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Effect of row spacing and inorganic fertilizer on yield and yield-related traits of *Amaranthus cruentus L.* in Becho District, Central Ethiopia

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Abstract

Amaranthus cruentus L., commonly known as amaranth, is an important pseudo-cereal and leafy vegetable crop valued for its high nutritional content, short growth period, and adaptability to adverse conditions (Gamel et al., 2006; Yosef et al., 2018). study addresses a critical knowledge gap in the optimization of agronomic practices for amaranth production under smallholder farming systems in Ethiopia. It was conducted in Becho District, Central Ethiopia, to evaluate the combined effects of row spacing and inorganic fertilizer on the yield and yield-related traits of amaranth under farmers' conditions. A factorial experiment consisting of three inter-row spacings (20, 30, and 40 cm) and two fertilizer levels (no fertilizer and 242 kg/ha NPSB + 79 kg/ha urea) was arranged in a randomized complete block design (RCBD) with three replications. **Data were analyzed using SAS (Version 9.3), and treatment means were**

compared using the least significant difference (LSD) test at a 5% significance level. Results revealed that fertilizer application significantly ($p < 0.01$) affected fresh leaf yield, grain yield, and most yield-related parameters, while row spacing significantly ($p < 0.05$) affected grain, biomass, and dry matter yields. The highest leaf yield (10.08 t/ha) and grain yield (4.63 t/ha) were recorded at 20 cm row spacing with the application of 242 kg/ha NPSB + 79 kg/ha urea. Farmers' conventional practice (no fertilizer) resulted in approximately 60% and 55% lower fresh leaf and grain yields, respectively, compared to the fertilized treatment. Fertilizer application also improved soil chemical properties, lowering soil pH from alkaline (7.67) to neutral (6.89) levels, **likely due to nitrification of urea**. Crude protein content increased from 21.07% to 26.81%, **though this difference was not statistically significant ($p > 0.05$. Based on one cropping season, the combination of 20 cm row spacing and 242 kg/ha NPSB + 79 kg/ha urea produced the highest yields. However, due to the non-significant fertilizer × spacing interaction, these results indicate additive rather than synergistic effects.** Multi-season validation is required before making generalized recommendations. Further multi-season trials with integrated organic and inorganic nutrient management are recommended.

Keywords: Inorganic fertilizer, plant population, leaf yield, grain yield, row spacing

Introduction

The genus *Amaranthus*, belonging to the family Amaranthaceae, includes over 70 species distributed globally as leafy vegetables, pseudo-cereals, and ornamentals (IPGRI, 2003). *Amaranthus cruentus L.*, native to Central and South America, is one of the major cultivated species due to its high nutritional value and adaptability (Stallknecht & Schulz-Schaeffer, 1993). In Ethiopia, *Amaranthus* is cultivated and consumed widely in Oromia, Benishangul-Gumuz, Gambella, and SNNP regions (Mekonnen et al., 2018). It is gaining increasing attention for its nutritional richness, drought resistance, and rapid growth cycle (Wambugu & Muthamia, 2009). Amaranth leaves are rich in protein, calcium, iron, vitamins A, C, and K, and essential amino acids such as lysine and methionine, which are often deficient in cereals (Pisarikova et al., 2005; Yosef et al., 2018).

Despite several studies on amaranth globally, research specific to Sub-Saharan Africa, particularly central Ethiopia, remains fragmented and often overlooks site-specific agronomic optimization (Reta et al., 2014). While spacing and fertilizer interactions have been studied elsewhere, they remain underexplored in Ethiopia, especially for dual-purpose (leaf and grain) amaranth production systems. **Recent studies in East Africa have demonstrated the potential of optimized plant density and nutrient management for indigenous vegetables (Nabukeera et al., 2022; Mrosso et al., 2023). Kebede et al. (2021) reported positive responses of amaranth to nitrogen and phosphorus fertilizers under central Ethiopian highland conditions.** However, limited information exists on the optimal agronomic practices, particularly the interaction between fertilizer rate and plant spacing, for maximizing yield under Ethiopian conditions (Olaniyi, 2007). This study addresses this gap by employing a factorial experimental design to systematically evaluate the interaction between row spacing and inorganic fertilizer application, providing evidence-based recommendations for smallholder farmers in central Ethiopia. Therefore, the objective of this study was to determine the **additive effects of** row spacing and inorganic fertilizer for improving leaf and grain yields of *Amaranthus cruentus L.* under smallholder farming conditions in the Becho district of central Ethiopia.

