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Research Article

Optimizing Spatial Arrangement and Variety Selection for Sustainable Maize–Common Bean Intercropping in Eastern Ethiopia

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Abstract

Addressing food security in land-constrained regions requires sustainable intensification practices. This study evaluated the effects of spatial arrangement and bean variety selection on productivity and economic returns of maize–common bean intercropping in East Hararghe, Ethiopia. A two-year field experiment was conducted across two locations using a randomized complete block design with three replications. Treatments included five intercropping arrangements (1: 1 and 1: 2 maize: bean rows) with two bean varieties (Awash 2 and KATB1), alongside sole cropping controls. Sole maize produced the highest grain yield (7579.9 kg ha^{-1}), but intercropping with Awash 2 in a 1: 1 arrangement achieved statistically similar maize yield (7208.9 kg ha^{-1}) while significantly enhancing system profitability. All intercropping systems demonstrated land use efficiency, with Land Equivalent Ratio (LER) values exceeding 1 (1.194–1.283). Awash 2 outperformed KATB1 in intercropped bean yield, pods per plant, and seeds per pod. The 1: 2 arrangement favored bean yield (599.3 kg ha^{-1} for Awash 2), whereas the 1: 1 arrangement optimized combined economic yield (7844.2 kg ha^{-1}) and Monetary Advantage Index (MAI = 80,939 ETB ha^{-1}). Maize intercropped with Awash 2 in a 1: 1 row arrangement offers the best compromise between maintaining maize yield and maximizing overall system productivity and profitability.

Keywords

Intercropping, Maize, Common Bean, Land Equivalent Ratio, Spatial Arrangement

1. Introduction

Meeting Ethiopia's rapidly growing food demand remains a critical challenge. For decades, the country has experienced a fundamental imbalance: food requirements have increased geometrically while agricultural land availability has declined sharply [20]. This imbalance is exacerbated by an annual agricultural growth rate of 1.4%, lagging the population growth rate of 2.49% [4]. Two primary pathways for increasing food production are recognized: horizontal expansion (bringing more land under cultivation) and vertical intensification (increasing productivity per unit land [8]. Given finite potential for land expansion, vertical intensification through sustainable practices offers a more viable solution.

Intercropping-the simultaneous cultivation of two or more crop species on the same field—has re-emerged as a strategy to enhance productivity, stability, and ecological resilience [8]. This is particularly relevant for Ethiopia, where agriculture

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supports over 80% of the population [3]. Conventional monoculture systems often lead to soil degradation, increased pest pressure, and inefficient resource use [1]. By contrast, cereal-legume intercropping, such as maize (*Zea mays* L.) with common bean (*Phaseolus vulgaris* L.), leverages complementary resource use: maize provides structural support, while bean fixes atmospheric nitrogen [6].

The productivity of maize-bean intercropping is highly influenced by varietal selection and spatial arrangement. Maize architecture affects light availability for understory bean, while bean growth habit and nitrogen fixation efficiency determine competitiveness [12]. Optimizing spatial configuration minimizes interspecific competition and maximizes facilitative interactions [7]. The Land Equivalent Ratio (LER) serves as a key metric for evaluating intercropping efficiency, with values >1.0 indicating yield advantage over monocropping [2]. This study aimed to determine optimal spatial arrangement and varietal combinations to maximize production efficiency and component yields under Ethiopian conditions.

2. Materials and Methods

2.1. Study Site Description

The experiment was conducted over two growing seasons (2023/24 and 2024/25) at two locations: Fadis Agricultural Research Station and Debine FTC, in East Hararghe Zone, Ethiopia. Both sites are characterized by sub-humid agroecology with bimodal rainfall patterns (annual rainfall 1000–1400 mm) and mean temperatures 15–28 ℃. Soils are Nitisols with moderate fertility (pH 5.5–6.5, organic matter 1.5–3.5%). Elevation ranges from 1,600 to 1,750 m above sea level.

