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RESEARCH PAPER

Biomass Productivity of Selected Improved Fallow Species and their Influence on Nitrogen input and Residual Sorghum Grain Yield

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ABSTRACT

Dwindling soil fertility remains a major restraint to smallholder crop production, thus impacting food security in Kenya. Soil fertility challenges are further exacerbated by the high cost of mineral fertilizer. Intentional planting of nitrogen-fixing fast-growing legume fallows has potential for improving soil fertility in smallholder farming systems, among other benefits such as fuel wood supply. However, data on biomass productivity of improved fallows and their influence on sorghum grain yields are still limited. The current study evaluated foliage, wood, and total above-ground biomass productivity of selected improved fallows in Siaya County. It also evaluated the effect of selected improved fallows on nitrogen input and sorghum grain yield. A Randomized Complete Block Design (RCBD) was used to set up the experiment. The experiment had 12 treatments comprising mixed species and monoculture fallows, each replicated thrice. The highest foliage biomass of 15.7 t ha^{-1} was recorded in the *Desmodium uncinatum* treatment, which was 392% above the natural fallow (control). Further, pure *Crotalaria grahamiana* stand had the highest total above-ground biomass (AGB) and wood biomass (WB) of 62.3 t ha^{-1} and 47.1 t ha^{-1}, respectively. The highest N input of 62.1 kg ha^{-1} was recorded in *Crotalaria grahamiana.* The mixture of *Sesbania sesban* and *Desmodium uncinatum* resulted in the highest grain yield of 1.8 t ha^{-1}. Significant positive linear relationships were reported between foliage biomass and N input, and between N input and sorghum grain yield.

HIGHLIGHTS

- The productivity of improved fallow species is dependent not only on the type of species used but also on their planting arrangement.
- Single-species fallows produced higher foliage and woody biomass compared to mixed-species combinations.
- Mixed-species fallows are best suited for both nutrient cycling through biomass production and fuelwood generation.
- A combination of *Sesbania sesban* and *Tephrosia vogelii* emerged as the most promising option for both soil fertility enhancement and fuelwood supply.

Keywords: Improved fallows, biomass, above ground biomass, grain yield

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Agriculture is the lifeline of most people across Africa, particularly in Kenya, where it forms the backbone of the economy. Despite its significance, smallholder crop production has been hindered by declining soil fertility, which threatens sustainable food security (Amadalo *et al.* 2003; Kaya *et al.* 2007; Onyuka *et al.* 2025; Shao *et al.* 2025; Mugo *et al.* 2021; Hossain *et al.* 2021). Such degradation is mainly attributed to continuous farming, exorbitant mineral fertilizer prices, and widespread poverty (Nungula *et al.* 2023; Munthali *et al.* 2014; Krishna *et al.* 2024; Hemasree *et al.* 2025). Traditionally, long fallow periods were used to restore soil fertility, but increasing population densities have made such practices impractical (Kwesiga *et al.* 2002; Kaya *et al.* 2007).

In Kenya, with an annual population growth rate of 2.3%, the situation is particularly critical in Siaya County, where the annual population growth is 1.2% (KNBS, 2019). Nitrogen deficiency is one of the primary constraints to crop productivity throughout Kenya and the African continent (Kwesiga *et al.* 2002; Nduwimana *et al.* 2020), with nutrient depletion further compounded by unsustainable agricultural practices and nutrient leaching (Kiraithe *et al.* 2008; Nungula *et al.* 2023; Maheswari *et al.* 2025). Annual nutrient losses of up to 22 kg ha^{-1} nitrogen, 15 kg ha^{-1} potassium, and 2.5 kg ha^{-1} phosphorus have been recorded in some areas, notably in Western Kenya, where nitrogen and phosphorus deficiencies are prevalent (Amadalo *et al.* 2003: Hossain *et al.* 2021: Santosh *et al.* 2024).

Utilizing efficient agricultural technologies is essential for improving farm productivity and reducing food insecurity and poverty (Alkharabsheh *et al.* 2024; Mukesh *et al.* 2024; Mohamed, 2025; Maitra *et al.* 2024). Among these technologies, improved fallows involving selected tree and shrub species offer a sustainable approach to increasing crop yields (Styger *et al.* 2009; Kisaka *et al.* 2023; Sahoo *et al.* 2024; Sairam *et al.* 2025). Previous studies have demonstrated that such fallows can boost maize yields by as much as 300% and provide significant amounts of household fuel wood (Amadalo *et al.* 2003; Kiraithe *et al.* 2008; Ndufa *et al.* 2009; Maitra *et al.* 2025a). Gathumbi *et al.* (2004) reported that legume fallows enhanced nutrient cycling through litter fall and biomass addition. The study further revealed that biomass production potential differs significantly among species and sites. The current study thus sought to evaluate biomass productivity of selected improved fallow species and further evaluate their potential for enhancing nitrogen input and sorghum grain yield.

