum probability density of land use items and thereafter by scaling to become one as summation of total probability density.

2.3.2 2-temporal Scattergram: This method was based on the feature that NDVI of winter wheat showed a maximum at its flowering stage in May and considerably low value after harvesting in June. In consideration with this feature the value of NDVI in the middle of May was allocated in X axis and the value in the middle of June in Y axis. This temporal feature of NDVI represented in the scattergram could be discriminative from the patterns of other land use types and also might bring a formula of estimation of winter wheat sown area. The advantageous point of this method is that no higher spatial resolution data would be required, if the formula is once set up and applied commonly to the case of different years.

3. RESULTS AND DISCUSSION

Figure 2 shows the color composite image of 10-day maximum composite NDVI, which is assigned the value in the mid-April in 2001 as blue, mid-May as green and mid-June as red. This figure indicates that the parts represented by resembling color tone should have a similar temporal feature of NDVI during the period from April to June. It is possible, therefore, to classify the Huang-Huai-Hai plain into 2 areas, i.e. the northern part and the southern part, in terms of temporal changes of NDVI. This suggests that the common parameters would be employed in the estimation method for either classified area, respectively. In this study the author picked up the northern part, where the cropping pattern would be less complicated, for the examination of adoptability of estimation methods. 7 counties represented by the capital in the figure were the sites used to estimate end-member values as well as to verify the estimation results. These counties were Shunyi (S) in Beijing Capital Area, Xushui (X), Dacheng (D), Wuyi (W) and Feixing (F) in Hebei Province, and Yandxin (Y) and Gaotang (G) in Shanding Province.

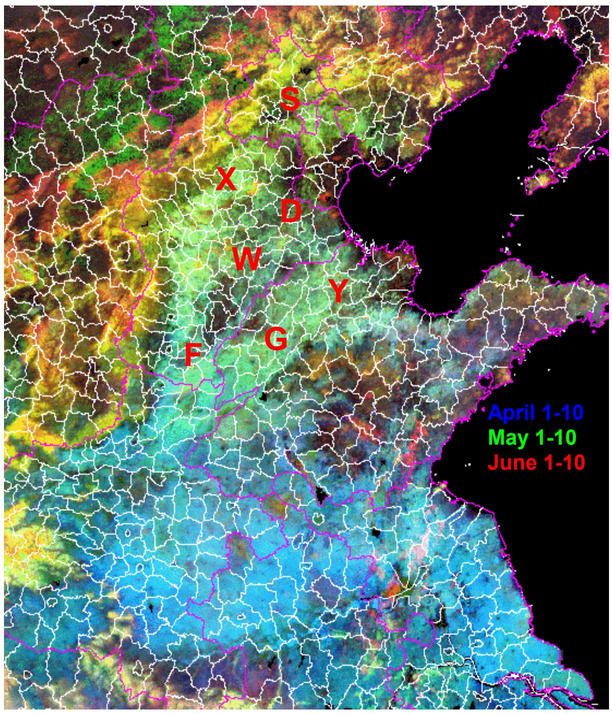

Figure 2. Color composite image of 3-temporal NDVI overlaid by indication of location of 7 counties used in the analysis

The author classified LANDSAT-ETM+ data covering the northern part of Huang-Huai-Hai plain, and identified 4 major categories, which were winter wheat, mixed vegetation, bare land and forest, in consideration with the temporal characteristics of NDVI in the spring season. The NDVI values over winter wheat showed the distinctive maximum in the first-May and the sharp decrease after the time of maximum. Mixed vegetation was a category comprised with rural settlements, vegetable fields, bushes, miscellaneous grasses and small trees, and its NDVI recorded the lower values than winter wheat before May and the higher in June. The NDVI values over bare land were the constantly lowest among the categories. The category of forest showed the increasing tendency of NDVI in the spring season and the level in June was higher than that of mixed vegetation. From the practical point of view, the author excluded forest and employed 3 categories for the further examination, because forest area having a considerable acreage was appeared only in a small part of the plain.

End-member values of NDVI of specific land use estimated by the method mentioned above might not be fit each other among counties. One of the causes could be the heterogeneous distribution of atmospheric effect on the value of digital data. Accuracy of geometric correction would be another cause because the pixel value was sensitive to the components of land use, which might be considerably modified by the slight gap of location. Actually end-member values of winter wheat calculated for 7 counties show similar temporal profile but difference of the values in some cases (Figure 3). Therefore, the author employed the averaged values to estimate winter wheat sown area in this study.

