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Intra-Household Decision-Making and Labor Dynamics in Diversified Cereal–Legume Cropping Systems in Northern Tanzania

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Abstract

This study examined associations between two strip-cropping innovations, cereal–legume (Mbili-Mbili) and legume–legume (doubled-up legume, DUL), and intra-household decision-making, labor allocation, and control over production benefits among smallholder farmers in Babati, northern Tanzania. Household survey data were collected from 157 households using a multi-stage cluster sampling approach, capturing variation by gender, age groups, and household characteristics. Across technologies, households were predominantly male-headed (91.7%), with men comprising 71.3% of respondents and managing 66.9% of trial plots. Decision-making on production, marketing, and income use was predominantly led by men, with joint decision-making accounting for approximately 24–32% of income-related decisions. Women contributed a larger share of field labor across both systems, providing 17.7% more labor than men under Mbili-Mbili and 29.7% more under DUL. Economically, Mbili-Mbili was associated with higher average net benefits (US$731 ha^{-1}) and benefit–cost ratios (2.5) than DUL (US$213 ha^{-1}; BCR = 0.7). More than half of Mbili-Mbili participants (53.3%) reported modifying the trial design, compared with 18.4% of DUL participants; Mbili-Mbili farmers trained more non-project farmers on average (4.0 vs. 0.9) and allocated larger areas for expansion (0.5 vs. 0.3 ha). Exploratory analysis suggested descriptive associations between productivity and economic outcomes and selected household characteristics, including labor availability and education. Overall, Mbili-Mbili exhibited stronger economic performance but higher labor requirements, with women contributing disproportionately to field operations under both technologies. These findings highlight the need for gender-responsive design, labor-saving options, and inclusive decision-making arrangements to support equitable and sustainable adoption of diversified strip-cropping innovations.

Keywords: Mbili-Mbili; doubled-up legume; gender; labor allocation; intra-household decision-making

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1. Introduction

Cereal–legume intercropping has long been central to smallholder farming systems in East Africa, particularly in semi-arid environments such as Babati District in northern Tanzania, where maize (*Zea mays*) and pigeonpea (*Cajanus cajan*) underpin both food security and cash income. Conventional maize–legume arrangements (e.g., 1:1 or 2:1 row configurations) often prioritize maize at the expense of legumes, resulting in suppressed legume productivity, limited biological nitrogen fixation, and reduced dietary and income diversification [1,2]. Crop rotation has been promoted as a response to these constraints, yet its adoption remains limited among land constrained smallholders and exposes households to heightened biotic and abiotic risks during sole crop phases [3,4].

In response, a range of strip- and niche-based intercropping innovations have been developed to exploit spatial and temporal complementarity among crops while maintaining cereal yields [5,6]. In Malawi, DUL systems combines two legume species in strips to exploit differences in growth duration and resource demand [7,8]. Similarly, the MBILI system in Kenya alternates paired rows of maize with paired rows of a single legume species to improve light interception and reduce interspecific competition [9]. Building on these design principles, the pigeonpea–groundnut (*Arachis hypogaea*) or –soybean (*Glycine max*) configuration used in Malawi was adapted to pigeonpea–bean (*Phaseolus vulgaris*) combinations, while the single-legume double rows in MBILI were diversified into three rows comprising two legume species under the Mbili-Mbili system [10].

Empirical evidence indicates that these strip-cropping innovations can outperform conventional maize–legume intercrops in both agronomic and economic terms. Mbili-Mbili has been associated with stable maize yields alongside higher and more diversified legume production in Babati [10,11], while DUL systems have demonstrated high land equivalent ratios and enhanced soil fertility through increased nitrogen fixation [6,12,13]. Collectively, this evidence positions strip-cropping systems as promising options for sustainable intensification in smallholder contexts.

However, agronomic and economic performance alone does not determine the sustainability or equity of agricultural innovations. A substantial documentation of gender and household economics literature shows that technology adoption, labor allocation, and benefit distribution in smallholder systems are shaped by intra-household power relations, social norms, and control over assets and information [14,15]. Across cereal–legume systems in sub-Saharan Africa, men commonly control land, technology choice, and marketing decisions, while women contribute substantial labor but retain limited influence over production decisions and income [16]. Changes in cropping configuration may therefore affect not only yields, but also labor burdens, access to knowledge, and control over crop outputs.

Despite growing evidence on the agronomic and economic performance of Mbili-Mbili and DUL systems, little is known about how these innovations reshape the intra-household relations, particularly the labor organization, access to agronomic knowledge, and control over outputs and income. Existing studies often assume that productivity gains translate directly into household-level benefits, overlooking well-documented gendered dynamics that shape who bear the cost of labor intensification and who enjoys the benefits. This study examines how Mbili-Mbili and DUL strip-cropping systems are associated with differences in intra-household labor allocation, decision-making authority, and benefit distribution among smallholder households in Babati District, northern Tanzania. Specifically, the study examines (i) whether decision-making on production, marketing, and income differs between households implementing Mbili-Mbili and DUL; (ii) how labor burdens vary by technology, crop operation, and household size; and (iii) whether higher profitability is associated with trade-offs in labor equity and control over benefits. By addressing these

questions, the study aims to inform the design of cropping system innovations that are both productive and socially inclusive.

2. Materials and Methods

2.1. Study Area Description

This study was conducted in Babati District, of northern Tanzania, located between latitudes 3° and 4° South and longitudes 35° and 36° East (Figure 1). This area receives an average rainfall of between 750 and 1100 mm. The size of arable land in this region is gradually shrinking, leaving local farmers with a current range of 1–2 hectares in the high-rainfall midlands and 3–10 hectares in the low-rainfall lowlands (own data). Female-headed households in Babati own on average 0.7 ha lesser land holdings than male-headed households [17]. Farmers mainly produce maize, beans, and pigeonpea. Maize and beans are the common staple crops for farmer households, with excess being sold at local markets. Only 11% of total pigeonpea produced is consumed as a vegetable (during the short phase when pods are green); however, the rest is sold as dry gains in the export market [18]. Marketing of maize and pigeon is mainly carried out by men [19] while for beans, control by men is dominant in households where the primary focus of the crop is income generation [20]. Soils are dominantly Ferralsols, characterized by limitations of N and P [21] and micronutrients such as Zn and B in specific areas [22]. Loss of soil fertility is compounded by continuous cultivation with low adoption of soil conservation strategies [23]. The most common local practice encompasses the growing of single legumes (pigeonpea and common beans) as intercrops in maize-based systems [24]. Maize and pigeonpea are broadcasted on the same plough line, resulting in deep seed placement and uneven plant populations. Only 15% of farmers apply inorganic fertilizer [25].

