Welcome to Nanjing, Jiangsu Province
Welcome to China

Xia YAO
yaoxia@njau.edu.cn
Dr. Xia YAO (姚霞), professor, vice dean

Research focus on

- Information Agriculture
- Unmanned aerial vehicles (UAVs)
- Hyperspectral remote sensing of vegetation
- Crop growth/stress/senescence monitoring
- Quantification of crop biophysical properties
- Vegetation mapping
Research Objectives

① To accurately monitor the growth parameters for recommending the optimal fertilizer

② To early monitor the disease/pest for reducing the amount of pesticide

③ To fast provide the input parameters for running the growth model at large scale

④ To select the wavelength or spectral feature for developing our own right portable instrument
Outline

I. Introduction of Nanjing Agriculture University, Nanjing (NAU)

II. Introduction of National Engineering and Technology Center for Information Agriculture (NETCIA)

III. Introduction of my research
Introduction of NJAU

China, Jiangsu Province, Nanjing City, Nanjing agricultural university

Location
Nanjing Agricultural University—NAU

Pioneer of modern agricultural education in China (since 1914)

A state key university, member of “211 Project” (since 2000)
Colleges (19)

1. Agriculture
2. Horticulture
3. Plant Protection
4. Grassland Science
5. Animal Sci. & Tech.
6. Veterinary Medicine
7. Engineering
10. Life Sciences
12. Sciences
13. Economics & Management
14. Finance
15. Foreign Studies
16. Humanities and Social Sci.
17. Public Administration
18. Rural Development
19. International Education
## Enrollment

<table>
<thead>
<tr>
<th>Category</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total enrollment</strong></td>
<td>26,385</td>
</tr>
<tr>
<td>① Undergraduates</td>
<td>17,535</td>
</tr>
<tr>
<td>② Postgraduates</td>
<td>8,950</td>
</tr>
<tr>
<td>③ International students</td>
<td>820</td>
</tr>
</tbody>
</table>

### Programs

- Bachelor
- Master
- Ph.D.
Funding

--over 2.5 billion RMB competitive research fund

--200 million RMB from industries
Introduction of NETCIA

http://www.netcia.org.cn

National Engineering and Technology Center for Information Agriculture
The NETCIA was established by the Ministry of Industry and Information Technology, China in November, 2010.

Facility

Entrance

Meeting room

Chemical analysis room

Library

Technology show room
Experiment station
Faculty Members

Director of NETCIA

- **Professor Weixing Cao**, PhD Supervisor, is now Vice-minister of Ministry of Land and Resources, China, and the President of the Crop Science Society of China.
- **1986-1989**, received his PhD in crop physiology from Oregon State University;
- **1989-1994**, served as a post-doctor, research scientist in crop ecology at the University of Wisconsin;
- **In 1994**, returned to NAU, being a professor and PhD supervisor.

Staff members (24):
- Professors (10); Assoc. Profs. (13); Lecturer (1)

Graduate students (60); Post-doctors (2); Visiting scholars (2)

All of use are from colleges of:
- Agriculture; Information Science & Technology; RS; GIS; Resource & Environmental Sciences; Agricultural Engineering
Members

➢ Faculty members (24)
  ➢ Professors (14)
  ➢ Assoc. Profs. (7)
  ➢ Lecturer (3)
➢ Graduate students (>70)
➢ Post-doctors (2)
➢ Visiting scholars (2)

All of them are from colleges of:
➢ Agriculture
➢ Information Science & Technology
➢ Resource and Environmental Sciences
➢ Agricultural Engineering
① Agricultural Remote Sensing
② Crop System Modeling
③ Precision Farming and Management
④ Agro-Information Engineering

Research Groups

crop growth and productivity

① to monitor
② to predict
③ to manage
④ to develop

Growth models
Retrieval algorithms
Growth status

Productivity
Portable devices, DSS

Fertilizer/Water
Agricultural Remote Sensing

- This research group strives to promote the use of advanced remote sensing (RS) technologies in the process of modern crop production.
- The research activities are built on the sophisticated multi-scale platforms for acquiring timely remotely sensed data over crop fields. Low-altitude UAV and satellite imagery are the sources for automated identification of crop types and crop phenology over large areas.
- The multi-source data serve as the bases to develop robust and practical methods for retrieving agronomic parameters such as leaf area index and leaf nitrogen content at leaf, canopy, field and regional levels. The goal of this research theme is to implement the timely and accurate monitoring of agricultural conditions such as crop growth, abiotic/biotic crop diseases and crop acreage and the forecasting of crop yield and grain quality. The derived information on agricultural conditions is crucial for implementing precision management practices and for making informed decisions on food security policies.
Crop System Modeling

- Using the process-based modeling approach, this research group strives to analyze and quantify the relationships of crop growth with environmental factors, management practices and cultivar characters.

- Crop simulation models are developed for quantitative descriptions of the mechanisms and processes of the crop system, including crop growth, development, yield and quality formation, crop-soil nutrient and water balances. Model-based decision support systems and visualization platforms are further developed by integrating simulation models, GIS and remote sensing for prediction and early-warming of crop productivity, management strategies and designing of ideal cultivars, and assessments of climate change impact on crop production.

A schematic diagram for the crop growth model (CropGrow)  
Prediction and visualization of crop growth  
A flowchart for regional prediction of crop productivity
This research theme establishes general knowledge models for crop management, including sub-models for the design of seasonal cultivation plans and growth indicators. These knowledge models are integrated with GIS technology for developing rational and effective spatial zoning methods and precise management prescriptions.

