- ***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

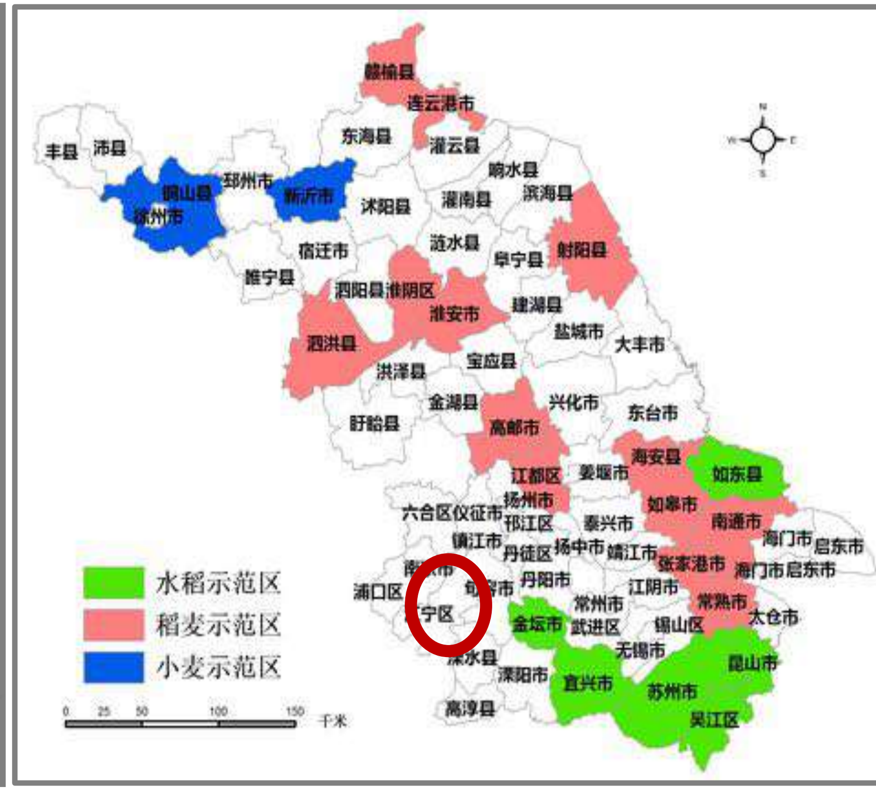
Outline

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

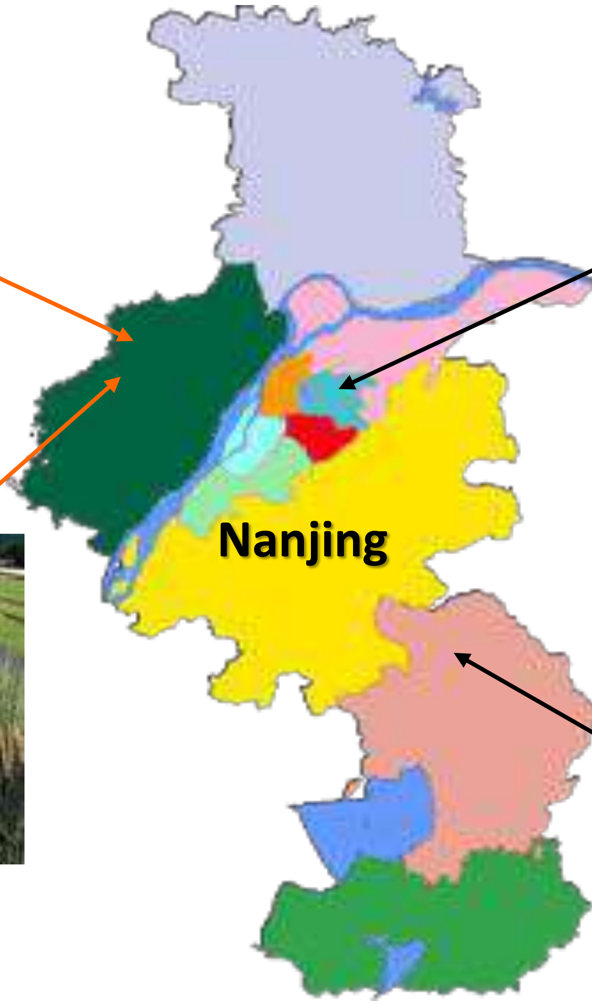
Pioneer of modern agricultural education in China (since 1914)

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

Four campus

PuKou (50 ha)

ZhuJiang (450 ha)



WeiGang (60 ha)

BaiMa (360 ha)

Colleges (19)

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

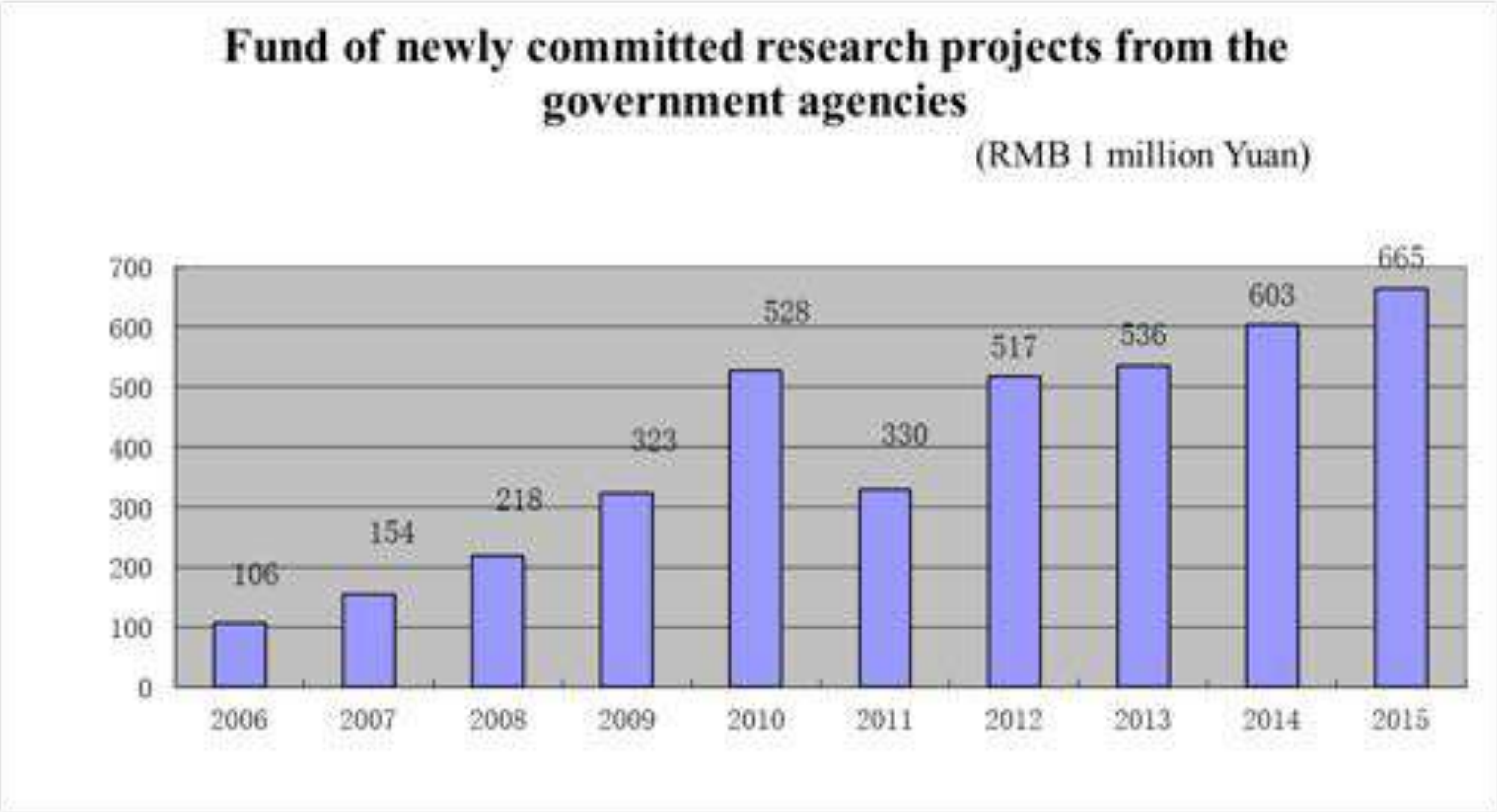
Enrollment

Total enrollment	26,385
①Undergraduates	17,535
②Postgraduates	8,950
③International students	820

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

History

The NETCIA was established by the Ministry of Industry and Information Technology, China in November, 2010.

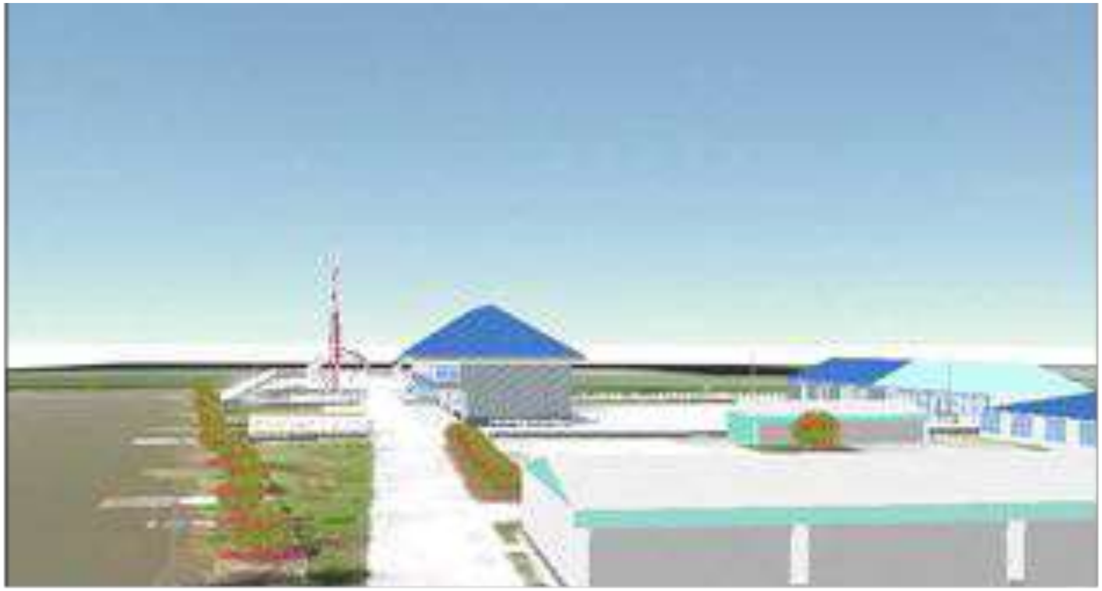
Facility

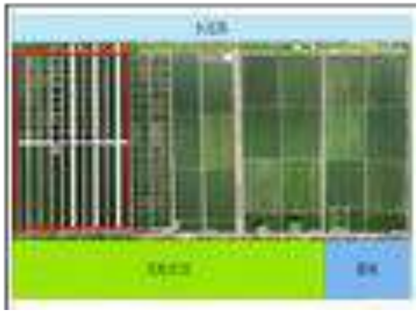

Chemical analysis room


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

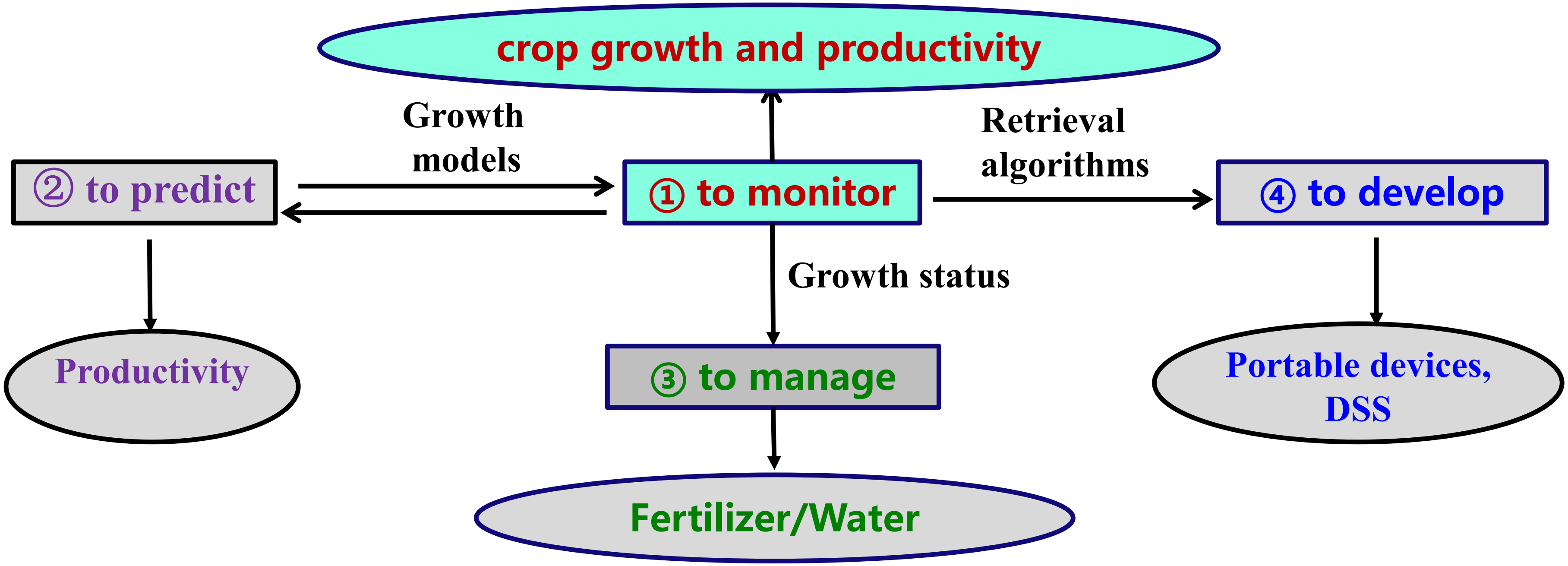
- Faculty members (24)
  - Professors (14)
  - Assoc. Profs. (7)
  - Lecturer (3)
- Graduate students (>70)
- Post-doctors (2)
- Visiting scholars (2)

All of them are from colleges of:

- Agriculture
- Information Science & Technology
- Resource and Environmental Sciences
- Agricultural Engineering

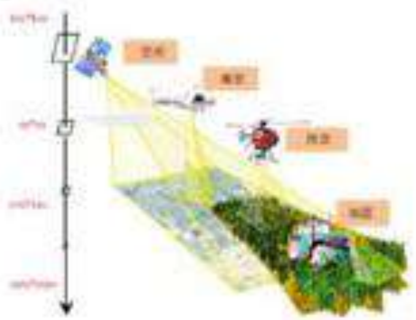
Research Groups

① Agricultural Remote Sensing
② Crop System Modeling
③ Precision Farming and Management
④ Agro-Information Engineering

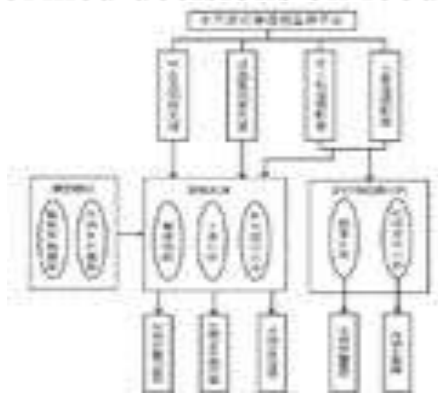


Agricultural Remote Sensing

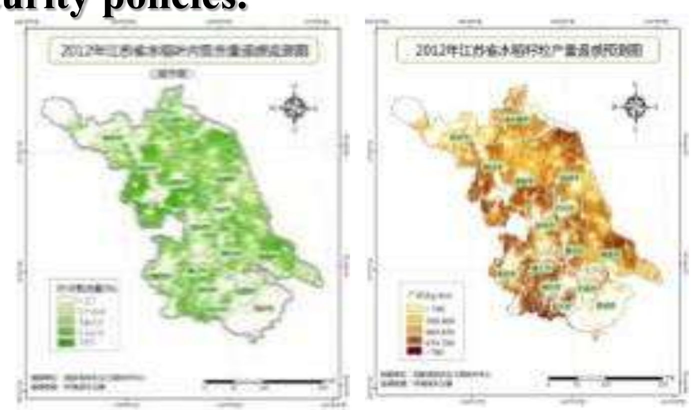
- This research group strives to promote the use of advanced remote sensing (RS) technologies in the process of modern crop production.
- The research activities are built on the sophistical multi-scale platforms for acquiring timely remotely sensed data over crop fields. Low-altitude UAV and satellite 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.



Multi-scale platforms for agricultural condition monitoring



A schematic diagram of the RS based technologies for multi-scale agricultural monitoring



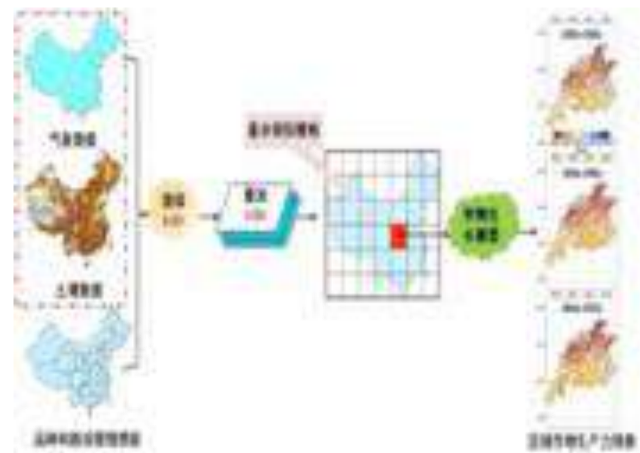
Satellite-derived maps of leaf nitrogen content and grain yield for rice crops in Jiangsu

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 impactson crop production.

A schematic diagram for the crop growth model (CropGrow)

Prediction and visualization of crop growth

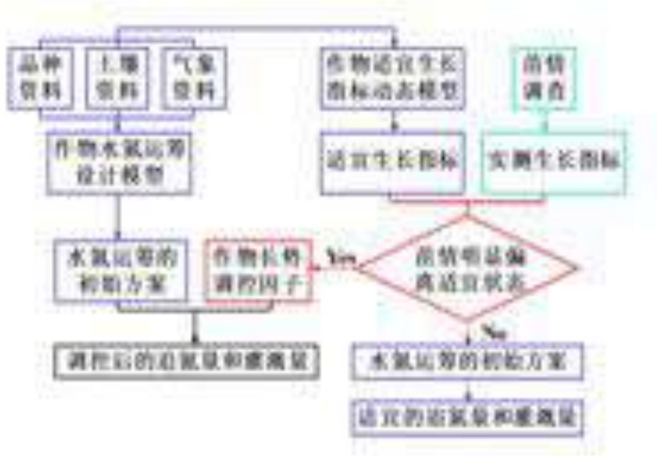


A flowchart for regional prediction of crop productivity

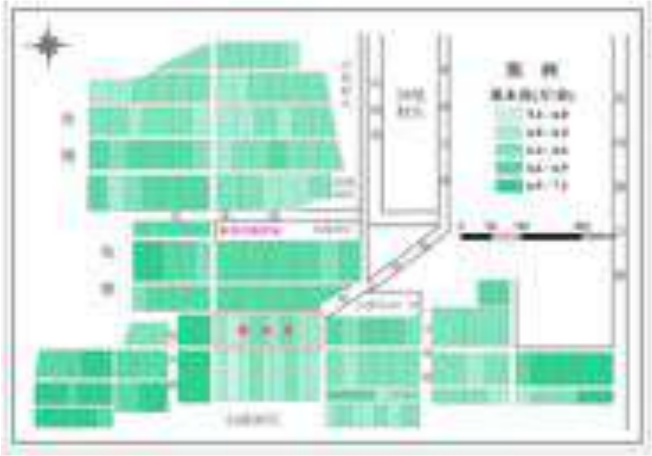
Precision Farming and Management

- 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.

An overview of related technologies for precision management



A workflow diagram for the diagnosis of crop growth status and regulation of fertilization and irrigation strategies



A map for prescribed transplanting density of rice in Tongli Demonstration Base

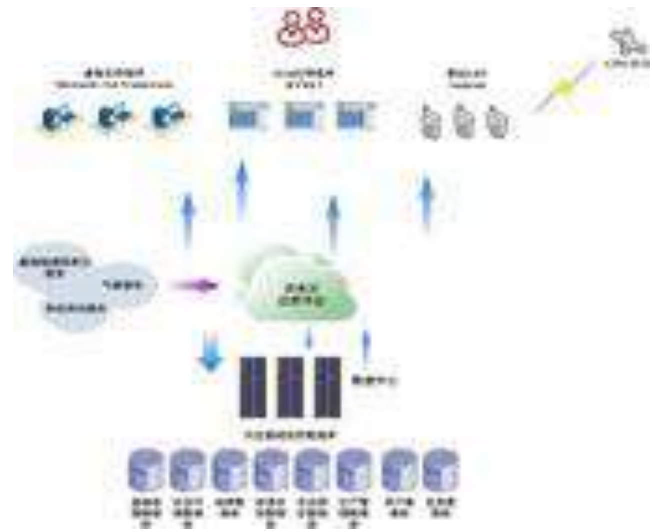
Agro-Information Engineering

- 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.

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.

Distribution of technology demonstration regions

Field workshop on rice precision cultivation

Comparison between the precision plan and the conventional plan

Technical Training

Field Tour

江苏

河南

江西

Press & Media


人民日报

“数字化种田”魅力初显


科技日报

Exchange & Collaboration

- **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.**

International Collaboration Activities

Academic visiting

Exchange & Collaboration

Workshops & Symposiums

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 follows, 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

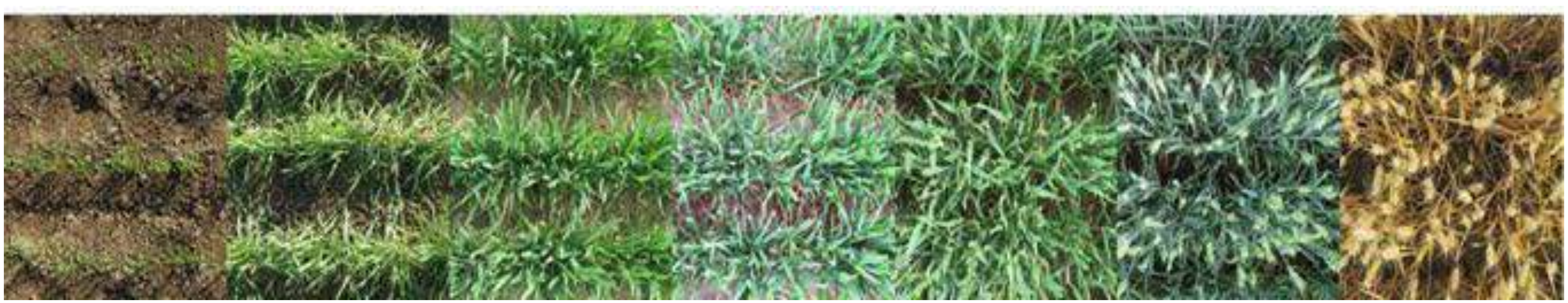
Xia YAO

yaoxia@njau.edu.cn

How many techniques from sowing to maturity for crops ?

How sowing? **How growth?**

How fertilizer/ irrigation? **How productivity?**



Seeding Tillering Jointing Booting Heading Anthesis Grain filling

Crop Production Process

1. Key technology

1. How sowing?

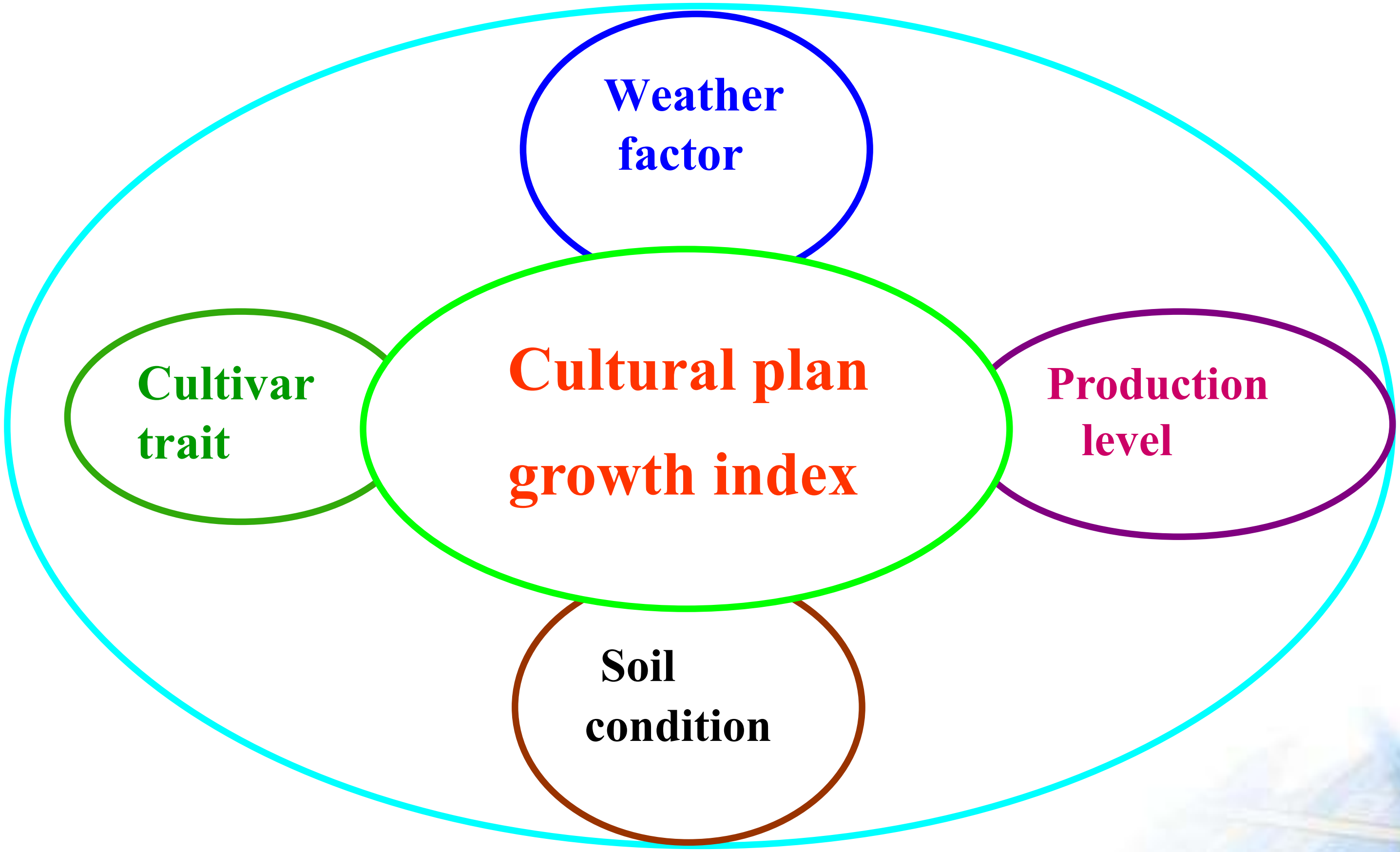
Knowledge Model----Design the sowing strategy

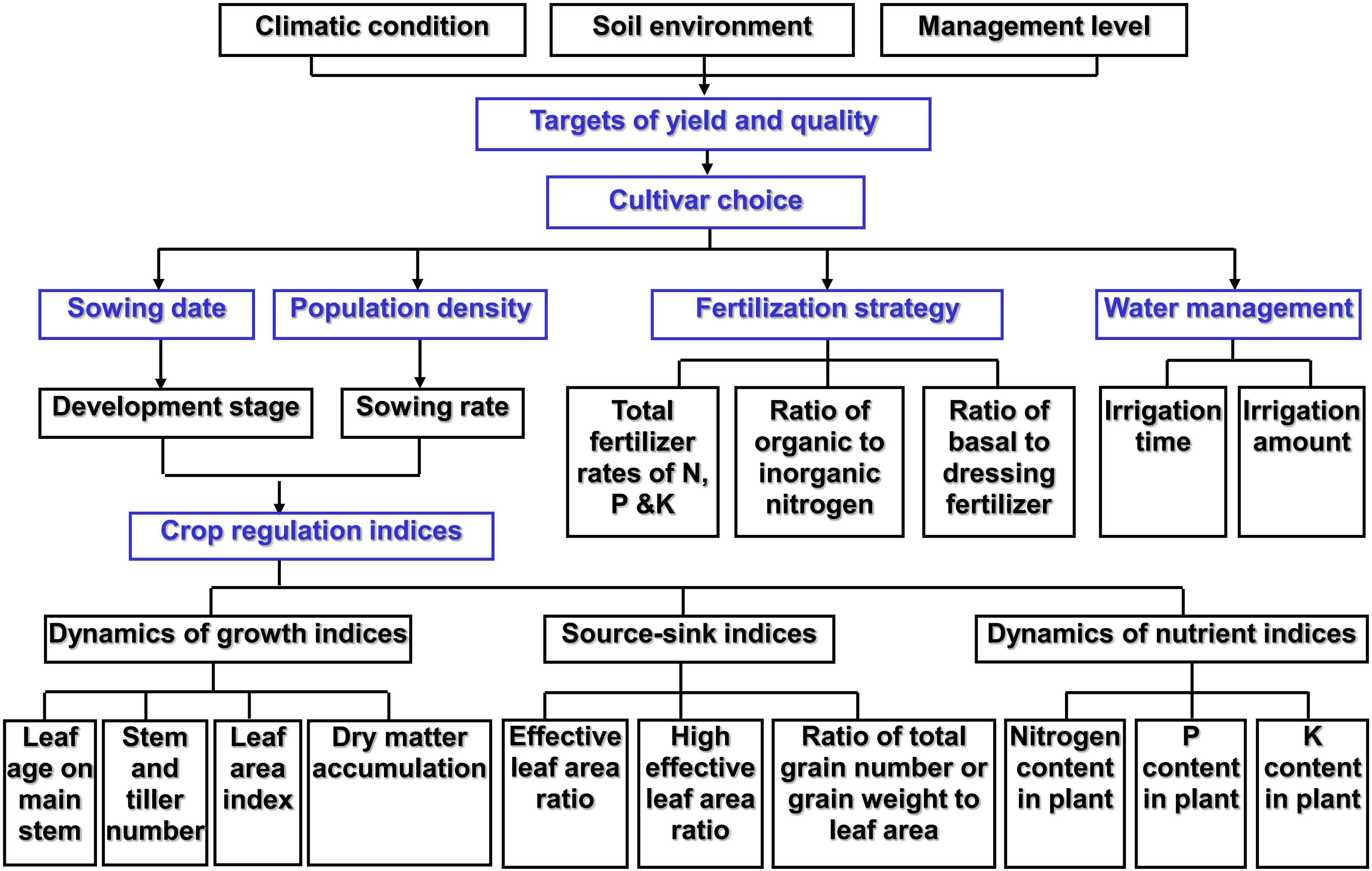
What is Knowledge model

◆ **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





Conceptual knowledge model of Crop

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=∑((Tmax(i)+Tmin(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 = PSN / SSN

– SSN = ATE * STN * VETSR

– STN = 0. 3205 * exp(0.4949 * CLA)

– CLA = TLN - TIN - ETLNJ + 3

– ETLNJ = 0.5 * 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

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

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*MNCG +（1/ HI - 1）*Y*MNCSTR

Nitrogen uptake: NA = NAS + NAF

(1) NAS = YNF*MNCG +（1/ HI - 1）* YNF *MNCSTR

(2) NAF = NFA*NCF*NEF

ND=NU

Nitrogenous fertilizer amount: NFA = (ND - NAS)/(NCF*NEF）

Y — yield
MNCG — minimum nitrogen content in wheat grain (0.01)
MNCSTR — minimum nitrogen content in wheat straw(0.004)
HI — harvest index
NAS — nitrogen absorbed from soil
NAF — nitrogen absorbed from fertilizer
YNF — yield without nitrogen fertilizer
NCF — nitrogen content in nitrogenous fertilizer
NEF — nitrogenous fertilizer use efficiency

Tiller number dynamic algorithm

$$OPTN(GDD) = PN + (OPTN_{MAX} - PN) \times e^{\frac{-c\times(d-GDD)^2}{GDD^2}}$$

$$c1 = -\ln\left(\frac{PTN_{BW} - PN}{OPTN_{MAX} - PN}\right) \times \frac{GDD_W^{\ 2}}{(GDD_J - GDD_W)^2}$$

$$c2 = -\ln\left(\frac{1.05 \times SPN_Y - PN}{OPTN_{MAX} - PN}\right) \times \frac{GDD_H^{\ 2}}{(GDD_H - GDD_J)^2}$$

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

PN — plant number per unit area

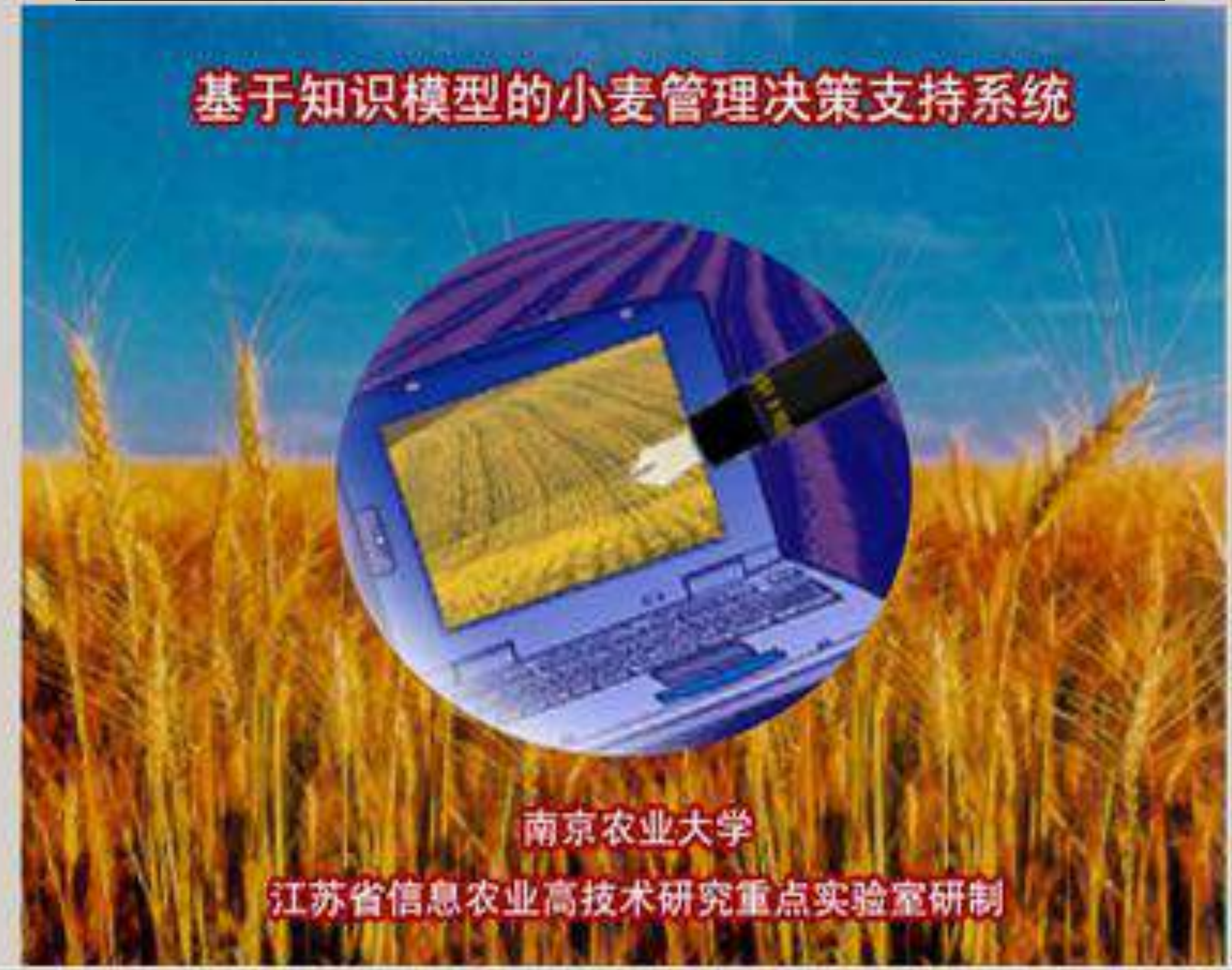
$OPTN_{MAX}$ — maximum stem and tiller number per unit area

