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Research Article

# Effects of Multiple Harvests and Different Manure Fertilization levels on the Yield and Feed Value of Kenaf (*Hibiscus Cannabinus* L.)

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**Abstract** | Investigation to evaluate the effect of varying levels of manure fertilization on the productivity and feed quality of kenaf (*Hibiscus cannabinus* L.) during bi-weekly harvests was conducted in Gyeongbuk province, Republic of Korea, over a span of two years. The experimental design adopted a randomized complete block with four harvesting periods (100, 110, 120, and 130 days after planting - DAP) and four manure fertilization levels (0, 150, 200, and 250 kg N/ha), each replicated thrice. The findings revealed a positive correlation between manure fertilization application and kenaf growth, with the greatest plant height observed at the highest manure fertilization levels. The manure fertilization application level of 200 kg N/ha resulted in the highest dry matter (DM) yield, coupled with the highest crude protein (CP) content in kenaf leaves. Elevating manure fertilization level had a significant diminishing effect on acid detergent fiber (ADF) content, concurrently escalating neutral detergent fiber (NDF) content. Notably, the manure fertilization levels of 200 and 250 kg N/ha exhibited the highest total digestible nutrient (TDN) content. The temporal progression of kenaf growth was characterized by increasing height, while no statistically significant differences were detected in DM yield. In summation, optimal growth and development of the kenaf plant were attained through a manure fertilization application level of 200 kg N/ha, coupled with harvesting between 110 and 120 DAP. The adoption of these practices holds the potential to enhance both local and international kenaf markets, while concurrently addressing environmental concerns associated with conventional farming practices.

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## Introduction

The Intergovernmental Panel on Climate Change (IPCC) estimated that the management of manure contributed approximately 6% to global anthropogenic methane emissions during the 26th Conference of Parties (COP26) in 2021. Subsequently, a global initiative, the Methane Pledge, was launched, with participation from over 100 countries, including Korea, all committing to a 30% reduction in methane emissions by the year 2030. To tackle this environmental challenge, the Food and Agriculture Organization of the United Nations (FAO, 2023) proposed several strategies to mitigate these emissions, focusing on enhancing manure management practices.

Manure is recognized for its well-balanced nutrient composition, which is essential for supporting plant growth (Xu *et al*., 2022). It has been reported that manure has highly advantageous in kenaf (*Hibiscus cannabinus* L.) cultivation, enhancing organic matter efficiency, promoting soil structure and fertility improvements, and optimizing the utilization of fertilizers. The global demand for kenaf has been gradually increasing (Mohd *et al*., 2013). Kenaf is considered as a warm-season crop with versatile applications and environmentally sustainable cellulose, establishing itself as a pivotal asset in both commercial and subsistence agriculture (Al-Mamun *et al*., 2023). The rapid growth cycle, robust plant characteristics, stress resistance, quality bast fiber, and high yield collectively render the crop an appealing and advantageous choice (An *et al*., 2017). Kenaf demands minimal inputs to attain maximum yield within a brief timeframe (Robynn *et al*., 2013), and the effective harvesting, typically conducted between 11 and 13 weeks after planting, results in appropriate CP content and plays a vital role in achieving a balance between forage quality and quantity (Nam *et al*., 2018). Harvesting periods significantly affect fresh biomass yield, dry matter yield, nutritional and mineral compositions, and forage quality parameters, with the soft dough stage identified as the optimal harvesting period (Poe *et al*., 2022).

The chemical composition and *in vitro* digestibility of kenaf position it as a valuable fodder plant, particularly in arid regions. It provides high nutritional value and serves as a protein supplement for ruminants, and all above-ground plant organs, including leaves, stems, flowers, and seeds, have the potential to contribute significantly to feed production (Hajer *et al*., 2020). According to Kujoana *et al*. (2023) the leaves of kenaf can be utilized as a source of roughage and protein for cattle and sheep due to their high digestibility. Additionally, because of their high palatability and significant crude protein content at an early stage of growth, kenaf stalks can serve as a potential protein supplement for animal feeding. Despite some farmers incorporating kenaf into fodder, there is insufficient information regarding its nutritional value and its potential as an animal feed resource. In Korea, realizing the suitability of kenaf as a forage crop and identifying optimal growth conditions is essential. This highlights the need for farmers to embrace scientific cultivation practices, fostering the expansion of local and international markets for kenaf fiber and products (Al-Mamun *et al*., 2023).

Moreover, comprehensive investigations into the application of livestock manure at different ratios can reduce the use of mineral fertilizers and improve crop yield and quality, as reported by Xu *et al*. (2022). Therefore, the primary objective of this two-year study is to ascertain the appropriate manure fertilization application level and identify the optimal harvesting period to maximize the nutritional benefits of kenaf for animal feed resources.

Table 1: *Physicochemical properties of soils.*

| Year | pH (1:5) | OM (g/kg) | EC (dS/m) | T-N (%) | Available $P_2O_5$ (mg/kg) | $Ca^{2+}$ | $K^+$ | $Mg^{2+}$ |
|---|---|---|---|---|---|---|---|---|
| | | | | | | (cmol+/kg) | | |
| 2019 | 7.3 | 12.0 | 0.23 | 0.14 | 422.3 | 6.07 | 1.18 | 2.07 |
| 2020 | 7.8 | 18.0 | 0.38 | 0.17 | 491.7 | 4.10 | 0.46 | 0.93 |

**pH:** *Potential of Hydrogen,* **OM:** *Organic Matter,* **EC:** *Electrical Conductivity,* **T-N:** *Total Nitrogen, Available phosphorus ($P_2O_5$).*

## Materials and Methods

*Field experiment and soil physicochemical properties*

Two growing seasons (2019 and 2020) experiment was conducted in Gyeongsan, South Korea, located at latitude 35° 54' 11.12" N and longitude 128° 51' 22.67" E. The soil's physicochemical properties before the application of manure are detailed in Table 1. The soil primarily comprised a blend of sand and clay, exhibiting favorable physicochemical characteristics that did not significantly hinder plant growth. Laboratory assessments indicated higher levels of pH, organic matter (OM), electrical conductivity (EC), total nitrogen (T-N), and available phosphorus ($P_2O_5$) in 2020 compared to 2019. Conversely, concentrations of calcium, potassium, and magnesium ions slightly decreased from 2019 (6.07, 1.18, and 2.07 cmol+/kg, respectively) to 2020 (4.10, 0.48, and 0.93 cmol+/kg, respectively).

