Influence of different cutting time-points on the yield and forage quality of sweet sorghum and sorghum Sudangrass hybrid varieties

Fırat Alatürk Corresp. [1]

[1] Faculty of Agriculture Department of Field Crops, Canakkale (18th March) University, Canakkale, Canakkale, Turkey

Corresponding Author: Fırat Alatürk
Email address: alaturkf@comu.edu.tr

Background. This research was conducted in the Research and Application Field of Canakkale Onsekiz Mart University, Faculty of Agriculture, during the 2020 and 2021 growing seasons. This study sought to determine the effects of different harvesting heights on forage yields and crude ash, fat, protein, and C and N content of leaves and stalks of sweet sorghum (SS) and sorghum sudangrass hybrid (SSH) cultivars. **Methods.** Nutri Honey and Nutrima varieties of SSH and the M81-E and Topper-76 varieties of SS were used in this study. The experiment was conducted using the randomized complete block design with four replications. The main plots each included two early and late varieties of SS and SSH cultivars, while the subplots were used to test different harvesting heights (30, 60, 90, 120, 150 cm) and physiological parameters of each crop. **Results.** The results of this study showed that as plant harvesting height increased, the amount of dry forage increased, while crude protein, ash, and fat content decreased. The nutrient content of the leaves was higher than that of the stalks. All varieties had similar forage yield and quality, but the Nutrima and M81-E sorghum varieties are recommended for summer roughage production and future cultivation.

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Fırat Alatürk

[1] Field Crops, Canakkale Onsekiz Mart University, Canakkale, Canakkale, Türkiye

Corresponding Author: Fırat Alatürk
Canakkale Onsekiz Mart University Faculty of Agriculture Department of Field Crops, Canakkale, Canakkale, 17100, Türkiye
Email address: alaturkf@comu.edu.tr

Abstract

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Introduction

The livestock sector has rapidly changed in Türkiye. Cattle breeding has increased to meet demand for meat, milk and dairy products. More cattle necessitate the cultivation of more forage crops in larger areas at lower costs without competing with food production. Sorghum sudangrass hybrid (SSH) cultivars play an important role in animal nutrition because of their ability to rapidly regrow after harvesting. However, the success of a forage crop in animal nutrition depends on several factors, including lignin (Kaplan et al., 2019). Lignin, which is found in forage crops, reduces feed consumption efficiency in animals (Casler et al., 2002).

Lignin is the second-most complex structural polymer in the plant cell wall (Li et al., 2015). Lignin content increases with the plant's maturity stage, while digestibility of the plant decreases (Casler and Vogel, 1999). Lignin accumulates in plant cell walls, negatively affecting rumen microbial degradation and the digestion of feed by intestinal enzymes (Liu and Yu., 2011). Lignification is the main factor limiting the digestibility of plant cell wall polysaccharides in vitro (Jung et al., 2012) and also its in vitro digestibility (Reddy et al., 2005). Fresh and dry forage of sorghum varieties are used as silage and haylage as well as for grazing purposes (Undersander, 2003, Avcıoğlu et al., 2009). Sorghum has been characterized as the "camel of the plant kingdom" because of its high tolerance to temporary drought conditions and its ability to regrow after drought conditions have disappeared (Sanderson et al., 1992, Açıkgöz, 2001). Sweet sorghum's drought tolerance and high-water use efficiency make it a good option for global warming and drought scenarios and an important forage crop for silage production and energy agriculture in Türkiye (Yücel et al., 2017). Since sweet sorghum has a high ethanol yield (Bayram and Turgut, 2015), research about this crop has generally focused on its potential in sugar and ethanol production. To maximize efficiency, it is important to determine the optimal harvesting times of SSH varieties in both fresh and dry forage forms. These varieties can produce 1-1.5 tons of fresh forage/ha with 4-5 cuttings in summer, main crop growing conditions and 2-3 cuttings in second crop growing conditions (İptaş et al., 2001, Salman and Budak, 2015). Studies on optimal harvesting times, especially those specific to grazing management, are extremely limited. This study was conducted to determine the best harvesting and grazing practices of hybrid sorghum sudangrass and sweet sorghum cultivars for all use cases.

