

Date	Submitted	Accepted	Published
	14 th July 2025	19 th January 2026	3 rd March 2026

EFFECTS OF AGROECOLOGICAL INTENSIFICATION PRACTICES TRAINING ON SMALLHOLDER MAIZE AND BEAN PRODUCTIVITY IN UGANDA

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ABSTRACT

Smallholder agriculture in Uganda faces pressures from land scarcity and soil degradation, threatening food security. Agroecological Intensification (AEI) offers sustainable solutions, but adoption remains low. This study assessed the application of AEI practices and their influence on maize and beans productivity among smallholder farmers in Kamuli district, Uganda, following a promotional intervention conducted between October 2022 and April 2024. The study entailed a quasi-experimental design involving baseline (October 2022) and endline (April 2024) surveys with 100 farmers selected via two-stage sampling. The intervention, which included farmer training and demonstration plots focused on AEI practices, was implemented between surveys. Data on socio-demographics, AEI practice frequency, perceived constraints, and crop yields (maize, beans) were collected. Statistical analyses using Statistical Package for Social Sciences (SPSS)-25 included descriptive statistics, and multiple linear regression to establish factors influencing log-transformed yield and Land Equivalence Ratio (LER) for beans ($n=92$) and maize ($n=78$). Significant increases ($p<0.05$) occurred in the 'usual' application of organic waste recycling, erosion control, and water harvesting from baseline to endline, while intercropping significantly decreased. Farmers reported reduced severity of agroecological constraints between the baseline and endline. Regression of productivity (yield/LER) on other factors for beans ($n=92$) production showed positive associations ($p<0.05$) with manure use, mixed farming, education, and being a full-time farmer, and negative associations with intercropping and household size. For maize, regression of productivity (yield/LER) on other factors ($n=78$) indicated positive associations with water harvesting and constraint frequencies, but power (51%) was insufficient for reliable conclusions. Promotion of AEI practices over a period of nearly 1.5 years resulted in increased uptake of several AEI practices and lessened perceived ecological constraints. This, however, did not lead to significant ($P>0.05$) overall yield gains or LER for maize and beans within the intervention time frame. Specific practices were significantly associated with improved beans productivity. Results on maize require cautious interpretation due to inadequate statistical power. Promoting practices with demonstrated positive associations (like manure for beans) is recommended, alongside integrated support addressing socio-economic constraints.

Key words: Agroecology, Extension Services, Production Constraints, Sustainable Agriculture, Uganda

Citation: **Bukenya R, Kisakye J, Ogenrwoth B, Mugisha J, Sekalema H, Kalange Y, JH Muyonga** Effects of Agroecological Intensification Practices Training on Smallholder Maize and Bean Productivity in Uganda. *Afr. J. Food Agric. Nutr. Dev.* 2026; **26(2)**: 28689-28712.

<https://doi.org/10.18697/ajfand.149.26175>



INTRODUCTION

Smallholder agriculture significantly contributes to food security and livelihoods in Uganda. However, mounting pressure from population growth, increasing land scarcity, and soil degradation are key constraints to smallholder agriculture. Enhancing crop productivity sustainably on limited land resources is therefore critical for achieving food security and broader Sustainable Development Goals (SDGs). The AEI practices, which entail applying ecological principles to optimize agricultural systems, aiming to improve yields, enhance resilience, and promote environmental health simultaneously, offer promising options for addressing production constraints [1]. Key AEI principles involve increasing biodiversity, improving soil health through organic inputs and minimal disturbance, enhancing nutrient cycling, and integrating practices like intercropping, crop rotation, manure application and integrated pest management [1].

Despite AEI's potential benefits and farmer awareness, adoption rates among smallholders in Uganda remain relatively low [2,3]. This low adoption is particularly evident in regions like Kamuli district (Eastern Uganda), which is dominated by subsistence farming. Kamuli is characterized by declining productivity, pest and disease pressure, fragmented landholdings, and limited extension services [4] — challenges AEI could potentially mitigate. Recognizing this potential, this study sought to promote AEI practices among farmers in Kamuli district and to evaluate the results of the promotion. Specifically, the study established the baseline situation regarding farmers' AEI knowledge, attitudes and practices (KAP). It also determined the associated changes in productivity of two crops (maize and beans) commonly grown in Kamuli district.

By providing context-specific evidence on current AEI use as well as the association of AEI practices and productivity, this research has potential to provide valuable insights towards optimizing AEI promotion strategies in Kamuli and similar agroecological contexts.

MATERIALS AND METHODS

Study area

The study was conducted in Kamuli district, situated in the Busoga region of Eastern Uganda. Covering 1,622 km², Kamuli had a total population of 540,252, with approximately 74.6% residing in the rural areas and primarily engaged in subsistence farming [4]. Kamuli district experiences a bimodal rainfall pattern, with main rains from March to May (approx. 110 mm/month) and secondary rains from August to October (approx. 70 mm/month), supporting diverse agricultural activities. The district possesses varied natural resources, including fertile soils suitable for



crops like maize, beans, sweet potatoes, cassava, bananas, and coffee, alongside livestock rearing (cattle, goats, pigs, poultry). Despite this potential, agriculture is often constrained by low productivity, pests and diseases, land fragmentation, limited adoption of improved technologies, and inadequate extension services, with an extension worker to farming household ratio of 1: 2,050, far below the recommended 1:500 [4,5].

Study design

This study employed a quasi-experimental design with baseline and endline assessments framing an Agroecological Intensification (AEI) intervention. A baseline survey was conducted in October 2022 to gather initial data. Following the intervention phase (March 2023 to July 2023), an endline survey was conducted in April 2024 to assess changes in AEI practices, constraints, and productivity.

Recruitment of participants

A two-stage sampling procedure selected 100 smallholder farmers. In stage 1, five farmer groups (Edhikokolima, Tugezeku, Mukisa, Tibikoma, and Nakulyaku) were purposively selected from nine groups previously associated with Volunteer Efforts for Development Concerns (VEDCO), a non-governmental organization. Selection criteria for these groups included: prior engagement with VEDCO, balanced gender representation, crop diversity and geographic location within Kamuli District (Namasagali and Butansi sub-counties, and Kamuli Municipality Southern Division). In stage 2, twenty farmers were randomly selected from the membership list of each of the five selected groups, obtaining a total sample size of 100 participants. Participation was voluntary.

