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INFLUENCE OF CLEANING CUT TIMING AND NITROGEN APPLICATION ON *Andropogon gayanus* SEED YIELD IN BENISHANGUL-GUMUZ, WESTERN ETHIOPIA

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ABSTRACT. A study was conducted from 2019 to 2021 at the Assosa Agricultural Research Center to evaluate the effects of nitrogen (N) fertiliser application and cleaning cut timing on the seed yield and quality of *Andropogon gayanus*. The experiment used a split-plot design in a randomised complete block arrangement with four replications. Four N levels [0(control), 23, 46, and 69 kg ha^{-1}] were assigned to the main plots, and four cleaning cut timings (15, 30, 45, and 60 days after rainfall onset) were assigned to the subplots. Analysis of variance showed significant ($p < 0.05$) effects of N rate, cleaning cut interval, and their interaction on seed yield and most yield-related traits. The highest inflorescence density (147.38 m^{-2}) was recorded at 69 kg ha^{-1} N, and the 15-day cut produced the most racemes per inflorescence (6.91). The maximum seed yield (675.05–722.03 kg ha^{-1}) and optimal seed germination (>68%) were attained when N rates of 23–69 kg ha^{-1} were combined with a cleaning cut at 30–45 days. Based on the seed yield and quality, applying 23–69 kg ha^{-1} N with a 30–45-day cleaning cut is recommended to optimise seed production for *A. gayanus* in the study area and similar agroecologies. Future research should expand on these findings by evaluating economic cost–benefit analyses, alternative N sources, such as biofertilisers, and the long-term storage potential of seeds through germination tests seven months after harvest.

Keywords: *Andropogon gayanus*; cleaning cut timing; forage grass; nitrogen fertilisation; seed germination; seed yield.

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INTRODUCTION

Forage grasses are the most essential feed resource for livestock and adapt to diverse soil and climatic conditions. Among these forages, *Andropogon gayanus* Kunth is an adaptable tufted perennial grass native to the tropics, valued for its tolerance to drought, long dry seasons, acidic soils, and low-fertility environments (Cook *et al*., 2020; Queiroz Duarte *et al*., 2024). It is a vigorous, tall grass reaching up to 2.5 m. It bears numerous culms and a large, leafy false panicle (Kew Science, 2015). It covers major parts of the savanna vegetation across sub-Saharan Africa (Farr *et al*., 2024). As its establishment is easy, successful propagation relies on seeds, which offer logistical advantages over vegetative methods, making the sustainable production of quality seeds necessary for improving the production and productivity of forage-based livestock systems.

Benishangul-Gumuz is a promising region for the establishment of sustainable forage seed production in Ethiopia. This area supports high yields and optimal germination for *A. gayanus* due to its conducive environmental conditions (Abebe and Tesfamariam, 2016; Abebe *et al*., 2016). Efficient seed production is naturally complex and dependent on the successful management of key agronomic factors, including site selection, fertilisation, timing of regeneration cuts, and precise seed harvest (Kouassi *et al*., 2018).

Cleaning cut timing, which aims for a uniform number of tillers for higher seed set and harvesting efficiency, is a critical management practice for *A. gayanus* (Garcia-Carvalho *et al.*, 2025). However, determining the optimal cleaning cut timing is dependent on the site. Recent studies in Thailand have shown a narrow window for closing cuts, in which delaying the cut significantly reduces seed yields by shortening the reproductive phase and subjecting the crop to moisture stress during the critical flowering period (Garcia-Carvalho *et al*., 2025; Hare *et al*., 2013).

In addition to cleaning cut timing, nitrogen (N) fertilisation is also a key aspect of agronomic management for *A. gayanus* seed production. Although the species is mostly suited to low-fertility soils, some research has indicated that N fertiliser significantly enhances vegetative growth and tiller formation, directly affecting the inflorescence density and overall seed yield (Allah *et al*., 2020). In Nigeria, split-dose N applications (150 kg ha^{-1}) increase the tiller density (Allah *et al*., 2020). Additionally, a recent study has suggested that applying supplemental N at rates of 100–150 kg ha^{-1} is essential for stimulating early flowering branches, resulting in seed yields up to 90 kg ha^{-1} higher than unfertilised stands (Da Fonseca *et al*., 2025). Although this species can grow in poor soils, commercial seed production requires strategic N management to fulfill its high seeding potential (Bebawi *et al*., 2018; Feedipedia, 2022).

