# Effects of Pearl millet (*Pennisetum glaucum*) forage cropping pattern on biomass yield and in vitro NDF digestibility

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## Abstract

The study was conducted to evaluate four Pearl millet forage cropping pattern within the Guinea Savannah Agro-ecological zone of Ghana. Four cropping patterns (sole grass as control, grass cultivated on the borders of Pigeon pea crop, Grass cultivated as intercrop with Pigeon pea and Grass cultivated as spot in Pigeon pea) in RCBD were imposed on pearl millet forage. Agronomic data which included plant height, number of tillers, and total biomass yield was taken in both the initial establishment and regrowth. The biomass was separated into leaf, stem, and whole botanical fractions for chemical composition and *in vitro* NDF digestibility analysis. Cropping patterns significantly ($p< 0.05$) influenced all agronomic parameters except for plant height at first cut. The grass in spot cropping pattern had the highest plant height (1.48 m) at the first harvest. Meanwhile, intercropping in the second harvest produced the highest (23) number of tillers whilst spot planting in the third harvest gave the least number of tillers (8). Sole grass (control) produced the highest (1352.6 kg DM/ ha) biomass yield in the second harvest whereas spot planting gave the lowest biomass (45.6 kg DM/ha) in the third harvest. A total biomass yield of 2,755.3 kg DM/ha/annum, 1,695.7 kg DM/ ha/annum, 1,199.5 kg DM/ ha/annum and 594.2 kg DM/ ha/annum were produced for sole grass, border, intercrop, and spot respectively. In the first cut, the two-way interaction effect of cropping pattern and botanical fraction significantly ($p<0.05$) affected all chemical parameters except DM. The highest NDF and ADF were reported in the Whole fraction of the Spot cropping pattern and stem fraction respectively. Botanical fraction significantly ($p<0.05$) influenced digestibility parameters with the leaf fraction of spot planting recording the highest IVDMTD (870.4 g/kg DM) and NDFD (773.9g/kgDM) and the highest ME obtained in the leaf fraction of sole grass. The two-way interaction effect of cropping pattern and botanical fraction significantly ($p<0.05$) influenced all chemical parameters and ME with the highest NDF and ME recorded in the stem and leaf fractions of sole grass in the second cut. In the third cut however, botanical fraction significantly influenced all chemical parameters except DM and the two-way interaction effect of cropping pattern and botanical fraction affected all digestibility parameters analysed. The study concluded that pearl millet forage can be introduced as a border crop in a crop/livestock farming system in the savannah agro-ecological zone of Ghana.

**Keywords:** Forage, Cropping Pattern, Chemical composition, Digestibility, Farming system

## Introduction

Livestock keepers, particularly pastoralists and agro pastoralists, have for decades used herd mobility and daily grazing practices to take advantages of the native pastures in West Africa (Ayantunde et al., 2014; Zampaligré et al., 2014). Current population growth, urbanization, climate change and variability, and farmland expansion for crop production have challenged the pastoralist feeding strategies and there are recurrent violent conflicts between crop farmers and livestock keepers in Ghana and across the Sahel region and coastal countries (Tinsley and Gwiriri, 2022). The region routinely experiences recurrent feed gap, both in quantity and quality, during the long dry season (Moore et al., 2009). In addition to the spatial and temporal variability, and decline in pasture productivity, there is also high cost of agricultural by-products, such as cereal brans and cottonseed cakes (Ouédraogo et al., 2022), and commercial feeds, which are used as supplements to overcome pasture resource shortages during the dry season. Past efforts in disseminating and promoting cultivated fodder cultivars among small holder farmers in developing countries have gained little success due to lack of land resources and tenure, quality seed availability, farmers' technical skills, and socio-cultural factors (Bayala et al., 2014). Therefore, crop residues such as cereal straws and legume haulms have become key feed resources in the agro pastoral and integrated crop–livestock systems, particularly to overcome feed shortages during the long dry season (Amole and Ayantunde, 2016).

Pearl millet (*Pennisetum glaucum* L.) is a promising dual purpose (fodder and grain), and quick growing crop with salinity tolerance (Makarana et al., 2017). It has high tillering and ratoon abilities, comparatively high protein content (10-12%) can be grazed or cut and fed at any growth stage. Pearl millet has been also reported to have high tolerance to drought thus it can serve as an important crop to ensure good quality fodder for animals in the arid and semi-arid regions and elsewhere in the world under similar agro ecologies (Govindaraj et al., 2010).

However, it is still mostly cultivated for grain production in Asia and Sub-Saharan Africa (Babiker et al., 2015). There has been increased attention recently for pearl millet as a multi-cut forage crop for fresh feeding and silage production (Jukanti et al., 2016), especially in Brazil, the Middle East, and Central Asia (Rai et al., 2012). Intensive research has been conducted in the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) to develop new pearl millet lines and hybrids; however, they are focused on evaluating the grain yield components of the new genotypes. Meanwhile, complete information on their forage potential is still lacking (Jukanti et al., 2016). Cultivation of forage is still not popular among smallholder livestock farmers and this is mostly due to the allocation of most cropping lands to the production of food crops. There is therefore the need to explore other methods of introducing forage crops within the crop livestock systems. Thus, this study evaluates the effect of different forage cropping patterns in the Guinea savannah agro ecological zone of Ghana.

## Materials and Methods

### *Study Area*

The study was conducted at the Nyankpala campus of the University for Development Studies in the Northern region of Ghana. The study area is located at an altitude of 167 m above sea level and falls within latitude 9°24′N and longitude 0°59′W. Annual rainfall is in the range of 1000 to 1100 mm and distributed fairly from April to late October with temperatures generally between 15°C and 42°C. The vegetation of the study area is guinea savannah with grasses being the most common plant species with scattered drought tolerant trees like *Adansonia digitata*, *Vitellaria paradoxa* and *Tamarindus indica*.

### *Land Preparation, Source of Planting Materials and Experimental Design*

The field was ploughed and harrowed with a tractor to obtain a level soil. Pearl millet forage seeds (Nutrifeed) were obtained from Advanta seed company. The seeds were planted at stake at about 2cm deep in the soil at a seeding rate of 7.5 kg/ha.

