Effects of farmyard manure and *Desmodium* intercropping on forage grass growth, yield, and soil properties in different agro-ecologies of Upper Blue Nile basin, Ethiopia

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**Abstract:** Enhancing forage production through organic fertilization is an important option for smallholder farmers. In north-western Ethiopia, a field experiment was conducted to assess the effects of farmyard manure (FYM) and *Desmodium intortum* intercropping on the morphological characteristics, dry matter yield, and crude protein yield of Napier and desho grass, as well as their effects on soil physicochemical properties. The experiment was carried out in three replications using randomized complete block design with factorial arrangements at the Aba Gerima and Guder watersheds, which represent midland and highland agro-ecologies, respectively. The treatments used were Napier or desho grass alone [control], Napier or desho with *Desmodium*, Napier or desho with FYM, and Napier or desho combined with *Desmodium* and FYM. The results showed that fertilizer treatments had positive influence on morphological characteristics in both watersheds. The dry matter yield and crude protein yield were higher (p < 0.001) with FYM as well as FYM combined with *Desmodium* (9.1 to 9.6 t ha⁻¹ and 866.7 to 792.4 kg ha⁻¹) at Aba Gerima and (7.0 to 7.1 t ha⁻¹ and 795.3 to 510.5 kg ha⁻¹) at Guder, respectively. The fertilizer treatments, that is, FYM and combined use of FYM and *Desmodium* groups, showed soil organic carbon (18.4% and 20.5%) and available phosphorous (16.3% and 23.0%) content increments over the control at the Aba Gerima watershed. The findings suggested that applying FYM and combining FYM and *Desmodium* improved...
forage grass growth and yield by maintaining soil health in the dryland areas of Ethiopia’s Upper Blue Nile basin.

**Subjects:** Agriculture & Environmental Sciences; Plant & Animal Ecology; Soil Sciences

**Keywords:** Desmodium intortum; dryland; dry matter yield; farmyard manure; fertilizer treatments; forage grasses

1. Introduction

In the tropics, livestock production is an important economic activity that produces both food and non-food commodities. The Ethiopian livestock sub-sector contributes 10% to total export earnings, primarily through the export of ruminant animals (Food and Agriculture Organization of the United Nations (FAO), 2019). Furthermore, the sector accounts for 45% of agricultural GDP, including economic values and non-marketed services, such as draft power and manure (Food and Agriculture Organization of the United Nations (FAO), 2019) and 37% to 87% of household income (Behnke & Metaferia, 2013). Despite its significant contribution, livestock productivity in Ethiopia is lower than the African average, owing primarily to feed shortages both in quality and quantity (Gelayenew et al., 2020). To exploit the potential of livestock, use of improved forages is one of the strategies in Ethiopia smallholder farmers (Tolera et al., 2012).

The major feed resources in Ethiopia are grazing pasture, crop residue, improved feed, hay, by-products, and others, which contribute 54.5%, 31.1%, 0.57%, 7.4%, 2.0%, and 4.4% of the feed demand, respectively (Central Statistical Agency (CSA), 2021). However, the area of grazing land is decreasing from time to time due to poor management and encroachment of crop cultivation (Food and Agriculture Organization of the United Nations (FAO), 2004). This decrease is accompanied by an increase in the role of crop residues, which are generally of low nutritional value (Zerbini & Thomas, 2003). Thus, the role of improved forage grass and legume species with high biomass yield and nutritional value is very important (Adugna et al., 2012). Nevertheless, its contribution to livestock feed resources was less than 1% (Central Statistical Agency (CSA), 2021). According to Lemma et al. (2010), only 0.15% of smallholder farmers practice on-farm improved forage production. Land shortage, low access and high cost of seed and planting materials, and lack of awareness of their importance and production are the major impediments to low practice of improved forage production by smallholder farmers (Abebe et al., 2018; S. Mengistu et al., 2021).

Several grass and legume forage crops have been identified and introduced into Ethiopian farmer fields over the last five decades. Among the adapted forage grasses are Napier grass (*Pennisetum purpureum*) and desho grass (*Pennisetum pedicellatum*), which were the most common forages used by livestock producers in northwestern Ethiopia (Asmare et al., 2017; Zewdu et al., 2002). In addition, the legume *Desmodium intortum* has been introduced and is being grown on various land uses as a mixed pasture, with multiple advantages over the monoculture of forage grasses. *Desmodium’s* common benefits included forage production, nitrogen fixation, and soil erosion control (A. Mengistu et al., 2017). The growth, yield, and nutritive value of forage crops are a function of various factors, such as soil fertility, agro-ecology, fertilizer type, land preparation, and management. The dominating soils in the experimental locations are luvisols in midland agro-ecologies and acrisols in highland agro-ecologies (Ebabu et al., 2020), which are ideal for a wide range of plant species. Fertilization practices for forages in Ethiopia are not uniform in terms of application or fertilizer form (Asmare et al., 2016). The amount of chemical fertilizer applied to crop production is low in Ethiopia due to its high cost for resource-poor smallholder farmers (Endale, 2016). Furthermore, inorganic fertilizers do not last long in the soil and must be reapplied frequently. Farmyard manure (FYM) is an organic fertilizer that improves the chemical properties of the soil, specifically nitrogen (N), phosphorous (P), and potassium (K), allowing for increased growth and sustainable production (Eghball et al., 2004).
Several researchers reported that FYM and legume intercropping improved forage morphological characteristics, biomass yield, nutritive value, and soil physicochemical properties (Ma et al., 2020; Maleko et al., 2019; Utamy et al., 2018; Zewdu et al., 2002). However, there is limited research on the extent to which integration of forage grasses with FYM and legumes like Desmodium intortum as fertilizer treatments affects the growth and yield of forage grasses. Moreover, there is limited information on soil physicochemical properties under different climatic conditions for longer production times in the study areas. Therefore, the study was carried out to assess the effects of FYM and Desmodium intortum on the growth characteristics, yield, and soil physicochemical properties of Napier and desho grass in different agro-ecologies for sustainable and environmentally friendly forage production in the Upper Blue Nile basin, Ethiopia.