**Table 2:** *Weather characteristics during the study periods.*

| Year | Items | Classification | May | June | July | August | September |
|---|---|---|---|---|---|---|---|
| 2019 | Temperature (°C) | Minimum | 11.3 | 16.3 | 21.4 | 22.5 | 17.9 |
| | | Maximum | 27.7 | 28.2 | 30.0 | 32.1 | 27.2 |
| | | Average | 19.5 | 21.9 | 25.4 | 26.7 | 22.1 |
| | Precipitation (mm) | Total (701.5) | 23.0 | 242.1 | 105.7 | 174.4 | 157 |
| 2020 | Temperature (°C) | Minimum | 12.0 | 17.3 | 18.9 | 23.3 | 15.5 |
| | | Maximum | 24.4 | 29.1 | 25.8 | 31.9 | 25.0 |
| | | Average | 18.0 | 23.0 | 22.0 | 27.0 | 19.8 |
| | Precipitation (mm) | Total (975.1) | 46.4 | 142 | 338.5 | 246.6 | 201.6 |
| 30-year average (1989-2018) | Temperature (°C) | Minimum | 10.7 | 16.3 | 21.0 | 21.1 | 15.4 |
| | | Maximum | 24.8 | 27.5 | 30.0 | 30.4 | 26.2 |
| | | Average | 17.7 | 21.6 | 25.1 | 25.3 | 20.3 |
| | Precipitation (mm) | Total (803.4) | 84.6 | 122.4 | 230.4 | 228.8 | 137.2 |

**A-C:** *Different letters in the same column are significantly different ($p<0.05$),* **CP:** *Crude Protein,* **OM:** *Organic Matter,* **ADF:** *Acid Detergent Fiber,* **NDF:** *Neutral Detergent Fiber,* **TDN:** *Total Digestible Nutrients.*

**Table 3***: Manure characteristics*

| Composition | MC (%) | TS (%) | VS (%) | TN (%) | TP (%) | $NH_4$-N (mg/kg) | Cu | Mg | Zn |
|---|---|---|---|---|---|---|---|---|---|
| Mean | 6.0 | 94.0 | 68.2 | 21.5 | 9.2 | 43.7±0.6 | 21.4±1.1 | 7,869±153 | 137±4 |

**MC:** *Moisture Content,* **TS:** *Total Solids,* **VS:** *Volatile Solids,* **TN:** *Total Nitrogen,* **TP:** *Total Phosphorus,* **$NH_4$-N:** *Ammonium. Data represent mean ± Standard deviation*

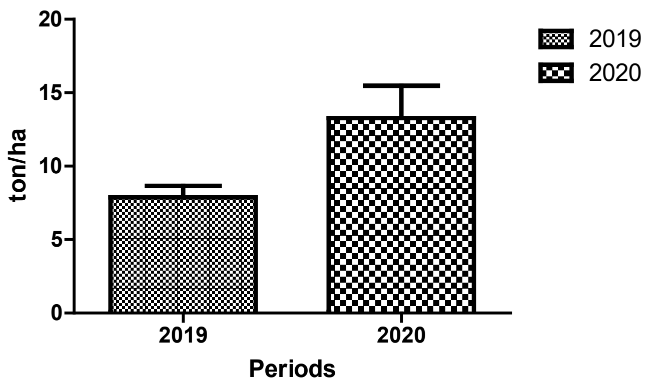


**Figure 1:** *DM yield of kenaf as affected by manure fertilization across two growing years.*

*Weather characteristics of the field experiment*

Meteorological information, about temperature and precipitation, for the two-year experiment is presented in Table 2. The mean temperature exhibited a gradual rise from May to August in both years, aligning with the 30-year mean. Notably, the maximum temperature in 2019 surpassed that of 2020, potentially reflecting the impact of recent global warming. Furthermore, precipitation in 2020 notably exceeded the levels recorded in 2019, creating more favorable conditions for the growth of kenaf (Figure 1).

*Experimental treatments and data collection*

The two-year experimental setup employed a randomized complete block design, incorporating four main plot treatments (Treatment 1: 100 DAP, Treatment 2: 110 DAP, Treatment 3: 120 DAP, Treatment 4: 130 DAP), each replicated three times. The subplots received four manure fertilization levels (0 kg N/ha - control, 150, 200, and 250 kg N/ha), with each level replicated three times. Initial manure fertilization occurred post-planting, supplemented by additional fertilization during the growth period. Table 3 provides the characteristics of the manure materials. For the evaluation of forage productivity under various manure fertilization levels and harvesting periods, the kenaf variety "Hongma 74-3" was utilized. Standardized agricultural science and technology research surveys (RDA, 2012) were conducted to assess agricultural growth, traits, and forage yield, encompassing parameters such as plant height, leaf ratio, stem ratio, and dry matter yield.


Links Researchers

*Land preparation, planting methods, and harvesting periods*

Each replication comprised a 5×1 m plot. Kenaf was planted under four distinct manure fertilization levels, initially applied post-planting, with supplementary organic fertilization during the growth phase. Seed broadcasting was carried out by hand, with a seeding level of 80 kilograms/ha onto dry soil, resulting in a planting density of 20×20 cm. The first experiment spanned from May 8th to September 15th, 2019, while the second experiment took place between May 16th and September 23rd, 2020. In 2019, the harvests took place on August 16th, August 26th, September 5th, and September 15th, while in 2020, they occurred on August 24th, September 3rd, September 13th, and September 23rd.

*Chemical composition analysis*

Samples were collected from each experimental section, subjected to a 3-day drying process in a dry oven, and subsequently weighed. Leaves and stems underwent separate drying, and their respective dry weights were determined. The analysis of forage chemical composition followed the scientific methodologies outlined by the Association of Official Analytical Chemists - AOAC (2012). Crude protein (CP) content was ascertained through the Kjeldahl digestion method, while fiber analysis, encompassing neutral detergent fiber (NDF) and acid detergent fiber (ADF), was conducted using the procedure outlined by Van Soest *et al.* (1991). Total digestible nutrients (TDN) were computed utilizing the formula by Moore and Undersander (2002): TDN = 88.9 - (0.79 × ADF).