The experiment followed a randomized complete block design with each plot area of 5 m x 4 m and four cropping patterns; sole grass as control (sole grass), grass cultivated on the borders of Pigeon pea crop (border), grass cultivated as intercrop with Pigeon pea (Intercrop) and grass cultivated as spot in Pigeon pea (Spot) as and the treatments replicated five times. Grasses planted as control, borders and intercrop were planted with a spacing of 1 m x 0.5 m whiles the spot planting were done with a spacing of 0.3 m in ring form at three (3) locations within the plot. Compound fertilizer (NPK) was applied 14 days after planting at a rate of 60 kg/ha and was repeated after each cut. The fertilizer was buried using the side placement technique.

### *Data Collection and Chemical Analysis*

Five (5) plants were randomly selected from each plot and plant height and number of branches were taken from the third week. Plant height was measured from the base of the plant to the tip of the plant using tape measure and number of branches were physically counted.

The grasses were harvested at six weeks after planting in the first cut whiles the second and third cuts (regrowth) were done at three weeks interval. The total harvests per plot at each cut were weighed for the estimation of aboveground biomass. Samples of the harvests were taken from each plot, chopped and oven dried at 60°C for 48 h for dry matter (DM) determination. Sub-samples were also taken and separated into leaf, stem, and whole botanical fractions, chopped, and milled with the aid of a Hammer mill for laboratory analysis according to the method of AOAC (1990).

Dry matter, CP and ash contents were estimated using the AOAC (1990) method whereas NDF and ADF were determined according to the Van Soest et al. (1991) limited of residual ash through sodium sulphite and α- amylase using Ankom$^{200}$ fibre analyser (Method 5 for ADF and method 6 for NDF).

The batch *in vitro* gas production technique of Theodorou et al. (1994) was adopted with some modification in the source of rumen fluid (Ansah et al., 2018) to evaluate the In vitro dry matter true digestibility (IVDMTD). Rumen fluid was collected at the Tamale abattoir from four slaughtered Sanga cattle (300 ± 15 kg) managed on naturally growing indigenous pasture. The rumen fluid was filtered through double layer cheese cloth with continuous supply of carbon dioxide. McDoughal's buffer was prepared and kept warm in a water bath (39° C) and mixed with the rumen fluid in a ratio of 1: 4 under continuous supply of Carbon dioxide to get the incubation media. 0.50 g DM of the milled forage sample was weighed into Ankom$^{200}$ filter bag, sealed, and inserted in a 50 ml test tube with five replicates per treatment in two separate batch cultures. About 30 ml of the warm and anaerobic incubation media was dispensed into the test tubes and incubated for 48 h in a water bath. The incubated samples were washed in distilled water and oven dried for 3-4 h at a temperature of 102° C (±2°C). NDF was determined on the incubated samples using Ankom$^{200}$ fibre analyser (Method 6) to get the residual NDF.

IVDMTD and the NDF digestibility parameters were calculated using the equations below according to Mertens, (2015):

$$\mathbf{IVDMTD\ (\%DM)=100*(DMwt-NDFres\ /\ DMwt)}$$

Indigestible NDF (iNDF) was obtained using the equation:

$$\mathbf{iNDF\ (\%DM) = 100 - IVDMTD}$$

Digestible NDF (dNDF) and NDF digestibility (NDFD) were calculated using the equations

**dNDF (%DM) = NDF – iNDF** and **NDFD (%DM) = 100* dNDF/NDF** respectively.

### *Statistical Analysis*

The data on biomass yield, plant height and number of branches were analysed as one-way ANOVA from Genstat 11th edition (Payne et al., 2008). The chemical composition and digestibility parameters were analysed as two-way ANOVA. F-test means which were significant at 5% were separated using Tukey HSD.

## Results

### *Growth and biomass yield of Pearl millet forage under different cropping patterns*

The plant height of pearl millet forage at harvest is shown in figure 1. There was a significant increase in plant height at second and third cuts. The highest plant height (1.48 m) was observed in spot planting at first cut, however, there was no significant difference among cropping pattern in the first cut.

Tiller number of pearl millet forage cultivated under different cropping pattern is shown in Figure 2. There was a significant ($p<0.001$) increase in the number of tillers among cropping pattern in all cuts. Planting grass as intercrop produced the highest number of tillers in the second cut whiles spot planting produced the least number of tillers in all the cutting sessions.

Biomass yield of pearl millet at harvest under different cropping patterns is shown in figure 3. There was a significant ($p< 0.05$) difference among cropping patterns in all cuts. The control (sole grass) produced the highest biomass yield in all three cuts where the highest yield (1352.6 KgDM/ha) was produced in the second cut. When contrasting the different cropping patterns and excluding the control

