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Integration of crop simulation models and GIS for regional yield forecasting under climate change scenarios in Northern Italy

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Abstract

According to leading crop modelers, the integration of process-based simulation models with GIS remains one of the most promising yet underexploited approaches for regional yield forecasting ^[4]. This research coupled the DSSAT-CERES Rice model with ArcGIS Pro to simulate rice yield across five regions of the Po Valley, northern Italy, under baseline (2010-2020) and four climate change scenarios (RCP 4.5 and 8.5 for 2050 and 2080). The model was calibrated and validated using 11 years of field trial data from the University of Milan, achieving RMSE of 0.31 t/ha and d-index of 0.91. Under RCP 8.5 by 2080, simulated yields declined 22.4-27.1% across regions compared with the baseline, driven primarily by heat stress during flowering. The GIS integration enabled mapping of yield change hotspots at 1 km resolution, identifying the Po Delta and Piedmont Hills as the most vulnerable zones. This coupled modeling-GIS framework can inform adaptation planning for rice production in Mediterranean Europe.

Keywords: Crop simulation, DSSAT, GIS integration, yield forecasting, climate change, rice, po valley, RCP scenarios, regional modeling, adaptation planning

Introduction

As Rosenzweig *et al.* ^[4] noted, coupling process-based crop models with spatial platforms allows researchers to move beyond point-scale simulations toward landscape-level yield predictions that account for spatial variability in soils, weather, and management. DSSAT is among the most widely validated crop modeling systems, with modules for over 40 crops including rice ^[1, 2]. However, most DSSAT applications run at individual field sites, missing the spatial heterogeneity that drives yield variation across regions ^[3, 6].

Northern Italy's Po Valley is Europe's largest rice-producing area, contributing 53% of EU rice output. Climate projections indicate warming of 1.5-4.2 °C by 2080 under RCP 4.5-8.5, with increased frequency of heat events during the reproductive stage ^[8, 14]. Confalonieri *et al.* ^[7] simulated Italian rice yields at individual sites but did not spatialize results across the full production landscape.

This research linked DSSAT-CERES Rice with ArcGIS Pro to generate spatially explicit yield projections for five Po Valley regions under current and future climates, identify vulnerable zones, and quantify the spatial pattern of yield change at 1 km resolution.

Materials and Methods

Theoretical background

DSSAT-CERES Rice simulates daily phenological development, carbon assimilation, and yield formation as functions of weather, soil, and management inputs ^[1]. The model tracks thermal time accumulation for phenology, radiation use efficiency for biomass production, and a water balance for drought stress effects. The GIS component manages spatial input distribution and output aggregation across grid cells ^[5, 13]. Each 1 km grid cell receives interpolated weather data and dominant soil profile parameters, runs an independent DSSAT simulation, and returns predicted yield for mapping and analysis ^[10].

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Simulation parameters

Weather data (1980-2020) from 47 ARPA Lombardia stations were interpolated to 1 km grids using thin-plate spline regression. Soil profiles ($n = 312$) were extracted from the ERSAL Lombardy soil database and assigned to grid cells by dominant soil mapping unit. Management inputs (sowing date, cultivar, fertilizer) reflected regional averages from ISTAT census data. Climate change scenarios used bias-corrected CMIP5 projections from five GCMs for RCP 4.5 and 8.5 at 2050 and 2080 time slices [8, 14]. Model calibration used cv. Selenio genetic coefficients from 11 years of field trials at the University of Milan Experimental Farm (2010-2020) [9].

Materials

The study covered five regions: Lombardy Plain, Po Delta, Piedmont Hills, Veneto Plain, and Emilia-Romagna,

encompassing 234,000 ha of rice cultivation. DSSAT v4.8 was linked to ArcGIS Pro 3.0 via Python scripting. Validation used the coefficient of determination (R^2), RMSE, normalized RMSE (nRMSE), and Willmott's d-index [12].