Materials & Methods

Study Location: This study was carried out in the Research and Application Field of Canakkale Onsekiz Mart University, Faculty of Agriculture during the 2020 and 2021 growing seasons. The long-term average temperature of Canakkale province is 15.09 °C according to the Turkish General Directorate of Meteorology. Average temperatures on research years were recorded as 17.01 °C in 2020 and 17.58 °C in 2021, which were both above average. Average precipitation in the area from the first week of May to the last week of October is 149.9 mm. Total precipitation was higher than the average for both years of the study, with 157.5 mm of precipitation measured in 2020 and 201.2 mm measured in 2021 in this time period (Figure 1).

Soil Sampling: Soil samples were taken at a depth of 0 to 30 cm from many spots throughout the study area and then combined to create a representative sample of the area. Soil samples were analyzed in the soil testing laboratory of the Canakkale Onsekiz Mart University, Science and Technology Application and Research Center (ÇOBİLTUM) according to the methods outlined by Müftüoğlu et al. (2012). Soils in the research area had a clay-loam texture and were neutral in terms of soil reaction. The soils were determined to be medium calcareous, medium in organic matter, medium in phosphorus content, and deficient in potassium (Table 1).

Applications: Seed sowing was carried out on 16th May in the first year (2020) of the study and on 5th May in the second year (2021). Annealing irrigation was performed before sowing and then the area was plowed deeply with a plow. The seed bed was prepared by pulling a cultivator and disc harrow, and then 1 kg of nitrogen, phosphorus and potassium per hectare were added to the soil with composite fertilizer (15-15-15) before deep plowing. Ammonium sulfate was applied as surface fertilizer at a rate of 50 kg nitrogen per hectare immediately after seed sprouting (Avcıoğlu et al., 2009). Soil samples were taken from the experiment plots and then analyzed before fertilizer application. Plants were then irrigated with drip irrigation and irrigation frequency was adjusted based on air temperature and precipitation. In July and August, plants were irrigated about every seven days. Weeds that emerged during the research period were removed manually by individually removing weeds growing in the rows and hoeing weeds between the rows. This experiment used a randomized complete block design with four replications. The main experiment plots included the cultivars and the subplots were used to test different harvesting heights. Sweet sorghum (SS) cultivars were sown 8 cm apart in rows with 70 cm between rows. Sorghum sudangrass hybrid (SSH) cultivars were also sown 8 cm apart, but with 35 cm between rows (Mahmood and Honermeier, 2012). Experiment plots were 5 m in length, with SS cultivar plots arranged in four rows and SSH cultivar plots arranged in six rows. There was no space dividing the experiment plots, but the experiment blocks were divided by a distance of 1 m.

Hay parameter: Two cultivars of sweet sorghum (Topper-76 and M81-E) and two cultivars of hybrid sorghum sudangrass (Nutrima and Nutri Honey) were used as materials in this study, as shown in Table 2. The cultivars of sweet sorghum used in this study were developed at the University of Nebraska and are among the cultivars considered to be promising based on previous research conducted in Türkiye (Yücel et al., 2017). The SSH cultivars used in this study are the registered cultivars sown in Türkiye.

Hay yields were obtained by first removing 50 cm sections from the beginning of the plots that were considered edge effects during plant sampling. The side rows were also included in the harvesting area since there was no space between the plots. When the plants reached the planned harvesting heights, the 5.6 m^2 harvest area was mowed with a harvester machine and/or sickle, leaving 15 cm of stubble, and the harvested plants were weighed immediately with a hand scale to obtain their fresh weight (Lang, 2001). The obtained values were calculated as fresh hay yield/plot in kg/da. Samples weighing over 1 kg were then taken from these fresh plants, placed into paper bags and brought to the laboratory. The samples were separated into stems, leaves and clusters in the laboratory and air dried. They were then moved to a drying oven set at 60 ºC until sample weight was constant (for 48 hours) and then the samples were weighed (AOAC, 2000). Dry matter ratios (%) were determined by proportioning the weights of the dried samples to their fresh sample weights, as follows:

Dry matter ratio (%) = (Dry hay yield /Fresh hay yield)*100
Whereas, the dry hay yields were obtained first and then multiplied with fresh hay yield and dry matter ratio, and then calculated as kg/da:
Dry hay yield (kg/da) = Fresh hay yield (kg/da)*Dry matter ratio (%)

