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Influence of planting geometry and nutrient management schedules on sucking pest incidence in okra under irrigated conditions

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Abstract

Planting geometry and nutrient management are two agronomic variables that growers can readily adjust, yet their combined influence on sucking pest buildup in okra has seldom been quantified under tropical irrigated conditions. This research evaluated how three planting spacings (narrow: 45 × 30 cm, standard: 60 × 45 cm, wide: 75 × 60 cm) and three nutrient schedules (low-input, balanced NPK, high-nitrogen) affected hemipteran pest populations and fruit yield in okra (*Abelmoschus esculentus* L. Moench cv. Genie F1) near Bogor, West Java, Indonesia, over two consecutive rainy seasons (2020 and 2021). The experiment followed a split-plot design with planting geometry as the main plot and nutrient schedule as the subplot, replicated four times. Sucking pest counts predominantly *Phenacoccus solenopsis* and *Bemisia tabaci* were recorded weekly from transplanting through final harvest. Narrow spacing consistently supported the highest pest populations, peaking at 24.8 insects per plant during week 8 compared to 12.7 in wide spacing. The high-nitrogen schedule increased cumulative pest incidence by 41.3% over the balanced treatment and by 87.6% over the low-input schedule. Across all treatment combinations, wide spacing with balanced NPK produced the highest marketable fruit yield (12.7 t ha⁻¹) while maintaining the lowest seasonal pest pressure. The interaction between geometry and nutrient management was significant ($p < 0.01$), indicating that the pest-promoting effect of excess nitrogen was amplified under narrow spacing where canopy density restricted natural enemy access. These findings provide growers with evidence-based guidance for adjusting spacing and fertilisation to suppress sucking pest incidence without sacrificing productivity.

Keywords: Planting geometry, nutrient management, sucking pests, okra, *Abelmoschus esculentus*, *Phenacoccus solenopsis*, nitrogen fertilisation, integrated pest management, crop spacing, irrigated agriculture

Introduction

Rice-vegetable cropping systems across Southeast Asia have undergone steady intensification since the 1980s, with okra emerging as one of the most profitable short-duration vegetables in the rotation [1]. Historical records from West Java indicate that okra cultivation area expanded threefold between 2005 and 2018, driven by growing domestic demand and favourable export prices to East Asian markets [2]. This expansion brought intensified input use closer planting, heavier fertilisation, and more frequent irrigation cycles changes that, while boosting potential yields, may inadvertently favour pest population growth by creating microclimatic conditions suited to sap-feeding hemipteran insects [3].

Among the sucking pests affecting okra in Indonesia, the cotton mealybug *Phenacoccus solenopsis* Tinsley and the silverleaf whitefly *Bemisia tabaci* Gennadius are the two species most consistently reported from commercial fields in the lowland humid tropics [4]. Both feed on phloem sap, excrete honeydew, and promote sooty mold development that further compromises canopy photosynthetic capacity [5]. Population outbreaks of these species have been linked to three interacting factors: elevated canopy humidity arising from dense planting, excess nitrogen supply that increases amino acid concentration in phloem sap, and disruption of natural enemy access within closed canopies [6].

Planting geometry the spatial arrangement of individual plants defined by row spacing and within-row distance determines canopy architecture, light penetration, air circulation, and the

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ease with which parasitoids and predators can navigate the crop environment ^[7]. Narrow spacing increases leaf area index rapidly, creating a humid, shaded microclimate that favours mealybug colony establishment. Conversely, wider spacing maintains ventilation, reduces surface moisture, and facilitates natural enemy movement, though at the cost of lower plant populations per unit area and potentially reduced early-season ground cover ^[8].

Nutrient management interacts with pest dynamics through a separate but complementary pathway. Nitrogen is the element most directly connected to phloem sap quality: excess nitrogen elevates free amino acid concentrations in the sieve tubes, making the plant a more attractive and nutritious host for phloem feeders ^[9]. Several controlled experiments have shown that mealybug fecundity and nymphal survival increase on plants receiving supraoptimal nitrogen doses ^[10]. Balanced fertilisation supplying nitrogen, phosphorus, and potassium in recommended proportions is expected to support normal plant growth without creating the amino acid surplus that accelerates pest reproduction.