*Statistical Analysis*

The statistical analysis of all experimental data, including agricultural growth, yield, and feed value under various manure fertilization application levels and harvesting periods, was conducted using SAS Statistical Package Program (version 9.1; SAS Institute Inc.; Cary, USA). The least significant difference (LSD) tests were employed to identify significant differences among treatment mean values. Differences were considered significant if the p-value was less than 0.05.

## Results and Discussion

*Agricultural growth, traits, and kenaf yield under varied harvesting periods*

The impact of diverse harvesting periods (100, 110, 120, and 130 DAP) on kenaf's plant height, DM ratio, leaf ratio, stem ratio, and DM yield is presented in Table 4. The most substantial kenaf growth was noted during the 130 DAP harvesting period for both 2019 and 2020, as well as the two-year mean. A noteworthy escalation in plant height ($p<0.05$) was observed as kenaf growth advanced. Remarkably, the plant height in 2019 and 2020 exhibited a significant difference between the control and other harvesting periods, with the mean plant height in 2020 slightly surpassing that of 2019. These variations in plant height were likely influenced by fluctuations in rainfall patterns during the growth period, resulting in a year-by-treatment interaction. Kenaf, being photosensitive, responds to the timing of planting, which can be affected by climate change (Adetumbi *et al.*, 2022). The peak DM ratio for kenaf during the summer of 2019 and the two-year mean, impacted by varying harvesting periods, was identified during the earlier harvesting period of 100 DAP. Conversely, in the summer of 2020, the DM ratio of kenaf exhibited no statistically significant difference among all treatments ($p>0.05$). Similar findings were reported by Nam *et al.* (2018), indicating a lack of statistically significant difference in the DM ratio among various treatments. In the summer of 2019, the leaf ratio demonstrated a noteworthy increase during the harvesting period of 110 DAP, while the stem ratio exhibited a significant rise during the harvesting periods of 120 and 130 DAP compared to the earlier periods. In contrast, throughout the summer of 2020, the leaf ratio experienced a notable increase as kenaf growth advanced from 100 to 130 DAP, while the stem ratio exhibited a significant decrease ($p<0.05$). During the summer of 2019, the DM yield of kenaf, subject to various harvesting periods, peaked in the earlier harvesting period, with no significant difference observed between the harvesting periods of 120 and 130 DAP ($p>0.05$). Interestingly, in the summer of 2020, as kenaf matured, a substantial increase in DM yield was noted. Adetumbi *et al.* (2022) reported that global climate effects, characterized by variations in the seasonal amount, timing, distribution, and intensity of precipitation, have a significant impact on crop productivity. The two-year mean of the DM yield of kenaf under different harvesting periods indicated no significant difference among all treatments ($p>0.05$). Nevertheless, the DM yield of kenaf appeared to be higher in the harvesting periods of 100 and 130 DAP. Nam *et al.* (2018) suggested that late-maturing kenaf crops generally exhibit superior yields compared to early-maturing ones.

**Table 4:** *Effects of multiple harvesting periods on the agriculture growth, traits and yield of kenaf.*

| Year | Days after planting | Plant height (cm) | DM ratio (%) | Shoot ratio (%) | | DM yield (ton/ha) |
|---|---|---|---|---|---|---|
| | | | | Leaves | Stem | |
| 2019 | 100 | 141.0±40$^{D}$ | 25.3±4.0$^{A}$ | 36.0±7.0$^{AB}$ | 64.0±7.0$^{AB}$ | 11.2±3.0$^{A}$ |
| | 110 | 167.3±27$^{C}$ | 21.0±3.0$^{B}$ | 42.6±12$^{A}$ | 57.4±12$^{AB}$ | 8.5±3.0$^{AB}$ |
| | 120 | 180.8±48$^{B}$ | 16.7±1.0$^{C}$ | 30.8±5.0$^{B}$ | 69.2±5.0$^{A}$ | 6.1±5.0$^{B}$ |
| | 130 | 207.9±27$^{A}$ | 18.6±2.0$^{BC}$ | 31.6±5.0$^{B}$ | 68.4±5.0$^{A}$ | 5.7±1.0$^{B}$ |
| | p-value | <0.0001 | <0.0001 | 0.0125 | 0.0125 | 0.0125 |
| 2020 | 100 | 148.2±38$^{D}$ | 29.0±4.0 | 37.0±7.0$^{B}$ | 63.0±7.0$^{A}$ | 9.1±4.0$^{B}$ |
| | 110 | 176.0±55$^{B}$ | 22.9±6.0 | 36.7±9.0$^{B}$ | 63.3±9.0$^{A}$ | 9.9±5.0$^{B}$ |
| | 120 | 161.8±44$^{C}$ | 29.4±8.0 | 46.3±8.0$^{A}$ | 53.7±8.0$^{B}$ | 11.2±6.0$^{B}$ |
| | 130 | 216.5±61$^{A}$ | 25.6±8.0 | 48.6±3.0$^{A}$ | 51.4±3.0$^{B}$ | 22.7±17$^{A}$ |
| | p-value | <0.0001 | 0.2796 | 0.0014 | 0.0014 | 0.0206 |
| 2-year mean | 100 | 144.6±42$^{C}$ | 27.1±5.0$^{A}$ | 36.5±8.0 | 63.5±8.0 | 10.2±4.0 |
| | 110 | 171.6±44$^{B}$ | 22.0±4.0$^{B}$ | 39.6±11 | 60.4±11 | 9.2±5.0 |
| | 120 | 171.3±48$^{B}$ | 23.1±9.0$^{AB}$ | 38.6±10 | 61.4±10 | 8.6±6.0 |
| | 130 | 212.2±51$^{A}$ | 22.1±7.0$^{B}$ | 40.1±10 | 59.9±10 | 14.2±9.0 |
| | p-value | <0.0001 | 0.0081 | 0.6380 | 0.6380 | 0.2125 |

$^{A-D}$ *Different letters in the same column are significantly different (p<0.05)*

