Heterogeneous efficiency effects of agro-ecological fruit fly management transition and intensification among smallholder mango farmers: a latent class stochastic metafrontier approach

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Introduction

Since its detection in 2003 in Kenya, the invasive fruit fly *Bactrocera dorsalis* has become a significant threat to mango production and marketing. To combat its impact, many mango producers in Kenya and other Sub-Saharan African countries have relied on synthetic insecticides. However, these insecticides are costly for smallholder farmers and pose environmental impacts and health risks to orchard managers, workers, and consumers. This has prompted the need for more sustainable pest management practices, aligning with global efforts like the United Nations' "Decade on Ecosystem Restoration" (2021–2030), which emphasises ecological balance and sustainable agricultural practices. This study investigates the efficiency effects of adopting and intensifying 18 [1] agro-ecological pest management (APM) practices among smallholder mango farmers in Kenya.

Study area and data collection

The study was conducted in Makueni County, Kenya's leading mango-producing region, where farmers primarily cultivate the Apple, Kent, and Tommy Atkins varieties for local consumption and export. A household survey conducted between August and September 2023 involved 434 orchard managers, with 418 valid observations analysed.

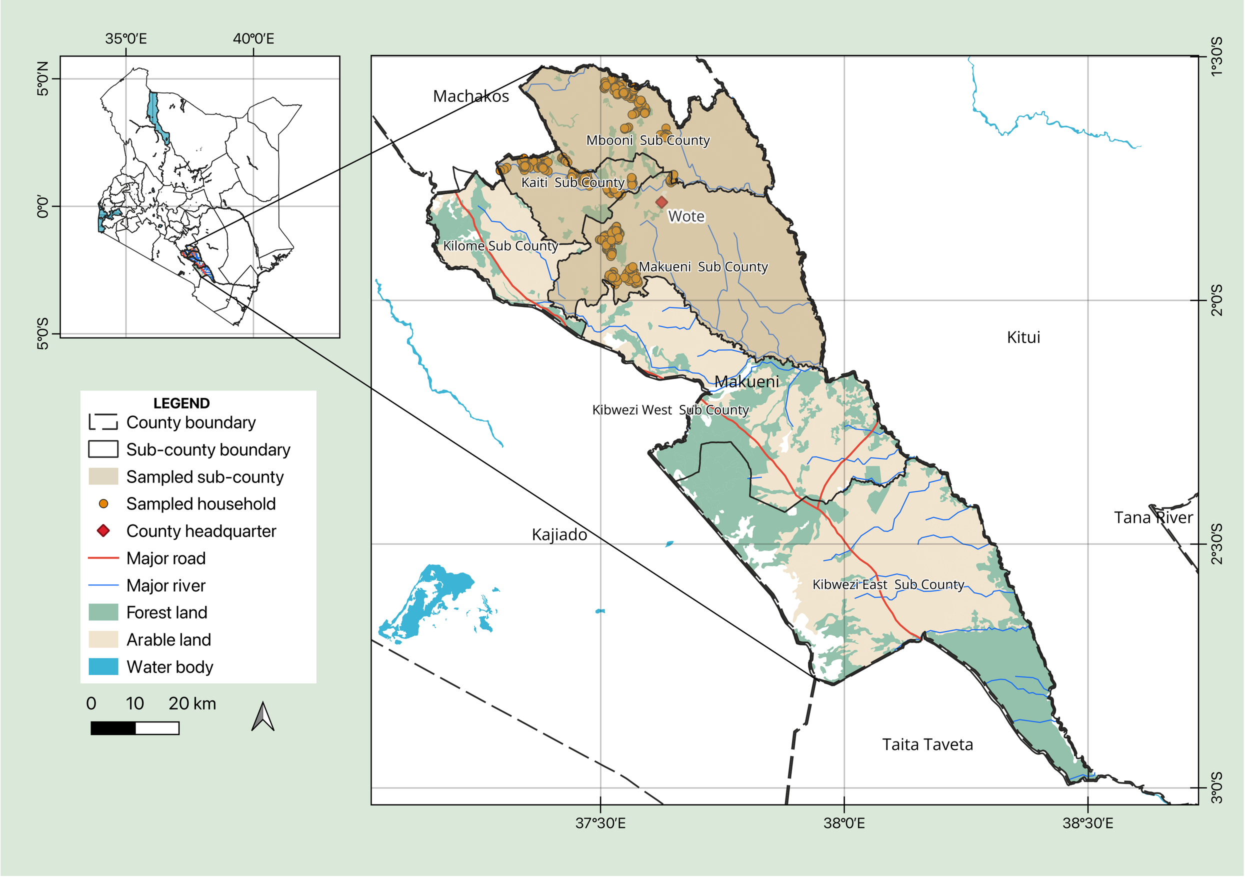


Figure 1. Map of the study sites in Makueni County, Kenya. **Source:** [1]