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

基于知识模型的水稻管理决策支持系统

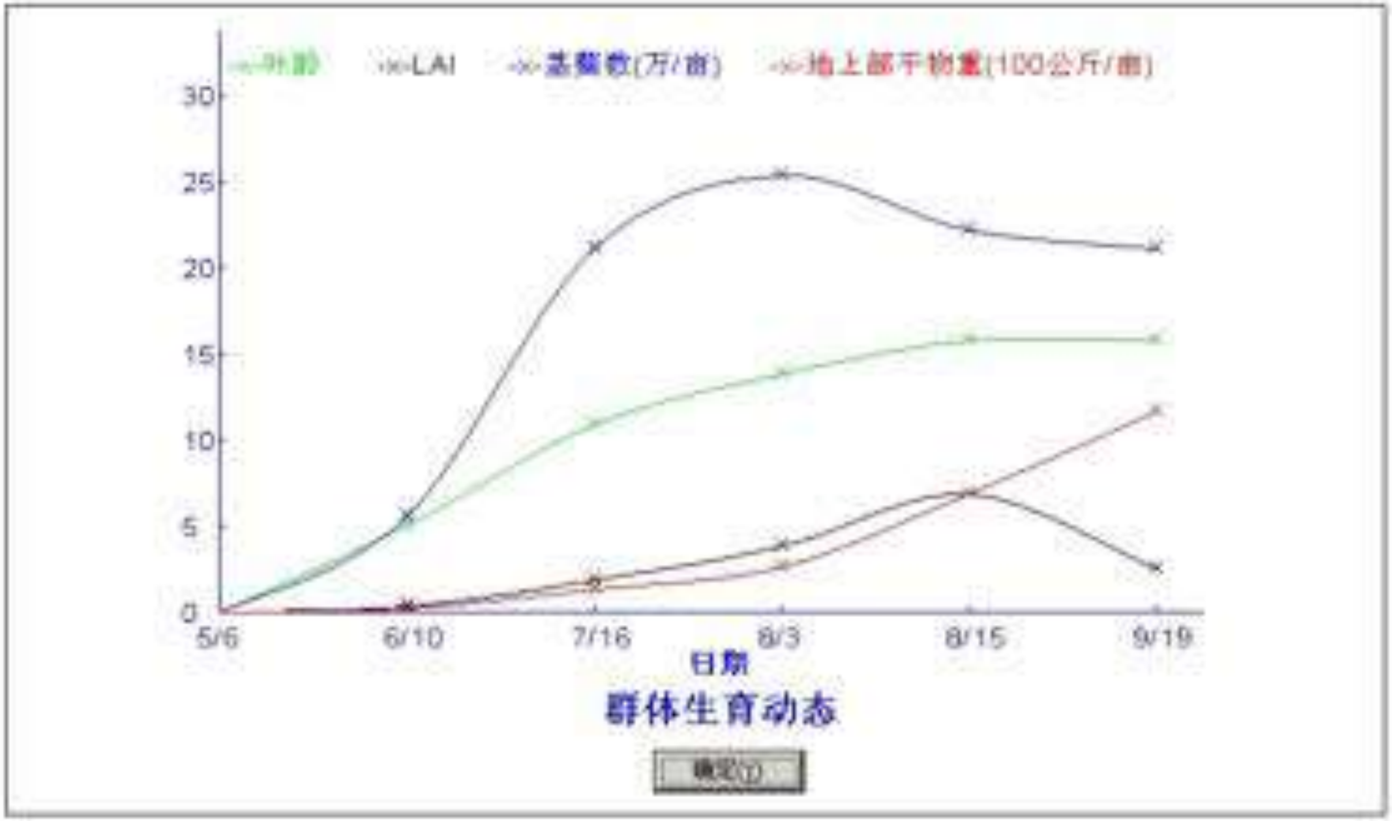
综合方案

指标	具体值
品种名称	6427
置信度	0.94
播期	1996/04/12—1996/06/02
秧田亩播种量[千克]	67.82
每亩秧田成秧苗数[万株]	140.64
每亩大田基本苗数[万株]	1.00
纯氮总量[千克/亩]	28.45
P2O5总量[千克/亩]	6.75
K2O总量[千克/亩]	4.12
基肥纯氮量[千克/亩]	17.25
追肥纯氮量[千克/亩]	11.19

['fɑsfərəs]

[pə'tæsɪəm]

Dynamic growth index



Suitable development stages

生育进程

时期	日期
播期	常年/10/27 ~ 常年/11/08
分蘖期	常年/11/04 ~ 常年/11/20
越冬期	常年/01/04
返青期	常年/02/06
拔节期	常年/04/04 ~ 常年/04/20
孕穗期	常年/04/21 ~ 常年/04/28
抽穗期	常年/04/28 ~ 常年/05/08
开花期	常年/05/08 ~ 常年/05/20
灌浆期	常年/05/16 ~ 常年/05/30
成熟期	常年/05/30 ~ 常年/06/05

Uniprocessor version

Knowledge Model-based DSS for Crop Management

Network version

Wheat：Decision Output - Microsoft Internet Explorer

Hi-Tech Key Laboratory of Information Agriculture, Jiangsu Province

江苏省信息农业高技术研究重点实验室

CUT HERE

【Fertilization Strategy】

Column	Output Item	Output Value
1	Nitrogen fertilizer(N)application amount[kg/mu]	19.27
2	Phosphorus fertilizer(P2O5)application amount [kg/mu]	4.57
3	Potash fertilizer(K2O)application amount[kg/mu]	8.40
4	Organic manure:Chemical fertilizer	0.66:9.34
5	Nitrogen fertilizer basal dressing:Tiller:Elongation and Booting:Seeds	5.73 : 1.05 : 2.15 : 0.00
6	Phosphorus fertilizer dressing rate of basal and top	7.45 : 2.55
7	Potash fertilizer dressing rate of basal and top	6.82 : 3.18

【Input Condition】

Region:Nanjing Variety type:Ningmai9hao Soil type:Nanjing01 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:0.35 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 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

Main interface

Interface of sowing date decision making

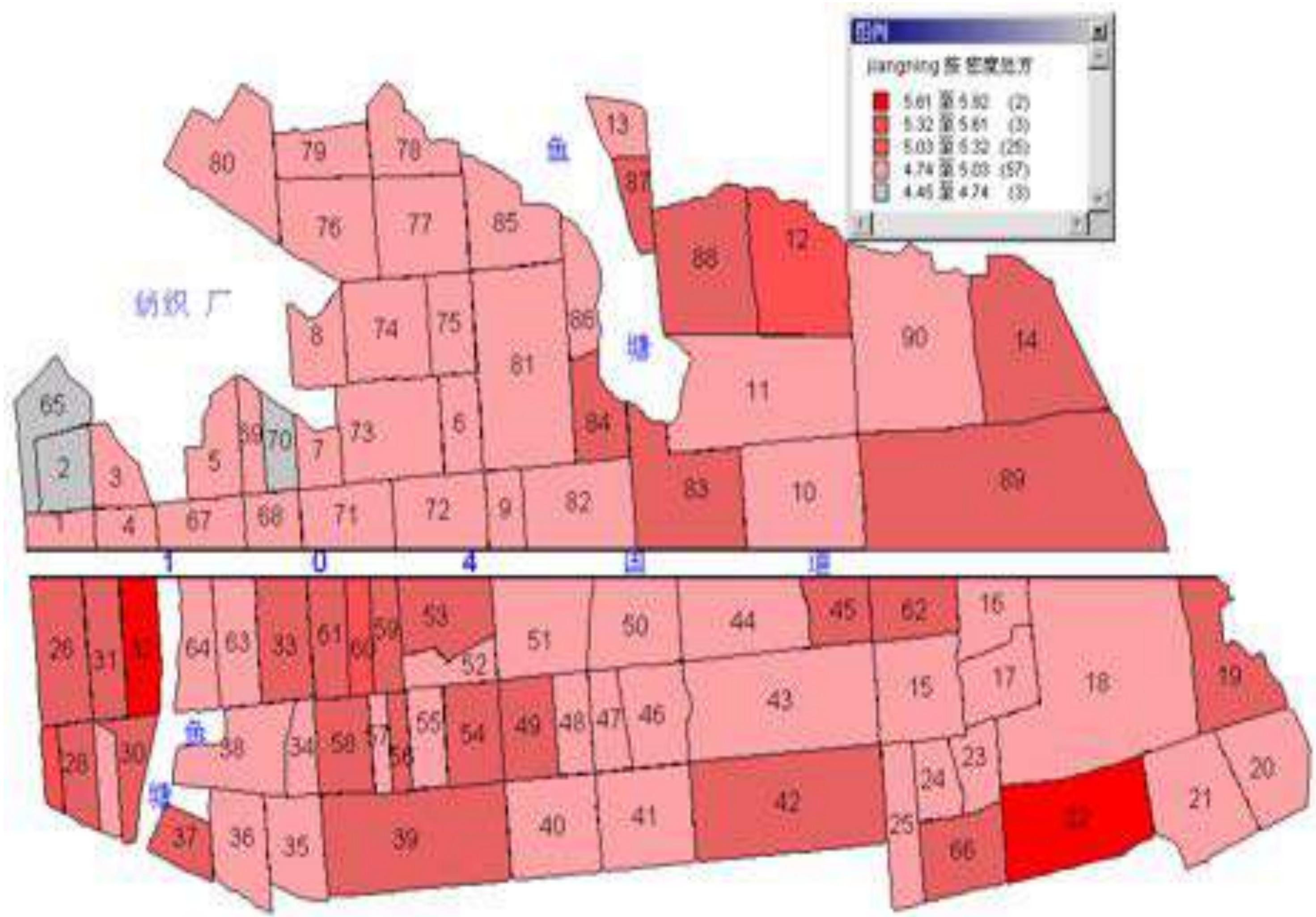
Interface of plant density decision making

Knowledge Model-based PDA for Rice Management

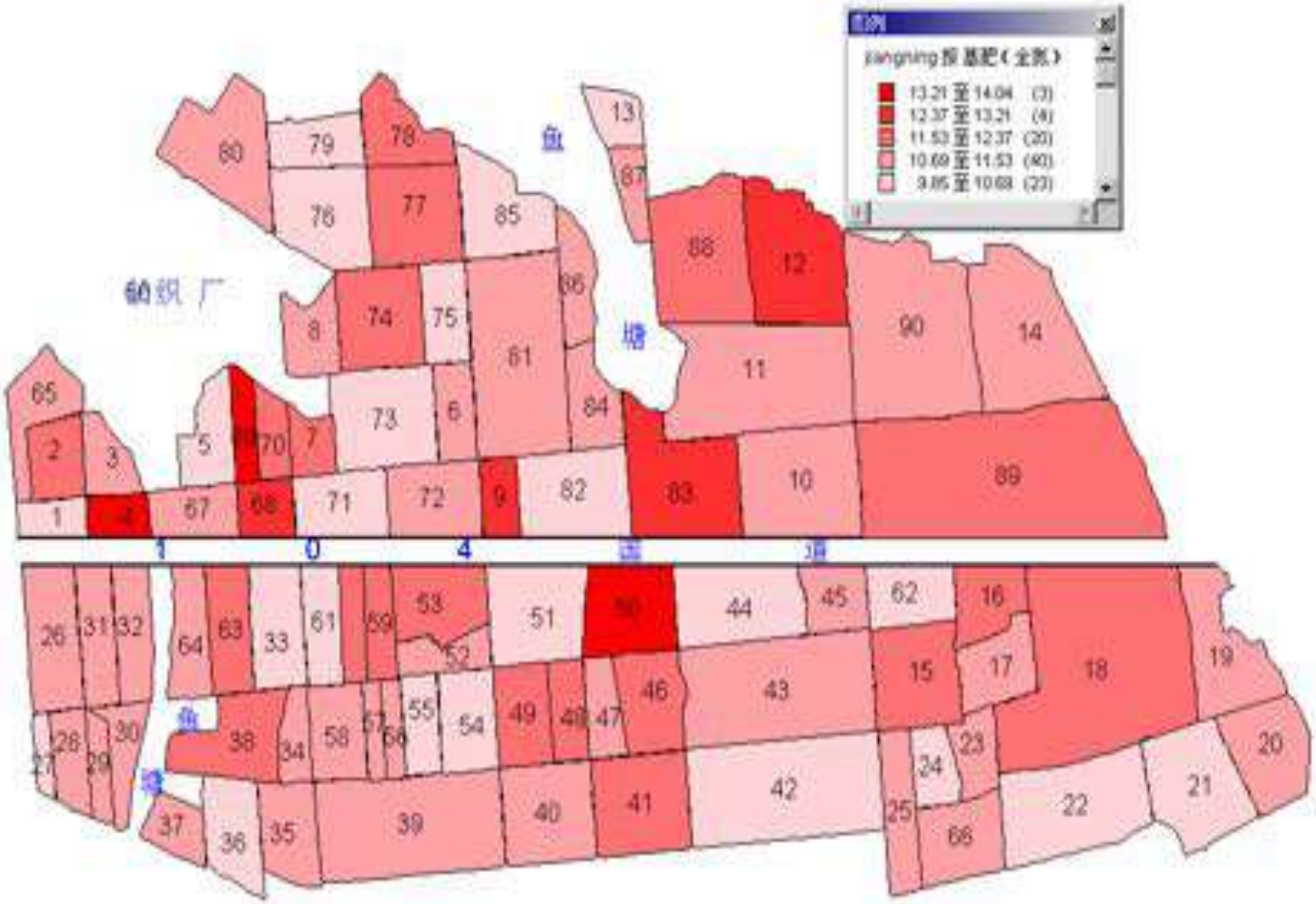
Input interface of fertilization decision making **Output interface**

Demo: Design the sowing strategy (Model & DSS)

❖ **Prescription map of plant density**



❖ Prescription map of basal N rate



2. Key technology

How growth?

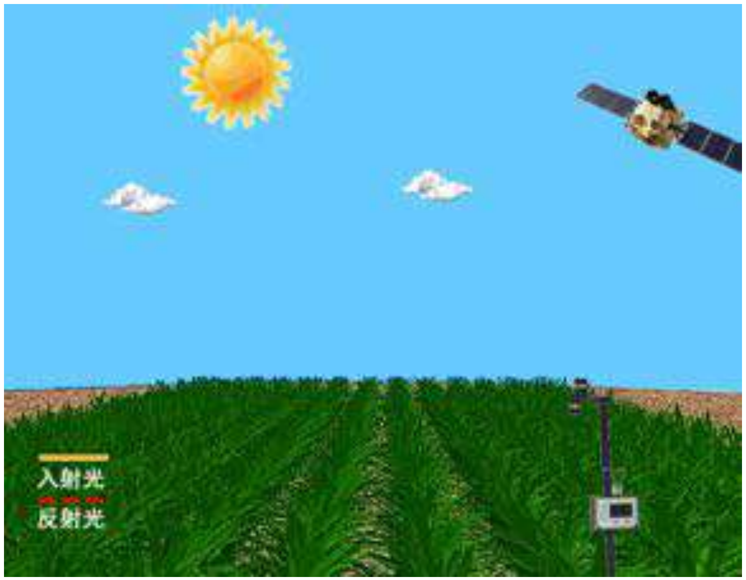
Remote Sensing----Monitor the growth index; Predict the yield

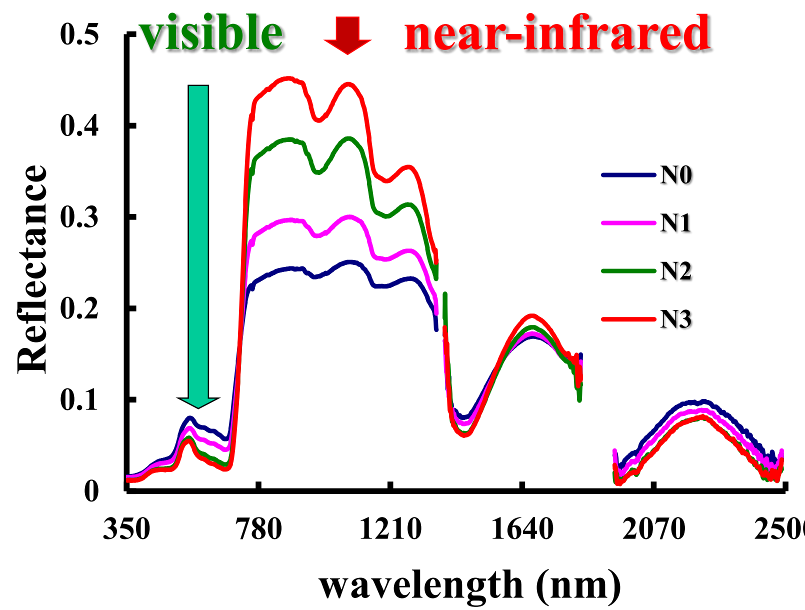
① Crop acreage
② Canopy leaf nitrogen content and accumulation
③ Canopy leaf chlorophyll content and accumulation
④ Leaf area index
⑤ Canopy leaf dry weight
⑥ Grain yield and protein content
⑦ Crop disease
⑧ Straw burning
⑨ Track growth process

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?





Variety：Aikang 58（Jointing)

- 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.

Sensors parameters

	Sensor	Band	Price (yuan)	Weight (g)	Manufacturer
Imaging	UHD-185 (passive, hyperspectral)	450 ~ 900 nm	438,900	470	Germany Cubert
	Mini MCA6 (passive, multispectral)	NIR(900nm,800nm) RE(720nm) R(680nm) G(550nm) B(490nm)	120,000	700	USA Tetracam
	Canon 5D Mark III	R、G、B	30,000	860	Japan Canon
	Canon SX260 HS	NIR(670~770nm) G、B	2,000	200	Japan Canon
Non-imaging	RapidSCAN CS-45 （active, multispectral）	NIR(780nm) RE(730nm) R(670nm)	40,000	800	USA Holland Scientific
	CGMD-602 （passive, multispectral）	NIR(815nm) RE(730nm)	8,000	500	NAU NETCIA

Satellite imagery and characters

	Satellite	Highest spatial resolution (m)	Revisiting period (day)	Band Number	Price (yuan/Km^2)	Country
Medium resolution	Landsat 8	15	16	11	free	USA
	Sentinel-2	10	5	13	free	ESA
	HJ-1 (A/B)	30	2	4	free	China
High resolution	WorldView-2	0.46	1.1	9	220	USA
	RapidEye	5	1	5	17	Germany
	GF-1	2	2	9	0.89	China
	GF-2	1	5	5	80	China

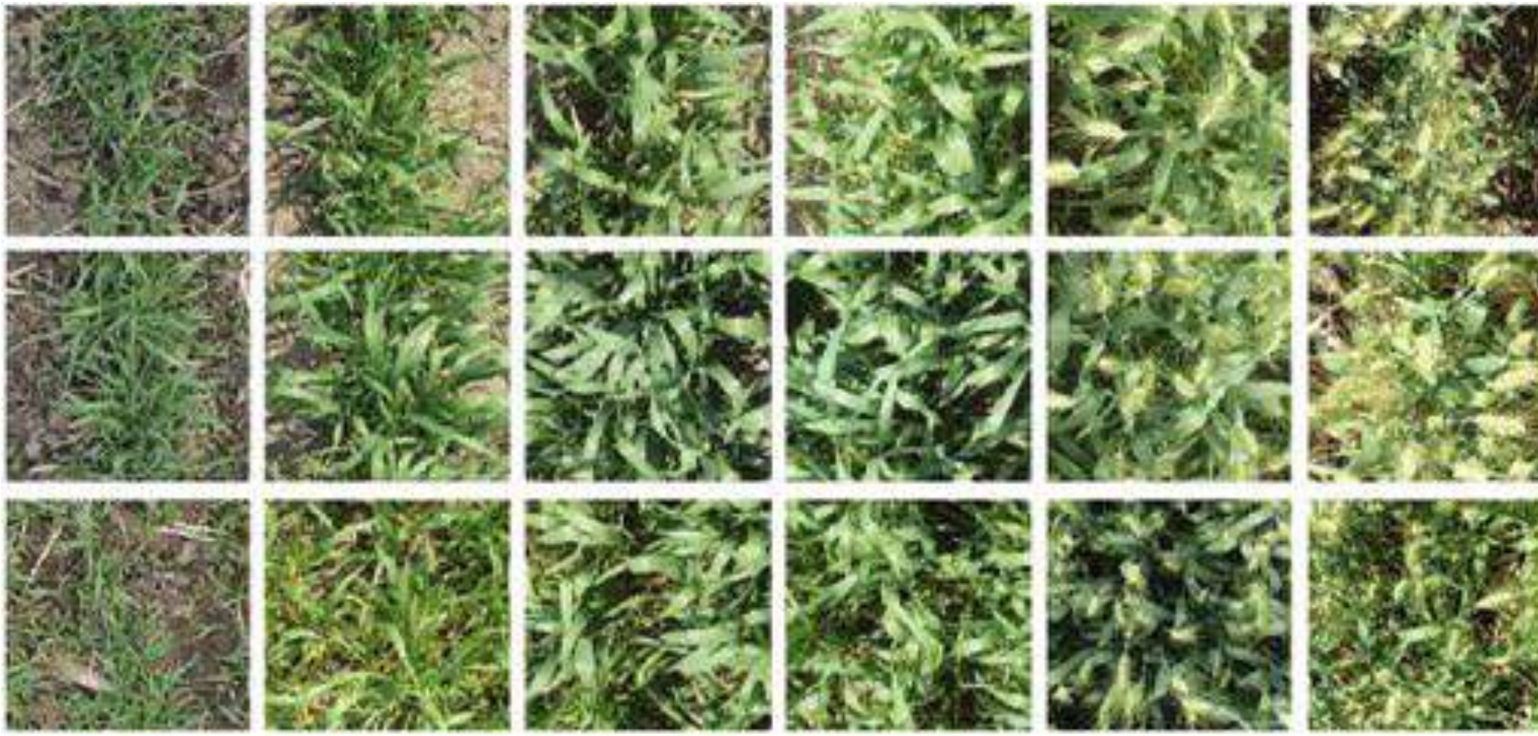

Platforms for remote sensing
from Leaf to Globe
(Inoue, 2000)
NIAES

The field pictures of different planting densities and nitrogen levels at varied growth stages in wheat

Low density low Nitrogen (D1N1) D1:40cm

Low density high nitrogen (D1N3) D1:40cm

High density low nitrogen (D2N1) D2:20cm



Progress	Reviving	Jointing	Booting	Heading	Anthesis	Filling
GDD(^{o}C·d)	810	1114	1438	1547	1715	1931

Software

erdas
The Earth to Business Company

ArcMap 10.1

IDL

photoscan...

RiSCAN PRO

MATLAB R2014a

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** [ˌpænkrə'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**

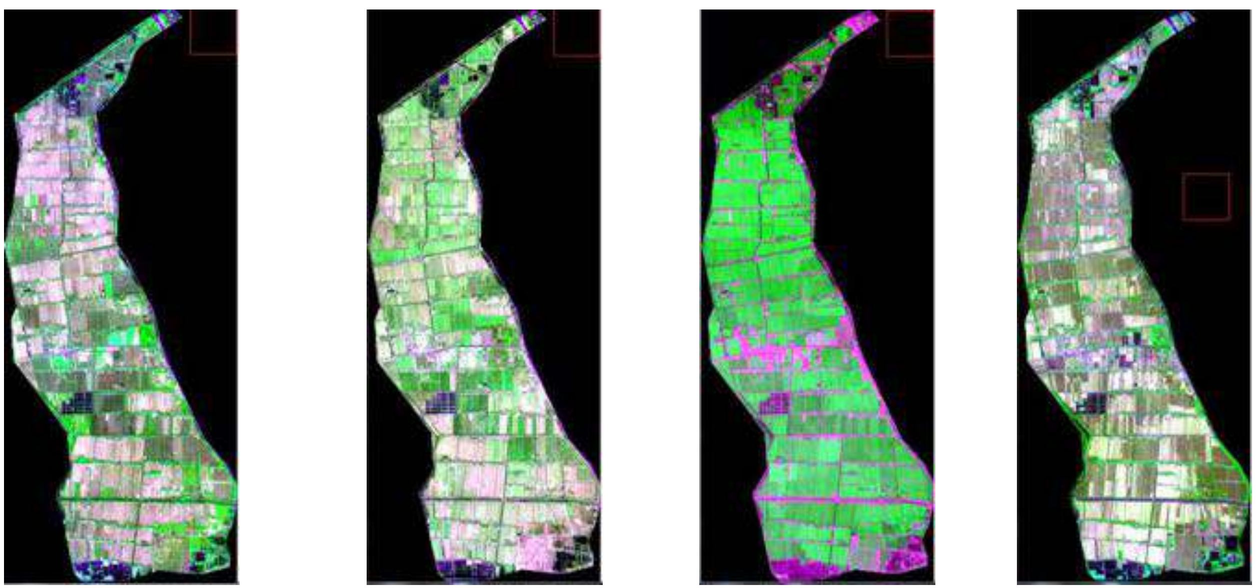
True color

False color

(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全色波段影像

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

Pan Multispectral Fused

Source: www.geosage.com

QuickBird images

Hyperspectral images

- **Very few data from satellite platforms (Hyperion)**
- **mostly acquired from aircraft**

  -- AVIRIS, HyMap, CASI, …

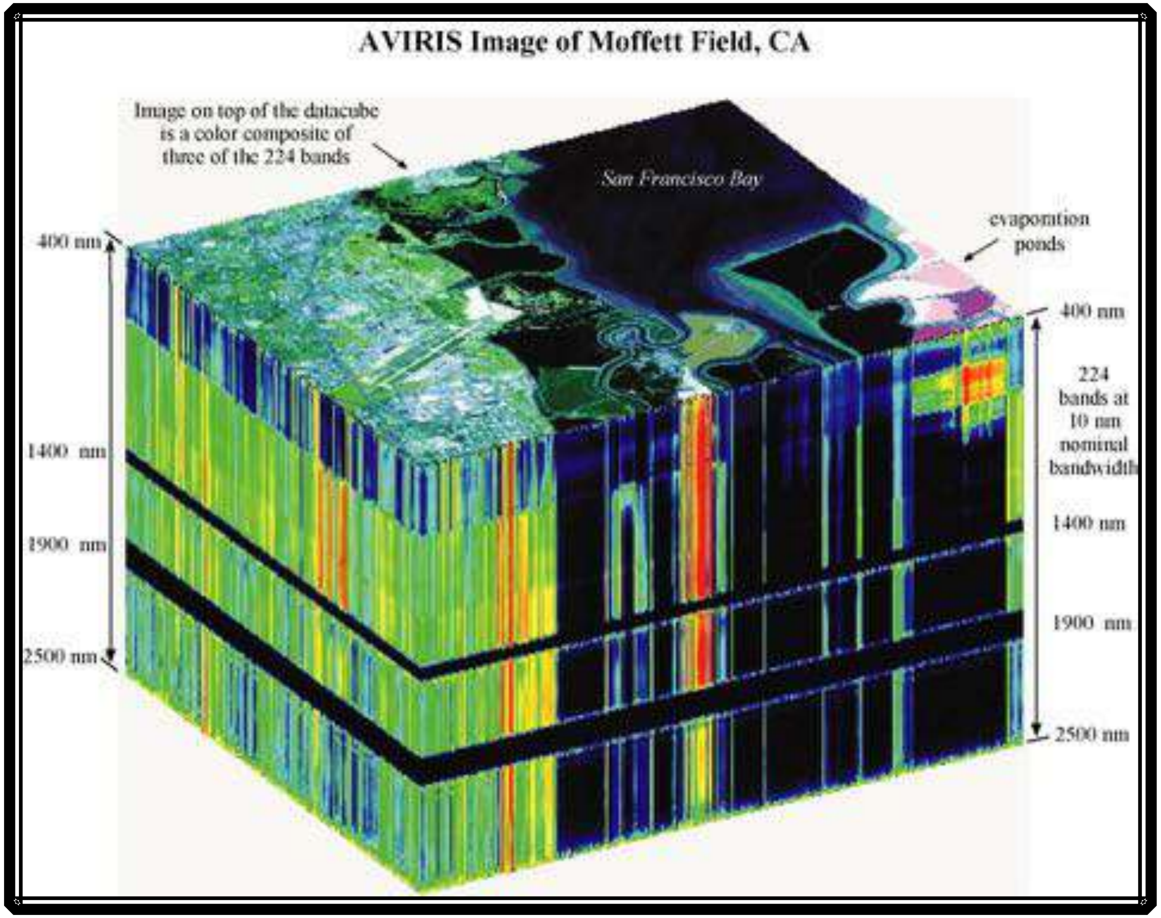


Figure from Jensen (2006)

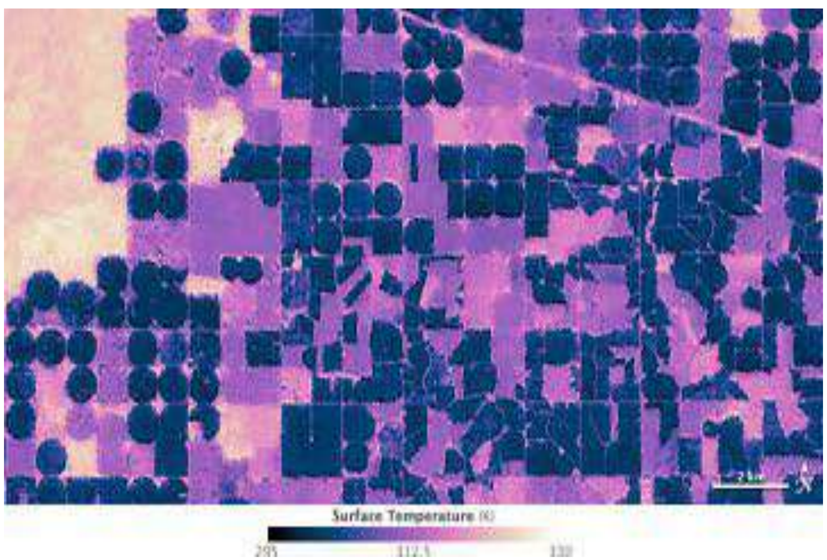
Thermal images

- lower resolution than VNIR images
- not many sources
- in several bands(1-2）

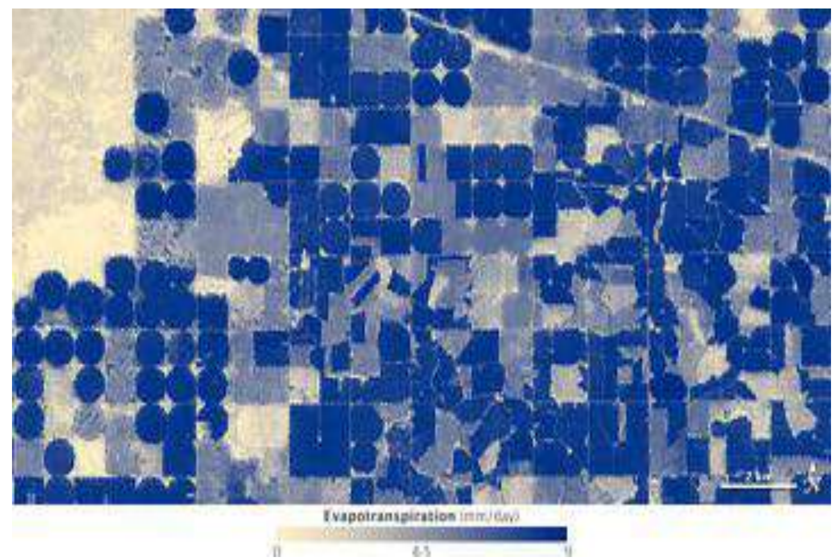
— Landsat 7 ETM+ band 6

— Landsat 8 TIRS bands 10, 11

- very useful for studying land surface temperature and energy radiation



Land surface temperature



Evapotranspiration

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

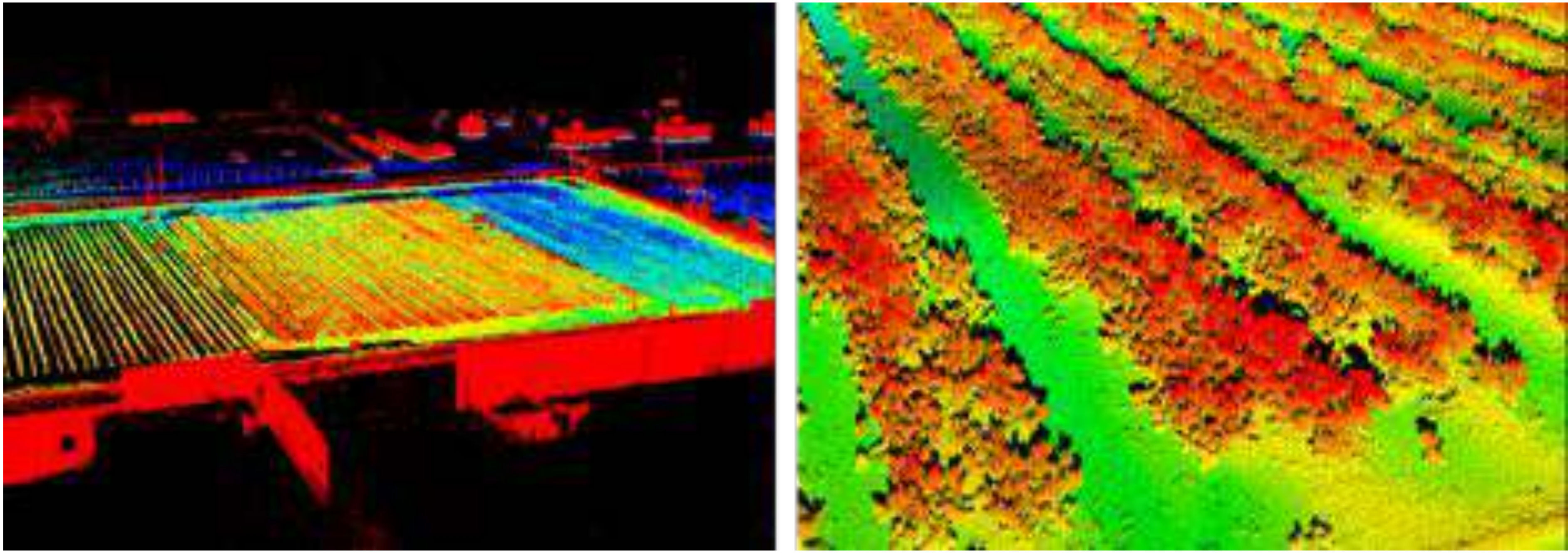
Radarsat images

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**

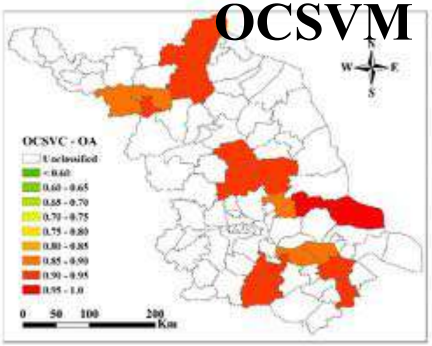


Texas A&M University soybean test site

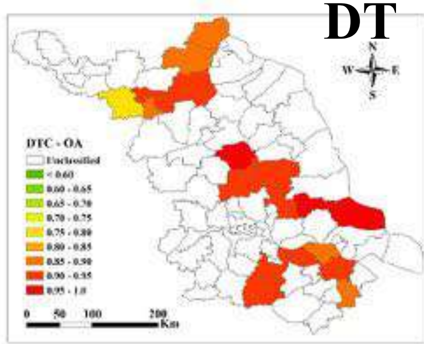
Source: TAMU Dr. Sorin Popescu

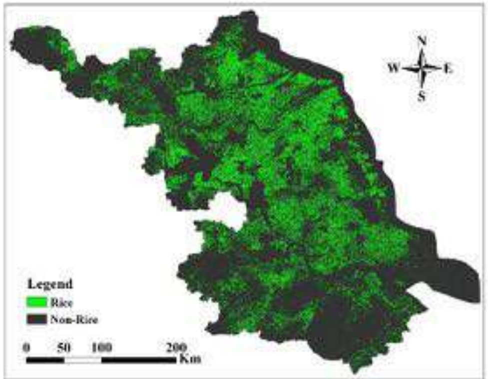
Rice identification and planting area monitoring on satellite RS

