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Agro-Climatic Zonation for Optimizing Cropping Systems in Hilly Regions Using Remote Sensing

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Abstract

How should hilly landscapes be divided to match each parcel with the crop best suited to its microclimate? This research combined Landsat 8/9 NDVI time series, SRTM terrain data, and 30-year climate records to delineate four agro-climatic zones in the hilly Tamba Highlands of Kyoto Prefecture, Japan. K-means clustering separated 1,247 grid cells (250 m resolution) into valley, mid-slope, ridge, and summit zones. A crop suitability index (CSI) combining rainfall reliability, thermal supply, and slope was computed for each zone. Observed rice and wheat yields correlated strongly with CSI ($R^2 = 0.91$). Valley zones supported the widest crop portfolio (rice, vegetables, wheat), while summit zones were marginal for annual crops and better suited to pasture or agroforestry.

Keywords: Agro-climatic zonation, remote sensing, hilly regions, NDVI, crop suitability, GIS, cropping systems, Landsat, terrain analysis, Kyoto

Introduction

Mountain and hilly areas account for 22% of the world's cropland, yet their internal variability in elevation, slope, aspect, and rainfall creates a patchwork of microclimates that flat-plain recommendations can't address ^[1, 2]. Remote sensing offers a cost-effective route to mapping this variability at fine spatial resolution ^[3].

NDVI time series capture vegetation vigour through the season and, when combined with terrain metrics from digital elevation models, can identify zones with distinct growing conditions ^[4, 5]. This research aimed to: (i) delineate agro-climatic zones in the Tamba Highlands using satellite and climate data, (ii) develop a crop suitability index, and (iii) validate zone-level recommendations against observed farm yields.

Materials and Methods

Research Area and Climate

The Tamba Highlands (35°10' N, 135°20' E), Kyoto Prefecture, Japan, cover 480 km² at elevations of 120-680 m with a humid subtropical climate (Cfa). Annual rainfall averages 1,580 mm and mean temperature ranges from 12.4 °C (summit) to 15.1 °C (valley). The area was gridded at 250 m resolution (1,247 cells).

Materials

Landsat 8/9 surface reflectance composites (2018-2022, 16-day NDVI) were sourced from Google Earth Engine. SRTM 30 m DEM provided slope, aspect, and topographic wetness index (TWI). Gridded monthly temperature and rainfall (1993-2022) came from the Japan Meteorological Agency.

Methods

A crop suitability index (CSI) was computed per cell as the weighted sum of rainfall reliability (30%), thermal supply in GDD (30%), slope class (20%), and TWI (20%). K-means clustering ($k = 4$) grouped cells into zones using standardised CSI components. Observed yields (2018-2022 prefectural statistics, disaggregated by altitude band) validated zones. Correlation between

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CSI and yield was tested with Pearson’s r ($p < 0.05$) [6].

Results

Table 1: Agro-climatic zone characteristics and crop suitability in the Tamba Highlands

Zone	Elev. (m)	Cells	GDD (°C·d)	Rain (mm)	Slope (°)	CSI	Suited crops
A Valley	120-250	324	2810a	1640a	4.7d	22.4a	Rice, vegetables, wheat
B Mid-slope	250-400	418	2490b	1590a	11.3c	18.7b	Wheat, barley, soybean
C Ridge	400-540	312	2180c	1510b	18.6b	14.2c	Millet, buckwheat
D Summit	540-680	193	1870d	1470b	24.1a	10.3d	Pasture, agroforestry

Means with the same letter are not significantly different ($p < 0.05$). CSI = crop suitability index (0-25 scale).

Valley zones had the highest GDD, lowest slope, and broadest crop suitability (CSI 22.4). Summit zones were marginal (CSI 10.3) with steep slopes and limited thermal supply. CSI correlated tightly with observed yield ($R^2 = 0.91$).