Description of the intervention

Following the baseline survey, an AEI intervention was implemented. The intervention entailed the following activities:

Manual Development: Experts from Makerere University developed an AEI training manual tailored to the local context and refined it during initial farmer training. The manual produced under the European Union-funded Food and Local, Agricultural, and Nutritional Diversity (FoodLAND) project, provides guidance for training extension staff and farmers in Kamuli district, Uganda, on Agro-Ecological Intensification (AEI) practices. The manual covers topics such as agricultural extension principles, the concept of agroecology, and specific agroecological technologies and practices such as mulching, mixed farming, integrated pest management, intercropping, and the use of manure and crop waste. It emphasizes practical application, adult learning principles, and interactive methods (discussions, peer practice, field visits), including assessment and evaluation techniques.



Training of Trainers: Four extension workers from VEDCO Kamuli were trained by the Makerere University team on AEI principles and extension practices for one day.

Model Farmer Training: To enhance peer-to-peer learning and on-farm support, ten model farmers (two from each of the five participating groups) received intensive two-day training. The training, which was done by the Makerere University team and trained extension workers, focused on practical aspects including manure preparation and use, mulching techniques, intercropping combinations, and spacing, organic pest management (repellents, traps), and integrated pest management (IPM).

Farmer Training: The trained extension workers and model farmers conducted on-farm training sessions for two days with 100 participating farmers. These sessions combined theoretical and practical components, emphasizing AEI principles, indigenous knowledge linkages, resource mobilization (local inputs), and practical application techniques.

Demonstration Plots: Each farmer group established two demonstration sites (a total of 10 plots). Practices demonstrated were based on farmer priorities and commonly included intercropping with manure application (5 plots), mulching with manure (3 plots), or manure application alone (2 plots). Eight demonstrations also integrated mixed farming elements, utilizing manure from cattle, goats, pigs, or poultry available within the groups. A follow-up training session was conducted by the Makerere team in July 2023 to reinforce knowledge and skills at the demonstration sites.

Data collection

Data were collected at baseline (October 2022) and endline (April 2024) using a semi-structured questionnaire administered via face-to-face interviews by trained enumerators. The same questionnaire was used for both time periods, capturing information on socio-demographic characteristics (age, gender, education level of the farmer, marital status of the farmer, occupation of the farmer, household size), and farm characteristics (land size, crop diversity, livestock ownership). Others were agroecological practices, applied by farmers (for example, manure use, mixed farming, intercropping, mulching, crop rotation, IPM, erosion control, water harvesting, waste recycling), and the frequency of application (categorized as 'not applied', 'rarely', 'usually'). Crop Production and Constraints: Data included the quantity (kg) of maize and beans harvested, land area (acres) allocated to each crop, perceived production constraints (rated by importance and frequency), and household food supply stability.



Variables

Outcome Variables

- **Crop yield in kg/acre (maize and bean):** calculated by dividing the total harvested quantity (kg) of the crop by the land area (acres) on which it was grown by each farmer.
- **Partial Land Equivalence Ratio (LER):** Calculated for maize and beans separately by dividing the farmer's actual yield (kg/acre) by the expected average yield for the variety grown. Expected yields without intercropping were Beans (Local: 500 kg/acre, improved: 1500 kg/acre), Maize (Local: 400 kg/acre, Improved: 1323 kg/acre).
- **Transformation:** yield and LER values were logarithmically transformed (natural log) to improve normality for regression analysis.

Probable predictor variables

- **Agroecological intensification (AEI) practice application:** Measured using dummy variables (0 = No, 1 = Yes), indicating the adoption status of specific practices (for example, manure use, mixed farming, intercropping, mulching, crop rotation, waste recycling, IPM, erosion control and water harvesting).
- **Socio-demographic variables:** gender of the farmer (0=male, 1 =female), age of the farmer (years), marital status of the farmer (1=single, 2=Married/cohabiting, 3=Divorced/separated, 4=Widowed), education level of the farmer (0=no education, 1=nursery, 2=Lower primary, 3=Upper primary, 4=Ordinary level secondary, 5=Advanced Level secondary, 6 =Vocational training, 7=Other tertiary), main occupation of the farmer (0=other jobs, 1=farmer), household size (continuous).
- **Farm characteristics:** total land farmed (continuous, acres).
- **Constraint perception:** Perceived importance and frequency ratings of specific constraints (for example, low soil fertility, limited land) were used as predictors in some maize and beans models.
- **Time:** a dummy variable (0 = baseline [Oct 2022], 1 = endline [April 2024]) was included in regression models (Model 2) to assess change over time.

Data analysis

Data were cleaned and managed using Microsoft Excel 2016 and analyzed using International Business Machines Corporation (IBM) Statistical Package for Social Sciences (SPSS)-version 25.0.



Descriptive statistics were calculated, including frequencies and percentages for categorical variables (demographics, AEI practice usage) and means, standard deviations (SD), medians, minimums, and maximums for continuous variables (age, household size, yield, LER). The primary crops grown, maize and beans were included in the analysis.

Chi-square (χ^2) tests were used to determine if there were statistically significant differences in the proportions of farmers applying AEI practices (specifically, the 'usually' applied category) between the baseline and endline surveys.

Due to the continuous nature of the dependent variable and several independent variables, multiple linear regression analysis was employed separately [6]. The two separate MLR models were run to assess the influence of AEI practices and socio-demographic factors on: 1) the natural log-transformed yield (maize and beans), and 2) the partial Land Equivalent Ratio (LER). Separate models were executed: Model 1, including baseline predictors only, and Model 2, which added the time variable (Baseline vs. Endline) to assess temporal change in the outcome. The general model form was: $Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_k X_k + \epsilon$, where Y represents the dependent variable (log-yield or log-LER), X_k are the predictor variables, β_k are the regression coefficients, and ϵ is the error term. Model significance (F-statistic and p-value), variance explained (Adjusted R^2), R^2 change between models, and Mean Squared Error (MSE) were reported. The residuals had equal variance and normality as observed from graphical outputs for the two multiple regression analyses (Fig. 1 and 2). Lack of multicollinearity among dependent variables was observed using collinearity diagnostics (Variance Inflation Factor, $VIF < 5$; Tolerance > 0.2) in Tables 2 and 3. Statistical significance was set at $p < 0.05$.

A power analysis was conducted using G*Power and documented procedures [7, 8] to assess the adequacy of the final regression sample sizes for beans ($n=92$) and maize ($n=78$) using G*Power and documented procedure [7,8]. The effect size (R^2) of 0.3, sample size ($n =92$), and 15 predictors in the regression model for beans (Table 2) yielded power ($1 - \beta$) of 90%, which is greater than the minimum 80% indicating that sample size used for analysis of beans was adequate. Using effect size (R^2) of 0.17, sample size ($n =78$), and 15 predictors in the regression model for maize (Table 3) yielded power ($1 - \beta$) of 51%, which is lower than 80%, indicating sample size used for maize was not adequate, even though the model was significant. The results should be cautiously interpreted and can be used as preliminary results for future studies. Future studies will need to use a higher sample size than that used in this analysis. The statistical significance was set at $p < 0.05$.