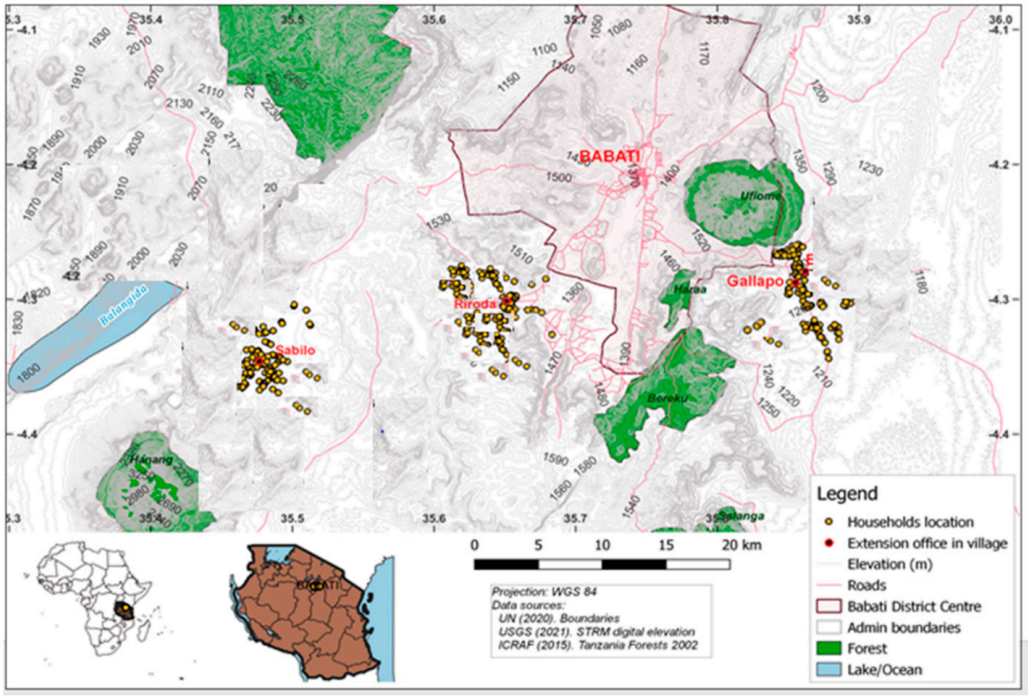

Figure 1. Map of Babati District indicating the three villages where the study was conducted.

2.2. Experimental Design and Sample Selection

In 2018, two sustainable intensification innovations, i.e., DUL and Mbili-Mbili, were developed and introduced for testing by the Africa RISING project in researcher-managed trials with the aim of addressing the low legume yields prevalent under maize–legume interactive systems. For DUL, two rows of beans at 20 cm × 10 cm were planted between

two pigeonpea rows spaced at 90 cm × 50 cm. Mbili-Mbili had a more diverse crop association with double rows of maize at 50 cm × 25 cm alternated with two rows of pigeonpea at 90 cm × 50 cm and a row of beans sneaked between the dual pigeonpea rows with an intra-row spacing of 10 cm.

In the 2019 cropping season, participatory on-farm testing of the two strip-cropping innovations was conducted in three villages (Gallapo, Riroda and Sabilo) in Babati. To capture variation across households while remaining feasible within the project budget, approximately 40 farmers were targeted per village. Farmer selection followed a multi-stage cluster sampling approach to ensure representativeness of the local maize–legume farming population. With support from village extension officers, lists of maize–legume farmers were retrieved for each village. Farmers were stratified into clusters based on household headship, sex, age group and asset ownership. Within each stratum, farmers were randomly selected in proportion to the size of the cluster, resulting in a sample that reflected the demographic and socio-economic composition of the farming population for each village. Selected farmers established one of the strip-cropping innovations on 0.1 ha plot. Seeds (maize, bean, and pigeonpea) and fertilizers were provided by the project, and farmers selected seed packages corresponding to specific strip-cropping technology they chose to test. Although farmers were randomly sampled in the study, assignment to specific strip-cropping technologies was not randomized, and comparisons across groups are therefore observational rather than causal. At the start of each cropping season, participating farmers received standardized training on the layout and management of the selected intercropping system. In the second year of implementation, demand for participation increased, and the number of farmers participating rose to approximately 50 per village.

2.3. Data Management and Analysis

2.3.1. Survey Design, Piloting and Interviews

After two seasons of technology testing, a household survey was conducted at the end of the 2020 cropping season. This survey was conducted for all households involved in testing the strip-cropping innovations. The assessment was aimed at evaluating how the introduction of Mbili-Mbili and DUL innovations affected their intra-household decision-making, labor productivity and control of benefits emanating from these innovations. Only households with an adult member (either husband, wife, or adult child) directly involved in the management of the trials were individually interviewed. To provide a benchmark for prevailing farmer practices, a randomly sampled observational comparison group of 44 non-participating farmers was included during the household survey (Table 1). These farmers were randomly sampled from the rest of farmers who did not participate in trial testing and excluded immediate neighbors of trial participants, to minimize spillover effects. The group had not received project inputs, training, or field-level engagement and represent existing maize–legume intercropping practices of the study area. The group was targeted during the survey to provide insights into gendered decision-making in conventional field management.

Table 1. Sample size selection for DUL, Mbili-Mbili and control farmers in Babati, Tanzania.

Village	DUL	Mbili-Mbili	Control	Across Trial
Gallapo	10 (17.9)	34 (60.7)	12 (27.3)	56 (100)
Riroda	9 (21.4)	18 (42.9)	15 (34.1)	42 (100)
Sabilo	19 (32.2)	23 (39)	17 (38.6)	59 (100)
Across villages	38 (24.2)	75 (47.8)	44 (20.4)	157 (100)

Values are arranged as the number of farmers and their proportion in parentheses.

For the survey, an assessment tool was developed to capture the farmer households' composition and characteristics, type of technology implemented, type and amount of inputs applied, amount of labor invested, number of other farmers trained, and participation in farmer groups. To understand the gendered effects of introduced technologies on participating households, 16 decision-making variables were generated, i.e., who in the household made the choice of technology to test, decided on land area allocation for the trial, re-designed the technology, decided on time and method of land preparation, fertilizer application, weeding, pest and disease management, and harvest, and controlled the benefits. In addition, sources of labor for planting, weeding, pest and disease control, harvest, and post-harvest management were assessed.

Recall data on attained yields, quantity sold, farm-gate prices and total variable cost of each intercropping component were recorded and used to calculate benefits derived from each cropping system. The tool and data collection procedures were reviewed and approved by the relevant Institutional Review Board (Africa RISING—2020-IRB14). Prior to the survey, the tool was pretested with households not included in the final sample to refine question clarity and administration procedures [26]. Interviews were conducted by trained enumerators who adhered to established ethical protocols for social research. Informed consent was obtained from all participants prior to each interview after respondents were briefed on the objectives of the study, their voluntary participation and their right to decline participation or refuse to answer any question without penalty. To safeguard confidentiality, no personal identifiers were recorded, and all responses were anonymized during analysis. Interviews were conducted in private settings within or near the homestead to minimize influence from other household members. To enhance gender sensitivity, the enumeration team comprised both male and female enumerators, and respondents were interviewed by enumerators of the same sex.

2.3.2. Data Analysis and Management

Socio-economic characteristics and intra-household decision-making

Group differences in baseline categorical characteristics were assessed using Fisher's exact test for categorical variables, while continuous variables were compared using one-way ANOVA or the Kruskal–Wallis test where assumptions were violated. To account for multiple comparisons across baseline characteristics, the Benjamini–Hochberg procedure was applied to control false discovery rate at 5%. Farmers implementing Mbili-Mbili and DUL were characterized to identify the household attributes and dynamics shaping who make key agricultural decisions. These characteristics were examined because intra-household decision-making and labor allocation are shaped by access to land, education, and social capital, which influences those who control production choices and benefits. Correspondence analysis (CA) was used to examine how different household members participate in decisions across a range of farm activities under DUL and Mbili-Mbili [27]. This analysis explicitly explored how decision-making authority is distributed within households, using the R version 4.5.1 software and package 'ca' to investigate decisions around control of crop derived incomes by four categories of household decision-makers (household head, spouse, household head + spouse and other household members). The multivariate approach allowed visualization of patterns in decision authority related to production, labor and income management.