**Table 5:** *Effects of different manure application levels on the agricultural growth, traits and yield of kenaf.*

| Year | Manure application levels (kg N/ha) | Plant height (cm) | DM ratio (%) | Shoot ratio (%) | | DM yield (ton/ha) |
|---|---|---|---|---|---|---|
| | | | | Leaf | Stem | |
| 2019 | 0 | 156.4±39$^{C}$ | 20.8±2.0 | 35.2±5.0 | 64.8±5.0 | 6.6±3.0$^{B}$ |
| | 150 | 168.8±27$^{B}$ | 19.9±3.0 | 37.8±10 | 62.2±10 | 6.7±2.0$^{B}$ |
| | 200 | 176.3±47$^{B}$ | 20.7±4.0 | 30.5±5.0 | 69.5±5.0 | 8.3±2.0$^{AB}$ |
| | 250 | 195.5±31$^{A}$ | 20.2±3.0 | 37.6±9.0 | 62.5±9.0 | 9.9±4.0$^{A}$ |
| | p-value | <0.0001 | 0.8819 | 0.1922 | 0.1922 | 0.0040 |
| 2020 | 0 | 155.9±47$^{B}$ | 28.1±7.0 | 40.7±7.0$^{B}$ | 59.3±7.0$^{A}$ | 9.7±5.0$^{B}$ |
| | 150 | 182.4±46$^{A}$ | 25.5±6.0 | 40.8±8.0$^{B}$ | 59.2±8.0$^{A}$ | 13.5±8.0$^{AB}$ |
| | 200 | 179.8±59$^{A}$ | 28.0±10 | 39.2±7.0$^{B}$ | 60.8±7.0$^{A}$ | 19.4±9.0$^{A}$ |
| | 250 | 184.4±47$^{A}$ | 25.2±4.0 | 47.9±5.0$^{A}$ | 52.1±5.0$^{B}$ | 10.5±4.0$^{AB}$ |
| | p-value | <0.0001 | 0.7810 | 0.0094 | 0.0094 | 0.0090 |
| 2-year mean | 0 | 156.1±45$^{C}$ | 24.5±6.0 | 37.9±8.0$^{AB}$ | 62.1±8.0$^{AB}$ | 8.1±4.0 |
| | 150 | 175.6±40$^{B}$ | 22.7±5.0 | 37.9±12$^{AB}$ | 60.7±12$^{AB}$ | 10.1±6.0 |
| | 200 | 178.0±58$^{B}$ | 24.3±9.0 | 34.9±9.0$^{B}$ | 65.1±9.0$^{A}$ | 13.8±7.0 |
| | 250 | 190.0±41$^{A}$ | 22.7±5.0 | 42.7±10$^{A}$ | 57.3±10$^{B}$ | 10.2±5.0 |
| | p-value | <0.0001 | 0.7593 | 0.0093 | 0.0093 | 0.2570 |

$^{A-C}$ *Different letters in the same column are statistically different (p<0.05)*

*Agricultural growth, traits, and kenaf yield under various manure application levels*

Table 5 outlines the influence of varied manure fertilization application levels (0, 150, 200, and 250 kg N/ha) on kenaf's parameters such as plant height, DM ratio, leaf ratio, stem ratio, and DM yield. The kenaf plant height in 2019, 2020, and the two-year mean exhibited a discernible response to manure fertilization applications, with each successive increment in nitrogen dose significantly enhancing kenaf plant height. This observation is in accordance with the findings of Olanipekun *et al.* (2021), which emphasize the positive impact of increased livestock manure application and various other types of combined fertilizers on agronomic growth, including plant height. During the summer experiment of 2020, the leaf ratio displayed a tendency to be slightly higher compared to the previous year. The two-year mean leaf ratio of kenaf, influenced by various manure fertilization application levels, demonstrated no significant difference between the control and the manure fertilization application level of 150 kg N/ha ($p>0.05$). However, the highest leaf ratio of kenaf was observed at the nitrogen fertilization application level of 250 kg N/ha ($p<0.05$). Conversely, the stem ratio in the summer experiment of 2020 tended to be slightly lower than that of the previous year. In this study, the stem ratio of kenaf decreased significantly as the nitrogen content in the manure fertilization increased ($p<0.05$). Comparable trends were observed in the study by Nam *et al.* (2018), indicating a significant increase in the leaf ratio of kenaf with higher organic fertilization levels, accompanied by a significant decrease in stem ratio. The DM yield in 2020 slightly surpassed that of 2019 (Table 5**,** Figure 1), likely due to the significantly higher precipitation levels in 2020, which created more favorable conditions for the growth of kenaf (Table 2). The two-year mean of DM yield, influenced by various manure fertilization application levels, indicated that the highest DM productivity was observed at the manure fertilization application level of 200 kg N/ha. However, no significant difference was noted among all the manure fertilization treatments. This discovery is consistent with the findings of Danalatos and Archontoulis (2010), who reported no variance in kenaf fresh matter yield between nitrogen levels of 0, 50, 100, and 150 kg N/ha. They proposed that this lack of difference could be attributed to the plant's low nitrogen requirements or the high initial available nitrogen in the soil.