Analytical framework

The study employed a latent class stochastic metafrontier approach:

$$\ln \hat{f}^j(X_{i|j}, \beta) = \ln f^M(X_{i|j}, \beta) - u^M_{i|j} + v^M_{i|j} \quad (1)$$

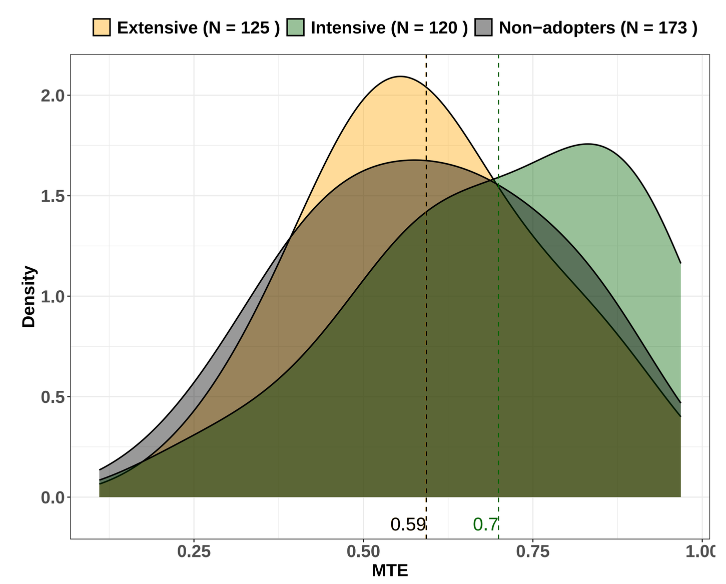
where $\ln \hat{f}^j(X_{i|j}, \beta)$ denotes the pooled fitted values from the class-specific frontiers (the model identified two distinct classes of adopters – extensive and intensive adopters), $u^M_{i|j}$ represents the non-negative technology gap component and $v^M_{i|j}$ asymptotically normally distributed noise component. We created an environmentally-adjusted efficiency and assessed its determinants as :

$$\text{MTE}^{\text{adj}}_{i|j} = \prod_{k \in \{\text{MTE}, \text{MEE}\}} k_{i|j} \quad (2)$$

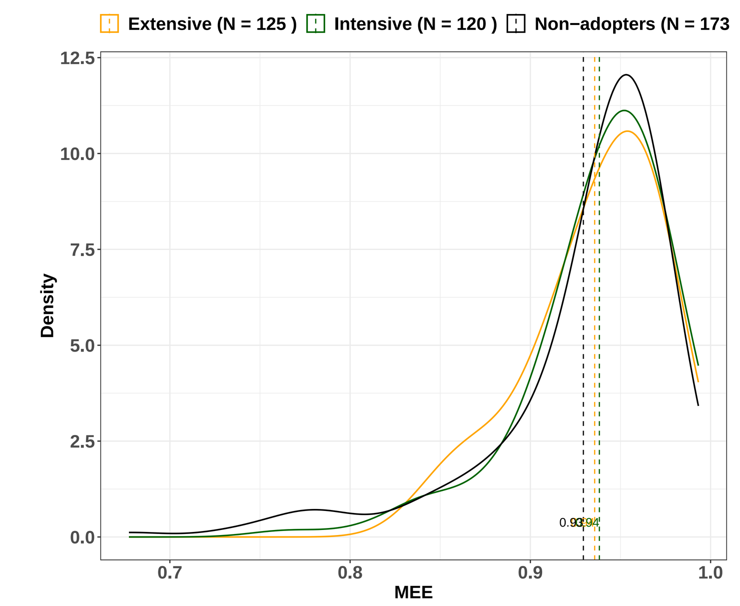
$$\sigma^2_{\text{MTE}^{adj}_{i|j}} = G(\delta; Z) = \delta_0 + \delta_1 Z_{1i|j} + \delta_2 Z_{2i|j} + \cdots + \delta_n Z_{ni|j} \quad (3)$$

Results:

(a) Metatechnical efficiency (MTE) & Meta-ecoefficiency (MEE)