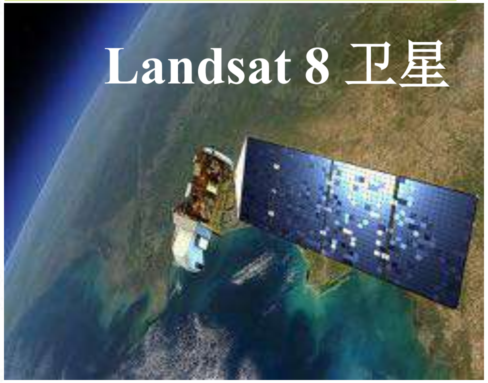
OCSVM



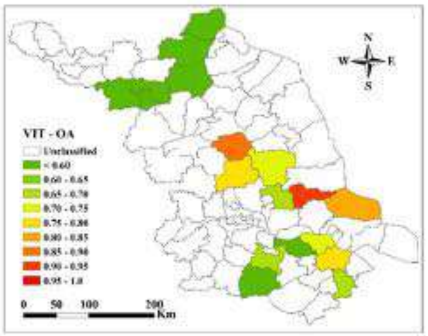
DT



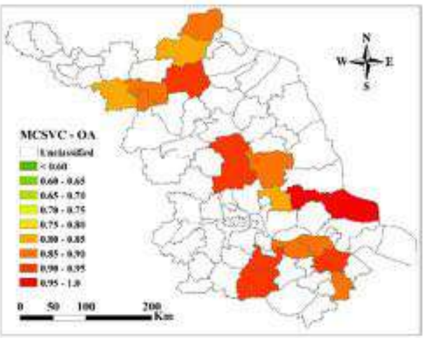


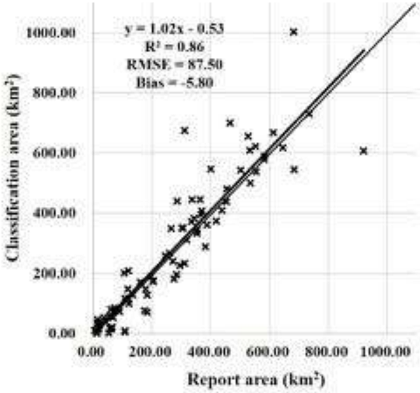


VIT



MCSVM



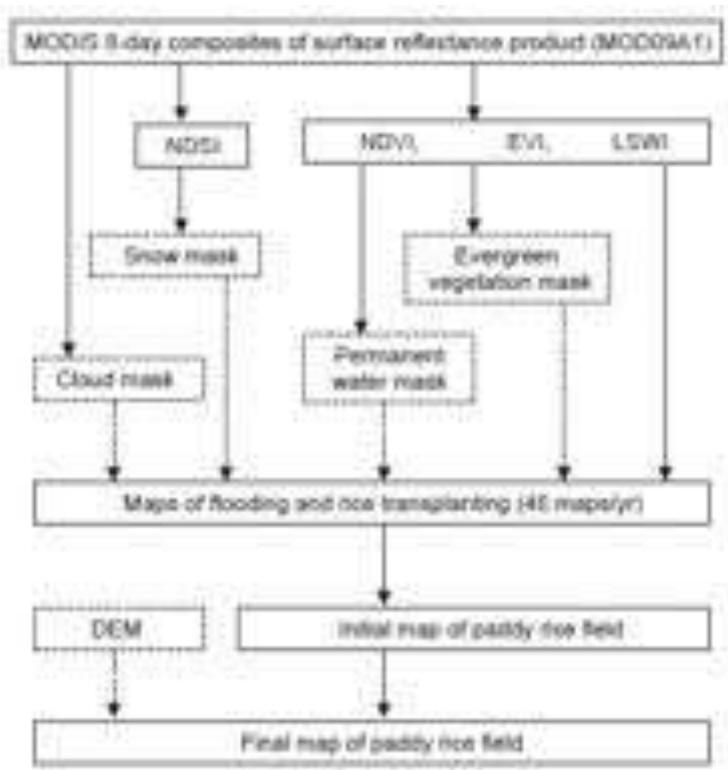


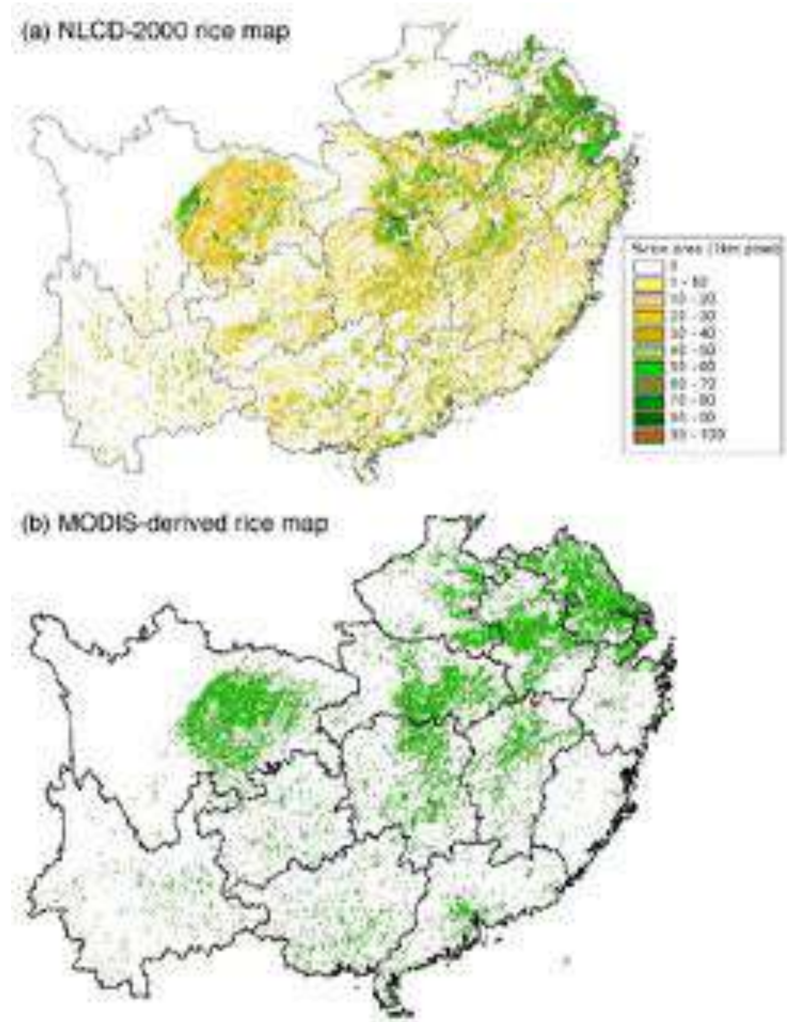
Research on Rice Identification and Planting Area Monitoring Based on Satellite Remote Sensing

- **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.

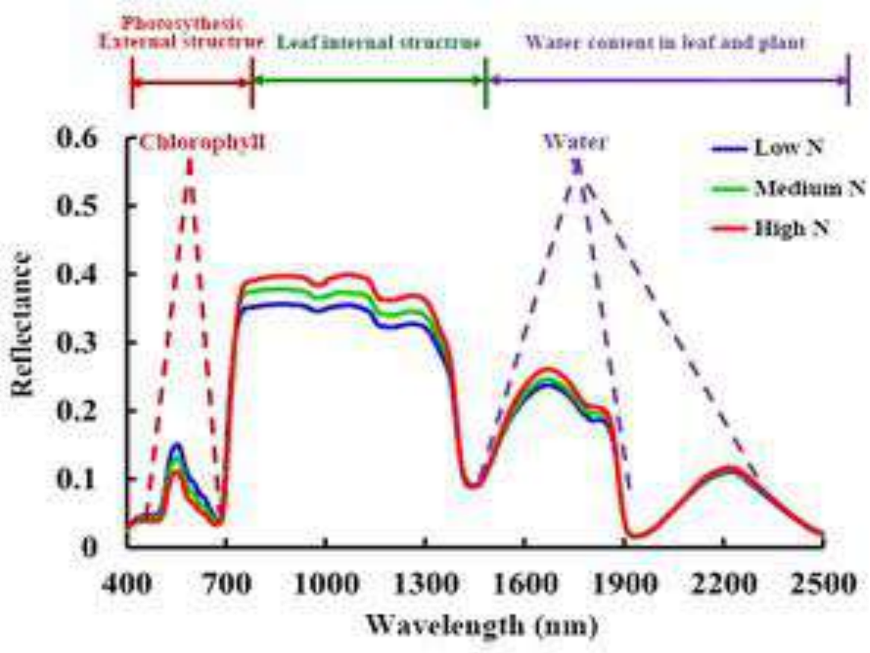


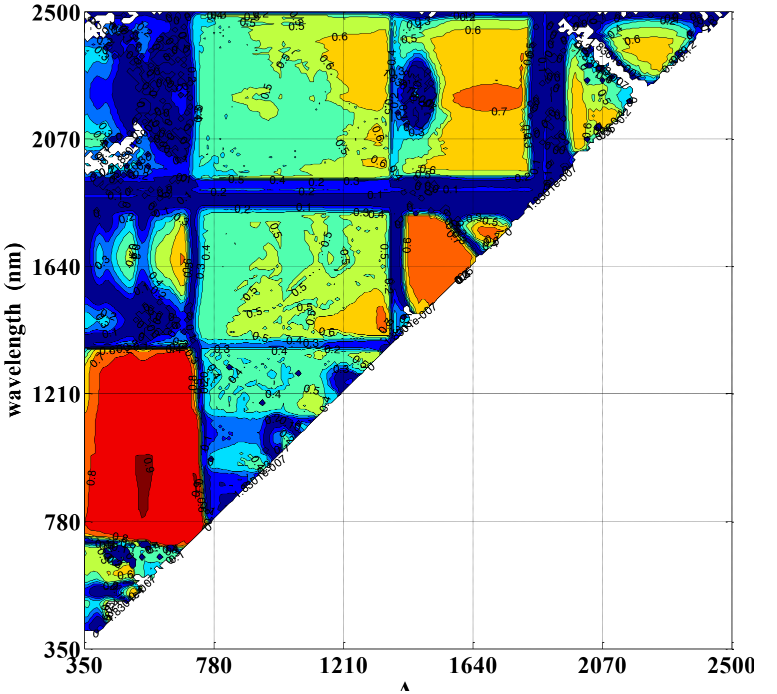


(Xiao et al. 2005, RSE)

◆ What is the sensitive wavelength to nitrogen?

◆ How to select the sensitive feature of nitrogen?



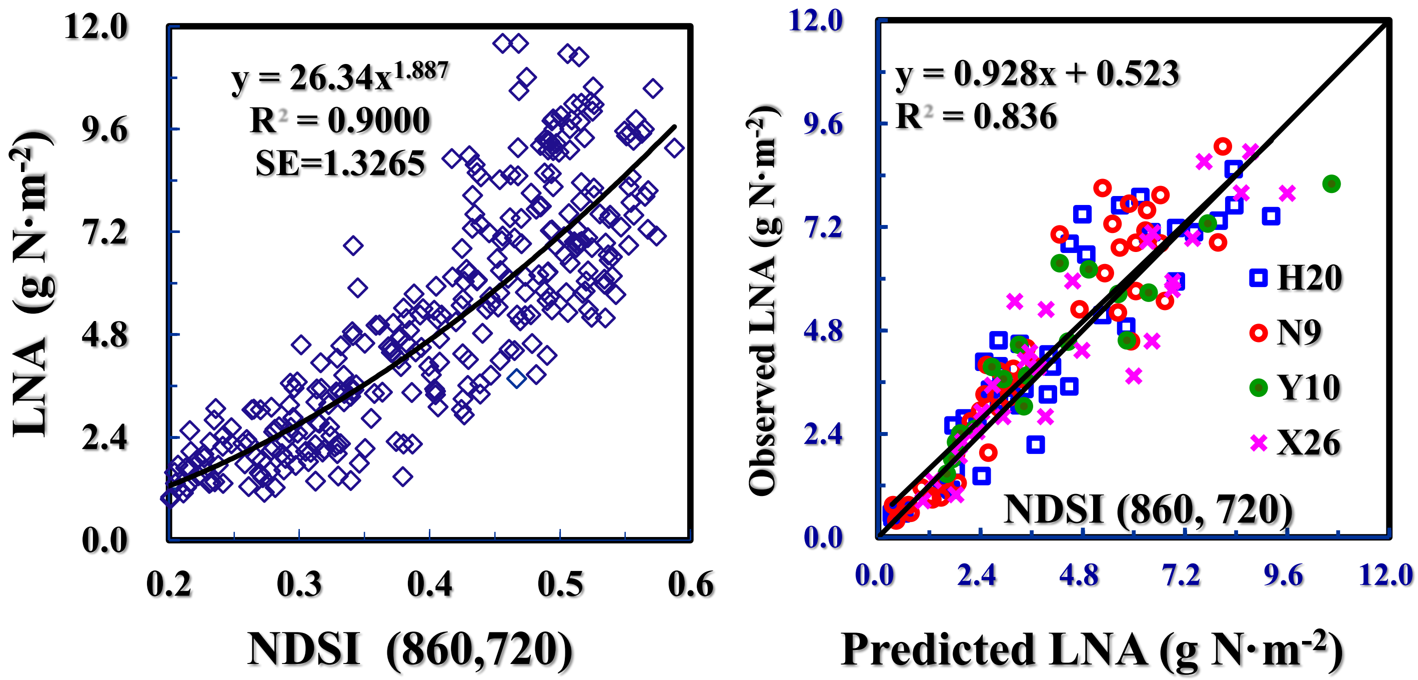


$$NDSI(R_1, R_2) = (R_1 - R_2) / (R_1 + R_2)$$

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 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

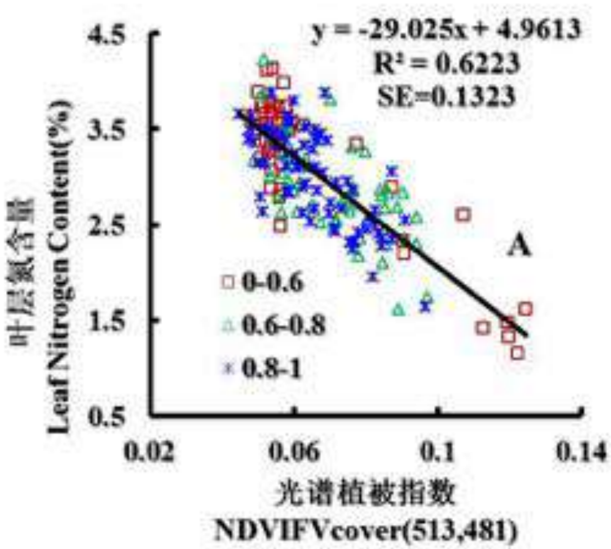
NDSI (860, 720) = $(R_{860}-R_{720}) / (R_{860}+R_{720})$
R_{860} : the reflectance at 860nm wavelength,
R_{720} : the reflectance at 720nm wavelength
LNA: Leaf nitrogen accumulation
R^2: Log style

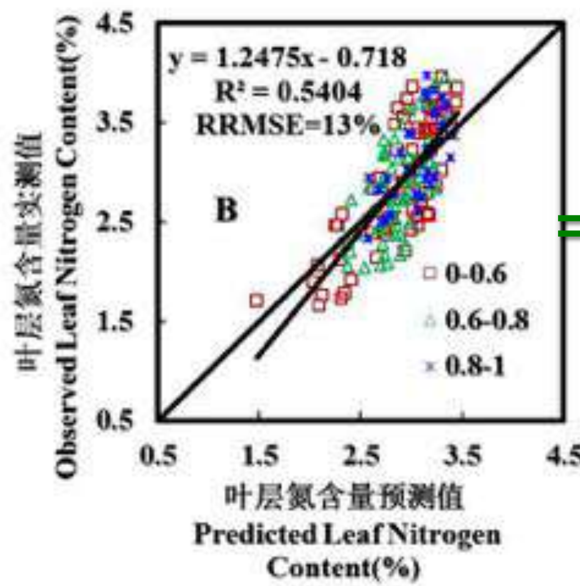
H20, N9, Y10, X26 are 4 varieties

① Yao, X. et al. 2010. International Journal of Applied Earth Observation and Geoinformation.
② Yao, X. et al. 2009. Chinese agriculture science

◆ How to reduce the noise of background (Soil)

To Develop New Vegetation Index Adjusted by Soil Cover





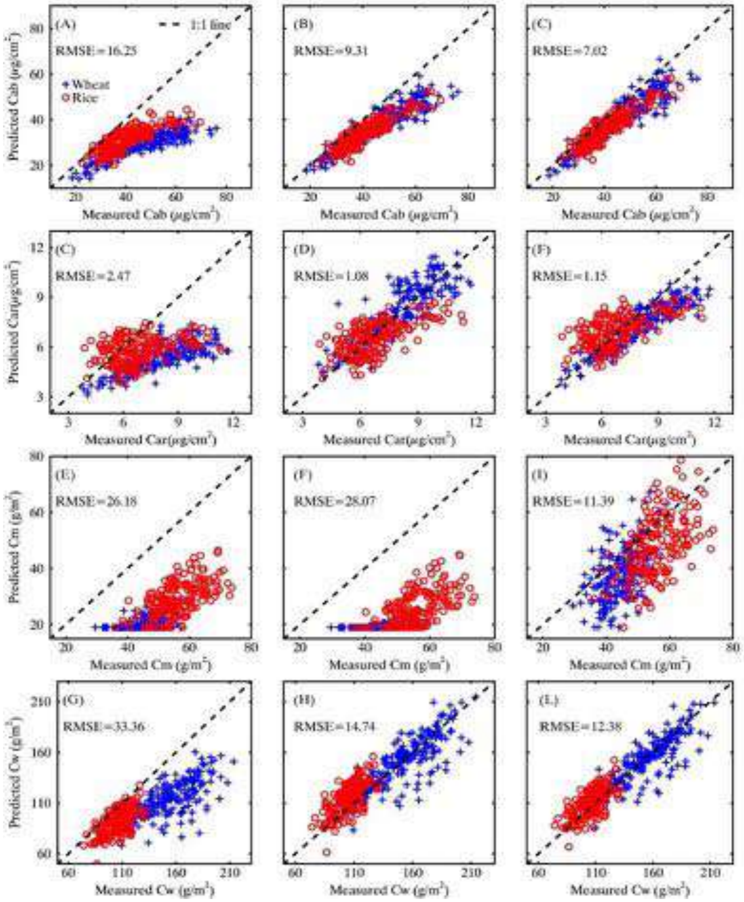
$$NDVI(R_{513},R_{481})/Fvcover = \frac{(R_{513}-R_{481})}{[(R_{513}+R_{481})*Fvcover]}$$

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

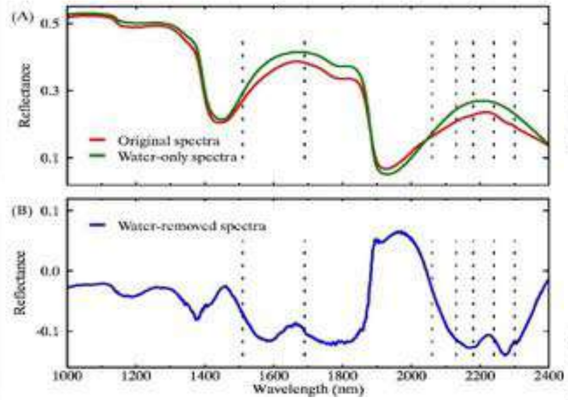
① Yao, X. et al., 2014, International Journal of Applied Earth Observation and Geoinformation

Monitoring Leaf biochemical parameters on continuous wavelet spectrum

Reflectance **PROCOSINE** **PROCWT**

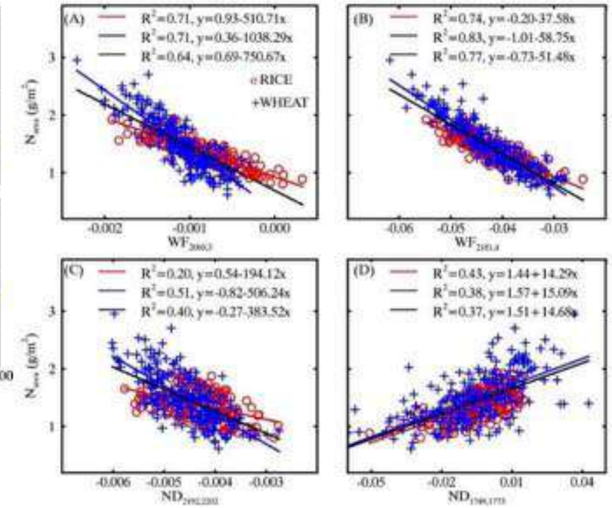


鲜叶光谱



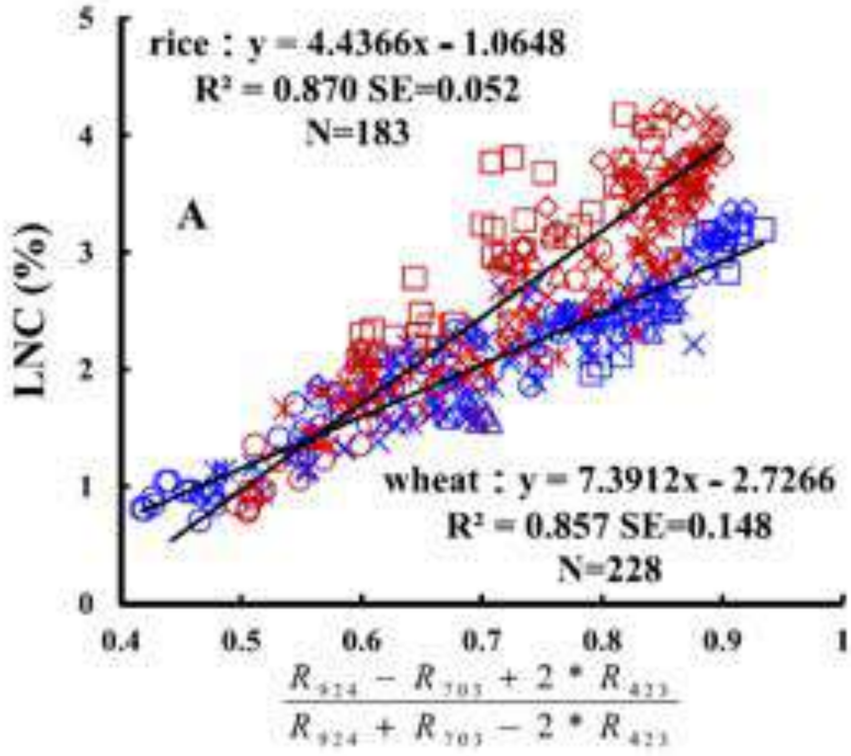
去水光谱

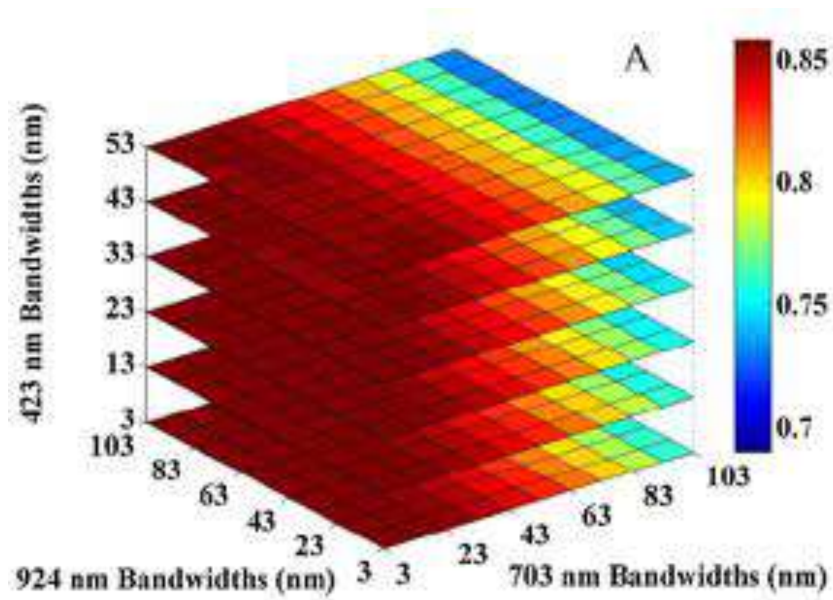
去水前 去水后



- **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

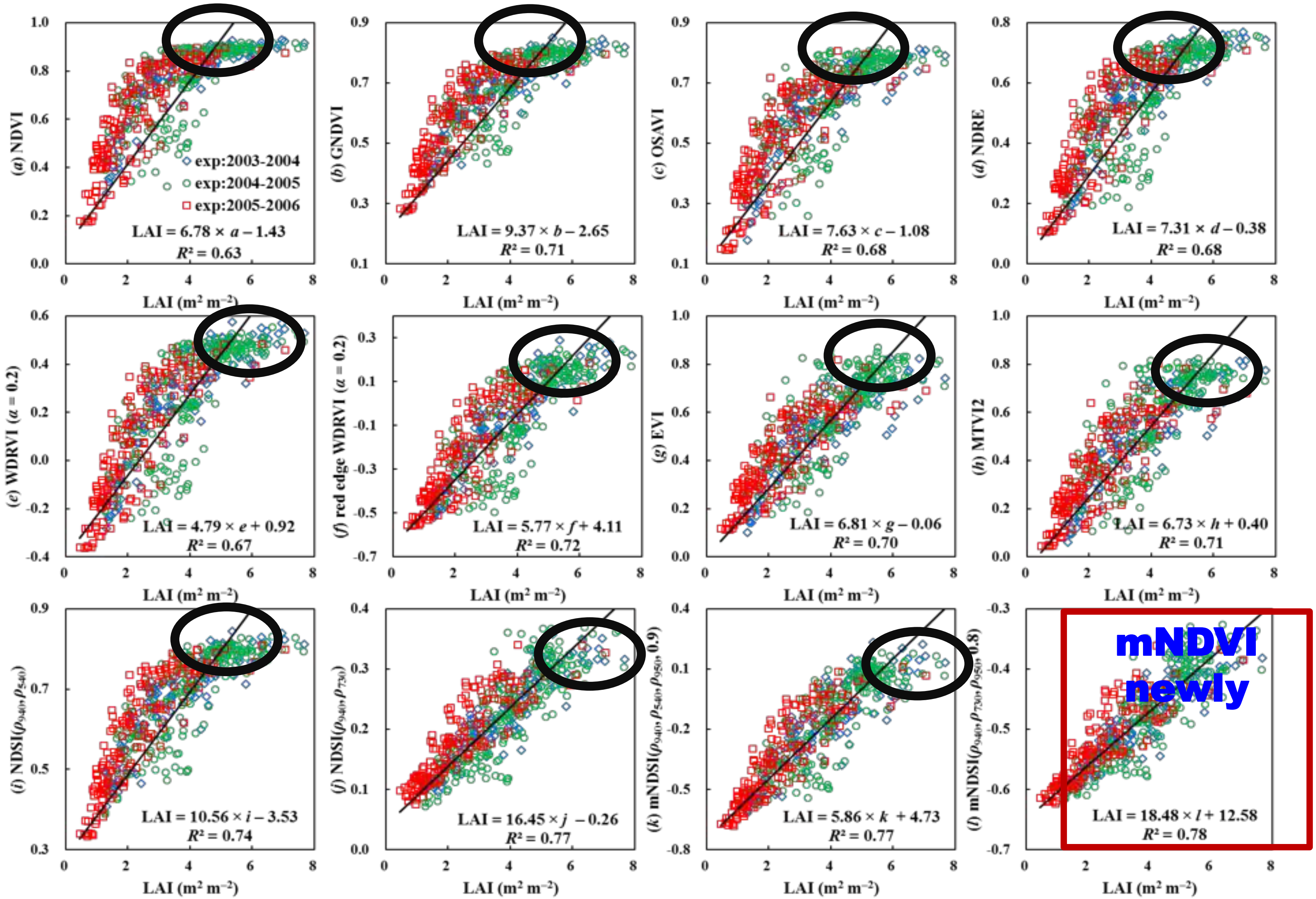




The search of optimal bands for predicting a specific parameter.

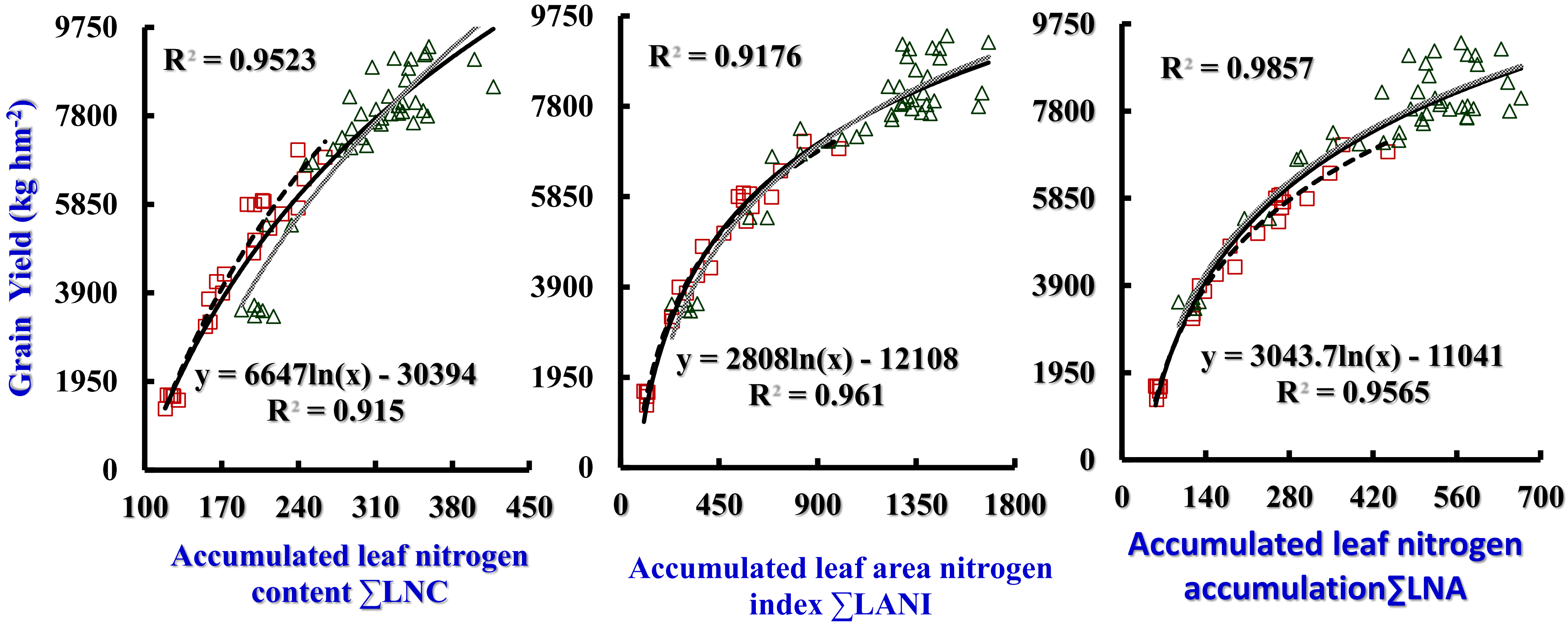
(Wang et al., 2012, FCR)

Leaf area index for wheat



Calibration comparisons:
the relationship between LAI and previous VIs / the newly developed $_{m}$NDVI

Predict the grain yield



Grain yield estimation
with accumulated nitrogen between jointing and maturity

Estimate the grain protein content

Characteristics spectral index--->

Leaf nitrogen status at anthesis--->

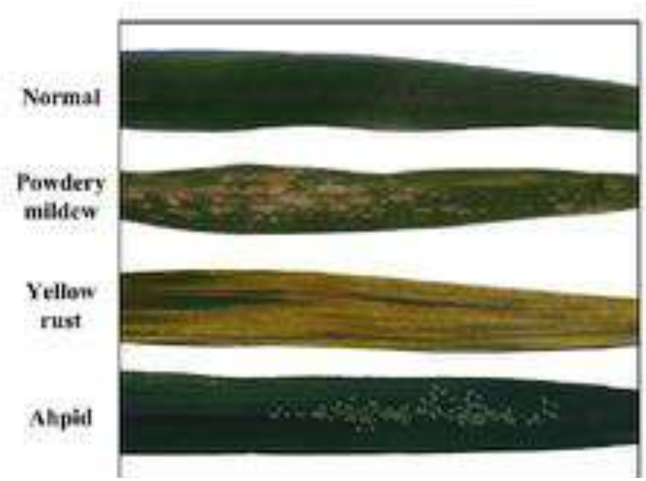
Grain protein content

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

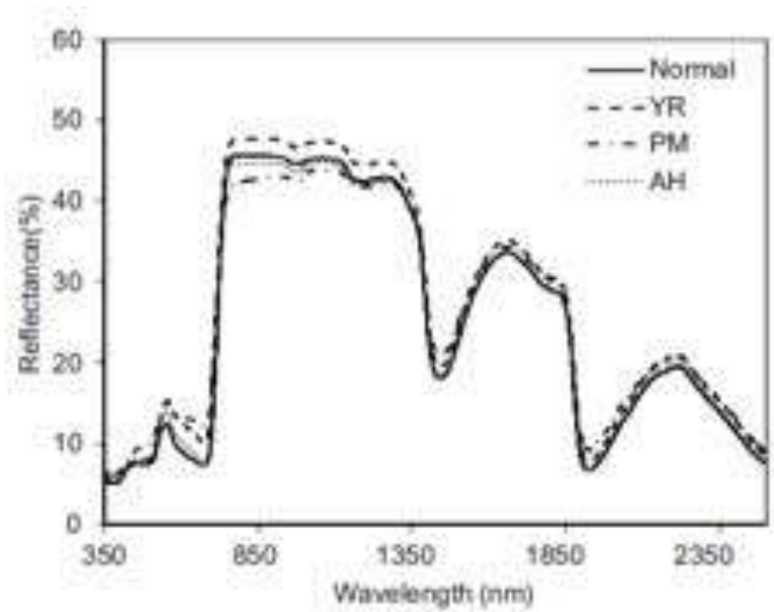
Spectral parameter	Regression equation	Fitness between measured and predicted (Exp.4, *n*=24)		
		R^2	RMSE	RE
mND705	$y = 10.9075x + 4.7447$	0.759	0.625	0.046
REPle	$y = 0.1925x – 125.348$	0.723	1.272	0.095
FD742	$y = 6.2475x + 8.1482$	0.675	1.239	0.095
SDr/SDb	$y = 0.3036x + 7.4205$	0.708	0.862	0.065