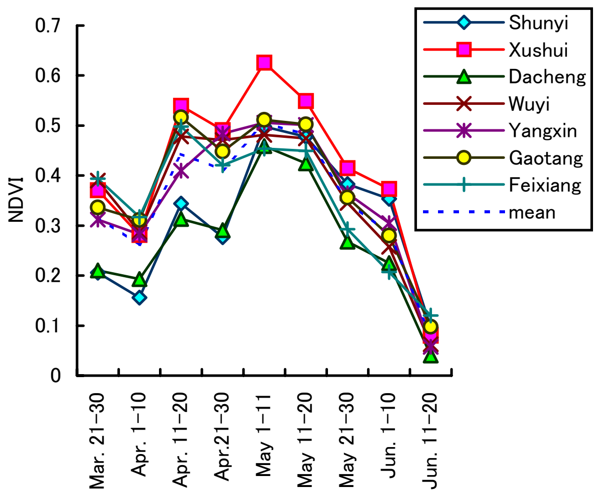

Figure 3. Comparison of temporal change of end-member values of winter wheat

A constraint in the first method exists in the condition that it could require end-member values, which were obtained by the combination of the high spatial resolution data. This condition may not be satisfied for the wide area in the appropriate season of sequential years. The second method had an intention to mitigate this constraint. Figure 4 depicts the relation between 2-temporal values of NDVI at mid-May and mid-June and the probability density of land use in a pixel for the case of Shunyi county, where a larger circle indicates the higher probability density, e.g. the largest one is 95% followed by 85%, 75%, so on. This figure evidently shows the feature that the position would approach to the vertex of a triangle for the type of winter wheat, bare land and forest according to the increase of probability density.

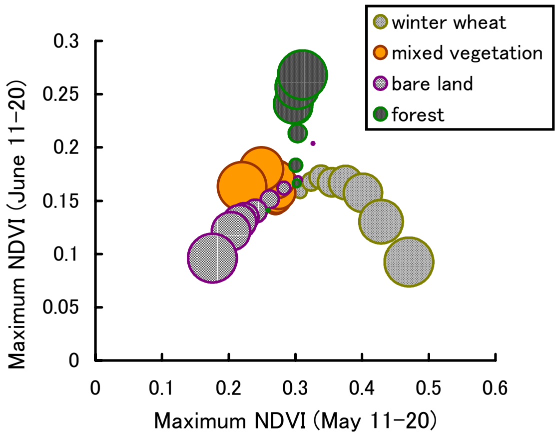

Figure 4. Relation between 2-temporal NDVI and the probability density of land use

Figure 5 shows the values of winter wheat for 7 counties. It is recognized that there is a common point, to which all the values approach in accordance with the increase of probability density. This could induce a schematic diagram as described in Figure 6.

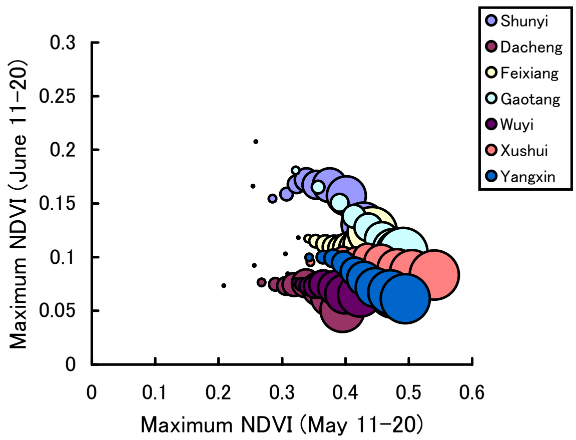

Figure 5. Comparison of allocation by the probability density of winter wheat sown area

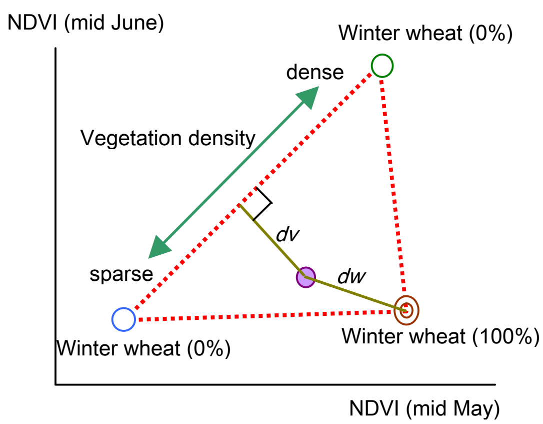

Figure 6. Schematic diagram of relation between winter wheat percentage and 2-temporal NDVI