As a result, a precision management system can be established with the combination of knowledge models and GIS. The purpose of this research theme is to implement the precision design of cultivation plans at different spatial and temporal scales under various production conditions of rice and wheat, such as target yield, cultivar selection, plant density, fertilization and irrigation strategies, and dynamic growth parameters.
By combining engineering technologies with related sciences in crop growth simulation, condition monitoring and precision management, we strive to develop easy-to-use handheld or machine-mounted devices for crop growth monitoring and diagnosis.

These devices can be integrated into information systems developed for PC, Web, and Mobile platforms. The purpose of this research theme is to develop hand-held or machine-mounted equipment and practical application systems for precision farming and to promote large-scale applications of agricultural engineering products.

---

**Agro-Information Engineering**

- Portable spectrometers for crop growth monitoring and diagnosis
- Machine-mounted devices for crop growth monitoring and diagnosis
- Internet of Things in the field
- Cloud-based service infrastructure for smart agriculture
Technology Extension

Since 2001, more than 30 county-level demonstration and extension bases have been established in Jiangsu and neighboring provinces for demonstrating and applying the technologies of crop cultivation plan design and crop growth monitoring in rice and wheat.

By adopting crop management decision support systems in PC, Web-based and Mobile versions, the technology of crop cultivation plan design is demonstrated and applied in the form of quantitative cultivation prescriptions from field to regional scales. Meanwhile, through employing the crop growth monitoring and diagnosis instruments and support systems, the technology of crop growth monitoring is demonstrated and applied in the form of diagnosis and regulation prescriptions with real-time growth indices, fertilization and irrigation plans. Further combining with technical training and field tours and workshops, the large-scale technology demonstration and extension are being performed in wheat and rice crops, which help enhance management level and maximize production profit, while facilitating agricultural informatization and modernization.
NETCIA has established extensive exchanges and collaborations with top universities and institutes not only from China, but also from the U.S., Australia, Japan, and the Netherlands. Most faculty members have earned overseas academic experiences through sabbatical visiting and international conferences. Many distinguished scientists and scholars from home and abroad visit our center for lecturing and research collaborations every year. Besides, the center has successfully organized and sponsored a number of international academic conferences and workshops in topics on information agriculture.
Exchange & Collaboration

Workshops & Symposia
Achievements

Papers and Books
Over 400 research papers on key journals (more than 160 papers indexed by Web of Science and EI) and six research books are published in the past five years.

Patents
The center owns 26 invention patents, 10 utility-model patents and 22 software copyrights.

Professional Development
Eight postdoctoral fellows, 73 PhD students and 78 Master’s students have graduated from NETCIA. A number of faculty members have been selected into national and provincial talent programs, such as the Distinguished Young Scholars of National Natural Science Foundation of China.

Awards
Four Second-Class National Awards for Progress in Science and Technology, three First-Class Awards for Progress in Science and Technology by Jiangsu Government, three First-Class Awards for Progress in Science and Technology by the Ministry of Education.
Funding (Average 10 million / year)

- New Century Exceptional Talent Program of China
- National High-Tech Research & Development Program
- National Natural Science Foundation of China
- Natural Science Foundation of Jiangsu Province
- Innovative Scholar Program of Jiangsu Province
Information Technology in Crop Production Process and Its Application

Xia YAO

yaoxia@njau.edu.cn
How many techniques from sowing to maturity for crops?

How sowing?  How growth?

How fertilizer/irrigation?  How productivity?

Crop Production Process

Seeding  Tillering  Jointing  Booting  Heading  Anthesis  Grain filling
1. Key technology

1. How sowing?

Knowledge Model----Design the sowing strategy
Definition:

The dynamic knowledge model is to quantify the relationships of growth characters and cultural techniques to geographic and seasonal environments (CropKnow, a digital expert system).
Structural components of knowledge model

Cultural plan
growth index

- Weather factor
- Cultivar trait
- Soil condition
- Production level
Development principle of submodel

- **Target yield** is designed based on the average yield and yield increasing index;
- **Suitable variety** is selected based on the fitness between genotype and environment;
- **Sowing date** is calculated based on the principle of strong seedling before winter and safe jointing after winter in winter wheat/safe jointing and heading in rice;
- **Planting density** is designed based on final population spike number per unit area and effective spike number of single plant;
- **Fertilization strategy** is determined based on the nutrient balance between demand and supply;
- **Optimum development stages and dynamic growth index** are modeled based on the planting strategy;
### Sowing date algorithm

**ATBW** = **EM** + **LNBW** * **PHYLL**

**EM** = 40 + 10.2 * **SDEPTH**

**LNBW** = (2.8087 + 2.0143 * ln(SSTNBW / ATE))

**SSTNBW** = **PSTNBW** / **PN**

**GDD** = \(\sum((T_{\text{max}}(i) + T_{\text{min}}(i))/2)\)

**ATBW** = **GDD**

- **ATBW** - accumulated temperature demand before wintering stage
- **EM** - accumulated temperature demand between sowing and emergency
- **LNBW** - leaf number on main stem before wintering
- **PHYLL** - phyllochron (GDD)
- **SDEPTH** - sowing depth
- **ATE** - actual tillering efficiency
- **SSTNBW** - stem and tiller number of single plant before wintering per unit area
- **PSTNBW** - population stem and tiller number before wintering per unit area
- **PN** - plant number per unit area
- **Tmax(i)** - daily maximum temperature
- **Tmin(i)** - daily minimum temperature
Plant number algorithm

\[ PN = \frac{PSN}{SSN} \]

- \( SSN = ATE \times STN \times VETSR \)
- \( STN = 0.3205 \times \exp(0.4949 \times CLA) \)
- \( CLA = TLN - TIN - ETLNJ + 3 \)
- \( ETLNJ = 0.5 \times TLN - 2 \)

