Comparison of winter wheat growth with multi-temporal remote sensing imagery

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Abstract. Leaf area index (LAI) is an important index for crop growth monitoring. This paper focused on estimation of winter wheat LAI dynamics in different growth stages based on Landsat TM data. In order to retrieve wheat LAI from remote sensing data, LAI measurements were initiated when Landsat satellite pass over the study region. Three Landsat5 TM images were acquired on April 15, May 17, and June 2, 2009, corresponding to jointing stage, flowering stage and milking stage of wheat. LAI was measured at each stage in thirty wheat fields distributed in Beijing suburb. Based on the TM images, spectral indices including NDVI, MSAVI, SAVI, RDVI, SR, ISR, MSR and NLI were calculated. Univariate correlation analysis was then conducted between LAI data and corresponding TM spectral variables. The analysis results indicated that TM ISR on April 15, TM Band4 on May 17, and TM ISR on June 2 were very significantly correlated with LAI, and the coefficient values were 0.736, 0.548 and 0.493, respectively. LAI map of winter wheat for whole study area was produced based on optimal non-linear correlation models. The three LAI maps were used to winter wheat growth analysis and comparison of different growth stages. Study results indicated that from April 15 to May 17, LAI value for 14.88% of winter wheat fields (9131 ha) increased less than 1, 64.43% (39421 ha) increased between 1 to 2, 20.67% (12685 ha) increased more than 2. LAI decreased from May 17 to June 2. 45.34% of winter wheat fields (27828 ha) decreased less than 1, 45.20% (27738 ha) decreased between 1 to 2, 9.33% (5725.42 ha) decreased more than 2.

1. Introduction
Winter wheat is a typical crop widely planted in northern China. Field investigation indicates that wheat growth is different across crop land due to changes in landscape position, nutrient availability, soil chemical and physical properties, cropping history and soil type.

Recently, along with the development of remote sensing (RS) technology, satellite RS has become an important tool for monitor and management of spatial variability of crop growth. It allows us to obtain a complete picture of an area and check crop growth at a given time. The leaf area index (LAI) of crop is an important structural variable for assessing crop growth. Significant efforts have been
made to estimate vegetation parameters in a spatially complete manner[1] from empirical algorithms relating LAI to spectral vegetation indices (VI) [2]. While numerous studies have shown a strong relationship between vegetation parameters and LAI, these studies have also noted that observed relationships are highly site-specific [3]. Red-NIR VI typically increase over an LAI range from 0 to about 3-5 before an asymptote is reached [4-11]. Therefore, to use the VI approach, an LAI-VI equation must be established for each crop growth stage, which requires substantial LAI measurements and corresponding remote sensing data.

In this study, satellite remote sensing imagery was used to estimate LAI in winter wheat fields at different growth stages. The objectives are to map and compare the spatial variability of winter wheat LAI at different growth stages.

2. Material and Methods

2.1. Study Area and Ground Data Collection

This study was conducted in Beijing suburb,- N 39.1° to 41° in latitude and - E115.9° to 117.3° in longitude. The study area is in a dry sub-humid region with an annual mean precipitation of 550 mm. Between 70 and 80% of precipitation occurs from July to September.

A total of 30 fields, each more than 5 hectares, were selected as the sample fields during the winter wheat growth season of 2009. Survey experiments were conducted on April 15, May 17 and June 2 of 2009, with synchronous passing of satellite over the study area. At each sites, field sampling was conducted within a square of 30m×30m. Five LAI samples distributed in the four corners and center of the square were collected for each field. The winter wheat LAI sample for each site was collected with 4 rows of 50 centimeters long. The wheat plants were put into sealed plastic bag and sent to laboratory for LAI measurements (lamina mass per unit area method). Measurements of LAI in each site were then averaged to provide LAI value for the experiment field. The geo-referenced coordinates for each of the site were determined by a handheld Geographic Positioning System (GPS).