Labor use and productivity

Data relating to labor sources were summarized to identify the major contributors to key farm operations, with labor input disaggregated by household membership to reflect intra-household decision outcomes. The proportion of labor contributed by each household category was calculated for all major field activities.

Labor requirements were estimated as the product of the number of persons involved and the time required to complete each task, expressed in man-hours ha^{-1}. Total labor demand was calculated by summing inputs for field preparation, planting, weeding, and harvesting. Continuous variables, including labor contributions and labor requirements, were analyzed using one-way ANOVA to compare differences across household member categories. To assess the implications for farm performance, two-way ANOVA models were used to examine differences between cropping systems and household headship in proportions of produce sold, timing of crop sales, maize equivalent yields, and net economic benefits.

Cropping system profitability

The profitability of cropping systems was estimated as the difference between the total variable costs (TVC) and revenues, using village-specific input and output prices. Total variable costs comprised expenses related to land preparation, purchase of inputs (fertilizers and seed), and farm operations including planting, weeding, pest management, harvesting and post-harvest handling. Labor costs were estimated based on recall interviews with local agricultural officers at each site to reflect prevailing wage rates during the production season. Input prices were obtained from local agro-dealers while output prices were based on farm-gate prices at harvest. The costing framework is consistent with previously validated methods for the same study area and cropping systems [10], which explicitly account for spatial and inter-annual price variability. Yields of crops other than maize were converted to maize equivalent yields to enable comparability of production gains across crops following Anjeneyulu et al. [28] (Equation (1)).

$$\mathrm{MEY}\left(\mathrm{tha}^{-1}\right) = \mathrm{Y}_{\mathrm{maize}} + \mathrm{Y}_{\mathrm{bean}} \times \frac{\mathrm{P}_{\mathrm{bean}}}{\mathrm{P}_{\mathrm{maize}}} + \mathrm{Y}_{\mathrm{pigen\ pea}} \times \frac{\mathrm{P}_{\mathrm{pigeon\ pea}}}{\mathrm{P}_{\mathrm{maize}}} \quad (1)$$

where MEY was the maize equivalent yield, Y is grain yields and P is the prevailing prices in the local markets. This conversion provides an economic measure of output comparability but does not account for differences in nutritional value (e.g., protein content) or food security contributions across crops.

2.3.3. Socio-Economic Factors Influencing Cropping System Productivity

A multiple linear regression model was conducted using 'glm' procedures to explore associations between socio-economic predictors, MEY and economic parameters. Net benefits of the two systems were regressed against variables describing household characteristic and field management activities (Equation (2)) with predictor definitions provided in Table 2.

$$\mathrm{y_i} = \beta_o + \beta_{1xi1} + \beta_{2xi2} + \beta_{3xi3} + \cdots + \beta_{pxip} + \epsilon \quad (2)$$

where y_i = dependent variable, xi = explanatory variables. B_0 = y-intercept (constant term), βp = slope coefficients for each explanatory variable, and ϵ = the model's error term. Categorical predictors were included as factor variables in the model using dummy coding. Reference categories were defined as follows: education (below primary), household type (male-headed), marital status (not married), group membership (yes) and agricultural training (yes).

Given the large number of potential predictor–outcome combinations (n = 55) relative to the available sample size (n = 75 with 11 candidate predictors), linear regression analyses were implemented within an exploratory framework. To reduce risks of overfitting and inflated Type I error, model robustness was assessed using least absolute shrinkage and selection operator (LASSO) regularization. Penalized regression models were estimated using cross-validation, and conservative model selection was based on the one-standard-error (λ_1SE) criterion to evaluate predictor stability under constrained sample sizes. In addition, the regression analysis was not intended to estimate causal effects. Several covariates, such

as the number of farmers trained and scale-up area, represent post-adoption outcomes and may be endogenous to unobserved household characteristics (e.g., motivation, wealth, or social capital). These variables were therefore included for exploratory purposes only, and coefficients are interpreted descriptively rather than causally.

Table 2. Description of regression model parameters for assessment of intra-household decisions in smallholder systems in Babati.

Variables	Variable Descriptions	Variable Types	Measurement Units and Response Categories
Independent variables			
Trial maize yield	Maize yield from trial fields	Numeric	ton ha^{-1}
Trial bean yield	Bean yield from trial fields	Numeric	ton ha^{-1}
Trial pigeonpea yield	Pigeon pea yield from trial fields	Numeric	ton ha^{-1}
Net benefit	Net revenue from innovation	Numeric	US$ ha^{-1}
MEY	Maize equivalent yields	Numeric	ton ha^{-1}
Dependent variables			
Education	Education of household head	Binary	0 = Below primary level, 1 = above primary level
Household type	Type of household	Binary	1 = Male-headed, 0 = female-headed
Group membership	Member of agricultural group	Binary	1 = Yes, 0 = No
Agriculture training	Attended agriculture training	Binary	1 = Yes, 0 = No
Marital status	Marital status of household head	Binary	1 = Married, 0 = not married
Farm size	Total farm size of household	Numeric	Hectare (ha)
Household size	Total members of household	Numeric	-
Age	Age of household head	Numeric	Years
Total farm labor	Total labor for farm operations	Numeric	Man-hours ha^{-1}
Number of farmers trained	Number of other farmers each participant trained	Numeric	-
Expansion area	Intended scale area for innovation	Numeric	Hectare (ha)

2.3.4. Limitations of the Study

This study is subject to several limitations. Economic data on yields, prices, and costs were collected retrospectively at the end of the season and were not independently triangulated using receipts or market transaction records. Although village-specific farm-gate and input prices were used, short-term temporal price fluctuations within seasons and across markets were not explicitly modelled, which may have introduced uncertainty in estimated profitability. Sample size constraints, within the DUL technology group, limited statistical power and precluded robust subgroup and multiple analyses; consequently, observed differences are interpreted descriptively rather than as confirmatory tests. The number of predictors relative to sample size further constrained regression analyses, and LASSO regularization indicated insufficient power to identify stable associations, leading to results being treated as exploratory and hypothesis-generating. In addition, reliance on self-reported data for labor allocation, decision-making roles, and farmer perceptions might have introduced recall or social desirability bias. Finally, the cross-sectional nature of the study captures short- to medium-term responses to newly introduced technologies and does not reflect longer-term adoption dynamics or changes in intra-household relations, underscoring the need for longitudinal studies with larger and more balanced samples.

3. Results

3.1. General Characteristics of the Sample Population

The analytical sample comprised households that either implemented Mbili-Mbili or DUL innovation or were selected as non-participant controls. In total, 157 farmers

were included in the analysis, consisting of 38 farmers (24.2%) who tested DUL system, 75 farmers (47.8%) who tested Mbili-Mbili and 44 farmers (28%) who served as a comparison group. An additional 12 farmers received project input and participated in training but did not establish the trial plots. These households were contacted solely to document reasons for non-implementation and were excluded from all analyses requiring trial experience. Reported reasons for non-implementation included delayed access to inputs (n = 4), lack of time (n = 4), inadequate technical understanding (n = 2) and competing labor demands on other plots (n = 1). One farmer reported adopting a 'wait and see' approach, preferring to observe trial performance in other farmers' fields before implementation.

Eighty-four percent of the comparison group reported using certified maize seeds while the remainder recycled seeds from the previous harvest. Their planting method involved broadcasting seeds behind ox-drawn (72%), or tractor-drawn ploughs (25%), and only one farmer adhered to recommended plant spacing. Inorganic fertilizers were applied by 3% of comparison farmers, whereas 59% used animal manure; only 9% applied both fertilizer and manure.