The hay yield of the rangeland in kg/ha was calculated by weighing the hay, and the average was taken. Plant samples were harvested from the rangeland and ground. Then, the crude protein ratios of the samples were determined using the Kjeldahl method (Bremner, 1960). C and N ratios of the plant samples were determined by the Eastern Anatolia High Technology Application and Research Center (DAYTAM). A LECO brand CHNS-932 analyzer device, calibrated using the sulfamethazine standard, was used to perform the elemental analysis. This analysis was performed by first weighing the sample in a tin capsule using a scale (Sartorius) to ensure it was less than 2 mg and then the capsule was placed in the automatic sampling system. The plant sample was then sent to the combustion reactor (1050 °C) via the automatic sampling system and burned with O_2 accompanied by carrier gas. The % values of the elements were automatically calculated by the software device (Kirsten, 1983). Then, 3 g of each of the plant samples were dried, ground, weighed and then placed in a porcelain crucible and burned in a furnace set to 550 °C until white ash was obtained. After the combustion process completed, the sample was removed and weighed, and the difference between the initial weight and the final weight was considered the total ash ratio (AOAC, 2000). Crude oil analysis of the dried and ground plant samples was performed using the analytical methods reported by AOAC (2000).

Statistical analysis: The data obtained from the research were subjected to variance analysis using the SAS (SAS Inst. 1999) program. Whether the difference between the obtained averages was significant or not was determined by the Duncan test. The mean squares and deterministic statistics of the data are given in Table 3.

Results

Dry forage yield: Variance analysis results of dry forage yields are shown in Table 4. In both study years, dry forage yields increased with increased harvesting heights. In the first year of the study, the highest dry forage yields (25,620.0 kg/ha) occurred in the experiment plots harvested at the physiological maturity stage (PMS), while the lowest dry forage yields (9,330.0 kg/ha) were obtained from the experiment plots harvested at a height of 30 cm. By variety, the highest dry forage yield was measured at 17,660.0 kg/ha from the SS M81-E variety, followed by the SSH Nutrima (16,590.0 kg/ha), Nutri Honey (15,930.0 kg/ha) and SS Topper-76 (15,740.0 kg/ha) varieties. The total average dry forage yield was 16,480.0 kg/ha in the first year and increased to 17,140.0 kg/ha in the second year of the study. In the second year of the study, total dry forage yields varied between 16,020.0-18,660.0 kg/ha by variety, with the highest dry forage production observed in the M81-E variety (31,490.0 kg/ha) and the lowest dry forage production in the Topper-76 (7,660.0 kg/ha) variety.

Nutrient ingredients

Leaf carbon ratio: Variance analysis results of the carbon contents of leaves are shown in Table 5. In general, the carbon content of leaves decreased with increased harvesting heights. The lowest leaf carbon ratios (39.70% in 2020, 38.11% in 2021, 38.91% average) were measured in plants harvested at the PMS. The highest leaf carbon ratios were measured around 42% in plants harvested at heights of 30 cm, 60 cm and 90 cm. Leaf carbon ratios of the cultivars were between 41.08-42.64% in the first year, 40.57-40.87% in the second year, with an average range of 40.92-41.60% of the two years. Significant differences were observed between the leaf carbon ratios of the cultivars in the first year, with SSH varieties having more carbon in their leaves. There was no significant difference in carbon content between varieties in the second study year. When combining cultivars with harvesting heights, Nutrima harvested at 120 cm in 2020 had a higher carbon content than other varieties in M81-E leaves harvested at 60 cm and 90 cm in 2021, and also the average of the two years. The average carbon content of the leaves in the first year was 41.75%, which decreased to 40.74% in the second year (Table 5).

Stalk carbon ratio: Variance analysis results of the carbon contents of stalks are shown in Table 6. Carbon content in stalks increased with increased harvesting height. The highest carbon contents were observed in the thickest stalks and in stalks harvested at the PMS, as these stalks had the most mature cells. At the PMS, the average stalk carbon ratios were recorded as 40.19% in the first year and 40.40% in the second year, with an average of 40.30% of the two years. The average stalk carbon ratios of plants harvested between 30 cm to 90 cm were between 37.99-38.65% in 2020 and 37.94-38.53% in 2021, with an average range of 37.97-38.59% of the two years. By variety, the lowest stalk carbon ratios were measured in Topper-76 (37.46% in 2020, 38.54% in 2021, 38.00% average), with no significant difference in the stalk carbon ratios of all other cultivars. When combining cultivars with harvesting heights, the highest two-year average stalk carbon ratio was measured in the M81-E variety harvested at the PMS, and the lowest carbon ratio was measured in the Topper-76 variety harvested at 90 cm, with no significant difference between cultivars harvested at 90, 120 and 150 cm heights. The carbon content of the stalks changed significantly between the two years of the study, with the average carbon ratio recorded at 38.53% in the first year and 39.09% in the second year of the study (Table 6).