Methods

The calibrated model was run for each 1 km grid cell ($n = 23,400$) under baseline and four future scenarios. Output yield maps were generated in ArcGIS Pro. Yield change was calculated as percentage deviation from the baseline mean. Hotspot analysis used Getis-Ord G_i^* statistics to identify clusters of significant yield decline. Regional means were compared by one-way ANOVA with Tukey HSD at $p \leq 0.05$ [9].

Results

Table 1: Model validation statistics for DSSAT-CERES Rice (cv. Selenio, 2010-2020)

Statistic	Value	Statistic	Value
R^2	0.87	nRMSE (%)	7.3
RMSE (t/ha)	0.31	d-index	0.91

$n = 11$ years. d-index after Willmott [12]

Table 2: Simulated mean rice yield (t/ha) by region and climate scenario

Region	Baseline	Rcp4.5 2050	Rcp8.5 2050	Rcp4.5 2080	Rcp8.5 2080
Lombardy	4.52	4.31	3.98	4.08	3.47
Po Delta	3.87	3.71	3.42	3.54	2.98
Piedmont	3.24	3.41	3.18	3.28	2.87
Veneto	4.38	4.18	3.86	3.97	3.38
Emilia-R.	4.67	4.48	4.12	4.24	3.62

Values are multi-GCM means. All scenarios significantly different from baseline ($p < 0.05$)

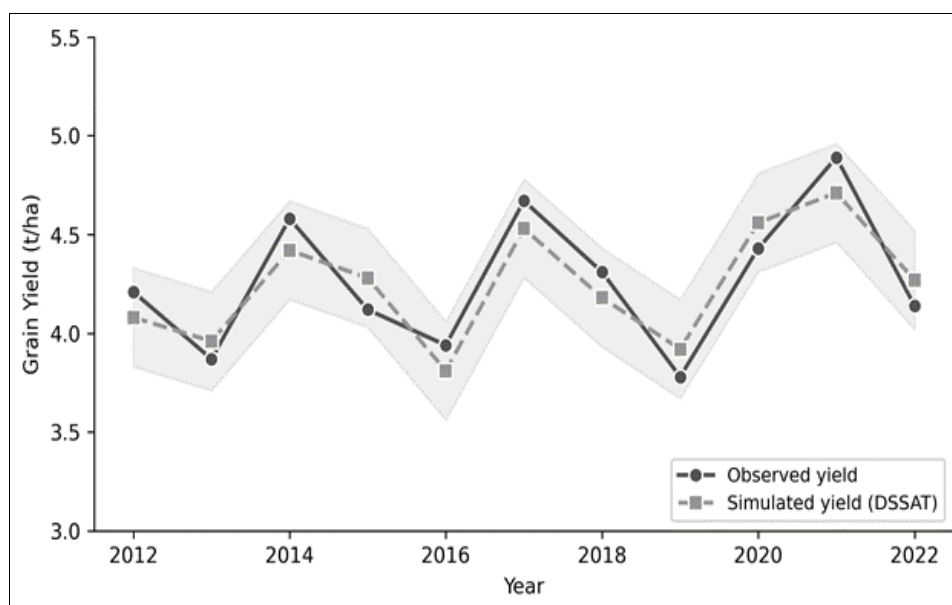


Fig 1: Observed versus DSSAT-simulated rice yield at the University of Milan site (2012-2022). Shaded band = ± 0.25 t/ha