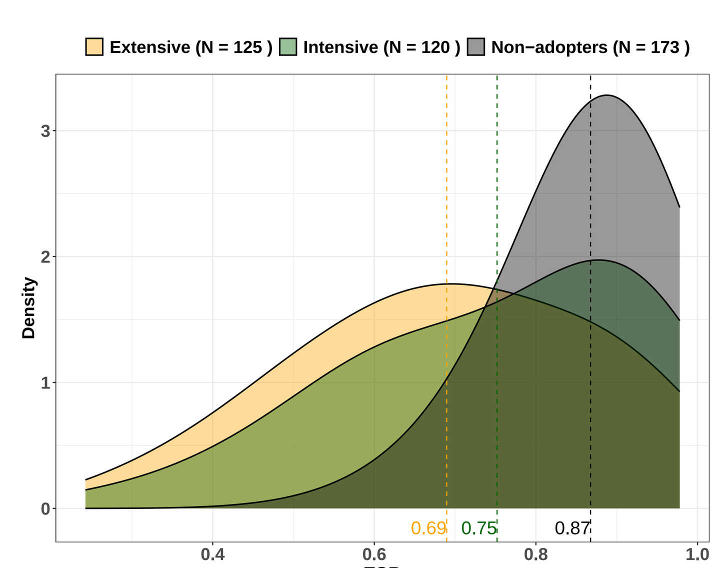
(a) Distribution of MTE.



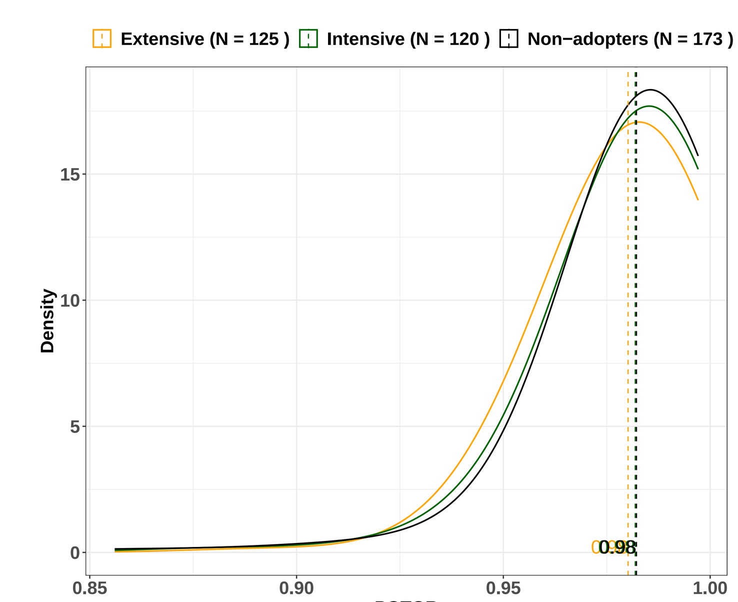
(b) Distribution of MEE.

Figure 2. Distribution of MTEs and MEEs for different adoption categories.

(b) Technology-gap ratio (TGR) and pressure-generating technology-gap ratio (PGTGR)



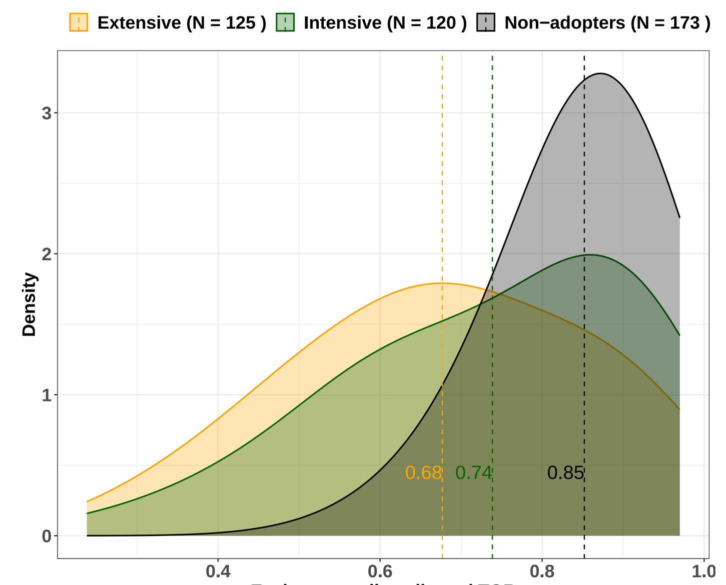
(a) Distribution of TGR.