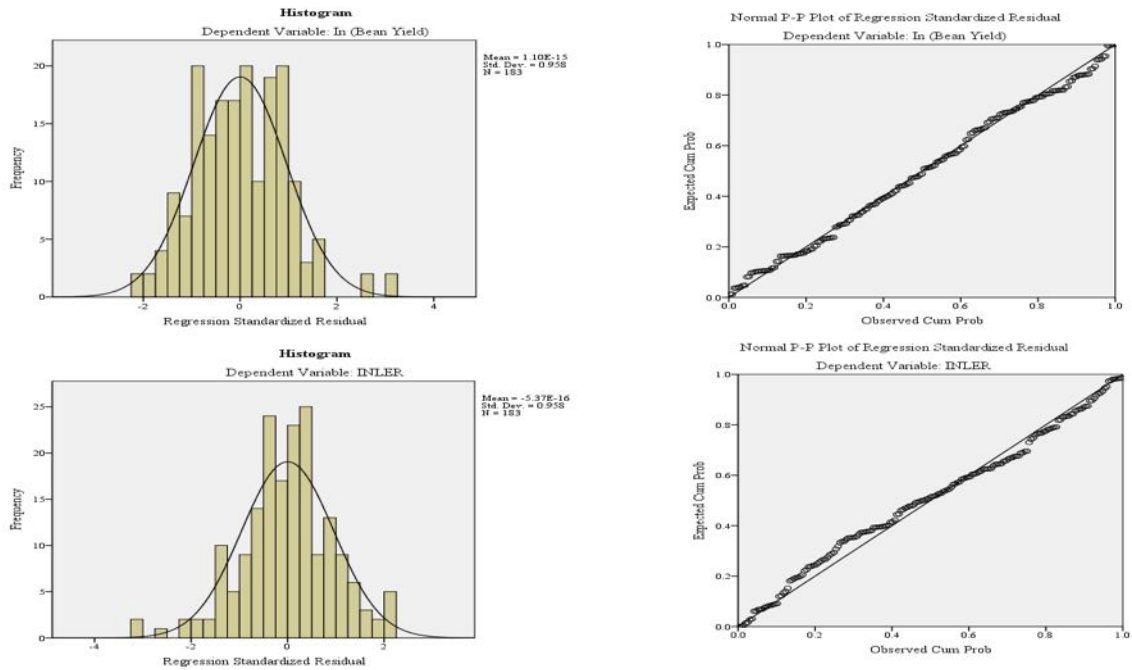


Figure 1: Equality of variance and normality of residuals for yield (kg/acre) and Land equivalence of beans using transformed data

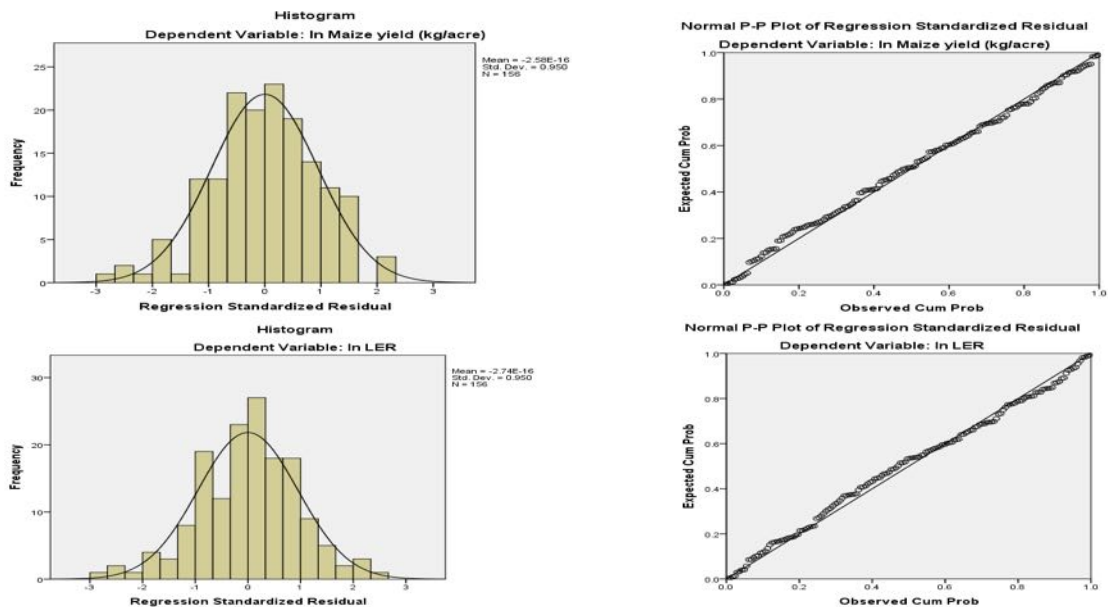


Figure 2: Equality of variance and normality of residuals for yield (kg/acre) and Land equivalence ratio of maize using transformed data

Ethical considerations

Ethical approval was sought from the Uganda National Council for Science and Technology (Ref: A95ES). Informed consent was obtained from all participating farmers prior to data collection at both baseline and endline. Participants were informed about the study's purpose, procedures, potential risks and benefits, their right to withdraw at any time without penalty, and measures taken to ensure confidentiality. Data were anonymized before analysis.

RESULTS AND DISCUSSION

Demographic characteristics of farmers

Of the 100 farmers recruited, 78 cultivated maize and 92 cultivated beans at both baseline (October 2022) and endline (April 2024); subsequent analyses focus on these farmers for their respective major crops. Socio-demographic characteristics were broadly similar for both beans and maize cultivators (Table 1). Participants were predominantly female (63.0% beans farmers, 61.5% maize farmers) and married/cohabiting (83.7% beans, 84.6% maize). The average age was approximately 43 years (Mean \pm SD: beans 42.5 \pm 13.0; Maize 42.7 \pm 13.3) and the average household size was 8 persons (Mean \pm SD: Beans 8.1 \pm 3.4; maize 7.9 \pm 3.2). Most participants had received some formal education (85.9% beans, 88.5% maize), although a notable portion had no education (14.1% beans, 11.5% maize). The majority identified as full-time farmers (88.0% beans, 82.1% maize).

Application of Agroecological Intensification (AEI) practices

The most applied AEI practices among both beans and maize farmers at baseline and endline included manure application, mixed farming, intercropping, and waste recycling (Figures 3 and 4).