Despite the global importance of N fertilisation and the proper timing of cleaning cuts, there is limited information in Ethiopia on the specific combination of suitable cleaning cut timing and optimal N fertiliser level needed to maximise *A. gayanus* seed production in the agroecological conditions of Benishangul-Gumuz and similar areas.

Therefore, this study aimed to identify the cleaning cut timing and optimal N fertiliser level that maximises the seed yield and quality of *A. gayanus* in the study environment and in regions with similar agroecologies.

MATERIALS AND METHODS

Description of the study area

The study was conducted across three consecutive rainy seasons from 2019 to 2021 at the Assosa Agricultural Research Center in the Benishangul-Gumuz Regional State of Western Ethiopia. This site is situated at an altitude of 1576 m a.s.l, at 10°30'N latitude and 34°20'E longitude (Abebe and Tesfamariam, 2016). According to Almaw (2021) and Anbessa (2022), the soils at the study site are predominantly Humic Nitisols, characterised by a clay to clay–loam texture. These soils exhibit a strongly acidic reaction, with pH values ranging between 4.5 and 5.5, a condition that limits nutrient availability. In terms of chemical fertility, the status of the study site is generally categorised as low to moderate. Specifically, the total N content ranges between 0.20 and 0.34%, and the available phosphorus remains consistently low, with concentrations ranging from 6.14 to 6.80 ppm. As illustrated in *Figure* 1, the experimental site is characterised by a distinct unimodal rainfall pattern. The wet season typically begins in April or May and reaches peak intensities in July (325.68 mm) and September (297.59 mm). The prolonged dry season extends from November to March, with January and February experiencing negligible precipitation. The highest maximum temperature occurs during the months of March and April, averaging approximately 41°C. However, with the onset of heavy rain in June and July, the maximum temperature drops significantly to approximately 28°C.

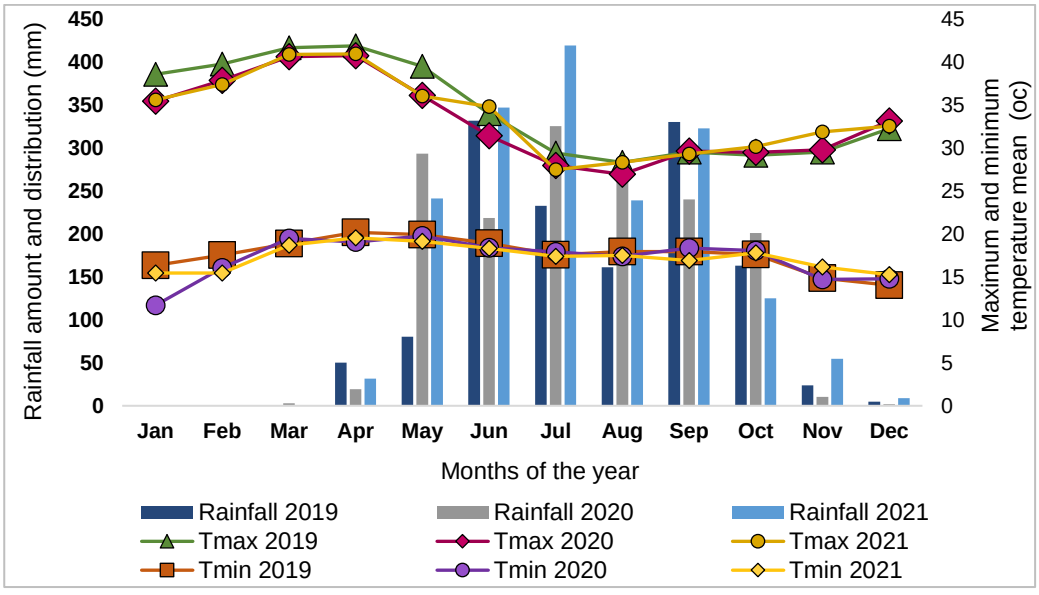

Figure 1 – Mean monthly rainfall (mm) and mean monthly maximum and minimum temperature (°C) at the experimental site over three years (2019–2021)

The minimum temperature remains relatively stable year-round, fluctuating narrowly between 14 and 20°C.

Experimental design and treatments

The experiment was conducted on an established stand of *A. gayanus* using a split-plot design arranged in a randomised complete block design with four replications.