MATERIALS AND METHODS

Study site

The study was carried out in Sidindi, located at 0.166390° N and 34.417400° E, in Siaya County, Kenya. The 2019 Kenya population and housing census revealed that Siaya County had a population of 993,183, with an annual growth rate of 1.2% (KNBS, 2019). The region is characterized by moderately high population density and small land holdings. Siaya falls within the Lower Midland agro-ecological zone, experiencing a bimodal rainfall pattern. Typically, long rains occur from March to July, while the short rainy season runs from October to December. The average annual rainfall in Siaya ranges between 1,000 mm and 1,750 mm. However, recent climate changes have caused variations in rainfall patterns. The predominant soil type in this area is acrisols.

Experimental set-up

A Randomized Complete Block Design (RCBD) was employed for the experiment setup. Trials involving improved fallows were initiated in May 2021, with both monoculture and mixed-species fallows being established using certified seeds. There were 12 treatment groups, each replicated three times. Woody species were spaced at 75 cm within rows and 75 cm between rows, while herbaceous species were planted with a spacing of 30 cm between rows and 75 cm within rows. In the mixed-species fallows, a 1:1 substitution pattern was used. The specific treatments employed in the experiment are outlined in Table 1.

Table 1: Treatments of the study

Treatment No.	Treatments Description	Treatment code
T1	Natural fallow (control)	CONT
T2	*Sesbania sesban*	SES
T3	*Crotalaria grahamiana*	CG
T4	*Tephrosia vogelii*	TEV
T5	*Mucuna pruriens*	MUP

T6	*Cajanus cajan*	CC
T7	*Desmodium uncinatum*	DU
T8	Sesbania + Crotalaria	SES+CG
T9	Sesbania + Tephrosia	SES+TEV
T10	Sesbania + Mucuna	SES+MUP
T11	Sesbania + Cajanus	SES+CC
T12	Sesbania + Desmodium	SES+DU

Soil characterization

Prior to establishing the experiment, soil sampling was undertaken and samples analyzed using standard procedures outlined by Okalebo et al. (2002). Samples were taken at a depth of 0-15 cm using a zig-zag sampling method. The analysis covered key soil parameters, including pH, total nitrogen, calcium, sodium, magnesium, potassium, phosphorus, and total organic carbon. The baseline soil status (as shown in Table 2) indicated that the pH was moderately low with P deficiency. The soil also had low organic carbon, an indication of low organic matter in the soil, whereas total N was moderate.

Table 2: Baseline soil characteristics

Parameter	Nutrient levels
pH	6.02
Total N (%)	0.32
Total C (%)	1.99
Available P (mg/kg)	4.09
Available Ca (mg/kg)	1253.20
Available K (mg/kg)	199.93
Available Mg (mg/kg)	237.60

Improved fallow harvesting and biomass quantification

Twelve months after planting, the improved fallows were harvested, and their biomass was quantified. Biomass was divided into foliage (leaves and twigs) and woody components (stems and branches), following the methodology described by Ndufa *et al.* (2009). Fresh weight was measured using a spring balance, and sub-samples were taken to quantify moisture content. These sub-samples were oven-dried at 60°C for 72 hours until a constant weight was obtained. The total above-ground biomass (AGB) was calculated by adding the dry weights of foliage and woody biomass.

Sorghum experiment establishment and management

Fresh foliage biomass was incorporated into the soil after planting and planting of sorghum (1st season), planted after 3 days. However, due to inadequate rainfall, the sorghum could not reach maturity therefore, a subsequent trial was established to test the residual effect of the treatments on sorghum grain yield. The second trial was established in September 2022. The plant spacing used was 25cm within rows and 75cm between rows. The test crop used was the Gadam sorghum variety. All plots received equal amounts of potassium (25 kg K_2O ha^{-1}) and phosphorus (50 kg P_2O_5 ha^{-1}), in the form of muriate of potash and triple super phosphate, respectively. Weeding of the experimental plot was done twice during the experiment period.

Sorghum harvesting and yield determination

Harvesting of sorghum was done 120 days after planting. Sun-drying of sorghum heads was done for a period of 5 days before threshing, and winnowing was done to obtain a clean grain yield. Further, sub-samples were oven-dried at 60 º C for 72 hours until a constant weight was obtained. The sorghum grain yield moisture content was then determined at 13%.