Beans cultivation: Comparing baseline to endline usage percentages for beans farmers (Figure 3), showed significant increases in the proportion of farmers who 'usually' applied waste recycling ($\chi^2 = 56.04$, $p < 0.001$), integrated pest management (IPM) ($\chi^2 = 7.64$, $p = 0.022$), erosion control measures ($\chi^2 = 17.00$, $p < 0.000$), and water harvesting techniques ($\chi^2 = 9.94$, $p = 0.007$). Conversely, there was a significant decrease in the proportion 'usually' applying intercropping ($\chi^2 = 8.27$, $p < 0.05$), crop rotation ($\chi^2 = 92.50$, $p < 0.001$), and cover crops ($\chi^2 = 18.70$, $p < 0.001$).



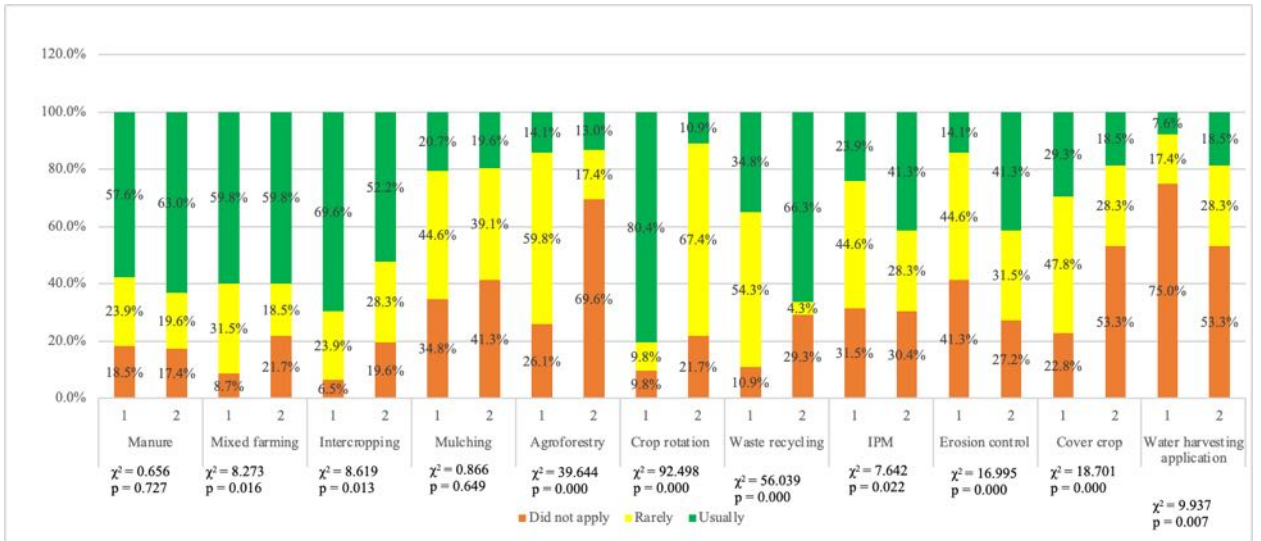


Figure 3: Application of agroecological intensification practices among beans farmers
 (Figure represents baseline (1) and endline (2) and that the chi-square and p-value show increased usual application of manure, IPM, Erosion control, and water harvesting. However, reported usual intercropping and crop rotation was reduced.)

Maize cultivation: Among maize farmers (Figure 4), significant increases occurred between baseline and endline in the 'usual' application of waste recycling ($\chi^2 = 22.67, p < 0.001$), soil erosion control ($\chi^2 = 16.91, p < 0.001$), cover crops ($\chi^2 = 18.86, p < 0.001$), agroforestry ($\chi^2 = 35.29, p < 0.000$) and water harvesting ($\chi^2 = 14.54, p = 0.001$). Like bean farmers, a significant reduction was observed in the 'usual' application of intercropping ($\chi^2 = 12.12, p = 0.002$).

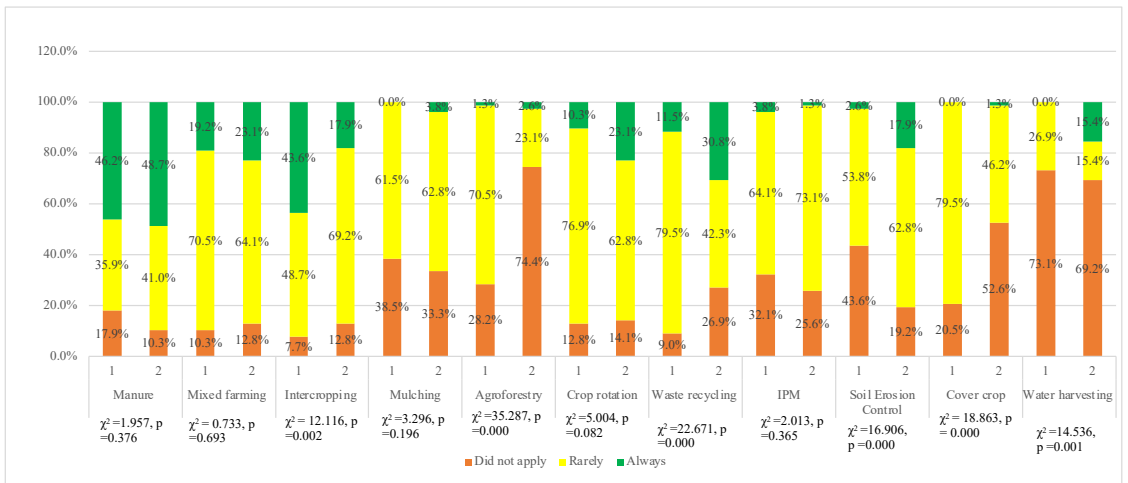


Figure 4: Application of agroecological intensification practices among maize farmers
 (Figure represents baseline (1) and endline (2) and that the chi-square and p-value show increased usual application of Waste recycling, soil Erosion control, and water harvesting. However, reported usual intercropping rate reduced)



AEI adoption dynamics

The results confirmed increased adoption of several AEI practices during the intervention period, notably waste recycling, erosion control, and water harvesting, suggesting a positive response to the intervention's focus on utilizing locally available resources and addressing key constraints such as soil fertility decline and weather variability [4]. This aligns with the AEI philosophy of enhancing resource use efficiency [1]. The training and demonstration plots likely played a role in building capacity and showcasing the feasibility of these specific practices.

Conversely, the significant decrease in the 'usual' application of intercropping (for both crops) and crop rotation (for beans) requires consideration. The decline in intercropping might reflect farmer concerns about competition negatively impacting the yield of a primary staple, consistent with the negative association found between intercropping and beans yield in the current study regression analysis and supported by literature suggesting careful management is needed to optimize component crop performance [9,10]. The reduction in crop rotation could stem from practical challenges like land scarcity limiting rotation options, or perhaps a lower perceived efficacy against persistent local pests and diseases compared to other management strategies emphasized during training.