2. Materials and methods

2.1. Description of study areas

The field experiment was undertaken in rain-fed conditions from May 2018 to December 2019 in two selected watersheds in the Amhara Region, Upper Blue Nile basin, Ethiopia: Aba Gerima and Guder (Bas-eguana), representing midland and highland agro-ecologies, respectively (Figure 1).

The Aba Gerima watershed is found in the Bahir Dar Zuria district and lies within 37°29’35”E-37°30’52”E and 11°38’51”N-11°40’34”N with an altitude of 1970 m above sea level and a total area of 426 ha. The experimental years’ rainfall and temperature were collected from the northwestern Bahir Dar meteorological station. The total rainfall at Aba Gerima watershed in the 2018 and 2019 cropping seasons was 1330 and 1786 mm, respectively. The annual mean minimum and maximum temperatures varied from 13.0°C to 27.5°C for the year 2018, while for 2019 the value was 13.6°C to 27.6°C (Figure 2). Furthermore, the mean annual rainfall at nearby meteorological stations was 1343 mm from 1999 to 2015, with mean annual minimum and maximum temperatures ranging from 13°C to 27°C (Ebabu et al., 2019). The main livelihoods for farmers in the watershed are mixed crop cultivation and livestock rearing. The main livestock species reared by most farmers are cattle (Bos primigenius), sheep (Ovis aries), goats (Capra hircus), and donkeys.

Figure 1. Map of study areas.
(Equus africanus). In the watershed, finger millet (Eleusine coracana), maize (Zea mays), and tef (Eragrostis tef) are the major crops grown (Ebabu et al., 2019).

The Guder watershed is located at an elevation of 2577 m above sea level within 36°54′09″E–36°55′55″E and 10°59′34″N–11°01′01″N in the district of Fagta Lekoma. The pattern of rainfall is similar to that in Aba Gerima, and the values were 2438 and 2302 mm for the 2018 and 2019 cropping seasons, respectively. In 2018, the average minimum and maximum temperatures ranged between 10.2°C and 25.0°C, and 10.9°C and 25.3°C in 2019 (Figure 3). Among the livestock species reared in the watershed are cattle (Bos primigenius), sheep (Ovis aries), and horses (Equus caballus). Tef (Eragrostis tef), barley (Hordeum vulgare), wheat (Triticum aestivum), and potato (Solanum tuberosum) are the most important crops grown in the watershed (Ebabu et al., 2019).

2.2. Treatments and experimental design
The entire experimental land was 630 m² and comprised a total of 24 plots with three blocks (replications), each of which comprised eight plots (4 m x 3 m each) with a 1-m buffer zone.
between plots. For two years, the experiment was conducted with a randomized complete block design in factorial arrangements (two forage grasses by four fertilizer treatments) and three replications. The forage grasses (Napier grass, Pennisetum purpureum, acc. 16,791; and desho grass, Pennisetum pedicellatum, Kulumsa DZF-592) were collected from a nearby research center (Andassa Livestock Research Center), which were well adapted to the area, having good biomass yield with better nutritive value (Zewdu et al., 2003). The legume Desmodium intortum was brought from Debre Zeit Agricultural Research Center with a 90% germination percentage. The treatments used were Napier grass alone, desho grass alone, Napier grass + Desmodium, desho grass + Desmodium, Napier grass + FYM, desho grass + FYM, Napier grass + Desmodium + FYM and desho grass + Desmodium + FYM, a total of eight treatment combinations in two watersheds for two consecutive years.

2.3. Sampling and analysis of soil
Before applying treatments (farmyard manure and Desmodium intortum) in May 2018 (the first year), one-kg soil samples were collected from each plot with a soil auger at 0–20 cm depth, and a composite sample was collected for each watershed per treatment. Furthermore, at the end of the experiment in December 2019 (the second year), soil samples were collected from each plot in the same manner as described above. In a shed, both soil samples were air dried and crushed with a mortar before being passed through a 2 mm sieve for physicochemical analysis. The soil samples were mixed 1:2.5 with water and mechanically shaken for 1 h until a uniform solution was formed for the pH and electrical conductivity (EC) analyses. After calibration with standard solutions, the sample suspensions were measured with a pH and conductivity meter. Five hundred milligram of soil was taken for total nitrogen (TN) and soil organic carbon (SOC) analysis, and TN and SOC were determined using an automatic carbon/nitrogen analyzer (CN coder; Shimadzu Japan). The method of Bray and Kurtz (1945) was used to calculate available phosphorus (Pav). Exchangeable cations were extracted with 1 M ammonium acetate at pH 7.0 and measured using inductively coupled plasma spectrometry after shaking for 1 h at 120 rpm (Thomas, 1982).