Here, the author introduced a modified distance (***D***) from the line connecting two vertices, where the probability density of winter wheat was presumed as 0 %.

$$D = \frac{dv}{dv + dw} \tag{2}$$

The author examined the relationship between D and the percentage of winter wheat sown area in a pixel. As he plotted the data on graph, the distribution pattern tended to align along the line of logistic function. Then, he discovered a relationship expressed by a logistic formula shown in Equation (3). The parameters used in Equation (3) were given in the case of 2001 and its coefficient of determination (R^2) was 0.8006.

$$P(\%) = \frac{100}{1 + 89.1928 \exp(-9.024D)} \tag{3}$$

Figure 7 shows the estimated distribution of winter wheat sown area in and around Gaotang county for the case of 2001. Figure 7(a) represents the calculated probability density of winter wheat sown area obtained from LANDSAT-ETM+ data within 33 by 33 pixels window. Figure 7(b) represents the result of a linear unmixing method, where the value indicates the average of estimation for 4 combinations of NDVI data, i.e. May 1-10 and June 1-10, May 1-10 and June 11-20, May 11-20 and June 1-10, and May 11-20 and June 11-20. This process was aimed at the reduction of estimation error due to the spatial heterogeneity of influence of atmospheric condition on 10-day composite NDVI data. Figure 7(c) represents the result of application of the logistic function shown in (3). This figure describes that the patterns of distribution of high and low percentage areas are generally reproduced by either method. However, by examination of the result at pixel level, the estimated values would not be properly expressed at the parts of medium level of percentage especially for the method using logistic function. This could be mainly caused by the result of geometric correction, which remained some tolerance of registration of geographic location of pixel.

Even though the estimated values involve small errors in terms of percentage of acreage in a pixel, it would be useful to obtain the distribution of winter wheat sown area at an appropriate spatial unit in the wide range. Figure 8 shows the comparison of percentage area of winter wheat sown area aggregated by county as a unit. The estimated values by the method applying linear unmixing indicates the higher correlation with the values obtained from LANDSAT-ETM+ data. The values by the other method also shows considerably good correlation, so that the estimated values by either method would be accepted to apply to analyze the characteristics of temporal changes of the winter wheat in the Huang-Huai-Hai plain.

Because the author could not collect the high spatial resolution data for every year, the method using logistic function was selected to analyze the change of winter wheat sown area. Figure 9 shows the results of estimation. He noticed that the fluctuations with large amplitude were figured for all the counties before 1997. Contrastively the systematic patterns of change were recorded after 1998. This feature was presumably caused by the problem of pre-processing of the original dataset and not by the defect of the estimation method. Then, the estimated values after 1998 could be used to analyze temporal characteristics of winter wheat sown area.