- PSN — spike number per unit area
- SSN — spike number of single plant
- VSN — variety spike number
- ATE — actual tillering efficiency
- STN — theoretic stem and tiller number at CLA
- VETSR — ratio of final spike number to effective tiller number for a specific cultivar
- TY — target yield
- VY — variety yield
- CLA — critical leaf age for generating effective tillers
- TLN — total leaf number
- TIN — total internode number
- ETLNJ — leaf number of effective tiller at jointing
Sowing rate algorithm

$$SR = \frac{PN \times TGW}{100 \times SP(\%) \times GR(\%) \times ER(\%)}$$

- SR — sowing rate
- PN — plant number or density
- TGW — thousand grain weight
- SP — seed purity rate
- GR — germination rate
- ER — emergency rate
Fertilization plan algorithm

**Nitrogen demand:** \( ND = Y \times \text{MNCG} + \left( \frac{1}{\text{HI}} - 1 \right) \times Y \times \text{MNCSTR} \)

**Nitrogen uptake:** \( NA = NAS + NAF \)

1. \( NAS = YNF \times \text{MNCG} + \left( \frac{1}{\text{HI}} - 1 \right) \times YNF \times \text{MNCSTR} \)
2. \( NAF = NFA \times \text{NCF} \times \text{NEF} \)

\( ND = NU \)

**Nitrogenous fertilizer amount:** \( NFA = \frac{(ND - NAS)}{(\text{NCF} \times \text{NEF})} \)

\( Y \) — yield
\( \text{MNCG} \) — minimum nitrogen content in wheat grain (0.01)
\( \text{MNCSTR} \) — minimum nitrogen content in wheat straw (0.004)
\( \text{HI} \) — harvest index
\( \text{NAS} \) — nitrogen absorbed from soil
\( \text{NAF} \) — nitrogen absorbed from fertilizer
\( \text{YNF} \) — yield without nitrogen fertilizer
\( \text{NCF} \) — nitrogen content in nitrogenous fertilizer
\( \text{NEF} \) — nitrogenous fertilizer use efficiency
**Tiller number dynamic algorithm**

\[
\text{OPTN}(\text{GDD}) = \text{PN} + (\text{OPTN}_{\text{MAX}} - \text{PN}) \times e^{-c(x-d\text{GDD})^2/\text{GDD}^2}
\]

\[
c_1 = -\ln\left(\frac{\text{PTN}_{\text{BW}} - \text{PN}}{\text{OPTN}_{\text{MAX}} - \text{PN}}\right) \times \frac{\text{GDD}_W^2}{(\text{GDD}_J - \text{GDD}_W)^2}
\]

\[
c_2 = -\ln\left(\frac{1.05 \times \text{SPN}_Y - \text{PN}}{\text{OPTN}_{\text{MAX}} - \text{PN}}\right) \times \frac{\text{GDD}_H^2}{(\text{GDD}_H - \text{GDD}_J)^2}
\]

**OPTN(GDD) —** Optimal population stem and tiller number per unit area at GDD

**PN —** plant number per unit area

**OPTN_{MAX} —** maximum stem and tiller number per unit area

**d —** GDD at jointing

**PTN_{BW} —** actual population stem and tiller number per unit area before wintering

**GDD_W, GDD_J, GDD_H —** GDD at wintering, jointing and heading
Knowledge Model-based DSS for Wheat Management
Knowledge Model-based DSS for Rice Management
Cultural plan designed by RiceKnow

<table>
<thead>
<tr>
<th>指标</th>
<th>具体值</th>
</tr>
</thead>
<tbody>
<tr>
<td>品种名称</td>
<td>6427</td>
</tr>
<tr>
<td>置信度</td>
<td>0.94</td>
</tr>
<tr>
<td>播期</td>
<td>1996/04/12—1996/06/02</td>
</tr>
<tr>
<td>秧田亩播种量[千克]</td>
<td>67.82</td>
</tr>
<tr>
<td>每亩秧田成秧苗数[万株]</td>
<td>140.64</td>
</tr>
<tr>
<td>每亩大田基本苗数[万株]</td>
<td>1.00</td>
</tr>
<tr>
<td>纯氮总量[千克/亩]</td>
<td>28.45</td>
</tr>
<tr>
<td>P2O5总量[千克/亩]</td>
<td>6.75</td>
</tr>
<tr>
<td>K2O总量[千克/亩]</td>
<td>4.12</td>
</tr>
<tr>
<td>基肥纯氮量[千克/亩]</td>
<td>17.35</td>
</tr>
<tr>
<td>追肥纯氮量[千克/亩]</td>
<td>13.19</td>
</tr>
</tbody>
</table>
Dynamic growth index
Suitable development stages

<table>
<thead>
<tr>
<th>时期</th>
<th>日期</th>
</tr>
</thead>
<tbody>
<tr>
<td>播期</td>
<td>常年/10/27 ~ 常年/11/08</td>
</tr>
<tr>
<td>分蘖期</td>
<td>常年/11/04 ~ 常年/11/20</td>
</tr>
<tr>
<td>越冬期</td>
<td>常年/01/04</td>
</tr>
<tr>
<td>返青期</td>
<td>常年/02/06</td>
</tr>
<tr>
<td>拔节期</td>
<td>常年/04/04 ~ 常年/04/20</td>
</tr>
<tr>
<td>孕穗期</td>
<td>常年/04/21 ~ 常年/04/28</td>
</tr>
<tr>
<td>抽穗期</td>
<td>常年/04/28 ~ 常年/05/08</td>
</tr>
<tr>
<td>开花期</td>
<td>常年/05/08 ~ 常年/05/20</td>
</tr>
<tr>
<td>灌浆期</td>
<td>常年/05/16 ~ 常年/06/30</td>
</tr>
<tr>
<td>成熟期</td>
<td>常年/05/30 ~ 常年/06/05</td>
</tr>
</tbody>
</table>
Knowledge Model-based DSS for Crop Management