Materials and Methods

Description of the Study Area

The field experiment was conducted during the 2020 cropping season at Becho District, located in the South-West Shewa Zone of Oromia Region, approximately 80 km southwest of Addis Ababa (Fig. 1). The district lies between 8°35′N latitude and 38°15′E longitude, with an altitude ranging from 2106 to 2600 m a.s.l. The area receives an annual rainfall of about 1300 mm, with mean temperatures between 16°C and 25°C. The predominant soil type is vertisol with moderate fertility. Farmers practice mixed crop-livestock farming, mainly producing teff, wheat, and chickpea (District Office of Agriculture and Natural Resources, 2016).

Experimental Design and Treatments

A factorial experiment involving three row spacings (20, 30, and 40 cm) and two fertilizer levels (0 and 242 kg/ha NPSB + 79 kg/ha urea) was laid out in a randomized complete block design (RCBD) with three replications.The Mandirra II variety of *Amaranthus cruentus* was used. **plot measured 5 m² with 0.5 m spacing between plots and 1 m between blocks. Each plot consisted of 5 rows for the 20 cm spacing, 4 rows for the 30 cm spacing, and 3 rows for the 40 cm spacing, maintaining a consistent plot width.** Seedlings were transplanted at the 4-5 true-leaf stage, with intra-row spacing maintained at 10 cm across all treatments. The crop received two harvests for leaves at 45 and 60 days after transplanting (DAT), with grain harvested at physiological maturity (90 DAT).

Fertilizer Application

All NPSB fertilizer (242 kg/ha) was applied at transplanting. Urea (79 kg/ha) was split: 50% at transplanting and 50% at first harvest to minimize nitrogen losses and match crop demand (Olaniyi et al., 2008).

Soil Sampling and Analysis

Soil samples (0-20 cm depth) were collected as five composite samples per plot using a systematic sampling pattern before planting and after harvest. Samples were analyzed for pH, total N, available P, S, and other nutrients. Analytical methods included: pH-H_2O (ES ISO 10390:2014, 1:2.5), texture (Bouyoucos hydrometer), organic carbon (Walkley-Black), total nitrogen (ES ISO 11261:2015, Kjeldahl), EC (ES ISO 11265:2014, 1:5), and available P, Ca, K, Mg, Si, and B (Mehlich-3 extraction). Cu, Fe, Mn, and Zn were determined by DTPA extraction.

Data Collection

Growth and yield parameters including plant height (cm), number of harvested leaves per plant, number of main branches per plant, fresh leaf yield per plant (g), fresh leaf yield per hectare (ton), grain yield per hectare (ton), aboveground biomass yield per hectare (ton), aboveground dry matter yield per hectare (ton), specific leaf area (cm^2), and leaf area index were recorded.

Statistical Analysis

Data were analyzed using SAS (Version 9.3). **The assumptions of ANOVA (normality and homogeneity of variance) were checked using Shapiro-Wilk test and Levene's test, respectively. No data transformation was required.** Treatment means were compared using the least significant difference (LSD) test at a 5% significance level.

Results and Discussion

Soil and Plant Nutrient Response

Fertilizer application significantly ($p < 0.01$) affected most measured parameters, including fresh leaf yield, grain yield, and biomass yield (Appendix I). The highest fresh leaf yield (10.08 t/ha) and grain yield (4.63 t/ha) were recorded under 20 cm row spacing with the application of 242 kg/ha NPSB + 79 kg/ha Urea. In contrast, unfertilized plots yielded 4.08 t/ha and 2.08 t/ha for leaf and grain yield, respectively. Row spacing alone did not significantly influence leaf yield but affected grain and biomass yield ($p < 0.05$ for grain yield; $p < 0.01$ for biomass and dry matter), with narrower spacing (20 cm) producing higher yields per unit area (Pourfarid et al., 2014). **The fertilizer × row spacing interaction was not significant for all measured parameters ($p > 0.05$; Appendix I), indicating that the yield response to fertilizer was consistent across all spacing levels.** Similar findings were reported by Kebede et al. (2021) in central Ethiopia, where amaranth responded positively to NP fertilizers regardless of planting density.

Fertilizer application enhanced crude protein content in plant tissue from 21.07% in unfertilized plots to 26.81% with fertilizer application (Table 1). **However, this difference was not statistically significant ($p > 0.05$; LSD=ns)**. This increase, while not statistically significant, suggests a numerical trend toward improved nutritional quality with fertilizer application. Recent studies in Kenya highlight the role of balanced fertilization in improving the nutritional quality of indigenous vegetables, including amaranth (Onyango et al., 2023).

