



# マルチスケールリモートセンシングと3Dモデリングによる東アジアにおける白菜の生育モニタリング

## Growth monitoring of Chinese cabbage over East Asia with multi-scale remote sensing and 3D modeling

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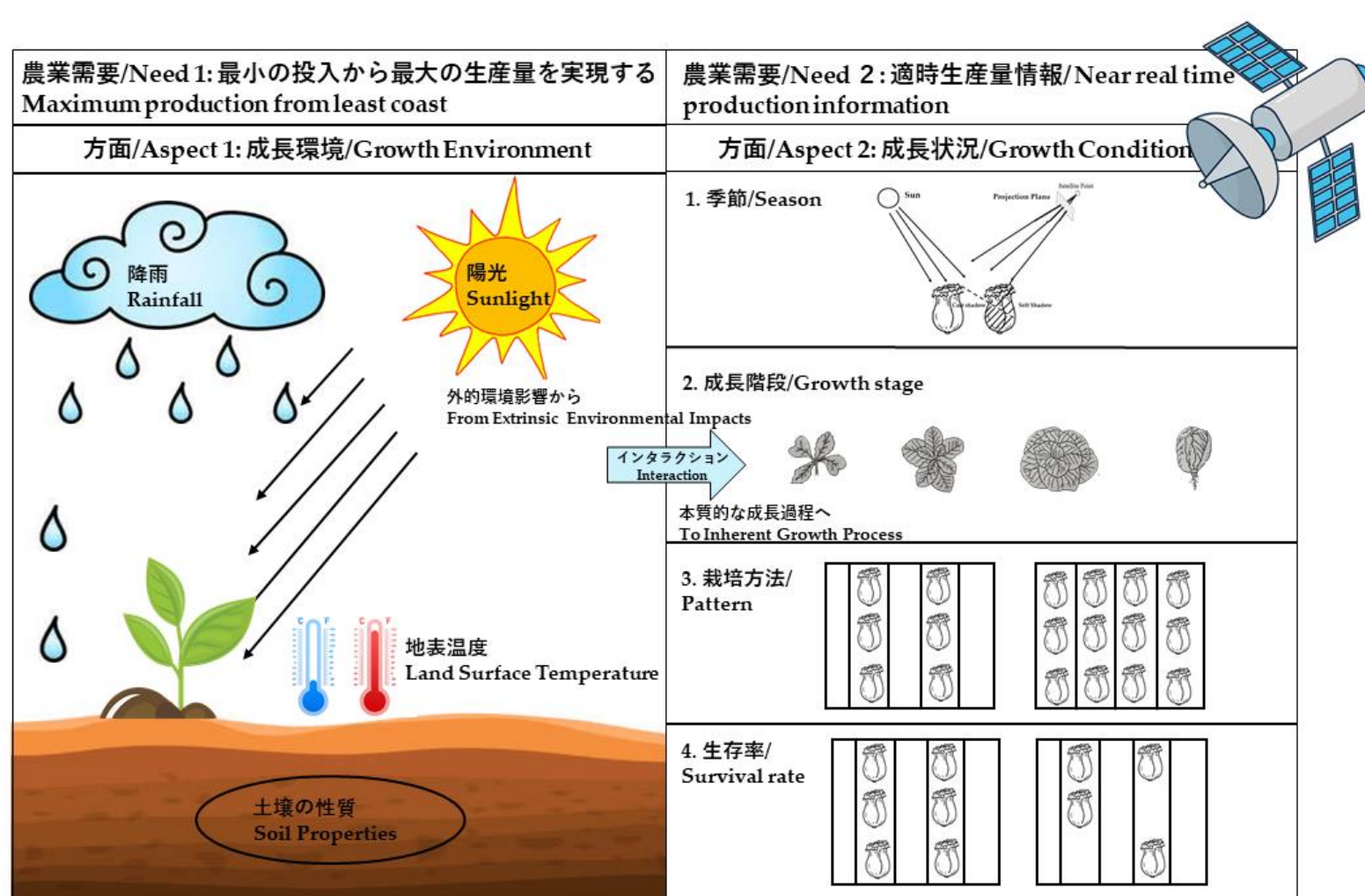
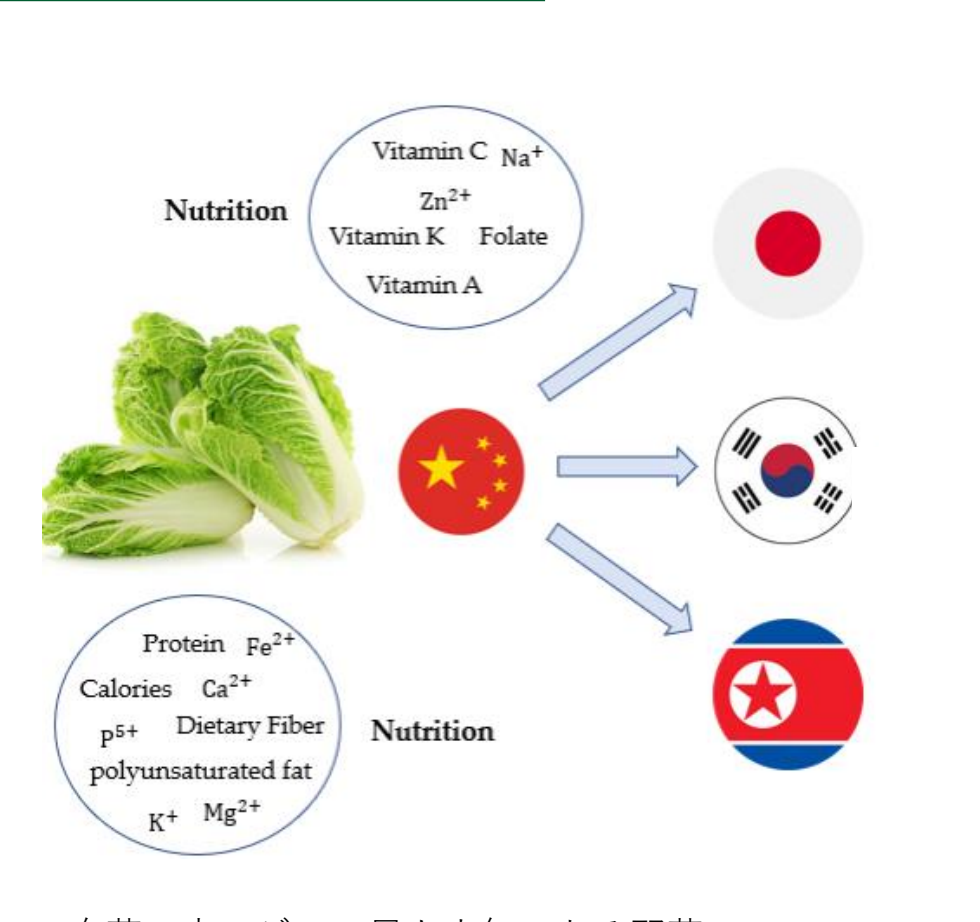
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**要旨:** 世界的な気候変動と農地への持続的な影響が続いているため、作物の成長のモニタリングはますます重要となっている。このモニタリングは、十分な作物の生産性を確保し、世界的な食糧危機を緩和するために重要である。東アジア料理の中で欠かせない白菜は、日常の中で摂取する必要がある栄養素を提供する重要な役割を果たしており、東アジア全域でのより一層モニタリングが必要である。本研究では、白菜の成長に関連する2つの主要な側面、つまり成長環境と成長状況に焦点を当て、マルチスケール衛星リモートセンシングおよび3Dモデリング技術を組み合わせ、東アジア全域での白菜の成長を効果的にモニタリングするための包括的なフレームワークを開発することを目指す。