### *Effects of varied harvesting periods on the nutritional value of kenaf leaves*

The CP, OM, ADF, NDF, and TDN contents of kenaf leaves harvested at 100, 110, 120, and 130 DAP are displayed in Table 6. As the kenaf plants developed, the 2-year mean CP content of their leaves, which varied depending on the harvesting season, showed no significant difference ($p>0.05$) and varied between 12.9 and 16.2 percent. In a previous study, Kim *et al.* (2018) examined several kenaf crop types in Korea and found that the CP level in the leaves ranged from 22.1 to 26.2 percent, which is higher than the CP level of the present study. But according to the present study, the kenaf collected in the summer of 2019 had a little lower mean CP concentration than the kenaf gathered in 2020. Due to different harvesting periods in 2019, the OM content in kenaf leaves varied from 8 to 9, with the maximum concentration recorded at 120 DAP. Consistent with the results of this investigation, Kim *et al.* (2018) revealed that the OM concentration of kenaf leaves ranged from 5.2 to 6.6 percent, slightly greater than the OM level of kenaf stems. On the other hand, when the plants grew and the kenaf development advanced over the summer of 2020, the OM content of the kenaf leaves considerably reduced ($p<0.05$). When harvest intervals were extended from 3.5 to 10.5 weeks after planting, Hajer *et al.* (2020) observed a significant decrease in leaf OM content from 15.9 to 12.0 in research with almost similar parameters. ADF content in kenaf leaves during a two-year period, impacted by different harvesting periods, showed a substantial ($p<0.05$) decline when harvesting was postponed from 100 to 130 DAP. These results are consistent with those of Omenna *et al.* (2016), who found that harvesting kenaf near the start of the blooming phase yields the maximum fiber content. Under various harvesting conditions, the NDF content of kenaf leaves in 2019 had the greatest level at 120 DAP. According to the 2-year mean NDF content of kenaf leaves, the maximum amount was found during the early harvesting period and at 120 DAP. Due to varying harvesting periods, the TDN content of kenaf leaves in 2019 and 2020 as well as the 2-year mean revealed the highest level at 130 DAP. The TDN content of kenaf leaves considerably increased ($p<0.05$) as kenaf development progressed. This is not the case with the research by Nam *et al.* (2018), where the TDN content of kenaf increased dramatically with the growth of kenaf.

### *Effects of varied manure application levels on the nutritional value of kenaf leaves*

The CP, OM, ADF, NDF, and TDN content of kenaf leaves at varying manure fertilization application levels of 0, 150, 200, and 250 kg N/ha are shown in Table 7. In 2019, the CP content of kenaf leaves was considerably increased ($p<0.05$) by an increase in nitrogen content from the manure fertilization but the mean CP concentration was slightly lower compared to the kenaf harvested in 2020 (Table 7 and Figure 2**)**. The 2-year mean showed that, with the manure fertilization application level of 200 kg N/ha, the CP concentration in kenaf leaves was the highest among

**Table 6:** *Effects of multiple harvesting periods on the feed value (chemical composition, %) of kenaf leaves.*

| Year | Days after planting | CP | OM | ADF | NDF | TDN |
|---|---|---|---|---|---|---|
| 2019 | 100 | 12.9±0.80 | 8.3±0.10$^{D}$ | 24.5±1.51$^{A}$ | 37.1±1.27$^{B}$ | 69.6±1.18$^{B}$ |
| | 110 | 14.2±1.88 | 8.7±0.16$^{C}$ | 21.0±0.74$^{B}$ | 32.3±2.03$^{C}$ | 72.3±0.59$^{A}$ |
| | 120 | 14.1±0.51 | 9.8±0.12$^{A}$ | 24.7±3.66$^{A}$ | 41.9±4.47$^{A}$ | 69.4±1.45$^{B}$ |
| | 130 | 13.7±1.12 | 9.0±0.17$^{B}$ | 21.9±0.78$^{B}$ | 35.1±0.81$^{BC}$ | 71.6±0.61$^{A}$ |
| | **p-value** | 0.2061 | <0.0001 | <0.0001 | 0.0002 | <0.0001 |
| 2020 | 100 | 13.0±0.69 | 9.9±0.30$^{A}$ | 22.6±0.47$^{A}$ | 34.8±0.53$^{A}$ | 71.0±0.37$^{D}$ |
| | 110 | 15.0±1.62 | 9.1±0.07$^{B}$ | 20.4±1.84$^{B}$ | 30.8±1.73$^{C}$ | 72.8±1.45$^{C}$ |
| | 120 | 14.2±2.29 | 8.5±0.04$^{C}$ | 17.4±0.40$^{C}$ | 31.3±0.78$^{C}$ | 75.2±0.32$^{B}$ |
| | 130 | 16.2±1.27 | 8.5±0.03$^{C}$ | 15.9±0.38$^{D}$ | 33.6±0.72$^{B}$ | 76.4±0.30$^{A}$ |
| | **p-valu**e | 0.2070 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| 2-year mean | 100 | 12.9±1.27 | 9.1±0.9 | 23.5±2.25$^{A}$ | 35.9±2.29$^{A}$ | 70.3±1.78$^{C}$ |
| | 110 | 14.6±2.38 | 8.9±0.44 | 20.7±1.86$^{BC}$ | 31.5±2.82$^{B}$ | 72.6±1.47$^{AB}$ |
| | 120 | 14.1±1.95 | 9.1±0.75 | 21.1±4.29$^{B}$ | 36.6±7.14$^{A}$ | 72.3±3.39$^{B}$ |
| | 130 | 15.0±2.34 | 8.7±0.32 | 18.9±3.82$^{C}$ | 34.3±3.07$^{AB}$ | 74.0±3.02$^{A}$ |
| | p-value | 0.2130 | 0.2784 | 0.0005 | 0.0028 | 0.0005 |

*$^{A-D}$ Different letters in the same column are significantly different (p<0.05),* **CP:** *Crude Protein,* **OM:** *Organic Matter,* **ADF:** *Acid Detergent Fiber,* **NDF:** *Neutral Detergent Fiber,* **TDN:** *Total Digestible Nutrients*

**Table 7:** *Effects of different manure application levels on the feed value (chemical composition, %) of kenaf leaves.*