3.2. Socio-Economic Characteristics of Participant Households

Household socio-demographic characteristics were largely comparable across technology implementation groups (Table 3). After correction for multiple comparisons across 11 baseline variables, only farming experience differed significantly among groups (adjusted $p = 0.04$). Control farmers reported the most farming experience (27.3 years) followed by Mbili-Mbili (21.7 years) and DUL implementers (19.1 years). All other socio-demographic characteristics showed no statistically significant differences after multiple testing correction (at $p = 0.05$). Across the technologies, men constituted most respondents (71.3%) and households were predominantly male-headed (91.7%). Education transition was generally low, with 85% of households having attained at most primary-level education.

Table 3. Socio-economic characteristics of farmers who tested DUL and Mbili-Mbili technologies against a control group in Babati, Tanzania.

Variables and Response Categories		Technology			Across Technology	Fisher's Exact Test (*p*-Value)	H-B Adjusted *p*-Value
		DUL	Mbili-Mbili	Control			
No. of farmers		38	75	44	157	-	-
Gender	Female	16 (42.1)	20 (26.7)	9 (20.5)	45 (28.7)	0.08	0.29
	Male	22 (57.9)	55 (73.3)	35 (79.5)	112 (71.3)		
Headship	Female-headed	3 (7.9)	7 (9.3)	3 (9.4)	13 (8.3)	0.93	0.93
	Male-headed	35 (92.1)	68 (90.7)	41 (90.6)	144 (91.7)		
Plot manager	Female-managed	17 (44.7)	19 (25.3)	12 (37.5)	48 (33.1)	0.10	0.28
	Male-managed	21 (55.3)	56 (74.7)	20 (62.5)	97 (66.9)		
Age of HHH		42.2 ± 2.4	45.4 ± 1.6	53.1 ± 2.8	46.2 ± 1.2	0.02	0.09
Marital status	Married	31 (81.6)	63 (84.0)	42 (95.5)	136 (86.6)	0.10	0.22
	Not married	7 (18.4)	12 (16.0)	2 (4.5)	21 (13.4)		
Education	Up to primary	33 (86.8)	62 (82.7)	40 (90.9)	135 (86.0)	0.53	0.58
	Above primary	5 (13.1)	13 (17.3)	4 (9.1)	22 (14.0)		
Group member	No	29 (78.4)	50 (66.7)	10 (83.3)	89 (71.8)	0.35	0.48
	Yes	8 (21.6)	25 (33.3)	2 (16.7)	35 (28.2)		
Attend trainings	No	23 (60.5)	39 (52)	8 (53.3)	70 (54.7)	0.42	0.51
	Yes	15 (39.5)	36 (48)	7 (56.7)	58 (45.3)		
Household size		6.3 ± 0.4	6.6 ± 0.3	7.7 ± 0.5	6.8 ± 0.2	0.13	0.24
Farm size (ha)		1.6 ± 0.2	2.1 ± 0.3	1.9 ± 0.2	1.9 ± 0.2	0.28	0.44
Farming experience (yrs)		19.1 ± 2.0	21.7 ± 1.6	30.2 ± 2.6	22.6 ± 1.1	0.00	0.04 *

HHH represents household head, H-B represents Benjamini–Hochberg procedure. For categorical variables, values are arranged as frequencies and column percentages (in parentheses). Continuous variables are presented as means ± standard error of means and statistically compared using one-way ANOVA or the Kruskal–Wallis test. * Represent significance at adjusted $p = 0.05$.

3.3. Intra-Household Decision-Making and Control

Decision-making patterns showed similar gender dynamics across technology groups, with husbands most frequently reported as primary decision-makers for most field management activities (Table 4). In DUL households, husbands accounted for 29.0–65.8% of decisions across field activities, compared with 46.9–73.2% in Mbili-Mbili households. Involvement of their female spouses ranged from 10.5 to 36.7% in DUL systems and from 8.2 to 25.0% under Mbili-Mbili, while joint husband–wife decision-making represented a substantial share of decisions in both systems (up to 31.6% in DUL and 28.2% in Mbili-Mbili), particularly for decisions related to the use of income from crop sales.

Table 4. Household decision-making on field management activities conducted under DUL and Mbili-Mbili in Babati, Tanzania.

Decision-Making Variable	DUL (n = 38)				Mbili-Mbili (n = 75)			
	Husband	Wife	Husband + Wife	Other HH Members	Husband	Wife	Husband + Wife	Other HH Members
Choice of technology	14 (36.8)	10 (26.3)	3 (7.9) *	11 (28.9)	44 (60.3)	10 (13.7)	8 (11.0)	11 (15.1)
Land area allocation	25 (65.8)	6 (15.8)	5 (13.2)	2 (5.3) *	49 (67.1)	8 (11.0)	14 (19.2)	2 (2.7) *
Time and method of top dressing	-	-	-	-	38 (70.4)	6 (11.1)	8 (14.8)	2 (3.7) *
Land preparation method	25 (65.8)	6 (15.8)	4 (10.5) *	3 (7.9) *	47 (64.4)	6 (8.2)	16 (21.9)	4 (5.5) *
Labor source for planting	25 (65.8)	12 (31.6)	1 (2.6) *	0 (0.0) *	52 (71.2)	7 (9.6)	9 (12.3)	5 (6.8)
When to weed	24 (64.9)	12 (32.4)	1 (2.7) *	0 (0.0) *	51 (69.9)	10 (13.7)	9 (12.3)	3 (4.1) *
Labor source for weeding	23 (62.2)	13 (35.1)	1 (2.7) *	0 (0.0) *	52 (71.2)	9 (12.3)	9 (12.3)	3 (4.1) *
Time to harvest beans	16 (53.3)	11 (36.7)	2 (6.7) *	1 (3.3) *	15 (46.9)	8 (25.0)	7 (21.9)	2 (6.3) *
Labor source for harvesting beans	16 (53.3)	11 (36.7)	2 (6.7) *	1 (3.3) *	19 (59.4)	5 (15.6)	6 (18.8)	2 (6.3) *
Time to harvest maize	-	-	-	-	52 (73.2)	8 (11.3)	10 (14.1)	1 (1.4) *
Labor for harvesting maize	-	-	-	-	51 (71.8)	9 (12.7)	9 (12.7)	2 (2.8) *
Time to harvest pigeonpea	19 (59.4)	10 (31.3)	3 (9.4) *	0 (0.0) *	38 (64.4)	11 (18.6)	9 (15.3)	1 (1.7) *
Labor source for harvesting pigeonpea	9 (29.0)	9 (29.0)	8 (25.8)	5 (16.1)	41 (69.5)	7 (11.9)	9 (15.3)	2 (3.4) *
Decision on spending pigeonpea income	19 (50.0)	5 (13.0)	12 (31.6)	2 (5.3) *	36 (51.4)	11 (15.7)	19 (27.1)	4 (5.7) *
Decision on spending beans income	17 (44.7)	6 (15.8)	12 (31.6)	3 (7.9) *	36 (51.4)	12 (17.1)	17 (24.3)	5 (7.1)
Decision on spending maize income	17 (44.7)	4 (10.5) *	12 (31.6)	5 (13.2)	35 (49.3)	14 (19.7)	20 (28.2)	2 (2.8) *

Values arranged as frequencies and row percentages calculated based on effective responses (in parentheses). Percentages are row-based within each technology group. Cells with * represent cases where $n < 5$ and should be interpreted with caution. Dashes (-) indicate activities not applicable to DUL technology.