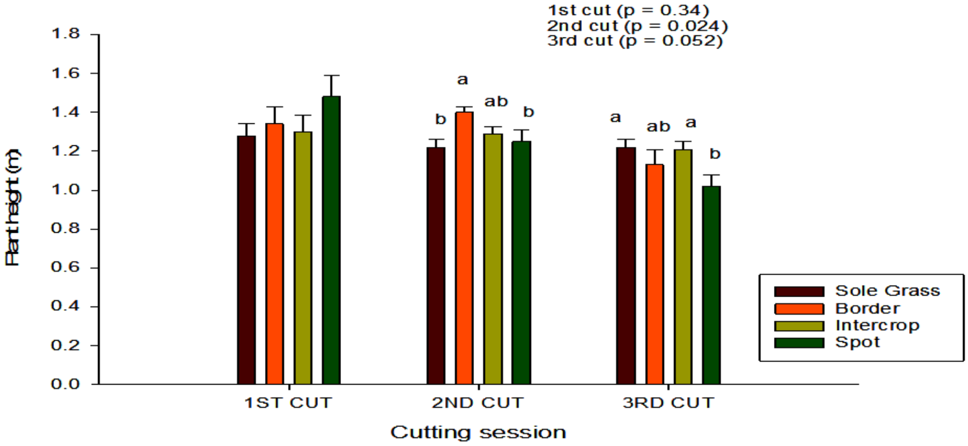

**Figure 1** Plant height of Pearl millet forage in different cropping pattern

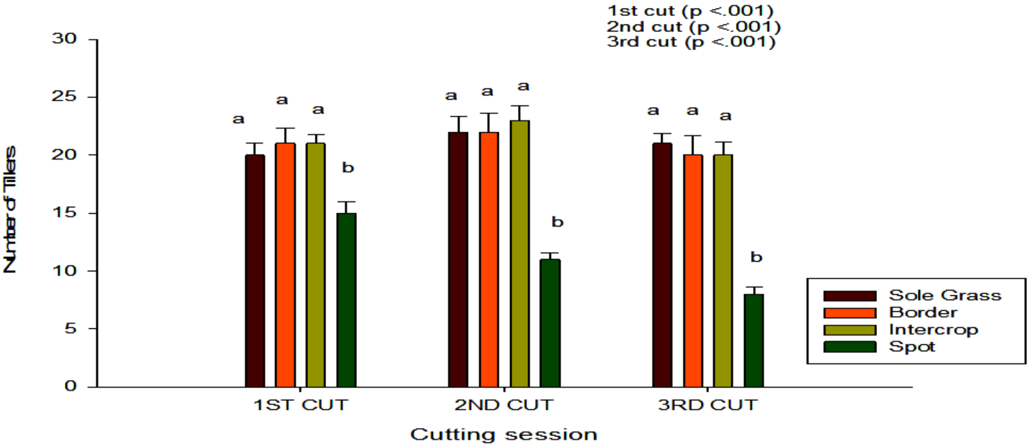

**Figure 2** Number of tillers of Pearl millet forage in different cropping pattern

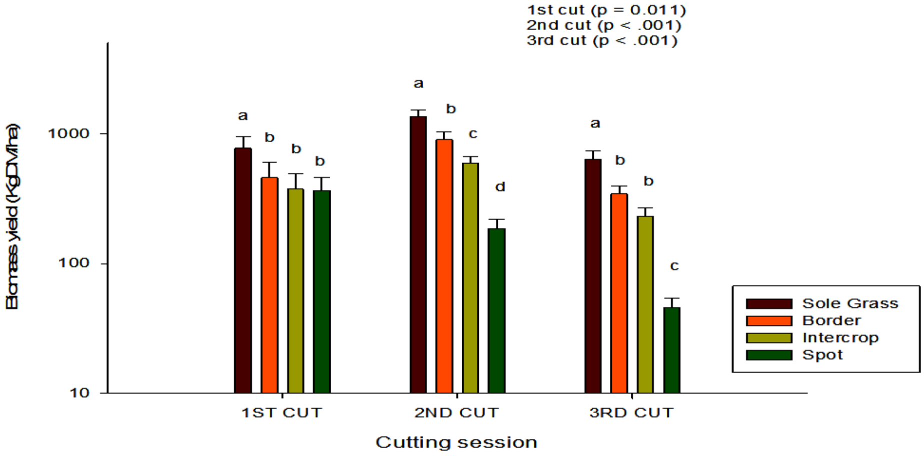

**Figure 3** Biomass yield of pearl millet forage in different cropping pattern

(sole grass), there was no statistical ($p>0.05$) difference among the border, intercrop, and spot planting in the first cut. However, there was significant difference among border, intercrop, and spot planting in the second and third cuts where border planting produced higher biomass and spot planting producing the lowest biomass. The three cutting periods produced a total biomass yield of 2,755.3kg DM/ha, 1,695.7 kg DM/ ha, 1,199.5 kg DM/ ha and 594.2 kg DM/ ha for sole grass, border, intercrop, and spot respectively.

*Chemical composition and In vitro digestibility of Pearl millet forage planting in different cropping patterns*

The chemical composition of Pearl millet forage under different cropping patterns at first cut is shown in Table 1. All parameters were significantly ($p< 0.05$) affected by cropping pattern, botanical fraction and the two-way interaction effect of cropping pattern and botanical fraction except dry matter. The leaf fractions recorded higher concentrations of CP where the highest and lowest CP (194.8 g/kg DM and 72.7 g/kg DM) were recorded in the leaf and stem fractions of spot and sole grass cropping patterns respectively. The NDF concentrations were higher in the stem and whole fractions whiles the stem fractions recorded higher concentrations of ADF and ash.

The results on the chemical composition of Pearl millet forage at second cut under different cropping patterns is shown in Table 2. Two-way interaction effect of cropping pattern and botanical fraction significantly ($p< 0.05$) affected all chemical parameters except dry matter. The CP ranged between 205.3 g/ kg DM in the leaf fraction of spot cropping pattern and 55.9 g/kg DM in the stem fraction of sole grass cropping pattern. The leaf and whole fractions of planting grass as intercrop and spot respectively produced the highest DM while the stem fractions recorded higher NDF and ADF in all cropping patterns.

**TABLE 1**

Chemical composition of Pearl millet forage as influenced by different cropping pattern on dry matter basis (g/kgDM) at first cutting