Farmer-perceived production constraints

Farmers' ratings of the importance and frequency of major production constraints at baseline and endline are shown below.

High importance constraints: Plant diseases and weather variability were consistently ranked as the most significant constraints at baseline for both crops (Supplementary Figure 1a and 1b and 2a and 2b). However, the proportion of farmers reporting these as highly and very highly important generally decreased by endline, most notably the 40.2 percentage point drop in weather variability for beans farmers (from 70.6% to 30.4%). Other highly important constraints included low crop prices (beans: 57.6% vs 53.3%, maize: 57.7% vs 60.2%), high input costs (beans: 57.6% vs 49.0%, maize: 60.2%, 55.2%), and income shortages (beans: 56.5% vs 47.8%, maize: 60.3% vs 56.4%).

High frequency constraints: Plant diseases were regarded as the most frequent constraint (high/very high frequency (Supplementary Figure 1a and 1b and 2a and 2b): 59.7% vs 43.5% beans, 61.5% vs 53.9% maize). Other frequent constraints included weather variability (beans: 47.9% vs 27.9%, maize: 50.0% vs 26.9%), high input costs (beans: 40.2% vs 42.4%, Maize: 26.9% vs 44.9%), low crop prices (beans: 33.7% vs 33.5%, maize: 35.9% vs 47.4%), and income shortages (beans: 34.8% vs 29.4%, maize: 34.6% vs 37.2%).



Changes over time: Generally, the perceived severity and frequency of agroecological constraints like plant diseases and weather variability decreased from baseline to endline, while socio-economic constraints like low prices (especially for maize) and access/cost of inputs showed mixed or worsening trends.

Beans and maize yields

Yields (kg/acre) and partial Land Equivalence Ratios (LER) were compared between baseline and endline. The results are described below.

Beans: The mean beans yield was 336.8 ± 395.7 kg/acre at baseline and 342.5 ± 400.1 kg/acre at endline (Fig. 5). The corresponding mean partial LER was 0.40 ± 0.31 at baseline and 0.30 ± 0.50 at endline. Although the yield at endline was higher than at baseline, no statistically significant differences ($p > 0.05$) were found between baseline and endline for raw yield, log-transformed yield, raw LER, or log-transformed LER for beans. The LER ratios at both baseline and endline were less than 1 indicating that farming practices at both time periods did not produce significant yield advantages in bean plots.

Maize: The mean maize yield was 818.6 ± 1146.2 kg/acre at baseline and 788.9 ± 1249.3 kg/acre at endline (Fig. 6). The corresponding mean partial LER was 1.11 ± 2.55 at baseline and 1.17 ± 2.86 at endline. Similar to beans, no statistically significant differences ($p > 0.05$) were observed between baseline and endline for maize yield or LER, whether using raw or log-transformed data. The LER ratios at both baseline and endline were greater than 1 indicating that farming practices at both time periods had significant yield advantages in bean plots.



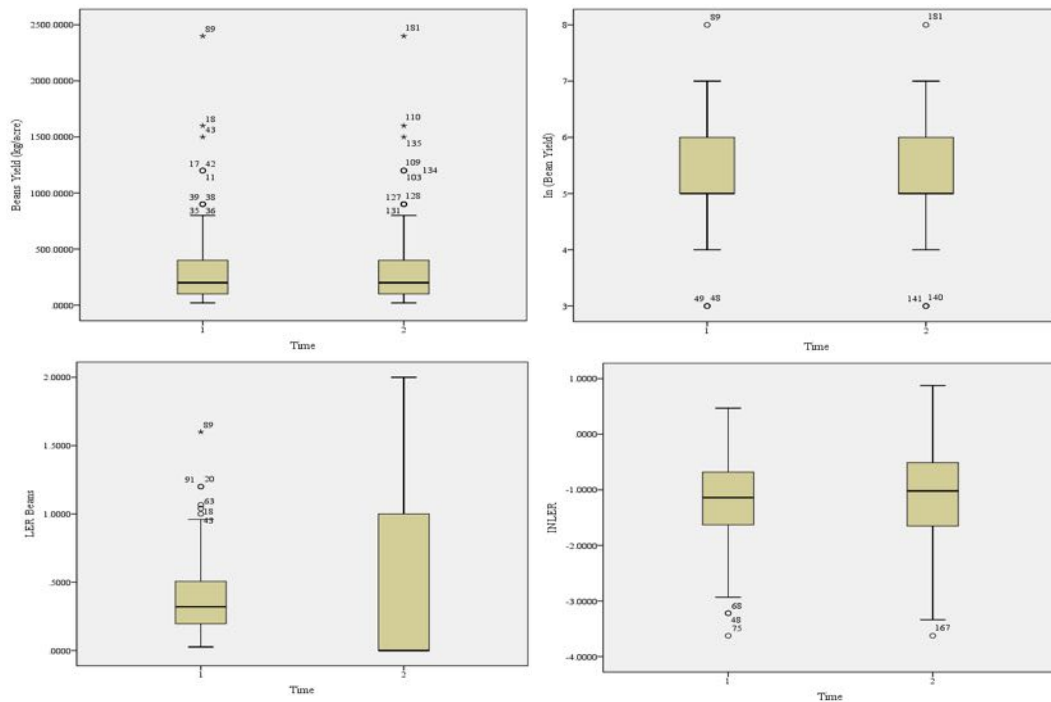


Figure 5: Yield (kg/acre) and Land equivalence ratio of beans using raw and transformed data