Soil samples were identified before the experiment began, and the proportions of clay, silt, and sand content were classified as 67.5%, 19.6%, and 12.9% at Aba Gerima and 58.7%, 30.6%, and 10.7% at Guder, respectively, both of which were classed as clay in texture. In addition, the pH at Guder was 5.1–5.3 (strongly acidic) and at Aba Gerima, 5.3–5.8 (moderately acidic) before the application of treatments (Table 1). The dominant soils in the experimental areas are classified as luvisols at Aba Gerima and acrisols at Guder (Ebabu et al., 2020).

| Table 1. Soil properties of experimental plots prior to treatment application (May, 2018) and farmyard manure properties |
|--------------------------------------------------|------------------|------------------|
| **Soil properties**                        | **Experimental sites** | **Farmyard manure properties** |
| | **Aba Gerima** | **Guder** | |
| SOC (%) | 1.29 | 3.98 | 17.5 |
| TN (%) | 0.13 | 0.36 | 1.5 |
| Pav (mg kg⁻¹) | 8.4 | 14.9 | 32.8 |
| ECEC (cmol, kg⁻¹) | 13.0 | 6.1 | 82.0 |
| EC (mSm⁻¹) | 6.8 | 4.0 | 0.34 |
| pH | 5.5 | 5.2 | 7.4 |
| **Soil texture** | | | |
| Sand (%) | 12.9 | 10.7 | |
| Silt (%) | 19.6 | 30.6 | |
| Clay (%) | 67.5 | 58.7 | |
| **Soil textural class** | Clay | clay | |

SOC: soil organic carbon; TN: total nitrogen; Pav: available phosphorus; ECEC: effective cation exchange; EC: electric conductivity, and pH: soil reaction
2.4. Land preparation, planting, and management

The experimental land was ploughed three times at the onset of the rainy seasons before planting. The FYM (cattle manure with small amount of roughage feed residues and urine) was collected from Bahir Dar University, Zenzelma campus. The FYM was applied at the rate of 12 t ha⁻¹ (Ayichew 2017)) for Napier and other similar grasses in dry matter basis. In the field FYM was first crushed and mixed with the soil manually by disturbing the plot for ease of decomposition one month before planting of forage grasses. The forage grasses were planted by selecting healthy root splits. Desho grass was spaced 50 cm between both inter and intra rows (Yirgu et al., 2017). While, Napier grass was planted 1 m inter-rows and 50 cm intra-row spacing. When Napier and desho grasses reach at the age of one month, the plot was first manually weeded and harrowed and drilled *Desmodium* seed between two forage grass rows with 5 kg ha⁻¹ seed rate; at 1 cm soil depth kept the seed and covered slightly for ease of germination (Lice & Vin, 2016). Weed control and harrowing were done frequently for each year manually as necessary to ensure weed-free plots.

2.5. Data collection and measurements

Plant height (PH), leaf length (LL), leaf width (LW), and number of tillers per plant (NTPP) were all measured on five randomly chosen plants from the middle rows (Zewdu et al., 2003). For good biomass yield and nutritional value, Napier grass was harvested when it reached 1 m in height (Zewdu et al., 2002), while desho grass was harvested at a height of 50–60 cm in the plot for similar properties (Bereket et al., 2016). By removing the boundary rows from the plot, harvesting was done by hand with a sickle, leaving a stubble height of roughly 5–10 cm above the ground (Lounoglwan et al., 2014). Sub-samples were taken from each plot by weighing with a sensitive balance (0.01 g) and drying in an oven at 65°C for 72 hours until constant weight was achieved to calculate dry matter (DM) percentage and subsequent chemical analysis.

The dry matter yield (DMY) was computed by multiplying the dry matter percentage with the fresh biomass taken from the sampling area and converting the result to t ha⁻¹. Furthermore, the leaf-to-stem ratio (LSR) was calculated by harvesting leaves and stems separately from center rows in a plot with a sampling area of 1 m², then partitioning the harvested sample into leaf and stem components and drying the sample for DM yield estimation, as indicated above. However, root variables like root length (RL) and number of roots per plant (NRPP) were measured for each treatment with its replication once in the second year of harvest by careful excavation and pulling with soil to avoid root damage and losses. Then, the excavated roots with soil were transferred from the field to the laboratory in a plastic container, placed in a bucket of water, and washed gently with running tap water to clean off the remaining soil and other debris. Finally, the shoots and roots were carefully separated using scissors and dried in a 65°C oven for 72 h until they attained a steady weight for DM determination. For each treatment, a shoot-to-root ratio (S: R) was computed based on shoot and root biomass yield (RBY).

2.6. Statistical analysis

Data from the evaluation of improved fodder grasses (morphological traits, yield, and soil physicochemical parameters) were pooled across the year and evaluated using two-way ANOVA for each watershed/location using Statistical Analysis Software SAS_JMP13 (SAS, 2016). However, below ground root characteristics were one-year data and analyzed following the same procedure as above. Tukey’s honest significance test was used to indicate significant differences between treatment means at p < 0.05.