2.2. Experimental Design and Treatments

A randomized complete block design (RCBD) with three replications was used. Seven treatments were evaluated (Table 1). Maize variety Melkassa-2 and two common bean varieties (Awash 2: moderate climbing; KATB1: bush type) were used. Common beans were planted two weeks after maize. Sole maize spacing was 75 cm × 25 cm; sole bean spacing was 40 cm × 10 cm. In intercropped plots, maize rows were maintained at 75 cm.

Table 1. *Treatment combinations for maize–common bean intercropping.*

Treat Code	Treatment Description	Arrangement
T1	1 Maize: 1 Row Awash 2	1: 1
T2	1 Maize: 1 Row KATB1	1: 1
T3	1 Maize: 2 Rows Awash 2	1: 2
T4	1 Maize: 2 Rows KATB1	1: 2
T5	Sole Maize (M-2)	Sole
T6	Sole Awash 2	Sole
T7	Sole KATB1	Sole

Fertilizer rates: 100 kg ha^{-1} N and 150 kg ha^{-1} P_2O_5 (as UREA and NPS) for maize; 100 kg P_2O_5 ha^{-1} for beans (no N to encourage biological fixation). All P applied at planting; N applied at knee height for maize.

2.3. Data Collection

For common bean: days to maturity (DM), number of branches per plant (NBPP), pods per plant (NPPP), seeds per pod (NSPP), and grain yield. For maize: days to maturity (DTM), plant height (PH), cobs per plant (CPP), cob length (CL), and grain yield (kg ha^{-1}, adjusted to 12.5% moisture).

2.4. Efficiency and Profitability Indices

Land Equivalent Ratio (LER): LER = (Yim/Ysm) + (Yib/Ysb), where Yi and Ym are intercrop and monoculture yields [10].

Land Equivalent Coefficient (LEC): LEC = $LER_1 \times LER_2$. Values >0.25 indicate yield advantage (Ejigu et al., 2020).

Crop Equivalent Yield (CEY): CEY = Ys × (Ps/Pm), where Ps (80 ETB kg^{-1}) and Pm (50 ETB kg^{-1}) are bean and maize prices (local market).

Monetary Advantage Index (MAI): MAI = (Pm × Ym × (LER–1))/LER [5].

2.5. Statistical Analysis

Data was analyzed using R software (version 4.2.0). Combined ANOVA across locations and years was performed after confirming homogeneity of variances. Treatment means were separated using LSD at $p \leq 0.05$.

3. Results and Discussion

3.1. Maize Performance

Intercropping significantly influenced maize grain yield and cob length, while effects on DTM, plant height, and cobs per plant were non-significant (Table 2). Sole maize (T5) produced the highest grain yield (7579.9 kg ha^{-1}), significantly outperforming most intercropped treatments except T1 (1M: 1Row Awash 2; 7208.9 kg ha^{-1}), which was statistically similar. This agrees with Tadesse et al [15], who reported sole maize yield superiority but noted minimal reduction with compatible bean varieties and optimal spacing.

Cob length was greatest in sole maize (20 cm), followed by

T4 (1M: 2Row KATB1; 19 cm). Yield reduction in intercropped maize was most pronounced in T2 (1M: 1Row KATB1; 6334.5 kg ha^{-1}) and T3 (1M: 2Row Awash 2; 6191.1 kg ha^{-1}). The resilience of T1 suggests better spatial complementarity and reduced competition, consistent with Mushagalusa et al. [14], who found that less aggressive bean cultivars and optimized geometry minimize shading.

Table 2. *Maize performance under intercropping and sole cropping.*

Treatment	DTM	PLH (cm)	CPP	CL (cm)	Yield (kg/ha)
T1 (1M: 1Row Awash2)	151.7	160	1	16.67 bc	7208.9 ab
T2 (1M: 1Row KATB1)	148.3	150	1.3	17.0 bc	6334.5 c
T3 (1M: 2Row Awash2)	154.3	162.3	1.3	16.17 c	6191.1 c
T4 (1M: 2Row KATB1)	150	165.8	1.3	19.0 ab	6824.9 bc
T5 (Sole M-2)	147.7	165	1.3	20.0 a	7579.9 a
LSD (5%)	NS	NS	NS	2.7	661.1
CV%	4.1	13.3	44.4	8	8.1
Cropping System					
Sole cropping	147.8	163.3	1.5	20	7579.9 a
Intercropping	150.8	161.5	1.25	17.4	6639.9 b
LSD (5%)	NS	NS	NS	NS	660.3
CV%	4.95	18	34.81	9.51	10.25