| Cropping pattern | Botanical fraction | Parameters (g/kgDM) | | | | | |
|---|---|---|---|---|---|---|---|
| | | **DM** | **CP** | **NDF** | **ADF** | **HEM** | **ASH** |
| Sole grass | Leaf | $188.5^{a}$ | $167.5^{bc}$ | $629.7^{abcd}$ | $295.9^{c}$ | $346.9^{a}$ | $115.0^{d}$ |
| | Stem | $103.8^{e}$ | $72.7^{g}$ | $642.9^{ab}$ | $439.8^{a}$ | $200.1^{ef}$ | $157.5^{bc}$ |
| | Whole | $139.2^{cd}$ | $114.5^{e}$ | $639.9^{abc}$ | $429.6^{ab}$ | $200.1^{ef}$ | $155.0^{bc}$ |
| | Leaf | $173.4^{ab}$ | $166.3^{bc}$ | $598.0^{abcd}$ | $306.1^{c}$ | $326.5^{a}$ | $155.0^{bc}$ |
| Border | Stem | $101.7^{e}$ | $84.9^{fg}$ | $654.0^{a}$ | $352.9^{bc}$ | $245.1^{cd}$ | $202.5^{a}$ |
| | Whole | $123.5^{de}$ | $131.8^{de}$ | $632.7^{abc}$ | $416.2^{ab}$ | $237.8^{cde}$ | $160.0^{bc}$ |
| | Leaf | $174.0^{ab}$ | $179.0^{ab}$ | $567.0^{d}$ | $288.5^{c}$ | $278.5^{bc}$ | $152.5^{c}$ |
| Intercrop | Stem | $102.6^{e}$ | $143.7^{cd}$ | $577.2^{bcd}$ | $350.3^{bc}$ | $226.8^{def}$ | $197.5^{a}$ |
| | Whole | $146.4^{bcd}$ | $115.4^{e}$ | $616.1^{abcd}$ | $343.5^{bc}$ | $272.7^{bc}$ | $182.5^{ab}$ |
| | Leaf | $160.3^{abc}$ | $194.8^{a}$ | $574.1^{cd}$ | $306.7^{c}$ | $267.5^{bcd}$ | $122.5^{d}$ |
| Spot | Stem | $95.0^{e}$ | $109.8^{ef}$ | $625.0^{abcd}$ | $442.3^{a}$ | $182.7^{f}$ | $155.0^{bc}$ |
| | Whole | $115.1^{de}$ | $159.0^{bc}$ | $646.5^{a}$ | $343.5^{bc}$ | $303.1^{ab}$ | $157.5^{bc}$ |
| S. e. d. | | 10.03 | 6.17 | 16.61 | 21.45 | 10.94 | 7.40 |
| | Cropping pattern pattern | 0.004 | < .001 | 0.001 | 0.004 | 0.027 | < .001 |
| P value | Fraction | < .001 | < .001 | 0.005 | < .001 | < .001 | < .001 |
| | Cropping pattern x Fraction | 0.430 | < .001 | 0.020 | 0.004 | < .001 | 0.019 |

Mean with different superscripts are significantly different at $P<0.05$, CP= Crude Protein, DM= Dry Matter, NDF= Neutral Detergent Fibre, ADF= Acid Detergent Fibre, HEM= Hemicellulose

**TABLE 2**
Chemical composition of Pearl millet forage as influenced by different cropping pattern on dry matter basis (g/kgDM) at second cutting

| Cropping pattern | Botanical fraction | Parameters (g/kgDM) | | | | | |
|---|---|---|---|---|---|---|---|
| | | DM | CP | NDF | ADF | HEM | ASH |
| Sole grass | Leaf | $197·8^{a}$ | $159.7^{c}$ | $622.4^{bcd}$ | $275.5^{e}$ | $346.9^{a}$ | $122.5^{cd}$ |
| | Stem | $122.0^{c}$ | $55.9^{f}$ | $683.1^{a}$ | $366.3^{abc}$ | $316.9^{ab}$ | $107.5^{d}$ |
| | Whole | $148.1^{bc}$ | $132.9^{d}$ | $636.5^{bc}$ | $394.1^{ab}$ | $242.4^{cde}$ | $125.0^{cd}$ |
| | Leaf | $181.1^{ab}$ | $188.4^{b}$ | $586.6^{d}$ | $307.4^{cde}$ | $279.1^{bcd}$ | $131.5^{bc}$ |
| Border | Stem | $123.4^{c}$ | $71.0^{f}$ | $646.4^{ab}$ | $364^{abc}$ | $282.5^{bcd}$ | $140.0^{bc}$ |
| | Whole | $138.2^{bc}$ | $140.0^{d}$ | $584.1^{d}$ | $297.1^{de}$ | $287.1^{abcd}$ | $160.0^{a}$ |
| | Leaf | $182.3^{ab}$ | $201.4^{ab}$ | $584.1^{d}$ | $287.3^{e}$ | $296.9^{abc}$ | $140.0^{bc}$ |
| Intercrop | Stem | $133.7^{c}$ | $68.0^{f}$ | $633.5^{bc}$ | $356.5^{abcd}$ | $277.1^{bcde}$ | $112.5^{d}$ |
| | Whole | $157.3^{abc}$ | $135.8^{d}$ | $611.6^{bcd}$ | $398.0^{a}$ | $213.6^{e}$ | $147.5^{ab}$ |
| | Leaf | $149.7^{bc}$ | $205.3^{a}$ | $587.6^{d}$ | $329.7^{bcde}$ | $257.9^{bcde}$ | $132.5^{bc}$ |
| Spot | Stem | $115.0^{c}$ | $100.7^{e}$ | $607.8^{bcd}$ | $362.7^{abcd}$ | $245.1^{cde}$ | $150.0^{ab}$ |
| | Whole | $129.1^{c}$ | $141.5^{d}$ | $603.9^{cd}$ | $376.1^{ab}$ | $227.8^{de}$ | $137.5^{bc}$ |
| S. e. d. | | 13.28 | 3.75 | 10.28 | 16.51 | 15.89 | 4.695 |
| | Cropping pattern pattern | 0.004 | < .001 | < .001 | 0.028 | < .001 | < .001 |
| P value | Fraction | < .001 | < .001 | < .001 | < .001 | < .001 | < .001 |
| | Cropping pattern x Fraction | 0.440 | < .001 | 0.029 | 0.002 | 0.007 | < .001 |

Mean with different superscripts are significantly different at P<0.05, CP= Crude Protein, DM= Dry Matter, NDF= Neutral Detergent Fibre, ADF= Acid Detergent Fibre, HEM= Hemicellulose

The effect of different cropping patterns on the chemical composition of Pearl millet forage at third cut is shown in table 3. Cropping pattern and botanical fraction significant ($p<0.05$) influenced all parameters whiles the two-way interaction effect of cropping pattern and botanical fraction significantly ($p<0.05$) affected CP, NDF and hemicellulose. The stem fractions generally recorded higher concentrations of NDF and ADF whiles the leaf fractions had higher concentrations of ash and CP. The CP concentration ranged between 156.7 g/kg DM and 49.1 g/kg DM in the leaf and stem fractions of Border and sole grass cropping pattern.