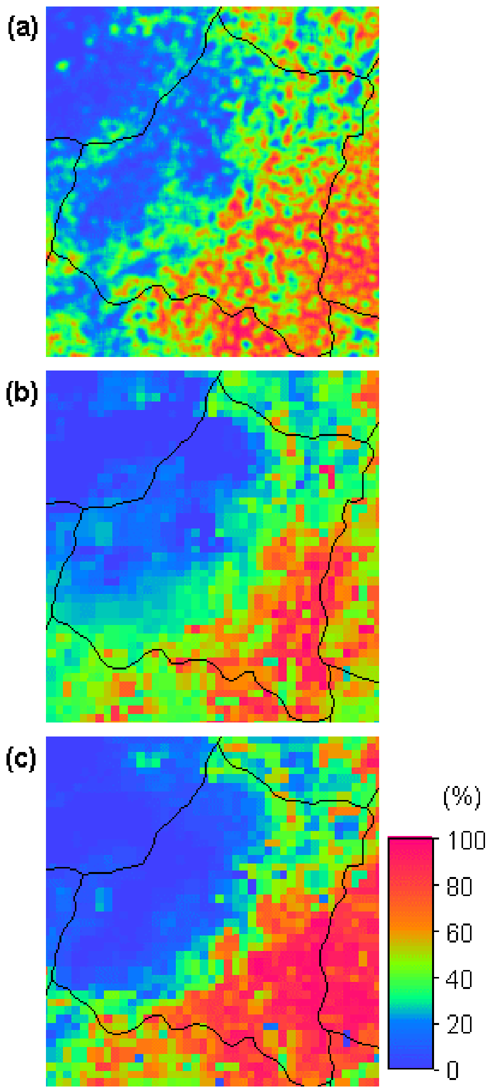

Figure 7. Comparison between methods to estimate winter wheat sown area in and around Gaotang county ((a) LANDSAT-ETM+, (b) linear unmixing, (c) logistic on 2-temporal scattergram)

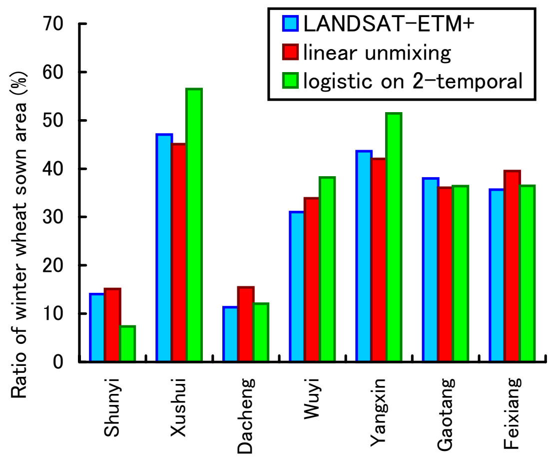

Figure 8. Comparison of percentage area of winter wheat by county among different estimation methods

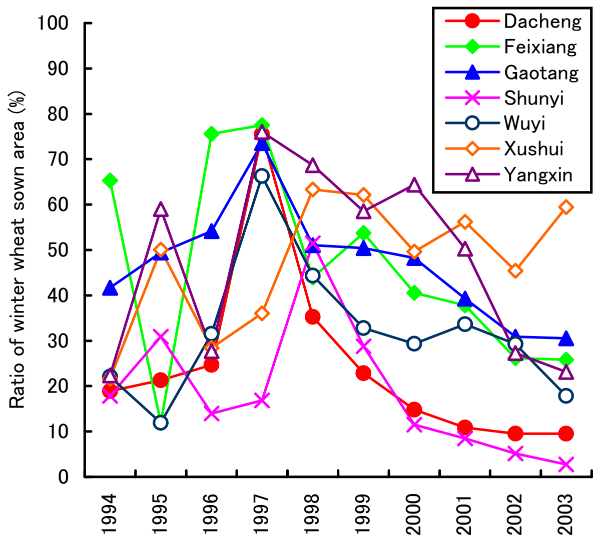

Figure 9. Temporal change of the ratio of winter wheat sown area for 7 counties estimated by the method using logistic function on 2-temporal scattergram

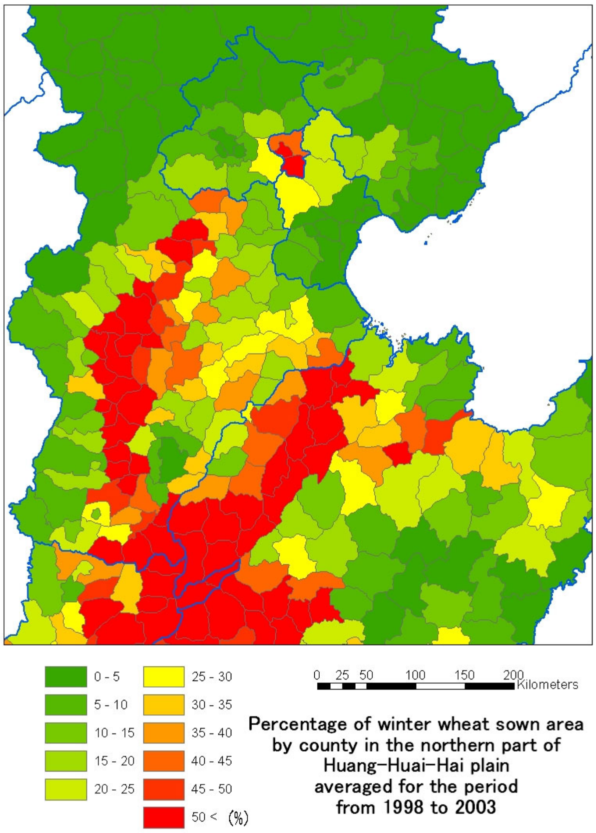

Figure 10. Estimated winter wheat sown area by county

The estimated winter wheat sown area by county in this study would be useful for the purpose of analyzing not only spatial distribution pattern but also temporal changes in recent years. It is because the statistic data of agricultural land use after the year of 2001 compiled by the unit of county has not yet published.