The main plots were assigned the control treatment and three N doses (23, 46, and 69 kg ha^{-1}), and the subplots contained four cleaning cut intervals (15, 30, 45, and 60 days after the main rain onset). N, sourced from urea, was applied in two stages: at the time of the cleaning cut and again just before flowering at the vegetative stage. Each plot measured 12 m^2 (3 m × 4 m) and contained 10 rows spaced 30 cm apart, established with a seeding rate of 10 kg ha^{-1}. The same fertiliser schedule and management practices were consistently maintained throughout all three years of the experiment.

Data collection

Each year, the seed yield and associated parameters were collected in each subplot and averaged to provide a stable estimate of agronomic trends. Following the methodology established by Gobius *et al*. (1998) and Phaikaew *et al*. (2002), the inflorescence density was recorded by counting the number of seed-bearing tillers in a $1m^2$ quadrat in each subplot. In the same area, the number of racemes per inflorescence was counted on five randomly selected plants. Twenty inflorescences were harvested from each subplot to count the number of spikelets per raceme.

Seeds were collected 28 days after full anthesis by bagging the panicles in a $1m^2$ area of each subplot using nylon bags as described by Abebe *et al*. (2016). The harvested seeds were air-dried for 3–4 days, cleaned, and sent for laboratory analysis to determine their purity, moisture content, and germination percentage. The cleaned seed was stored in paper bags at room temperature, and a germination test was conducted over 21 days at seven months post-harvest. The seed moisture content, 1000-seed weight, and seed germination were all determined based on International Seed Testing Association seed-testing methods. The total seed yield and 1000-seed weight were adjusted to a standard 10% moisture content.

Data analysis

Data analyses were conducted using the PROC MIXED procedure in SAS (Version 9.4), employing a split-plot arrangement in a randomised complete block design. Treatment means were separated using Duncan's multiple range test at a significance level of $p < 0.05$.

The evaluation followed a two-stage process: an initial combined analysis of variance (ANOVA) across years using averaged data, followed by year-specific analyses. For parameters in which the interaction between N fertiliser levels and cleaning cut timing was non-significant in the combined model, individual year-by-year analyses were performed to separate the effects of both factors in each production year. The statistical model used for the split-plot was as follows (*Equation* 1):

$$Yijk = \mu + Ri + Nj + (RN)ij + Hk + + (NH)jk + \epsilon ijk \quad (1)$$

where Yijk is the observed response for the ith replication, j^{th} N level, and k^{th} cleaning cut time; μ is the overall mean;

Ri is the effect of the i^{th} replication (i = 1, 2, 3, 4); Nj is the effect of the j^{th} N level (main plot factor) (j = 0, 23, 46, 69 kg ha^{-1}); (RN)ij is the interaction between replication and N level; Hk is the main effect of the k^{th} harvesting frequency (subplot factor) (k = 15, 30, 45, 60 days); (NH)jk is the interaction effect between N level and harvesting cycle; and ϵijk is the random error term.

RESULTS

Main and interaction effects of nitrogen and cleaning cut timing

As shown in *Table 1*, ANOVA revealed that the N level had a highly significant effect ($p < 0.001$) on the number of inflorescences per square metre, number of spikelets per raceme, seed yield, 1000-seed weight, and seed germination percentage. The impact of N level on the number of racemes per inflorescence was also significant ($p < 0.05$). Cleaning cut timing had a highly significant influence ($p < 0.001$) on the number of racemes per inflorescence, number of spikelets per raceme, seed yield, and seed germination. It had a significant effect ($p < 0.01$) on the 1000-seed weight. However, cleaning cut timing did not significantly affect the number of inflorescences per square metre. The interaction effect between N level and cleaning cut timing was highly significant ($p < 0.001$) for the number of spikelets per raceme, seed yield, 1000-seed weight, and seed germination. The interaction was significant ($p < 0.01$) for the number of racemes per inflorescence but not for the number of inflorescences per square metre.

Table 1 – Analysis of variance for seed yield and yield components of *A. gayanus* under different nitrogen fertiliser levels and cleaning cut timing