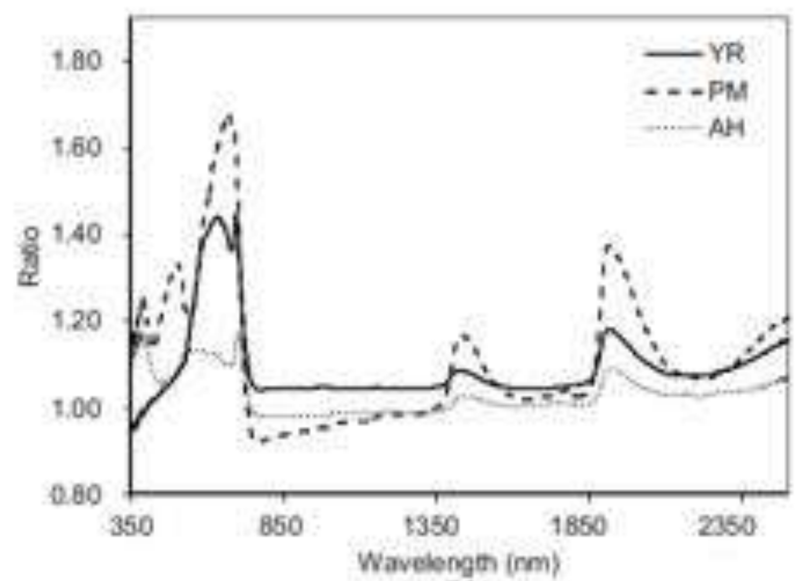
Crop disease

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



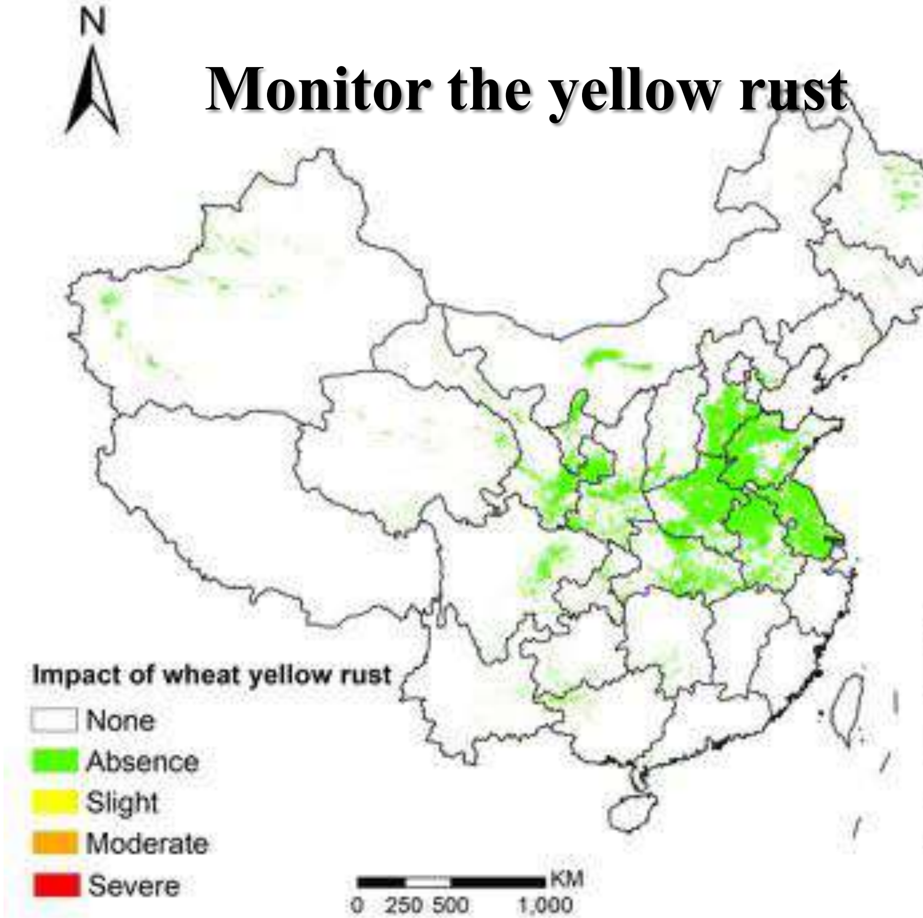
蚜虫



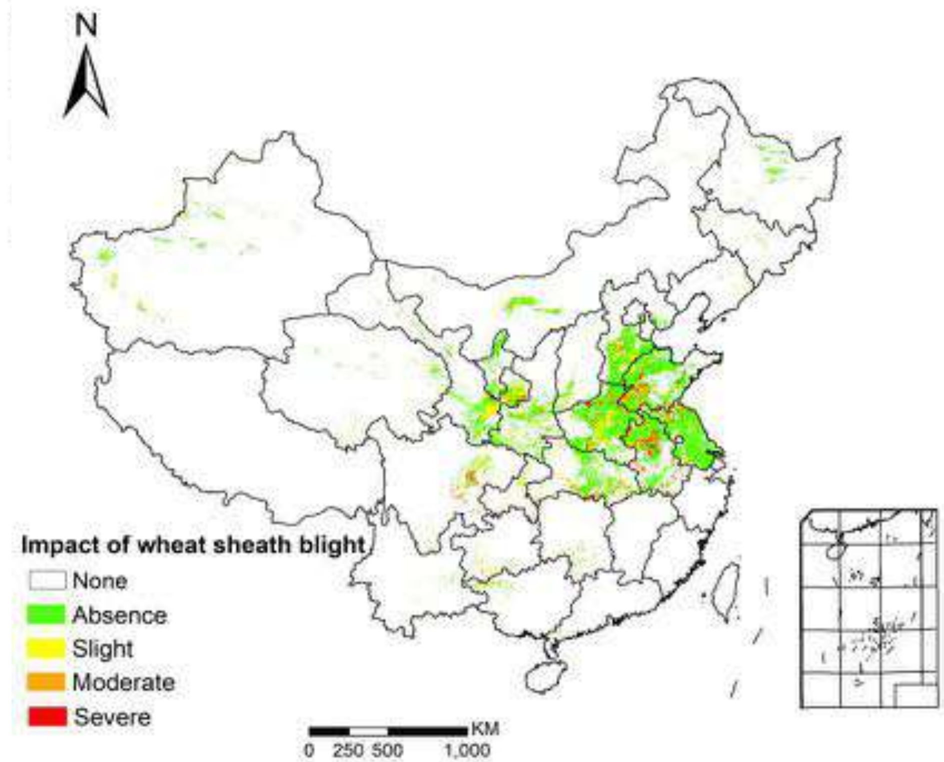


(Yuan et al., 2014, FCR)

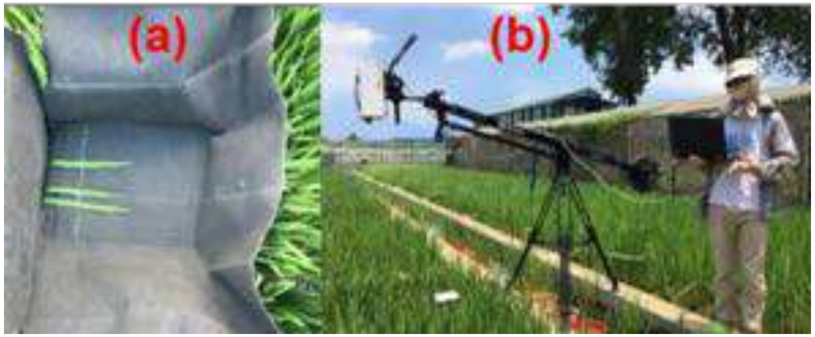
Monitor the yellow rust

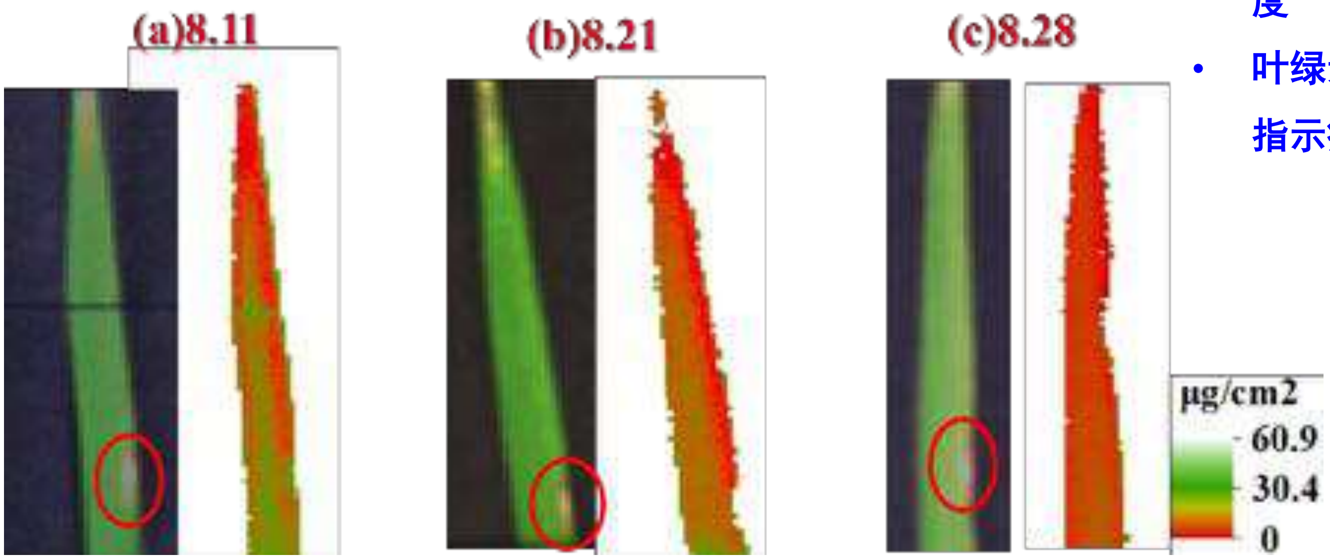


Monitor the sheath blight



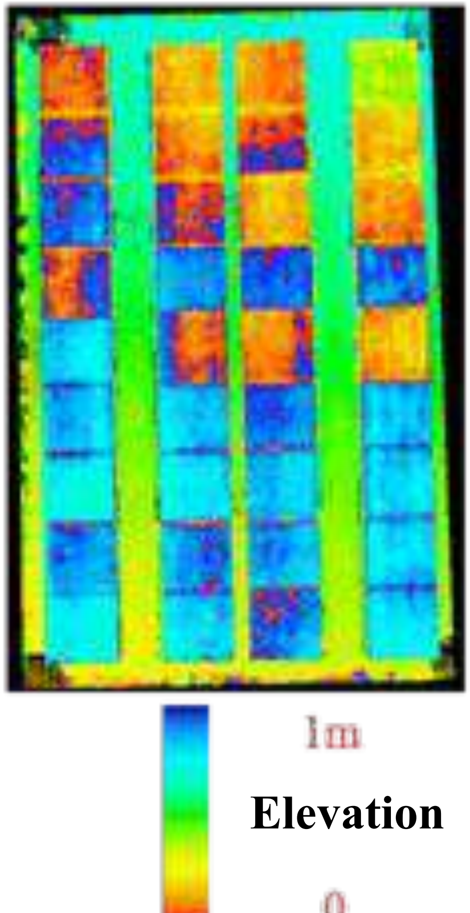
Monitoring the early rice blast on hyperspectral RS



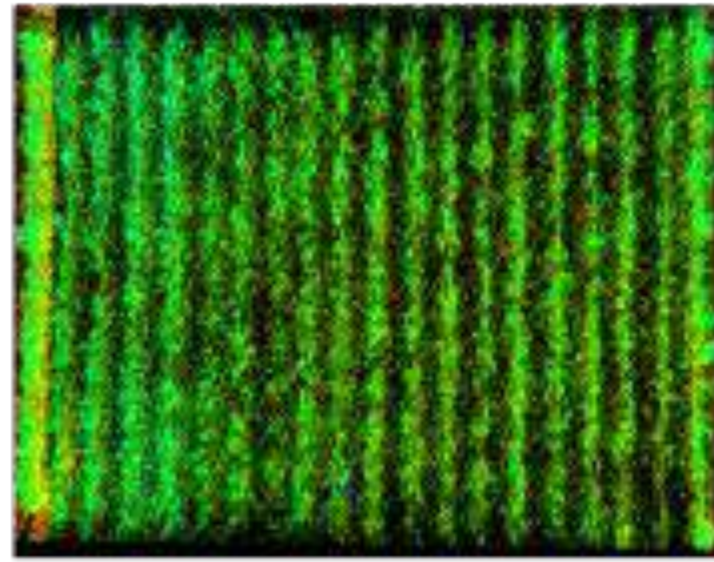


- 随病情严重度变化，单叶叶绿素，花青素，水分均随之变化;
- 单一生化指标相关植被指数不能很好监测病情严重度
- 叶绿素时空分布变化可以指示病情严重度变化

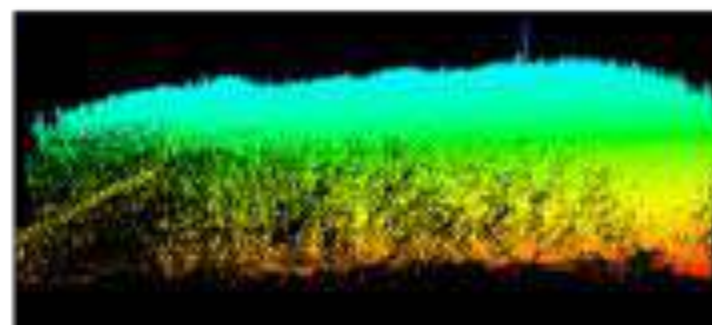
➢ How to predict wheat height with Lidar



Vertical view

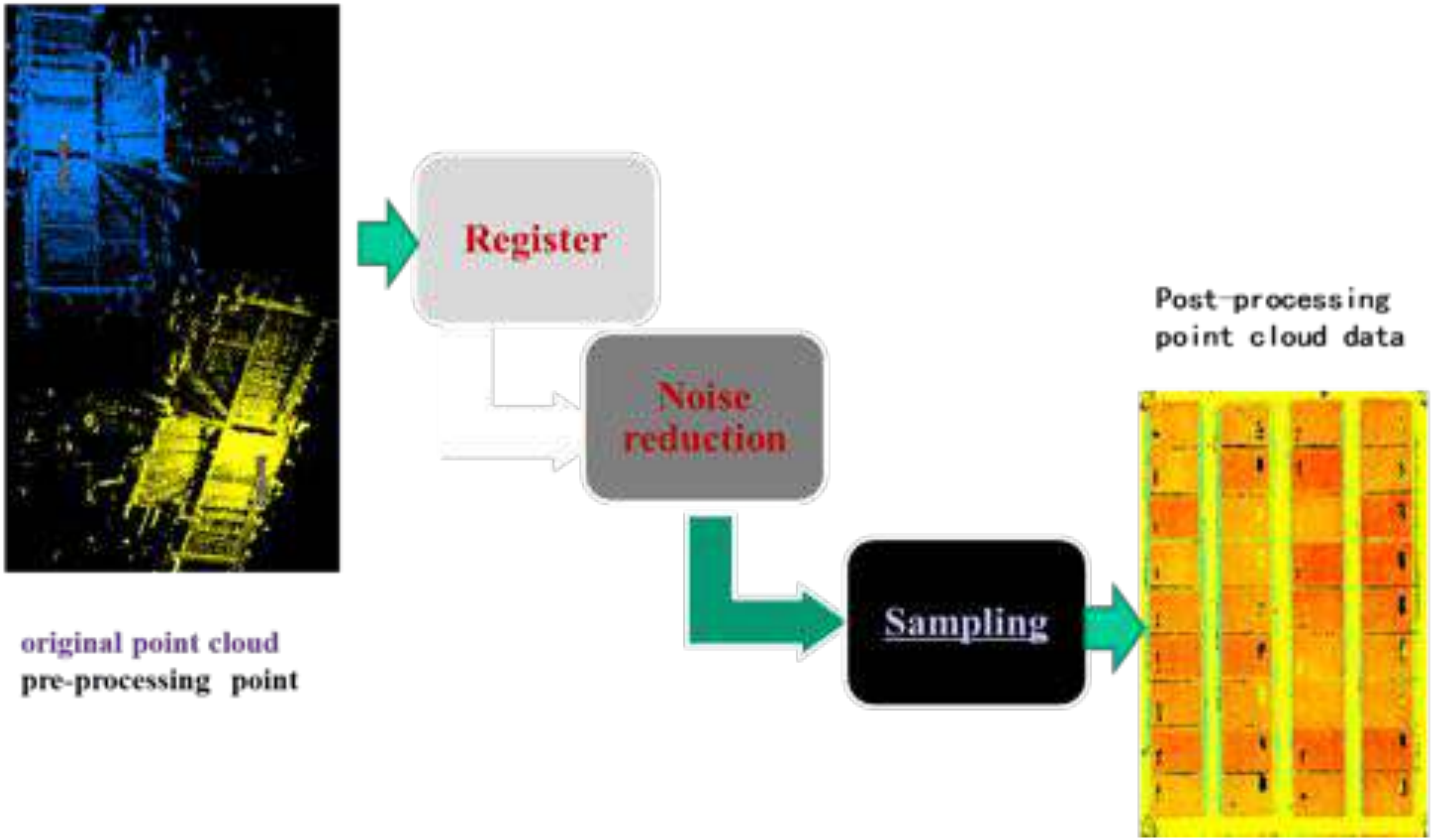


Side view



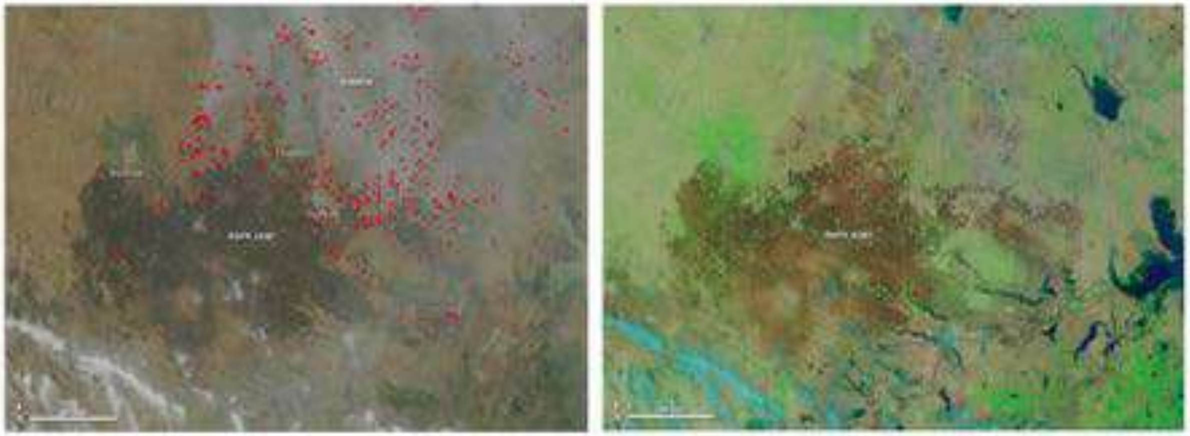
the original point cloud image of wheat

Point cloud data preprocessing flow



original point cloud
pre-processing point

Monitor the burning straw （MODIS）

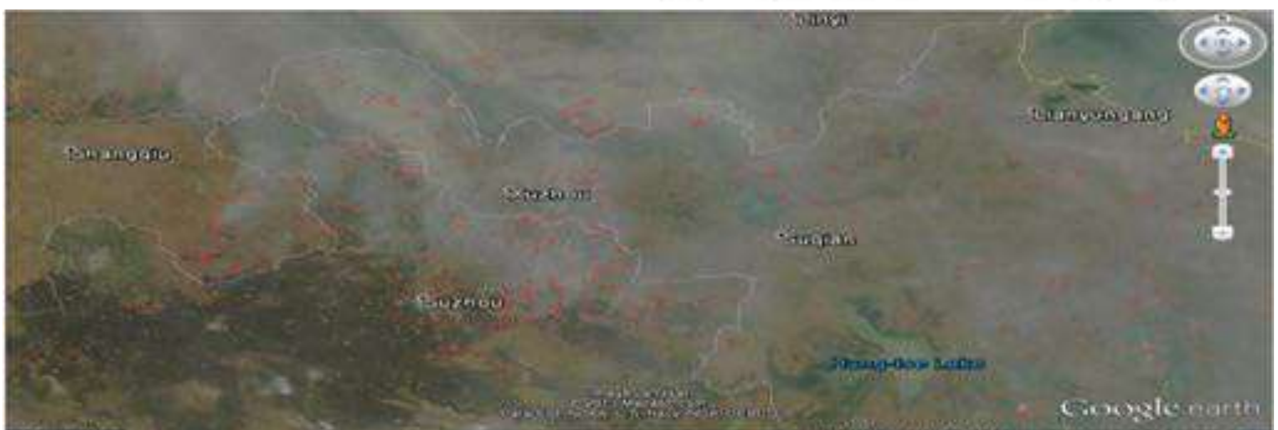


True color MODIS/Terra, 2012/6/13 False color

Red outlines: burning fires Green: unburned vegetation

In June, farmers burn the remaining plant residue to fertilize the soil for the upcoming maize crop. (wheat-maize rotation)

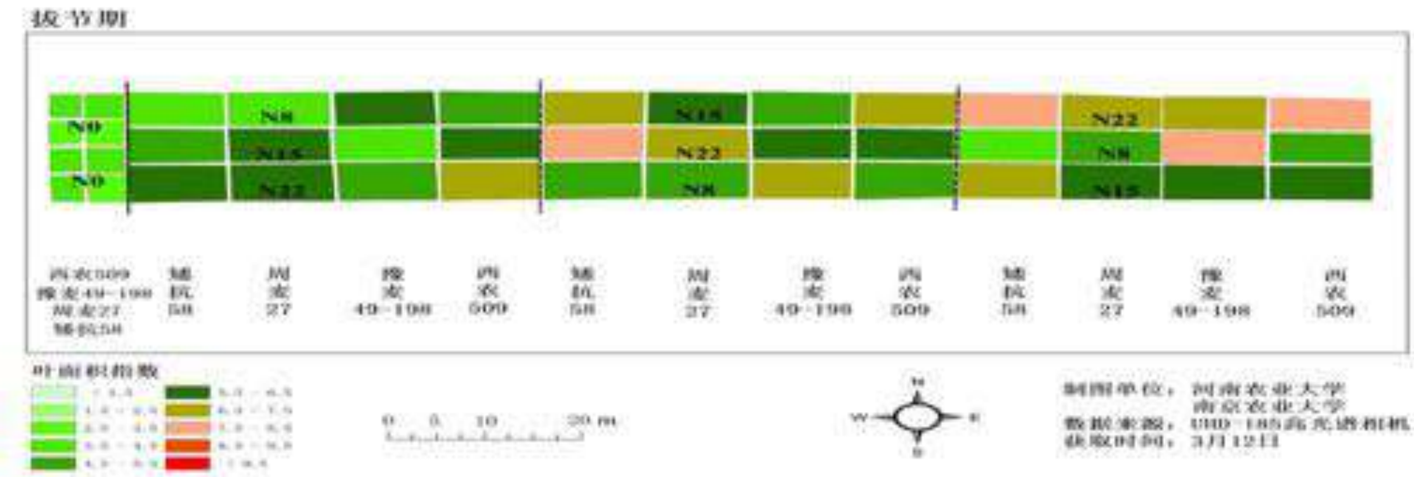
NASA image courtesy Jeff Schmaltz, LANCE MODIS Rapid Response

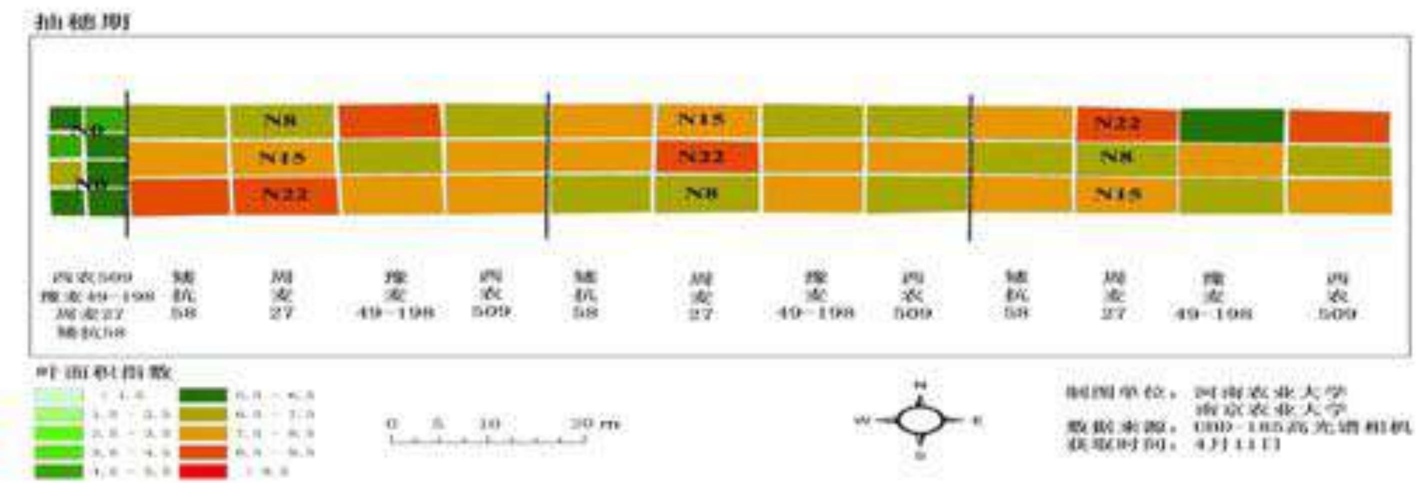


◆ Track growth process (product traceability)

Remote Video

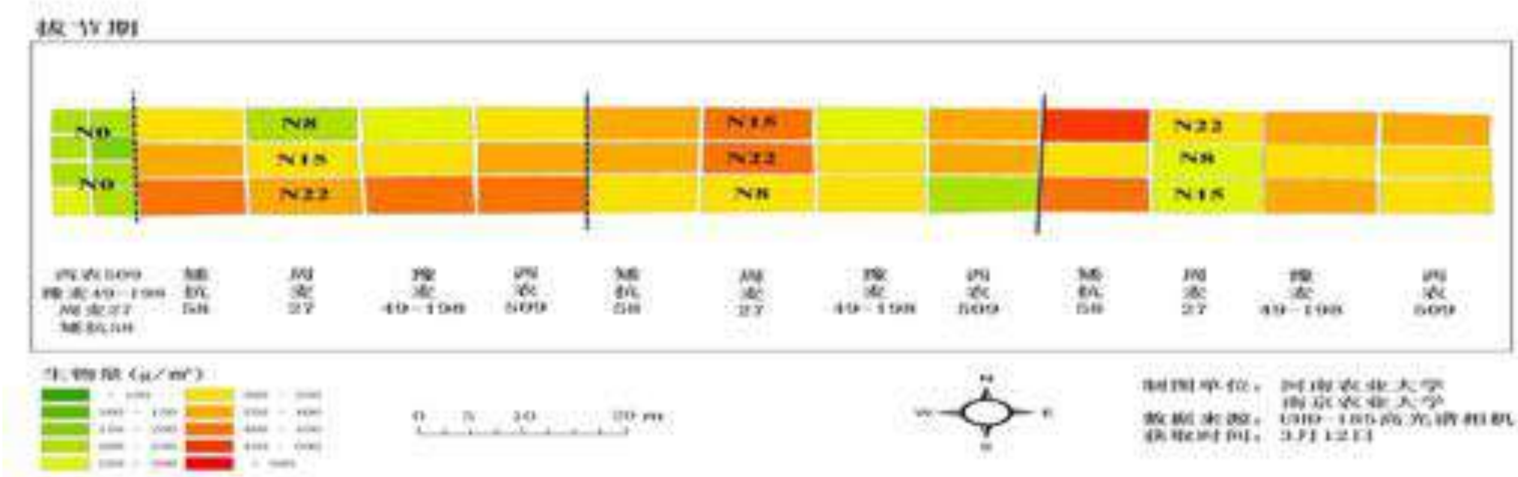
wheat leaf area index mapping on UAVs in Changge plot