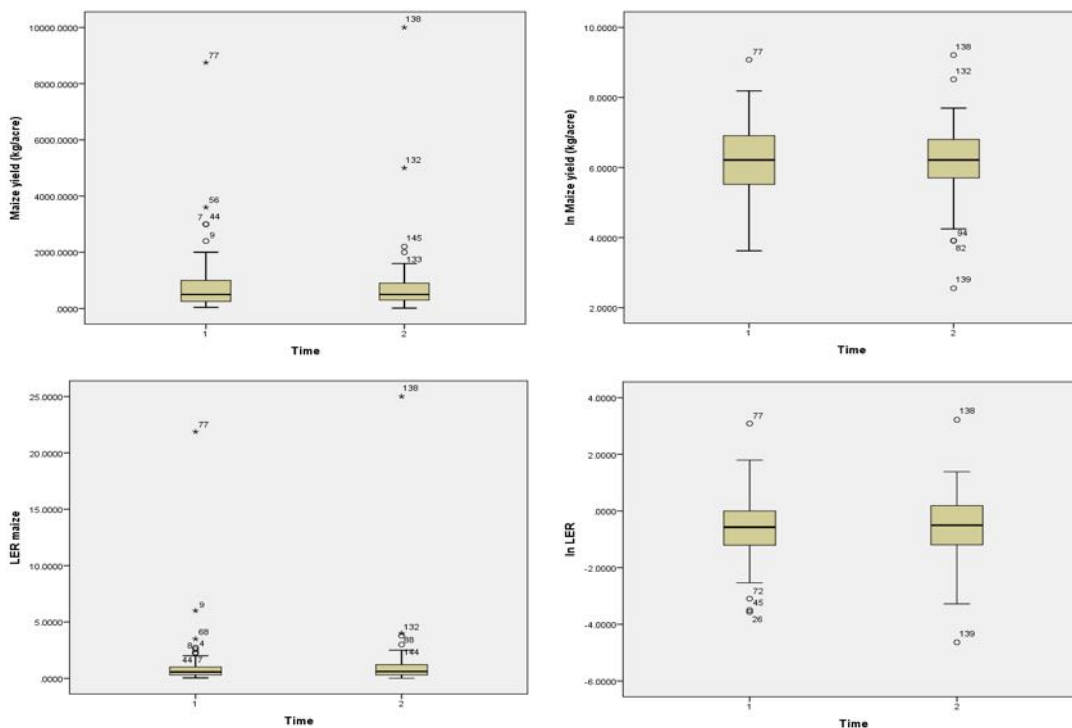


Figure 6: Yield (kg/acre) and Land equivalence ratio of maize using raw and transformed data

Overall yield trends and AEI effects

The central finding that overall mean maize and beans yields did not significantly change between baseline and the April 2024 endline, despite shifts in AEI practices, warrants careful discussion. While AEI practices aim to enhance long-term productivity, ecological improvements, particularly soil health gains through organic matter accumulation (for example, manure application, cover cropping, residue recycling), often require a longer timescale than the approximately 1.5-year study period to manifest as significant, farm-level yield increases [11–13]. Furthermore, high inherent yield variability driven by factors like rainfall patterns, pest pressure (which remained a key constraint), and seed quality in these smallholder systems can easily obscure subtle positive effects of practice changes over this duration. It is also possible that the adoption intensity or synergistic combination of practices was insufficient to drive widespread yield gains across the sample.

Despite the stable overall yields, the reduction in perceived severity and frequency of agroecological constraints (plant diseases, weather variability) suggests farmers may be experiencing other valuable benefits from AEI, such as increased system resilience or potentially reduced reliance on certain inputs. This aligns with the broader goals of AEI beyond yield maximization alone. However, the persistence of socio-economic constraints (low prices, high input costs) underscores that technical AEI adoption needs complementary support addressing market and financial barriers, as farmers may still face costs associated with AEI (for example, purchasing manure if livestock are insufficient).

Influence of AEI practices and farmer characteristics on crop productivity (regression analysis)

A Multiple Linear Regression Model (MLRM) was used to assess factors associated with log-transformed yield and LER (Tables 2 and 3).

Determinants of bean productivity

Multiple linear regression of log-transformed yield and LER on beans on several factors including AEI practices is reported in Table 2 and explained below.

Log (Yield): At baseline (Model 1), factors significantly associated with beans yield included higher education level of the farmer ($\beta = 0.19$, $p = 0.011$), occupation of the farmer (being a full-time farmer vs. other: $\beta = 0.16$, $p = 0.019$), household size ($\beta = -0.25$, $p = 0.001$), use of manure ($\beta = 0.21$, $p = 0.002$), mixed farming ($\beta = 0.2$, $p = 0.006$), and intercropping ($\beta = -0.33$, $p < 0.001$). This model explained 30.0% of the variance in Log yield of beans (Adjusted $R^2 = 0.300$, $F [14, 168] = 6.58$, $p < 0.001$). Adding the time variable (Model 2) did not significantly improve the model (R^2 change = 0.000, $p = 0.952$), and the same predictors remained significant.



Log (LER): For beans LER (Model 1), significant predictors were occupation (full-time farmer: $\beta = 0.22$, $p = 0.003$), household size ($\beta = -0.18$, $p = 0.034$), and intercropping ($\beta = -0.23$, $p = 0.008$). This model explained 18.1% of the variance in Log LER for beans (Adjusted $R^2 = 0.181$, $F [14, 168] = 3.87$, $p < 0.001$). Again, the time variable (Model 2) did not add significant explanatory power (R^2 change = 0.001, $p = 0.713$).

Determinants of maize productivity

Multiple linear regression of log-transformed yield and LER on maize on several factors including AEI practices is reported in Table 3 and explained below.

Log (Yield): Based on Model 1 estimates, factors significantly associated with maize yield included reporting low soil fertility frequency ($\beta = -0.31$, $p < 0.001$), reporting labor shortage frequency ($\beta = 0.16$, $p = 0.044$), reporting limited land frequency ($\beta = 0.21$, $p = 0.017$), and application of water harvesting ($\beta = 0.19$, $p = 0.012$). This model explained 17.4% of the variance (Adjusted $R^2 = 0.174$, $F [14, 141] = 3.34$, $p < 0.001$). Adding the time variable (Model 2) did not significantly improve the model (R^2 change = 0.005, $p = 0.312$), and the same predictors remained significant.

Log (LER): For maize LER (Model 1), significant predictors were reporting low soil fertility frequency ($\beta = -0.35$, $p < 0.001$), reporting limited land frequency ($\beta = 0.27$, $p = 0.002$), and application of water harvesting ($\beta = 0.18$, $p = 0.021$). This model explained 15.0% of the variance (Adjusted $R^2 = 0.150$, $F [14, 141] = 2.96$, $p = 0.001$). Again, the time variable (Model 2) did not add significant explanatory power (R^2 change = 0.000, $p = 0.83$).

Factors associated with crop productivity

Regression analyses identified significant associations between AEI practice adoption, socio-demographic factors, constraint perceptions, and variations in crop productivity. However, the maize findings must be interpreted with caution due to documented limitations in statistical power.

Beans: The analysis, supported by adequate statistical power, confirmed positive associations between beans productivity (yield/LER) and manure use, mixed farming, higher farmer education, and being a full-time farmer, while finding negative associations with intercropping and larger household size. These findings align well with literature on the benefits of organic inputs, focused farm management, and potential competition in intercrops [14–16]. The unexpected negative association between reported IPM application and beans yield warrants further investigation, potentially related to confounding factors like pest pressure severity or application nuances [17,18].