The results on IVDMTD, NDFD, dNDF, iNDF and metabolizable energy of Pearl millet cultivated under different cropping patterns at first cut is presented in table 4. Cropping pattern significantly ($p<0.05$) affected dNDF and ME whiles botanical fraction significantly ($p < 0.05$) influenced IVDMTD, NDFD, dNDF, iNDF and ME. The highest IVDMTD (870.4 g/kg DM) and NDFD (773.9 g/kg DM) were recorded in the leaf fractions of grass cultivated as spot planting while the leaf fractions generally had higher dNDF and ME. The influence of different cropping patterns on the IVDMTD, NDFD, dNDF, iNDF and metabolizable energy of Pearl millet forage at second cut is shown in table 5. There was no significant ($p> 0.05$) effect of cropping pattern, botanical fraction, and their interaction effect on all digestibility parameters. Meanwhile, ME was significantly influenced by cropping pattern, botanical fraction, and the interaction effect of cropping pattern and botanical fraction. The highest ME (10.61 MJ/kg/ DM) was obtained in the leaf fraction of the control (sole grass) whiles the lowest ME (8.97 MJ/ kg/ DM) was obtained in the whole fraction of grass planted as intercrop.

The IVDMTD, NDFD, dNDF, iNDF and metabolizable energy of Pearl millet forage under different cropping patterns at third cut is shown in table 6. All digestibility parameters

**TABLE 3**

Chemical composition of Pearl millet forage as influenced by different cropping pattern on dry matter basis (g/kgDM) at third cutting

| **Cropping pattern** | **Botanical fraction** | **Parameters (g/kgDM)** | | | | | |
|---|---|---|---|---|---|---|---|
| | | **DM** | **CP** | **NDF** | **ADF** | **HEM** | **ASH** |
| Sole grass | Leaf | 225.8$^{ab}$ | 156.2$^{a}$ | 578.4$^{cde}$ | 313.7$^{ab}$ | 264.7$^{abc}$ | 115.0$^{abcd}$ |
| | Stem | 240.1$^{a}$ | 49.1$^{e}$ | 616.1$^{abc}$ | 343.5$^{ab}$ | 272.7$^{abc}$ | 70.0$^{e}$ |
| | Whole | 203.8$^{ab}$ | 92.7$^{cd}$ | 659.9$^{a}$ | 329.5$^{ab}$ | 330.3$^{a}$ | 107.5$^{bcde}$ |
| | Leaf | 204.0$^{ab}$ | 156.7$^{a}$ | 565.7$^{de}$ | 313.1$^{ab}$ | 252.7$^{bc}$ | 127.5$^{abc}$ |
| Border | Stem | 213.4$^{ab}$ | 54.0$^{e}$ | 643.5$^{ab}$ | 366.3$^{ab}$ | 277.3$^{abc}$ | 95.0$^{cde}$ |
| | Whole | 190.6$^{b}$ | 122.3$^{b}$ | 626.3$^{ab}$ | 313.3$^{ab}$ | 313.1$^{ab}$ | 115.0$^{abcd}$ |
| | Leaf | 210.4$^{ab}$ | 154.8$^{a}$ | 626.3$^{ab}$ | 353.5$^{ab}$ | 272.9$^{abc}$ | 151.0$^{a}$ |
| Intercrop | Stem | 224.2$^{ab}$ | 51.8$^{e}$ | 646.3$^{ab}$ | 383.9$^{a}$ | 262.4$^{abc}$ | 75.0$^{de}$ |
| | Whole | 196.0$^{ab}$ | 114.2$^{bc}$ | 606.0$^{bcd}$ | 364.0$^{ab}$ | 242.0$^{c}$ | 126.5$^{abc}$ |
| | Leaf | 212.2$^{ab}$ | 155.9$^{a}$ | 540.8$^{e}$ | 306.1$^{b}$ | 234.7$^{c}$ | 140.0$^{ab}$ |
| Spot | Stem | 196.3$^{ab}$ | 87.2$^{d}$ | 656.5$^{a}$ | 373.9$^{ab}$ | 282.7$^{abc}$ | 90.0$^{cde}$ |
| | Whole | 200.6$^{ab}$ | 138.3$^{ab}$ | 622.4$^{abc}$ | 346.9$^{ab}$ | 275.5$^{abc}$ | 127.5$^{abc}$ |
| S. e. d. | | 13.03 | 6.34 | 11.19 | 18.77 | 17.56 | 10.03 |
| | Cropping pattern pattern | 0.028 | < .001 | 0.056 | 0.017 | 0.041 | 0.013 |
| P value | Fraction | 0.007 | < .001 | < .001 | 0.002 | 0.009 | < .001 |
| | Cropping pattern x Fraction | 0.399 | 0.004 | < .001 | 0.536 | 0.019 | 0.182 |

Mean with different superscripts are significantly different at $P<0.05$, CP= Crude Protein, DM= Dry Matter, NDF= Neutral Detergent Fibre, ADF= Acid Detergent Fibre, HEM= Hemicellulose

**TABLE 4**

Digestibility and Metabolizable energy of Pearl millet forage as influenced by different cropping pattern at first cutting