Clear differences were evident for specific activities. For example, decisions on labor for harvesting pigeonpea were evenly shared between husbands and wives in DUL households (29%), whereas in Mbili-Mbili households, these decisions were predominantly made by husbands (69.5%), with wives accounting for 11.9%. Decisions on the use of income from pigeonpea, beans, and maize followed similar patterns across both technologies, with husbands making 44.7–50.0% of decisions, joint decisions accounting for 24.3–31.6%, and wives contributing 10.5–17.1%.

Across the study sample, at least 34% of households reported selling their crop produce, with maize accounting for the highest proportion of sales, followed by pigeonpea and beans (Figure 2a). Sales typically happened soon after harvest, with 58% of maize-selling households, 83% of bean-selling households and 88% of pigeonpea-selling households selling their produce within one month of harvest (Figure 2b). Decision-making over crop sales was predominantly led by men. Male household heads were most frequently

reported as the primary decision-makers on the quantities sold (47%) and participation in produce sales (69%), although joint decision-making between spouses was also observed (Figure 2c). On the contrary, income control patterns indicates that decisions over income derived from maize and pigeonpea sales were largely concentrated with men, either individually or jointly with women, whereas income from bean sales showed relatively greater involvement of women (Figure 2d).

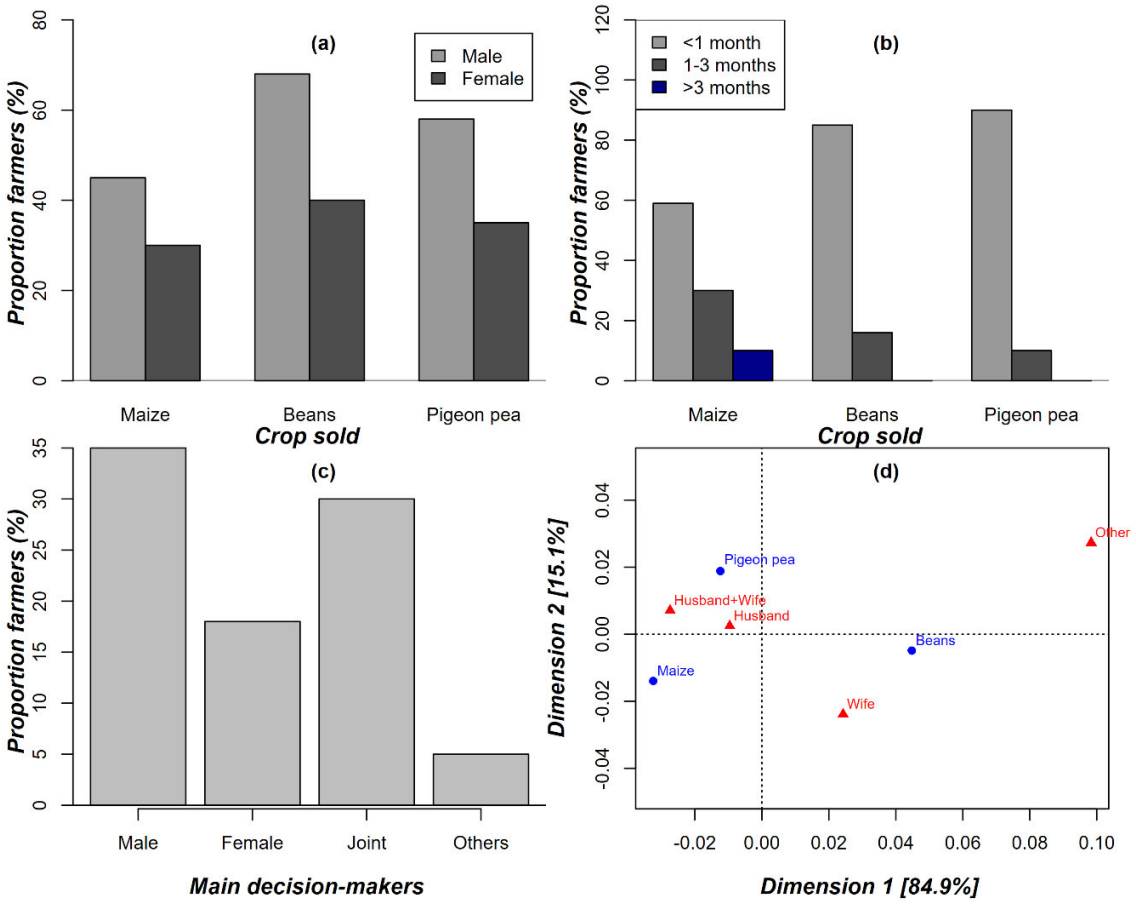

Figure 2. Intra-household decision-making related to crop sales, showing (**a**) gender of decision-makers by crop, (**b**) timing of crop sales after harvest, (**c**) main household decision-makers and (**d**) control over income derived from maize, bean and pigeonpea sales.

3.4. Technology Adaptation and Scaling Behavior by Household

Economic outcomes are reported for systems implemented by farmers, including adaptive modifications to reflect real-world performance rather than strict adherence to prescribed designs. Consistent with this, Mbili-Mbili participants were more likely to modify the original trial design than those testing DUL, with 53.3% reporting modifications compared with 18% of DUL households (Table 5). The reported modifications included the omission of one or more component crops, adjustment of legume row configurations, substitution with alternative crop species, and in a small number of cases, conversion of DUL plots to Mbili-Mbili. Among Mbili-Mbili adopters, who omitted beans, a substantial proportion substituted them by alternating double maize rows with two rows of pigeonpea.

Scaling and knowledge-sharing behaviors also differed across technologies. On average, Mbili-Mbili participants trained more non-project farmers (mean = 4) than DUL participants (mean = 0.9) and committed larger areas of land for expansion (0.5 ha versus 0.3 ha, respectively). Trial plots under Mbili-Mbili were also located closer to homesteads,

on average, which may reflect greater management intensity due to the perceived importance of the innovation.

Table 5. DUL, Mbili-Mbili and conventional systems implementation characteristics by farmers in Babati, Tanzania.

Variables	Response Categories	Technology		Across Technology
		DUL	Mbili-Mbili	
Who received farm inputs?	Husband	19 (50.0)	59 (78.7)	78 (69.0)
	Wife	14 (36.8)	14 (18.7)	28 (24.8)
	Husband + wife	1 (2.6) *	1 (1.3) *	2 (1.8) *
	Other HH member	4 (10.5) *	1 (1.3) *	5 (4.4)
Planted bean in trial	Yes	37 (97.4)	46 (61.3)	83 (73.5)
	No	1 (2.6) *	29 (38.7)	30 (26.5)
Bean phases planted in trial	One phase	32 (86.5)	37 (80.4)	69 (83.1)
	Two phases	5 (13.5)	9 (19.6)	14 (16.9)
Planted bean in conventional system	Yes	21 (55.3)	45 (60.0)	66 (58.4)
	No	17 (44.7)	30 (40.0)	47 (41.6)
Planted pigeonpea in trial	Yes	34 (89.5)	64 (85.3)	98 (86.7)
	No	4 (10.5) *	11 (14.7)	15 (13.3)
Planted pigeonpea in conventional system	Yes	34 (89.5)	49 (65.3)	83 (73.5)
	No	4 (10.5) *	26 (34.7)	30 (26.5)
Who owns land under technology?	Husband	24 (64.9)	49 (69.0)	73 (67.6)
	Wife	4 (10.8) *	6 (8.5)	10 (9.3)
	Husband + wife	5 (13.5)	15 (21.1)	20 (18.5)
	Other HH member	4 (10.8) *	1 (1.4) *	5 (4.6)
Soil status under technology	Very fertile	2 (5.3) *	6 (8.0)	8 (7.1)
	Moderately fertile	26 (68.4)	51 (68.0)	77 (68.1)
	Less fertile	8 (21.1)	15 (20.0)	23 (20.4)
	Infertile	2 (5.3) *	3 (4.0) *	5 (4.4)
Whether the trial was modified	Yes	7 (18.4)	40 (53.3)	47 (41.6)
	No	31 (81.6)	35 (46.7)	66 (58.4)
Trial plot distance from homestead (km)		1.3 ± 1.5	0.9 ± 1.0	-
Number of farmers trained		0.9 ± 1.5	4.0 ± 11.9	-
Scale area (ha)		0.3 ± 0.3	0.5 ± 0.4	-

For categorical variables, values are arranged as frequencies followed by column percentages. Continuous variables are presented descriptively; group comparisons are not the focus of this table. Cells with * represent cases where $n < 5$ and should be interpreted with caution.