Uniprocessor version
Network version
### Fertilization Strategy

<table>
<thead>
<tr>
<th>Column</th>
<th>Output Item</th>
<th>Output Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Nitrogen fertilizer (N) application amount [kg/mu]</td>
<td>19.27</td>
</tr>
<tr>
<td>2</td>
<td>Phosphorus fertilizer (P2O5) application amount [kg/mu]</td>
<td>4.57</td>
</tr>
<tr>
<td>3</td>
<td>Potash fertilizer (K2O) application amount [kg/mu]</td>
<td>8.40</td>
</tr>
<tr>
<td>4</td>
<td>Organic manure:Chemical fertilizer</td>
<td>0.66:9.34</td>
</tr>
<tr>
<td>5</td>
<td>Nitrogen fertilizer basal dressing:Tiller:Elongation and Booting:Seeds</td>
<td>5.73 : 1.05 :</td>
</tr>
<tr>
<td>6</td>
<td>Phosphorus fertilizer dressing rate of basal and top</td>
<td>7.45 : 2.55</td>
</tr>
<tr>
<td>7</td>
<td>Potash fertilizer dressing rate of basal and top</td>
<td>6.82 : 3.18</td>
</tr>
</tbody>
</table>

### Input Condition

- Region: Nanjing
- Variety type: Mingmai9hao
- Soil type: Banjing01
- First Year of weather data: 1986
- End Year of weather data: 1987
- Target Yield [kg/mu]: 400
- Average Yield of last three years [kg/mu]: 350
- Utilization ratio of nitrogen fertilizer: 0.30
- Utilization ratio of phosphorus fertilizer: 0.30
- Utilization ratio of potash fertilizer: 0.55
- Cultivation management level: Middle and Higher level
- Prevention Level of disease and insect: Middle and Higher level
- Water management level: Middle and Higher level
- Fertilization level: Middle and Higher level
- Variety type: Common
- Wheat Depth The maximum leaf area index: 7.0
- Earliest sowing date: perennial/10/01
- Latest harvest period: perennial/06/01
Knowledge Model-based PDA for Wheat Management
Knowledge Model-based PDA for Rice Management

Input interface of fertilization decision making

Output interface
Demo: Design the sowing strategy (Model & DSS)

- Prescription map of plant density
Prescription map of basal N rate
2. Key technology

How growth?

Remote Sensing----Monitor the growth index; Predict the yield

① Crop acreage
② Canopy leaf nitrogen content and accumulation
③ Canopy leaf chlorophyll content and accumulation
④ Leaf area index
⑤ Canopy leaf dry weight
⑥ Grain yield and protein content
⑦ Crop disease
⑧ Straw burning
⑨ Track growth process
What is remote sensing?

• Definition: “Photogrammetry and remote sensing are the art, science, and technology of obtaining reliable information about physical objects and the environment, through the process of recording, measuring and interpreting imagery and digital representations of energy patterns derived from non-contact sensor systems” adopted by ASPRS. (Colwell, 1997)

• “Remote sensing is the noncontact recording of information from the ultraviolet, visible, infrared, and microwave regions of the electromagnetic spectrum by means of instruments such as cameras, scanners, lasers, linear arrays, and/or area arrays located on platforms such as aircraft or spacecraft, and the analysis of acquired information by means of visual and digital image processing.” (Jensen, 2006)
Does the spectral reflectance response to varied N rates?

- Sun radiates to the ground object, some energy were transferred to the reflectance, some were absorbed, and the other were transmittance.
- According the field experiment of varied nitrogen, with the increasing N rate, the reflectance will decrease in the visible region, and rise in the near-infrared region, which is consistent at different eco-sites and varieties.
<table>
<thead>
<tr>
<th>Sensor</th>
<th>Band</th>
<th>Price (yuan)</th>
<th>Weight (g)</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Imaging</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UHD-185 (passive, hyperspectral)</td>
<td>450 ~ 900 nm</td>
<td>438,900</td>
<td>470</td>
<td>Germany Cubert</td>
</tr>
<tr>
<td>Mini MCA6 (passive, multispectral)</td>
<td>NIR(900nm,800nm) RE(720nm) R(680nm) G(550nm) B(490nm)</td>
<td>120,000</td>
<td>700</td>
<td>USA Tetracam</td>
</tr>
<tr>
<td>Canon 5D Mark III</td>
<td>R、G、B</td>
<td>30,000</td>
<td>860</td>
<td>Japan Canon</td>
</tr>
<tr>
<td>Canon SX260 HS</td>
<td>NIR(670~770nm) G、B</td>
<td>2,000</td>
<td>200</td>
<td>Japan Canon</td>
</tr>
<tr>
<td><strong>Non-imaging</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RapidSCAN CS-45 (active, multispectral)</td>
<td>NIR(780nm) RE(730nm) R(670nm)</td>
<td>40,000</td>
<td>800</td>
<td>USA Holland Scientific</td>
</tr>
<tr>
<td>CGMD-602 (passive, multispectral)</td>
<td>NIR(815nm) RE(730nm)</td>
<td>8,000</td>
<td>500</td>
<td>NAU NETCIA</td>
</tr>
</tbody>
</table>
## Satellite Imagery and Characters