| **Cropping pattern** | **Botanical fraction** | **Parameters** | | | | |
|---|---|---|---|---|---|---|
| | | **IVDMTD (g/kg DM)** | **NDFD (g/kg DM)** | **DNDF (g/kg DM)** | **iNDF (g/kg DM)** | **ME (MJ/Kg/ DM)** |
| **Sole grass** | Leaf | 826.6$^{ab}$ | 730.4$^{ab}$ | 469.5$^{ab}$ | 173.4$^{ab}$ | 10.34$^{a}$ |
| | Stem | 799.2$^{ab}$ | 686$^{abc}$ | 439.1$^{abc}$ | 200.8$^{ab}$ | 8.41$^{c}$ |
| | Whole | 842.8$^{ab}$ | 749.8$^{ab}$ | 472.5$^{ab}$ | 157.2$^{ab}$ | 8.54$^{bc}$ |
| | Leaf | 856.4$^{ab}$ | 773$^{a}$ | 489.1$^{a}$ | 143.6$^{ab}$ | 10.19$^{a}$ |
| **Border** | Stem | 809.2$^{ab}$ | 680.7$^{bc}$ | 407.3$^{bc}$ | 190.8$^{ab}$ | 9.57$^{ab}$ |
| | Whole | 809.7$^{ab}$ | 708.4$^{abc}$ | 463.8$^{ab}$ | 190.3$^{ab}$ | 8.72$^{bc}$ |
| | Leaf | 837.1$^{ab}$ | 712.5$^{abc}$ | 404.1$^{bc}$ | 162.9$^{ab}$ | 10.43$^{a}$ |
| **Intercrop** | Stem | 788.3$^{b}$ | 632.9$^{c}$ | 365.4$^{c}$ | 211.7$^{a}$ | 9.61$^{ab}$ |
| | Whole | 839.2$^{ab}$ | 738.9$^{ab}$ | 455.3$^{ab}$ | 160.8$^{ab}$ | 9.69$^{ab}$ |
| | Leaf | 870.4$^{a}$ | 773.9$^{a}$ | 444.5$^{ab}$ | 129.6$^{b}$ | 10.19$^{a}$ |
| **Spot** | Stem | 825.7$^{ab}$ | 720.1$^{ab}$ | 450.7$^{ab}$ | 174.3$^{ab}$ | 8.37$^{c}$ |
| | Whole | 822.3$^{ab}$ | 725.3$^{ab}$ | 468.9$^{ab}$ | 177.7$^{ab}$ | 9.69$^{ab}$ |
| **S. e. d.** | | 19.37 | 35.91 | 31.24 | 19.37 | 0.287 |
| | Cropping pattern pattern | 0.391 | 0.245 | 0.050 | 0.391 | 0.004 |
| **P value** | Fraction | 0.004 | 0.008 | 0.024 | 0.004 | < .001 |
| | Cropping pattern x Fraction | 0.194 | 0.379 | 0.403 | 0.194 | 0.004 |

Means with different superscript are significantly different at $P<0.05$, IVDMTD = *In vitro* dry matter true digestibility, NDFD = NDF digestibility, dNDF = Digestible NDF and iNDF = Indigestible NDF and ME = Metabolizable energy

**TABLE 5**

Digestibility and Metabolizable energy of Pearl millet forage as influenced by different cropping pattern at second cutting

| Cropping pattern | Botanical fraction | Parameters | | | | |
|---|---|---|---|---|---|---|
| | | IVDMTD (g/kg DM) | NDFD (g/kg DM) | dNDF (g/kg DM) | iNDF (g/kg DM) | ME (MJ/Kg/ DM) |
| **Sole grass** | Leaf | 856.2 | 769 | 478.6 | 143.8 | $10.61^{a}$ |
| | Stem | 780.4 | 679 | 463.5 | 219.6 | $9.39^{cde}$ |
| | Whole | 804.3 | 692 | 440.9 | 195.7 | $9.02^{de}$ |
| **Border** | Leaf | 833.7 | 716 | 420.3 | 166.3 | $10.18^{abc}$ |
| | Stem | 805.9 | 700 | 452.3 | 194.1 | $9.42^{cde}$ |
| | Whole | 838.7 | 724 | 422.8 | 161.3 | $10.32^{ab}$ |
| **Intercrop** | Leaf | 832.8 | 714 | 416.9 | 167.2 | $10.45^{a}$ |
| | Stem | 797.7 | 680 | 431.3 | 202.3 | $9.52^{bcde}$ |
| | Whole | 797.9 | 670 | 409.5 | 202.1 | $8.97^{e}$ |
| **Spot** | Leaf | 797.4 | 654 | 385 | 202.6 | $9.88^{abcd}$ |
| | Stem | 810.5 | 688 | 418.4 | 189.5 | $9.44^{bcde}$ |
| | Whole | 818.8 | 700 | 422.7 | 181.2 | $9.26^{de}$ |
| **S. e. d.** | | 29.54 | 51.7 | 33.96 | 29.54 | 0.221 |
| **P value** | Cropping pattern pattern | 0.730 | 0.605 | 0.100 | 0.730 | 0.028 |
| | Fraction | 0.151 | 0.595 | 0.539 | 0.151 | < .001 |
| | Cropping pattern x Fraction | 0.455 | 0.643 | 0.802 | 0.455 | 0.002 |

Means with different superscript are significantly different at P<0.05, IVDMTD = *In vitro* dry matter true digestibility, NDFD = NDF digestibility, dNDF = Digestible NDF and iNDF = Indigestible NDF and ME = Metabolizable energy

**TABLE 6**

Digestibility and Metabolizable energy of Pearl millet forage as influenced by different cropping pattern at third cutting

| Cropping pattern | Botanical fraction | Parameters | | | | |
|---|---|---|---|---|---|---|
| | | IVDMTD (g/kg DM) | NDFD (g/kg DM) | dNDF (g/kg DM) | iNDF (g/kg DM) | ME (MJ/Kg/ DM) |
| **Sole grass** | Leaf | $816^{bcd}$ | $681.9^{bc}$ | $394.5^{b}$ | $184^{abc}$ | $10.09^{ab}$ |
| | Stem | $798.2^{cd}$ | $672.3^{bc}$ | $414.3^{ab}$ | $201.8^{ab}$ | $9.69^{ab}$ |
| | Whole | $790.9^{d}$ | $683.1^{bc}$ | $450.8^{ab}$ | $209.1^{a}$ | 9.88ab |
| **Border** | Leaf | $867.9^{a}$ | $766.6^{a}$ | $433.6^{ab}$ | $132.1^{d}$ | 10.11ab |
| | Stem | $784.6^{d}$ | $665.3^{c}$ | $428.1^{ab}$ | $215.4^{a}$ | 9.39ab |
| | Whole | $839.1^{abc}$ | $742.9^{ab}$ | $465.4^{a}$ | $160.9^{bcd}$ | 10.1ab |
| **Intercrop** | Leaf | $813.8^{bcd}$ | $702.6^{abc}$ | $440.1^{ab}$ | $186.2^{abc}$ | $9.56^{ab}$ |
| | Stem | $803^{cd}$ | $694.7^{abc}$ | $449.3^{ab}$ | $197^{ab}$ | $9.16^{b}$ |
| | Whole | $790.6^{d}$ | $654.4^{c}$ | $396.6^{b}$ | $209.4^{a}$ | $9.42^{ab}$ |
| **Spot** | Leaf | $848.6^{ab}$ | $719.9^{abc}$ | $389.4^{b}$ | $151.4^{cd}$ | $10.19^{a}$ |
| | Stem | $788.5^{d}$ | $677.9^{bc}$ | $445.1^{ab}$ | $211.5^{a}$ | $9.29^{ab}$ |
| | Whole | $805.5^{cd}$ | $687.6^{bc}$ | $427.9^{ab}$ | $194.5^{ab}$ | $9.65^{ab}$ |
| **S. e. d.** | | 10.27 | 18.48 | 16.72 | 10.27 | 0.251 |
| **P value** | Cropping pattern pattern | 0.002 | 0.005 | 0.131 | 0.002 | 0.017 |
| | Fraction | < .001 | 0.004 | 0.051 | < .001 | 0.002 |
| | Cropping pattern x Fraction | 0.003 | 0.015 | 0.008 | 0.003 | 0.536 |