**Abstract:** The monitoring of crop growth has become increasingly important due to the ongoing global climate change and the persistent anthropogenic impacts on agricultural lands. This monitoring is crucial for ensuring sufficient crop productivity and mitigating the potential global food crisis. Chinese cabbage, a staple in Asian cuisine that provides essential nutrients for daily consumption, plays a critical role, necessitating enhanced monitoring of its growth across East Asia. This study aims to develop a comprehensive framework that focuses on two primary aspects related to Chinese cabbage growth: the growth environment and the growth condition. To achieve this, we propose the utilization of multi-scale satellite remote sensing, in conjunction with smartphone-based photogrammetry and 3D modeling techniques, to effectively monitor the growth of Chinese cabbage throughout the East Asian.

### 1. 背景/Background



- 目的/Objective:**
  - 本研究では、マルチスケール衛星リモートセンシングとスマートフォンによる写真測量から得られる3Dモデリングを組み合わせ、白菜の成長環境と成長状況を総合的にモニタリングする枠組みを提案する。
  - This study proposed to develop a comprehensive framework to monitor the growth of Chinese cabbage regarding aspects of growth environment and growth condition relying on multi-scale satellite remote sensing coupling of in-situ smartphone-based photogrammetry derived 3D modeling.
- 新規性/Novelty:**
  - シャドウフラクションは、白菜の成長段階の判別に応用されている。
  - Shadow fraction has been applied to identify growth phenotypes of Chinese cabbage;
  - Sentinel-2画像の反射率について、影を補正した仮想白菜畑のシミュレーションを行う。
  - Virtual Chinese cabbage fields with shadow compensation have been simulated for the reflectance of Sentinel-2 imagery.

➢ 白菜: 東アジアで最も人気のある野菜の一つ  
➢ Chinese Cabbage: One of the most popular vegetable in East Asia