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Highest spatial resolution (m)</th>
<th>Revisiting period (day)</th>
<th>Band Number</th>
<th>Price (yuan/Km²)</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat 8</td>
<td>15</td>
<td>16</td>
<td>11</td>
<td>free</td>
<td>USA</td>
</tr>
<tr>
<td>Sentinel-2</td>
<td>10</td>
<td>5</td>
<td>13</td>
<td>free</td>
<td>ESA</td>
</tr>
<tr>
<td>HJ-1 (A/B)</td>
<td>30</td>
<td>2</td>
<td>4</td>
<td>free</td>
<td>China</td>
</tr>
<tr>
<td>WorldView-2</td>
<td>0.46</td>
<td>1.1</td>
<td>9</td>
<td>220</td>
<td>USA</td>
</tr>
<tr>
<td>RapidEye</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>17</td>
<td>Germany</td>
</tr>
<tr>
<td>GF-1</td>
<td>2</td>
<td>2</td>
<td>9</td>
<td>0.89</td>
<td>China</td>
</tr>
<tr>
<td>GF-2</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>80</td>
<td>China</td>
</tr>
</tbody>
</table>
Platforms for remote sensing
from Leaf to Globe

(Inoue, 2000)
The field pictures of different planting densities and nitrogen levels at varied growth stages in wheat

<table>
<thead>
<tr>
<th>Progress</th>
<th>Reviving</th>
<th>Jointing</th>
<th>Booting</th>
<th>Heading</th>
<th>Anthesis</th>
<th>Filling</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDD(°C·d)</td>
<td>810</td>
<td>1114</td>
<td>1438</td>
<td>1547</td>
<td>1715</td>
<td>1931</td>
</tr>
</tbody>
</table>

- **Low density low Nitrogen (D1N1)**
  - D1: 40 cm

- **Low density high nitrogen (D1N3)**
  - D1: 40 cm

- **High density low nitrogen (D2N1)**
  - D2: 20 cm
Software

- ENVI 5
- ArcMap 10.1
- IDL
- C#
Categories of remotely sensed data

① **Optical imagery:** acquired in the visible-infrared and thermal region (0.35-1000 um)
   - Aerial color photos
   - Panchromatic images \([,\text{pænkrə'mætɪk}]\)
   - Multispectral images
   - Hyperspectral images
   - Thermal images

② **Microwave imagery:** acquired in the microwave region (1 mm~1m)
   - Radar images
   - LiDAR images (or data cloud)

③ **Spectra**
Color aerial photos 航拍照片颜色

- Traditional data
- Mainly used for making color composites

(Jensen, 2000)
Multispectral images

- Composed of less than 10 bands
- The most popular category
- Available for many satellites
  - Landsat
  - MODIS
  - HJ-1A/B, ZY-3, GF-1

The 2013-2014 wheat season of Baima Lake Farm as seen from Landsat
Panchromatic images 高色波段影像

- In single band
- Usually at high spatial resolution
- Bundled with multispectral images

Source: www.geosage.com
Hyperspectral images

- Very few data from satellite platforms (Hyperion)
- Mostly acquired from aircraft
  -- AVIRIS, HyMap, CASI, ...

Figure from Jensen (2006)
Thermal images

- lower resolution than VNIR images
- not many sources
- in several bands (1-2)
  - Landsat 7 ETM+ band 6
  - Landsat 8 TIRS bands 10, 11
- very useful for studying land surface temperature and energy radiation

Source: Idaho water resources dept.
Radar images

• synthetic aperture radar (SAR), with a different imaging mode.

• satellite sensors:
  — Europe ERS-1/2, ENVISAT-1
  — Japan JERS-1, ALOS-PALSAR
  — Germany TerraSAR-X
  — Canada RadarSat
  — China HJ-1C

• Advantages:
  — not affected by cloud
  — can penetrate vegetation and bare soil in the top layer
  — sensitive to surface roughness
Radarsat images

5 m Radarsat-2 image

Figure from http://eijournal.com/2012/intriguing-images-of-2012-2
LiDAR data

- LiDAR (Light Detection and Ranging)
- acquired with laser beams
- acquisition wavelength at visible and NIR bands
- raw data in point cloud and transferrable to image data

Texas A&M University soybean test site

Source: TAMU Dr. Sorin Popescu
Compared to multi-class classification method (eg. MCSVM & DT), OCSVM can significantly improve the classification efficiency and accuracy at the same time.

The resultant 30m rice map of Jiangsu of 2016 performed well in classification accuracy and area estimation accuracy.
Crop planting area

Crop acreage is needed for productivity statistics.

(Xiao et al. 2005, RSE)
What is the sensitive wavelength to nitrogen?
How to select the sensitive feature of nitrogen?

\[
\text{NDSI} (R_1, R_2) = \frac{(R_1 - R_2)}{(R_1 + R_2)}
\]

\(R_1, R_2\) is the reflectance of the randomly wavelength in 350-2500 nm

720 nm, 860 nm

Concentration map of coefficient of determination \(R^2\) for power linear relationship between all the possible \(\text{NDSI} (R_1, R_2)\) and leaf nitrogen accumulation (LNA).
**Left:** Quantitative relationships of LNA to spectral parameters NDSI ($R_{860}$, $R_{720}$)

**Right:** the 1:1 relationship between the predicted and observed LNA in wheat

\[ \text{NDSI (860, 720)} = \frac{(R_{860} - R_{720})}{(R_{860} + R_{720})} \]

- $R_{860}$: the reflectance at 860nm wavelength,
- $R_{720}$: the reflectance at 720nm wavelength
- LNA: Leaf nitrogen accumulation
- $R^2$: Log style

- H20, N9, Y10, X26 are 4 varieties

② Yao, X. et al. 2009. Chinese agriculture science
How to reduce the noise of background (Soil)

Growth stage

Green up  Jointing  Booting  Anthesis  Filling

To Develop New Vegetation Index Adjusted by Soil Cover

NDVI(R_{513}\text{-}R_{481})/\text{Fvcover} = \frac{(R_{513}\text{-}R_{481})}{(R_{513}+R_{481})*\text{Fvcover}}

Calibration and validation on NDVI(R_{513},R_{481})/\text{Fvcover} under varied crop cover

Monitoring Leaf biochemical parameters on continuous wavelet spectrum

- **PROCWT**: Compared with the traditional method, the inversion precision is significantly improved, especially the content of dry matter LMA.
- **WRCWA**: After removing the influence of water absorption, the absorption characteristics of nitrogenous compounds were more obvious, and the correlation between the little port sign and leaf nitrogen content was significantly improved.
Leaf nitrogen content: rice and wheat

The search of optimal bands for predicting a specific parameter.