Soil analysis revealed that fertilized plots had lower pH values (from 7.67 to 6.89), which improved phosphorus and micronutrient availability. **This pH reduction is likely due to the nitrification of urea, a process that releases hydrogen ions and acidifies the soil (Assefa et al., 2024)** . This change improved nutrient retention compared to control plots, suggesting potential long-term soil fertility benefits (Futuless & Bagale, 2007). Adjusting soil pH through fertilizer application aligns with recent recommendations for alkaline soil management in East African highlands (Assefa et al., 2024).

The high coefficients of variation observed for several traits (CV up to 56.26% for LAI; Table 2) indicate considerable experimental variability. This may be attributed to inherent spatial variability in farmers' fields, which is common in on-farm trials under smallholder conditions. While this variability is acknowledged, it does not invalidate the main treatment effects, which remained significant.

Yield and Growth Parameters

Fertilizer application significantly increased plant height, number of harvested leaves per plant, number of branches, fresh leaf yield per plant and per hectare, grain yield per hectare, biomass, and leaf area index (Table 2). The effect of row spacing was significant for grain yield per hectare, aboveground biomass, and dry matter yield, with 20 cm spacing yielding the highest values. **Replication effects were highly significant ($p < 0.001$) for most parameters (Appendix I), reflecting spatial variability across the three farmer sites (Ababu, Lelo, and School sites).**

The findings corroborate previous studies (Olaniyi et al., 2008; Yarnia, 2010) which reported positive effects of nitrogen and phosphorus on *Amaranthus* growth and yield. Higher yields at closer spacing are attributed to efficient light interception and nutrient utilization per unit area (Miah, 2013). Recent agronomic research in Uganda supports the optimization of plant density for leafy amaranth, with 20-30 cm spacing yielding optimal biomass (Nabukeera et al., 2022). Overall, the integration of appropriate spacing and fertilizer management can substantially enhance productivity and soil health in the Becho area.

Conclusions

The results demonstrated that the combined application of 242 kg/ha NPSB + 79 kg/ha urea and 20 cm inter-row spacing **produced the highest** fresh leaf and grain yields of *Amaranthus cruentus L.* in Becho District. **However, due to the non-significant fertilizer × spacing interaction, these effects are additive rather than synergistic.** Fertilizer applications also reduced soil pH from alkaline to neutral levels, likely due to urea nitrification, contributing to improved nutrient availability.

Farmers may consider adopting this fertilizer rate and spacing to increase productivity. However, due to the single-season nature of this study and the high experimental variability observed, these findings should be considered preliminary. A simple yield-cost analysis would be beneficial but requires economic data not collected in this study.

Future research should integrate organic nutrient sources such as compost, farmyard manure, or green manure to develop cost-effective and sustainable integrated soil fertility management (ISFM) packages. Recent initiatives in Tanzania have demonstrated the viability of integrated nutrient management systems for indigenous vegetables (Mrosso et al., 2023). **Multi-season trials involving integrated organic and inorganic fertilizer combinations are recommended to validate and refine these findings for broader agro-ecological zones (Reta et al., 2014).** Scaling these findings to other agro-ecologies in Ethiopia should consider local soil types, rainfall patterns, and farmer resource availability.

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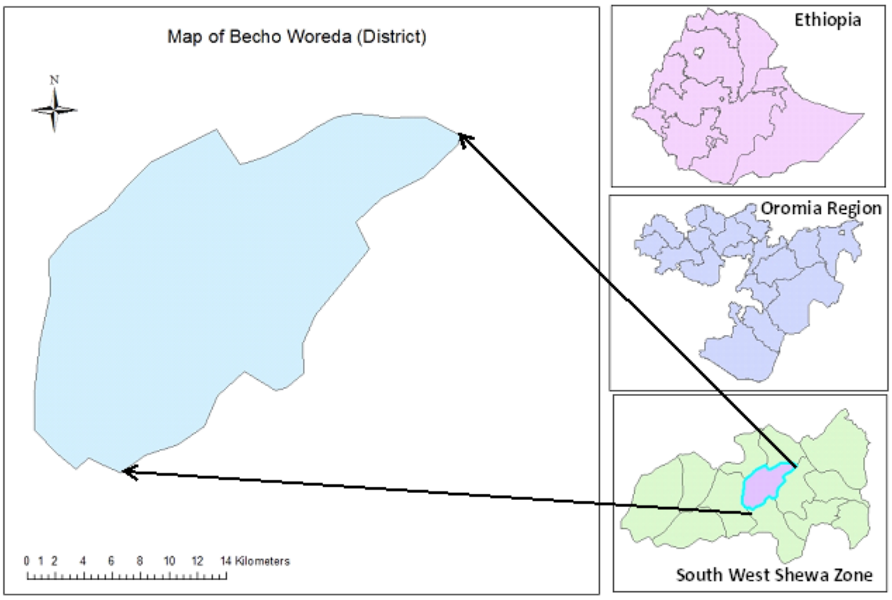