*Means within a column followed by different letters are significantly different at $p<0.05$. NS = Not significant. *

Phenological parameters of maize were not significantly influenced by cropping system. This is likely due to the low competitive nature of beans, consistent with Temesgen et al. [17] and Muoneke et al. [13] who reported that intercropping with legumes did not alter maize development stages.

3.2. Common Bean Performance

Intercropping pattern significantly affected bean yield and yield-related traits (Table 3). Among intercropping treatments, T3 (1M: 2Row Awash 2) yielded highest (599.3 kg ha^{-1}), maintaining favorable pod and seed numbers. T2 and T4 (KATB1) recorded significantly lower yields, demonstrating genotype-specific responses. Sole bean yields were highest (T6: Awash 2, 1285.5 kg ha^{-1}). The yield reduction in intercropping is a common phenomenon attributed to competitive suppression by maize [19].

Awash 2 consistently outperformed KATB1 in NPPP, NSPP, and grain yield under both sole and intercropped conditions. This highlights the importance of variety selection in intercropping systems, as varieties with shade tolerance and efficient nitrogen fixation are better suited [9].

Table 3. *Common bean performance under intercropping and sole cropping.*

Treatment	NBPP	NPPP	NSPP	GYLD
T1 (1M: 1Row Awash2)	5.3 b	20 a	4.8 ab	397.04 c
T2 (1M: 1Row KATB1)	5.3 b	11.3 c	3.7 c	281.48 cd
T3 (1M: 2Row Awash1)	4 b	18 ab	4.8 ab	599.26 b
T4 (1M: 2Row KATB1)	4.7 b	10.3 c	3.8 c	216.59 d
T6 (Sole Awash2)	8.0 a	22.7 a	5.3 a	1285.48 a
T7 (Sole KATB1)	5.7 b	15 bc	4 bc	735.56 b

Treatment	NBPP	NPPP	NSPP	GYLD
LSD%	2.18	4.92	0.97	156.68
Variety				
V1 (Awash2)	5.78	20.22 a	4.96 a	760.59 a
V2 (KATB1)	5.22	12.22 b	3.81 b	411.21 b
LSD%	NS	2.84	0.56	90.46
CV%	21.77	16.68	12.17	14.7
Cropping System				
Sole cropping	6.83 a	18.83	4.67	1010.6 a
Intercropping	4.83 b	15.58	4.42	373.6 b
LSD (P<0.05)	1.4	NS	NS	104.7
CV%	24	31	18.1	16.86

NBPP = Number of branches per plant; NPPP = Number of pods per plant; NSPP = Number of seeds per pod.

3.3. Land Use Efficiency and Economic Performance

All intercropping treatments recorded LER > 1, ranging from 1.194 (T4) to 1.283 (T3) (Table 4), indicating that intercropping makes more efficient use of land than sole cropping -a critical advantage in land-constrained systems [18]. The highest LER in T3 suggests spatial arrangement and variety jointly influence resource complementarity.

Table 4. *Land use efficiency and economic performance indices.*

Treatment	LER	LEC	CEY (kg/ha)	GMV (ETB/ha)	MAI (ETB/ha)
T1 (Awash2 1: 1)	1.260	0.294	7,844.16	392,208.20	80,939.05
T2 (KATB1 1: 1)	1.219	0.320	6,784.87	339,243.40	60,946.29
T3 (Awash2 1: 2)	1.283	0.381	7,149.92	357,495.80	78,851.47
T4 (KATB1 1: 2)	1.194	0.265	7,171.44	358,572.20	58,277.48
T5 (Sole Maize - Control)	1.000	–	7,579.90	378,995.00	0