3. Results

3.1. Effects of fertilizer treatments on the morphology and yield of forage grasses in the aba gerima watershed

The effects of morphological characteristics and yield of two forage grasses under four fertilizer treatments are shown in Table 2. Plant height, LL, LW, LSR, and yield all differed significantly (P < 0.001) between Napier and desho grass in the Aba Gerima watershed. Similarly, when
Table 2. Effects of fertilizer treatments and production years on the morphology and yield of forage grasses in the aba gerima watershed

| Variables                     | PH | LL  | LW | NTTP plant^-1 | LSR | DMY t ha^-1 | CP g kg^-1 | CPY kg ha^-1 |
|-------------------------------|----|-----|----|----------------|-----|-------------|------------|--------------|
| **Forage grasses**            |    |     |    |                |     |             |            |              |
| Napier grass                  | 101.1^a | 73.9^a | 2.8^a | 35.3^b         | 2.3^a | 9.2^a       | 91.3^a     | 887.8^a      |
| Desho grass                   | 50.7^b  | 29.1^b  | 1.5^b  | 96.9^a         | 1.6^b  | 6.1^b       | 69.4^b     | 468.4^b      |
| SL                            | ***   | ***  | *** | ***            | ***  | ***         | ***        | ***          |
| SEM                           | 1.12  | 0.64 | 0.03 | 2.54           | 0.04  | 0.18        | 2.13       | 25.71        |
| **Fertilizer treatments**     |    |     |    |                |     |             |            |              |
| Control                       | 71.4^b  | 48.9^c  | 2.1   | 56.6^a         | 1.9   | 5.9^a       | 85.0       | 536.7^b      |
| Desmodium                    | 72.1^b  | 49.6^c  | 2.1   | 59.7^bc        | 2.0   | 6.1^b       | 78.6       | 604.8^b      |
| FYM                          | 73.5^a  | 53.0^ab | 2.2   | 72.8^bc        | 2.0   | 9.6^a       | 78.2       | 762.2^a      |
| Desmodium & FYM              | 81.5^a  | 54.6^a  | 2.2   | 75.4^a         | 2.0   | 9.1^a       | 79.5       | 808.8^a      |
| SL                            | ***   | ***  | **  | ns             | ***  | ns          | ***        | ***          |
| SEM                           | 1.59  | 0.89 | 0.04 | 3.59           | 0.08  | 0.26        | 3.01       | 36.37        |
| **Year**                      |    |     |    |                |     |             |            |              |
| 2018                          | 74.8  | 50.6 | 2.1^a  | 36.3^b         | 1.9^a  | 3.9^a       | 81.1       | 321.6^b      |
| 2019                          | 77.1  | 52.3 | 2.2^a  | 95.9^a         | 2.0^a  | 11.5^a      | 79.6       | 1034.7^a     |
| SL                            | ns    | ns   | **   | ***            | *     | ***         | ns         | ***          |
| SEM                           | 1.12  | 0.64 | 0.03 | 2.54           | 0.04  | 0.18        | 2.13       | 25.71        |
| Overall mean                  | 75.9  | 51.5 | 2.2   | 66.1           | 1.9   | 7.7         | 80.3       | 678.1        |
| CV (%)                        | 7.3   | 6.1  | 6.8   | 18.8           | 11.5  | 11.7        | 10.4       | 18.6         |
| Interaction                   |    |     |    |                |     |             |            |              |
| F*FS                          | ns    | ns   | ns    | ns             | ns    | ns          | ns         | *            |
| F*Y                           | ns    | ns   | ns    | ns             | ns    | ***         | ns         | *            |
| FS*Y                          | ***   | ns   | ***   | ***            | ***   | ***         | ns         | ***          |
compared to control and Desmodium with forage grasses, most measured morphological characteristics (PH, LL, and NTPP) were significantly improved in both FYM and the combined use of FYM and Desmodium. Mean PH was higher with FYM as well as Desmodium (81.5 cm) and FYM (73.5 cm) as compared to control (71.4 cm) and with Desmodium alone (72.1 cm). Moreover, NTPP followed the same trend, with 75.4 in the combined use of FYM and Desmodium and 72.8 in FYM treatment. All growth parameters were significantly higher for Napier grass than for desho grass, except for NTPP, for which the value for desho grass was significantly higher (96.9 versus 35.3). Other growth and yield parameters showed significant ($P < 0.001$) variation in the forage grass year interaction, with the exception of LL and crude protein (CP) content.

The dry matter and crude protein yield (CPY) followed similar trends with growth characteristics, and the value was higher in FYM as well as in the combined use of FYM and Desmodium than in control and Desmodium treatments at the Aba Gerima watershed. We found that Napier grass had higher DMY and CPY than desho grass. The CP content of Napier grass was higher than that of desho grass, though no difference was observed between fertilizer treatments. In addition, all growth and yield parameters were higher in 2019 than in 2018. The DMY was increased by 2.2%, 39.7%, and 34.8% in the second year for forage grasses treated with Desmodium, FYM, and a combination of FYM and Desmodium, respectively, compared to the control at Aba Gerima.

### 3.2. Effects of fertilizer treatments on the morphology and yield of forage grasses in the guder watershed

In Table 3, the effects of fertilizer treatments and production year of two forage grasses on growth properties and yield are presented for the Guder watershed. Forage growth characteristics followed a similar pattern to that of the Aba Gerima watershed and the values were significantly higher ($P < 0.001$) in FYM as well as in the combined use of FYM and Desmodium treatment groups. The height of Napier grass was longer than that of desho grass, while NTPP was higher in desho grass than in Napier grass. Moreover, similar to Aba Gerima, all growth properties showed higher value in 2019 than in the 2018 production year.