Source	DF	F-value + Mean square					
		Number of inflorescences per m^2	Number of racemes per inflorescence	Number of spikelets per raceme	Seed yield (kg ha^{-1})	1000-seed weight (g)	Seed germination (%)
Replication	3	0.38 + 305.88^{ns}	1.55 + 0.80^{ns}	0.58 + 0.13^{ns}	1.00 + 5101.79^{ns}	0.15 + 0.05^{ns}	2.14 + 36.76^{ns}
Nitrogen level (NL)	3	38.23 + 31053.09***	2.08 + 1.08^{ns}	39.78 + 8.93***	54.22 + 277315.57***	5.35 + 1.65***	24.00 + 411.85***
Cleaning cut timing (CT)	3	1.19 + 970.41^{ns}	4.88 + 2.53**	61.41 + 13.79***	254.27 + 1300583.26***	1.69 + 0.52^{ns}	246.52 + 4229.92***
NL*CT	9	0.37 + 300.94^{ns}	2.39 + 1.24*	12.63 + 2.84***	4.06 + 20774.90***	4.27 + 1.32***	35.70 + 612.52***
Coefficient of variation (%)		23.24	10.90	4.77	15.40	10.35	7.51
Overall F-value		4.70	2.23	15.68	36.16	2.28	42.94

Note: ns = non-significant; * = p < 0.05; ** = p < 0.01; *** = p < 0.001; DF = degrees of freedom.
Cell entries represent F-values, mean squares and their associated significance levels.
The bottom rows indicate the coefficient of variation (%) and the overall F-value for each measured variable

Main effects of nitrogen and cleaning cut timing on the number of inflorescences

As indicated in *Table 2*, N fertiliser application had a highly significant influence ($p < 0.001$) on the number of inflorescences. For each production year and the combined means, the number of inflorescences increased as the N level increased. For the combined mean, the highest density was recorded at 150 and 100 kg ha^{-1} N (147.38 and 137.63 per square metre, respectively), while the control treatment recorded the lowest (90.25 per square metre). In contrast, the cleaning cut timing significantly affected the mean number of inflorescences during the 2019 production season.

Interaction effects of nitrogen application and cleaning cut timing on the number of racemes and spikelets

As indicated in *Table 3*, the interaction between the N level and cleaning cut timing had a significant effect ($p < 0.01$) on the number of racemes per inflorescence. The highest raceme count (7.37) was recorded at an N rate of 46 kg ha^{-1} combined with a 15-day cleaning cut timing; this was statistically similar to applying 69 kg ha^{-1} N at 30- (7.18) and 15-day (6.98) intervals. Conversely, the lowest number of racemes (5.98) was observed in the control treatment at a 30-day interval. In general, extending the cleaning cut timing to 60 days resulted in a lower raceme count across most N levels than the 15-day cleaning cut timing.

A highly significant interaction ($p < 0.001$) was observed for the number of spikelets per raceme. The highest number of spikelets (10.98) was achieved with 69 kg ha^{-1} N at a 30-day cleaning cut timing, which was statistically similar to the same N level at a 45-day cleaning cut timing (10.90), 50 kg ha^{-1} N rate at a 45-day cleaning cut timing (10.80), and the control treatment at a 45-day cleaning cut timing (10.58). The lowest number of spikelets was recorded at the 23 kg ha^{-1} N level with a delayed cleaning cut timing of 60 days (8.61) and the 46 kg ha^{-1} N level at a 30-day cleaning cut timing (8.89).

Although increasing N up to 69 kg ha^{-1} enhanced spikelet formation, delaying the cleaning cut timing to 60 days consistently and significantly reduced the number of spikelets, regardless of the N dosage.

Interaction effects of nitrogen and cleaning cut timing on the seed yield, 1000-seed weight, and seed germination

The seed yield, 1000-seed weight, and seed germination percentage of the tested grass are presented in *Table 4*.

The interaction between the N level and cleaning cut timing had a significant effect on seed yield. The highest seed yield (722.03 kg ha^{-1}) was obtained with the application of 69 kg ha^{-1} N combined with a 30-day cleaning cut timing. This was statistically similar to the yield obtained from the same N level at a 15-day cleaning cut timing (675.05 kg ha^{-1}).

Conversely, the lowest seed yields were recorded when the cleaning cut timing was delayed to 60 days, particularly at the control treatment (183.85 kg ha^{-1}) and 23 kg ha^{-1} N level (217.88 kg ha^{-1}). Overall, delaying the cleaning cut to 60 days resulted in a decline in seed yield across all N levels, whereas a 30-day cleaning cut timing

consistently supported higher yields, especially when combined with N fertilisation.

Regarding the 1000-seed weight, the interaction effect was also significant. The maximum weight (5.82 g) was recorded at 69 kg ha^{-1} N with a 60-day cleaning cut timing, which was statistically similar to the 69 kg ha^{-1} N rates at a 30-day cleaning cut timing (5.75 g), 23 kg ha^{-1} N at a 60-day cleaning cut timing (5.72 g), 50 kg ha^{-1} N rates at a 15-day cleaning cut timing (5.68 g), control treatment at a 30-day cleaning cut timing (5.60 g), 46 kg ha^{-1} N rates at a 45-day cleaning cut timing (5.45 g), and 23 kg ha^{-1} N rates at a 45-day cleaning cut timing (5.43 g).