2.2. Remote Sensing Data Acquisition and Processing

Three scenes of Landsat 5 TM images (path 136 / row 32) were acquired on April 15, (Apr15 TM), May 17(May17 TM), and June 2 (Jun02 TM), 2009, respectively. These satellite images were processed for geometric and radiometric corrections using ENVI 4.3. Atmospheric and radiometric corrections were conducted through the FLAASH model of ENVI. After correction, the digital number (DN) values were converted to reflectance values. Eight vegetation indices (VIs) which have high correlation with field measured LAI were extracted from remote sensed imagers (list of table 1).

| Index  | Description                                                                 | Reference                  |
|--------|-----------------------------------------------------------------------------|----------------------------|
| NDVI   | $NDVI = (\rho_{\text{NIR}} - \rho_{\text{R}})/(\rho_{\text{NIR}} + \rho_{\text{R}})$ | Rouse, et al., 1974[12]    |
| MSAVI  | $MSAVI = 0.5*(2*\rho_{\text{NIR}} + 1) - SQRT((2*\rho_{\text{NIR}} + 1)^2 - 8*(\rho_{\text{NIR}} - \rho_{\text{R}})))$ | Qi et al., 1994b[13]       |
| SAVI   | $SAVI = (1 + 0.5)*(\rho_{\text{NIR}} - \rho_{\text{R}})/(\rho_{\text{NIR}} + \rho_{\text{R}} + 0.5)$ | Huete et al.,1988[14]      |
| RDVI   | $RDVI = (\rho_{\text{NIR}} - \rho_{\text{R}})/(\rho_{\text{NIR}} + \rho_{\text{R}})$ | RougeanandBreon, 1995[15]  |
| SR     | $SR = (\rho_{\text{NIR}} / \rho_{\text{R}})$                                 | Baret and Guyot,1991[16]   |
| ISR    | $ISR = (\rho_{\text{NIR}} / \rho_{\text{SWIR}})$                           | Fernandes et al.,2002[17]  |
| MSR    | $MSR = ((\rho_{\text{NIR}} / \rho_{\text{R}}) - 1) /((\rho_{\text{NIR}} / \rho_{\text{R}})^{1/2} + 1)$ | Gong et al.,2003[18];Chen,1996[19] |
| NLI    | $NLI = (\rho_{\text{NIR}} - \rho_{\text{R}})/(\rho_{\text{NIR}} + \rho_{\text{R}})$ | Gong et al.,2003;Goel and Qin,1994[20] |

Note: $\rho_{\text{NIR}}$, $\rho_{\text{R}}$ and $\rho_{\text{SWIR}}$ denoted as reflectance in near-infrared(TM4),red(TM3) and short wave infrared (TM5) wavelengths.
3. Results and Discussion

3.1. Statistical analysis for LAI data

Table 2 shows the summary of LAI measurements, taken on April 15, May 17 and June 2, 2009. The mean value of LAI was 1.63 on April 15, increased to 3.08 on May 17 and decreased to 2.14 on June 2. The standard deviation of LAI was 0.76 and range of LAI is between 0.40 – 3.03 at jointing stage, demonstrating high spatial variability of the winter wheat field cover. The standard deviation of LAI was 1.26, the range was between 1.21 to 5.37 at flowering stage on May 17. At milking stage, the standard deviation was 0.86 and range was between 0.93 to 3.74.

Table 2. LAI measurement data descriptive statistic

| Dates    | Number | Min  | Max  | Mean | S.D. |
|----------|--------|------|------|------|------|
| Apr15 LAI | 30     | 0.40 | 3.03 | 1.63 | 0.76 |
| May17 LAI | 30     | 1.21 | 5.37 | 3.08 | 1.26 |
| Jun02 LAI | 30     | 0.93 | 3.74 | 2.14 | 0.86 |

3.2. Relationship between Vegetation Indices and LAI

Correlation and regression analysis between LAI and spectral variables were conducted. As shown in Table 3, significant or extremely significant correlations between LAI and TM spectral parameters were found at jointing, flowering, and milking stages.