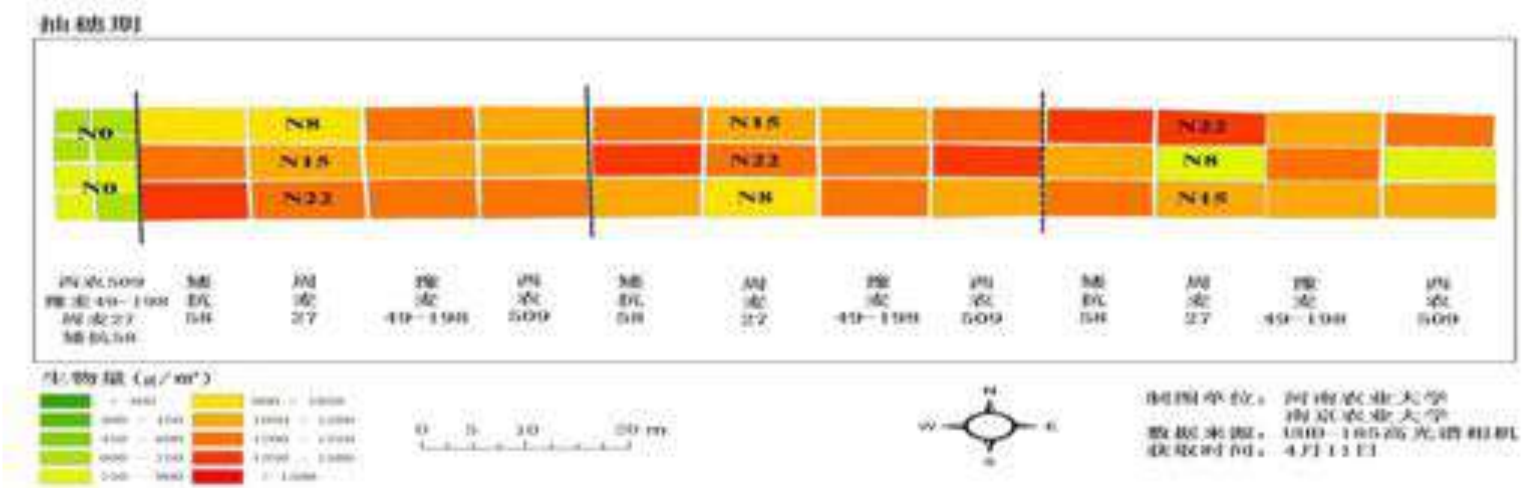




长葛试验小区小麦叶面积指数无人机监测图

wheat aboveground biomass map on UAVs in Changge plot

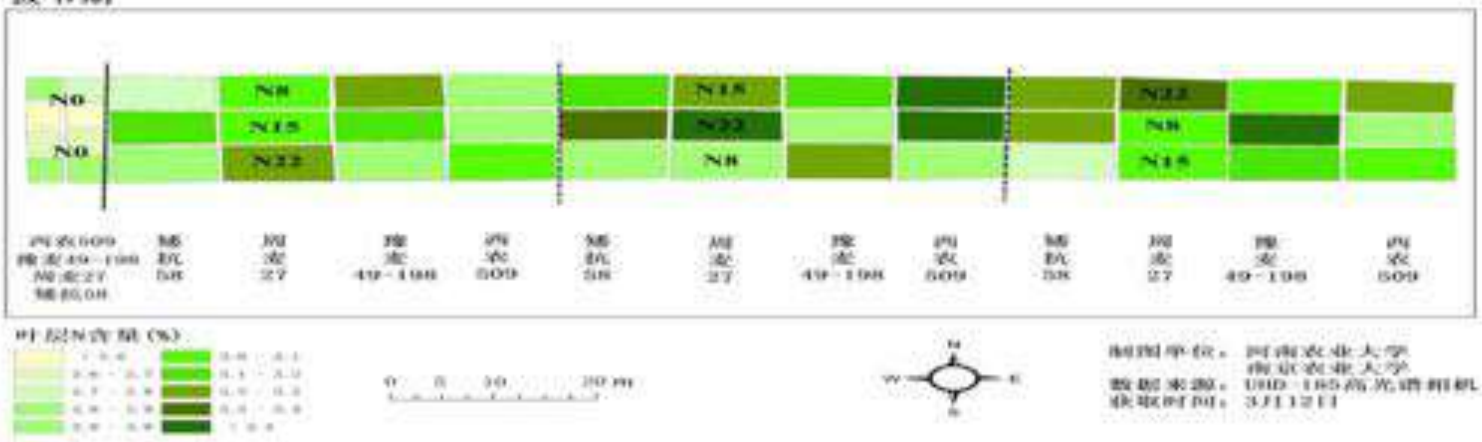




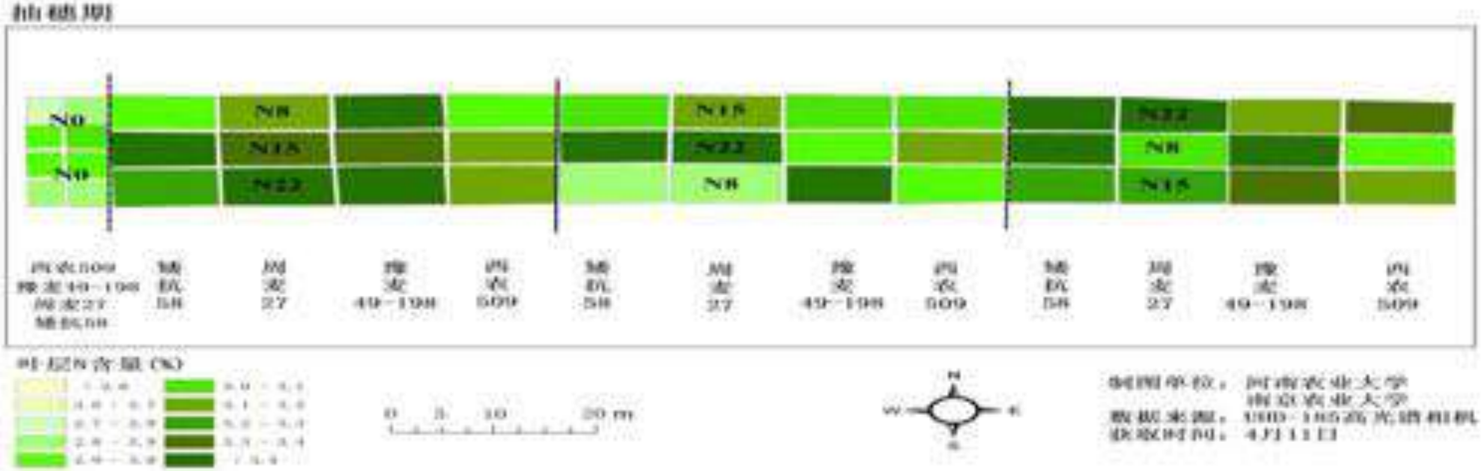
长葛试验小区小麦地上干物重无人机监测图

wheat leaf nitrogen content mapping on UAVs in Changge plot

拔节期



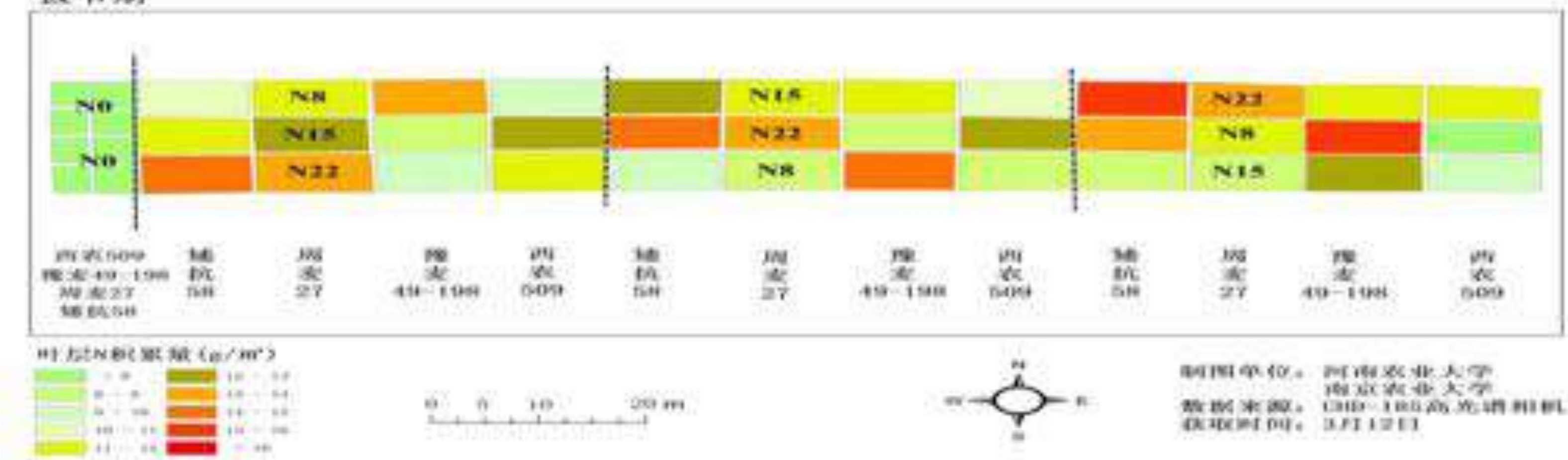
抽穗期



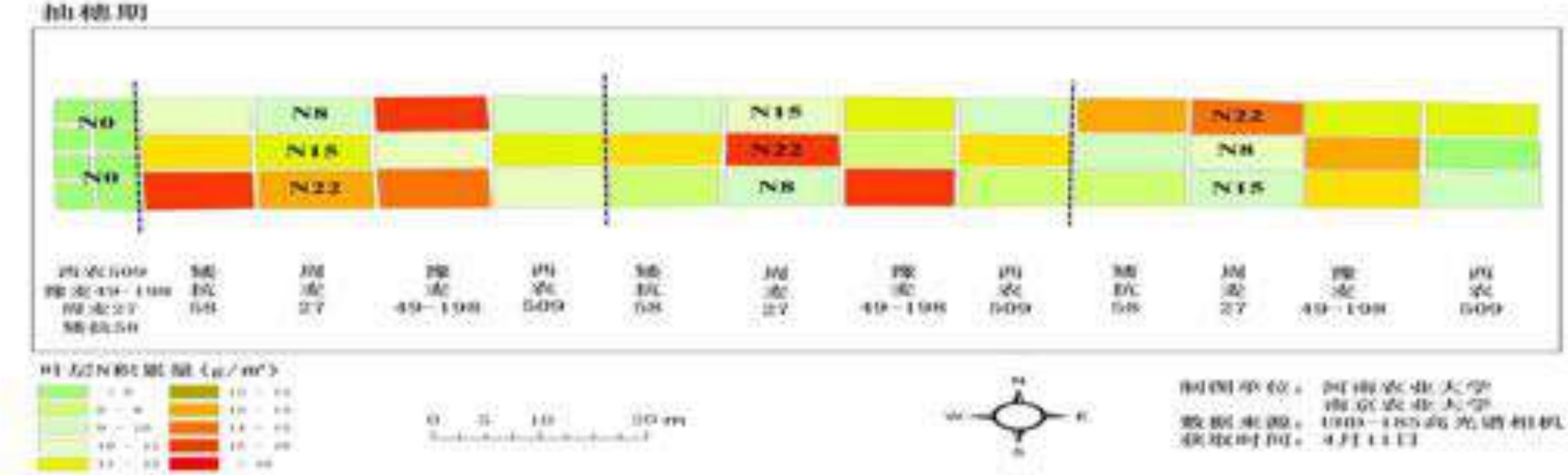
长葛试验小区小麦叶层氮含量无人机监测图

wheat leaf nitrogen accumulation mapping on UAVs in Changge plot

拔节期

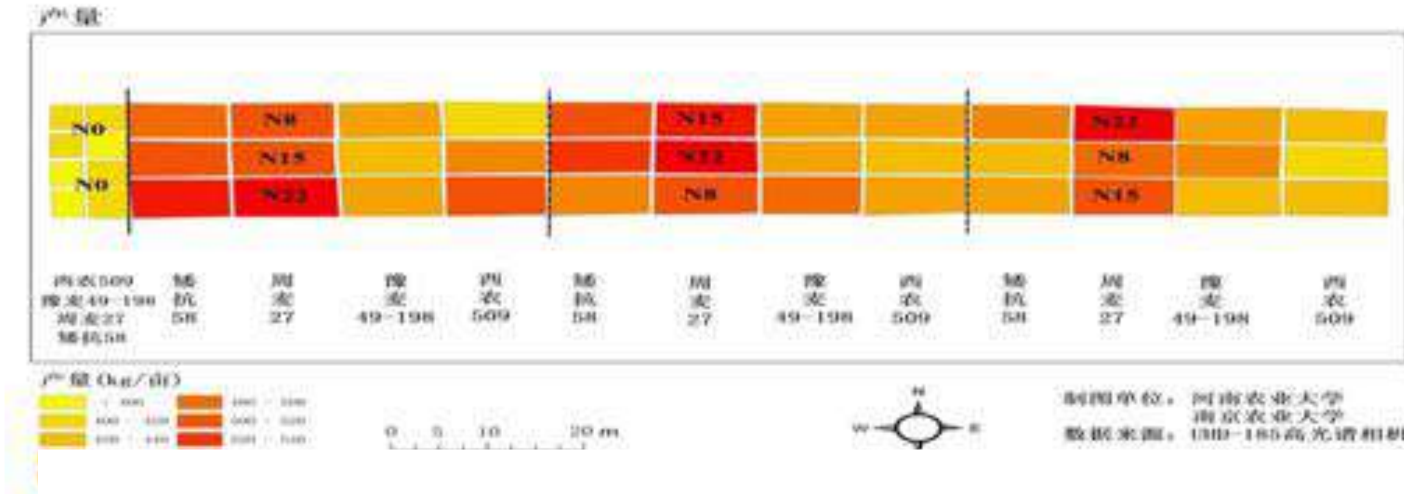


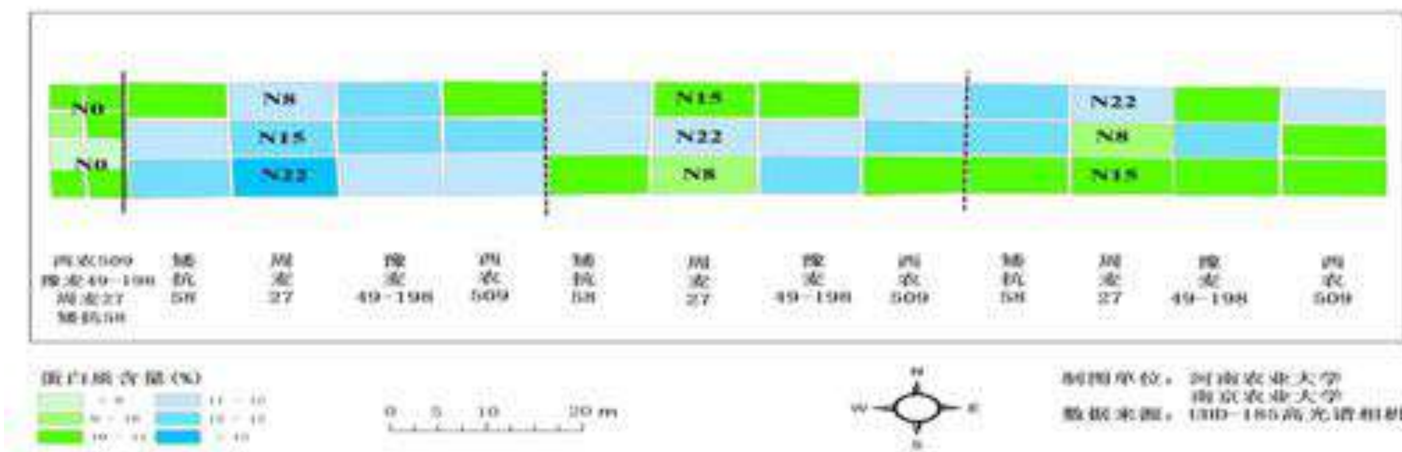
抽穗期



长葛试验小区小麦叶层氮积累量无人机监测图

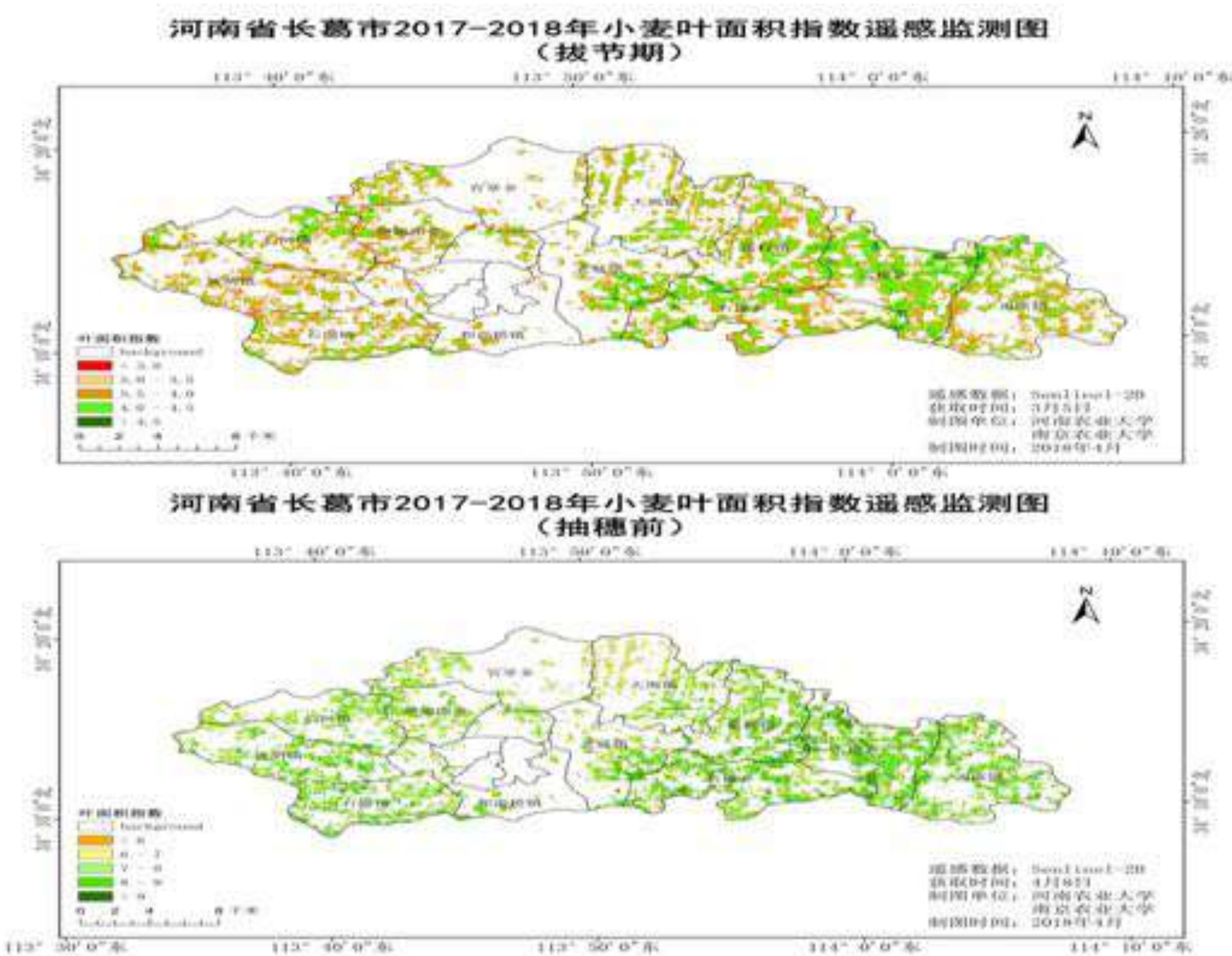
wheat yield and quality mapping on UAVs in Changge plot





长葛试验小区小麦产量品质无人机预测图

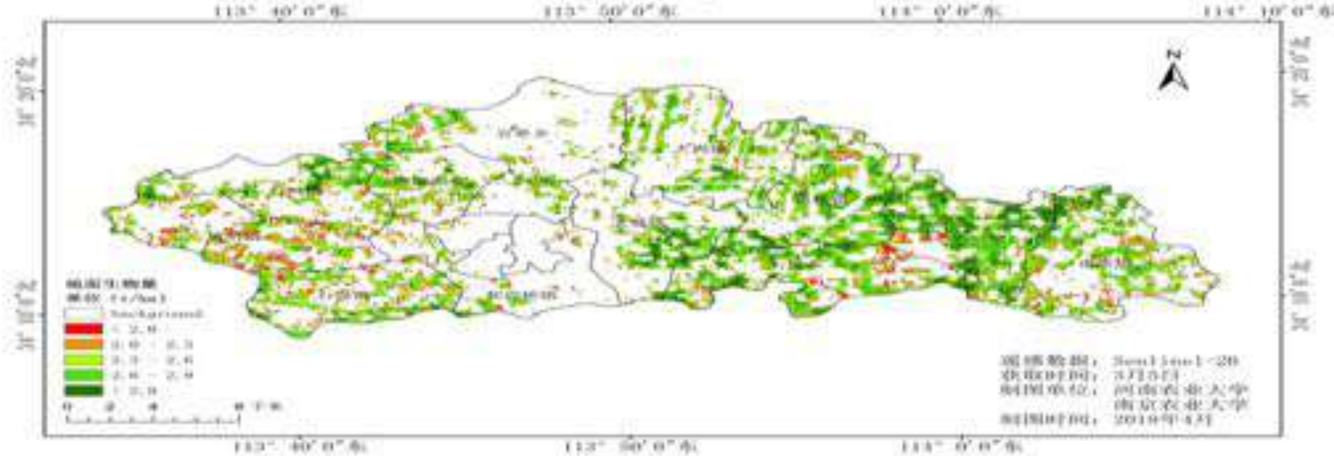
wheat leaf area index mapping on sentinel-2B in Changge city



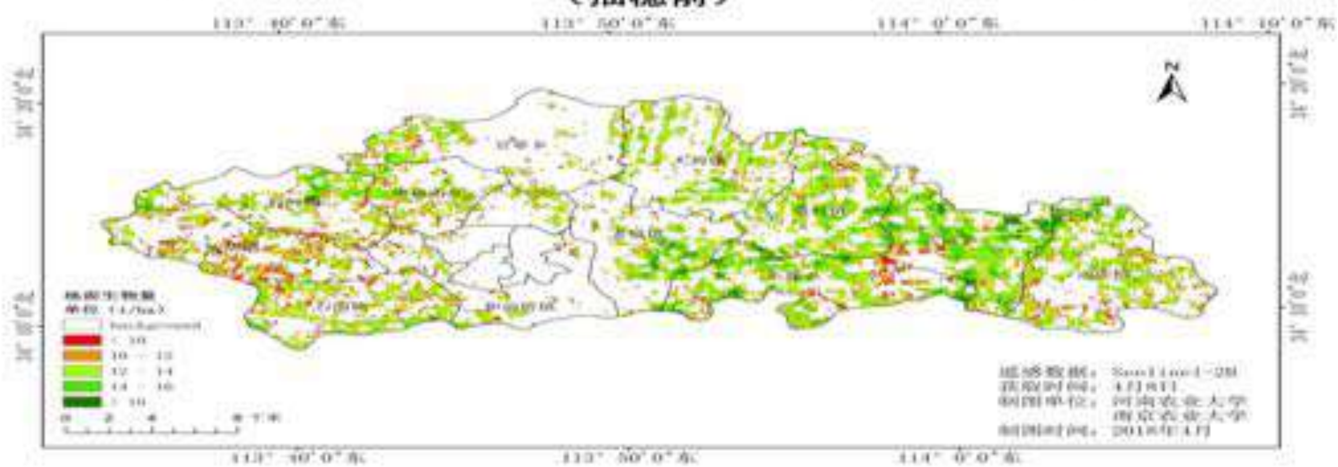
长葛小麦叶面积指数遥感监测图

wheat aboveground biomass mapping on sentinel-2B in Changge city

河南省长葛市2017–2018年小麦地面生物量遥感监测图
（拔节期）

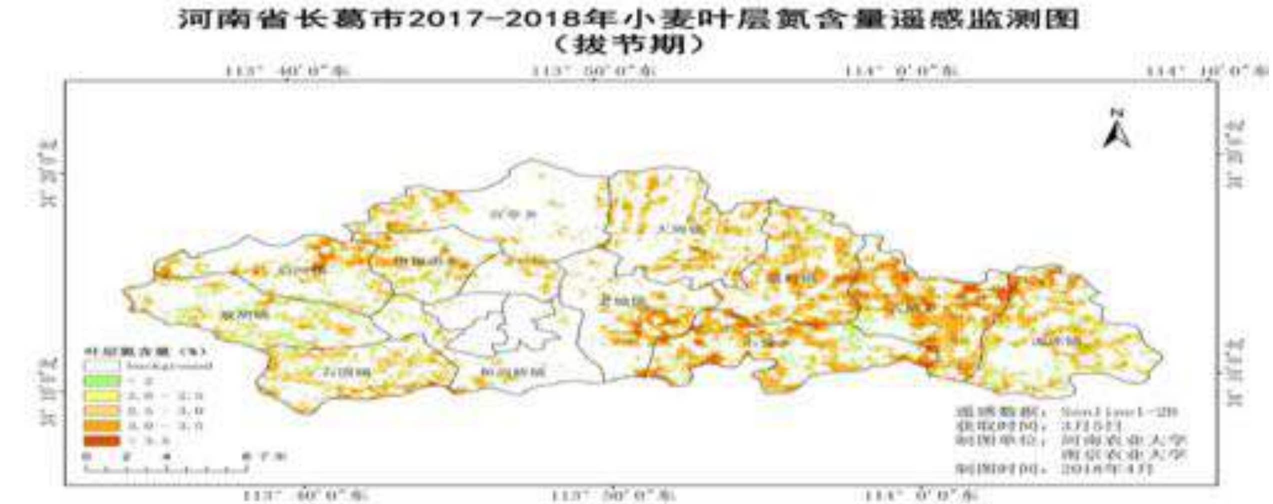


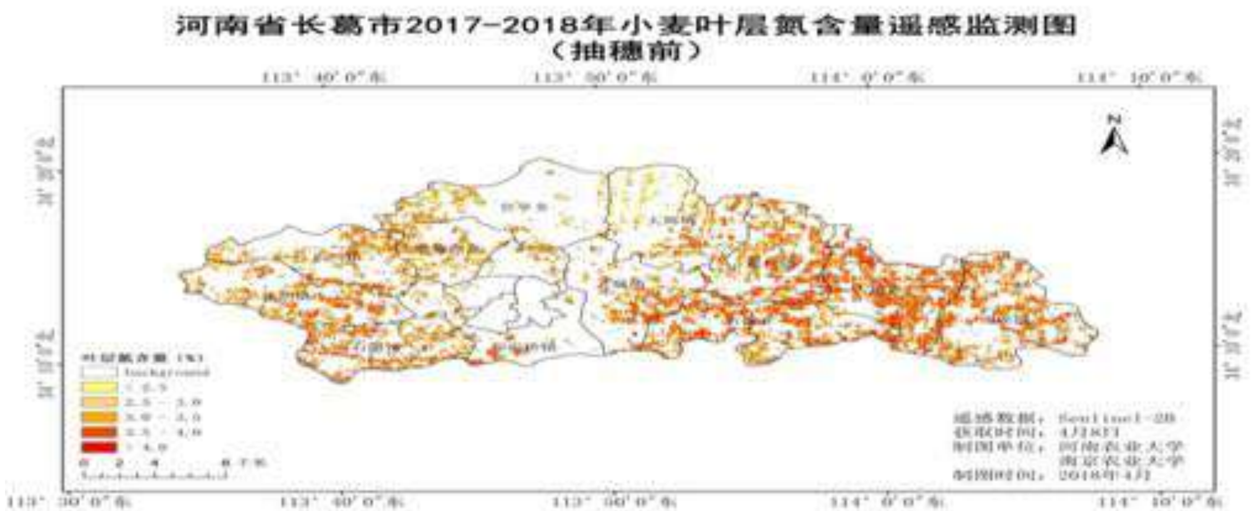
河南省长葛市2017–2018年小麦地面生物量遥感监测图
（抽穗前）



长葛小麦生物量遥感监测图

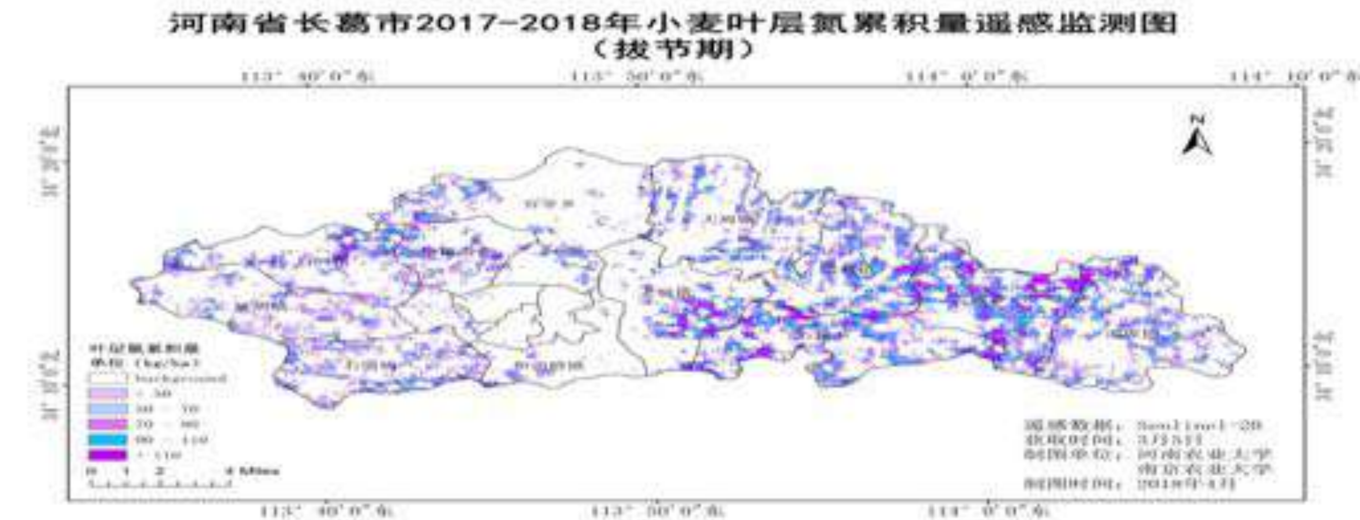
wheat leaf nitrogen content mapping on sentinel-2B in Changge city

