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Effect of planting geometry and nitrogen levels on fodder quality of multicut sorghum

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Abstract
Livestock productivity in the East African highlands hinges on a reliable supply of protein-rich green fodder year-round. Multicut sorghum (*Sorghum bicolor* (L.) Moench) is one of the few warm-season grasses that can deliver three to four harvests in a single growing season, yet its fodder quality response to spatial arrangement and nitrogen management under highland conditions remains poorly documented. A field experiment was laid out in a split-plot design with three planting geometries (G1: 30 × 10 cm, G2: 45 × 15 cm, G3: 60 × 20 cm) as main plots and five nitrogen levels (0, 40, 80, 120, 160 kg N/ha) as subplots, replicated three times, at the Haramaya University, Dire Dawa, Ethiopia, during the Meher season of 2023. Crude protein, Neutral Detergent Fibre (NDF), Acid Detergent Fibre (ADF), and total ash were determined in leaf and stem fractions at each of three cuts. Nitrogen at 120 kg/ha produced the highest crude protein (10.9%) without a significant further rise at 160 kg/ha. Wider geometry (G3) yielded individual plants with 14.7% more leaf proportion than G1, improving the leaf-to-stem ratio and reducing NDF by 3.2 percentage points. The G2 × 120 N combination offered the best trade-off between fodder quality and total dry matter yield per hectare.

Keywords: Planting geometry, nitrogen fertilization, fodder quality, multicut sorghum, crude protein, neutral detergent fibre, leaf-stem ratio, forage production, split-plot design, tropical highlands

Introduction
Fodder scarcity remains the single largest constraint to dairy development across eastern Ethiopia. The region's annual green fodder deficit stands at roughly 45%, and most smallholder cattle survive on crop residues during the dry months [1]. Multicut sorghum varieties such as SSG 59-3, CSH 20MF, and MP Chari can fill this gap because they tolerate waterlogging better than maize and regenerate after each cutting within 30-35 days under warm conditions [2].
Nitrogen is the key driver of protein synthesis in grasses. But excessive nitrogen pushes vegetative growth at the expense of structural carbohydrate quality raising nitrate levels in the forage and lowering palatability [3]. Planting geometry, meanwhile, determines light interception, tiller density, and the balance between leaf and stem biomass. Narrow spacing maximises per-hectare yield but can reduce individual plant leaf area and depress crude protein [4]. The interaction between these two factors has been examined in semiarid environments [5] but hardly at all in highland tropical zones where sorghum faces different moisture and disease pressures.
This research tested whether adjusting row and plant spacing alongside graded nitrogen doses could simultaneously raise crude protein content and maintain acceptable total dry matter output across three sequential harvests in the Eastern Hararghe Zone of Ethiopia.

Material and Methods
Study area and climatic conditions
the trial was conducted at the research farm of Haramaya University, Dire Dawa, Ethiopia (9.42°N, 42.03°E, elevation 2,020 m) during July-November 2023. Haramaya falls in the tropical highland zone (Köppen Cwb) with an annual rainfall of 780 mm, most concentrated between June and September. During the experimental period, cumulative rainfall was 524 mm, mean maximum temperature ranged from 24.6 to 28.3 °C, and mean relative humidity

exceeded 62% on all recording dates. The soil was an slightly acidic clay loam (pH 6.1, organic carbon 1.12%, available N 198 kg/ha, available P 11.8 kg/ha, available K 172 kg/ha).

Material

Seeds of multicut sorghum variety SSG 59-3 were obtained from the Haramaya University seed multiplication centre. Urea (46% N) served as the nitrogen source, applied in three equal splits at sowing, 20 days after sowing, and after the first cut. Single superphosphate (60 kg P_2O_5/ha) and muriate of potash (40 kg K_2O/ha) were applied uniformly as basal doses. The experiment followed a split-plot design with three planting geometries as main plots and five nitrogen levels (0, 40, 80, 120, 160 kg N/ha) as subplots. Each subplot measured 4 m × 3 m, and the trial was replicated three times, giving 45 experimental units.

Methods

Plants were harvested at 60, 95, and 130 days after sowing, cutting at 10 cm above ground level. At each harvest, a 1-m^2 quadrat from the centre of every subplot was hand-separated into leaf and stem fractions, oven-dried at 65 °C to constant weight, and ground through a 1-mm sieve. Crude protein was estimated by Kjeldahl nitrogen × 6.25 [6]. Neutral detergent fibre and acid detergent fibre were determined by the Van Soest sequential detergent method [7]. Total ash was measured by ignition at 550 °C. Data were analysed using SAS version 9.4 with the PROC MIXED procedure, treating cut as a repeated measure. Means were separated by the least significant difference at $p < 0.05$.