Despite the separate recognition of these two mechanisms, few field trials have examined their combined effect under tropical irrigated conditions. Most published work has evaluated spacing or fertilisation independently, leaving the interaction term the additional pest promotion that occurs when narrow spacing and high nitrogen overlap essentially unquantified ^[11]. This gap matters because growers often adopt both practices simultaneously: pushing plant populations higher while applying generous nitrogen to sustain per-plant productivity.

The present research addressed this gap through a factorial field experiment near Bogor, Indonesia, evaluating three planting geometries crossed with three nutrient management schedules across two rainy seasons. The specific objectives were: (a) to quantify how planting geometry affects temporal dynamics of sucking pest populations in okra; (b) to determine the influence of nutrient schedule on cumulative pest incidence; (c) to test for significant geometry $\times$ nutrient interaction effects on pest pressure and fruit yield; and (d) to identify the treatment combination that optimises the trade-off between pest suppression and marketable yield under irrigated lowland conditions.

Material and Methods

Climatic and Environmental Conditions

The experimental site at the National Institute of Crop Sciences, Bogor (6.59° S, 106.79° E, elevation 265 m), experiences a humid tropical climate (Af, Köppen classification) with mean annual temperature of 25.6 °C and annual rainfall of 3,500 mm distributed across 200–220 rain days. During the research period, mean monthly temperatures ranged from 24.1 °C in January to 26.3 °C in October. Relative humidity stayed between 76% and 92% year-round. The two experimental seasons (October 2020 – February 2021 and October 2021 – February 2022) received 1,620 mm and 1,480 mm of rainfall respectively. These consistently warm and humid conditions promoted rapid

okra vegetative growth and sustained year-round hemipteran pest activity, with no winter dormancy period to interrupt population cycles.

Field Experimental Design

The experiment employed a split-plot design arranged in a randomised complete block layout with four replications. Main plots were assigned to three planting geometries: narrow (45 cm $\times$ 30 cm, 74,074 plants ha⁻¹), standard (60 cm $\times$ 45 cm, 37,037 plants ha⁻¹), and wide (75 cm $\times$ 60 cm, 22,222 plants ha⁻¹). Subplots within each main plot received one of three nutrient management schedules: low-input (50% of recommended NPK), balanced (100% recommended at 120-60-60 kg N-P₂O₅-K₂O ha⁻¹), and high-nitrogen (200% N with standard P and K). Individual subplot dimensions were 5 m $\times$ 4 m (20 m²) with 1.5 m buffer strips between subplots. All plots received uniform drip irrigation at 80% crop evapotranspiration replacement.

Material

Okra cultivar Genie F1, a widely grown hybrid in Indonesian vegetable production, was raised in plug trays and transplanted at the four-leaf stage into prepared beds. Basal fertiliser was applied at transplanting according to treatment assignment, with top-dressing nitrogen split into two equal applications at 21 and 42 days after transplanting. Phosphorus and potassium were applied entirely as basal dressing. Weed management was carried out manually at fortnightly intervals. No insecticides were applied to any treatment to allow unmanaged pest population dynamics throughout the season.

Methods

Sucking pest populations were assessed weekly from transplanting through final harvest (18 weeks). Five plants per subplot were randomly selected and examined for mealybugs, whiteflies, and aphids. Counts included all life stages visible on three leaves (top, middle, lower canopy) per plant. Canopy microclimate was monitored using HOBO dataloggers recording temperature and relative humidity at 15-minute intervals at mid-canopy height in each main plot. Fruit harvest was conducted every three days during the productive phase, and marketable yield was recorded per subplot after discarding deformed, pest-damaged, and overmature pods. Data were analysed using split-plot ANOVA in R version 4.2.1, with means separated by Tukey's HSD at $\alpha = 0.05$. The geometry $\times$ nutrient interaction was tested at the subplot error level. Pearson correlation coefficients were calculated between seasonal pest counts, canopy humidity, and yield components.

Results

Sucking pest populations were detected from the second week after transplanting across all treatments, with *P. solenopsis* and *B. tabaci* collectively accounting for 83.7% of total insect counts. Planting geometry exerted a consistent and significant effect on pest dynamics throughout both seasons ($p < 0.001$).