Statistical analysis

Data collected during the study were analysed using R software (version 4.3.1 for Windows). Analysis of variance was performed at a 95% confidence level. Means were separated using Duncan's multiple range tests, while Pearson correlation was used to evaluate relationships between different variables.

RESULTS AND DISCUSSION

Foliage and Total Above-Ground Biomass (AGB) of Selected Improved Fallow Species

The quantity of foliage biomass varied significantly among the treatments, as shown in Table 3 ($p<0.0001$). The highest foliage biomass was recorded in the *Desmodium uncinatum* treatment, which produced 15.69 t ha^{-1}, closely followed by *Crotalaria grahamiana* with 15.23 t ha^{-1}. In comparison, the control (natural fallow) produced the least foliage biomass of 3.19 t ha^{-1}. These results show that *Desmodium uncinatum* and *Crotalaria grahamiana* yielded 491.8% and 477.4% more foliage biomass than the control, respectively. The lowest foliage biomass among the single-species fallows was recorded in *Mucuna pruriens*, producing only 3.45 t ha^{-1}, which was just 8.2% higher than the control.

Among mixed-species fallows, the combination of *Sesbania sesban* and *Tephrosia vogelii* yielded the most foliage biomass, with 10.72 t ha^{-1}, a 236.1% increase over the control. However, mixed-species treatments generally resulted in lower foliage biomass compared to single-species treatments. For instance, *Sesbania* mixed with *Crotalaria* resulted in a reduction of 18.6% in foliage biomass compared to their single-species counterparts. Other reductions were observed in *Sesbania* mixed with *Desmodium* (7.9%) and *Sesbania* combined with *Cajanus cajan* (34.2%).

Table 3: Foliage and total above-ground biomass (AGB)

Treatment	Foliage biomass (t ha^{-1}) ± SE	Total AGB (t ha^{-1}) ± SE
Natural fallow (control)	3.19±0.96^{e}	3.19±0.96^{e}
Sesbania sesban	4.43±0.84^{e}	26.43±4.40^{d}
Crotalaria grahamiana	15.23±3.12^{a}	62.29±8.44^{a}
Tephrosia vogelii	5.36±0.48^{e}	42.94±5.97^{bc}
Mucuna pruriens	3.45±0.80^{e}	3.45±0.80^{g}
Cajanus cajan	5.83±0.75^{de}	21.98±2.98^{de}
Desmodium uncinatum	15.69±2.13^{a}	15.69±2.13^{ef}
Sesbania + Crotalaria	8.04±0.56^{cd}	38.24±0.31^{c}
Sesbania + Tephrosia	10.72±1.79^{b}	47.69±4.38^{b}
Sesbania + Mucuna	4.26±0.28^{e}	13.50±1.51^{f}
Sesbania + Cajanus	3.41±0.46^{e}	17.18±2.75^{ef}
Sesbania + Desmodium	9.32±1.40^{bc}	18.86±3.51^{ef}
$f_{(11,24)}$	31.22	65.56
p value	0.0001	0.0001

Note: *Means represented by the same letter down the column are not substantially different.*

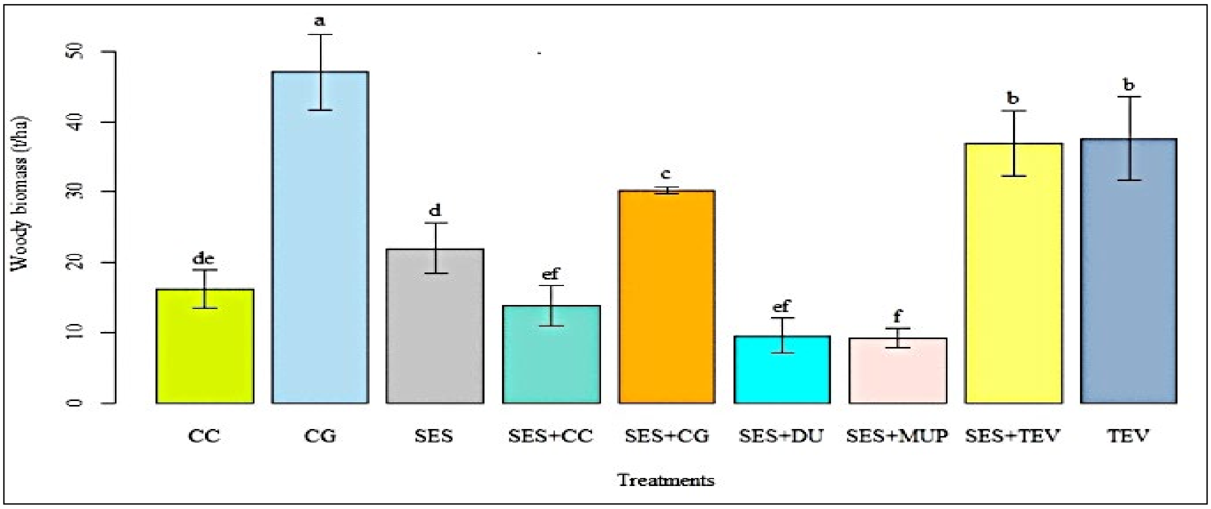
The AGB also differed substantially among the treatments ($p<0.0001$), with *Crotalaria grahamiana* yielding the highest AGB of 62.29 t ha^{-1}, followed by *Sesbania* mixed with *Tephrosia* (47.69 t ha^{-1}). The control had the lowest AGB (3.19 t ha^{-1}). Among the single-species fallows, *Crotalaria grahamiana* recorded the highest AGB, while *Mucuna pruriens* had the lowest (3.45 t ha^{-1}). *Tephrosia vogelii* yielded the second-highest AGB of 42.94 t ha^{-1}. Among the mixed-species fallows, *Sesbania sesban* combined with *Tephrosia vogelii* produced the highest AGB (47.69 t ha^{-1}); this was followed by SES+CG (38.24 t ha^{-1}), whereas *Sesbania* mixed with *Mucuna pruriens* recorded the lowest AGB (13.50 t ha^{-1}). However, the AGB in SES+MUP was 323.2% higher than the natural fallow (control).