3.5. Labor Requirements and Gendered Contributions Across Cropping Systems

Implementing Mbili-Mbili system required substantially higher total farm labor than DUL and conventional systems, with labor inputs approximately 30% higher than DUL and 36% higher than conventional maize–legume systems (Figure 3). This aligns with farmers' estimates of an average increase of 38% in labor requirements under Mbili-Mbili relative to conventional intercrops. The higher labor demand reflects the increased complexity of Mbili-Mbili, particularly during land preparation and planting, which required up to four times more labor than the conventional maize–pigeonpea system, as well as moderately higher labor for weeding (29%). A similar pattern was observed for DUL, where establishment required substantially more labor for planting (approximately threefold) and modestly higher labor for weeding (16%) compared with conventional bean monoculture.

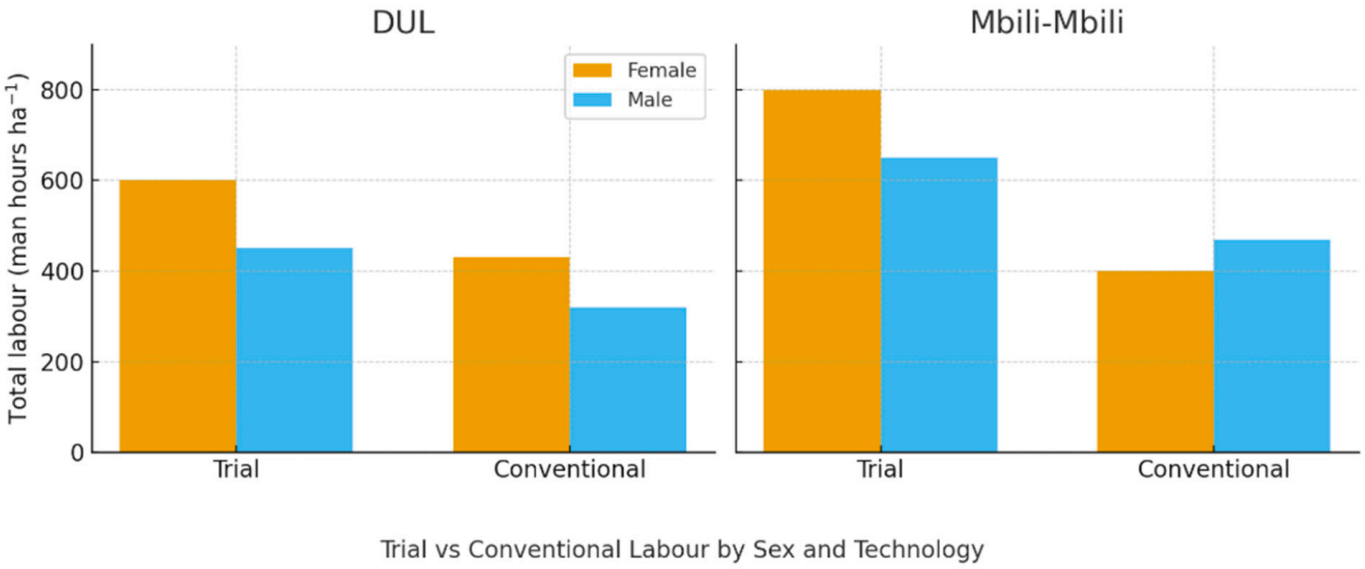

Figure 3. Labor contributions of male and female household members during implementation of DUL and Mbili-Mbili innovations.

Analysis of labor contributions by household members revealed clear gendered patterns. Across the participants, women contributed more (17.7%) labor than men under Mbili-Mbili and 29.7% more under DUL. In households testing DUL, women also contributed 25.6% more labor than men under conventional bean monoculture, whereas in households testing Mbili-Mbili, men contributed 10.3% more labor than women under conventional maize–legume systems.

Perceptions of labor burden did not always align with measured labor inputs. While 36% of participants perceived that additional labor associated with Mbili-Mbili would primarily affect women, a larger share (44%) indicated that men would experience increased drudgery.

3.6. Household Decisions Related to Crop Produce Sales

Descriptive analyses suggest that Mbili-Mbili fields achieved higher average profitability (US$731 ha^{-1}) and benefit–cost ratios (2.5) than DUL fields (US$213 ha^{-1}; BCR = 0.7). Mbili-Mbili net benefits showed positive directional associations with education level above primary (β = 413.5), scale-up area (β = 211.5), household size (β = 114.2), and total farm labor (β = 0.5; Table 6). Notably, these associations were not robust to LASSO regularization (Appendix A) with conservative parameter selection (λ-1se), which eliminated all predictors, indicating that the study was underpowered to identify reliable relationships given the number of candidate predictors (11) relative to sample size (n = 75 for Mbili-Mbili). Similarly, MEY showed positive directional associations with household size (β = 225.7), number of farmers trained (β = 200.1), and education level (β = 873.5). The influence of these socio-economic factors appears to operate indirectly through effects on intercrop component yields rather than as independent drivers.

For DUL, regression analyses revealed no consistent socio-economic patterns, with all coefficients small in magnitude. This may reflect both the smaller DUL sample size (n = 38) and the limited responsiveness of the legume system to household-level characteristics, though the smaller sample precluded meaningful regression analysis with 11 predictors.

Table 6. Exploratory regression coefficients for farm characteristics and crop outcomes.

Parameters	Maize Yield	Bean Yield	Pigeonpea Yield	Mbili-Mbili Net Benefits	MEY
	β (SE)	β (SE)	β (SE)	β (SE)	β (SE)
(Intercept)	−0.825 (1.374)	0.071 (0.440)	0.501 (0.508)	−626.3 (620.4)	−690.0 (1349.8)
Education: Below primary	0.517 (0.522)	0.254 (0.188)	0.017 (0.257)	413.5 (238.8)	873.5 (630.7)
Household type: Male-headed	0.405 (0.963)	−0.186 (0.302)	0.125 (0.351)	−212.5 (441.8)	−419.1 (941.2)
Number of farmers trained	0.107 (0.047)	−0.009 (0.016)	0.009 (0.023)	53.9 (21.8)	200.1 (63.3)
Scale-up area	−0.026 (0.257)	0.179 (0.077)	0.109 (0.114)	211.5 (117.8)	400.0 (285.8)
Group membership: Yes	0.593 (0.505)	−0.083 (0.164)	0.067 (0.205)	236.8 (231.4)	419.5 (557.9)
Agriculture training: Yes	0.177 (0.466)	0.115 (0.144)	0.258 (0.184)	142.1 (212.6)	545.3 (491.6)
Marital status: Not married	0.518 (0.736)	−0.029 (0.314)	−0.424 (0.313)	303.8 (334.7)	208.8 (810.0)
Farm size	−0.020 (0.038)	−0.010 (0.016)	0.011 (0.018)	−19.1 (17.4)	−13.3 (49.3)
Household size	0.211 (0.086)	0.031 (0.036)	−0.043 (0.040)	114.2 (39.0)	225.7 (102.9)
Age	0.014 (0.018)	−0.012 (0.007)	−0.006 (0.008)	5.6 (7.4)	−3.8 (21.2)
Total farm labor	0.001 (0.001)	0.000 (0.000)	0.001 (0.000)	0.5 (0.3)	2.0 (0.8)
R^2	0.271	0.411	0.157	0.315	0.244
Adjusted R^2	0.092	0.235	0.005	0.152	0.132

MEY represents maize equivalent yields of the three crop species under Mbili-Mbili; β are the coefficients and SE the standard errors.