The lowest 1000-seed weight (4.82 g) was observed at the highest N level (69 kg ha^{-1} N) when combined with a 45-day cleaning cut timing. The control treatment generally showed lower seed weights than the fertilised treatments, particularly at the early cleaning cut timing.

Table 2 – Number of inflorescences of *A. gayanus* at different nitrogen fertiliser levels and cleaning cut timings

Nitrogen level (kg ha^{-1})	Number of inflorescences per square metre			
	2019	2020	2021	Mean
0	85.50^{d}	90.63^{c}	94.63^{c}	90.25^{c}
23	91.75^{c}	125.00^{b}	129.00^{b}	115.25^{b}
46	117.75^{b}	145.56^{ab}	149.56^{ab}	137.63^{a}
69	120.75^{a}	158.69^{a}	162.69^{a}	147.38^{a}
Significance level	***	***	***	***
Cleaning cut timing (days)				
15	110.25^{b}	122.38	126.38	119.67
30	115.00^{a}	134.19	138.19	129.13
45	91.00^{d}	136.00	140.00	122.33
60	99.50^{c}	127.31	131.31	119.38
Significance level	***	ns	ns	ns
Treatment/overall mean	103.94	129.97	133.97	122.63
Coefficient of variation (%)	3.15	23.16	22.47	22.92

Note: ns = $p > 0.05$; *** = $p < 0.001$.
Means with different superscripts in columns are significantly different ($p < 0.05$).

Table 3 – The interaction effect of nitrogen fertiliser levels and cleaning cut timing on the number of racemes per inflorescence and the number of spikelets per raceme of *A. gayanus*

Nitrogen level (kg ha^{-1})	Cleaning cut timing (days)							
	Number of racemes per inflorescence				Number of spikelets per raceme			
	15	30	45	60	15	30	45	60
0	6.70^{bcd}	5.98^{e}	6.56^{bcde}	6.56^{bcde}	10.55^{bc}	10.14^{de}	10.58^{abc}	9.33^{g}
23	6.63^{bcde}	6.63^{bcde}	6.64^{bcde}	6.17^{de}	9.83^{ef}	9.33^{g}	10.80^{ab}	8.61^{h}
46	7.37^{a}	6.56^{bcde}	6.42^{cde}	6.45^{cde}	9.45^{fg}	8.89^{h}	10.30^{cd}	9.45^{fg}
69	6.98^{abc}	7.18^{ab}	6.65^{bcde}	6.27^{de}	9.89^{e}	10.98^{a}	10.90^{ab}	10.00^{de}
Overall mean		6.61			9.94			
Coefficient of variation (%)		11.03			4.70			
Significance level		**			***			

Note: ** = $p < 0.01$; *** = $p < 0.001$.
Means with different superscripts in columns are significantly different ($p < 0.05$).

Table 4 – Seed yield, 1000-seed weight, and seed germination percentage of *A. gayanus* as affected by the interaction of nitrogen fertiliser levels and cleaning cut timing

Nitrogen level (kg ha^{-1})	Seed yield (kg ha^{-1})				1000-seed weight (g)				Seed germination (%)			
	Cleaning cut timing (days)				Cleaning cut timing (days)				Cleaning cut timing (days)			
	15	30	45	60	15	30	45	60	15	30	45	60
0	414.16^{de}	601.60^{c}	297.04^{f}	183.85^{g}	4.98^{de}	4.98^{de}	5.60^{abc}	5.25^{bcde}	48.75^{g}	48.08^{g}	60.58^{e}	48.00^{g}
23	578.45^{c}	625.21^{bc}	352.37^{ef}	217.88^{g}	5.68^{ab}	5.63^{abc}	5.43^{abcd}	5.73^{ab}	46.17^{g}	54.50^{f}	68.08^{ab}	61.00^{de}
46	562.83^{c}	614.22^{bc}	404.20^{e}	356.13^{ef}	5.13^{cde}	5.38^{abcd}	5.45^{abcd}	5.05^{de}	38.00^{h}	64.50^{bcd}	61.00^{de}	53.58^{f}
69	675.05^{ab}	722.03^{a}	469.17^{d}	356.94^{ef}	5.15^{cde}	5.75^{ab}	4.82^{e}	5.82^{a}	34.50^{i}	68.58^{a}	65.00^{abc}	61.75^{cde}
Overall mean		464.45				5.36				55.13		
Coefficient variation (%)		15.50				10.12				7.75		
Significance level		**				***				***		

Note: **=p<0.01; *** = $p < 0.001$.
Means with different superscripts in columns are significantly different ($p < 0.05$).