The current study shows that biomass productivity is highly dependent on the species type, site characteristics, and planting configuration used, as shown in Table 3. In a previous study, Styger (2009) reported that improved fallow shrubs produced up to 20 t ha^{-1} of biomass. Sjögren (2015) further reported that 18 and 6-month-old fallows of *Sesbania sesban* yielded 61 t ha^{-1} and 21 t ha^{-1} of biomass, respectively. Stahl *et al.* (2002) also reported biomass productivity of up to 31.5 t ha^{-1}. In the current study, the least foliage biomass was recorded in Mucuna and Sesbania plots. Contrary to the present study, Walela *et al.* (2011) reported higher foliage biomass of up to 22.9 t ha^{-1} in one-year improved fallows. Similar to other studies, sole CG yielded higher total AGB compared to most fallows (Gathumbi *et al.* 2004; Ndufa *et al.* 2009; Maitra *et al.* 2025b; Maity *et al.* 2025).

Wood Biomass of Selected Improved Fallow Species

The amount of wood biomass also varied significantly across the different treatments ($p<0.0001$). *Crotalaria grahamiana* yielded the highest wood biomass at 47.06 t ha^{-1}, followed by *Tephrosia vogelii* (37.58 t ha^{-1}). Among the single-species treatments, *Crotalaria grahamiana* produced the most wood biomass, while *Cajanus cajan* recorded the least (16.15 t ha^{-1}), marking a 191.4% difference. Among the mixed-species treatments, the combination of *Sesbania sesban* and *Tephrosia vogelii* yielded the most wood biomass (36.97 t ha^{-1}), while *Sesbania* mixed with *Mucuna pruriens* produced the least (9.24 t ha^{-1}).

The production of woody biomass from improved fallows presents significant potential for smallholder farmers, both in meeting household fuelwood needs and enhancing soil fertility through the technology (Gathumbi *et al.* 2004). Similar to previous studies, Kimuli (2010) reported on soil fertility improvement and fuel wood production as the core stimulating factors for adoption of improved fallows in Kenya. Sjögren (2015) recorded woody biomass of up to



NB: Means represented by the same letter are not substantially different

Fig. 1: Wood biomass of different improved fallow species and planting configuration

2.9 t ha^{-1} from 18-months improved fallows. The current findings indicate that *Crotalaria grahamiana* and *Tephrosia vogelii* performed better in terms of wood biomass compared to *Sesbania sesban*, which aligns with the work of Gathumbi *et al.* (2004) and Sjögren (2015). The study also showed that mixed-species fallows generally produced lower wood biomass than pure stands, a trend observed by other researchers as well.

The study by Gathumbi *et al.* (2004) indicated that CG and TEV had higher woody biomass in comparison with *Sesbania* as observed in the current study. Further, Gathumbi *et al.* (2004) reported that *Cajanus cajan* gave the least woody biomass as reported in the present study with woody biomass decreasing in mixed stands in comparison to pure stands for selected improved fallow species. The decrease in woody biomass in mixed stands when compared with pure stands was also reported through the current study.