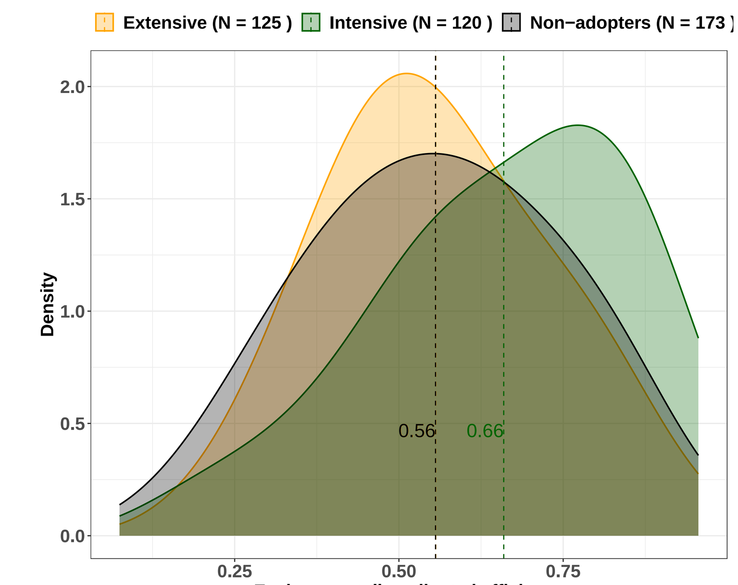
(b) Distribution of PGTGR.

Figure 3. Distribution of TGRs and PGTGRs for different adoption categories.

(c) Environmentally-adjusted TGR & efficiencies



(a) Distribution of environmentally-adjusted TGR



(b) Distribution of environmentally-adjusted efficiency

Figure 4. Distribution of environmentally-adjusted TGR and efficiencies for various adoption groups.

(d) Determinants of environmentally-adjusted (in)efficiency

Table 1. Estimates of bootstrap fractional probit for the determinants of inefficiency

Variable	Observed Coef.	Bootstrap SE	AME	Bootstrap SE
Formal education (years)	-0.014**	0.007	-0.006**	0.003
Household size (count)	-0.012	0.009	-0.004	0.003
Gender (1 = male)	-0.042	0.054	-0.016	0.021
APM Intensity (semicontinuous)	-1.383***	0.498	-0.532***	0.191
APM Intensity squared	4.521***	1.481	1.740***	0.566
Orchard prospects (1 = positive)	-0.190**	0.096	-0.073**	0.037
Age of trees (years)	-0.008**	0.003	-0.003**	0.001
$\log$(Tree density (tree acre^{-1}))	-0.056	0.035	-0.021	0.013
Number of orchards (count)	0.011	0.046	0.004	0.018
Group membership (1 = yes)	-0.139***	0.052	-0.054***	0.019
Credit access (1 = yes)	0.178**	0.089	0.068**	0.034
asinh(Off-farm income (KES year^{-1}))	-0.008	0.006	-0.003	0.002
Mango export quantity (kg)	-0.001***	0.000	-0.001***	0.000
Cocreation (1 = yes)	-0.123**	0.048	-0.044**	0.018
Extension access (1 = yes)	-0.023	0.052	-0.009	0.020
Distance to input market (meters)	0.007	0.020	0.003	0.007
Constant	0.657***	0.238		
Wald χ^2(**16**)	57.77***			
Replications	1000			
N	418			

Key findings

- Non-adopters had the highest TGR (85%) due to the quick effectiveness of inorganic pesticides, though at the cost of environmental sustainability.
- Extensive adopters showed **no efficiency gains** compared to conventional pesticide users.
- Intensive adopters achieved 66% efficiency (**10% higher** than extensive adopters and non-adopters).
- Efficiency gains by APM adopters stemmed from yield improvements rather than reduced input use or harmful outputs.
- Inefficiency decreased with greater APM adoption, education, knowledge-sharing, group membership, positive orchard outlook, and higher tree density.
- Efficiency gains from APM adoption diminished at higher levels of intensification, showing a **nonlinear** relationship.

Recommendations

- Provide subsidies and financial support to lower APM adoption costs.
- Ensure affordable, locally available organic pest control inputs.
- Offer participatory training on effective APM practices.
- Strengthen farmer groups to enhance social learning and resource sharing.

References:

[1] Sulman Olieko Owili, David Jakinda Otieno, Evans Ligare Chimoita, and Frederick Philbert Baijukya. Factors influencing adoption of agro-ecological pest management options for mango fruit fly under information constraints: a two-part fractional regression approach. *International Journal of Pest Management*, 70(4):1–19, 2024.

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