Does crop stage matter? Phenology-based drought–production vulnerability curves for paddy in Indonesia

Program PPMI FITB ITB 2026

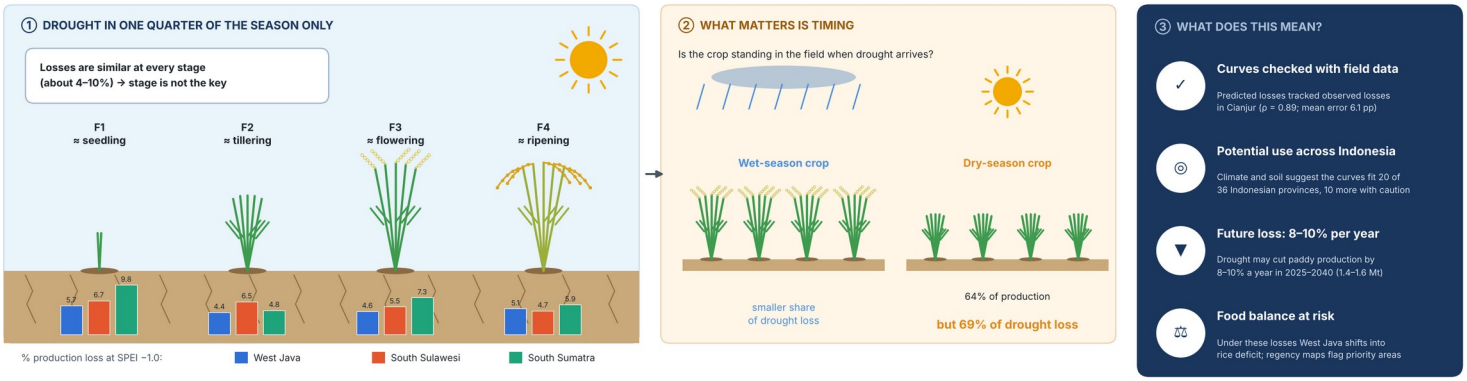
Riantini Virtriana[1,2], Farah Diba Aulia Yasmin[1], Irfan Nur Priya Nugraha[1], Agung Budi Harto[1,2], Ricky Jaya Kusuma[1], Dyah Ayu Retnowati[1], Albertus Deliar[1,2], Muhammad Rais Abdillah[3,4]

[1] Geodesy and Geomatics Engineering Study Program, [2] Geographic Information Science and Technology Research Group, [3] Meteorology Study Program, [4] Atmospheric Science Research Group, Faculty of Earth Sciences and Technology, Institut Teknologi Bandung

Abstract

When drought hits paddy, what matters more: the crop stage, or the timing?

Drought–production vulnerability curves for West Java, South Sulawesi and South Sumatra, Indonesia

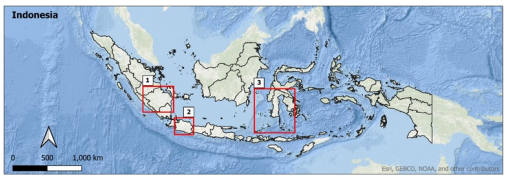


Keywords: Drought vulnerability curves · Crop stage · Regionalisation · Potential production loss · Food balance

Introduction

Rice is Indonesia's staple food, so paddy production is central to national food security. Drought dries the soil and stresses the crop, cutting yield; El Niño droughts lowered paddy production by 1.40% in 2023. Vulnerability curves translate drought intensity into expected loss, but existing curves come mostly from crop models and are rarely checked against observed production. To our knowledge, no such curves exist for Indonesian paddy, let alone curves that account for crop stage.

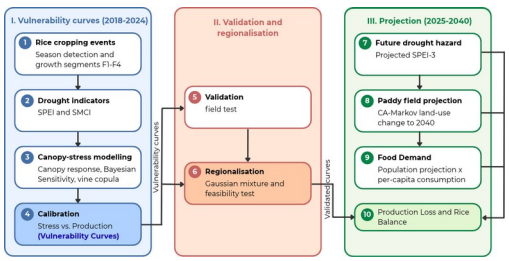
Objectives: (1) derive curves for four quarters of the season (F1–F4); (2) validate and transfer them across Indonesia; (3) project loss and rice balance to 2040.