Foliage and total above ground biomass (AGB) ratio of selected improved fallow species

The current study shows that the ratio of foliage biomass (FB) to total AGB was significantly different (p<0.0001) among selected improved fallows and different planting configuration as shown in Table 4. The present study shows that foliage biomass in SES+DU accounted for 49.77% of the total AGB while in SES+MUP, it accounted for 31.7% of AGB. Generally, the contribution of FB to total AGB was >50%. The lowest contribution of FB to total AGB was recorded in TEV (12.67%). Among monocultures, the highest contribution of FB to AGB was recorded in CC (26.7%). In mixed-species fallows, the lowest contribution of FB to AGB was recorded in SES+CC (20.27%).

Table 4: Ratio of FB to total AGB (%)

Treatments	Foliage to Total AGB ratio (%)
SES	16.77 ± 1.00^{ef}
CG	24.30 ± 1.61^{cd}
TEV	12.67 ± 2.32^{f}
CC	26.70 ± 3.86^{bc}
SES+CG	21.00 ± 1.35^{cde}
SES+TEV	22.60 ± 4.25^{cde}
SES+MUP	31.70 ± 2.43^{b}
SES+CC	20.27 ± 4.67^{de}
SES+DU	49.77 ± 4.70^{a}
$f_{(8,18)}$	33.49
p value	0.0001

***NB**: Means represented by the same letter are not substantially different.*

Mensah *et al.* (2016) observed that foliage to wood biomass ratios declined considerably with increasing tree size, irrespective of the species. In a study conducted in Western Kenya, Jama et al. (2008) reported that foliage biomass was lower than woody biomass as observed in the present study. Further, Jama *et al.* (2008) observed that the percentage of wood to total AGB was more than 50% ranging from 50 to 65%. Among the species tested, the percentage of wood to total AGB was 66% in

Crotalaria grahamiana and 71% in *Tephrosia vogelii;* an indication that foliage biomass only accounted for 29 to 34%. Similarly, Ndufa *et al.* (2009) reported that recyclable biomass accounted for 17 to 50% of the total biomass. The primary goal of improved fallow technology for soil fertility restoration is maximizing foliage biomass. There exists a positive correlation between nutrient contribution from improved fallows and amount of biomass added to the soil (Alkharabsheh *et al.* 2023; Sagar *et al.* 2025; Ray *et al.* 2024, 2025).

Foliage biomass quality of selected improved fallows

The current study shows that there were significant variations in carbon content among various improved fallows as shown in Table 5 ($p<0.0001$). The highest carbon content of 54.3% was observed in DU while the lowest (49.3%) was recorded in CC biomass; a difference of 10.2%. In the current study, biomass from sole stands had higher carbon content in comparison with mixed species except CC. The highest biomass carbon content among mixed species was recorded in SES + TEV (53.5%) while the lowest was recorded in SES + MUP (52.8%). Among monoculture fallows, the trend observed in terms of carbon content was DU > MUP > SES > CG > TEV > CC while in mixed-species fallows, the trend was SES + TEV > SES + CC > SES + DU > SES + CG > SES + MUP.

Total nitrogen in foliage biomass of selected improved fallows differed significantly among treatments as shown in Table 5 ($p<0.0001$). The highest foliage biomass nitrogen content was recorded in SES+TEV (4.77%) while the lowest was observed in the control treatment (1.6%), a difference of 198.1%. Among sole stands, the highest foliage biomass nitrogen content was recorded in TEV (4.13%); this was higher than the control by 158.1%. The lowest foliage biomass nitrogen content among sole stands was recorded in DU (3.4%); this was however, higher than the control by 112.5%. The lowest nitrogen content among mixed-species fallows was recorded in SES+MUP (2.23%) which was 39.4% higher than the control.

Further, the current study shows substantial differences among treatments in terms of foliage biomass C/N ratio ($p<0.0001$) as shown in Table 5. The natural fallow had the highest C/N ratio of 33.7 while the lowest was observed in SES + TEV (11.3), a difference of 198.2%. Generally, biomass from improved fallows had C/N ratio of <25 in both sole and mixed-species stands. The highest C/N ratio in sole stands was recorded in DU (16) while the lowest was recorded in TEV (13). Among sole stands, the trend of biomass C/N ratio was DU > MUP > SES > CC > CG > TEV while in mixed-species, fallows, the trend was SES + MUP > SES + DU > SES + CC > SES + CG > SES + TEV as shown in Table 5.