Figure 10 shows the percentage of acreage of winter wheat sown area in county averaged for the period from 1998 to 2003. It is noted that the counties having high percentage of winter wheat sown area were located in the mainly 2 parts; one was the southwestern part of Hebei Province and the other was the northeastern part of Shandong Province. The former part was located near the mountainous area and the latter was along the left bank of Yellow river, both of which the condition of availability of irrigation water was good enough. In between these productive regions there existed the counties where the winter wheat was not extensively cultivated. The major constraint of cultivation in this area could be the less suitability by the existence of alkaline soils as well as the deficit of irrigation water.

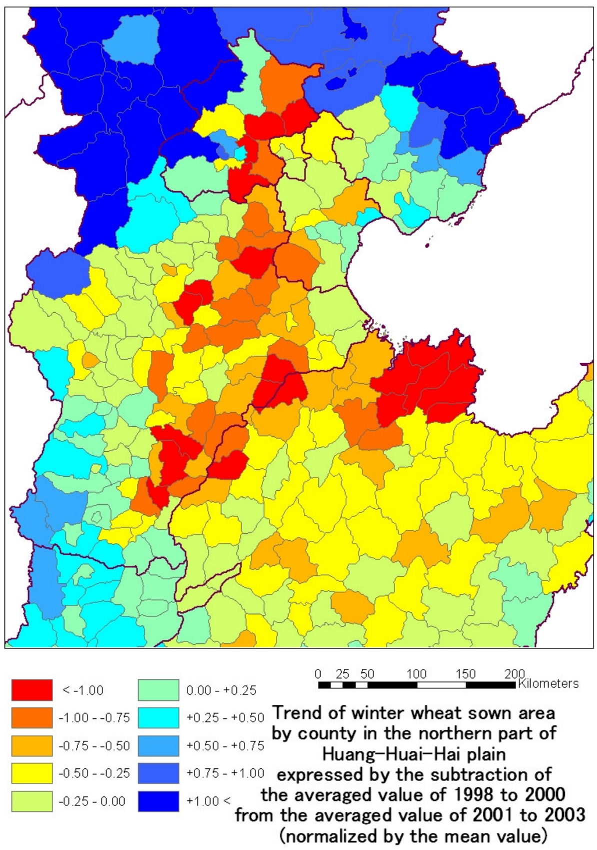

Figure 11. Trend of winter wheat sown area by county

Figure 11 shows the trend of winter wheat sown area by county, which is expressed by the subtraction of the averaged value of 1998 to 2000 from the averaged value of 2001to 2003 and then divided by the total mean value. This figure depicts that the parts having the trend of high decrease are located in the southeastern side of Hebei Province and the north side of Shandong Province. It is also noted that the rate of change was generally low for the counties having high percentage of winter wheat sown area. This means the most of the representative winter wheat production area in the plain had maintained to cultivate winter wheat in recent years, even though the national statistics data by FAO reported that the harvest area of wheat in the whole country reduced 26% from 1998 to 2003.

The author also calculated the coefficient of variation of the percentage of winter wheat sown area by county for the period from 1998 to 2003. The results show that the variation was generally low in the representative production areas. High value of the coefficient could be appeared in the suburban areas.