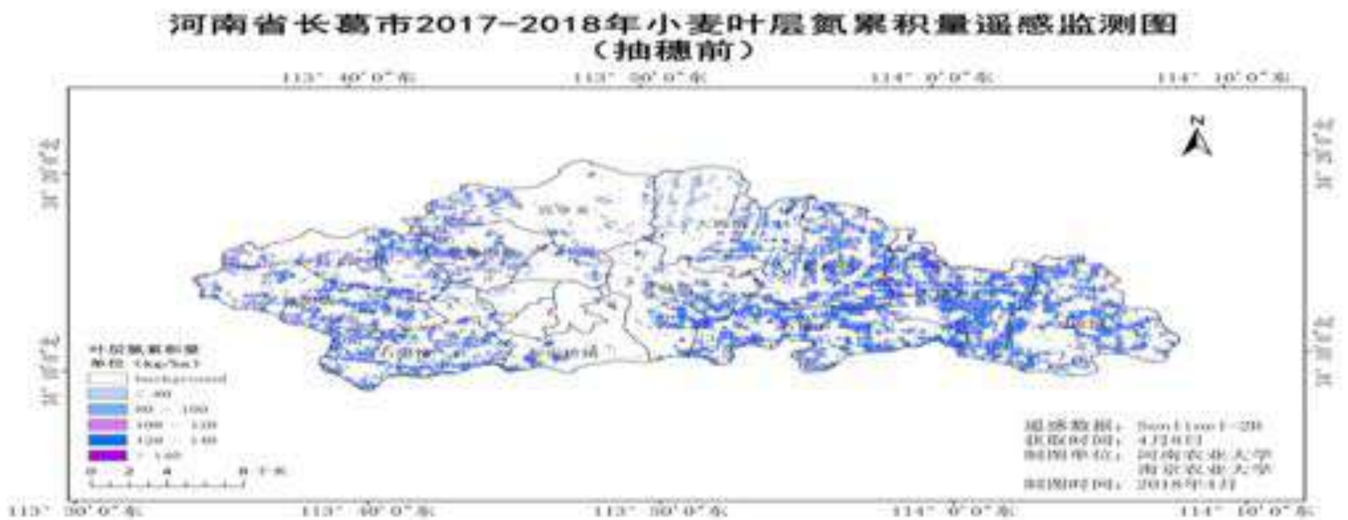




长葛小麦叶层氮含量遥感监测图

wheat leaf nitrogen accumulation mapping on sentinel-2B in Changge city

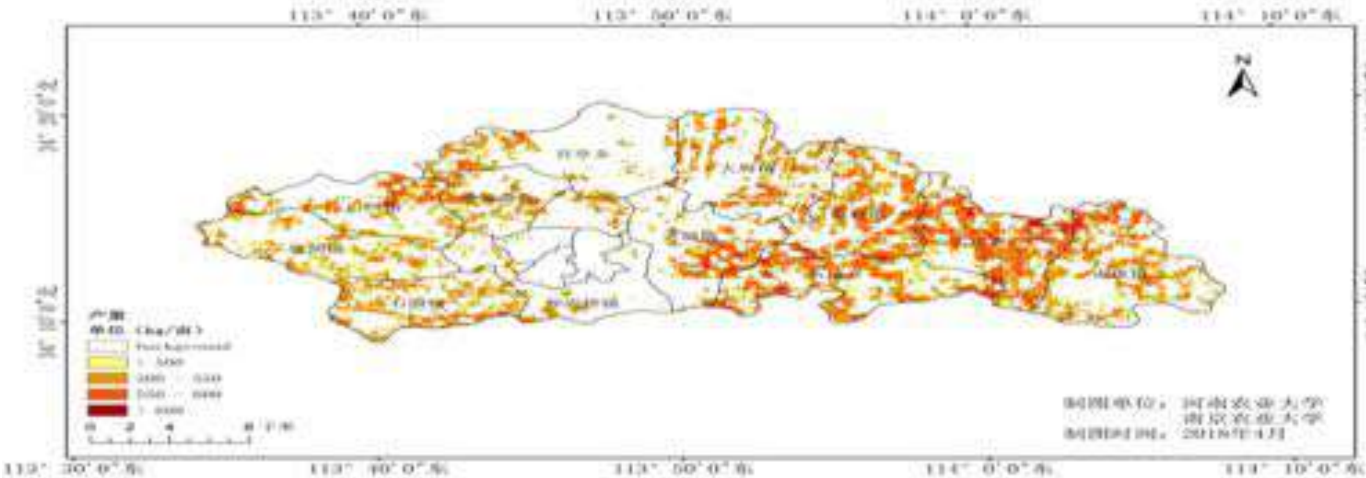




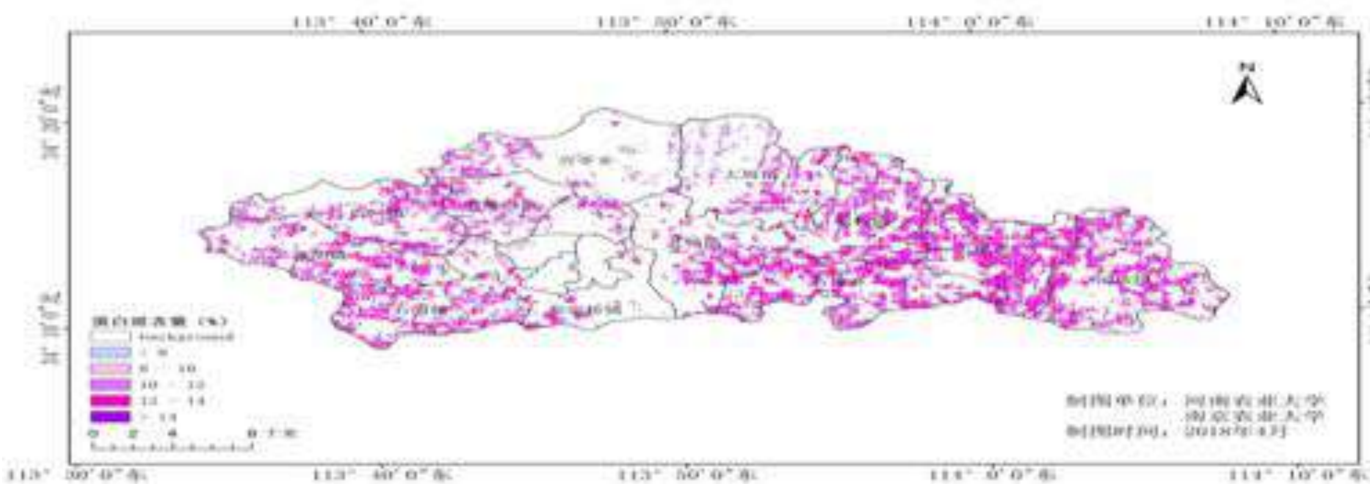
长葛小麦叶层氮积累量遥感监测图

wheat yield and quality mapping on sentinel-2B in Changge city

河南省长葛市2017–2018年小麦产量遥感预测图

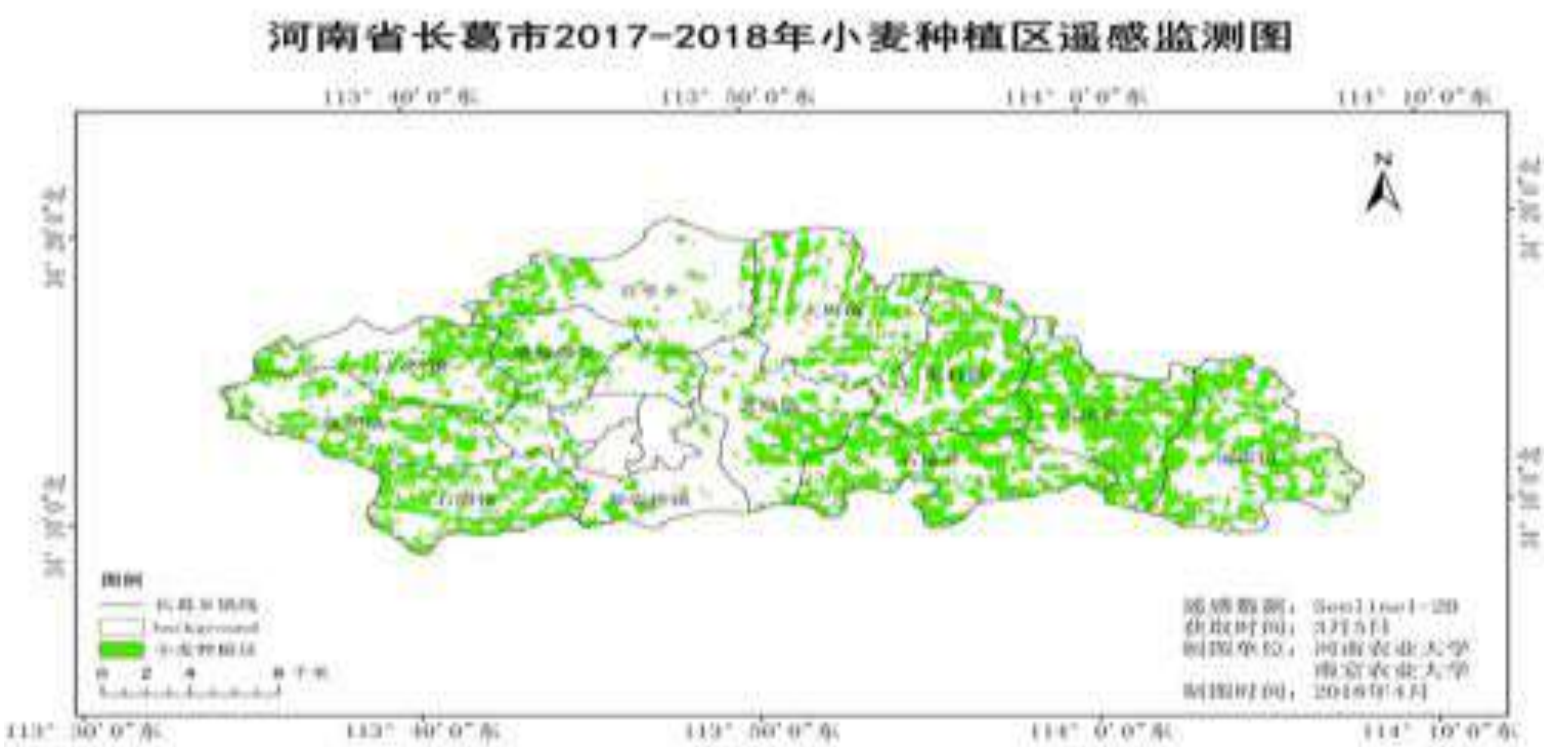


河南省长葛市2017–2018年小麦蛋白质含量遥感监测图



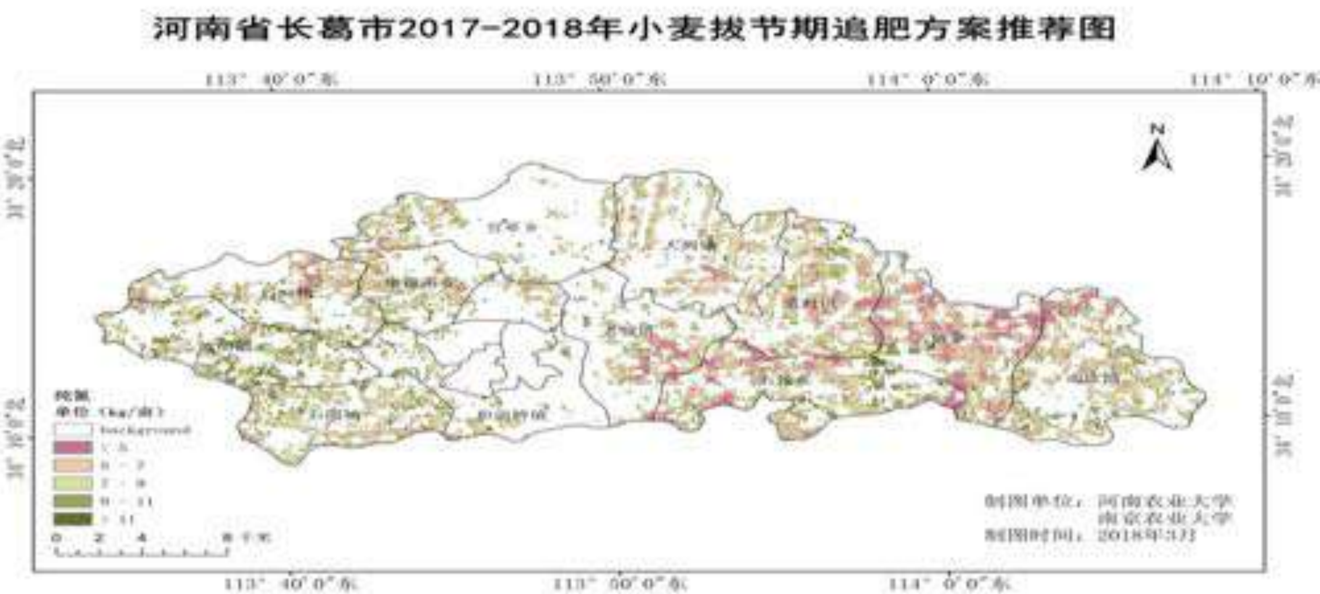
长葛小麦产量品质遥感监测图

wheat planting region mapping on sentinel-2B in Changge city



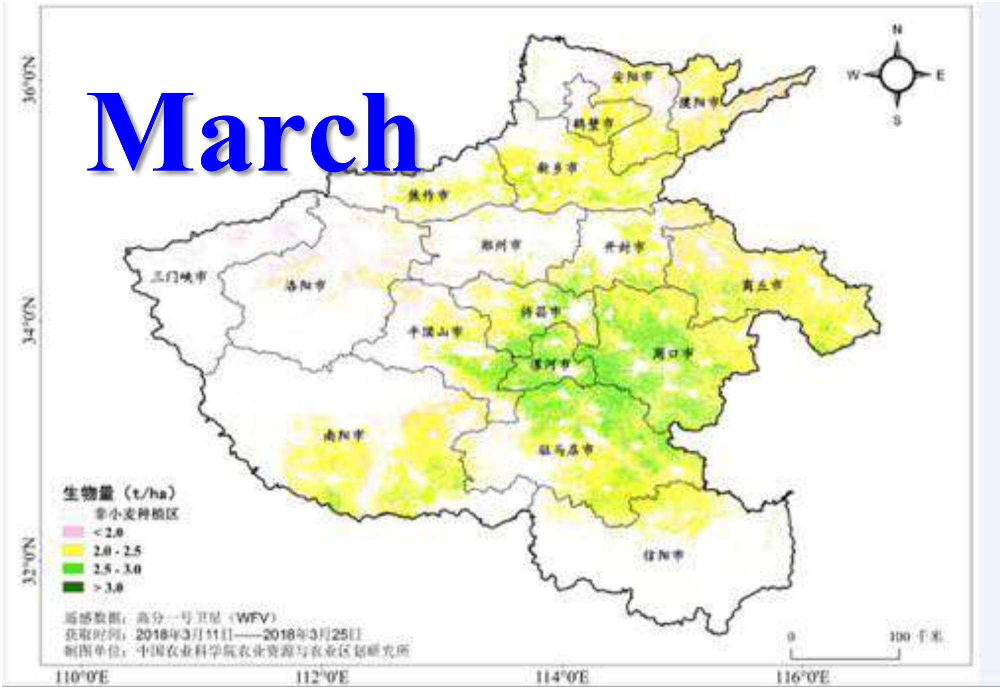
长葛小麦种植区遥感监测图

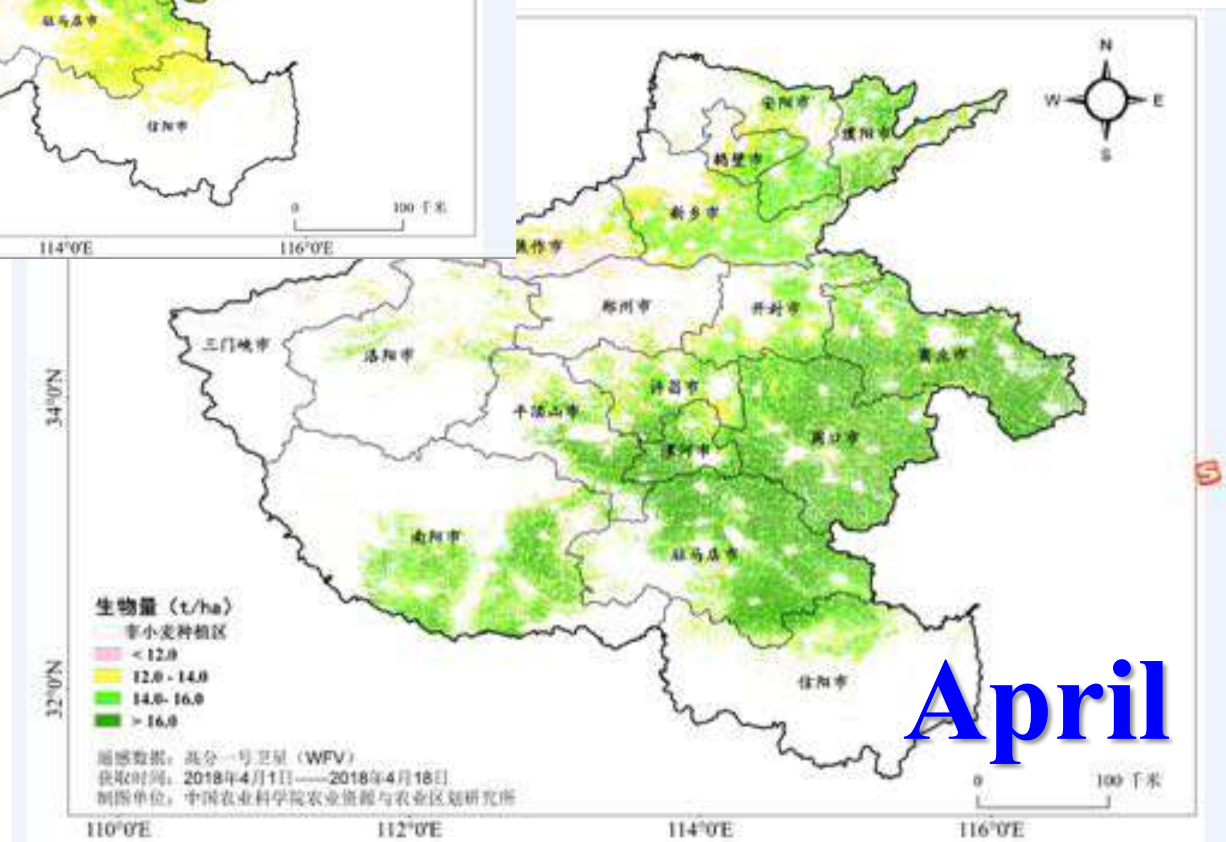
wheat aboveground biomass mapping on sentinel-2B in Changge city



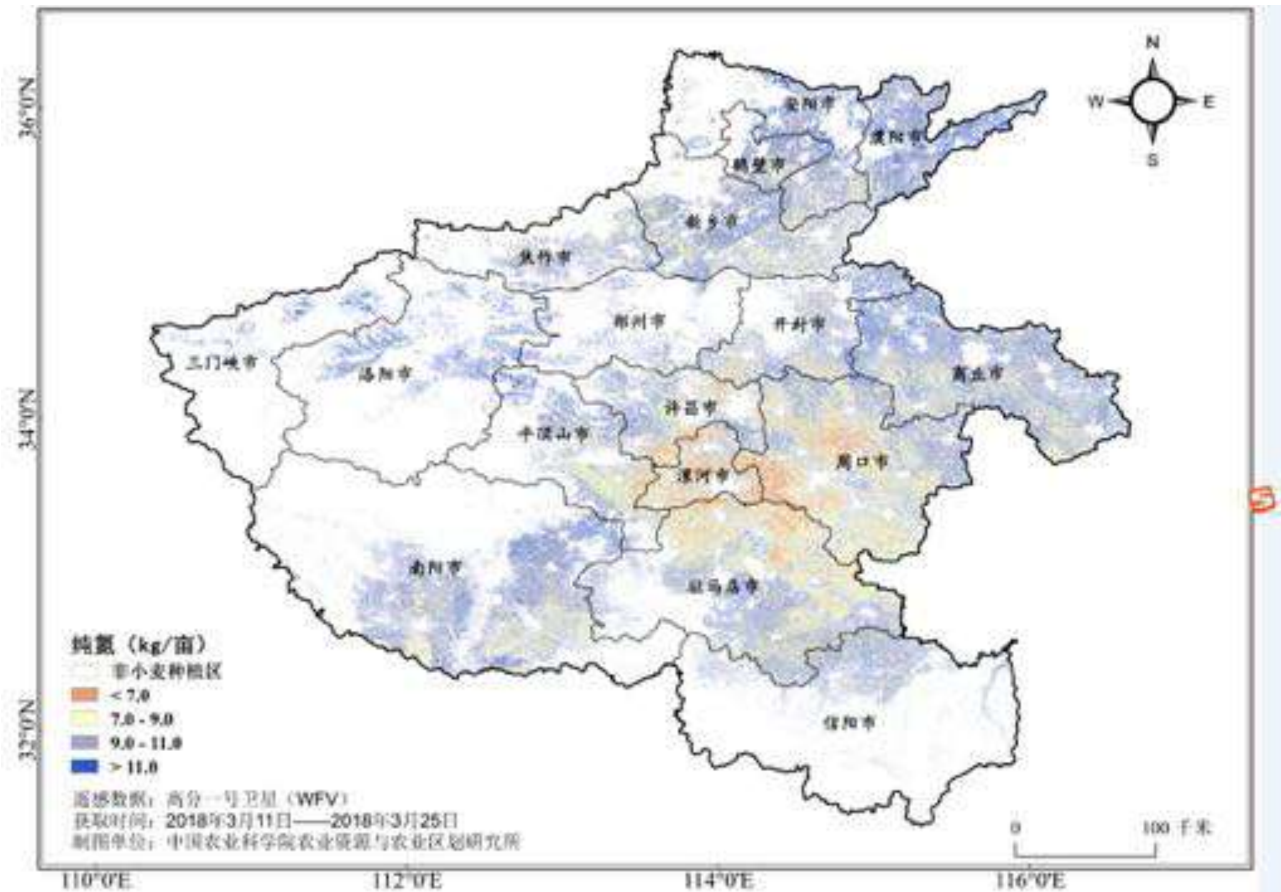
小麦追肥方案推荐图

Wheat Biomass Henan province on GF-1



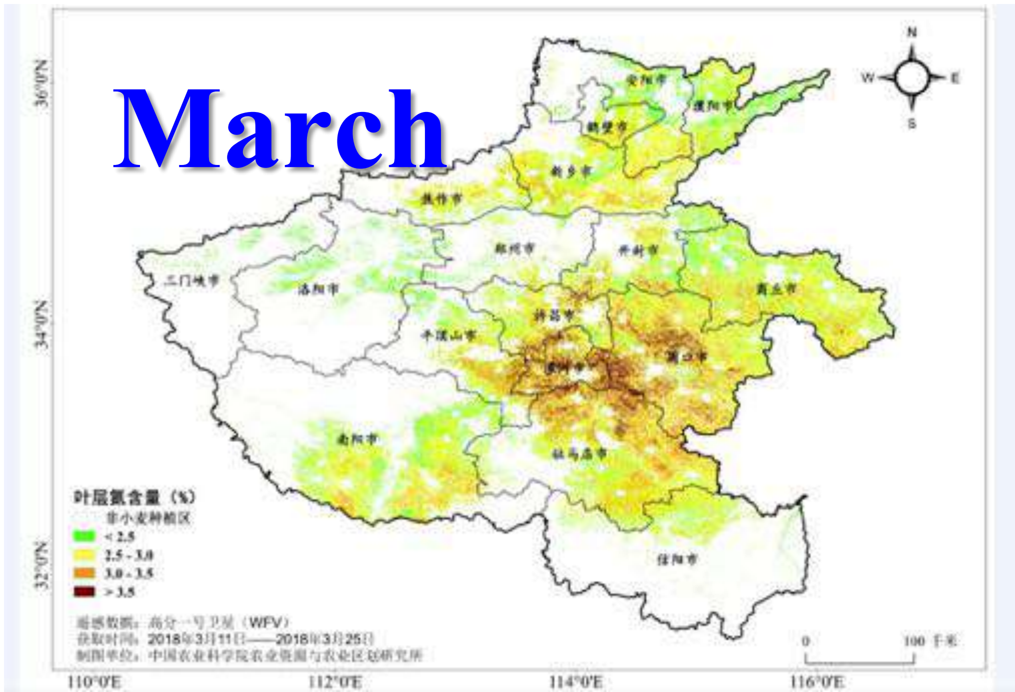


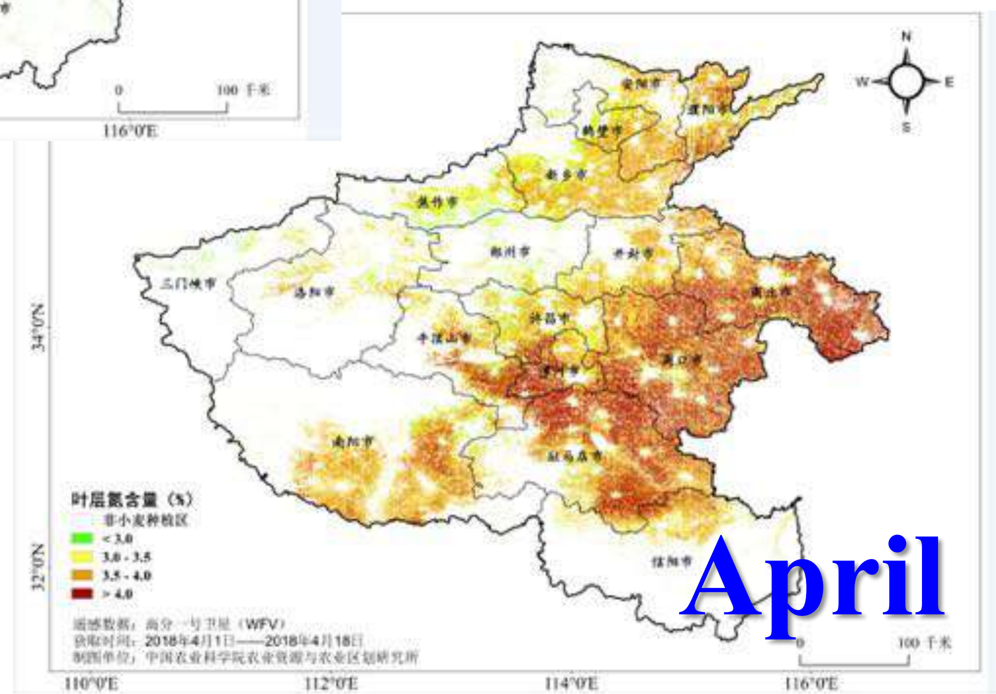
Wheat dressing fertilizer in Henan province on GF-1



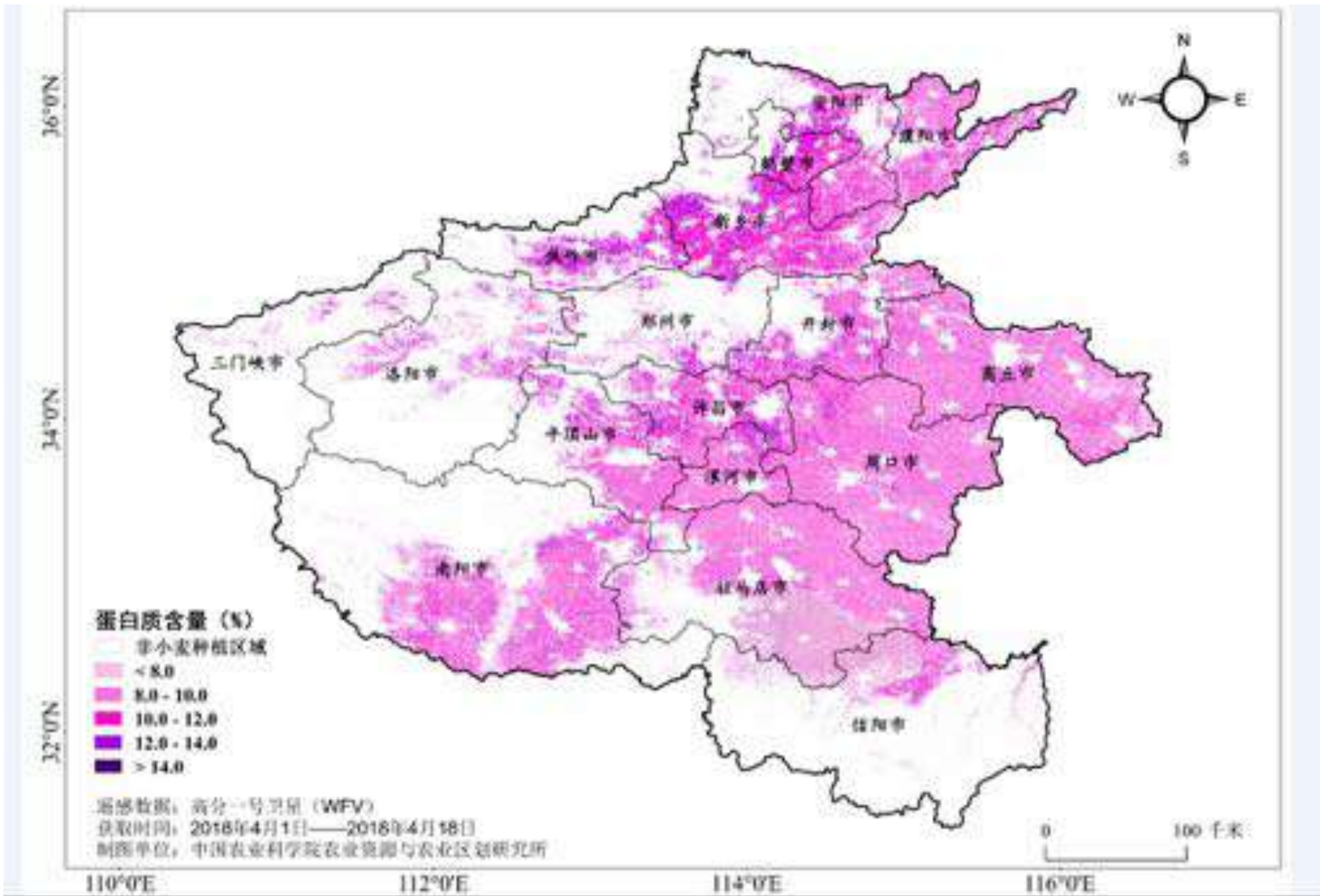
施肥方案

Leaf nitrogen content in Henan province on GF-1

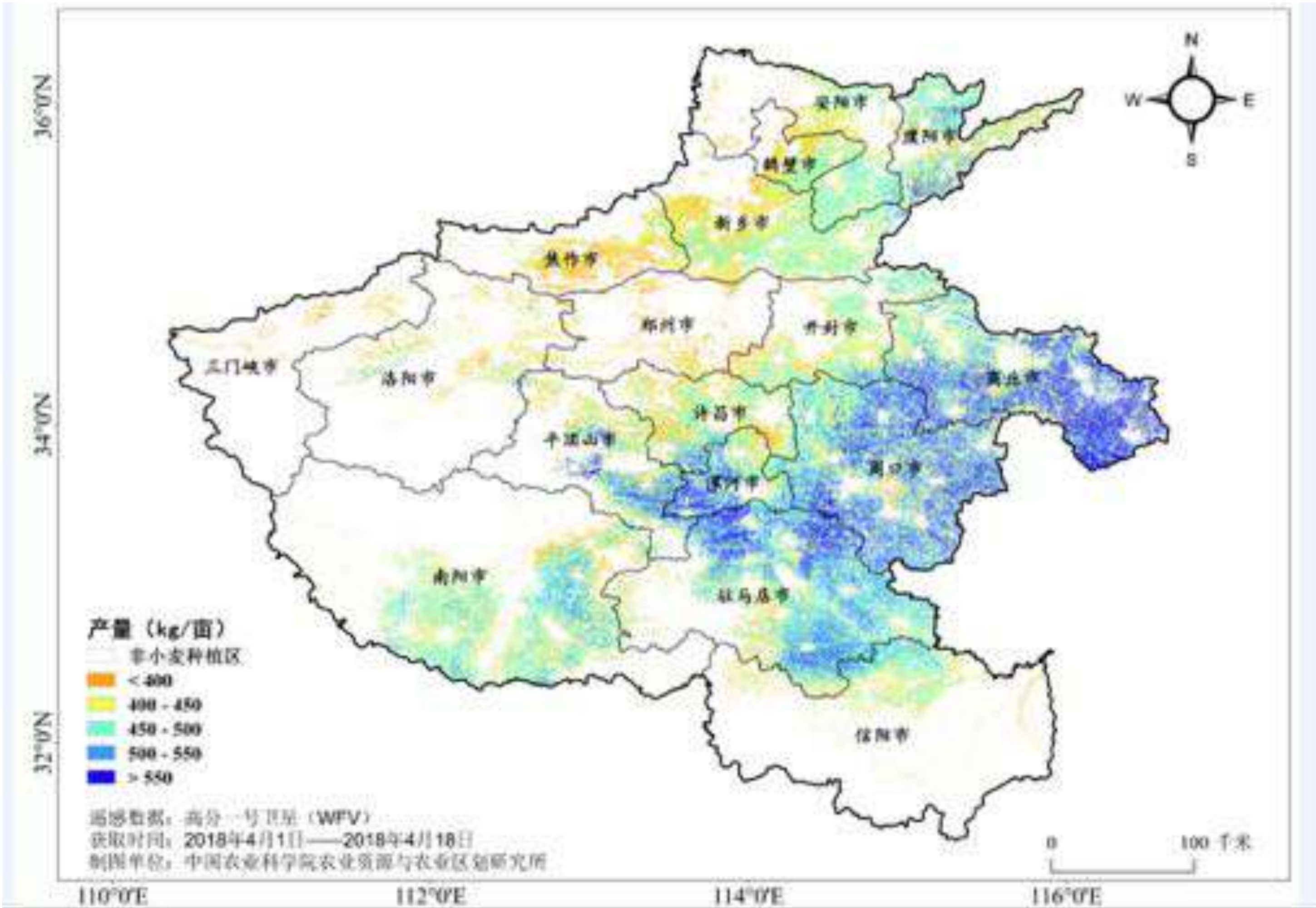




Wheat protein content in Henan province on GF-1



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) →

N_c :Critical nitrogen dilution

Rice:

$N_c = 3.53DM^{-0.28}$ (DM >1.55 t ha^{-1})

Wheat:

$N_c = 4.49DM^{-0.44}$ (DM>1.70 t ha^{-1})

↓

NNI = N_a / N_c

NNI ≥1 → **No dressing N**

NNI <1 → **N_{and}**

Nue → **Optimal dressing N**

N_c :Critical nitrogen dilution（N_c=aDM^{-b}）

N_a : Actual N concentration （%）

DM: Dry matter （t hm^{-2}）

NNI: Nitrogen nutrition index

N_{and} : Accumulated N deficit (kg ha^{-1})

Nue : 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

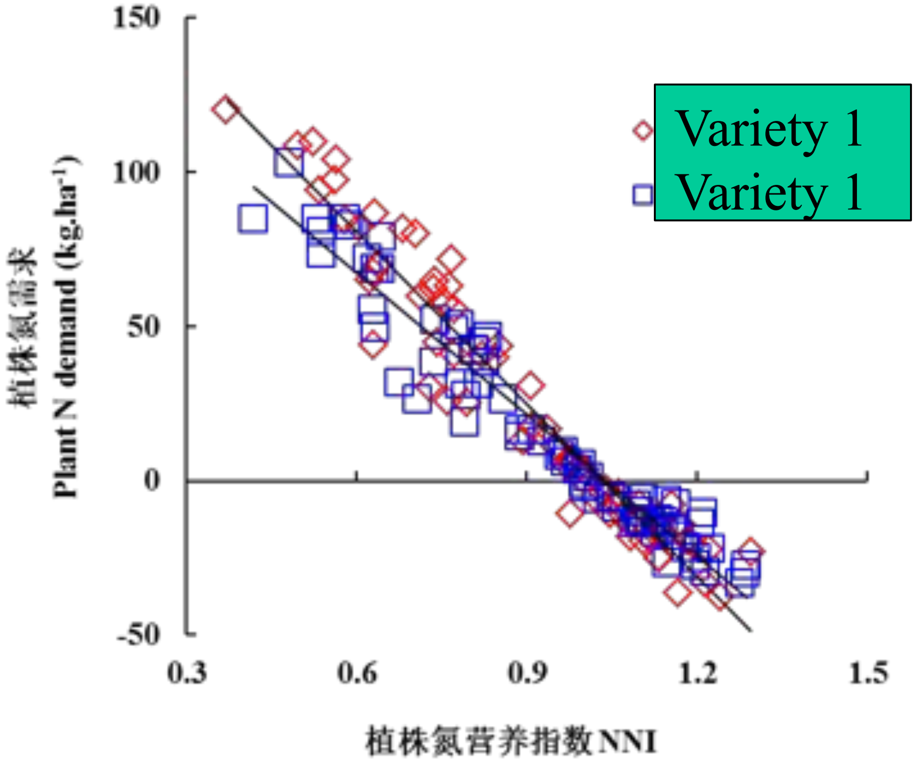
  (2) A vertical line corresponding to an increase in N concentration without variation in DM.

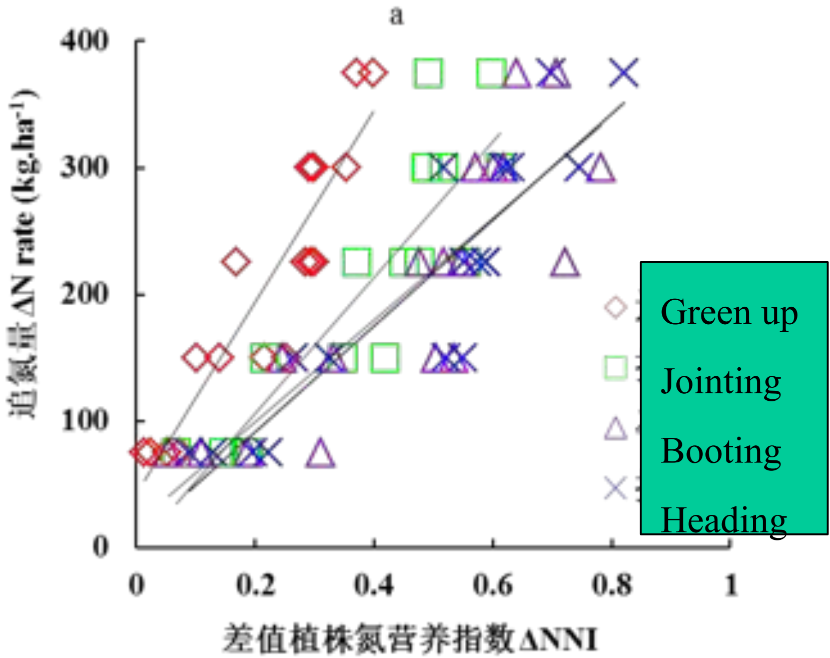
- The Nc correspond to the ordinate of the intersection point of oblique and vertical lines.

- 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}=-186.29NNI+192.27

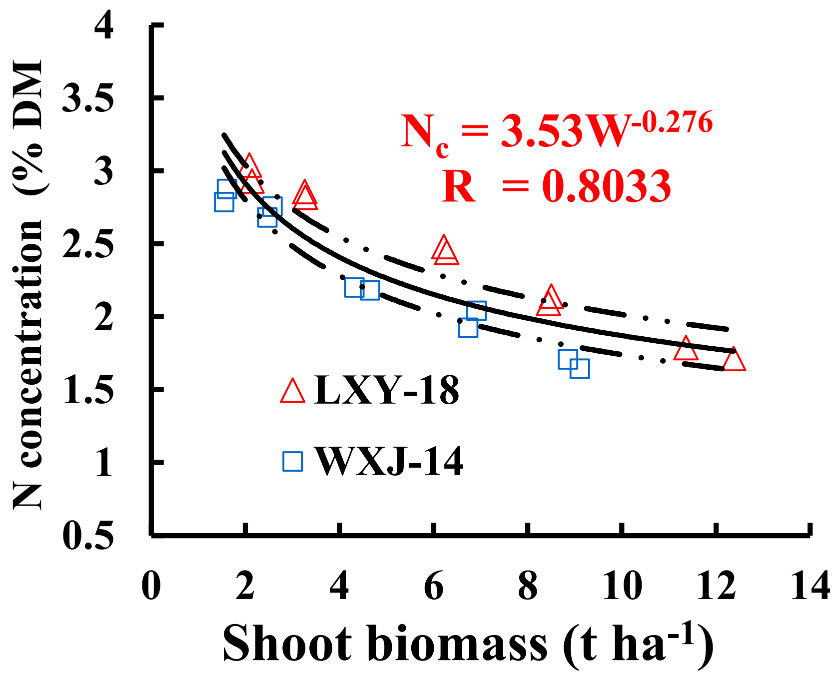
NM13：N_{and}=-152.81NNI+158.9

Turn green ΔN = 755.49ΔNNI + 42.556

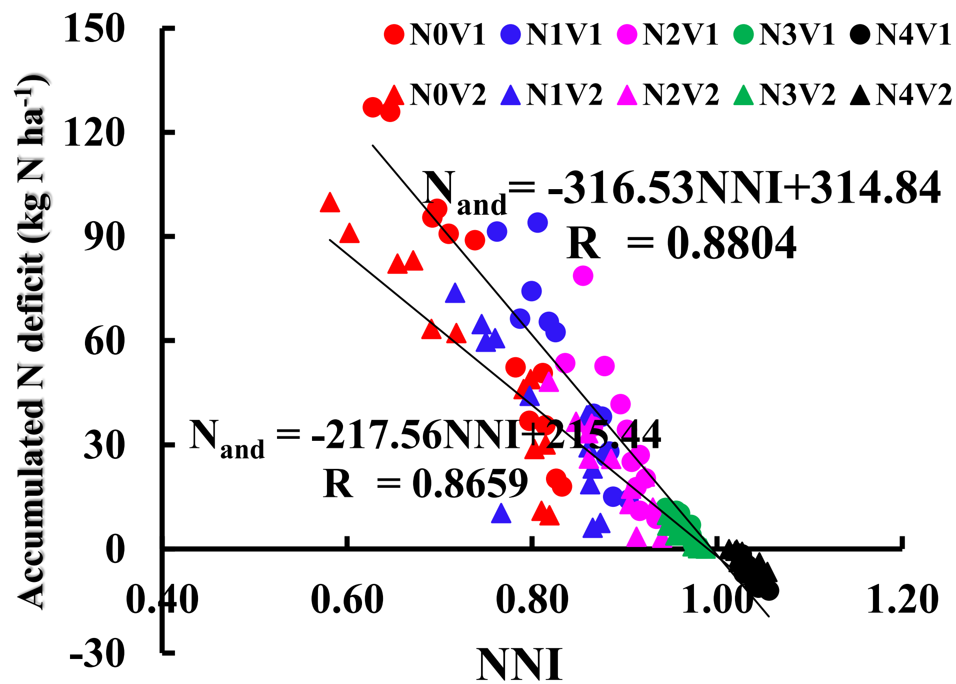
Jointing ΔN = 537.27ΔNNI - 1.8856

Booting ΔN = 417.58ΔNNI + 7.6688

Heading ΔN = 401.73ΔNNI + 19.195



Critical nitrogen (N_c) dilution curve for the shoot of rice

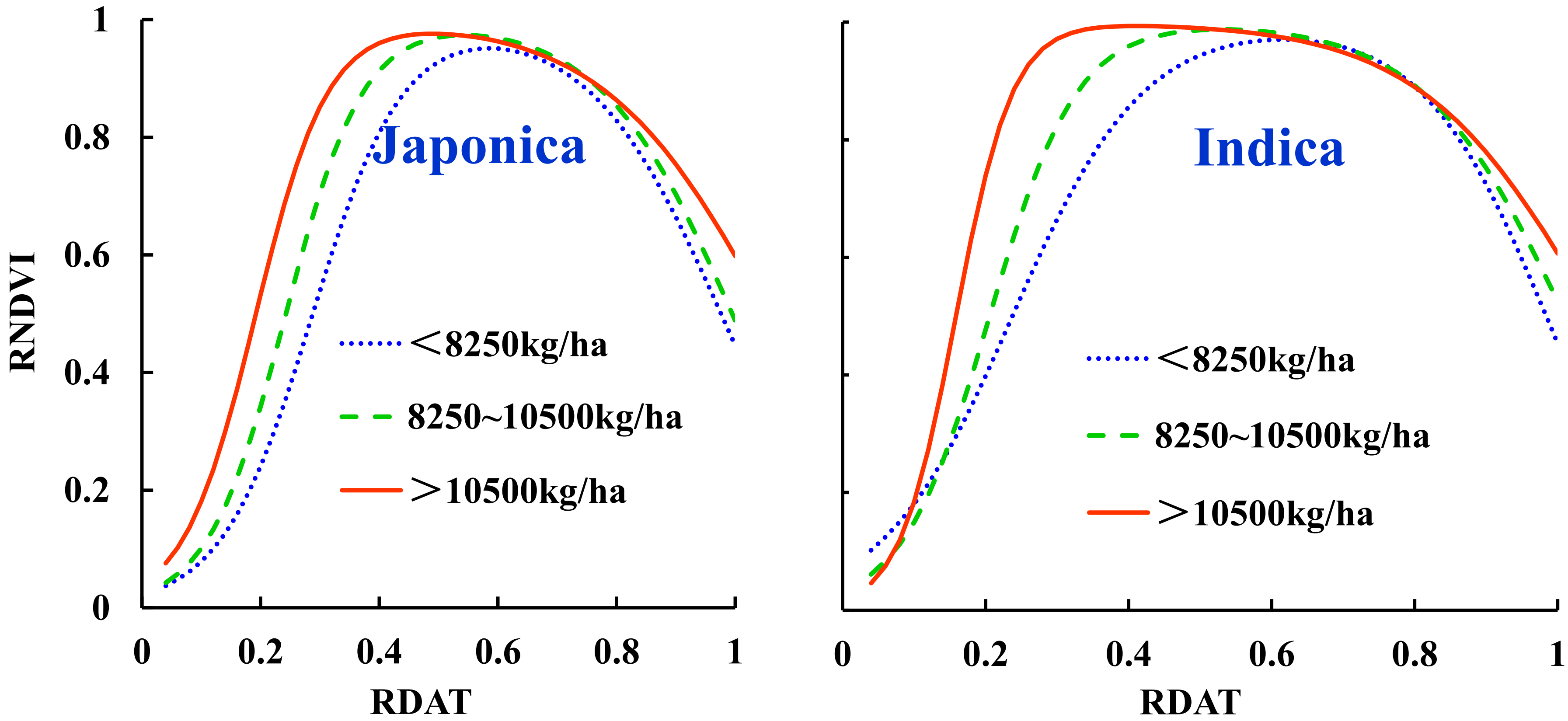


Relationship between nitrogen nutrition index (NNI) and accumulated nitrogen deficit (N_{and})

V1: LXY-18
V2: WXJ-14

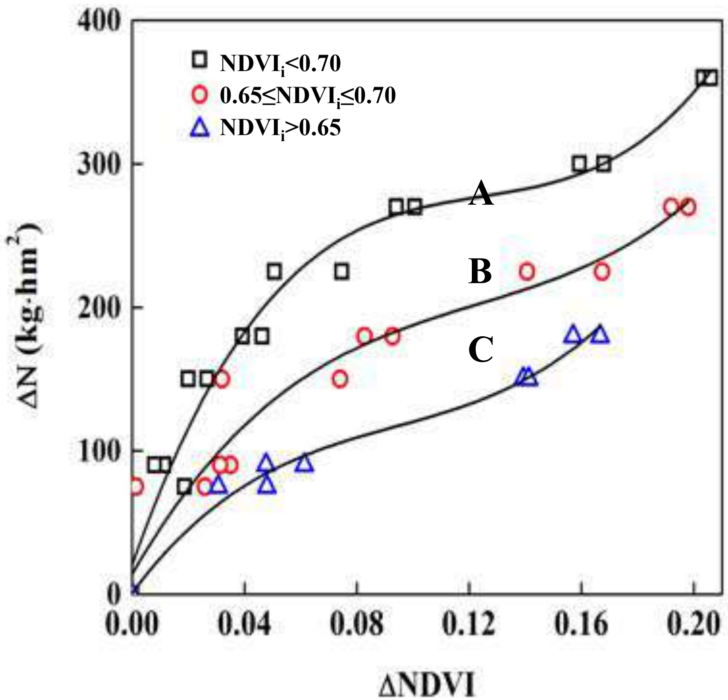
Diagnosis the nitrogen fertilizer on the dynamic NDVI