In terms on nitrogen input from improved fallow species, significant variations were observed

Table 5: Total C, N, C/N ratio and N input of selected improved fallow species

Treatment	Total N (%)	Total C (%)	C/N ratio	N input (Kg ha $^{-1}$)
CONT	1.60±0.10^{f}	53.63±0.76^{abc}	33.70±2.08^{a}	5.17±1.85^{f}
SES	3.83±0.35^{bcd}	53.80±0.70^{abc}	14.3±1.53^{cd}	17.20±4.75^{de}
CG	4.10±0.20^{bc}	53.67±0.15^{abc}	13.3±0.58^{cde}	62.07±9.68^{a}
TEV	4.13±0.21^{ab}	53.50±0.79^{abc}	13.0±0.01^{de}	22.27±3.06^{d}
CC	3.80±0/26^{bcd}	49.30±0.40^{d}	13.0±1.00^{de}	22.17±3.46^{d}
DU	3.40±0.53^{d}	54.30±0.10^{a}	16.0±2.65^{c}	52.63±1.65^{b}
MUP	3.70±0.56^{bcd}	54.13±0.50^{ab}	14.7±2.08^{cd}	12.47±0.91^{ef}
SES+CG	4.23±0.35^{ab}	53.07±0.25^{bc}	12.7±1.53^{de}	33.97±2.93^{c}
SES+TEV	4.77±0.21^{a}	53.47±0.42^{abc}	11.3±0.58^{e}	51.17±8.90^{b}
SES+MUP	2.23±0.15^{e}	52.80±0.95^{c}	23.7±1.53^{b}	9.47±0.42^{ef}
SES+CC	3.80±0.50^{bcd}	53.40±0.89^{abc}	14.3±1.53^{cd}	13.03±2.89^{ef}
SES+DU	3.47±0.40^{cd}	53.37±0.65^{abc}	15.7±1.53^{cd}	32.53±7.50^{c}
$f_{(11,24)}$	18.50	13.31	49.12	42.67
p value	0.0001	0.0001	0.0001	0.0001

NB: *Means denoted by the same letter are not significantly different.*

amongst treatments as shown in Table 5 (*$p<0.0001$*). The highest nitrogen input of 62.07 kg ha^{-1} was noted in CG while the minimum (5.17 kg ha^{-1}) was recorded in the control; a difference of more than 10 folds. The second highest N input was recorded in DU (52.63 kg ha^{-1}). Least N input of 12.47 kg ha^{-1} in sole stands was recorded in CC which was 141.2% higher than the control. Among mixed-species fallows, SES + TEV had the highest N input of 51.17 kg ha^{-1} while SES + MUP recorded the minimum.

A substantial positive linear relationship was observed between foliage biomass quantities and N input as shown in Fig. 2 (*$R = 0.95$, $p<0.0001$*). Approximately 95% of changes observed in N input can be attributed to foliage biomass quantities of the particular improved fallow. The study thus shows that improved fallow species that yield higher foliage biomass result to high N input.

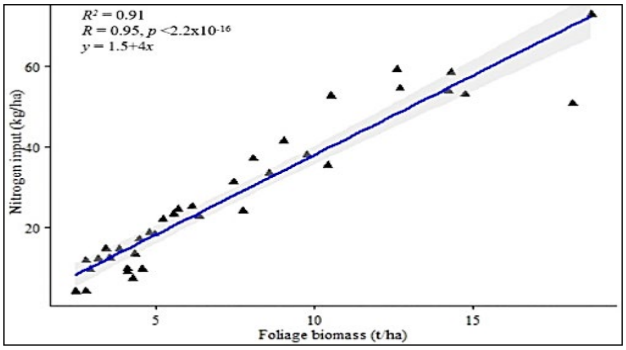


Fig. 2: Relationship between foliage biomass and N input from fallow species

While Pali *et al.* (2004) reported higher N fixation in CC (97%) than SES (84%), the current study revealed that SES biomass had higher nitrogen (3.83%) than CC (3.7%). The net N input is a function of N fixation rate in addition to N export from the field. Despite the benefits accrued to improved fallows in terms of N fixation, Kisaka *et al.* (2023) noted that no improved fallow was suitable for maintaining soil fertility in a continuous cropping system due to N removal from woody components of improved fallows. The current study shows that recyclable N was < 100 kg ha^{-1}. Gathumbi *et al.* (2004) recorded a decrease in N input in mixed species fallows. Similar to the current study, Gathumbi *et al.* (2004) relayed positive linear relationship between foliage biomass and N yield (input).