図1. 本研究の概要 Figure1. Graphical abstract of this study

### 2. 成長環境モニタリング/Growth Environment Monitoring

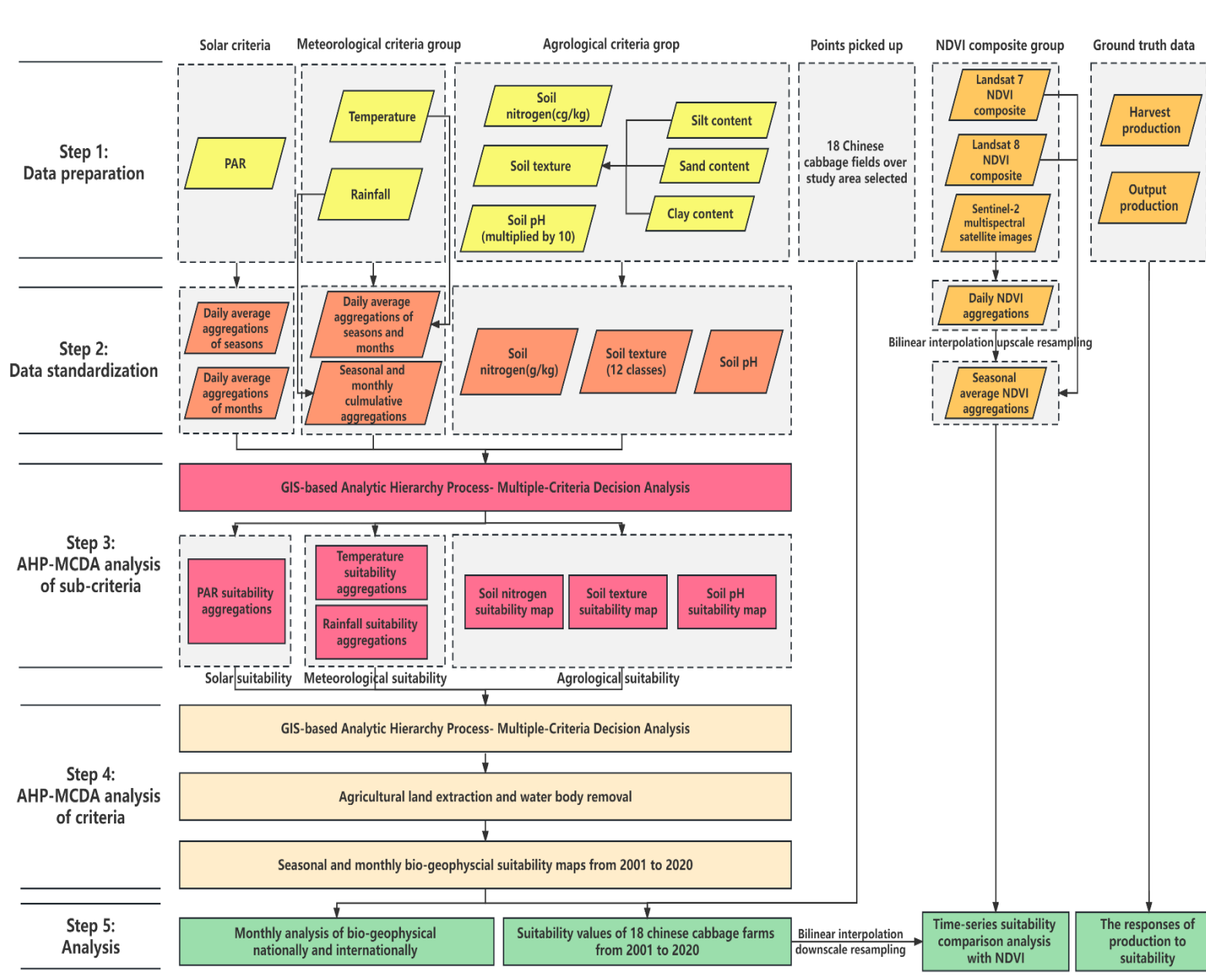


表1. データソース Table 1. Data sources

Data	Source	Product	Temporal Range	Temporal Resolution	Spatial Resolution
Temperature	NASA MODIS	MOD11A2 v06	18 February 2000 to present	8 days	1 km
Rainfall	JAXA	Near Real Time	1 January 2000 to present	1 h	0.1 degree
PAR	NASA MODIS	MCD18A2 v06	18 February 2000 to present	1 h	1 km
Soil nitrogen	WOSIS	Soil Grids 250 m 2.0	2017 to present	250 m	250 m
Soil texture	WOSIS	Soil Grids 250 m 2.0	2017 to present	250 m	250 m
Soil pH	WOSIS	Soil Grids 250 m 2.0	2017 to present	250 m	250 m
Agricultural land extraction and water body removal	GFSAD1000	Cropland Extent 1 km Multi-Scale Crop Mask Global Food Support Analysis Data	1 January 2010 to present	1 January 2010 to present	1 km
Global Land Cover	Glob Cover	Global Land Cover Map	1 January 2009 to present	3 days	300 m
Land use	USGS Landsat	Hansen Global Forest Change v1.9	1 January 2000 to present	1 January 2000 to present	30.92 m
Day NDVI Composite	USGS	Landsat 7 Collection 1 Tier 1 8-Day NDVI Composite	1 January 1999 to present	8 days	30 m
Day NDVI Composite	USGS	Landsat 8 Collection 1 Tier 1 8-Day NDVI Composite	7 April 2013 to present	8 days	30 m
Sentinel-2 MSI: Multispectral Instrument, Level-2A	ESA	Sentinel-2 MSI: Multispectral Instrument, Level-2A	28 March 2017 to present	10 days	10 m