Relative NDVI dynamic model for different yield target

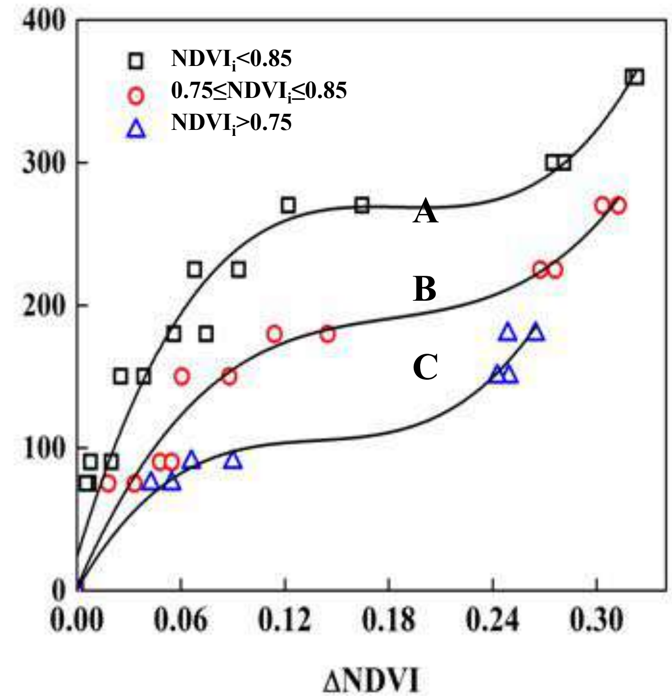


Recommend the nitrogen fertilizer

Jointing Stage



Booting Stage

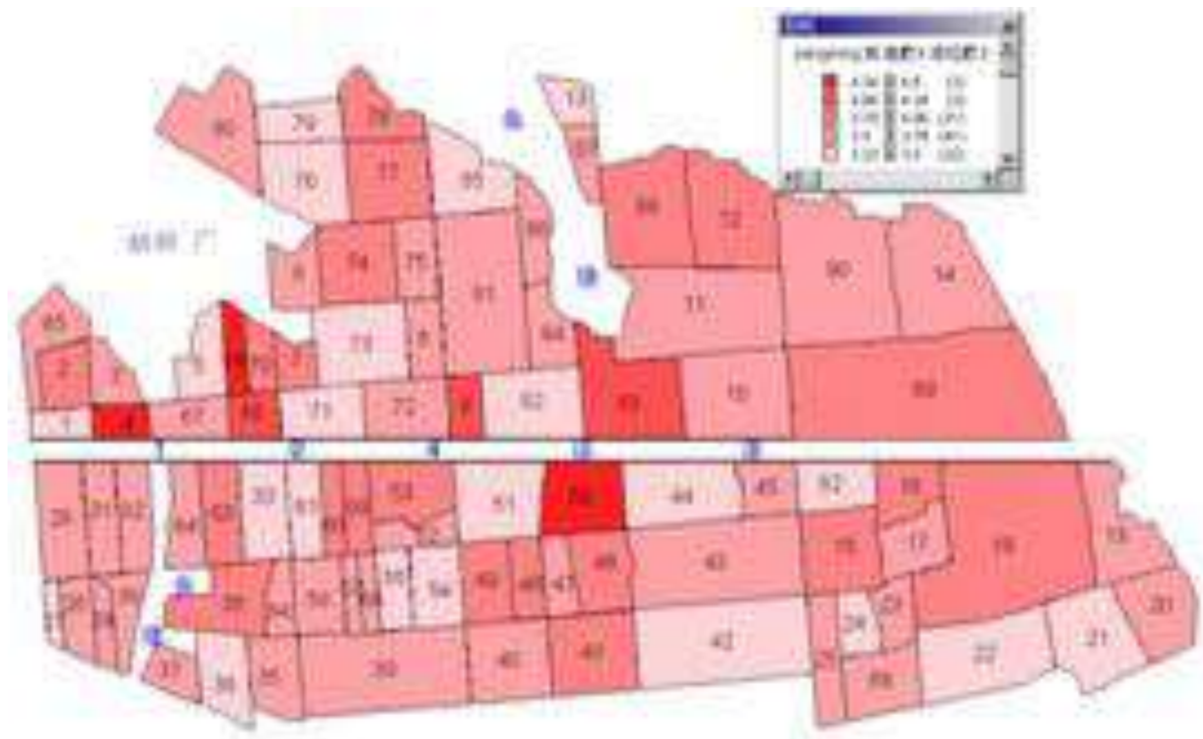


$\Delta NDVI = NDVI_{Ni} - NDVI_{Nj}$ $\Delta N = N_{Ni} - N_{Nj}$

（i=4，3，2；j=0，1，2，3；i>j）

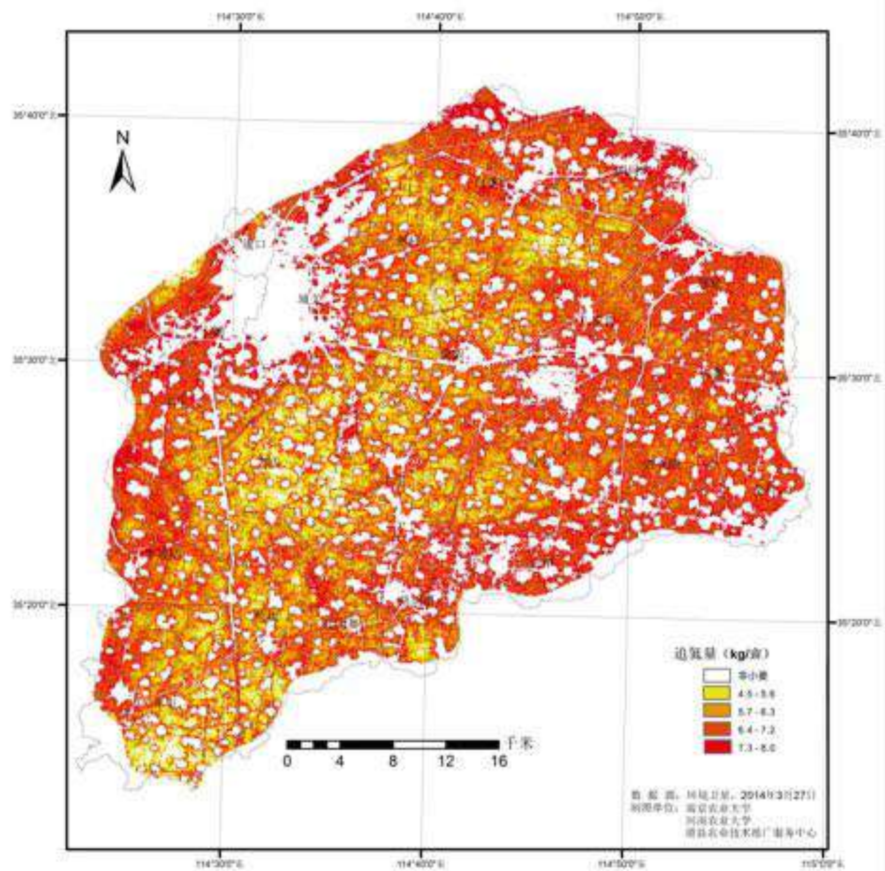
The relationship of △NDVI and △N

The rice dressing fertilizer at field level



at booting in Nanjing, Jiangsu province

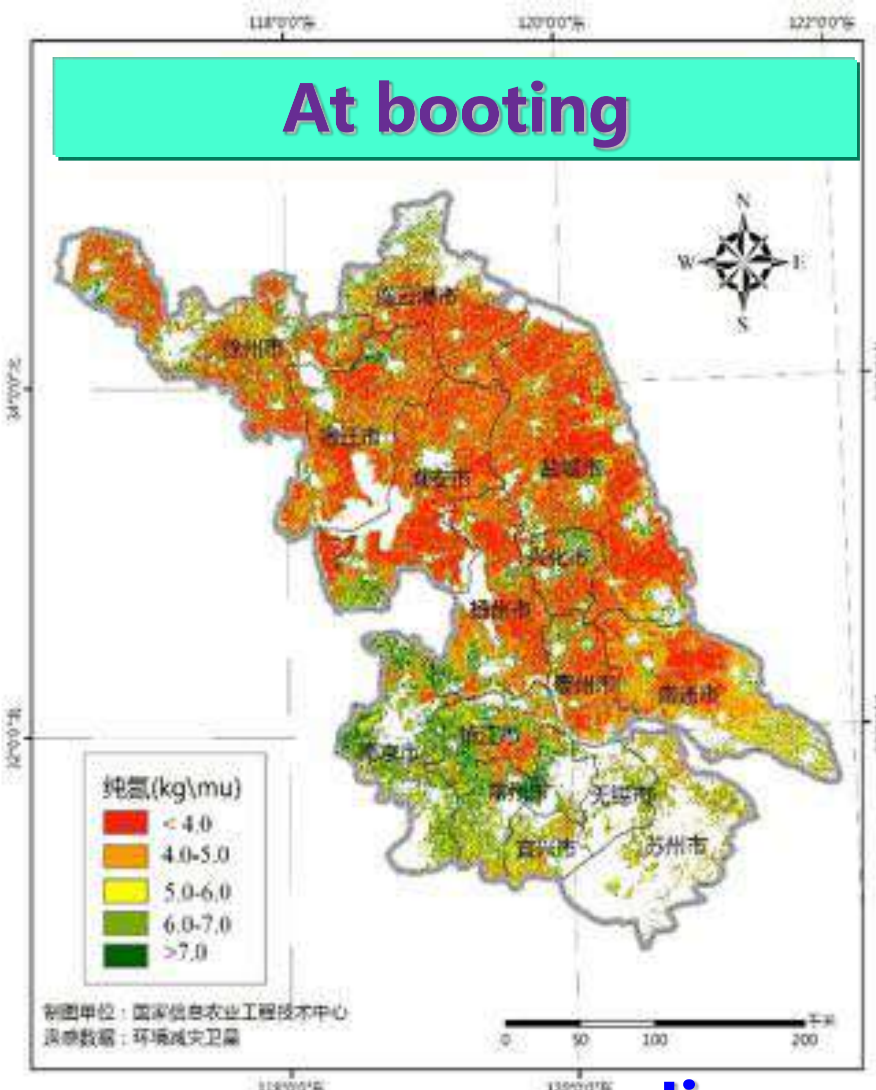
Wheat dressing fertilizer at county level

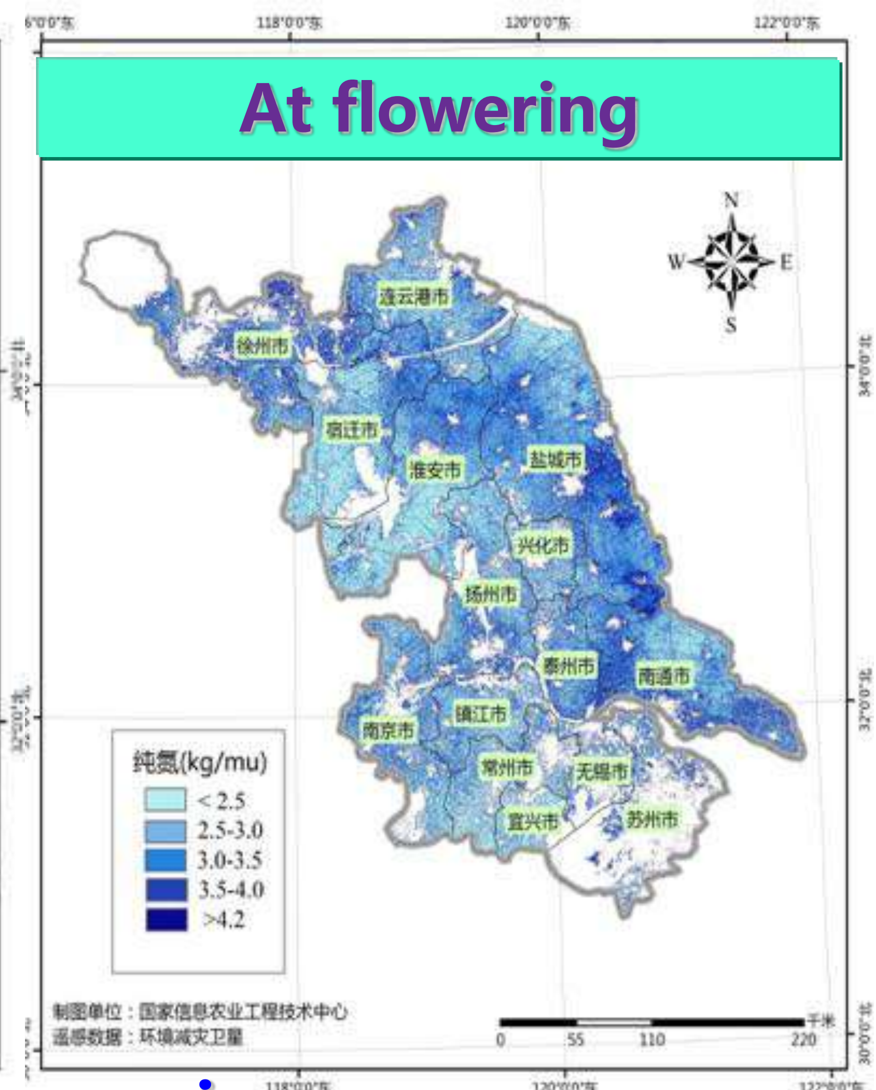


wheat Huaxian, in Henan Province

Image: HJ-1, China

Wheat dressing fertilizer at regional level





Jiangsu province

Image: HJ-1, China

site-specific fertilization 精确施肥

Real-Time Sensor / Sprayer

精确灌溉

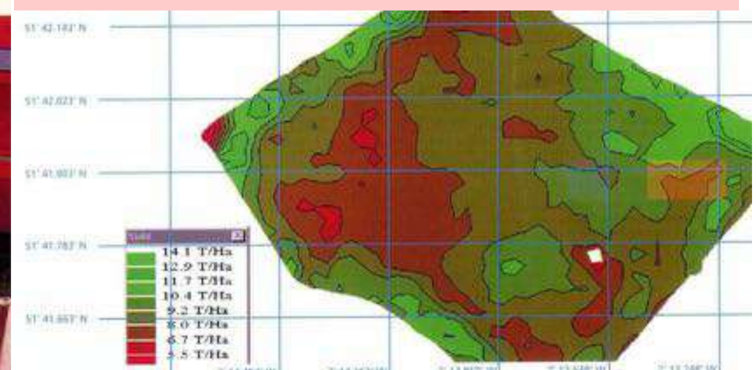
precision irrigation

Precision spraying 精确喷药

精确收获Precise harvest

产量空间分布图

Distribution of production



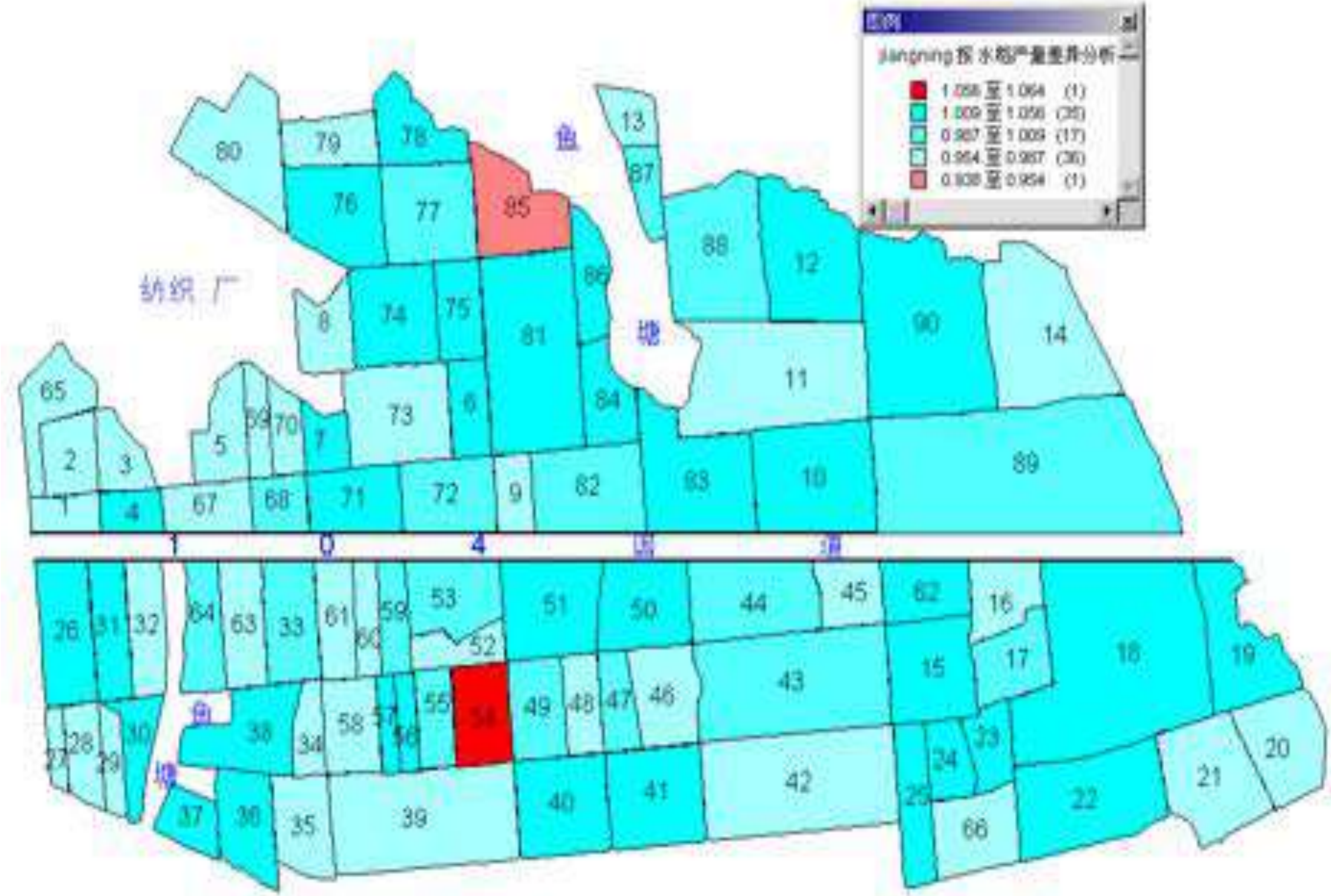
Spraying by Unmanned Aerial Vehicle

- High efficiency
- Non-toxic
- Low cost

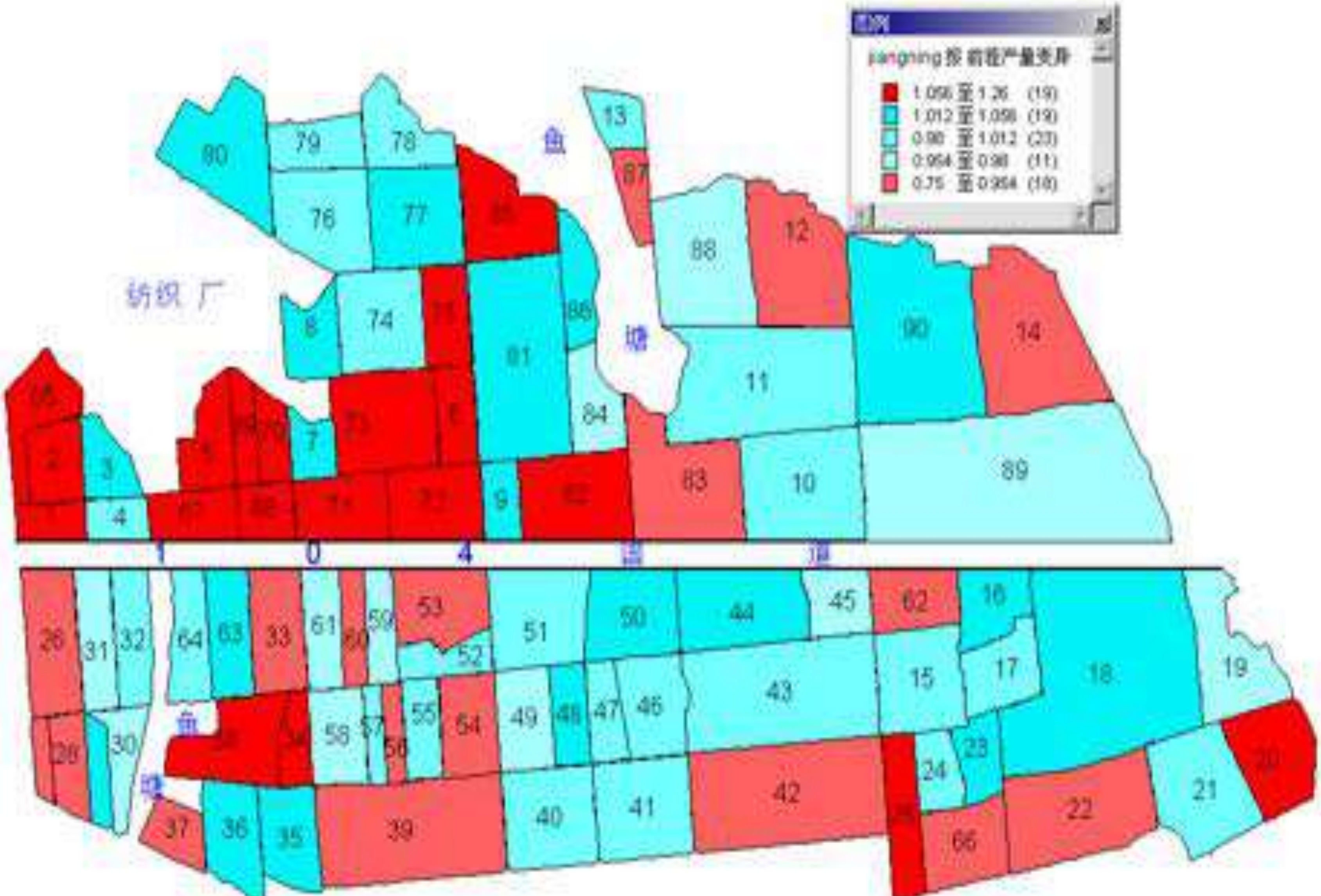
Benefits of Digital Farming for Rice

- 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?

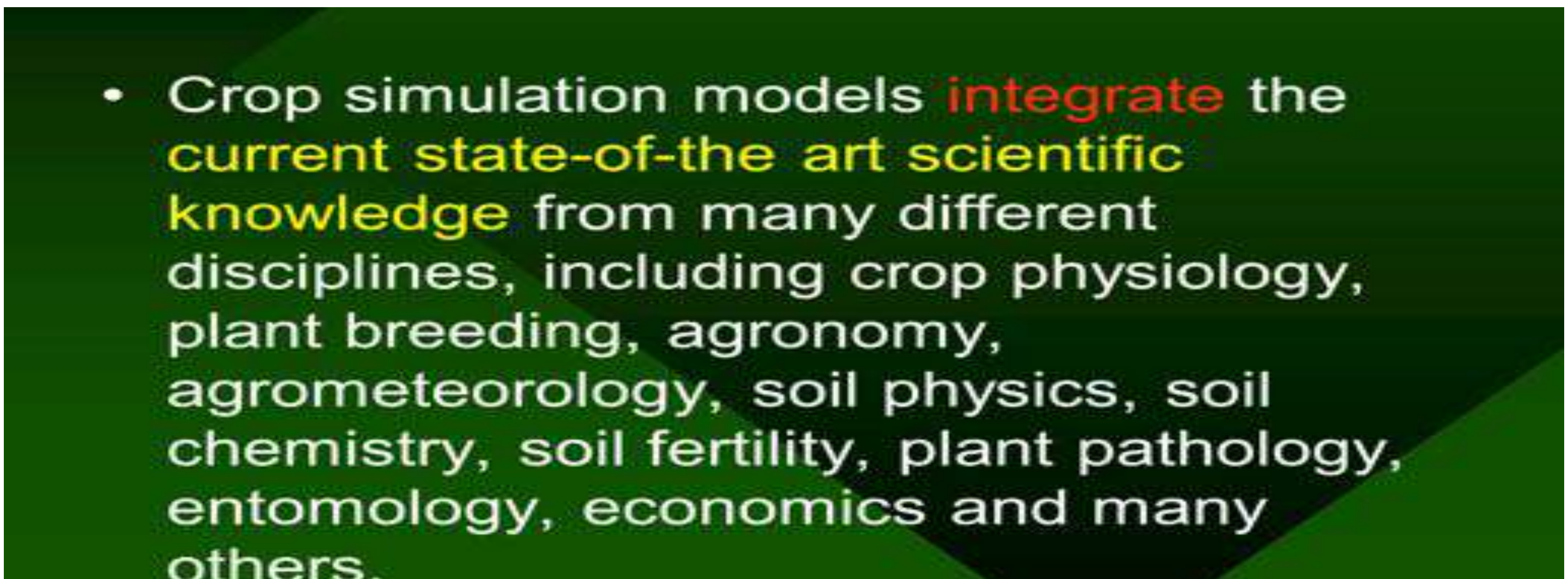
Growth Model---Predict the productivity

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.

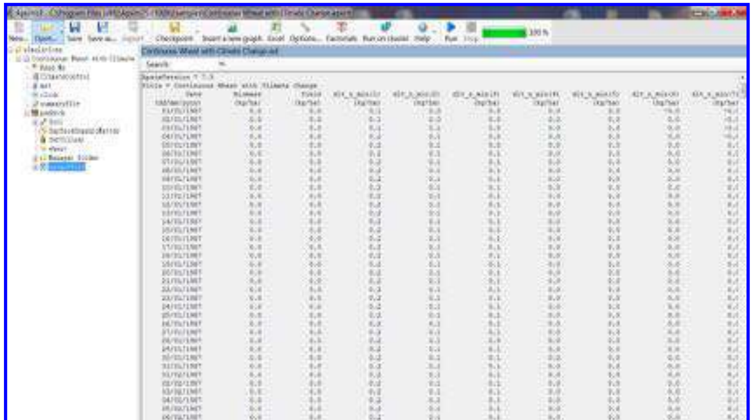


Simulation model

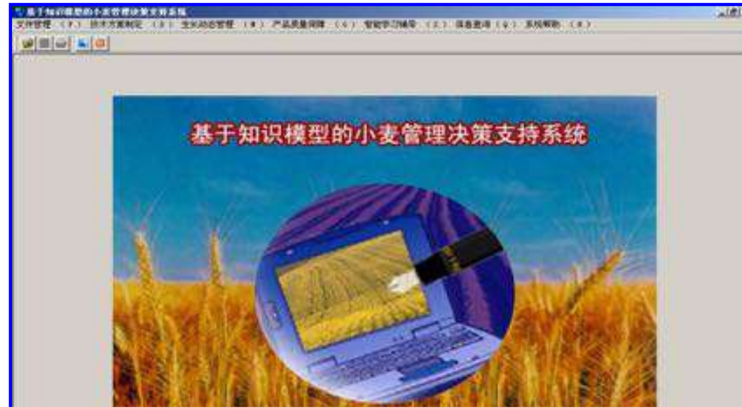
Information technology application in the field of agriculture began in the late 1970 s, with successful development and application of crop growth simulation model for the outstanding representatives.