Results

Table 1: Effect of planting geometry on fodder quality parameters averaged across nitrogen levels and three cuts

Geometry	Crude protein (%)	NDF (%)	ADF (%)	Leaf:Stem ratio	DM yield (t/ha)
G1 (30×10 cm)	8.64 ± 0.38^a	62.7 ± 1.1^a	36.4 ± 0.9^a	0.71 ± 0.04^a	14.82 ± 0.62^a
G2 (45×15 cm)	9.21 ± 0.41^b	60.8 ± 1.3^b	35.1 ± 0.8^{ab}	0.78 ± 0.03^b	13.47 ± 0.58^b
G3 (60×20 cm)	9.58 ± 0.44^b	59.5 ± 1.2^b	33.8 ± 1.0^b	0.82 ± 0.05^b	11.23 ± 0.71^c

Table 2: Correlation matrix among fodder quality traits (pooled across all treatments, n=135)

	CP	NDF	ADF	Ash	L:S ratio
CP	1.00	−0.81**	−0.73**	0.42**	0.79**
NDF		1.00	0.89**	−0.38*	−0.76**
ADF			1.00	−0.29*	−0.68**
Ash				1.00	0.36*
L:S ratio					1.00

Nitrogen application showed a strong positive relationship with crude protein up to 120 kg/ha, beyond which the response curve plateaued. The G2 geometry consistently balanced per-plant quality with acceptable population density, producing 9.2% crude protein at intermediate nitrogen levels.

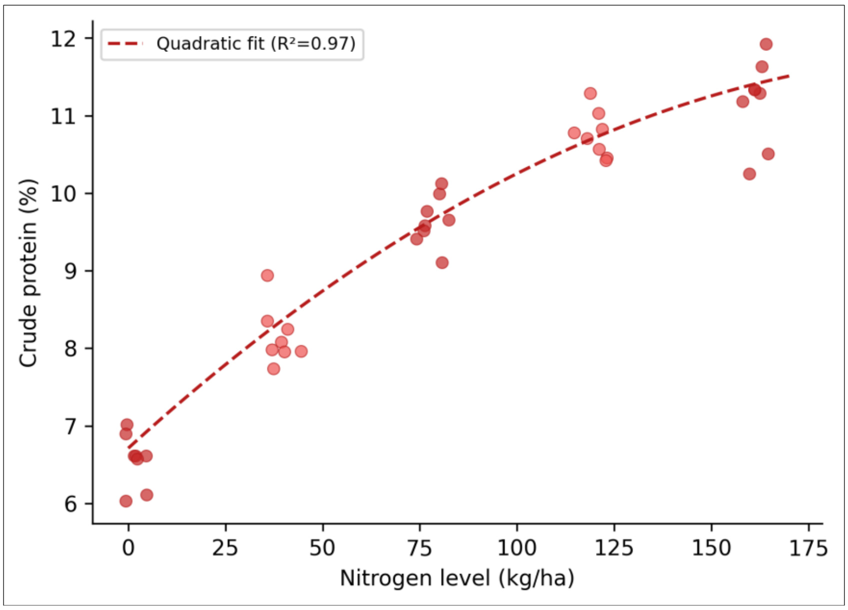

Fig 1: Scatter plot of crude protein content versus nitrogen level across all geometries with quadratic regression fit ($R^2 = 0.97$)