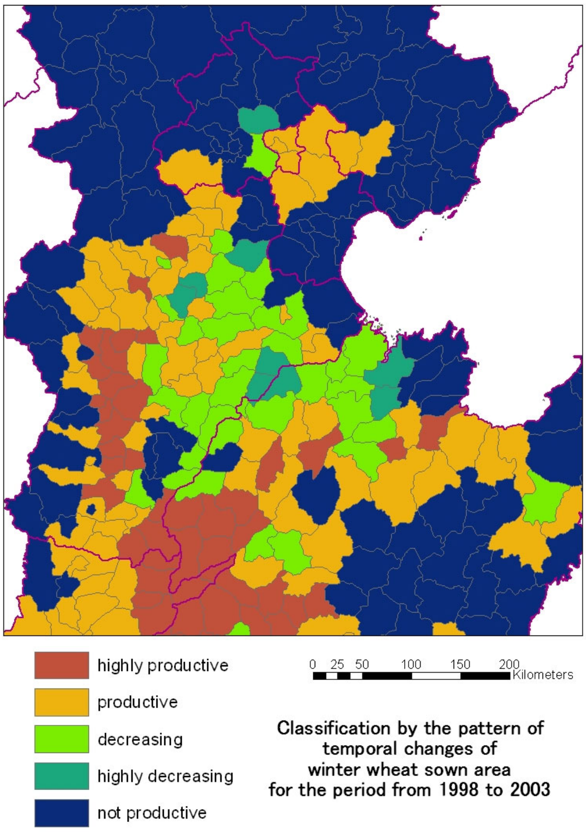

Figure 12. Classification of counties by the pattern of temporal changes of winter wheat sown area

(Average: <15%) ⇒**Not productive**
No ↓
(Trend: <-1.0) ⇒**Highly decreasing**
No ↓
(Trend: -1.0 - -0.5) ⇒**Decreasing**
No ↓
(Average: 45%<) & (Variation: <0.2) ⇒**Highly productive**
No ↓
(Otherwise) ⇒**Productive**

Figure 13. Decision criteria of classification of counties by the pattern of temporal changes

The author overlaid 3 factors of the estimated values mentioned above, and he could produce a classification map, which showed the pattern of temporal changes of winter wheat sown area for the period from 1998 to 2003. Figure 12 depicts the result of classification, where the criteria of each class is described in Figure 13. Figure 12 exhibits effectively the distribution of counties, which showed the temporal characteristics of changes of agricultural land use. For example, Shunyi county categorized into the class of highly decreasing had actually showed the drastic decreasing of winter wheat sown area since 2000, which was verified by the detail analysis using LANDSAT-TM/ETM+ data.

Both of the methods introduced in this article could provide the data of winter wheat sown area, as one of the major agricultural land use, for wide area. The advantageous points of these methods were first their simple structures in terms of the determination of parameters of the formula, and second the flexible applicability to other major agricultural land use. Actually, the author attempted to estimate the sown areas of both winter wheat and cotton in a part of Shandong Province using the linear unmixing method and could reproduce the pattern of distribution in general.

The significant constraint of the both methods could be their sensitivity to the accuracy of location at the process of overlaying multitemporal data. When we utilize the existing dataset of NDVI, and even if we perform the additional geometric correction to the data, the accuracy of location would be at best around 0.1 pixel, that might induce the critical error of estimation. In order to reduce the effect of the deviation of location, the performance of appropriate spatial aggregation would be a candidate of solution.

Another point of consideration is the variation of temporal profile of NDVI over the cultivated area of the specific crop. The methods adopted in this study neglected the influence of variation of NDVI at the same growth stage of wheat, which could be varied by the difference of factors such as morphological condition of plant, damage of growth, and so on. Therefore, it is required to integrate the studies on the relationship between NDVI and crop growth condition for the purpose of verifying the robustness of estimation method.

4. CONCLUSIONS

Monitoring of agricultural land use for wide area is expectable application of satellite remote sensing. This study attempted to develop methods to estimate the sown area of winter wheat in the major crop productive area of China using temporal characteristics of NDVI by rather primitive but easily applicable procedures to other crops. The results were not accurate enough to discuss the detail spatial distribution, however, were evaluated for providing the information, which would be used to characterize the pattern of temporal changes by setting an appropriate spatial unit.

A number of dataset of NDVI in regional scale have been produced from NOAA-AVHRR for the past and should be produced in the future from not only NOAA-AVHRR but also Terra-MODIS. Therefore, the sub-pixel classification to estimate the acreage of the specific land use type using these dataset is considered to be a key technique to contribute to the production of basic information on global environmental issues.

REFERENCE

Uchida, S., 2001. Sub-pixel classification of land use using temporal profile of NDVI. *J. Japan Society of Photogrammetry and Remote Sensing*, 40(1), pp.43-54.

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