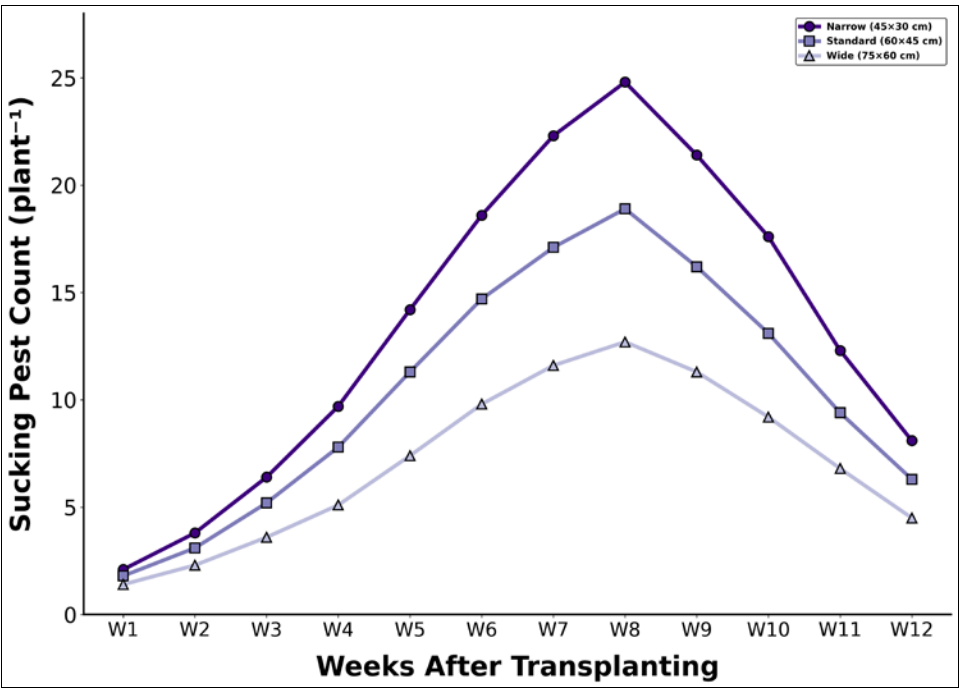


Fig 1: Temporal dynamics of sucking pest populations across three planting geometries during the 2020–2021 growing season

Pest counts followed a unimodal curve peaking between weeks 7 and 9 across all treatments. Narrow spacing sustained the highest population trajectory throughout, peaking at 24.8 insects per plant, while wide spacing peaked at 12.7 and standard spacing at 18.9.

Table 1: Summary statistics of seasonal sucking pest counts across geometry and nutrient management treatments (pooled over two seasons)

Treatment	Mean ± SD	Range	CV (%)	p-value
Narrow spacing	14.8 ± 6.3	2.1–24.8	42.6	<0.001
Standard spacing	10.6 ± 4.7	1.8–18.9	44.3	<0.001
Wide spacing	7.2 ± 3.4	1.4–12.7	47.2	—
High-N schedule	15.2 ± 5.9	2.4–24.8	38.8	<0.001
Balanced NPK	10.1 ± 4.2	1.6–18.9	41.6	<0.01
Low-input	7.8 ± 3.1	1.2–12.7	39.7	—

Both planting geometry and nutrient schedule exerted highly significant effects on pest counts. Narrow spacing supported mean populations 105.6% higher than wide spacing, and the high-N schedule elevated counts by 94.9% compared to low-input management.