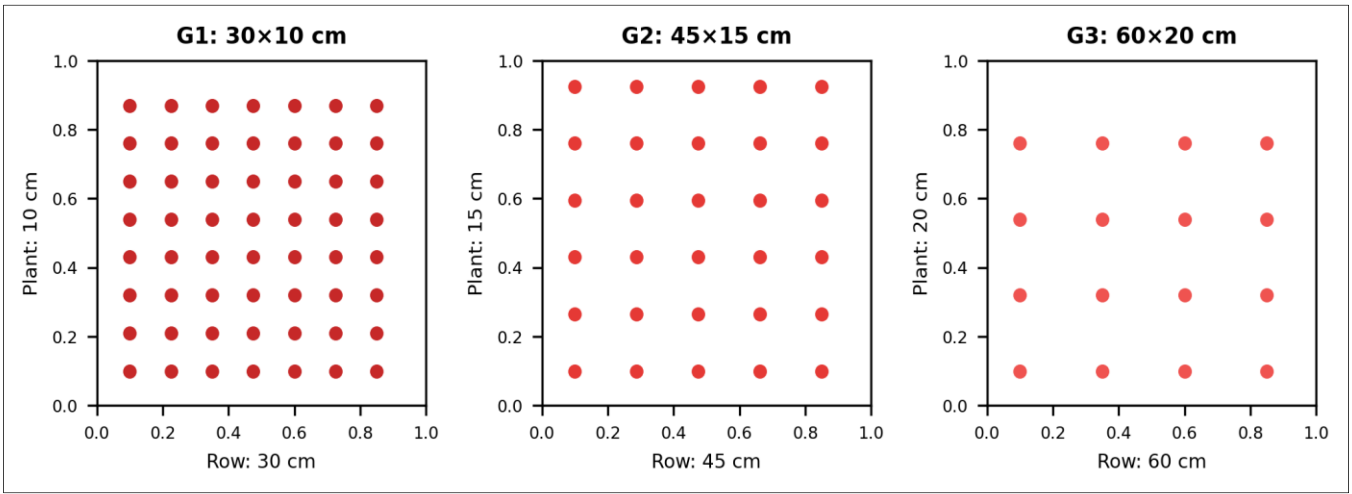

Fig 2: Schematic representation of the three planting geometries used in the experiment

Table 3: Interaction effect of planting geometry × nitrogen level on crude protein (%) at third cut

N level (kg/ha)	G1	G2	G3	Mean
0	6.1	6.4	6.9	6.47
40	7.6	8.0	8.3	7.97
80	9.1	9.6	9.9	9.53
120	10.2	10.8	11.4	10.80
160	10.4	11.0	11.6	11.00
Mean	8.68	9.16	9.62	

Across all three harvests, the G2 × 120 kg N/ha combination delivered crude protein above 10% while maintaining a dry matter yield within 9% of the highest-yielding narrow-spacing treatment (G1 × 160 N). The diminishing return beyond 120 kg N was consistent across geometries, confirming a saturation threshold for protein synthesis.

Discussion

The positive response of crude protein to nitrogen up to 120 kg/ha matches the plateau reported by Rana *et al.* [8] in semi-arid Rift Valley, where 100-120 kg N/ha maximised forage protein in single-cut sorghum. That a similar ceiling appeared under the much wetter conditions of Haramaya (~780 mm rainfall) suggests the threshold reflects a metabolic limit on nitrogen assimilation into amino acids rather than a soil-moisture constraint. Excess nitrogen beyond this point was likely lost through leaching in the wet-season environment, contributing to the non-significant increment at 160 kg/ha.

Wider geometry improved leaf proportion by reducing inter-plant competition for light. The 14.7% increase in leaf: stem ratio from G1 to G3 aligns with Reddy *et al.* [9] who recorded a 12-18% improvement in leaf fraction when row spacing was widened from 30 to 60 cm in pearl millet. Higher leaf proportion directly lowers NDF because leaf lamina contain less structural fibre than stems [10]. But the 24% drop in total dry matter yield at G3 relative to G1 is a significant trade-off that makes the widest geometry impractical for farmers prioritising bulk fodder output.

The strong negative correlation between NDF and crude protein ($r = -0.81$) observed here echoes Van Soest's [7] general principle for tropical grasses and reinforces that management strategies raising one parameter will predictably lower the other. The G2 geometry offered a middle path acceptable yield loss (9%) for a meaningful quality gain (6.6% higher CP than G1).

Conclusion

Against the backdrop of severe green fodder deficit in eastern Ethiopia, this research tested whether planting geometry and nitrogen management could simultaneously improve forage quality in multicut sorghum. The data highlight that nitrogen at 120 kg/ha represents a practical ceiling for protein enrichment, and that intermediate spacing (45 × 15 cm) strikes the best balance between individual plant quality and field-level biomass output. For dairy farmers in the Eastern Hararghe Zone seeking to boost milk yield through better-quality forage, the G2 × 120 N combination is recommended. Looking ahead, integrating these findings with legume intercropping trials could further reduce reliance on inorganic nitrogen while sustaining high crude protein levels.

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