In terms of DMY, CPY and CP content, the tendency was similar with Aba Gerima in that forage grasses with FYM and combined use of FYM and Desmodium significantly varied ($P < 0.001$) as compared to control. In addition, there was significant variation between production years in forage grasses and fertilizer treatments, while the CP content of forage grasses did not vary within years. The interactions between the forage species and fertilizer treatments did not vary in most growth and yield parameters, though some change was observed between forage species and year interaction in all growth and yield parameters.

### 3.3. Forage grass root biomass yield and shoot-to-root ratio

Tables 4 and 5 show the effects of fertilizer treatments on belowground root characteristics in the Aba Gerima and Guder watersheds, respectively. Fertilizer treatments had a significant ($p < 0.05$) effect on RBY but not on RL, S: R, root soil organic carbon (RSOC), or root total nitrogen (RTN) in Aba Gerima watershed. There was lower RBY in forage grasses with Desmodium as compared to other fertilizer treatment groups. In addition, RL and RBY of Napier grass were higher than that of desho grass, while NRP, RSOC, and RTN showed lower values for Napier grass in the same watershed.

On the other hand, fertilizer treatments showed no variation in all root characteristics and root chemical properties at the Guder watershed. Moreover, in the same watershed except for RTN, the other root characteristics did not show significant ($p > 0.05$) variation between Napier and desho grass.

### 3.4. Fertilizer treatments effects on soil physicochemical properties

The soil physicochemical properties after treatment application are shown in Figure 4 and 5 for Aba Gerima and Guder watersheds, respectively. Soil physical properties like bulk density (BD) varied between treatment groups in both watersheds. Both Napier and dseho grass planted with FYM and
Table 3. Effects of fertilizer treatments and production years on morphological characteristics and yield of forage grasses in the guder watershed

| Variables                  | PH       | LL       | LW      | NTPP plant⁻¹ | LSR     | DMY t ha⁻¹ | CP g kg⁻¹ | CPY kg ha⁻¹ |
|----------------------------|----------|----------|---------|--------------|---------|------------|-----------|-------------|
| Forage grasses             |          |          |         |              |         |            |           |             |
| Napier grass               | 88.2ᵃ    | 70.7ᵃ    | 2.2ᵇ    | 30.7ᵇ       | 2.3ᵇ   | 5.6        | 131.8ᵃ    | 795.3       |
| Desho grass                | 42.7ᵇ    | 24.5ᵇ    | 1.4ᵇ    | 97.3ᵇ       | 1.9ᵇ   | 6.0        | 98.2ᵇ     | 510.5       |
| SL                        | ***      | ***      | ***     | ***          | ***    | ns         | ***       | ***         |
| SEM                       | 1.06     | 0.67     | 0.03    | 2.51         | 0.04   | 0.18       | 2.04      | 28.30       |
| Fertilizer treatments      |          |          |         |              |         |            |           |             |
| Control                    | 61.3ᵇ    | 45.9ᵇ    | 1.7ᵇ    | 58.3ᵇ       | 2.0    | 4.4ᵇ       | 111.9ᵇ    | 454.2ᵇ      |
| Desmodium                 | 62.1ᵇ    | 45.6ᵇ    | 1.7ᵇ    | 57.7ᵇ       | 2.1    | 4.7ᵇ       | 108.8ᵇ    | 498.2ᵇ      |
| FYM                       | 70.4ᵃ    | 50.2ᵃ    | 1.9ᵃ    | 67.4ᵇ       | 2.1    | 7.0ᵇ       | 121.7ᵃ    | 866.7ᵇ      |
| Desmodium & FYM           | 67.9ᵃ    | 48.5ᵇ    | 1.8ᵇ    | 72.4ᵇ       | 2.1    | 7.1ᵇ       | 117.7ᵇ    | 792.4ᵇ      |
| SL                        | **       | **       | *       | *            | ns     | ***        | *         | ***         |
| SEM                       | 1.50     | 0.95     | 0.04    | 3.55         | 0.06   | 0.26       | 2.88      | 40.02       |
| Year                      |          |          |         |              |         |            |           |             |
| 2018                      | 55.5ᵇ    | 43.2ᵇ    | 1.6ᵇ    | 28.4ᵇ       | 2.0ᵇ   | 0.7ᵇ       | 114.3     | 80.7        |
| 2019                      | 75.3ᵃ    | 51.9ᵃ    | 2.0ᵃ    | 99.6ᵃ       | 2.2ᵃ   | 10.9ᵇ      | 115.8     | 1225.1      |
| SL                        | ***      | ***      | ***     | ***          | **     | ***        | ns        | ***         |
| SEM                       | 1.06     | 0.67     | 0.03    | 2.51         | 0.04   | 0.18       | 2.04      | 28.30       |
| Overall mean              | 65.4     | 47.6     | 1.8     | 64.0         | 2.1    | 5.8        | 115.0     | 652.9       |
| CV (%)                    | 7.9      | 6.9      | 7.9     | 19.2         | 10.1   | 15.3       | 8.7       | 21.2        |
| Interaction               |          |          |         |              |         |            |           |             |
| F*FS                      | *        | ns       | ns      | ns           | ns     | *          | ns        | ns          |
| F*Y                       | **       | ns       | ns      | ns           | ns     | *          | ***       | ***         |
| FS*Y                      | ***      | ***      | ns      | ***          | ***    | *          | ***       | ***         |