Maize: Regression analysis revealed positive significant associations between maize productivity (yield/LER) and application of water harvesting, and frequency of reporting low soil fertility, limited land, and labor shortage constraints. A negative association was obtained between maize productivity (yield/LER) and low soil fertility. The positive link to water harvesting highlights the importance of water management. The strong negative association with perceived low soil fertility frequency confirms this as a key yield-limiting factor [19]. However, the positive associations with reporting resource limitations (land, labor) more frequently are counterintuitive and difficult to interpret definitively. Crucially, the power analysis revealed that the sample size for the maize regression ($n=78$) was inadequate (Power = 51%), falling below the standard threshold of 80%. Therefore, these specific maize regression findings should be interpreted with significant caution and viewed as preliminary. While practices like manure application and erosion control showed increased adoption and are supported by literature for improving maize yields [20–23], they did not emerge as significant predictors in this specific, underpowered model.

Limitations of the study

Although this study offers crucial information to guide future interventions promoting AEI practices, it faces limitations. The quasi-experimental design without a parallel control group makes definitive attribution of changes to the intervention challenging. Purposive selection of farmer groups may limit generalizability. Reliance on farmer self-reporting for practice adoption and yield data introduces potential recall bias. Perhaps most importantly, the statistical power for the maize regression analysis was insufficient, meaning the study may have been unable to reliably detect true effects (or non-effects) of predictors on maize productivity. Therefore, these results must be treated with caution. Unmeasured variables (soil type variability, microclimatic conditions, market access, man-days, labour cost) could also influence outcomes. Finally, the study duration of about 1.5 years, may be insufficient to capture the full long-term ecological benefits of AEI.

Implications and future research

Despite limitations, the findings of this study suggest several implications:

1. Agroecological intensification (AEI) promotion initiatives should recommend practices strongly associated with improvement in beans productivity (manure, mixed farming) and those showing increased adoption and perceived benefits (waste recycling, erosion control, water harvesting).
2. Replication of the maize study with a larger sample size is essential to obtain adequately powered results on factors influencing its productivity. Longer-term monitoring (>3-5 years) is crucial to track yield trajectories and soil health



changes under AEI. Controlled trials comparing specific AEI packages would strengthen causal inference. Qualitative research could further explore reasons for practice adoption or non-adoption and the counter-intuitive associations observed. Cost-benefit analyses remain important.

CONCLUSION AND RECOMMENDATIONS FOR DEVELOPMENT

This study provided valuable insights into the dynamics of adoption of AEI practices following an intervention in Kamuli, Uganda. Farmers increased the use of several beneficial practices, reporting fewer agroecological constraints afterward. While significant aggregate yield improvements in maize and beans were not detected within nearly 1.5-year time frame, specific AEI practices showed positive associations with beans productivity, supported by adequate statistical power. The associations for maize productivity were less reliable due to insufficient power. The findings highlight that transitioning to AEI is a process requiring time, context-specific adaptation, and integrated support addressing both technical and socio-economic constraints, and robust research methodologies, particularly adequate sample sizes for complex analyses.

Author Contributions: Conceptualization, RB, JK, BO, JHM; Methodology, JK, RB, BO, JM; formal analysis, RB, JK, HS; investigation, JK, JHM, data curation, JK, JHM, JM; writing original draft preparation, RB, JK, HS; writing review and editing, RB, JK, BO, JM, HS, JHM; visualization, RB, JK; Supervision, JK, JHM; project administration, JK, JHM. All authors have read and agreed to the published version of the manuscript.

Funding: This research received funding from the European Union's Horizon 2020 Research and Innovation Programme Under grant agreement (No. 862802).

Conflicts of Interest: The authors declare no conflicts of interest.



Table 1: Demographic characteristics of sampled farmers

Baseline Characteristic	Beans		Maize	
	n	%, Median or Mean±SD	n	%, Median or Mean±SD
Gender of the farmer				
Female	58	63.0	48	61.5
Male	34	37.0	30	38.5
Marital status of the farmer				
Single-never married	4	4.3	3	3.8
Married/Cohabiting	77	83.7	66	84.6
Divorced/separated	1	1.1	1	1.3
Widowed	10	10.9	8	10.3
Education level of the farmer				
No education	13	14.1	9	11.5
Nursery	1	1.1	2	2.6
Lower primary education (P1-P4)	16	17.4	13	16.7
Upper primary education (P5 -P7)	17	18.5	18	23.1
Secondary School (O'Level)	34	37.0	29	37.2
Secondary School (A'Level)	4	4.3	3	3.8
Vocational training	6	6.5	4	5.1
Other tertiary	1	1.1		
Main occupation of the farmer				
Other or Salaried job	11	12.0	14	17.9
Full time farmer	81	88.0	64	82.1
Age (years)				
Mean±SD	92	42.48±12.96	78	42.65±13.29
Median (min, max)	92	40 (18, 80)	78	40 (18, 80)
Household size				
Mean±SD	92	8.07±3.35	78	7.86±3.15
Median (min, max)	92	9 (1, 17)	78	8 (1, 17)



Table 2: Regression of yield and Partial Land Equivalence Ratio of beans on AEI practices and other demographic characteristics among farmers (n=92)