4. Discussions

This study demonstrates that the performance, uptake, and scaling potential of cropping system innovations are shaped not only by their agronomic and economic characteristics but also by labor requirements, intra-household decision-making dynamics, and farmers' capacity to adapt technologies to local contexts. Across both Mbili-Mbili and DUL systems, household socio-demographic characteristics were broadly similar, suggesting limited selection bias in participation. However, clear differences emerged in how households allocated labor, made decisions, modified technologies, and shared benefits, underscoring the importance of integrating social dimensions into the design and evaluation of sustainable intensification strategies.

4.1. Gendered Decision-Making and Implications for Technology Adoption

The study generates evidence that intra-household decision-making plays an important role in shaping how smallholder households engage with agricultural innovations, influencing the allocation of land, labor and control over benefits. Across both cropping systems, husbands were most frequently reported as primary decision-makers for many production and income-related decisions, although joint decision-making between spouses was also common for several activities. Women's involvement tended to be more pronounced in specific field operations, particularly under the legume-based DUL system, but this involvement did not consistently translate into control over income from crop sales, reflecting a persistent gender gap between labor contribution and benefit capture. This disconnect was reflected in farmers' own accounts, as one female participant implementing Mbili-Mbili explained, "*I do most of the weeding and harvesting, especially beans, but when it is time to sell maize or pigeonpea, the decision is not mine*". The concentration of crop sales within one month of harvest also suggests that marketing decisions were largely driven by immediate liquidity and food security needs rather than strategic market timing, a context

that may further concentrate decision-making authority and constrain women's influence on income use.

The stronger preference for Mbili-Mbili among men is consistent with gender-and-technology adoption theory, which shows that control over agricultural innovations tends to align with crops that generate higher market returns and require greater capital and land investment. As production systems become more commercialized, men often assert greater decision-making authority over crop choice and income use, particularly in contexts where land ownership and access to markets are male-dominated. This pattern reflects broader intra-household bargaining dynamics in which control over assets and cash-oriented enterprises shapes technology adoption and benefit capture [29–32]. In contrast, DUL offered relatively greater space for women's participation in labor-related decisions, particularly for legume management, although this did not substantially alter income control. These patterns underscore how innovations may either reinforce or modestly shift gender dynamics without deliberate design for equity [33,34].

These outcomes are embedded within broader structural constraints that disproportionately affect women, including limited access to land, inputs, credits, information, and markets [35]. Higher participation of men in technology testing, reflecting prevailing norms around land ownership and decision-making in many smallholder systems, which may bias adoption toward technologies that prioritize monetary returns over labor-saving or food security objectives [36,37]. To enhance gender-responsiveness, interventions need to account explicitly for intra-household decision-making patterns and address barriers that limit women's access to productive resources and control over benefits. Integrating gender considerations across multiple dimensions of sustainable intensification is therefore essential, to ensure that agronomic interventions contribute equitably to productivity and livelihoods [38–41].

4.2. Labor Requirements, Gendered Contributions, and Implications for Adoption

Labor demands are a critical determinant of technology uptake and scalability among smallholder farmers, particularly where household labor is constrained and access to mechanization services is limited. This challenge is often more pronounced for women, who balance agricultural work with domestic responsibilities. The introduction of labor-intensive technologies can therefore pose adoption challenges, especially if additional labor requirements fall unevenly within households. In this study, both Mbili-Mbili and DUL were labor-intensive at establishment, reflecting the use of hand hoes and precision spacing during planting, which demands substantially more labor per unit area. This contrasts with the conventional practice where maize and pigeonpea are sown by broadcasting behind animal- or tractor-drawn ploughs [41]. Farmers described conventional practice as less laborious and more time-efficient, which may influence their relative attractiveness.

Perceptions of labor burden did not fully align with measured labor inputs. While a substantial share of respondents perceived that increased labor under Mbili-Mbili would primarily affect women, others anticipated greater impacts on men, highlighting differences between perceived and observed labor allocation. This divergence underscores the importance of combining quantitative labor assessments with intra-household perceptions when evaluating the gender implications of labor-intensive innovations. Consistent with evidence across SSA showing that women contribute a large share of agricultural labor despite limited access to productive resources [42], labor-intensive systems such as Mbili-Mbili, while economically attractive and offering climate-resilience benefits [10], may face adoption constraints if labor requirements are not addressed. Expanding access to labor-saving inputs, mechanization services, markets and credit, alongside deliberate integration

of crops commonly managed by women (i.e., cowpea (*Vigna unguiculata*) and beans), could help mitigate labor constraints and support more equitable adoption outcomes.

In response to these labor constraints, farmers seemed to have tried active adaptation of the innovations to better fit their resource availability, management preferences, and production objectives. The higher frequency of trial modification observed among Mbili-Mbili adopters suggests that households adjusted the system in ways that balanced labor demands, food preferences, and market orientation. Selective omission of beans and adjustments on crop configuration indicate that labor requirements played a central role in shaping these adaptations, with pigeonpea showing greater continuity between trial and conventional systems than beans. Such adaptive behavior is consistent with participatory innovation processes, where farmers experiment with and refine technologies rather than adopt them whole; as one male Mbili-Mbili implementing farmer indicated, "*Planting beans together with maize looked good at first, but when labor became tight, I preferred to keep only pigeonpea because it stays longer in field and later gives both food and cash*." The higher levels of peer-to-peer training and larger scale-up areas associated with Mbili-Mbili further point to strong social learning and dissemination dynamics, highlighting how labor pressures interact with farmer agency to shape the scaling of complex, multi-crop systems. The training of non-project farmers was not a planned extension activity but arose from voluntary farmer-to-farmer interactions and is therefore an indicator of informal diffusion rather than an intrinsic characteristic of the technology.

4.3. Socio-Demographic Factors Affecting Cropping System Productivity

Patterns observed across cropping systems suggest that productivity and economic performance are closely linked to household socio-demographic characteristics, particularly household size, access to social capital, and the ability to mobilize farm labor. The higher profitability observed for Mbili-Mbili among some households is consistent with the labor-intensive nature of the system, which requires timely operations such as planting and weeding. Larger households tend to have greater access to family labor, and higher food requirements, factors that may encourage experimentation with labor-demanding but potentially more productive options such as Mbili-Mbili [43].