The carbon to nitrogen (C/N) ratio is critical in composting processes, as it reflects the balance of key chemical components necessary for microbial growth and metabolic activity (Mwadalu *et al.* 2025). A lower C/N ratio facilitates quicker nitrogen release into the soil, making it readily available for crop uptake (Watson *et al.* 2002; Maina *et al.* 2025). When the C:N ratio exceeds 35, microbial immobilization occurs (Malo *et al.* 2025), while a ratio between 20 and 30 promotes a balance between nitrogen mineralization and immobilization. Organic matter consistently contains more carbon than nitrogen, as demonstrated in this study (Watson *et al.* 2002).

Sairam, M., Maitra, S., Sagar, L., Biswas, T., Bárek, V., Brestic, M. and Hossain, A., 2025. Application of precision nutrient tools for the optimization of fertilizer requirements and assessment of the growth and productivity of maize (*Zea mays* L.) in the northeastern Ghat of India. *J. Agric. Food Res.*, 21:101958, https://doi.org/10.1016/j.jafr.2025.101958

As observed in the current study, Gathumbi *et al.* (2004) and Ndufa *et al.* (2009) reported that N yield was positively correlated with biomass quantities of the selected improved fallow species. Ndufa *et al.* (2009) and Walela *et al.* (2011) reported recyclable fallow biomass N ranging from 70 to 313 kg ha^{-1}; these quantities are higher than those reported in the current study where recyclable biomass N was <70 kg ha^{-1}.

Effect of selected improved fallow species on sorghum grain yield

There were substantial differences in sorghum grain yield across the various improved fallow treatments ($p<0.0001$) as shown in Table 6. The highest grain yield was achieved by the combination of *Sesbania sesban* and *Desmodium uncinatum*, which produced 1.80 t ha^{-1}, double that of the control plot, which yielded 0.90 t ha^{-1}. Among the single-species fallows, *Desmodium uncinatum* also performed exceptionally well, producing yields that were considerably higher than the other species.

In addition to grain yield, the number of sorghum heads per hectare differed significantly ($p<0.001$) between treatments. The highest number of sorghum heads, 6,877 heads per hectare, was recorded in the *Sesbania sesban* and *Desmodium uncinatum* treatment, which was 82.3% greater than that in the natural fallow. These findings suggest that integrating specific improved fallow species, such as *Sesbania* and *Desmodium*, into cropping systems can greatly enhance grain yield and yield components.

Table 6: Residual sorghum grain yield under different improved fallow species

Treatment	Yields (t ha^{-1})	Sorghum heads ha^{-1}
CONT	0.90±0.08^{g}	3772.33±1078.42^{c}
SES	1.42±0.08^{cd}	5433.33±332.07^{a}
CG	1.14±0.13^{ef}	4344.33±511.16^{bc}
TEV	1.20±0.23^{def}	4378.00±686.30^{bc}
MUP	1.51±0.15^{bc}	4511.00±332.07^{bc}
CC	1.10±0.14^{ef}	4561.00±297.91^{bc}
DU	1.75±0.08^{a}	6683.33±332.07^{a}
SES+CG	1.65±0.07^{ab}	5478.00±1619.45^{a}
SES+TEV	1.28±0.07^{def}	4450.00±938.93^{bc}
SES+MUP	1.33±0.03^{cde}	5100.00±116.36^{bc}
SES+CC	0.91±0.14^{g}	3611.00±308.98^{c}
SES+DU	1.80±0.08^{a}	6877.67±309.43^{a}
$f_{(11,24)}$	18.24	4.40
p value	0.0001	0.001

***NB:** Means represented by the same letter do not differ significantly.*

Further analysis showed a positive linear relationship between the number of sorghum heads per hectare and sorghum grain yield (*R=0.84, p<0.0001*) as shown in Fig. 3. As the number of sorghum heads increased, grain yield rose accordingly. This indicates that improved fallow species enhance sorghum productivity, likely due to their ability to improve soil status with nitrogen through biological nitrogen fixation. Several previous studies corroborate this finding, showing that improved fallows boost crop yields by increasing nitrogen availability in the soil (Kaya *et al.* 2007; Jama *et al.* 2008; Mwadalu *et al.* 2022; Sairam *et al.* 2025).