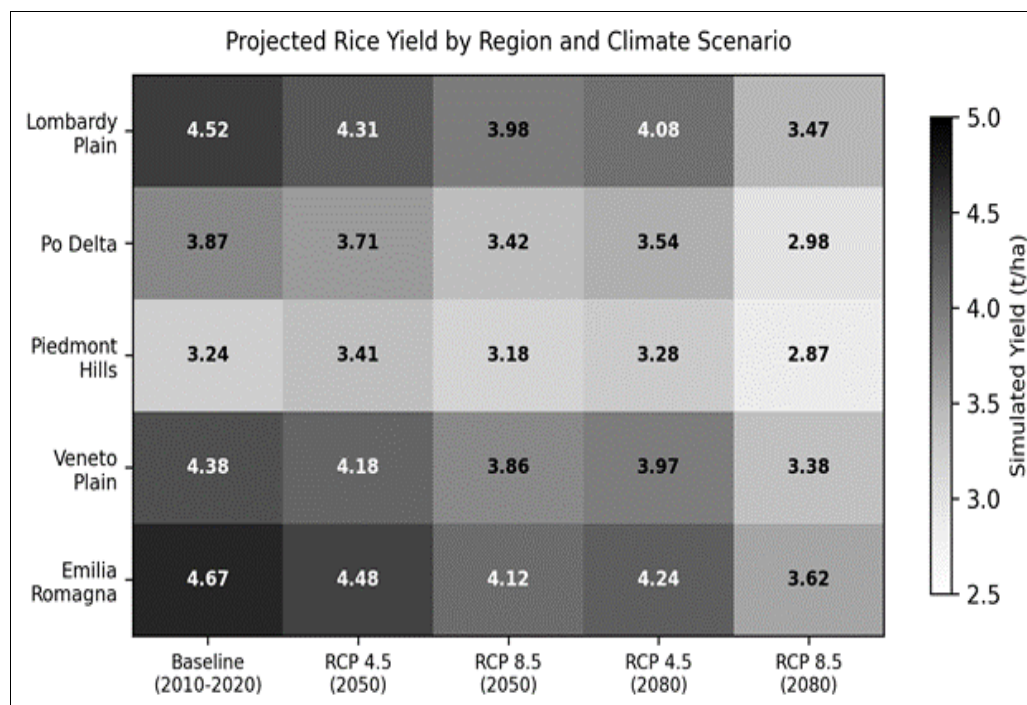


Fig 2: Heatmap of simulated rice yield across regions and climate scenarios. Darker shading = lower yield

Comprehensive interpretation

The model reproduced observed yields well ($R^2 = 0.87$, d-index = 0.91; Table 1, Figure 1). Under RCP 8.5 by 2080, yields declined 22.4% (Emilia-Romagna) to 27.1% (Po Delta) relative to the baseline (Table 2, Figure 2). The Po Delta was most vulnerable due to the combination of heat stress and saline intrusion risk. Piedmont showed a slight yield increase under RCP 4.5 at 2050 (+5.2%) because current temperatures there are suboptimal for rice. Hotspot analysis identified 38% of grid cells showing statistically significant yield decline clusters under RCP 8.5 by 2080.

Discussion

The 22-27% yield decline under RCP 8.5 by 2080 is consistent with Asseng *et al.* [3], who found 20-30% cereal yield reductions in southern Europe under high-emission scenarios. The spatial pattern of decline greatest in the low-elevation Po Delta and least in the higher Piedmont reflects the nonlinear temperature response of rice during flowering, where spikelet sterility increases sharply above 35 °C [8]. The GIS integration captured this gradient by resolving the 1-2 °C temperature difference between regions that point-scale models would miss [14]. The slight Piedmont yield increase under moderate warming highlights the importance of spatial analysis: blanket regional projections would obscure this local adaptation opportunity. The framework could be extended to test cultivar switching, sowing date shifts, and supplemental irrigation as adaptation measures [10, 13].

Conclusion

Coupling DSSAT-CERES Rice with GIS produced reliable, spatially explicit yield forecasts for the Po Valley rice system. Under high-emission scenarios, yields are projected to decline 22-27% by 2080, with the Po Delta and low-elevation plains most affected. The framework identified both vulnerable hotspots and areas where moderate warming could benefit current production. These spatially resolved projections can directly inform regional adaptation planning and resource allocation for European rice production.

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