The Combined Economic Yield (CEY) was highest in T1 (7,844.2 kg ha^{-1}), exceeding sole maize yield (7,579.9 kg ha^{-1}). Gross Monetary Value (GMV) was also highest in T1 (392,208 ETB ha^{-1}), surpassing sole maize (378,995 ETB ha^{-1}). All intercropping systems yielded positive MAI values, with T1 performing best (80,939 ETB ha^{-1}), followed by T3 (78,851 ETB ha^{-1}). Lower MAI values for KATB1 treatments reinforce the importance of variety choice in maximizing intercropping profitability. These findings align with Molla & Asfaw [11] and Tamado & Eshetu [16] who reported that cereal–legume intercropping improves total output and farm revenue in Ethiopia.

4. Conclusion and Recommendations

4.1. Conclusion

Maize-common bean intercropping is a viable strategy for enhancing land productivity and economic returns in East Hararghe, Ethiopia. While sole maize yielded highest individual grain output (7579.9 kg ha^{-1}), intercropping with Awash 2 in a 1: 1 arrangement (T1) achieved statistically comparable maize yield (7208.9 kg ha^{-1}) while significantly improving overall profitability. All intercropping configurations produced LER > 1.0 (1.194–1.283), confirming land-use efficiency advantage.

Awash 2 consistently outperformed KATB1 across all intercropping treatments, demonstrating greater adaptability to competitive intercropping environments due to its moderate climbing growth habit. The 1: 2 arrangement favored bean yield (T3: 599.3 kg ha^{-1}) but at greater cost to maize yield. The 1: 1 arrangement (T1) provided a more balanced outcome, minimizing interspecific competition while capitalizing on legume economic value.

Economically, T1 generated the highest GMV (392,208 ETB ha^{-1}) and MAI (80,939 ETB ha^{-1}), underscoring its potential to enhance farm income without additional land. These positions are intercropping as a key sustainable intensification practice for smallholder systems facing land constraints.

4.2. Recommendations

The maize-Awash 2 intercropping system with a 1: 1 row arrangement is recommended for farmers seeking to maximize profitability without significantly compromising maize yield. This configuration delivered the highest Monetary Advantage Index (MAI = 80,939 ETB ha^{-1}) while maintaining maize productivity comparable to sole cropping (7208.9 vs. 7579.9 kg ha^{-1}). Extension programs should prioritize the promotion of common bean variety Awash 2 for intercropping due to its superior shade tolerance, yield stability, and system compatibility compared to KATB1. Extension agents should advise farmers on; plant common beans two weeks after maize to reduce early-season competition, apply 100 kg P_2O_5 ha^{-1} to beans to enhance biological nitrogen fixation, implement timely weeding to minimize early-season competition. Long-term studies on soil fertility dynamics, nitrogen transfer efficiency, and evaluation of additional climbing bean varieties across diverse agro-ecologies are recommended.

Abbreviations

ANOVA	Analysis of Variance
CEY	Crop Equivalent Yield
CL	Cob Length
CPP	Cobs per Plant
DM	Days to Maturity
DTM	Days to Maturity
ETB	Ethiopian Birr
FAO	Food and Agriculture Organization of the United Nations
FTC	Farmers Training Centre
GMV	Gross Monetary Value
LEC	Land Equivalent Coefficient
LER	Land Equivalent Ratio
MAI	Monetary Advantage Index
NBPP	Number of Branches per Plant
NPPP	Number of Pods per Plant
NSPP	Number of Seeds per Pod
NPS	Nitrogen–Phosphorus–Sulfur
N	Nitrogen
P_2O_5	Phosphorus Pentoxide
PH	Plant Height
RCBD	Randomized Complete Block Design
UREA	Urea Fertilizer

Author Contributions

Zeleke Legesse: Conceptualization, Data curation, project administration, Formal Analysis, Investigation, Methodology, Writing – original draft, writing-review and editing

Fikadu Tadesse: Data curation Methodology, Visualization, Validation, Writing – review & editing

Birhanu Diribsa: Data curation, Methodology, Supervision, Validation, Writing – review & editing

Conflicts of Interest

The authors declare no conflict of interest.

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