The seed germination percentage was highly influenced by the interaction of cleaning cut timing and nitrogen fertilisation level.

The highest seed germination percentage (68.58%) was achieved with 69 kg ha^{-1} N at a 30-day cleaning cut timing, which was similar to the 23 kg ha^{-1} N at a 45-day cleaning cut timing (68.08%) and 69 kg ha^{-1} N at a 45-day cleaning cut timing (65.00%).

The lowest germination percentages were recorded at the earliest cleaning cut timing (15 days) under a high N regime, with the absolute lowest value (34.50%) observed at 69 kg ha^{-1} N with a 15-day cleaning cut timing.

Although high N levels maximised germination, they required a sufficient recovery period (at least 30 days) after the cleaning cut; cutting too early (15 days) at high N levels seemed detrimental to seed viability.

Correlation analysis

Pearson correlation analysis revealed moderate to weak associations among yield components and seed quality parameters. The inflorescence density (number of inflorescences per square metre) showed a significant, positive association with seed yield (r = 0.316) and a weak positive correlation with TSW (r = 0.284).

The number of racemes per inflorescence also had a positive association with TSW (r = 0.306). The number of spikelets per raceme did not show a significant correlation with seed yield or TSW ($p < 0.05$), but it demonstrated a weak positive association with seed germination (r = 0.246).

DISCUSSION

Number of inflorescences per square metre

The observed inflorescence density of 122.63 per square metre reflects a moderate level of reproductive performance, but it falls considerably short of the 246.00 per square metre reported by Abebe *et al.* (2016) for the same experimental material at Assosa, Ethiopia.

Table 5 – Correlation analysis of seed yield and yield-related components of *A. gayanus*

	Number of inflorescences per m²	Number of racemes per inflorescence	Number of spikelets per raceme	Seed yield (kg ha⁻¹)	1000-seed weight (g)	Seed germination (%)
Number of inflorescences per m²	1.000					
Number of racemes per inflorescence	0.149*	1.000				
Number of spikelets per raceme	0.087	−0.017	1.000			
Seed yield (kg ha⁻¹)	0.316***	0.262**	0.104	1.000		
1000-seed weight (g)	0.284***	0.306***	−0.037	0.015	1.000	
Seed germination (%)	0.148*	−0.146*	0.246**	−0.192*	0.114	1.000

Note: * = p < 0.05; ** = p < 0.01; *** = p < 0.001. TSW = 1000-seed weight.

Given the identical genetic material and agroecological zone, this disparity might stem from inter-annual climatic variability, as fluctuating rainfall and temperature during critical booting and flowering stages may have limited yield compared to more favourable prior years. Conversely, the current results significantly outperform the 58 inflorescences per square metre reported by Gobius *et al.* (1998) for the same grass species in India.

This superior performance suggests that the Benishangul-Gumuz region offers a more conducive tropical environment with edaphic and climatic factors better suiting the photoperiodic and moisture requirements of *A. gayanus* compared to other experimental sites. These broad variations underscore the high environmental plasticity of forage grasses, indicating that, in addition to genetic potential, site-specific drivers, such as climatic suitability, stand age, and management practices, are the decisive regulators of inflorescence density.

Number of racemes per inflorescence

The significant interaction between N level and cleaning cut times on the number of racemes per inflorescence highlights the dependence of floral architecture on both nutrient availability and the duration of the recovery period. The maximal raceme counts observed at moderate to high N levels (46–69 kg ha^{-1}) combined with early cutting intervals (15–30 days) suggest that N stimulates meristematic activity and increases the sink capacity of the inflorescence; however, this potential is only realised when the plant has sufficient time to develop.

Sakakibara (2006) and Takei *et al.* (2001) established that nitrogen availability acts as a primary signal for the biosynthesis of cytokinins, which are crucial for stimulating axillary bud outgrowth and floral initiation, thereby increasing the photosynthetic surface area needed to support reproductive development. However, the reduction in

the number of racemes observed when the cleaning cut was delayed to 60 days, regardless of the N level, indicates that defoliation timing is the limiting factor. A delayed cut drastically shortens the reproductive window, forcing the plant to transition to flowering before it can accumulate sufficient vegetative reserves to support large flower heads.