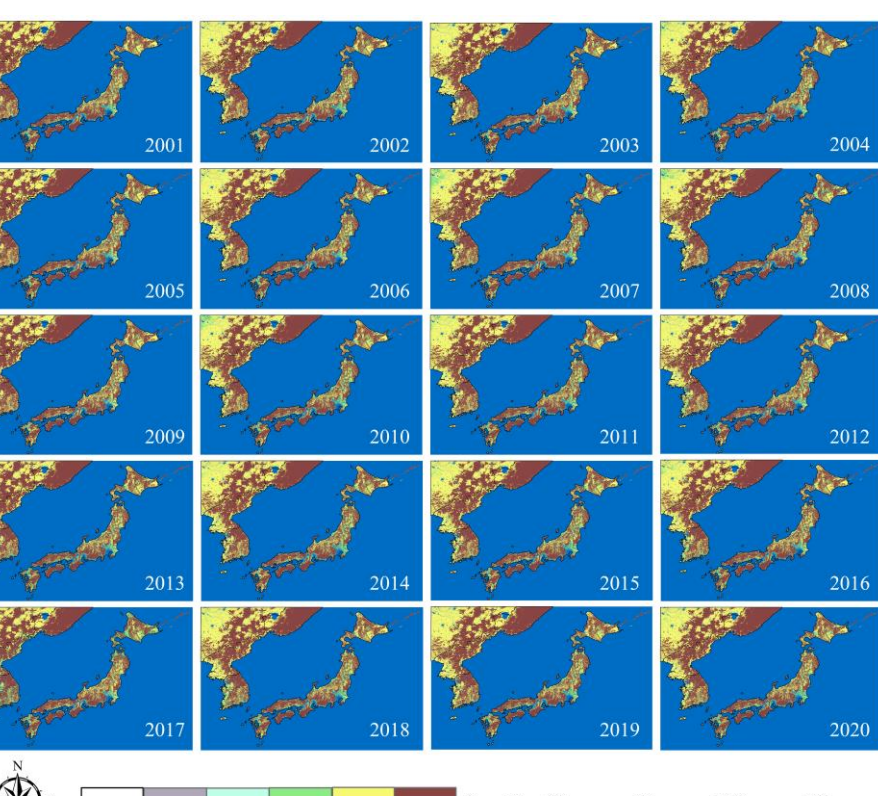


図4 2001年から2020年までの東アジアの夏の生物地球物理学的適性マップ  
Figure4. Bio-geophysical suitability maps of East Asia from 2001 to 2020 in Summer.

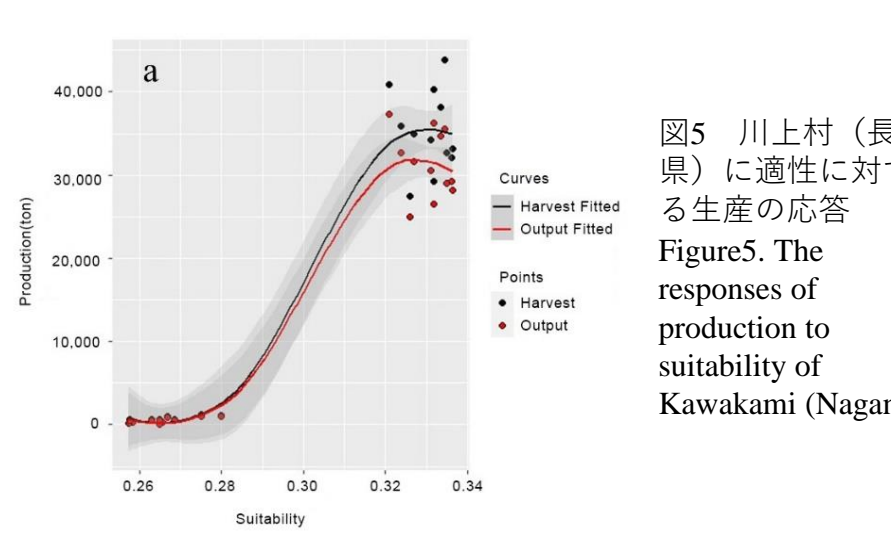


図5 川上村(長野県)に適性に対する生産の応答  
Figure5. The responses of production to suitability of Kawakami (Nagano)

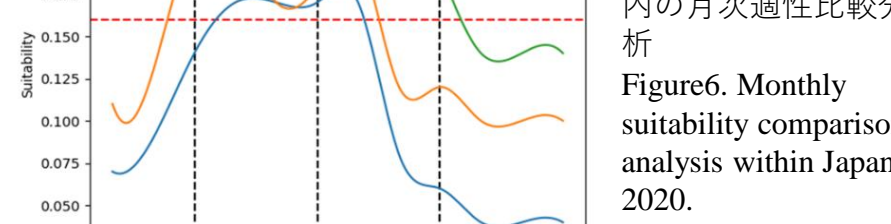


図6 2020年の日本国内の月次適性比較分析  
Figure6. Monthly suitability comparison analysis within Japan in 2020.

図3 岩見沢(北海道)のNDVIとの時系列適性比較  
Figure3. Time-series suitability comparisons with NDVI of Iwamizawa.

➢ 岩見沢を例に挙げる、東アジアの4カ国で選ばれた18カ所のうち11カ所で、適合度の変化傾向とNDVIの間に高い整合性が見られた。  
Taking Iwamizawa for an example, 11 out of 18 sites selected in four countries in East Asia showed high consistency between changing trend of suitability and NDVI.

- 東アジアでは、夏が白菜の栽培に最も適した季節であった。  
The summer season is the most favorable season for the cultivation of Chinese cabbage in East Asia.
- 図5の傾向から、適性が最適レベルに達すると、白菜の生産は安定する軌道に維持する。  
The trend in Figure 5 suggests that once suitability reached the optimal level, the production of Chinese cabbage maintained a stable trajectory.
- 図6を例にとると、国内スケールと国際スケールの比較結果から、播種と収穫の提案がなされている。  
Figure 6 as an example, sowing and harvest suggestions are given by the comparison results of national scale and international scale.