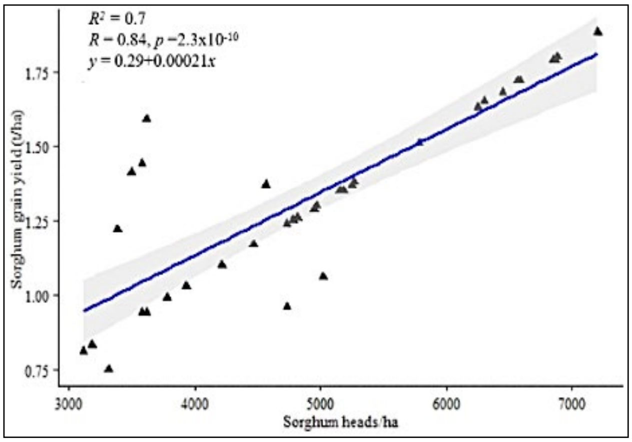


Fig. 3: Relationship between sorghum heads and sorghum grain yield

A positive linear correlation was also observed between the quantity of FB incorporated into the soil and sorghum grain yield as shown in Fig. 4. As more foliage biomass was added, the grain yield of sorghum increased, suggesting that the mineralization of nitrogen from the decomposed biomass contributed to higher nutrient availability. The present results are consistent with findings by Mamuye *et al.* (2020), who reported that short-term improved fallows significantly enhanced maize productivity by improving soil fertility, pH, and nitrogen levels. However, their study also highlighted the importance of adding phosphate fertilizer to enhance nitrogen fixation in legume-based fallows (Kaya *et al.* 2007; Jama *et al.* 2008; Ghosh *et al.* 2021; Cheruto *et al.* 2025).

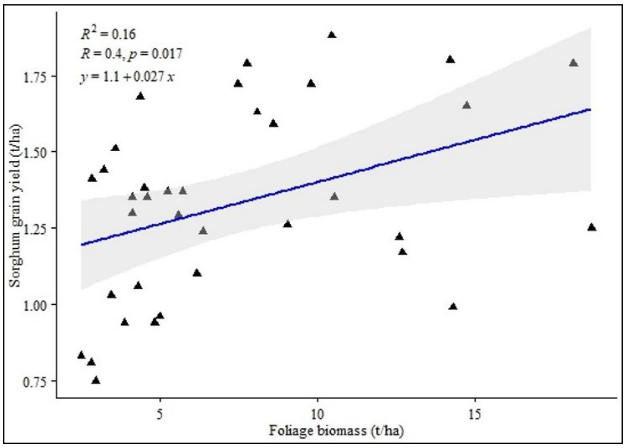


Fig. 4: Relationship between foliage biomass and sorghum grain yield

In addition, a linear relationship between nitrogen input from improved fallows and sorghum grain yield was reported (R=0.33, *p=0.05*) as shown in Figure 5. Sorghum grain yields increased with higher nitrogen inputs, highlighting the critical role of nitrogen in determining crop productivity. Research by Partey *et al.* (2017) and a review by Gumo *et al.* (2025) showed that with sufficient water and adequate levels of phosphorus and potassium, nitrogen inputs between 100-200 kg ha^{-1} could result in maize yields of 4-5 tons per season. Though similar studies on the impact of improved fallows on sorghum production are scarce, Mamuye *et al.* (2020) observed that improved fallows can boost crop yields by as much as 74% in the first season and 46% in the following season, though the labour involved in managing the fallows may sometimes outweigh the yield gains.

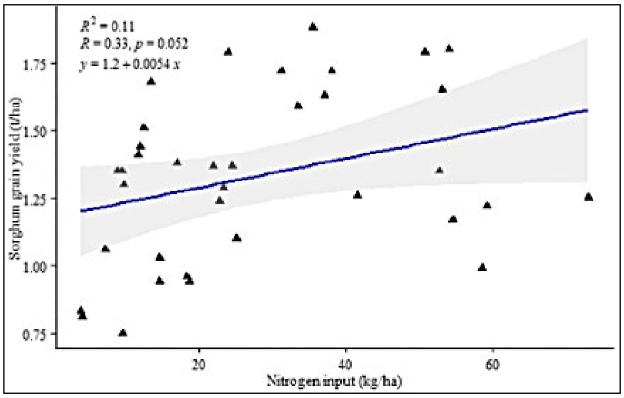


Fig. 5: Relationship between nitrogen input and sorghum grain yield

CONCLUSION AND RECOMMENDATIONS

This study demonstrates that the productivity of improved fallow species is substantially dependent on the type of species used and their planting arrangement. Generally, single-species fallows were found to produce higher foliage and woody biomass compared to mixed-species combinations. Nonetheless, for farmers aiming to benefit from both nutrient cycling through biomass production and fuelwood generation, mixed-species fallows present a viable option. The combination of *Sesbania sesban* and *Tephrosia vogelii* emerged as the most promising, producing 10.72 t ha^{-1} of foliage biomass and 36.97 t ha^{-1} of woody biomass, making it ideal for both soil fertility enhancement and fuelwood supply. On the other hand, in households where fuelwood is not a priority, *Desmodium uncinatum* offers a superior option, as it recorded the highest foliage biomass (15.69 t ha^{-1}) in the present study, which is essential for soil fertility improvement.

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