(Wang et al., 2012, FCR)
Leaf area index for wheat

Calibration comparisons:
the relationship between LAI and previous VIs / the newly developed $m_{NDVI}$
Grain yield estimation with accumulated nitrogen between jointing and maturity

Predict the grain yield

Grain Yield (kg hm^{-2})

Accumulated leaf nitrogen content $\sum LNC$

$y = 2808 \ln(x) - 12108$

$R^2 = 0.9176$

$R = 0.961$

Accumulated leaf area nitrogen index $\sum LANI$

$y = 6647 \ln(x) - 30394$

$R^2 = 0.9523$

$R = 0.915$

Accumulated leaf nitrogen accumulation $\sum LNA$

$y = 3043.7 \ln(x) - 11041$

$R^2 = 0.9857$

$R = 0.9565$
Estimate the grain protein content

Characteristics spectral index

Leaf nitrogen status at anthesis

Grain protein content

Table 5. Quantitative relationships of GPC ($y$) at maturity to key spectral parameters ($x$) at anthesis, and their performance in predicting GPC in wheat

<table>
<thead>
<tr>
<th>Spectral parameter</th>
<th>Regression equation</th>
<th>Fitness between measured and predicted (Exp.4, $n=24$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$R^2$</td>
</tr>
<tr>
<td>mND705</td>
<td>$y = 10.9075x + 4.7447$</td>
<td>0.759</td>
</tr>
<tr>
<td>REPlE</td>
<td>$y = 0.1925x - 125.348$</td>
<td>0.723</td>
</tr>
<tr>
<td>FD742</td>
<td>$y = 6.2475x + 8.1482$</td>
<td>0.675</td>
</tr>
<tr>
<td>SDr/SDb</td>
<td>$y = 0.3036x + 7.4205$</td>
<td>0.708</td>
</tr>
</tbody>
</table>
Crop disease

- Detect the presence and severity of disease by spectral analysis.
- Early detection is challenging.

(Yuan et al., 2014, FCR)
Monitor the yellow rust

Monitor the sheath blight
Monitoring the early rice blast on hyperspectral RS

- 随病情严重度变化，单叶叶绿素，花青素，水分均随之变化;
- 单一生化指标相关植被指数不能很好监测病情严重度;
- 叶绿素时空分布变化可以指示病情严重度变化
How to predict wheat height with Lidar

vertical view

side view

the original point cloud image of wheat
Point cloud data preprocessing flow

1. Register
2. Noise reduction
3. Sampling
4. Post-processing point cloud data
Monitor the burning straw (MODIS)

In June, farmers burn the remaining plant residue to fertilize the soil for the upcoming maize crop. (wheat-maize rotation)
Track growth process (product traceability)
wheat leaf area index mapping on UAVs in Changge plot
wheat aboveground biomass map on UAVs in Changge plot
wheat leaf nitrogen content mapping on UAVs in Changge plot
wheat leaf nitrogen accumulation mapping on UAVs in Changge plot

长葛试验小区小麦叶层氮积累量无人机监测图
wheat yield and quality mapping on UAVs in Changge plot
wheat leaf area index mapping on sentinel-2B in Changge city
wheat aboveground biomass mapping on sentinel-2B in Changge city
wheat leaf nitrogen content mapping on sentinel-2B in Changge city
wheat leaf nitrogen accumulation mapping on sentinel-2B in Changge city
wheat yield and quality mapping on sentinel-2B in Changge city
wheat planting region mapping on sentinel-2B in Changge city
wheat aboveground biomass mapping on sentinel-2B in Changge city
Wheat Biomass Henan province on GF-1

March

April
Wheat dressing fertilizer in Henan province on GF-1

施肥方案
Leaf nitrogen content in Henan province on GF-1

March

April
Wheat protein content in Henan province on GF-1
Wheat yield in Henan province on GF-1
3. Key technologies

How fertilizer?

Nitrogen Nutrient Index----Diagnosis the nutrient status

Four integrated technologies in the process of crop productivity from sowing to maturity
How to diagnosis the nitrogen fertilizer

Field Experiment

Vegetation Index (VI)

\[ N_a = F(VI) \]

\[ DM = F(VI) \]

\[ \text{NNI} = \frac{N_a}{N_c} \]

\[ N_{\text{NI}} < 1 \]

\[ N_{\text{NI}} \geq 1 \]

\[ N_{\text{NI}} \]

\[ N_{\text{and}} \]

\[ \text{Nue} \]

Optimal dressing N

No dressing N

\[ N_c : \text{Critical nitrogen dilution} \]

Rice:

\[ N_c = 3.53DM^{-0.28} \quad (\text{DM} > 1.55 \text{ t ha}^{-1}) \]

Wheat:

\[ N_c = 4.49DM^{-0.44} \quad (\text{DM} > 1.70 \text{ t ha}^{-1}) \]

\[ N_a : \text{Actual N concentration} \quad (\%) \]

DM: Dry matter \quad (\text{t hm}^{-2})

NNI: Nitrogen nutrition index

\[ N_{\text{and}} : \text{Accumulated N deficit} \quad (\text{kg ha}^{-1}) \]

\[ \text{Nue} : \text{Nitrogen use efficiency} \]
Principle of critical N dilution curve \( (N_c) \)

- The \( N_c \) dilution curve was determined by identifying the data points for \( N \)-limiting and non-\( N \)-limiting growth conditions.