This aligns with Wong and Stür (2018), who noted that late cleaning cuts often resulted in smaller, less developed inflorescences because the removal of apical dominance occurs too late in the season, potentially damaging developing floral primordia or limiting the photoperiod required for full morphological development.

Furthermore, their interaction implies that the benefits of high N inputs (69 kg ha^{-1}) are negated if the management practice (cleaning cut timing) is not synchronised.

According to Masclaux-Daubresse *et al*. (2010), nutrient use efficiency is only maximized when the vegetative recovery period is long enough to allow for the translocation of assimilated N from the leaves to the developing reproductive structures.

The recorded mean of 6.61 racemes per inflorescence was much lower than the 32.67 reported by Abebe *et al*. (2016) for the same grass species in Western Ethiopia.

Furthermore, the reduced number of racemes suggests potential limitations in soil nutrient availability, particularly N or moisture stress during the critical floral initiation phase, both of which are physiological bottlenecks that restrict inflorescence branching and size even when the overall plant density is adequate.

Number of spikelets per raceme

The highly significant interaction between N level and cleaning cut timing on the number of spikelets per raceme underscores the complexity of optimising this yield component. The maximum number of spikelets achieved at a moderate N rate of 23 kg ha^{-1} N combined with a 45-day cleaning cut is a particularly important finding. This suggests that achieving the maximum spikelet density does not necessarily require the highest N input; instead, it is highly dependent on the plant's physiological stage, which is regulated by the cleaning cut timing. The 45-day cleaning cut likely provides an optimal period for *A. gayanus* to regenerate after cutting and efficiently partition resources towards spikelet formation before the onset of the reproductive phase. The fact that the 45-day cleaning cut timing consistently outperformed other cleaning cut timings across all N levels suggests that cleaning cut timing is the primary management factor for this trait, regardless of the N application rate. This supports the idea that moderate N levels, when combined with appropriate management, are sufficient for optimising the density of seed-bearing structures in the raceme. The recorded mean of 9.94 spikelets per raceme was significantly lower than the 14.00 reported by Abebe *et al*. (2016) for *A. gayanus* at this specific experimental site. Despite utilising an identical agroecology and genetic material, the lower current value strongly suggests that interannual climatic variability played a decisive role. The lower values observed in this study, compared to previous findings of Abebe *et al. (2016),* are likely attributable to

moisture stress or suboptimal temperatures during critical reproductive phases. These stressors during anthesis and seed filling likely hindered spikelet differentiation and increased abortion rates to a greater extent than that observed in previous research. Additionally, the observed variation may stem from differences in soil fertility, such as N depletion between the two study periods. Reduced fertiliser efficiency likely limited assimilate supply during the current experimental period, preventing optimal raceme development and leading to the recorded yield differences.

Seed yield performance

Significant differences in seed yield were observed across N application levels, with higher application rates producing greater yields than lower treatment levels. Increased N availability likely boosts the photosynthetic efficiency and vigorous tillering, leading to a higher density of fertile panicles, which is the primary determinant of the total grass seed yield. Regarding the cleaning cut interval, the superiority of the 30-day cleaning cut timing suggests an optimal biological trade-off; this timing effectively removes senescent biomass to break apical dominance and stimulate synchronised tillering while preserving a sufficient growing season for the crop to complete its reproductive cycle. This sensitivity to timing aligns with the findings of Abebe *et al*. (2016), who reported that the harvest timing significantly influenced *A. gayanus* yields, with optimal results observed between 21 and 35 days after peak heading. Conversely, the yield reductions at later cleaning cut timings (45 and 60 days) indicated that delaying the cut forces the reproductive phase into a period of receding soil moisture, shortening the grain-filling duration. Similarly, the 15-day cleaning cut timing was likely too early to allow the accumulation of the carbohydrate reserves necessary to support a robust second flush of growth. The recorded combined seed yield of 464.45 kg ha^{-1} was lower than the 561.3 kg ha^{-1} reported by Abebe *et al.* (2016) for *A. gayanus* in Western Ethiopia. The reduction compared to the previous finding, despite utilising the same experimental material and agroecological zone, is likely driven by interannual climatic variability, as seasonal fluctuations in rainfall distribution or temperature during critical reproductive stages in the current study year may have limited tiller survival and grain filling compared to the more favourable conditions experienced during the previous study.