Means with different superscript are significantly different at P<0.05, IVDMTD = *In vitro* dry matter true digestibility, NDFD = NDF digestibility, dNDF = Digestible NDF and iNDF = Indigestible NDF and ME = Metabolizable energy and ME were significantly ($p< 0.05$) affected by cropping pattern, botanical fraction and the two-way interaction effect of cropping pattern and botanical fraction except dry matter. The highest IVDMTD (867.9g/kg DM) and NDFD (766.6g/kg DM) were recorded in the leaf fraction whiles the highest (465.4g/kg DM) dNDF was recorded in the whole fraction of grass cultivated at the borders. The leaf fraction of spot planting however recorded the highest (10.19 MJ/kg/ DM) metabolizable energy.

## Discussions

*Growth and fodder yield of pearl millet forage under different cropping patterns*

Higher plant recorded in spot planting in the first cutting may be attributed to closer spacing which led to increased competition for nutrients and other assimilates compared to other cropping patterns. Significant increase in height for border cropping in the second cut may have also occurred because of influence of 'border effect'. Sato and Takahashi (1983) stated that, main causes of border effect are advantageous environmental factors such as higher solar energy, air circulation, space and others. Consequently, crop plants of border row get more light and more opportunity for gaseous exchange like carbon dioxide intake and release of oxygen. In the third cut however, competitive increase in height of plants cultivated as intercrop may have also occurred because the grass may have benefited from the available nitrogen fixed by the legumes.

The grass intercropped with pigeon pea increased in tillering in all three cuttings. This could probably be attributed to the shading effect of pigeon pea which prevented the death of young or newly developed tillers (Casal et al., 1985). Significant decrease in number of tillers in spot planting may have occurred due to disadvantageous environmental factors such as space and higher competition for available nutrients to produce more tillers. Higher number of tillers produced by grass at the borders also conforms with report by Wang et al. (2013) that Plants in border rows produce higher number of tillers from those in the centre of plots. Mian (2021) also stated that plants at the borders get more aeration as compared to inner side or centre of the plot. Consequently, the rate of transpiration decreases in a canopy due to density of foliage, shading effect and decrease of air movement inside of the rows. Again, more light interception enhanced total photosynthesis of plant at the borders.

Higher biomass yield observed in the sole grass (control) may be attributed to higher plant population. However, the difference in biomass among the cropping patterns in the first cut was not significant. This may be ascribed to the plant height and number of tillers produced by the grasses. As plant increases in height and tillering numbers, there is the tendency for increment in Leaf Area Index (LAI), which subsequently motivates increase in photosynthetic activities of the plant. Tao et al. (2018) stated that, as LAI increases so does light interception, causing increases in photosynthesis up to a critical LAI value. More photosynthesis results in more net photosynthesis in the plant system which ultimately contributes to higher yield (Liu et al., 2019). The significant increase in biomass at border planting in the second and third cuts may have occurred due to inability of the pigeon pea which is a shrub to intercept sunlight and shade the grass which directly affects the growth of the grass. Casanova-Lugo et al. (2022) demonstrated that the level of shade intensity given by the trees or shrubs is one of the main factors that negatively affect grass production on tropical pasturelands. The intensity of shade by pigeon pea regarding leaf senescence, architecture, height, and tree density favoured the arrival of sufficient sunlight to the grasses at the borders. These factors facilitated photosynthesis, improved evapotranspiration efficiency, and provided nutrients for the grasses. The biomass yield observed in the spot planting may be linked to the low number of tillers that were produced and higher mortality of tillers under the cutting session (Silveira et al., 2010).

*Chemical composition of Pearl millet forage under different cropping patterns*

The nutrient composition of forages determines how much nutrients are available in feed for utilization by livestock.

Significant increase in dry matter in the leaf fraction in the first and second cuts indicates the ability of the crop to intercept more light for photosynthesis. Also, the stage at which the grass was harvested may have influenced the amount of dry matter accumulated in the leaf fraction of the grass as observed by Craufurd and Bidinger (1988) who stated that the stage and duration of the vegetative growth stage is a main determinant of dry matter contents in the organs of pearl millet forage. Higher dry matter observed in the stem fractions in the third cut however can be attributed to age and frequent cutting which increased the amount of carbohydrate reserves in the stem and whole plant compared to the leaves. This result is in conformity with the findings of Manjanagouda et al. (2015). The dry matter in grass planted as intercrop may be attributed to beneficial effects of mixing grasses and legumes. Thus, the different functional traits could contribute to positive interactions between the species resulting in higher yields for intercropping in comparison to monocultures and other planting patterns (Nyfeler et al., 2009). This result conforms to what was reported by Mwangi and Thorpe (2002) who observed increased DM by integrating axillaris (*Macrotyloma axillare*) and Greenleaf desmodium (*Desmodium intortum* cv Greenleaf) in Napier grass system in central Kenya.