- The variation of N concentration and DM was measured by bilinear relation.
  1. An oblique line of joint increase in DM and N concentration
  2. A vertical line corresponding to an increase in N concentration without variation in DM.

- The \( N_c \) correspond to the ordinate of the intersection point of oblique and vertical lines.

- The series which present only \( N \)-limiting or non-\( N \)-limiting data points were used for partial validation of the curve.

- The data points from experiment conducted in 2007 were used for comprehensive validation of the curve.
How to recommend the nitrogen fertilizer

YM16: \[ N_{and} = -186.29\text{NNI} + 192.27 \]
NM13: \[ N_{and} = -152.81\text{NNI} + 158.9 \]

Turn green: \[ \Delta N = 755.49\Delta\text{NNI} + 42.556 \]
Jointing: \[ \Delta N = 537.27\Delta\text{NNI} - 1.8856 \]
Booting: \[ \Delta N = 417.58\Delta\text{NNI} + 7.6688 \]
Heading: \[ \Delta N = 401.73\Delta\text{NNI} + 19.195 \]
Critical nitrogen ($N_c$) dilution curve for the shoot of rice

\[ N_c = 3.53W^{-0.276} \]
\[ R = 0.8033 \]

Relationship between nitrogen nutrition index (NNI) and accumulated nitrogen deficit ($N_{and}$)

\[ N_{and} = -316.53N_{NI} + 314.84 \]
\[ R = 0.8804 \]

\[ N_{and} = -217.56N_{NI} + 215.44 \]
\[ R = 0.8659 \]

V1: LXY-18
V2: WXJ-14
Diagnosis the nitrogen fertilizer on the dynamic NDVI

Relative NDVI dynamic model for different yield target

Japonica

- <8250kg/ha
- 8250~10500kg/ha
- >10500kg/ha

Indica

- <8250kg/ha
- 8250~10500kg/ha
- >10500kg/ha

RDAT

RNDVI
Recommend the nitrogen fertilizer

Jointing Stage

Booting Stage

\[ \Delta \text{NDVI} = \text{NDVI}_{N_i} - \text{NDVI}_{N_j} \]
\[ \Delta N = N_{N_i} - N_{N_j} \]

(\(i=4, 3, 2; \ j=0, 1, 2, 3; \ i>j\))
The rice dressing fertilizer at field level at booting in Nanjing, Jiangsu province
Wheat dressing fertilizer at county level

wheat Huaxian, in Henan Province

Image: HJ-1, China
Wheat dressing fertilizer at regional level

**Jiangsu province**

Image: HJ-1, China
site-specific fertilization
Real-Time Sensor / Sprayer

精确灌溉
precision irrigation
Precision spraying 精确喷药

精确收获Precise harvest

产量空间分布图 Distribution of production
Spraying by Unmanned Aerial Vehicle

- High efficiency
- Non-toxic
- Low cost
Benefits of Digital Farming for Rice

- Spatial yield variation decreased from 1.17 to 0.24;
- Grain yield increased by 12.2%
- Nitrogen rate decreased by 23.6%
- Economic profit increased by RMB720/ha
Yield variation after digital farming: 0.24
Yield variation before digital farming: 1.17
4. Key technologies

How predict productivity?

Growth Model---Predict the productivity

Four integrated technologies in the process of crop productivity from sowing to maturity
What is the simulation model (SM)?

Definition:
A Crop Simulation Model (CSM) is a simulation model that helps estimate growth process, crop yield, and water and N dynamics as a function of genetics (cultivar), weather factors, soil conditions, and choice of crop management practices.

- Crop simulation models integrate the current state-of-the art scientific knowledge from many different disciplines, including crop physiology, plant breeding, agronomy, agrometeorology, soil physics, soil chemistry, soil fertility, plant pathology, entomology, economics and many others.
Information technology application in the field of agriculture began in the late 1970s, with successful development and application of crop growth simulation models for the outstanding representatives.

Internationally recognized and wide application of crop growth simulation models are:

- United States: CERES
- Netherlands: SUCROS
- Australia: APSIM
- England: AFRC-Wheat
- France: STICS
- Philippines: ORYZA 2000
Australia: APSIM

USA: DSSAT Version 4.0

China: Crop growth

The second prize of national scientific and technological progress
Growth model
Development of CropGrow models

Diagram of matter and energy

- Physiological development time (PDT)
- Phasic stages
- Development rate
- RPE
- Repartitioning (C, N)
- Leaves
- Stems
- Roots
- Panicles
- Grain yield and quality
- Photosynthesis
- Partitioning (C, N)
- Biomass
- Assimilate pool
- Maintenance respiration
- Nutrition stress factor
- Water stress factor
- Soil water balance
- Soil N, P, K balance
- Weather, soil, variety, management data
- Water stress factor
- Growth respiration

Development of CropGrow models

Diagram of matter and energy
Sub-models of CropGrow (Rice/WheatGrow in NJAU)

- Phasic and phenological development
- Photosynthesis and biomass production
- Partitioning and organ establishment
- Grain yield and quality formation
- Water balance
- Nutrient (N, P, K) dynamics
Model-based decision support system

Growth Model-based DSS for Rice-Wheat Management
Input interface of rice simulation system