図2 成長環境モニタリングのフローチャート  
Figure2. Overflow of growth environment monitoring.

### 3. 成長状況モニタリング/Growth Condition Monitoring

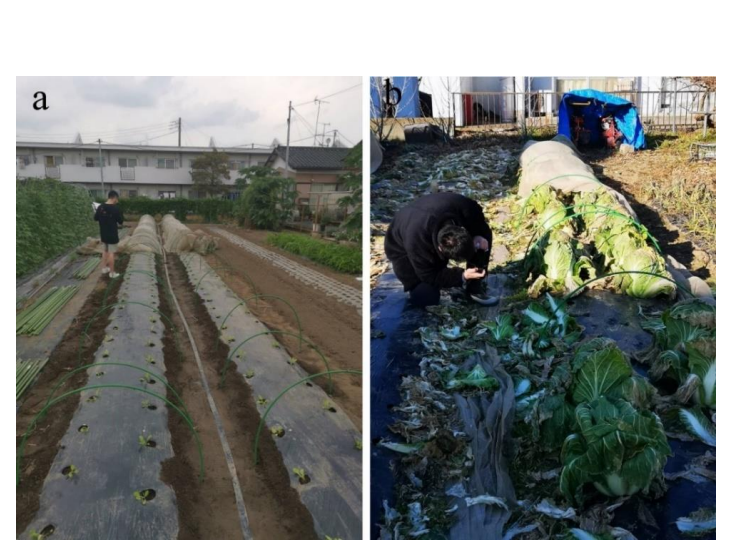
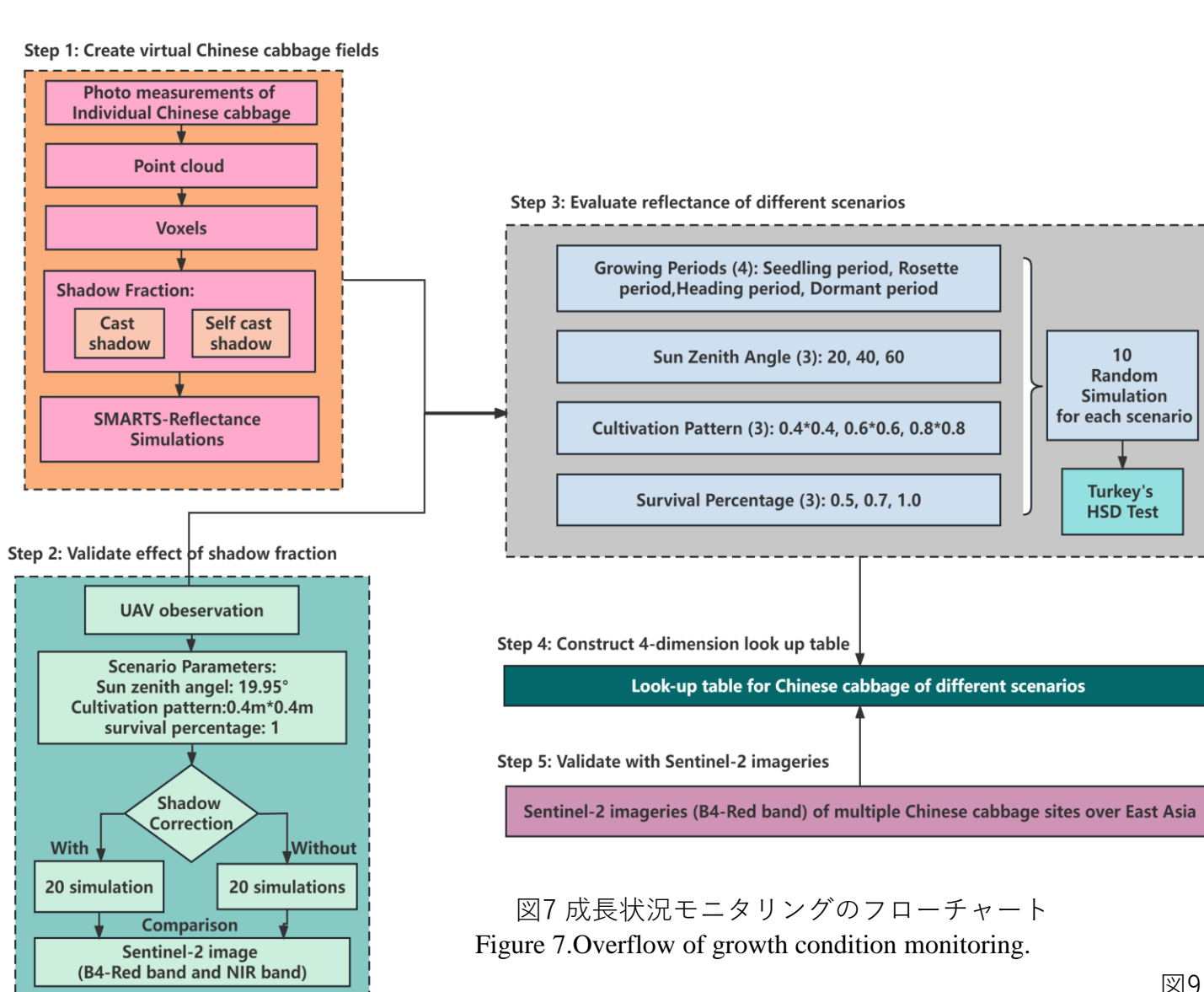