Beyond household structure, individual farmer characteristics such as age, experience, and education appear to shape adoption and performance patterns. Older farmers may combine greater farming experience, longer exposure to agricultural training and higher decision-making autonomy, which can influence their engagement with new technologies [44]. Similarly, higher education levels are often associated with improved capacity to access, interpret, and apply agronomic information, contributing to more effective implementation of complex practices [45,46]. The positive association between increased crop yields and the number of 'other' farmers trained further suggests that peer-to-peer learning may reinforce farmers' technical skills and confidence, supporting wider acceptance of Mbili-Mbili as a productive cropping option [47].

4.4. Challenges, Adaptations and Gaps in Intra-Household Decision-Making Around Mbili-Mbili and DUL

Farmers' engagement with new agricultural technologies is shaped by their need to address pressing food security, generate income and manage potential production risks under constrained resource conditions. Following the introduction of Mbili-Mbili and DUL, a substantial share of participants adapted the original designs, most notably through selective omission or substitution of component crops. Beans were more frequently omitted than pigeonpea, reflecting perceived trade-offs related to labor requirements, yield expectations, food preferences and market orientation [48]. Such perceptions are likely

influenced by prior farmer experience and prevailing norms, rather than by trial outcomes alone. This underscores the role of subjective evaluation in shaping technology use.

These adaptation patterns intersect with intra-household decision-making structures and gendered crop norms. Control over land and technology choice was predominantly exercised by men, consistent with broader patterns of land ownership and authority in smallholder systems. Crops associated with higher market value tended to attract greater male involvement, while legumes such as beans, often managed by women, were more likely deprioritized or modified within diversified systems. This aligns with evidence showing differential adoption of improved crop technologies along gendered lines, where uptake of improved bean varieties remains low compared with maize [49,50].

Farmers demonstrated active agency in refining the technologies to better fit their circumstances. The higher frequency of trial modification among Mbili-Mbili adopters indicates that farmers did not adopt the innovation blindly, but they experimented with configurations that balanced labor demands, production goals and risk considerations. Greater continuity of pigeonpea integration between trial and conventional systems suggests stronger alignment with household priorities, while selective omission of beans reflects negotiation between competing objectives. Such adaptive behavior is characteristic of participatory innovation process, where learning and refinement occur iteratively through practice [51].

Patterns of scaling and knowledge dissemination further illustrate these dynamics. Mbili-Mbili participants trained more non-project farmers on average and allocated larger areas for expansion than DUL participants, pointing to stronger peer-to-peer learning and dissemination. The uptake of all system components remained gradual. For example, only a minority of households planted beans in two phases within a season, reflecting unfamiliarity with the practice and cautious experimentation [51]. Market uncertainties, including volatility in pigeonpea markets, further influenced crop choices and integration decisions [52].

Together, these findings highlight that adoption of diversified cropping systems is not a binary process but a negotiated and adaptive one, shaped by labor constraints, gendered decision-making, land access, and market conditions. Without explicit attention to these factors, even technically promising innovations risk partial uptake or selective modification. Designing gender-responsive and scalable agronomic interventions therefore requires not only technical optimization, but also flexibility in system design, support for farmer experimentation, and measures that address structural barriers to equitable participation and benefit sharing [40,41].

4.5. Implications for Gender-Responsive Scaling and Policy Engagement

Building on the empirical findings, the study results can be translated into actionable implications for policymakers, non-governmental organizations, and agricultural extension services engaged in the design and scaling of diversified cropping systems. Consistent with evidence that intra-household decision-making and gender norms strongly shape technology uptake and benefit distribution [40,48], the results underscore the need to integrate social considerations alongside agronomic performance in sustainable intensification strategies.

First, intra-household decisions over crop sales and income use emerged as critical leverage points for food security and household welfare. Even under unfavorable seasonal conditions, produce sales were common and largely controlled by men, particularly for maize and beans. Given the central role of legumes in household nutrition, male dominance in produce marketing decisions poses risks to dietary outcomes if women's preferences are not represented. Strengthening women's voices in marketing and income-use decisions through inclusive market engagement, collective selling arrangements, and

gender-sensitive extension messaging is therefore essential to protect household nutrition and welfare [42,51].

Second, although men dominated many production decisions, evidence of joint decision-making, especially around income use, points to opportunities for more equitable outcomes. Joint decision structures tend to emerge where households recognize shared welfare benefits and coordinated financial management [53]. Policy and program interventions that promote couple-based training, household financial literacy, and participatory planning can reinforce shared decision-making while enhancing both productivity and resilience.

Third, labor allocation patterns reveal persistent gender asymmetries, with women contributing disproportionately to labor-intensive field operations while exercising limited control over labor decisions. Similar patterns have been widely documented across SSA, where women provide a substantial share of agricultural labor despite limited access to productive resources [40,54]. Scaling labor-intensive systems such as Mbili-Mbili without complementary support risks reinforcing gendered labor burdens. Targeted investments in labor-saving technologies, mechanization services, and agronomic practices suited to woman-intensive tasks are therefore critical to ensure that innovations reduce, rather than intensify, drudgery.

Finally, evidence that commercialization can shift control over crops and income from women to men [35,55] highlights the importance of gender-sensitive crop and technology targeting. Diversified systems should intentionally include crops and management practices valued by women alongside those prioritized by men, to prevent displacement of women's decision-making as technologies are being scaled. The observed movement toward more negotiated intra-household decision spaces suggests that gender-transformative approaches supported by sensitization, inclusive extension, and participatory innovation processes offer a viable pathway for ensuring that strip-cropping innovations deliver equitable productivity and livelihood benefits [43,44,52].

5. Conclusions

Findings from this study unveil that the uptake and scaling of diversified cropping system innovations are shaped not only by agronomic performance but also by intra-household decision-making, labor dynamics and farmers' adaptive responses. Across both technologies, men dominated key production, marketing and income-related decisions, reflecting persistent gender inequalities in access to land and productive resources. While DUL offered greater relevance for women through its emphasis on beans, limited control over land constrained its expansion. Contrastingly, the diversified structure of Mbili-Mbili created opportunities to integrate crops valued by both men and women, but its higher labor requirements especially during its establishment pose a significant barrier to wider adoption. Farmers responded to these constraints through active modification, selective crop omission, and gradual scaling, underscoring the importance of flexibility and learning in innovation uptake. In addition, specific entry points for intervention including couple-based training approaches that strengthen joint decision-making, targeted attention to crop sales and income-use decisions, and improved access to land and agricultural services like labor-saving practices for operations where women bear the greatest burden can be considered. While the results are derived from a cross-sectional study and are therefore not intended to be universally generalizable, they underscore the need for sustainable intensification strategies that combine technical performance with social inclusivity. Future longitudinal studies tracking households over multiple seasons could build on this work by examining how intra-household decision-making, labor allocation, and benefit sharing evolve as diversified cropping systems mature and scale across contexts.

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Informed Consent Statement: Informed consent for participation was obtained from all subjects involved in the study.

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Abbreviations

The following abbreviations are used in this manuscript:

ANOVA	Analysis of variance
BCR	Benefit–Cost Ratio
CA	Correspondence analysis
DUL	Double-up legume
HH	Household
ISFM	Integrated soil fertility management
MBILI	Managing beneficial interactions under legume intercrops
MEY	Maize equivalent yield
SE	Standard error
SSA	sub-Saharan Africa
TVC	Total variable cost
US$	United States dollar

Appendix A

Outcome	Predictors Selected (λ-min)	Predictors Selected (λ-1se)
Maize equivalent yield (MEY)	Marital status, household size and total farm labor	None
Net benefits	Total farm labor	
Pigeonpea yield	Household type, group membership and household size	
Bean yield	None	
Maize yield		

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