<table>
<thead>
<tr>
<th>指定气象资料：</th>
<th>系统将根据你选择的(省份)/(市)(/县)(/年份)在数据库中取得相应的气象资料</th>
</tr>
</thead>
<tbody>
<tr>
<td>选择省份：</td>
<td>江苏</td>
</tr>
<tr>
<td>指定年份：</td>
<td>2004-5</td>
</tr>
<tr>
<td>选择县市：</td>
<td>南京市</td>
</tr>
<tr>
<td>日照时数开关：</td>
<td>0-24日照时数</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>指定土壤资料：</th>
<th>系统将根据你选择的(省份)/(市)(/县)(/年份)在数据库中取得相应的土壤资料</th>
</tr>
</thead>
<tbody>
<tr>
<td>选择省份：</td>
<td>江苏</td>
</tr>
<tr>
<td>指定年份：</td>
<td>2004-5</td>
</tr>
<tr>
<td>选择县市：</td>
<td>南京市</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>水稻利用信息输入：</th>
<th>(品种、播期、施肥管理等信息)</th>
</tr>
</thead>
<tbody>
<tr>
<td>指定品种：</td>
<td>武育粳7号</td>
</tr>
<tr>
<td>播种量 (kg/ha) 1</td>
<td>10</td>
</tr>
<tr>
<td>播种量 (kg/ha) 2</td>
<td>184.7</td>
</tr>
<tr>
<td>播种量 (2005 kg/ha)</td>
<td></td>
</tr>
<tr>
<td>播种量 (2005 kg/ha)</td>
<td></td>
</tr>
<tr>
<td>播种量 (2005 kg/ha)</td>
<td></td>
</tr>
<tr>
<td>还田稻秆量 (kg/ha)</td>
<td>0</td>
</tr>
<tr>
<td>播种深度 (cm)</td>
<td>3</td>
</tr>
<tr>
<td>播种期</td>
<td>05-月20-日</td>
</tr>
<tr>
<td>播种期</td>
<td>05-月20-日</td>
</tr>
<tr>
<td>播种期</td>
<td>05-月20-日</td>
</tr>
<tr>
<td>播种期</td>
<td>05-月20-日</td>
</tr>
<tr>
<td>播种期</td>
<td>05-月20-日</td>
</tr>
<tr>
<td>播种期</td>
<td>05-月20-日</td>
</tr>
<tr>
<td>播种期</td>
<td>05-月20-日</td>
</tr>
</tbody>
</table>

| 开始按钮 | 关闭窗口 |
Output interface
Output interface
Model-based virtual wheat growth

基于模型的可视化（虚拟）小麦生长

叶片生长变化
Leaf growth change

叶色变化
Leaf color change

叶鞘sheath 麦穗ear 单茎single stem 小麦生长的虚拟输出
Model-based virtual rice growth

基于模型的可视化（虚拟）水稻生长
Integration of RiceGrow and GIS: Spatialized RiceGrow

- Plant cultivar
- Weather
- Cropping Technology
- Point Model
- Upscale
- Regional Model
- Soil
4. Prediction of regional rice productivity

4.1 Study region-----Southern China
Total sunshine hours during rice growing period

(a. 60’s b. 00’s c. change rate d. relative value of 60’s e. relative value of 00’s)
Total growing degree-days during rice growing period

(a. 60’s  b. 00’s  c. change rate  d. relative value of 60’s  e. relative value of 00’s)
Total precipitation during rice growing period

(a. 60’s      b. 00’s      c. change rate      d. relative value of 60’s      e. relative value of 00’s)
Spatial distribution of rice productivity in Southern China

Potential productivity: 7485 – 15492 kg ha\(^{-2}\)

Water limited productivity: 7100 – 14680 kg ha\(^{-2}\)

Legend as left
N limited productivity

Yield increasing potential

5210—10360 kg ha$^{-2}$

1910—7670 kg ha$^{-2}$
Demonstration and application of the technology

Jiangsu, Anhui, Zhejiang of rice and wheat double seasons rotation districts, Henan, Shandong, Hebei of winter wheat districts, and Jiangxi, Hunan of rice districts were carried in large-scale application and demonstration in recent years.
Performance of the fertilizer recommend technology

$N_1, N_3, N_5$: the traditional technology;  Low level, Medium level, High level

$N_{1r}, N_{3r}, N_{5r}$: regulated by our technology
Training Workshop
Field tour

2010, Rugao, Jiangsu

2010, Wujiang, Jiangsu

2012, Huaxian, Henan

2013, Tongshan, Jiangsu
Rice precise planting technology spot observation meeting in Jiangsu xinghua.
Technical training for different background users
Technical training tool for different background users
Conclusion: Technique Framework


Seeding Tilling Jointing Booting Heading Anthesis Grain filling

Model & Decision Support System
Design the sowing strategy
- Sowing date
- Sowing rate
- Basal NPK
- Water management

RS & GIS & DSS
- Monitor crop growth
- Optimize the resource
- LAI
- Biomass
- N./Water
- Disease
- Nutrition
- Water
- Pesticide

Integration of model with RS
Predict the productivity
- Yield
- Quality
- Use efficiency of resource
Graduate opportunities

- International students are wanted.
- International collaborations are welcome.

① Lidar / UAVs / Hyperspectral remote sensing of vegetation
② Crop growth/biotic/abiotic stress/senescence monitoring
③ Quantification of crop biophysical/biochemical properties
④ Field ecosystem dynamics
⑤ Crop-land use change
⑥ Vegetation mapping
Contact: Prof. Xia Yao (姚霞)

National Engineering & Technology Center for Information Agriculture (NETCIA)
College of Agriculture
Nanjing Agricultural University
Nanjing 210095, China
E-mail: yaoxia@njau.edu.cn
Phone: +86 25 8439 6565
Office: Life Science Building A4009
http://www.netcia.org.cn/XiaYao.html
Any question?