Picture 1. Study area: (1) South Sumatra, (2) West Java, (3) South Sulawesi

Why these provinces? They are among the five largest paddy producers (10.2, 5.4 and 3.6 Mt in 2025), supply rice to surrounding regions and represent irrigated, transitional-monsoon and rainfed–tidal rice systems.

Data: Sentinel-1/2, SPEI, SMCI, BPS paddy production (2018–2024), projected SPEI-3, CA Markov land use, population and rice consumption.



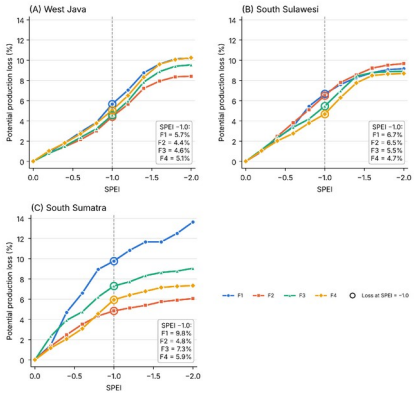
Picture 2. Research workflow

Research Method

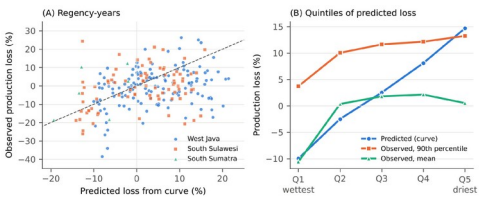
I. Vulnerability curves (2018–2024): detect cropping events and segments F1–F4, link SPEI and SMCI to canopy stress (Bayesian sensitivity, vine copula), then calibrate stress against production.

II. Validation and regionalisation: regency-level evaluation (Picture 4) and a field test, then Gaussian mixture clustering and a feasibility test.

III. Projection (2025–2040): projected SPEI-3 and CA-Markov paddy fields give future production and drought loss. Rice balance = production after drought loss minus demand (projected population × per-capita rice consumption).



Picture 3. Vulnerability curves: loss when drought hits only one quarter of the season (F1–F4)



Picture 4. Regency-level evaluation, 2018–2025

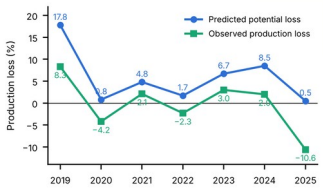
Research Outputs

Submitted: Natural Hazards (Springer), NHAZ-D-26-05607.

Published: Harto et al. (2026) Geomatics, Natural Hazards and Risk 17(1):2634202.

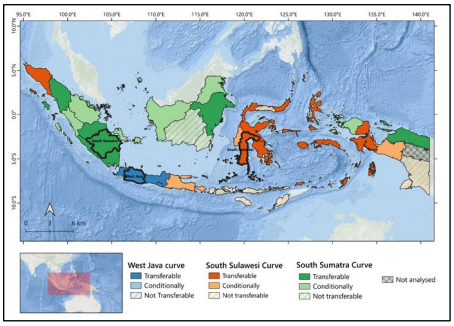
Discussion & Result

Loss rises with drought intensity: a moderate drought (SPEI −1.0) puts 18–25% of production at risk, yet losses differ little between quarters F1–F4 (4.4–9.8%; Picture 3). In a field test in Cianjur, predicted losses followed observed losses (Picture 5).



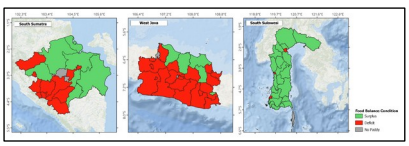
Picture 5. Cianjur field test (validation)

Judged by six climate and five soil characteristics, the curves can be transferred to 20 provinces, and conditionally to 10 more (Picture 6).



Picture 6. Where the curves can be transferred

When these losses enter the 2025–2040 rice balance of each regency, West Java tips into deficit (Picture 7).



Picture 7. Rice balance by regency, 2025–2040

Conclusion

Drought risk to Indonesian paddy depends less on which growth stage is hit than on whether a crop is standing when dry conditions arrive. Adaptation should therefore focus on the cropping calendar, securing water for the dry season crop and adjusting planting dates, rather than on protecting one sensitive stage.