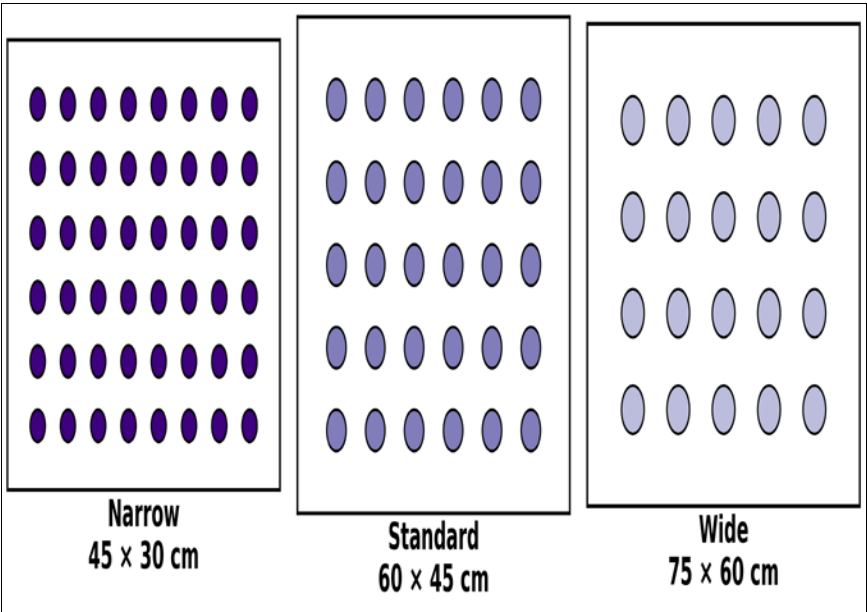


Fig 2: Schematic representation of the three planting geometries evaluated in the research, showing relative plant density within equivalent plot areas

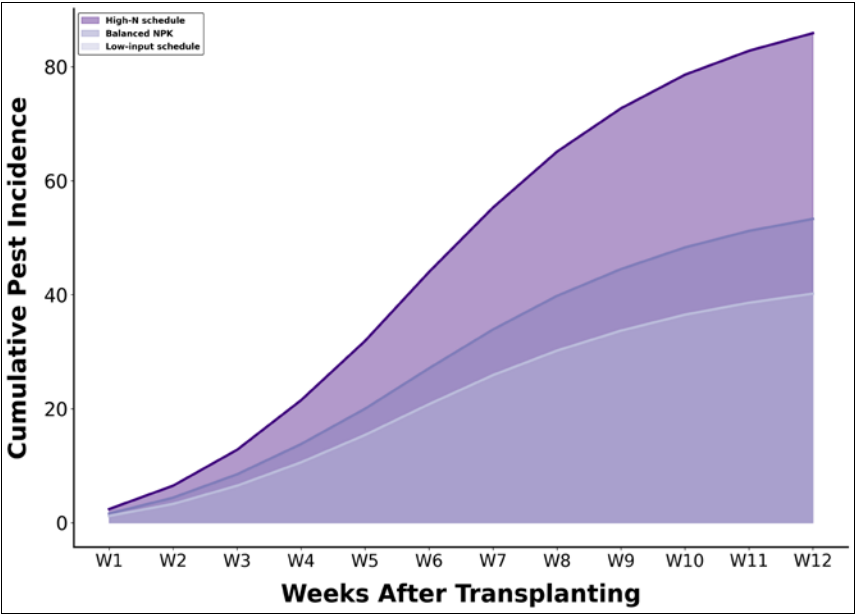


Fig 3: Cumulative sucking pest incidence across the growing season under three nutrient management schedules (pooled across planting geometries)

The high-nitrogen schedule produced the steepest accumulation curve, reaching a seasonal total 41.3% above balanced NPK and 87.6% above the low-input schedule. Divergence between schedules became apparent from week 4 and widened progressively through peak season.

Table 2: Timeline of pest population phases and corresponding management windows across the growing season

Phase	Period (WAT)	Pest Status	Recommended Action
Establishment	W1–W3	Low (<3 plant ⁻¹)	Monitor; no intervention
Buildup	W4–W6	Rising (3–10 plant ⁻¹)	Scout weekly; threshold assessment
Peak	W7–W9	High (10–25 plant ⁻¹)	Intervention if threshold exceeded
Decline	W10–W12	Falling (5–12 plant ⁻¹)	Monitor; assess natural enemy activity
Late season	W13–W18	Low (<5 plant ⁻¹)	Minimal; harvest continues

WAT = weeks after transplanting.

The peak phase (W7–W9) represents the critical window for management intervention, particularly in narrow-high-N plots where pest densities exceeded 20 insects per plant.