The values within a column that bear the same letter are not statistically different (p < 0.05); FS: forage species; Y: year; F: fertilizer treatments. FYM: farmyard manure; DMY: dry matter yield; CP: crude protein; CPY: crude protein yield; PH: plant height; LL: leaf length; LW: leaf width; NTPP: number of tillers per plant; LSR: leaf-to-stem ratio.
| Variables                  | RL (cm) | NRPP (No.) | S: R | RBY (t ha\(^{-1}\)) | RSOC | RTN |
|---------------------------|---------|------------|------|----------------------|------|-----|
| Forage grasses            |         |            |      |                      |      |     |
| Napier grass              | 37.6\(^a\) | 208.8\(^b\) | 1.6  | 4.9\(^b\)            | 36.3\(^b\) | 0.57\(^b\) |
| Desho grass               | 29.9\(^b\) | 327.2\(^b\) | 1.6  | 3.3\(^a\)            | 39.2\(^a\) | 0.64\(^a\) |
| SL                        | **      | ***        | ns   | ***                  | **   | *   |
| SEM                       | 1.31    | 12.67      | 0.08 | 0.15                 | 0.69 | 0.02|
| Fertilizer treatments     |         |            |      |                      |      |     |
| Control                   | 37.7    | 279.7\(^b\) | 1.6  | 3.8\(^a\)            | 38.8 | 0.61|
| Desmodium                 | 31.7    | 248.0\(^b\) | 1.8  | 3.6\(^b\)            | 38.0 | 0.59|
| FYM                       | 33.5    | 311.3\(^a\) | 1.5  | 4.4\(^a\)            | 38.4 | 0.60|
| Desmodium & FYM           | 32.2    | 232.8\(^b\) | 1.6  | 4.6\(^b\)            | 35.8 | 0.62|
| SL                        | ns      | *          | ns   | *                    | ns   | ns  |
| SEM                       | 1.85    | 17.92      | 0.11 | 0.21                 | 0.97 | 0.02|
| Overall mean              | 33.8    | 268.0      | 1.6  | 4.1                  | 37.8 | 0.60|
| CV (%)                    | 13.4    | 16.4       | 16.9 | 12.4                 | 6.3  | 9.9 |
Table 5. Effects of fertilizer treatments on belowground root characteristics at guder

| Variables          | RL (cm) | NRPP (No.) | S: R | RBY (t ha⁻¹) | RSOC | RTN |
|--------------------|---------|------------|------|--------------|------|-----|
| Forage grasses     |         |            |      |              |      |     |
| Napier grass       | 29.0    | 396.3      | 4.4  | 1.4          | 33.6 | 0.95
| Desho grass        | 26.5    | 485.5      | 4.6  | 1.3          | 32.6 | 0.70
| SEM                | ns      | ns         | ns   | ns           | ns   |     |
| SL                 | 1.07    | 45.36      | 0.45 | 0.12         | 0.92 | 0.06|
| Fertilizer treatments |       |            |      |              |      |     |
| Control            | 27.5    | 523.7      | 4.9  | 1.3          | 35.9 | 0.90|
| Desmodium          | 26.6    | 358.2      | 4.2  | 1.2          | 33.8 | 0.83|
| FYM                | 28.6    | 431.5      | 4.0  | 1.5          | 31.3 | 0.69|
| Desmodium & FYM   | 28.2    | 450.3      | 4.9  | 1.5          | 31.1 | 0.89|
| SEM                | ns      | ns         | ns   | ns           | ns   |     |
| Overall mean       | 27.7    | 440.9      | 4.5  | 1.4          | 33.0 | 0.82|
| CV (%)             | 13.4    | 25.6       | 24.7 | 21.2         | 9.7  | 24.0|

Values within a column that bear the same letter are not statistically different (p < 0.05); Control: forage grass alone; RL: root length per plant; NRPP: number of roots per plant count; S: R: shoot-to-root ratio; RBY: root biomass yield; RSOC: root soil organic carbon; RTN: root total nitrogen; CV: coefficient of variation; SEM: standard error of mean.
combined use of Desmodium and FYM showed significantly lower (p < 0.05) BD compared to two grasses alone and with Desmodium in both watersheds. However, there were no significant differences in BD among forage grass alone and with Desmodium treatments. In contrast, soil moisture levels improved by 22.9% and 24.7% in December for desho grass and 8.8% and 6.2% for Napier grass at Aba Gerima, respectively, with FYM and combined use of FYM and Desmodium. Moreover, in Guder, for similar fertilizer treatments, desho recorded 15.9% and 14.1%, while 21.0% and 5.8% for Napier grass (Figure S1). At Aba Gerima, the soil chemical properties SOC and TN differed significantly (p < 0.01) from the control and Desmodium, but not at Guder.

In Aba Gerima watershed, most soil chemical properties (SOC, TN and P<sub>av</sub>) showed significantly higher concentration in desho grass with FYM and combined use of Desmodium and FYM compared to forage grass alone and with Desmodium. Furthermore, P<sub>av</sub> was higher in forage grasses with FYM and combined use of Desmodium and FYM treatment groups compared with forage grasses alone at Guder watershed. Among forage grasses with FYM at Aba Gerima, compared to grass alone, SOC (18.4% and 20.5%), TN (15.4%) and P<sub>av</sub> (16.3% and 23.0%) were higher with FYM and combined use of Desmodium and FYM treatments, respectively. Despite the lack of significant differences in most soil chemical properties within treatments relative to forage grass alone at Guder, P<sub>av</sub> increased by 9.4% in FYM and 17% in combined use of FYM and Desmodium. On the other hand, the pH content of treatment groups when compared before the application of treatments, the improvement was greater; 0.4 with FYM and 0.5 with the combined use of FYM and Desmodium in both forage grasses (Figure 4 and 5).