| Year | Manure application levels (kg N/ha) | CP | OM | ADF | NDF | TDN |
|---|---|---|---|---|---|---|
| 2019 | 0 | 13.1±0.42$^{B}$ | 9.1±0.11$^{C}$ | 22.8±0.43$^{AB}$ | 34.8±1.19 | 70.9±0.40$^{AB}$ |
| | 150 | 12.9±2.08$^{B}$ | 10.5±0.15$^{A}$ | 23.9±1.04$^{A}$ | 38.0±0.49 | 70.0±0.82$^{B}$ |
| | 200 | 14.4±0.47$^{A}$ | 10.1±0.18$^{B}$ | 21.9±2.13$^{B}$ | 35.4±0.88 | 71.6±1.68$^{A}$ |
| | 250 | 14.5±1.05$^{A}$ | 10.2±0.11$^{B}$ | 23.4±1.24$^{A}$ | 38.0±6.01 | 70.4±0.98$^{B}$ |
| | p-value | 0.0197 | <0.0001 | 0.0150 | 0.2153 | 0.0149 |
| 2020 | 0 | 14.0±1.52 | 9.3±0.11$^{B}$ | 22.6±0.43$^{A}$ | 34.9±1.0$^{A}$ | 71.0±0.34$^{C}$ |
| | 150 | 14.7±1.07 | 10.2±0.17$^{A}$ | 18.4±0.62$^{B}$ | 31.2±0.85$^{B}$ | 74.3±0.51$^{B}$ |
| | 200 | 15.3±0.91 | 10.2±0.13$^{A}$ | 17.9±1.21$^{BC}$ | 30.4±0.33$^{B}$ | 74.8±0.13$^{AB}$ |
| | 250 | 14.4±2.38 | 9.4±0.05$^{B}$ | 17.4±0.81$^{C}$ | 34.0±1.83$^{A}$ | 75.2±0.64$^{A}$ |
| | p-value | 0.4544 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| 2-year mean | 0 | 13.5±1.59$^{B}$ | 9.2±0.82$^{C}$ | 22.7±1.02$^{A}$ | 34.9±1.85$^{AB}$ | 71.0±0.81$^{B}$ |
| | 150 | 13.8±2.53$^{AB}$ | 10.3±0.56$^{A}$ | 21.2±3.14$^{AB}$ | 34.6±3.80$^{AB}$ | 72.2±2.48$^{AB}$ |
| | 200 | 14.9±1.87$^{A}$ | 10.1±0.40$^{AB}$ | 19.9±4.21$^{B}$ | 32.6±4.08$^{B}$ | 73.2±3.32$^{A}$ |
| | 250 | 14.4±1.96$^{AB}$ | 9.8±0.55$^{B}$ | 20.4±3.86$^{B}$ | 36.0±5.98$^{A}$ | 72.8±3.08$^{A}$ |
| | p-value | 0.0539 | 0.0525 | 0.0485 | 0.0185 | 0.0482 |

*$^{A-C}$ Different letters in the same column are significantly different (p<0.05),* **CP:** *Crude Protein,* **OM:** *Organic Matter,* **ADF:** *Acid Detergent Fiber,* **NDF:** *Neutral Detergent Fiber,* **TDN:** *Total Digestible Nutrient*

the treatments. This indicates a significant departure from the control group and confirms the findings of Byamungu and Jo (2021), which show that nitrogen fertilization is critical to increasing yields and increasing the CP content in kenaf leaves. In comparison to the summer of 2020, the ADF of kenaf leaves in 2019 was somewhat lower. The study found that when the nitrogen fertilizer was applied at several levels (from 0 to 250 kg N/ha), the 2-year mean ADF content of kenaf leaves decreased significantly (p<0.05). Similarly, there was no discernible difference in the NDF content between the control and manure fertilization


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application level of 150 kg N/ha, according to the 2-year mean of NDF content of kenaf leaves, which showed the maximum NDF content at the manure fertilization application level of 250 kg N/ha. The NDF concentration rose considerably ($p<0.05$) when the nitrogen component in the manure fertilization formulation increased from 0 to 250 kg N/ha. Nonetheless, in this investigation, the ADF and NDF of kenaf leaves were less than those of the kenaf stem. This is consistent with research by Byamungu and Jo (2021), who observed that kenaf cultivars varied in their cell wall composition and function, leading to increased ADF in the stem as opposed to the leaf. There was no significant difference in the TDN content of kenaf leaves in 2019 between the application levels of 150 and 250 kg N/ha of manure fertilization and the greatest TDN content recorded at the manure fertilization application level of 200 kg N/ha. Nonetheless, in 2020, the application level of 250 kg N/ha yielded the greatest TDN content among the treatments ($p<0.05$). Different levels of manure fertilization application had an impact on the 2-year mean TDN content of kenaf leaves, which was 71.0, 72.2, 73.2, and 72.8 percent, respectively. The fertilizer application levels of 200 and 250 kg N/ha showed the greatest TDN concentration.

*Effects of varied harvesting periods on the nutritional value of kenaf stem*

The concentration of CP, OM, ADF, NDF, and TDN in kenaf stems harvested at 100, 110, 120, and 130 DAP is shown in Table 8. Due to varying harvesting periods, the CP content of kenaf stem in 2019 and 2020 as well as the 2-year mean showed that the greatest CP concentration was at 120 DAP, reaching 3.7 percent. In a recent study, Kim *et al.* (2018) evaluated the nutritional properties of leaves, stem bark, flowers, and seeds from various kenaf cultivars, including Jangdae, Baekma, Jeokbong, Jinju, and C14. They reported that the CP concentration in the leaves of these kenaf varieties was 4.7, 5.8, 5.5, 4.6, and 4.8 percent, respectively. At 100 and 120 DAP, the O Mcontent of kenaf stem showed the highest values in 2019. Nonetheless, when kenaf growth advanced in 2020 and the 2-year mean, the OM content in the stem considerably dropped ($p<0.05$), falling from 7.5 percent