Model	Coefficients (β)	t	p-value	Collinearity Statistics		Coefficients (β)	t	p-value	Collinearity Statistics	
				Tolerance	VIF				Tolerance	VIF
Dependent Variable	ln (Yield (kg/Acre))					ln (partial land equivalence ratio)				
1 (Constant)		11.298	.000				-3.235	.001		
Gender (0= Female, 1 Male)	.000	.005	.996	.769	1.300	-.004	-.054	.957	.769	1.300
Age (Years)	.111	1.246	.214	.484	2.068	.003	.028	.978	.484	2.068
Marital status (1= Single, 2= married/cohabiting)	-.073	-.833	.406	.495	2.021	-.092	-.962	.337	.495	2.021
Education level	.193	2.573	.011	.682	1.466	.075	.926	.356	.682	1.466
Occupation of HH (0 = other, 1= farmer)	.155	2.371	.019	.894	1.118	.217	3.056	.003	.894	1.118
HH size	-.254	-3.330	.001	.660	1.516	-.177	-2.138	.034	.660	1.516
Use of manure (0 = No, 1= Yes)	.212	3.070	.002	.807	1.239	.140	1.871	.063	.807	1.239
Mixed Farming (0 = No, 1= Yes)	.198	2.772	.006	.753	1.328	-.057	-.737	.462	.753	1.328
Intercropping (0 = No, 1= Yes)	-.326	-4.049	.000	.594	1.682	-.233	-2.683	.008	.594	1.682
Mulching (0 = No, 1= Yes)	.110	1.459	.147	.682	1.467	.155	1.912	.058	.682	1.467
Crop rotation (0 = No, 1= Yes)	.114	1.713	.089	.869	1.151	.080	1.118	.265	.869	1.151
Recycling and use of crop and animal waste (0 = No, 1= Yes)	-.080	-1.191	.235	.842	1.187	-.018	-.243	.808	.842	1.187
IPM (0 = No, 1= Yes)	-.121	-1.838	.068	.886	1.129	-.134	-1.874	.063	.886	1.129
Total land farmed (acres)	.057	.702	.483	.576	1.735	.141	1.593	.113	.576	1.735
2 (Constant)		10.242	.000				-3.092	.002		
Gender (0= Female, 1 Male)	.000	.005	.996	.769	1.300	-.004	-.055	.956	.769	1.300
Age (Years)	.111	1.243	.216	.484	2.068	.003	.029	.977	.484	2.068
Marital status (1= Single, 2= married/cohabiting)	-.073	-.830	.408	.495	2.021	-.092	-.958	.339	.495	2.021
Education level	.193	2.565	.011	.682	1.466	.075	.924	.357	.682	1.466
Occupation of HH (0 = other, 1= farmer)	.155	2.364	.019	.894	1.118	.217	3.047	.003	.894	1.118
HH size	-.254	-3.321	.001	.660	1.516	-.177	-2.133	.034	.660	1.516
Use of manure (0 = No, 1= Yes)	.212	3.060	.003	.807	1.239	.140	1.865	.064	.807	1.239
Mixed Farming (0 = No, 1= Yes)	.198	2.762	.006	.753	1.329	-.058	-.744	.458	.753	1.329
Intercropping (0 = No, 1= Yes)	-.326	-4.038	.000	.594	1.683	-.234	-2.680	.008	.594	1.683
Mulching (0 = No, 1= Yes)	.110	1.455	.148	.681	1.467	.156	1.910	.058	.681	1.467
Crop rotation (0 = No, 1= Yes)	.114	1.708	.089	.869	1.151	.081	1.116	.266	.869	1.151
Recycling and use of crop and animal waste (0 = No, 1= Yes)	-.081	-1.188	.236	.842	1.187	-.018	-.244	.808	.842	1.187
IPM (0 = No, 1= Yes)	-.121	-1.833	.069	.885	1.129	-.133	-1.867	.064	.885	1.129
Total land farmed (acres)	.057	.701	.484	.576	1.736	.141	1.594	.113	.576	1.736



Time (0= Baseline, 1= endline)	.004	.061	.952	.999	1.001	.025	.369	.713	.999	1.001
Model 1 Adjusted R ²	0.300					0.181				
F (14,168)	6.58					3.868				
p-value	0.000					0.000				
Model 2 Adjusted R ²	0.296					0.177				
F (15,167)	6.11					3.601				
p-value	0.000					0.000				
R2 change	0.000					0.001				
F (1, 167)	0.004					0.136				
p-value	0.952					0.713				

Table 3: Regression of yield and Partial Land Equivalence ratio of maize on AEI practices among farmers(n=78)

Model	Standardized Coefficients (β)	Collinearity Statistics				Standardized Coefficients (β)	Collinearity Statistics			
		T	p-value	Tolerance	VIF		T	p-value	Tolerance	VIF
1 (Constant)		14.658	.000			-.988	.325			
Age	.088	1.171	.244	.935	1.070	.050	.658	.512	.935	1.070
Intercropping	-.078	-.995	.321	.857	1.166	-.010	-.129	.897	.857	1.166
Soil erosion control measures	.120	1.518	.131	.849	1.178	.103	1.288	.200	.849	1.178
low soil fertility frequency	-.313	-3.640	.000	.719	1.390	-.346	-3.964	.000	.719	1.390
soil erosion frequency	-.080	-.863	.390	.623	1.604	-.037	-.397	.692	.623	1.604
labor shortage frequency	.157	2.031	.044	.887	1.128	.123	1.569	.119	.887	1.128
weeds frequency	.057	.658	.511	.709	1.410	.069	.788	.432	.709	1.410
high cost inputs frequency	-.136	-1.383	.169	.549	1.821	-.149	-1.491	.138	.549	1.821
access inputs frequency	.000	.000	1.000	.583	1.716	-.001	-.006	.995	.583	1.716
low prices frequency	.057	.510	.611	.434	2.306	.047	.416	.678	.434	2.306
limited land frequency	.211	2.417	.017	.700	1.429	.274	3.100	.002	.700	1.429
Manure application	.045	.571	.569	.861	1.162	-.026	-.321	.748	.861	1.162
Mixed farm application	-.131	-1.655	.100	.855	1.170	-.134	-1.667	.098	.855	1.170



	water harvesting application	.192	2.550	.012	.938	1.066	.179	2.338	.021	.938	1.066
2	(Constant)		13.092	.000				-.733	.465		
	Age	.087	1.151	.252	.935	1.070	.050	.651	.516	.935	1.070
	Intercropping	-.103	-1.247	.215	.785	1.273	-.016	-.186	.853	.785	1.273
	Soil erosion control measures	.146	1.758	.081	.768	1.302	.109	1.287	.200	.768	1.302
	low soil fertility frequency	-.314	-3.644	.000	.719	1.390	-.346	-3.951	.000	.719	1.390
	soil erosion frequency	-.065	-.697	.487	.609	1.642	-.034	-.359	.720	.609	1.642
	labor shortage frequency	.156	2.019	.045	.887	1.128	.123	1.561	.121	.887	1.128
	weeds frequency	.052	.599	.550	.707	1.414	.068	.771	.442	.707	1.414
	high cost inputs frequency	-.125	-1.266	.207	.543	1.842	-.147	-1.454	.148	.543	1.842
	access inputs frequency	-.004	-.040	.968	.582	1.719	-.001	-.015	.988	.582	1.719
	low prices frequency	.055	.494	.622	.433	2.307	.046	.411	.682	.433	2.307
	limited land frequency	.198	2.251	.026	.686	1.458	.272	3.028	.003	.686	1.458
	Manure application	.046	.583	.561	.861	1.162	-.025	-.318	.751	.861	1.162
	Mixed farm application	-.125	-1.574	.118	.850	1.176	-.132	-1.641	.103	.850	1.176
	water harvesting application	.208	2.701	.008	.901	1.109	.182	2.327	.021	.901	1.109
	Time (0 =baseline, 1= endline)	-.087	-1.015	.312	.733	1.364	-.019	-.215	.830	.733	1.364
	Model 1 Adjusted R ²		0.174					0.15			
	F (14,141)		3.34					2.958			
	p-value		0.000					0.001			
	Model 2 Adjusted R ²		0.175					0.144			
	F (15,140)		3.19					2.745			
	p-value		0.000					0.001			
	R ² change		0.005					0.000			
	F (1, 140)		1.03					0.46			
	p-value		0.312					0.83			



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