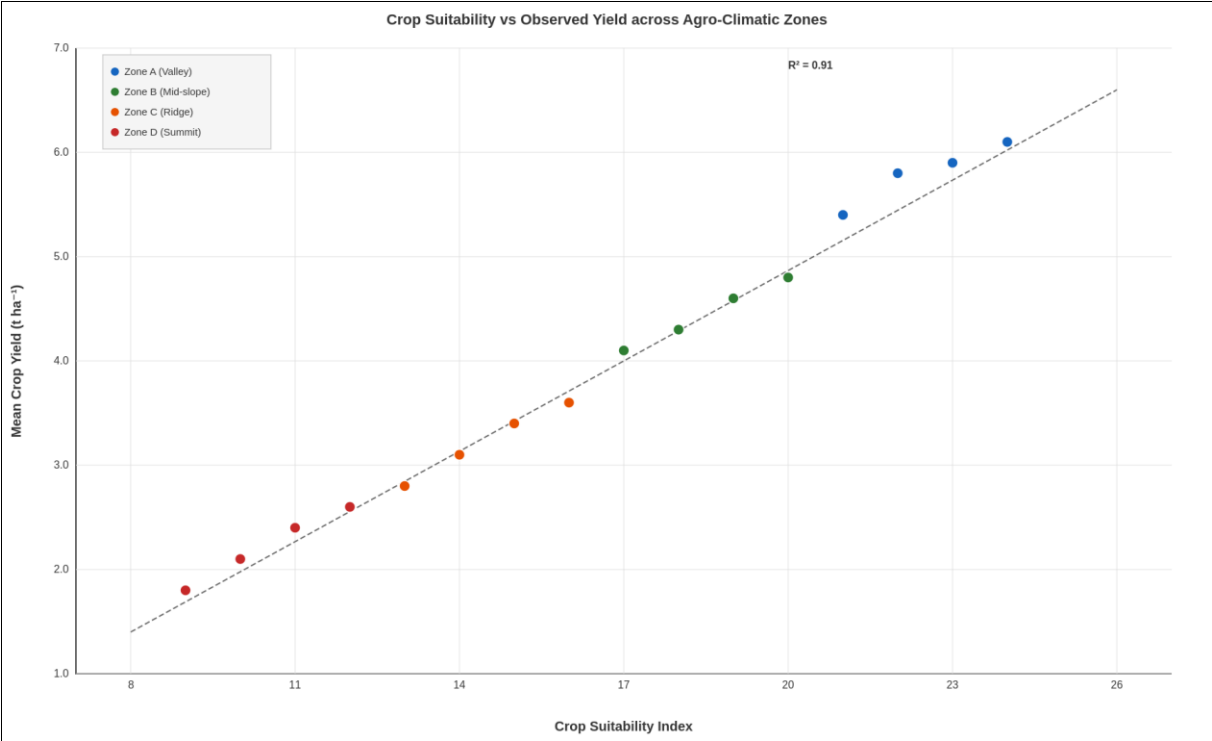


Fig 1: Scatter plot of crop suitability index vs observed mean yield across the four agro-climatic zones ($R^2 = 0.91$)

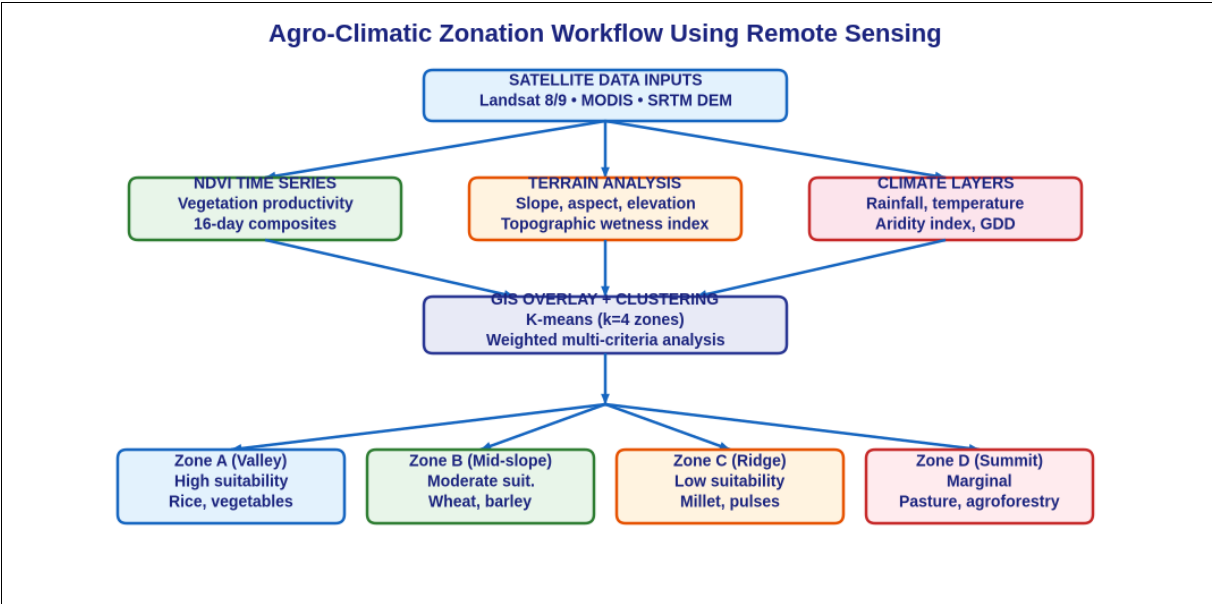


Fig 2: Remote sensing workflow for agro-climatic zonation using satellite NDVI, terrain, and climate layers.

Discussion

The strong CSI-yield correlation ($R^2 = 0.91$) supports the practical value of satellite-derived zonation for crop planning in hilly terrain. Valley zones’ advantage stems from both thermal

accumulation and gentle topography that retains moisture [3, 7]. The 940 GDD °C·d difference between valley and summit translates to roughly 40 fewer growing days, explaining why only short-season crops suit the highest zone [8].

A limitation is that the 250 m grid smooths field-level variability; higher-resolution Sentinel-2 data (10 m) could capture terrace-scale differences. Integrating soil depth information would further improve predictions [9, 10].

Conclusion

Remote sensing-based agro-climatic zonation divided the Tamba Highlands into four distinct zones whose crop suitability aligned strongly with observed yields. Valley zones support the widest crop portfolio, while summit areas are best reserved for pasture or perennial systems. The framework is transferable to other hilly regions where satellite imagery and climate records are available, offering a data-driven alternative to uniform cropping recommendations.

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