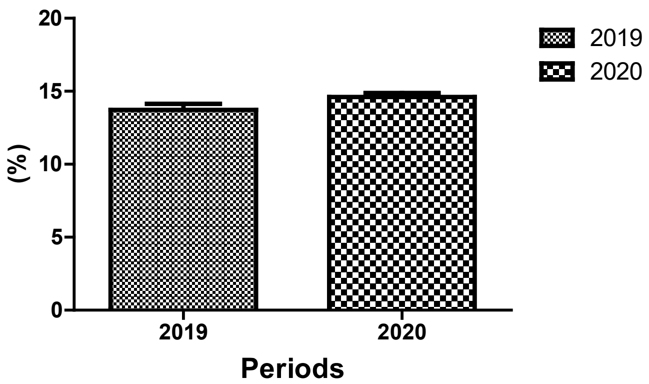


**Figure 2:** *CP content of kenaf leaves as affected by manure fertilization across two growing years.*

**Table 8:** *Effects of multiple harvesting periods on the feed value (chemical composition, %) of kenaf stem.*

| Year | Days after planting | CP | OM | ADF | NDF | TDN |
|---|---|---|---|---|---|---|
| 2019 | 100 | 3.5±0.79 | 7.4±0.15$^{A}$ | 56.0±1.53$^{B}$ | 69.0±1.57$^{B}$ | 44.6±1.21$^{A}$ |
| | 110 | 3.0±1.00 | 7.1±0.26$^{B}$ | 57.9±2.08$^{B}$ | 70.1±2.10$^{AB}$ | 43.1±1.58$^{A}$ |
| | 120 | 4.0±0.31 | 7.4±0.15$^{A}$ | 60.9±1.24$^{A}$ | 72.3±6.89$^{AB}$ | 40.8±0.98$^{B}$ |
| | 130 | 3.4±0.32 | 6.7±0.21$^{C}$ | 61.2±2.20$^{A}$ | 75.0±1.82$^{A}$ | 40.5±1.83$^{B}$ |
| | p-value | 0.2011 | <0.0001 | <0.0001 | 0.0454 | <0.0001 |
| 2020 | 100 | 2.4±0.63 | 7.6±0.37$^{A}$ | 57.1±0.49$^{C}$ | 70.0±0.46$^{B}$ | 43.8±0.39$^{A}$ |
| | 110 | 2.9±0.25 | 7.0±0.21$^{B}$ | 59.6±5.26$^{BC}$ | 70.3±0.80$^{B}$ | 41.8±4.17$^{AB}$ |
| | 120 | 3.4±0.22 | 6.8±0.63$^{BC}$ | 62.5±1.33$^{B}$ | 75.4±0.40$^{A}$ | 39.5±1.03$^{B}$ |
| | 130 | 3.0±0.43 | 6.6±0.15$^{C}$ | 69.8±0.81$^{A}$ | 75.3±0.72$^{A}$ | 33.8±0.64$^{C}$ |
| | p-value | 0.2002 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| 2-year mean | 100 | 3.0±1.07 | 7.5±0.47$^{A}$ | 56.6±1.66$^{C}$ | 69.5±1.93$^{B}$ | 44.2±1.31$^{A}$ |
| | 110 | 3.0±2.97 | 7.1±0.65$^{B}$ | 58.8±5.26$^{C}$ | 70.2±3.69$^{B}$ | 42.5±4.14$^{A}$ |
| | 120 | 3.7±1.03 | 7.1±0.36$^{B}$ | 61.7±3.08$^{B}$ | 73.9±5.37$^{A}$ | 40.1±2.50$^{B}$ |
| | 130 | 3.2±0.41 | 6.7±0.45$^{C}$ | 65.5±5.23$^{A}$ | 75.1±2.21$^{A}$ | 37.2±4.12$^{C}$ |
| | p-value | 0.2267 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |

$^{A-C}$ *Different letters in the same column are significantly different ($p<0.05$),* **CP:** *Crude Protein,* **OM:** *Organic Matter,* **ADF:** *Acid Detergent Fiber,* **NDF:** *Neutral Detergent Fiber,* **TDN:** *Total Digestible Nutrients*

**Table 9:** *Effects of different manure application levels on the feed value (chemical composition, %) of kenaf stem.*

| Year | Manure application levels (kg N/ha) | CP | OM | ADF | NDF | TDN |
|---|---|---|---|---|---|---|
| 2019 | 0 | 3.7±0.32$^{AB}$ | 6.3±0.20$^{C}$ | 58.2±1.67 | 70.2±0.98 | 42.9±1.32 |
| | 150 | 3.2±0.74$^{BC}$ | 7.9±0.21$^{A}$ | 60.0±0.86 | 74.6±1.44 | 41.5±0.68 |
| | 200 | 2.7±0.98$^{C}$ | 7.2±0.16$^{B}$ | 58.4±2.20 | 71.8±1.55 | 42.8±1.74 |
| | 250 | 4.3±0.36$^{A}$ | 7.3±0.19$^{B}$ | 59.4±2.24 | 70.0±8.40 | 42.0±1.77 |
| | p-value | 0.0004 | <0.0001 | 0.3378 | 0.3124 | 0.3367 |
| 2020 | 0 | 2.1±0.48$^{B}$ | 7.1±0.46$^{A}$ | 60.3±1.16$^{B}$ | 70.2±0.48$^{B}$ | 41.2±0.92$^{A}$ |
| | 150 | 3.2±0.30$^{A}$ | 7.2±0.12$^{A}$ | 60.9±0.81$^{B}$ | 73.7±0.55$^{A}$ | 40.8±0.64$^{A}$ |
| | 200 | 3.1±0.38$^{A}$ | 7.1±0.21$^{A}$ | 62.6±3.07$^{AB}$ | 73.3±0.54$^{A}$ | 39.4±2.42$^{AB}$ |
| | 250 | 3.3±0.28$^{A}$ | 6.6±0.10$^{B}$ | 65.1±2.85$^{A}$ | 73.7±0.81$^{A}$ | 37.4±2.25$^{B}$ |
| | p-value | <0.0001 | 0.0003 | 0.0120 | <0.0001 | 0.0120 |
| 2-year mean | 0 | 2.9±0.94$^{B}$ | 6.7±0.66$^{C}$ | 59.3±3.48$^{B}$ | 70.2±3.23$^{B}$ | 42.1±2.75$^{A}$ |
| | 150 | 3.2±1.10$^{AB}$ | 7.6±0.57$^{A}$ | 60.5±2.55$^{AB}$ | 74.2±1.73$^{A}$ | 41.1±2.56$^{AB}$ |
| | 200 | 2.9±1.30$^{B}$ | 7.1±0.26$^{B}$ | 60.5±4.52$^{AB}$ | 72.5±2.13$^{AB}$ | 40.1±3.57$^{AB}$ |
| | 250 | 3.8±0.74$^{A}$ | 6.9±0.44$^{BC}$ | 62.3±4.65$^{A}$ | 71.8±6.06$^{AB}$ | 39.7±3.67$^{B}$ |
| | p-value | 0.0428 | <0.0001 | 0.0019 | <0.0001 | 0.0019 |

*$^{A-C}$ Different letters in the same column are significantly different (p<0.05),* **CP:** *Crude Protein,* **OM:** *Organic Matter,* **ADF:** *Acid Detergent Fiber,* **NDF:** *Neutral Detergent Fiber,* **TDN:** *Total Digestible Nutrients*