1000-seed weight

The significant interaction observed for 1000-seed weight, where the maximum value (5.82 g) was achieved at the highest N level (69 kg ha^{-1}) combined with the longest recovery period (60 days), underscores the necessity of synchronising high nutrient availability with an extended vegetative phase to maximise grain filling. This aligns with Lawlor (2002), who attributed the increased seed weight to N-driven enhancements in photosynthetic capacity and assimilate availability, which are most effective when the plant has ample time to translocate resources to the seed. However, the seemingly contradictory finding that the same high N rate (69 kg ha^{-1}) resulted in the lowest 1000-seed weight (4.82 g) when coupled with a 45-

day cut suggests a source–sink imbalance or a dilution effect. According to Hampton and Hill (2002), high N inputs stimulate an excessive number of potential seeds (sink size) that the plant cannot adequately fill if the reproductive window is constrained or if lodging occurs, leading to lighter individual seeds.

Furthermore, the observation that unfertilised control plots produced significantly lower seed weights, particularly at early cutting intervals, confirms the findings of Pérez *et al.* (2021), who noted that plants fail to accumulate the necessary carbohydrate reserves for optimal seed maturation without adequate soil fertility to support rapid regrowth after defoliation. The similarity between the current mean 1000-seed weight (5.36 g) and that reported by Abebe *et al*. (2016) for the same region (5.1 g) confirms the stable nature of *A. gayanus* seed traits under Western Ethiopian ecological conditions.

Seed germination percentage

The observed variability in seed germination reflects a physiological trade-off between N-driven vegetative expansion and the time required for physiological maturity. This is consistent with the results of Pirredda *et al*. (2023), who found that seeds harvested before reaching full physiological maturity exhibited lower viability and a faster rate of aging due to incomplete morphological and biochemical development.

Consequently, maximising seed viability requires precise synergy between nutrient availability and the duration of the grain-filling period. The superior performance of the 23 kg ha^{-1} N treatment at 45 days suggests that moderate N levels provide an optimal nutritional balance, enhancing protein synthesis and embryo development without triggering excessive vegetative growth or delayed maturity, which are often associated with higher N inputs. These findings identify the 30–45-day cleaning cut timing as the critical physiological phase for *A. gayanus* to effectively translocate absorbed N to the reproductive sink, ensuring that the embryo is fully mature and viable. The germination rate of 52.13% identified herein was lower than the 68% reported by Abebe *et al*. (2016) for *A. gayanus* harvested 28 days after peak heading in Western Ethiopia.

The decline compared with Abebe *et al.* (2016), despite similar agro-ecologies, suggests that the current study may have experienced fluctuating climatic constraints during the maturation phase, such as untimely rainfall and high humidity, which can lead to reduced seed viability compared with the conditions in the 2016 study. Furthermore, the difference might be due to physiological dormancy management; *A. gayanus* possesses strong dormancy, and variations in the duration of the post-harvest storage period between the two studies would significantly vary germination percentages.

Correlation insights

Identifying inflorescence density and raceme number as the primary drivers of *A. gayanus* seed yield provided a clear basis for enhancing reproductive productivity. These correlations arise because yield was physiologically tied to the transition of vegetative meristems to reproductive ones: higher fertile tiller density increased the number of potential seed sites, while greater raceme numbers

enhanced photosynthate sink strength, thereby increasing thousand seed weight (TSW). For forage and forage seed producers, these findings indicate that maximizing yield requires management strategies such as strategic nitrogen application and well-timed defoliation that prioritised reproductive architecture and tiller uniformity over total vegetative biomass.

These results are consistent with the conclusions of Boelt and Studer (2010) and Abebe *et al.* (2016), who identified reproductive tiller density as the key yield component in forage grasses, and aligned with Sartie *et al.* (2018) regarding the structural synergy between inflorescence size and seed weight.

CONCLUSIONS

This study demonstrated that optimising cleaning cut timing and N fertiliser application significantly enhanced the seed yield and quality of *A. gayanus*. The findings underscore the study site's potential for both smallholder and commercial seed production, suggesting that practitioners should utilise moderate to high N levels combined with intermediate cleaning cut timing to maximise seed yield and quality. To ensure successful implementation, these agronomic strategies should be supported by strong extension services to help farmers transition into forage seed production.

Future research should focus on estimating cost–benefit analyses, investigating alternative N fertiliser sources, such as biofertilisers, and evaluating the long-term storage potential of seeds through germination trials seven months after harvest.

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