Table 3. Correlation coefficients between LAI and TM spectral variables in different dates

| LAI spectral variables | 15-Apr | 17-May | 2-Jun |
|-----------------------|--------|--------|-------|
| TM1                   | -0.519** | -0.210 | -0.319 |
| TM2                   | -0.626** | -0.416* | -0.350 |
| TM3                   | -0.604** | -0.361* | -0.355* |
| TM4                   | 0.603**  | 0.548** | 0.491** |
| TM5                   | -0.576** | -0.327  | -0.304 |
| TM7                   | -0.549** | -0.373* | -0.371* |
| NDVI                  | 0.666**  | 0.456** | 0.431* |
| RDVI                  | 0.681**  | 0.520** | 0.486** |
| SAVI                  | 0.682**  | 0.524** | 0.492** |
| MSAVI                 | 0.688**  | 0.528** | 0.491** |
| SR                    | 0.699**  | 0.466** | 0.414* |
| ISR                   | 0.736**  | 0.526** | 0.493** |
| NLI                   | 0.688**  | 0.501** | 0.464** |
| MSR                   | 0.700**  | 0.468** | 0.420** |

*. Correlation is significant at the 0.05 level.N=30
**. Correlation is significant at the 0.01 level.N=30

From April to June, correlation coefficients between LAI and VIs show a decreasing trend. On 15-Apr, the winter wheat jointing stage, correlation between LAI and fourteen TM spectral variables are all extremely significant. Since the flowering stage, the winter wheat was in full coverage. TM VIs saturates and is no longer sensitive to changes in vegetation, so the correlation coefficients decreased. At the flowering stage, correlation between LAI and TM4, NDVI, RDVI, SAVI, MSAVI, SR, ISR,
NLR, and MSR are very significant. But there were six VIs at extreme significant level and five VIs at the significant level at milking stage.

3.3. LAI Map

Then, three VIs, April 15 ISR, May 17 TM4 and June 2 ISR, which have the highest correlation coefficients with LAI at different growth stages, were selected for regression analysis. Three optimal non-linear correlation models, based on Apr15ISR, May17 TM4 and Jun 2 ISR were selected to estimate the winter wheat LAI for study area (table 4). The corresponding LAI estimation maps for different winter wheat growth stages are shown in figure 3.

| Spectral variables | Expression | $R^2$ | Std.Error of the Estimate |
|--------------------|------------|-------|---------------------------|
| Apr15 TM ISR       | $y = 0.785x^{1.377}$ | 0.569 | 0.363                     |
| May17 TM 4         | $y = 138.939x^2 - 68.711x + 10.451$ | 0.307 | 1.087                     |
| Jun02 TM ISR       | $y = 0.546e^{0.686x}$ | 0.249 | 0.380                     |

In the final LAI map, the red and orange color represents low LAI values (0-1). Higher LAI values (3-4) are represented by yellow tone and the highest LAI values associated with better growth of winter wheat are represented by the green tone.

![Figure 3](image)

**Figure 3.** Winter wheat LAI map of study area with TM data
(a) April 15 LAI map  (b) May 17 LAI map  (c) June 2 LAI map

3.4. Comparison of LAI at different growth stages

Figures 4a and 4b show the changes in LAI from the winter wheat jointing stage to flowering stage and from flowering to milking stage. We can see from the two maps that the LAI variation trends according to the growth of winter wheat in study area. From April 15 to May 17, LAI value in 14.88% winter wheat fields (9131ha) increased less than 1, 64.43% (39421 ha) increased between 1 to 2, 20.67% (12685 ha) increased more than 2. LAI decreased from the flowering stage to the milk stage, 45.34% winter wheat fields (27828 ha) decreased less than 1, 45.20% (27738 ha) decreased between 1 to 2, 9.33% (5725.42 ha) decreased more than 2.
4. Conclusion
Univariate correlation analysis was carried on between LAI data and TM spectral variables in this study. Analysis indicated that Apr15 TM ISR, May17 TM Band4, and Jun02 TM ISR correlated very significantly with LAI and the LAI map for wheat jointing, flowering and milking stage was conducted based on the optimal non-linear models. Winter wheat LAI variation for conjoint growth stages was estimated by three LAI maps. Analysis results indicated that from April 15 to May 17, LAI value for 14.88% winter wheat fields (9131ha) increased less than 1, 64.43 % (39421 ha) increased between 1 to 2, 20.67 % (12685 ha) increased more than 2. While it decreased from May 17 to June 2. There are 45.34% winter wheat fields (27828 ha) decreased by 0 to 1, 45.20 % (27738 ha) decreased by 1 to 2, 9.33% (5725.42 ha) decreased more than 2. The study indicate that multi-temporal Landsat TM imagery can be used for mapping pixel-based LAI and analysis, compariing the winter wheat growth at different growth stages.

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