Figure 1: Map of the experimental site (Becho District, source: Becho District Agricultural Office)

Table 1. Effects of NPSB and urea application on soil properties and nutrient content of amaranth plant tissue

Treatments	Soil							Plant tissue			
	Total N (%)	Available P (mg kg-1)	pH	OC (%)	EC (mS/cm)	S (mg kg-1)	B (mg kg-1)	Crude protein (%)	P (mg kg-1)	S (mg kg-1)	B (mg kg-1)
NPSB+ Urea (kg ha-1)											
0+0	0.23a	234.25a	7.67a	2.86a	0.08a	47.21a	2.83a	21.07a	4814.3a	3551.9b	58.21a
242+79	0.25a	236.62a	6.89b	2.51a	0.07a	52.04a	4.23a	26.81a	5062.9a	6586.4a	62.09a
mean	0.24	235.44	7.28	2.68	0.07	49.62	3.53	23.94	4938.61	5069.16	60.18
cv	28.5	19.91	1.48	33.62	39.47	22.99	29.3	15.77	7.09	3.9	8.79
LSD (5%)	ns	ns	0.38	ns	ns	ns	ns	ns	ns	694.86	ns

Means followed by the same letter within a column are not significantly different at 5% probability level; ns = not significant; CV = coefficient of variation (%); LSD = least significant difference at 5% probability level

Table 2. Mean agronomic traits of amaranth (Mandirra-II) under fertilizer rates and interrow spacing in Becho district (2020)

Factors	**Treatment means**										
Fertilizer	**PH**	**HLPP**	**BPP**	**FLYpp**	**FLYpha**	**GYpp**	**GYpha**	**AGBMYpha**	**AGDMYpha**	**SLA**	**LAI**
242 kg/ha NPSB+79 kg/ha Urea	1.16a	85.27a	10.61a	57.33a	10.08a	0.03a	4.63a	52.26a	4.18a	64.37a	10.28a
0 kg/ha NPSB+0 kg/ha Urea	0.86b	45.87b	7.00b	23.47b	4.08b	0.01a	2.08b	41.19b	3.29b	40.48b	3.30b
LSD (0.05)	0.14	17.44	1.83	20.68	3.63	0.01	1.22	11.03	0.88	8.16	4.01
Inter row Spacing											
20 cm	1.00a	64.69a	7.70a	35.37a	8.84a	0.02a	4.62a	62.50a	5.00a	49.94a	8.87a
30 cm	1.01a	65.69a	8.81a	40.03a	6.67a	0.02a	3.10b	43.98b	3.52b	52.32a	6.38a
40 cm	1.02a	66.32a	9.90a	45.81a	5.73a	0.02a	2.34b	33.68b	2.69b	55.02a	5.13a
means	1.01	65.57	8.80	40.40	7.08	0.02	3.36	46.72	3.4	52.42	6.79
CV (%)	13.54	25.32	19.81	48.73	48.78	32.14	34.55	22.48	22.48	14.82	56.26
LSD (0.05)	ns	ns	ns	ns	ns	ns	1.49	13.51	1.08	ns	ns

PH plant height (cm); HLPP= number of harvested leaves per plant; BPP number of main branches per plant; FLYpp= fresh leaf yield per plant (g); FLYpha= fresh leaf yield per hectare (ton); GYPha =grain yield per hectare (ton); AGBMYpha = above ground biomass yield per hectare (ton); AGDMYpha= aboveground dry matter yield per hectare (ton); SLA= specific leaf area; LAI= leaf area index; Means followed by the same letter within a column are not significantly different at 5% probability level; ns = not significant; CV = coefficient of variation (%); LSD = least significant difference at 5% probability level.