The differences in CP concentrations in the botanical fractions is an adaptive feature of forages to survive in its environment by accumulating structural carbohydrate in their stems and subsequent decrease in CP as they mature as described by Tang et al. (2008). Lemaire and Belanger (2020) also stated that the decline in CP in the stems of plants is because of the leaves positioned at the top of the canopy for reaching light with the mechanical constraint for developing relevant supporting tissues to support the plant.

Significant increase in CP concentrations in grass planted as spot may be due to the reduced mass of plants that reduced competition for nitrogen uptake. Greenwood et al. (1990) stated that plant nitrogen uptake declines monotonically as crop mass or tillers increases and the decline in nitrogen uptake is more pronounced when the nitrogen in the soil is limited to support plant growth. Again, Lemaire and Gastal (1997) demonstrated that, the percentage nitrogen is a consequence of the competition for light within dense canopies and the adaptive response of plants for positioning their leaf area within the illuminated layers of canopy. This phenomenon may have occurred since the other cropping patterns had higher plant tillers which increased the canopy and reduced the leaves' ability to intercept more light compared to that of the spot planting.

The NDF and ADF recorded significant increase in the sole grass, border and spot planting compared to the intercrop. This indicates that, the feed value of the fodder from the intercrop is high as it has been demonstrated that lower levels of NDF and ADF improves intake and digestibility of forages. These significant decrease in NDF and ADF when pearl millet grass was intercropped with the legume agrees with what was stated by Seresinhe and Pathirana (2000) who reported reduced NDF of guinea grass when intercropped with *Gliricidia sepium*. The differences in NDF and ADF observed in the cutting sessions may have occurred due to the harvesting age of the fodder. Mirza et al. (2002) stated that, plant structural components (NDF and ADF) may increase with the days of harvest. This phenomenon may have occurred in this study since the first cut was carried out 6Weeks After Planting and the second and third cuts were carried out at 3 weeks after the first and second cuts respectively. However, the values of NDF and ADF recorded in this study are higher than what was reported by Animasaun et al. (2018) but fall in a range regarded as good fodder that increases intake and digestibility.

Higher concentrations of ash recorded in the first cut compared to the second and third cuts are in line with what was reported by Brink et al. (2006) who investigated the changes in forage mineral concentrations and concluded that some forage mineral concentrations decreased with time and harvests during phenological development. The higher amount of ash content in the stem fractions in the first cut may be due to higher accumulation of soluble salt such as Na, K, Ca, and Mg in the stem. However, these salts were translocated to the leaf fraction after they were absorbed from the soil, and this probably may have occurred due to the genetic potential of pearl millet for accumulation of salt in various plant organs as stated by Makarana et al. (2018). These minerals absorption was necessary for rapid photosynthetic products to be synthesized and transported to the various tissues of the plants.

### *In vitro Digestibility and Metabolizable energy of Pearl millet forage under different cropping patterns*

Forage quality is most determined through dry matter digestibility which affects forage intake directly. The leaf fractions recording higher IVDMTD in all cuts is an indication of better dry matter digestibility than the stem fractions. Thus, the leaf fraction will allow greater dry matter intake for animals with intake limited by physical fill. The high IVDMTD could be explained by lower lignification in the leaf fraction as reported by Tremblay et al. (2002). However, the values of IVDMTD for all botanical fractions reported in this study are higher than the value (750 g/kg DM) reported by Bélanger et al. (2017) for sweet pearl millet.

The results of the digestibility of NDF (NDFD) of pearl millet in this study was more than 50% in all cuts and botanical fractions. The results indicate a potential higher intake and corresponding higher digestible energy for ruminant for growth and maintenance as demonstrated by Min et al. (2007) that increased NDF digestibility resulted in higher digestible energy and forage intake in lactating cows. It has also been established that, more digestible fibre is less filling because it is retained in the rumen for a shorter period. Since it is less filling in the rumen, diets containing highly digestible fibre allow greater dry matter intake for animals. The NDFD values recorded are higher than what was recorded by Leblanc et al. (2012) (average of 556 g/kg DM) and Bouchard et al. (2011) (average of 591 g/kg) for sweet pearl millet hybrid. Considerable higher dNDF in the whole fractions may be linked to the NDF observed in the whole fraction. Thus, the quantity of NDF digested as a percentage of the dry matter in the whole fraction was higher. This may have occurred due to the lower level of soluble carbohydrate in the whole fraction which increased rumen cellulolytic microbes responsible for digestion of NDF (Owens and Basalan, 2016). The relatively higher iNDF in the stem fractions is an indication of increased cell wall contents and lignin which may have affected ruminal digestion, retention, and rumen passage of feed.

Significant increase in ME observed in the leaf fraction is associated with the increase in digestibility of the leaf fraction which resulted in the release of energy. Also, the leaf fractions may have contained better digestive elements for microbial synthesis in the rumen. Wilson and Hatfield (1997) stated that the middle lamella in the leaf is made of vascular tissues which are mostly lignified, and this chemical structure of the middle lamella is said to reduce fermentation by rumen microbes leading to lower digestibility and ME (Guo et al. 2001). The age at which the grasses were harvested prevented the lignification of the middle lamella in the leaves and aided digestibility and subsequent production of higher ME in the leaf fraction. Meanwhile, the ME recorded in all the fractions are higher than 7 MJ/kgDM recommended by NRC (2007) for meeting the maintenance requirement of beef and dairy cattle.

## Conclusion

The cultivation of pearl millet forage using different cropping patterns elicited various growth patterns, yield, and nutritional quality at the various cuts. The control (sole grass) produced the highest biomass yield followed by border and spot planting yielding the least biomass. Planting pearl millet grass as intercrop however yielded better nutritional and digestibility quality with the leaf fractions recording increased CP, digestibility and ME and the stem fractions producing higher NDF and ADF. It can therefore be concluded that planting pearl millet forage as sole crop will give higher biomass but planting pearl millet forage as intercrop increases the chemical composition and digestibility of the forage.

The study therefore recommends that pearl millet forage can be introduced into farming systems as intercrop in a crop/livestock farming system in the Guinea Savannah Agro ecological zone of Ghana.

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