図8 白菜畑でのフィールドワーク  
Figure 8. Fields experiments on Chinese cabbage field.

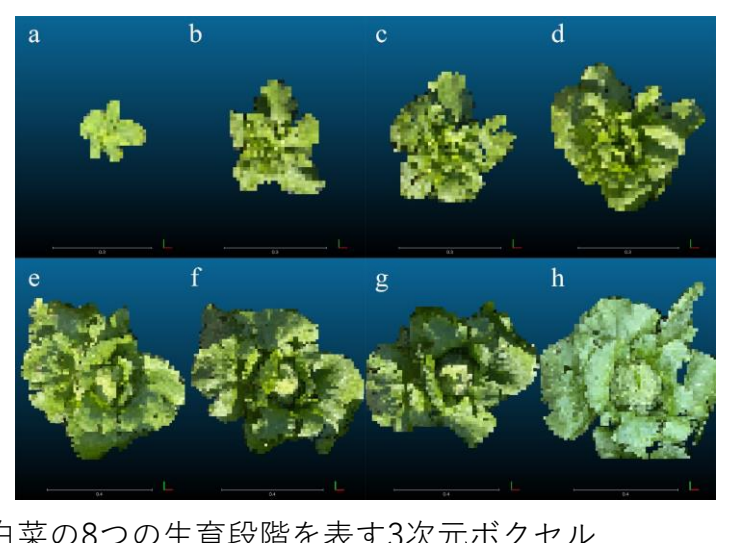


図9 白菜の8つの生育段階を表す3次元ボックスセル  
Figure 9. 3D visualization of voxelized Chinese cabbage of 8 growth stages

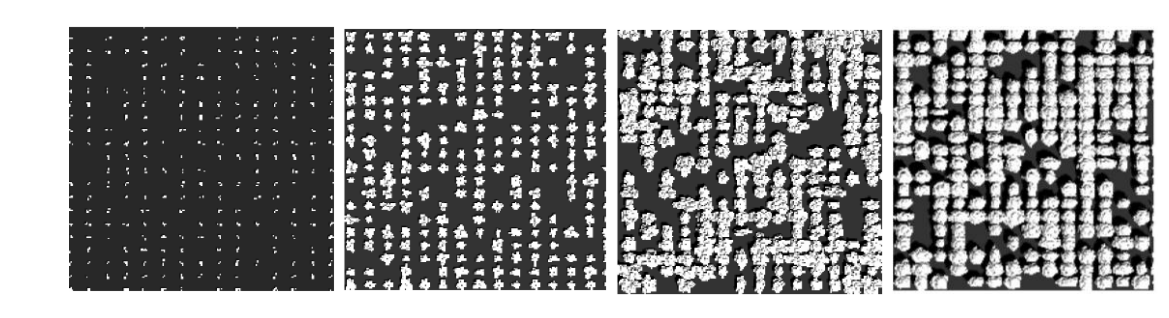


図10 成長状況の異なる仮想白菜畑  
Figure10. multiple virtual Chinese cabbage fields of different growth condition