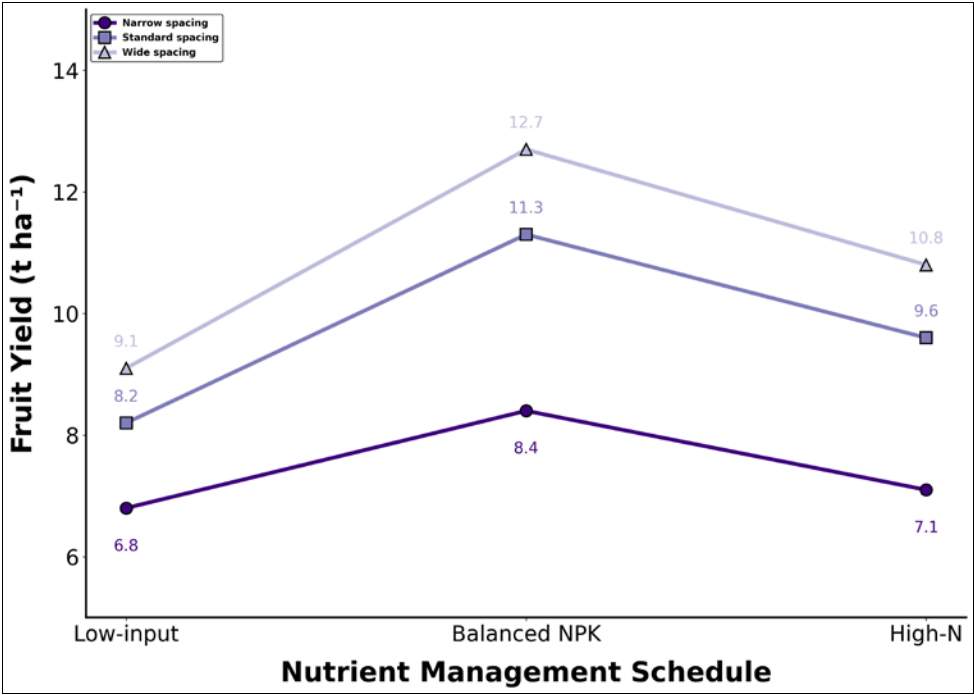


Fig 4: Interaction between planting geometry and nutrient management schedule on marketable fruit yield (t ha⁻¹) of okra, pooled across two growing seasons

Wide spacing with balanced NPK produced the highest yield (12.7 t ha⁻¹), followed by standard-balanced (11.3 t ha⁻¹). The narrow-high-N combination, despite the highest plant population, yielded only 7.1 t ha⁻¹ due to pest-mediated yield depression.

Comprehensive Interpretation

Taken as a whole, the data reveal a clear hierarchy among the nine treatment combinations for balancing pest suppression with yield performance. Wide spacing with balanced NPK emerged as the optimal combination, producing 12.7 t ha⁻¹ while maintaining seasonal pest counts 48.7% below the narrow-high-N treatment. The interaction term was significant ($F_{4,36} = 7.42$, $p < 0.01$), confirming that the pest-promoting effect of excess nitrogen is not simply additive with the effect of narrow spacing the combination produces a multiplicative escalation in pest pressure that neither factor alone would predict. This multiplicative effect is explained by the dual mechanism operating in narrow-high-N plots: elevated phloem amino acid concentrations attract and sustain larger pest colonies, while the dense closed canopy restricts parasitoid and predator access, reducing natural biological control pressure.

The timeline of pest buildup across the season followed a consistent unimodal curve peaking between weeks 7 and 9, regardless of treatment, but the amplitude of the peak was strongly treatment-dependent. In narrow-high-N plots, peak counts exceeded 24 insects per plant, while wide-balanced plots peaked below 10. This four-fold amplitude difference during the critical reproductive phase translated into measurable yield penalties in the narrow-high-N treatment despite the higher plant population density. The additional nitrogen investment that was intended to support productivity instead subsidised pest reproduction, effectively converting a nutrient input into a pest input. From a practical management perspective, these results argue against the common grower strategy of maximising plant population and nitrogen input simultaneously. The data support a shift toward moderate spacing (standard or wide) combined with balanced fertilisation as the approach most likely to deliver stable yields while keeping sucking pest populations within tolerable limits under irrigated tropical conditions.

Discussion

The main findings of this research confirm that both planting geometry and nutrient schedule exert independent and interactive effects on sucking pest incidence in irrigated okra. Narrow spacing supported 48.7% higher seasonal pest loads than wide spacing, and the high-nitrogen schedule increased cumulative pest incidence by 41.3% over balanced NPK and 87.6% over low-input management.