Figure 4. Soil physicochemical properties under various fertilizer treatments after treatment application at Aba Gerima watershed.
4. Discussion

4.1. Forage grass morphological characteristics

The forage grasses were relatively larger at middle elevations, which is similar to the findings of Asmare et al. (2017) for desho grass. Environmental conditions such as rainfall, temperature, and soil properties conducive to plant growth may be factors contributing to morphological variations in forage grasses. Plant growth and yield are influenced by the amount and distribution of precipitation, the amount of sunlight, and soil nutrient content (Snyman, 2002). The temperature and moisture near the soil surface affect the germination and establishment of pastures (Altin et al., 2011). Most morphological differences between the presence and/or absence of FYM could be attributed to the availability of essential nutrients provided by FYM for growth and production (Abusuwar, 2019) and greater soil moisture level under FYM as well as combined use of FYM and Desmodium in both watersheds (Fig. S1). Furthermore, FYM increases soil macro elements, such as nitrogen (N), phosphorous (P), and potassium (K; Eghball et al., 2004), resulting in maximum NPK uptake by the crop and improved soil organic carbon as well as available N, P, and K (Srivastava et al., 2014) for increased growth of forage grasses.
Our results are consistent with those of (Gelayenew et al., 2020) who report that more tillers per plant contribute to higher DMY in Napier intercropped with vetch. In agreement with our study, Laidlaw (2005) reported that tiller mass is an important characteristic of grasses as it increases the chances of survival and quantity of available forage. The same author reported that greater numbers of tillers formed by some grass species allow them to achieve maximum development at an earlier age and recover faster after defoliation. The present study is consistent with those of (Asmare et al., 2017; Bayble et al., 2007), who found similar growth characteristics for Napier grass and desho grass, respectively. Konlan et al. (2021) reported a difference in the number of tillers between Brachiaria ruziensis and Sorghum almum in Ghana, which agrees with our finding that in the same agro-ecology, desho grass produces more tillers per plant than Napier grass. The increase in NTPP with FYM as well as the combined use of FYM and Desmodium that we observed is consistent with reports for other grasses (Asmare et al., 2017; Bayble et al., 2007).

The value differs from the report of Rahetlah et al. (2014) in which NTPP at the first harvest did not differ between treatments and watersheds. The differences might be related to differences among forage species used, climate, and soil properties. However, the height of Mott grass increased at all growth stages with the application of N/FYM (Bilal et al., 2000), which is similar to the current study. In addition, the NTPP in the present study was relatively low as compared to Bilal et al. (2000) N/FYM treatment group in Napier grass. In plant growth, nitrogen is the most limiting nutrient in Ethiopian soil. It is found in chlorophyll, plant proteins, and nucleic acids, and it aids in vegetative development (G.Selassie, 2015). The differences between our results and those of previous studies might be associated with the addition of N fertilizer in those studies and differences in the rate of FYM application.

### 4.2. Dry matter and crude protein yield of forage grasses

The substantial increase in DMY and CPY of Napier grass treated with FYM as well as combined use of FYM and Desmodium might be associated with improvement of soil chemical properties, higher yield per frequency of harvest (Table S2 and S3), and increased soil moisture level (Fig. S1) in both watersheds. Furthermore, FYM increases soil macro elements, such as NPK (Eghball et al., 2004), there by resulting in maximum NPK uptake by the crop and improved SOC as well as available N, P, and K (Srivastava et al., 2014) for increased DMY and CPY of forage grasses. Moreover, due to combined poultry and cow manure application, DMY increments ranged from 53.7% to 118% in the first season and from 146% to 514% in the second (Abusuwar, 2019), which agrees with our findings. According to the report of Utamy et al. (2018), the availability of N and C in the soil after manure application might be considered adequate for subsequent cultivation of forage grasses. The positive and significant correlation between DMY and CPY with PH and NTPP indicated higher yield in our study (Table S1). The DMY of forage grasses with FYM application in our study is consistent with the value reported by Zewdu et al. (2002) for application of manure on Napier grass. The negative association between LSR with DMY in our study (Table S1) agrees with the reports of different authors (Asmare et al., 2017; Zewdu et al., 2002), which is an important factor associated with digestibility (Yasin et al., 2003) and considerably affects the nutritive value of grass, as leaves contain higher levels of nutrients and lower fiber than stems (Zewdu, 2005).

On the other hand, there was an increment in most yield characteristics in 2019 as compared to 2018, notably DMY and CPY. This might be associated with a slight increase in both temperature and rainfall for both watersheds (Fig. 2 and 3) and the additive effect of FYM and Desmodium in increasing uptake and availability of essential soil nutrients (NPK) for improved yield and the perennial nature of forage grasses as they become established (Zewdu et al., 2002). Moreover, the same author reported that full growth of roots, stems, and leaves in plant developmental stages may contribute to variation in growth and yield of forage grasses.