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

APPENDIX

Appendix I. ANOVA table showing mean squares from the analysis of variance for fresh leaf yield and other collected yield-related parameters

		Mean Square (MS)										
Source of variation	D.F	PH	HLPP	BPP	FLYpp	FLYpha	GYpp	GYpha	AGBMYpha	AGDMYpha	SLA	LAI
Fertilizer	1	0.4110***	6983.26***	58.64***	5159.59**	161.82**	0.001***	29.212***	551.551*	3.530*	2568.06***	218.96**
Inter row Spacing	2	0.0004ns	4.05ns	7.23ns	164.02ns	15.32ns	0.000ns	8.071*	1279.605**	8.189**	38.74ns	21.75ns
Fertilizer * Inter row Spacing	2	0.0030ns	23.18ns	0.35ns	11.38ns	3.85ns	0.000ns	0.093ns	69.309ns	0.444ns	3.69ns	9.47ns
Rep	2	0.6452***	3886.91***	65.78***	4686.38**	138.28**	0.001**	27.551***	7601.930***	48.652***	3831.19***	164.86**
Error	10	0.0187	275.65	3.04	387.62	11.93	0.000ns	1.344	110.325	0.706	60.37	14.60

D.F= Degree of freedom; PH Plant height (m); HLPP= number of harvested leaves per plant; BPP= number of main branches per plant; FLYpp= Fresh leaf yield per plant (g); FLYpha= Fresh leaf yield per hectare (ton); GYpp= grain yield per plant (kg); GYPha =grain yield per hectare (ton); AGBMYpha = aboveground biomass yield per hectare (ton); UGDMYpha= aboveground dry matter yield per hectare (ton); SLA= Specific leaf area (cm^2); LAI= Leaf area index; ns = Not significant;* = Significant at $p < 0.05$; ** = Significant at $p < 0.01$; *** = Significant at $p < 0.001$

Appendix II: soil physical and chemical properties of the experimental site, top 20 cm depth before planting.

Properties	**Sites (replications)**						**Replication mean**	
	Ababu (R1)		**Lelo(R2)**		**School(R3)**			
	Value	**Ratings**	**Value**	**Ratings**	**Value**	**Ratings**	**Value**	**Ratings**
Chemical properties								
EC (mS/cm)	0.13	low	0.11	low	0.09	low	0.11	low
PH	7.92	high	7.97	high	7.70	high	7.86	high
Organic carbon (%)	2.61	moderate	2.83	moderate	2.25	moderate	2.56	moderate
Total nitrogen (%)	0.24	moderate	0.20	moderate	0.16	moderate	0.20	moderate
C:N ratio	10.96		14.05		13.65		12.89	
Ca(Cmol(+)/kg soil)	24.36	high	27.05	high	24.49	high	25.30	high
Mg(Cmol(+)/kg soil)	7.75	high	8.57	high	7.53	high	7.95	high
K(Cmol(+)/kg soil)	7.26	high	4.00	high	2.97	high	4.74	high
Na(Cmol(+)/kg soil)	0.24	low	0.18	low	0.22	low	0.21	low
Available P (Mg/kg)	157.58	high	117.40	high	63.35	moderate	112.78	high
S (Mg/kg)	47.71	moderate	46.43	moderate	42.26	moderate	45.47	moderate
Fe(Mg/kg)	15.48	high	12.76	high	15.99	high	14.74	high
Mn(Mg/kg)	14.64	moderate	19.08	moderate	23.70	high	19.14	moderate
Zn(Mg/kg)	5.65	high	6.68	high	12.66	high	8.33	high
B(Mg/kg)	4.86	high	4.76	high	4.50	high	4.71	high
Cu(Mg/kg)	1.73	low	1.17	low	1.75	low	1.55	low
Si(Mg/kg)	822.62	high	872.35	high	839.52	high	844.83	high
Physical properties (%)								
Sand	18		18		14		17	
Clay	50		58		58		55	
Silt	32		24		28		28	
Texture class	clay		clay		clay		clay	

Examination Methods: PH-H2O=ES ISO 10390:2014 (1:2.5); Texture= Bouyoucos

Hydrometer; OC=Walkey Black; TN= ES ISO 11261:2015 (kjeldahl); EC=ES ISO 11265:2014 (1:5); P, Ca, K, Mg, Si and B= Mehlich-3; Cu, Fe, Mn, and Zn=DTPA extraction.

NOTE

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