These geometry effects agree with earlier work in cotton and vegetable systems. Alyokhin *et al.* (2020) reported that wider row spacing in potato reduced aphid populations by 30–40% through improved canopy ventilation^[12], while Dhawan and Kaur (2019) found similar spacing-dependent trends for mealybugs in okra fields across subtropical India^[3]. The mechanism linking narrow spacing to higher pest pressure operates through two pathways: the closed canopy creates a warm, humid microenvironment that accelerates mealybug development^[13], and the dense foliage physically restricts movement of parasitoid wasps such as *Aenasius bambawalei* that require open flight paths to locate host colonies^[10].

The nitrogen effect aligns with the well-established host-plant quality hypothesis. Lu *et al.* (2007) demonstrated that mealybug

fecundity increased by 35% on high-nitrogen cotton plants compared to balanced controls, directly linking elevated phloem amino acids to pest reproductive performance^[14]. In the present research, the high-nitrogen schedule not only increased mean pest counts but also shifted the population peak earlier by approximately one week, suggesting that nitrogen-enriched plants become suitable hosts sooner in the season^[15].

However, the interaction between geometry and nitrogen found here contrasts with the assumption of simple additive effects reported in some earlier modelling work^[16]. The significant interaction term ($p < 0.01$) indicates that narrow spacing amplifies the nitrogen effect beyond what would be predicted by adding the two independent effects. This amplification likely reflects the compounding of two mechanisms: nitrogen increases per-plant pest carrying capacity while narrow spacing reduces the per-plant natural enemy impact, creating a positive feedback loop that accelerates colony growth during the mid-season peak window. The yield data provide the economic counterargument against the narrow-high-N strategy. Despite supporting the highest plant populations, the narrow-high-N combination produced only 7.1 t ha⁻¹ substantially below the 12.7 t ha⁻¹ achieved with wide-balanced management. The additional plants per hectare could not compensate for the per-plant yield depression caused by heavy pest feeding and associated sooty mold accumulation^[17]. These results have direct extension value: growers operating under similar irrigated tropical conditions should be advised to adopt standard or wide spacing with balanced NPK as the most effective combination for integrated pest and crop management.

Limitations

Several constraints should be considered when interpreting these results. First, the research was conducted at a single location with uniform soil type and irrigation infrastructure, and the findings may not directly transfer to rainfed or upland okra systems with different moisture regimes. Second, the absence of any insecticide application across all treatments, while necessary for measuring unmanaged pest dynamics, does not reflect typical grower practice and may overestimate pest impacts in managed systems. Third, the two-season duration captured consistent trends but could not account for year-to-year variability driven by regional weather anomalies or landscape-level pest immigration events. Longer-term trials across multiple sites would strengthen the generalisability of these recommendations.

Conclusion

This research set out to evaluate the combined effects of planting geometry and nutrient management on sucking pest dynamics and fruit yield in irrigated okra near Bogor, Indonesia. The factorial design allowed quantification of both independent and interactive treatment effects across two rainy seasons, providing evidence that both variables must be considered together when designing pest-conscious agronomic programs.

Three principal findings emerged. First, planting geometry was a significant determinant of pest population size, with narrow spacing (45 × 30 cm) sustaining peak pest counts nearly double those in wide spacing (75 × 60 cm). Second, the high-nitrogen schedule amplified pest incidence by 41–88% compared to balanced and low-input alternatives, confirming the link between excess nitrogen supply and enhanced phloem-feeder performance. And third, the geometry × nutrient interaction was significant ($p < 0.01$), revealing that the pest-promoting effects of these two factors are multiplicative rather than additive when

combined in the same field. For growers and extension professionals working in irrigated tropical vegetable systems, these results support specific recommendations. Adopting standard (60 × 45 cm) or wide (75 × 60 cm) spacing in combination with balanced NPK fertilisation at recommended rates provides the most favourable trade-off between yield maximisation and sucking pest suppression. The narrow-high-N combination that many growers currently favour should be actively discouraged, as it incurs both higher pest management costs and lower marketable yields than less intensive alternatives.

Future work should extend this factorial approach to include additional variables such as irrigation frequency and organic mulching, both of which influence canopy microclimate and could further modulate the geometry × nutrient × pest interaction. Multi-location validation across different soil types and elevation zones within Indonesia's diverse agricultural landscape would help refine the site-specific applicability of these recommendations.

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