There was lower DMY in either Napier or desho grass associated with Desmodium, which is contrary to the report of Gierus et al. (2012) in that companion grass growth was facilitated by the N transferred from forage legumes. The same author reported better grass DMY and, accordingly,
higher mixed DMY in a legume–perennial ryegrass mixture. However, Maina et al. (2006) reported that Desmodium intortum has the potential to fix more N₂ but transfers only 5% of it to its companion grasses. Furthermore, Sant’Anna et al. (2018) stated that the contributions of legumes like Desmodium to N₂ fixation are relatively low in the first year but significantly improve in subsequent years. According to the same author, nitrogen in legumes derived from biological nitrogen fixation has a significant environmental advantage over synthetic nitrogen fertilizers. Our findings indicate that when integrating legumes like Desmodium with forage grasses, inorganic fertilization is required in the first year of planting for better forage grass establishment and DMY.

According to our findings, organic fertilizers, such as manure, had no effect on the CP content of forage grasses, which agree with the report of Yiberkew et al. (2020) for Brachiaria hybrid Mulato II grass in Ethiopia. In contrast to the current study, Bøyble et al. (2007) reported that combining Napier grass with Desmodium and Lablab purpureus improved forage grass CP content. In the current experiment, the mean CP content of desho grass and Napier grass was within the range reported for Pennisetum species by Kahindi et al. (2007). Several authors (Ahmad et al., 2011; Kamal et al., 2017; McRoberts et al., 2018) reported that organic or inorganic fertilizer improved the CP content of forage grasses noticeably.

4.3. Belowground root characteristics
The majority of belowground root characteristics of Napier and desho grasses differed from those observed by Yiberkew et al. (2020), who reported higher RL and NRPP in chemical fertilizer and manure treatments. The difference could be due to differences in forage species used, soil conditions, or climatic conditions in the experimental areas. The increase in RL for Napier grass compared to desho grass could be due to differences in plant spacing; plants with wider spacing produce the longest RL at low plant areal densities (Moniruzzaman, 2011). Furthermore, the higher RL and RBY for Napier grass compared to desho grass in our experiments may be related to plants with longer root structures; this leads to increased root biomass and thicker roots in the upper soil profile than in plants with small root systems (Figueroa-Bustos et al., 2018). The higher RBY in Napier grass than in desho grass that we observed is consistent with the findings of Bolinder et al. (2002) for various forage grasses. The higher RBY at Aba Gerima could be attributed to differences in climate and soil properties, as reported by Bolinder et al. (2002) for various forage species. Furthermore, the variations in S: R ratio observed among Guder and Aba Gerima are consistent with the findings of Bolinder et al. (2002), who found that S: R varies with location and climate.

4.4. Physicochemical properties of soil
Planting forage grasses with different fertilizer treatments had no effect on BD in our study. The lack of change in BD observed by us differed from that reported by Shirani et al. (2002), who found a significant decrease in soil BD immediately after harvesting a maize field treated with FYM. In a two-year field experiment in Iran, the same author discovered that root activity can increase soil porosity and decrease BD. However, the improvement in BD of soil planted with desho grass compared to Napier grass may be due to differences in growth habit and root biomass; desho grass has more tillers with many fibrous roots (Table 4 and 5), which may decrease soil erosion by increasing BD (Welle et al., 2006), whereas Napier grass has fewer tillers with an erect growth habit and less fibrous roots.

Soil pH rises in both watersheds as a result of forage grass planting, though at Guder it rises significantly more. This could be related to the ground cover provided by forage grasses reduces runoff, soil erosion and associated basic cations which resulted improved soil organic matter and soil pH (Kumar et al., 2019). Among the forage grasses tested in our study, desho grass improved pH the most; this may be due to its greater tillering capacity, which covers a wider area, implying that it has the potential to reduce runoff and soil loss (Welle et al., 2006). According to Sarwar et al. (2010), compost releases alkaline substances and cations such as Ca²⁺, Mg²⁺, and K⁺, which increase CEC and pH and counteract soil acidification.
We observed variations in some soil chemical properties at Aba Gerima after planting forage grasses with various fertilizer treatments. These variations could be attributed to variations in rainfall, temperature, and soil properties. Alternatively, according to different authors (Abususuwar, 2019; Sharpley et al., 2004; Shirani et al., 2002), manure application in both watersheds not only provides vital nutrients but also improves the chemical properties of the soil for subsequent forage production. Furthermore, manure application improved SOC and TN content significantly (Ma et al., 2020). Besides, FYM increases soil macro elements, such as NPK (Eghball et al., 2004), resulting in maximum NPK uptake by the crop as well as improved SOC and available N, P, and K. (Srivastava et al., 2014). Similar to our findings at Aba Gerima, increased N and C availability in the soil following manure application provides better nutrients for subsequent production and can be considered a substitute for chemical fertilizer (Utamy et al., 2018).

5. Conclusions
Our findings show that applying farmyard manure or in combination with Desmodium intortum significantly improved the growth characteristics, dry matter yield, and crude protein yield of desho and Napier grasses. Furthermore, it improved soil chemical properties at midland and moisture levels in both agro-ecologies. This research will help to ensure long-term feed availability in terms of quality and quantity for improved animal production by preserving soil health in environmentally friendly production systems. Thus, additional research on Napier grass and desho grass with integrated application of organic and inorganic fertilizer types for higher yields over longer periods of time would be beneficial in the future.

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