➢ 仮想白菜畑の反射率シミュレーションの式  
Equations for the reflectance simulation of virtual Chinese cabbage fields

$$R(y)_{Cabbage} = [R_{dir}(y)(1-CS) + R_{dif}(y)(1-SCS)] \frac{\rho(y)_{cabbage}}{\pi}$$

$$R(y)_{soil} = [R_{dir}(y)(1-CS) + R_{dif}(y)(1-SCS)] \frac{\rho(y)_{soil}}{\pi}$$

$$R_{sensor} = \frac{\int (R(y)_{Cabbage} \times F_{cabbage} + R(y)_{soil} \times F_{soil}) SRF(y) dy}{\int SRF(y) dy}$$

$$R = \frac{\pi R_{sensor}}{R_{dir} + R_{dif}}$$

Y: denotes the wavelength;  $R(y)_{Cabbage}$  and  $R(y)_{soil}$ : the radiance of Chinese cabbage and soil  
 $R_{dir}(y)$ : the direct horizontal irradiance;  $R_{dif}(y)$ : the diffuse horizontal irradiance  
 $\rho(y)_{cabbage}$  and  $\rho(y)_{soil}$ : the spectral reflectance of Chinese cabbage and soil  
 $R_{sensor}$ : the radiance observed by the sensor  
 $F_{cabbage}$  and  $F_{soil}$ : the ratios of the number of Chinese cabbage and soil voxels to the total number of voxels  
 $SRF(y)$ : the spectral response function of the Sentinel-2 sensor  
 $R_{dir}$  and  $R_{dif}$ : the mean values of direct horizontal irradiance and diffuse horizontal irradiance  
 $R$ : the reflectance of virtual Chinese cabbage field.

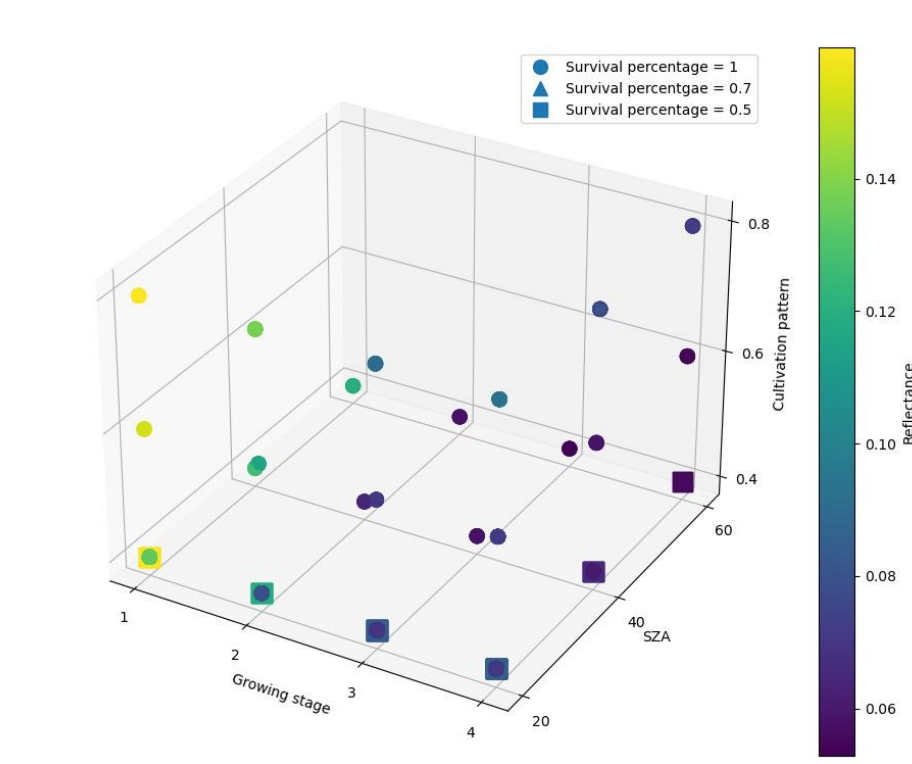


図11 Sentinel-2画像の赤色バンドの反射率の3Dルックアップテーブル。  
Figure 11. 3D look-up table for reflectance of red band of Sentinel-2 imageries.

- 東アジアにおける季節、成長段階、栽培方法、生存率など、生育条件の異なる白菜畑を上記のルックアップ表で確認できる。
- Chinese cabbage fields of different growth condition including season, growth stage, cultivation pattern and survival rate over East Asia can be checked out through above look-up table.