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



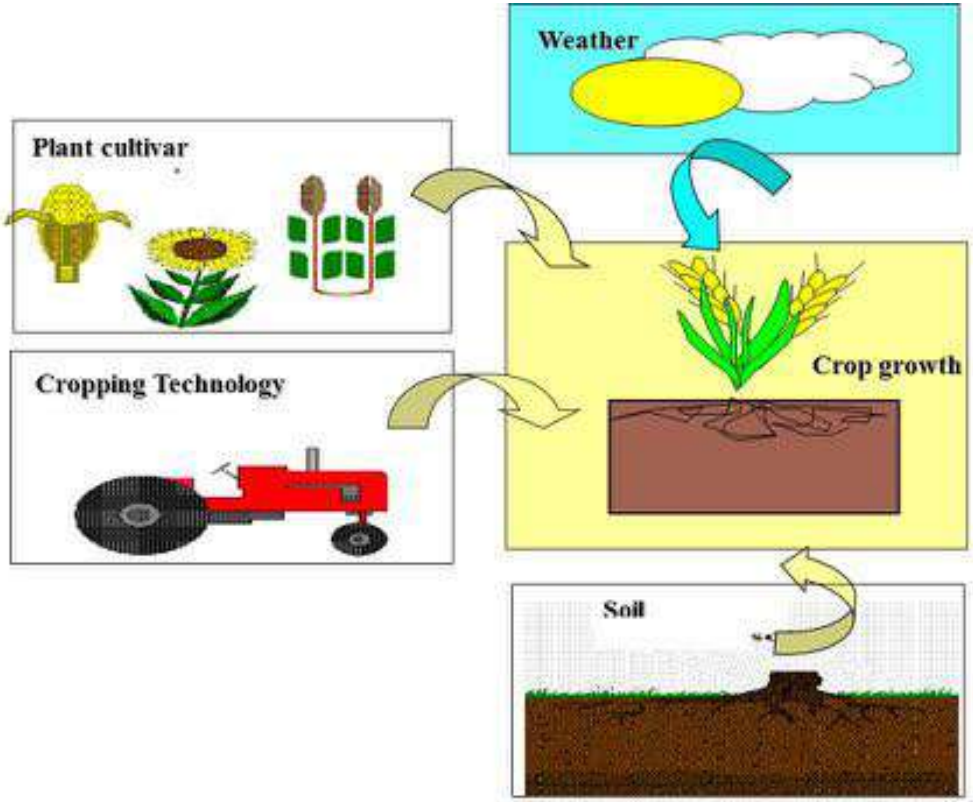
China: Crop growth

USA: DSSAT Version 4.0

China: Crop growth

The second prize of national scientific and technological progress

Growth model



Components of farming system

Development of CropGrow models

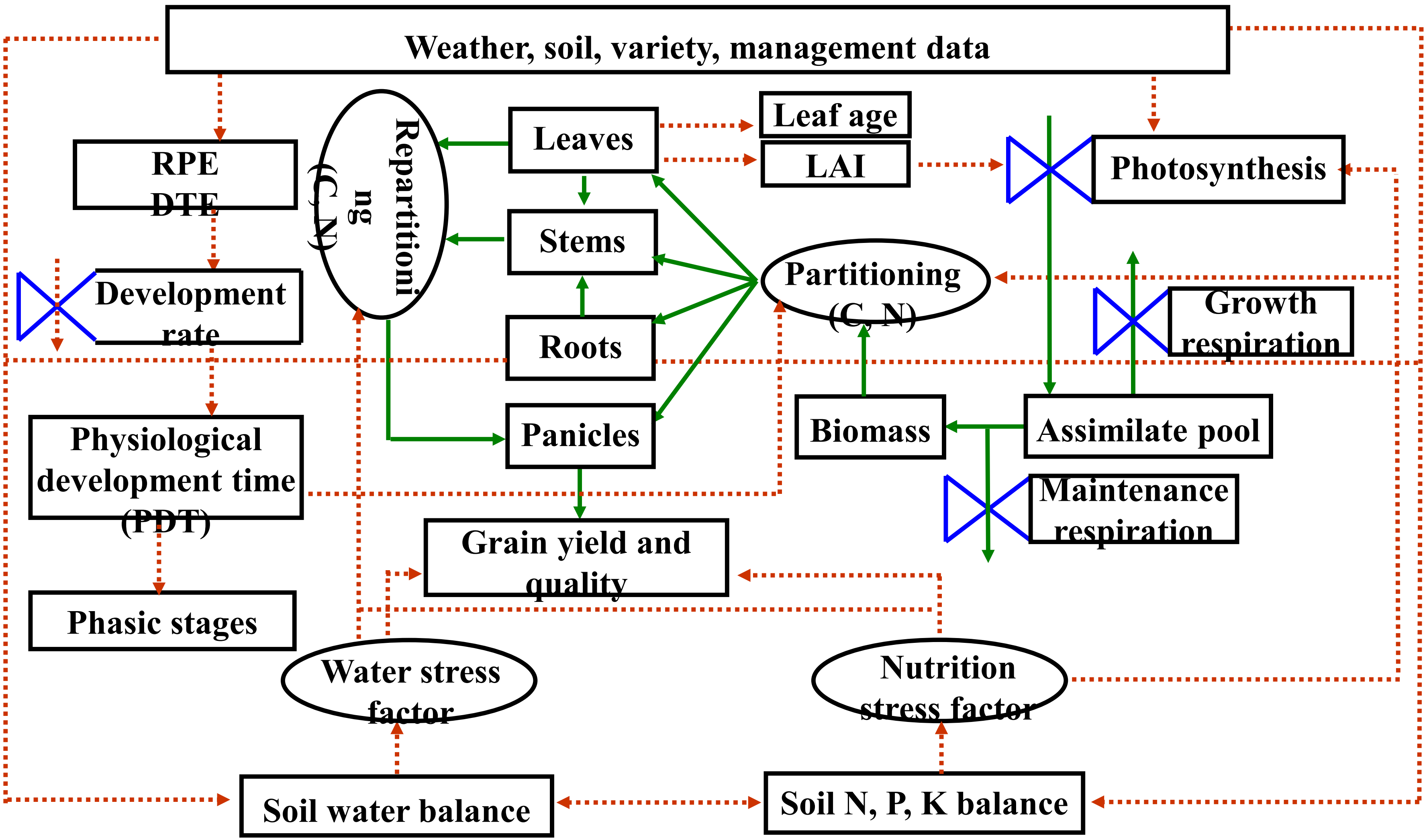


Diagram of matter and energy

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

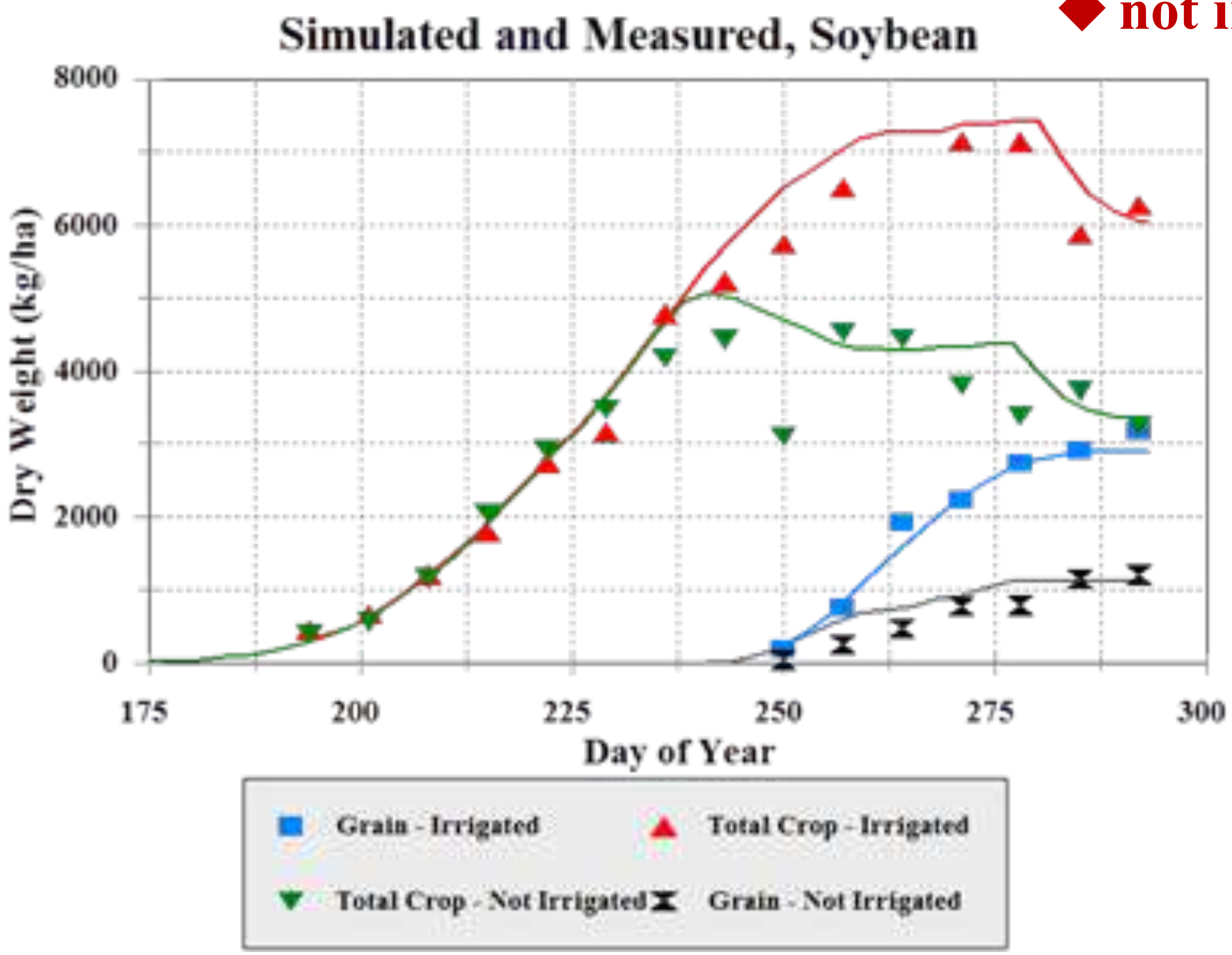
Model-based decision support system

Input interface of rice simulation system

Output interface

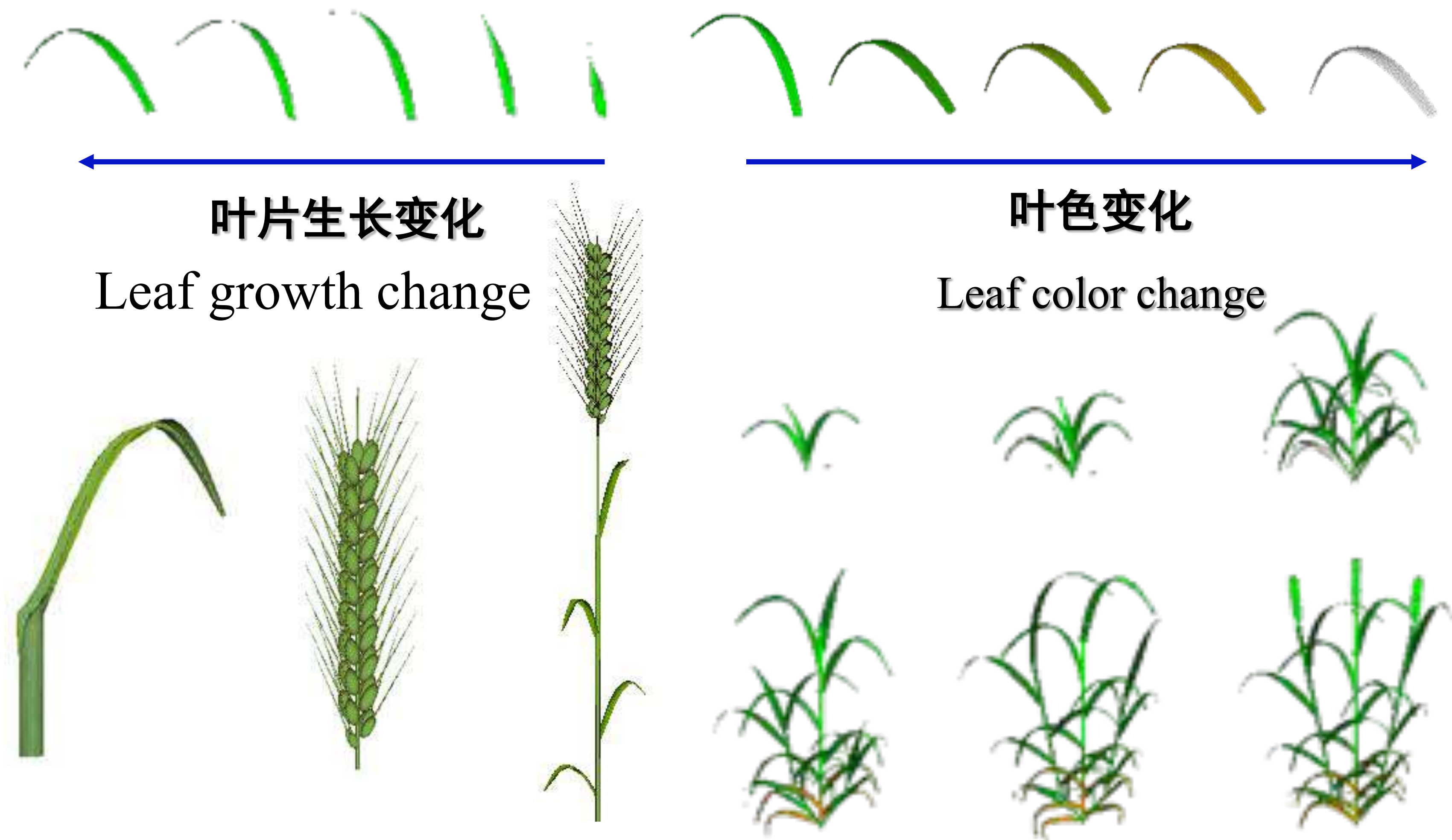
Output interface

◆ irrigated
◆ not irrigated



Model-based virtual wheat growth

基于模型的可视化（虚拟）小麦生长

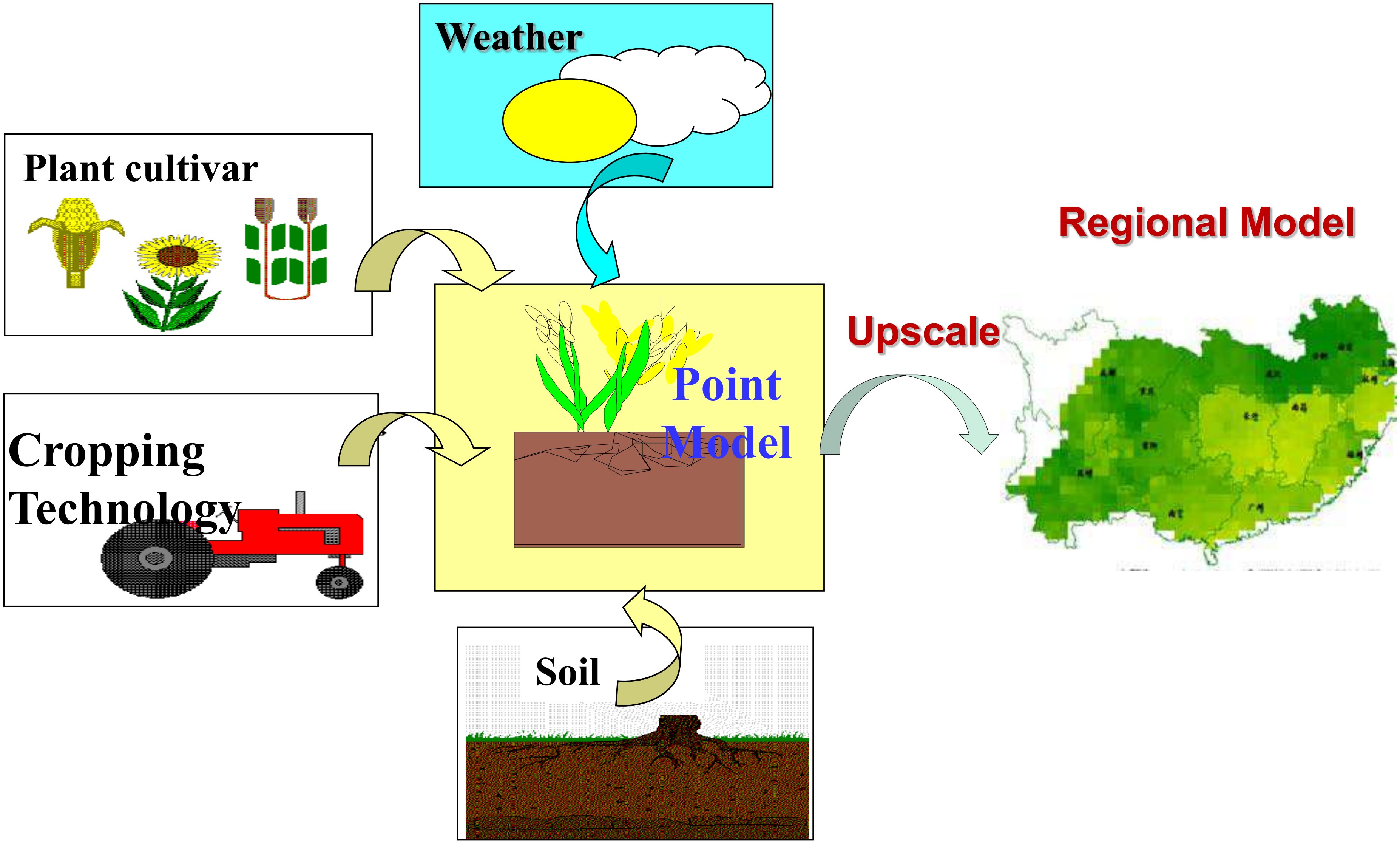


叶鞘sheath　麦穗ear　单茎single stem　　小麦生长的虚拟输出

Model-based virtual rice growth

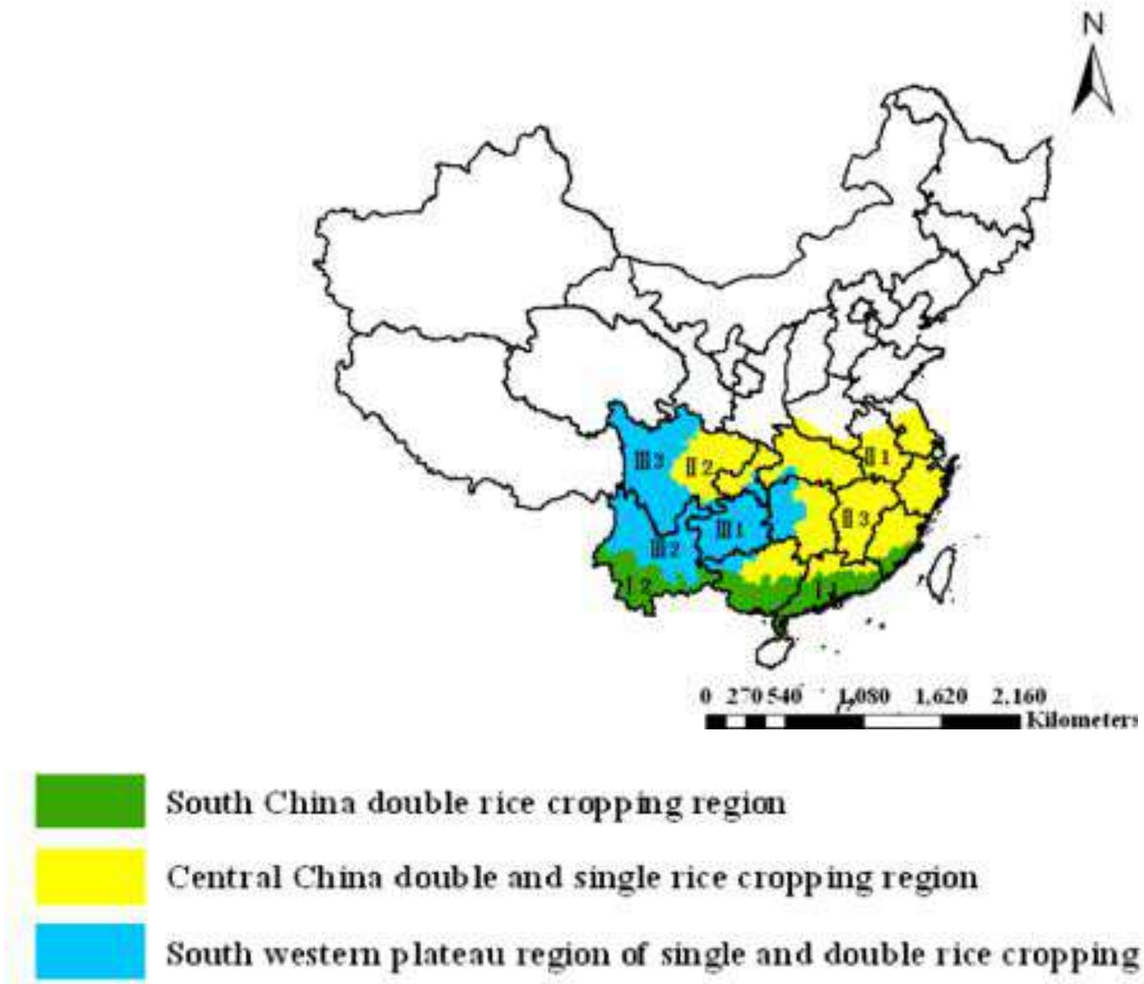
基于模型的可视化（虚拟）水稻生长

Integration of RiceGrow and GIS: Spatialized RiceGrow

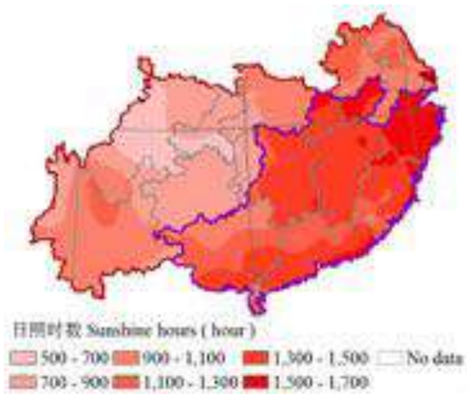


4. Prediction of regional rice productivity

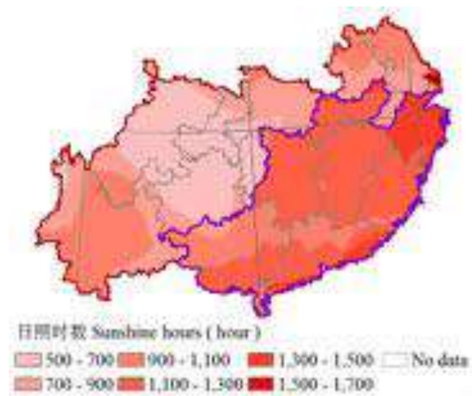
4.1 Study region------Southern China



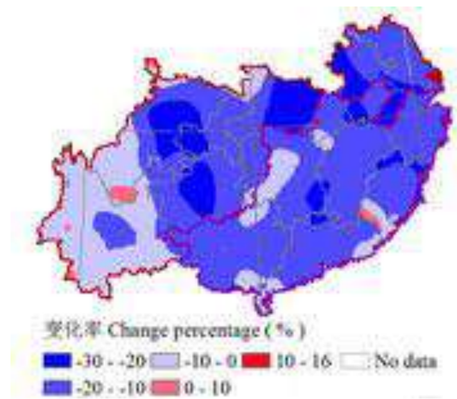
Total sunshine hours during rice growing period



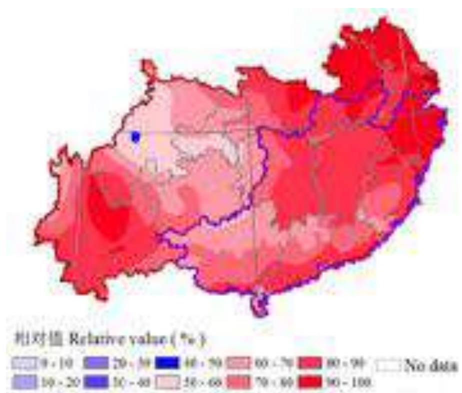
a



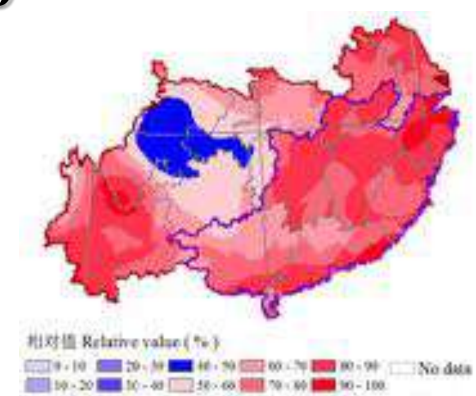
b



c



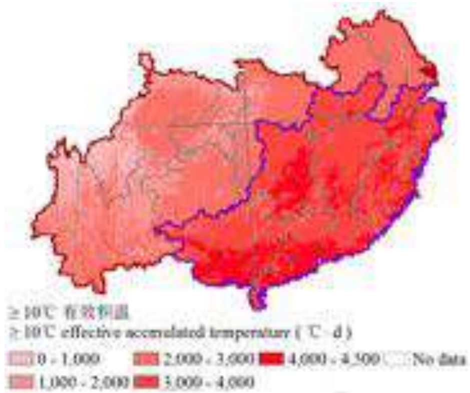
d



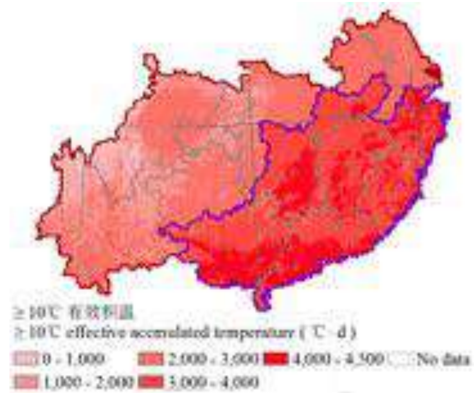
e

（a.60's b. 00's c. change rate d . relative value of 60's e. relative value of 00's）

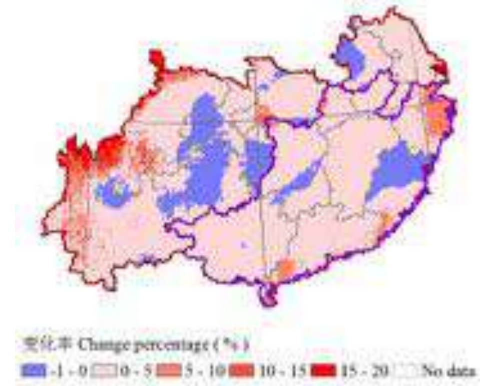
Total growing degree-days during rice growing period



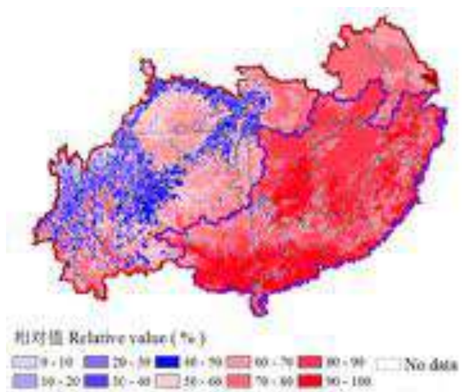
a



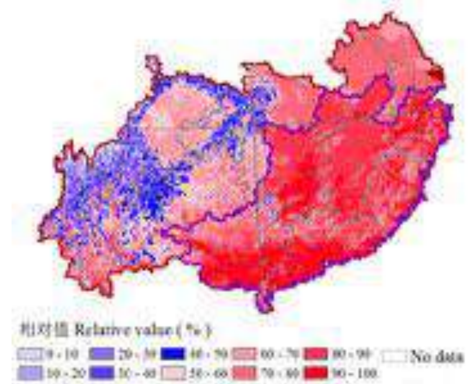
b



c



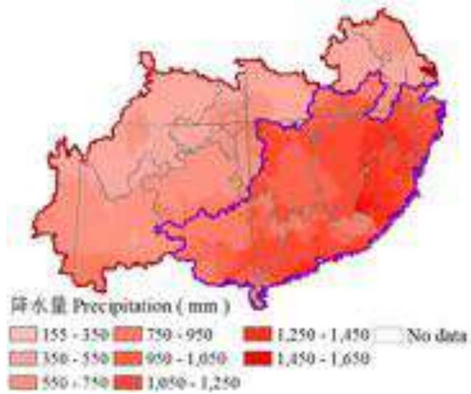
d



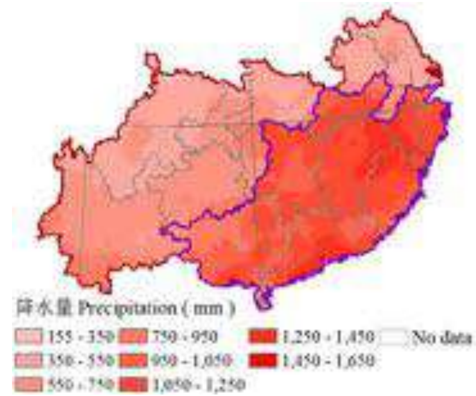
e

（a.60’s b. 00’s c. change rate d . relative value of 60’s e. relative value of 00’s）

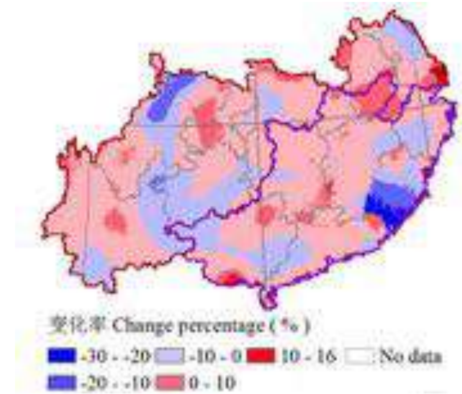
Total precipitation during rice growing period



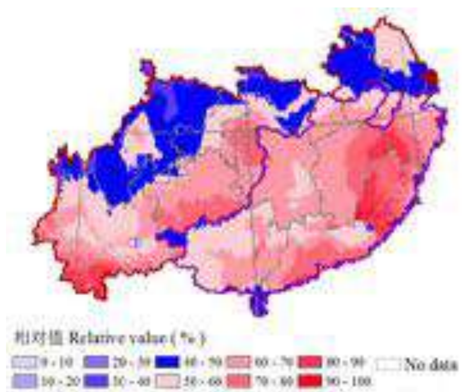
a



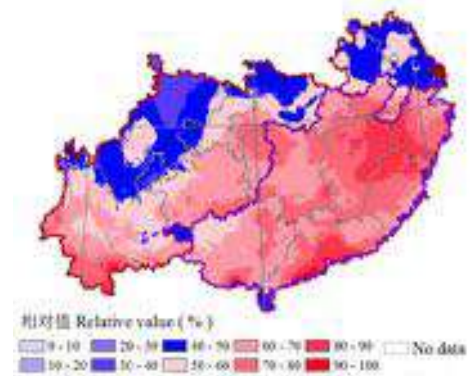
b



c



d

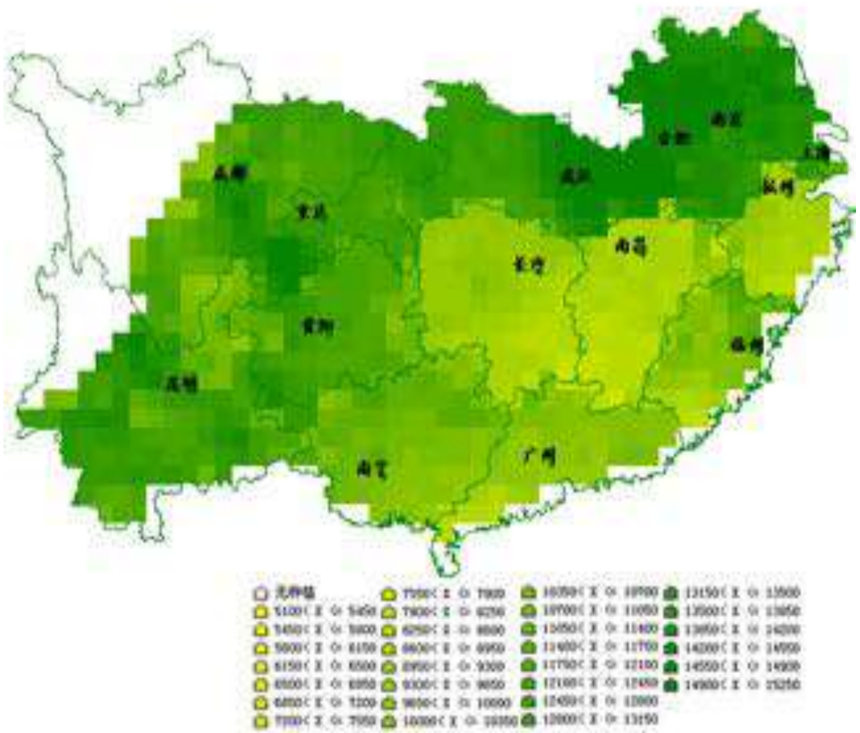


e

（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



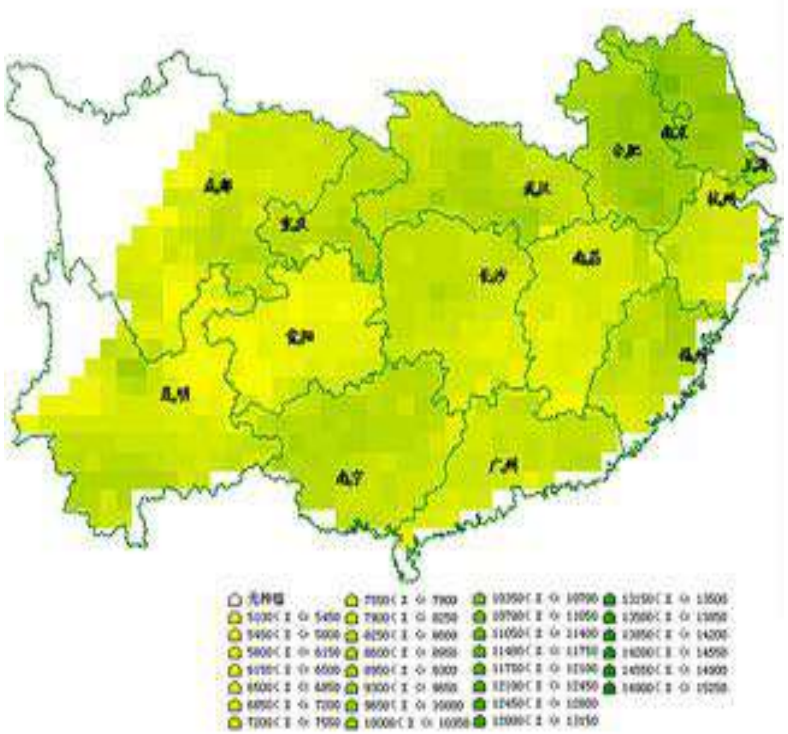
7485—15492kg ha^{-2}

Water limited productivity

Legend as left

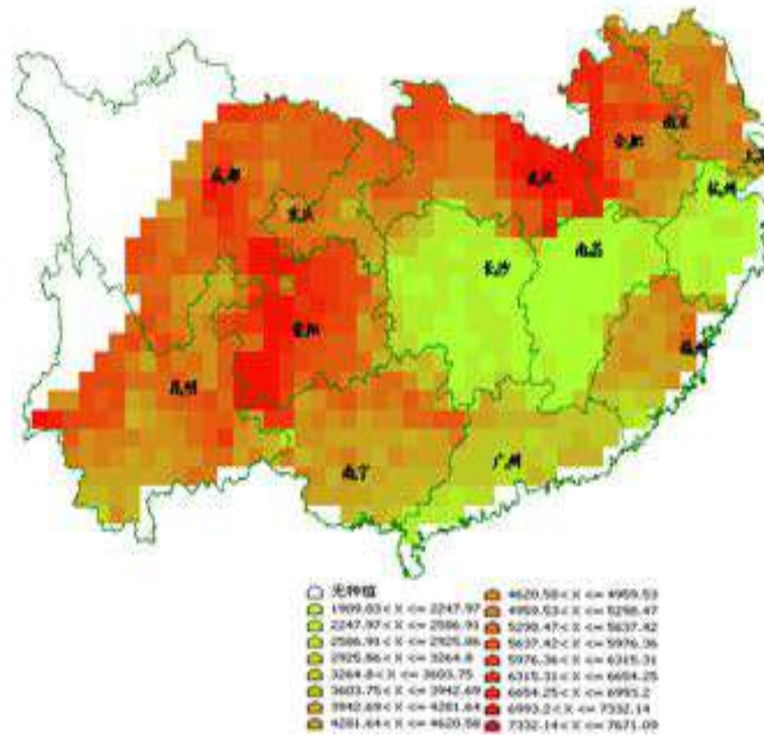
7100—14680 kg ha^{-2}

N limited productivity



5210—10360 kg ha^{-2}

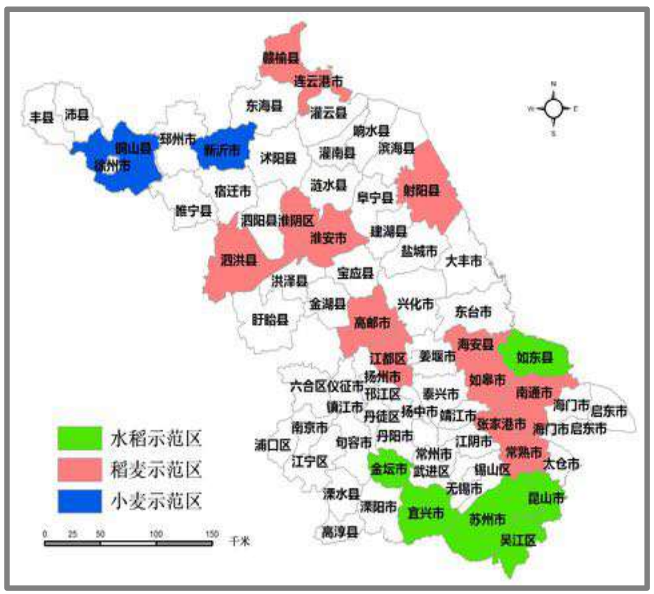
Yield increasing potential



1910—7670kg ha^{-2}

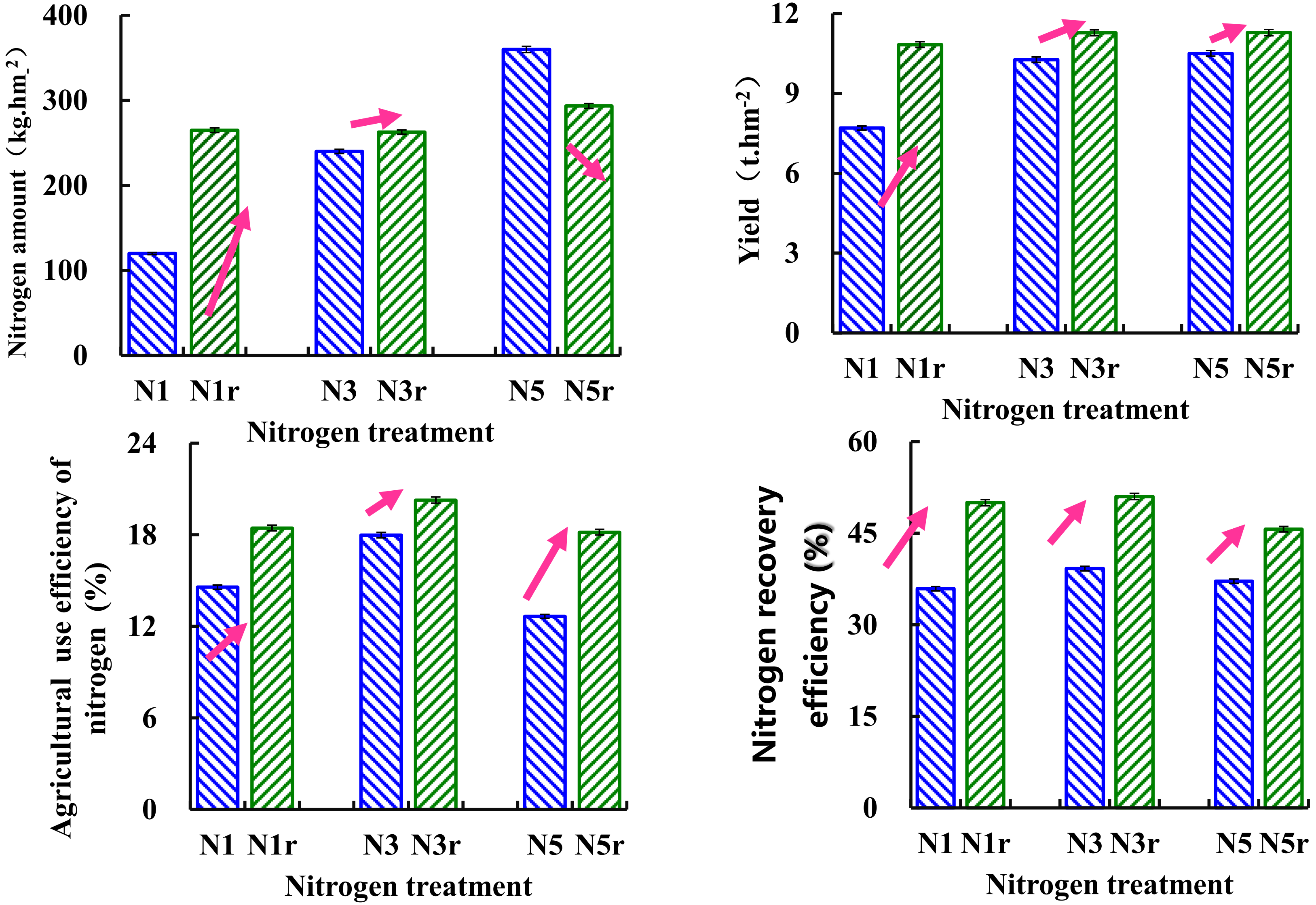
Demonstration and application of the technology

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.



Field, county, region

Performance of the fertilizer recommend technology



$N_1N_3N_5$: the traditional technology; Low level, Medium level, High level

$N_{1r}N_{3r}N_{5r}$: regulated by our technology

Training Workshop

Field tour

2013, Tongshan, Jiangsu

2012, Huaxian, Henan

2010, Wujiang, Jiangsu

2010, Rugao, Jiangsu

Rice precise planting technology spot observation meeting in Jiangsu xinghua .

江苏兴化水稻精确栽培技术现场观摩会(2017.9)

Technical training for different background users

面向不同用户层的技术培训

Technical training tool for different background users

微信推送
Weichat

农技耘
播撒科技・不辍耕耘

Mobile phone APP

Conclusion: Technique Framework

How sowing? How growth? How fertilizer? How irrigation? How productivity?





Seeding Tillering — 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.**

①Lidar /UAVs /Hyperspectral remo sensing of vegetation

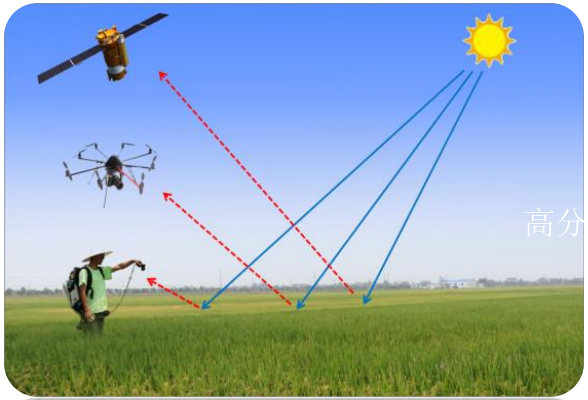
②Crop growth/biotic/abiotic stress/senescence monitoring

③Quantification of crop biophysical/biochemical properties

④Field ecosystem dynamics

⑤Crop-land use change

⑥Vegetation mapping



Contact: Prof. XiaYao（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?