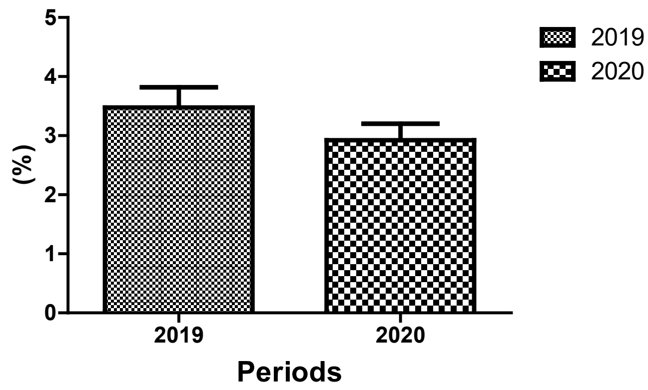


**Figure 3:** *CP content of kenaf stem as affected by manure fertilization across two growing years.*

to 6.7 percent. As kenaf maturity increased, the ADF content in the stem in 2019 and 2020, as well as the 2-year mean, showed a substantial rise (p<0.05). With increasing maturity, the NDF concentration of kenaf stem increased considerably (p<0.05) in 2019 and 2020 as well as the 2-year mean, which was impacted by varied harvesting seasons. This supports the research by Hajer *et al.* (2020), which demonstrates that the cell walls were more lignified in stems harvested at mature stages compared to those harvested at earlier stages. The 2-year mean, which showed the greatest TDN concentration in kenaf stem in 2020 and 2019, was noted in the earlier harvesting seasons. This suggests that TDN content significantly decreased (p<0.05) as kenaf growth advanced.

*Effects of varied manure application levels on the nutritional value of kenaf stem*

The CP, OM, ADF, NDF, and TDN content of kenaf stem with varying levels of manure fertilization application (0, 150, 200, and 250 kg N/ha) is presented in Table 9. The CP content of kenaf stems reached its highest values in 2019, 2020, and the 2-year mean when the highest manure fertilization application level was used. Xu *et al.* (2022) explained this increase, noting that applying livestock manure fertilization at various ratios can reduce the need for mineral fertilizers while enhancing crop yield and quality. Additionally, in this study, the CP content of kenaf stems in 2019 was slightly higher than that in 2020 (Table 9 and Figure 3). On the other hand, due to varying levels of manure fertilization application, the 2-year mean of the OM content in kenaf stem peaked at 150 kg N/ha. In 2019, there was no discernible variation in the ADF, NDF, and TDN content of kenaf stems under different levels of manure fertilization treatment. However, when the nitrogen content in the manure fertilization application levels increased from 0 to 250 kg N/ha in 2020, the ADF and NDF content of kenaf stem exhibited a considerable rise (p<0.05), whereas the TDN content dramatically reduced (p<0.05). As the nitrogen content of the manure fertilization rose, there was a substantial (p<0.05) drop in the 2-year mean of ADF concentration in kenaf stem, which was influenced by varied levels of manure fertilization application. Conversely, the kenaf stem's 2-year mean of NDF content revealed the greatest NDF content at 150 kg N/ha, with no significant difference between the 200 and 250 kg N/ha manure fertilization application levels. According to Kujoana *et al.* (2023), the fiber levels observed in this study are deemed suitable for ruminant nutrition. The 2-year mean showed the greatest TDN concentration in the control group; there was no significant difference in the manure fertilization application levels of 150, 200, and 250 kg N/ha. It's interesting to note that as the nitrogen concentration of the manure fertilization grew from 0 to 250 kg N/ha, the TDN content reduced dramatically ($p<0.05$).

## Conclusions and Recommendation

Comparing the treatments used in this study to the control, the effects on agricultural growth, characteristics, forage production, and feed value of kenaf were substantial and favorable. While there were no discernible changes in the DM yield of kenaf across different levels of manure fertilization application, the level of 200 kg N/ha proved to be particularly significant when compared to other treatments. Kenaf growth was shown to be positively correlated with manure application; the tallest plants were correlated with the greatest manure level. At a manure fertilization application level of 200 kg N/ha, the mean CP content in kenaf leaves was significantly greater. Furthermore, the mean ADF content decreased as the nitrogen levels in manure rose. Additionally, at the 110, 120, and 130 DAP harvesting periods, the 2-year mean CP content of kenaf leaves was higher, but the ADF content considerably dropped as kenaf development advanced. The 120 DAP period and the early harvesting period had the greatest NDF levels. The stem's 2-year mean NDF was greater during the 120 and 130 DAP periods, whereas the stem's mean CP content was higher during the 120 DAP harvesting period. In summary, optimal growth and development of kenaf were achieved with a manure fertilization level of 200 kg N/ha and harvesting between 110 and 120 DAP. It is strongly suggested that farmers use these guidelines in view of the worldwide pledges made to lower methane emissions and enhance manure management methods. By doing this, kenaf is not only better cultivated and produced, but its potential as a priceless source of enhanced nutritious animal feed is also maximized.

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## Novelty Statement

The research identifies that a manure rate of 200 kg N/ha and a harvest period between 110 and 120 days after planting optimize both yield and nutritional quality. This dual approach offers comprehensive insights into sustainable kenaf production and forage quality enhancement, aligning with global methane reduction initiatives through improved manure management.

## Author's Contribution

**Byamungu Mayange Tomple:** Conceptualized and designed the study, conducted field surveys, performed chemical analysis, wrote the abstract, introduction, methodology, collected data, entered data into SAS, conducted the statistical analysis, wrote the results and discussion, conclusion, and references.
**Ik-Hwan Jo:** Conceptualized, designed, and supervised the study.
**Rajaraman Bharanidharan:** Analyzed data, reviewed the manuscript, proofread, and conducted plagiarism checks.
**Seun-Gun Won:** Supervised the research, contributed to its design and provided intellectual content.
**Muhammad Mahboob Ali Hamid:** Supervised the study, reviewed the manuscript, performed proofreading, and revised the manuscript.

*Conflict of interest*

The authors have declared no conflict of interest.

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