Leaf nitrogen ratio: Variance analysis results of the nitrogen contents of leaves are shown in Table 7. The nitrogen content of leaves gradually decreased as the plants matured. In the first year, the highest nitrogen ratios were 3.29% and 3.17%, measured in the leaves of plants harvested at 30 cm and 60 cm heights, respectively, while the lowest nitrogen ratios (2.16%) were recorded in the plants harvested at their PMS. Among the cultivars, the average leaf nitrogen content was highest (3.14%) in Nutri Honey and lowest (2.42%) in M81-E. When combining cultivars with harvesting heights, the highest leaf nitrogen ratio (3.58%) was measured in the Nutri Honey variety harvested at 30 cm, while the lowest nitrogen ratio (1.61%)

was measured in the M81-E variety harvested at PMS. In the second year of the study, the nitrogen content of the leaves decreased significantly by harvesting height and varied between 0.92-2.55%. Among the cultivars, the highest nitrogen ratio was measured at 2.00% in Topper-76, followed by Nutrima (1.83%), M81-E (1.72%) and Nutri Honey (1.69%). When combining cultivars with harvesting heights, the highest nitrogen content was measured at 2.95% in the plants of the Topper-76 variety harvested at 30 cm, while the lowest nitrogen content was measured at 0.76% and 0.83% in the Topper-76 and M81-E varieties harvested at PMS, respectively. The highest two-year average nitrogen ratios were measured at 2.92% and 2.69% in the leaves of plants harvested at 30 cm and 60 cm, respectively, while the lowest nitrogen ratio was recorded as 1.54% in the leaves of plants harvested at their PMS (Table 7).

Stalk nitrogen ratio: Variance analysis results of stalk nitrogen content are shown in Table 8. In both study years, nitrogen content in the stalk decreased as the plants matured. The cultivar with the highest stalk nitrogen ratio (1.88%) was Topper-76 followed by Nutrima (1.58%), Nutri Honey (1.51%) and M81-E (1.51%). In the second study year, the average stalk nitrogen content varied between 0.66-1.16% by variety, with so significant difference observed between the varieties. The highest two-year average nitrogen content was measured in the stalks of plants harvested at 30 cm, 60 cm and 90 cm heights (1.86%, 1.65% and 1.72%, respectively). The lowest two-year average stalk nitrogen ratio (0.23%) was measured in plants harvested at the PMS. The two-year average stalk nitrogen ratio varied between 1.09-1.33% by cultivar. The average nitrogen content of stalks decreased significantly (by approximately 45%) in the second study year (Table 8).

Leaf crude protein ratio: Variance analysis results of the crude protein contents of leaves are shown in Table 9. In the first year of study, the Nutri Honey variety had the highest crude protein ratio among the cultivars, measured at 15.31%, followed by the Topper-76, M81-E and Nutrima varieties, measured at 12.22%, 11.77% and 11.58%, respectively. The crude protein content of leaves decreased with increased harvesting heights. By harvesting height, the highest crude protein ratios were 15.19% and 14.67% in plants harvested at 30 cm and 60 cm, respectively, followed by plants harvested at 90 cm, 120 cm and 150 cm heights, with crude protein ratios of 13.20%, 12.81% and 12.13%, respectively. The lowest crude protein ratio was recorded as 8.31% in the leaves of plants harvested at the PMS. In the second study year, the highest crude protein content in leaves was 11.74% in the Topper-76 variety, with all other varieties having measured values between 9.32-9.66%. The highest two-year average crude protein content was found in Nutri Honey and Topper-76 with values of 12.49% and 11.98%, respectively, followed by the Nutrima and M81-E varieties at 10.67% and 10.55%, respectively. By harvesting height, the highest two-year average crude protein content in leaves was 14.27% in plants harvested at 30 cm, while the lowest was recorded as 6.46% in plots harvested at their PMS. The average crude protein content of leaves decreased 20% between 2020 and 2021 (Table 9).

Stalk crude protein ratio: Variance analysis results of the crude protein contents of stalks are shown in Table 10. By variety, the highest crude protein content in the stalks was 9.84% in the Nutrima variety followed by Topper-76, M81-E and Nutri Honey at 8.22%, 8.03% and 7.42%, respectively. As seen in the crude protein content of the leaves, the crude protein content of the stalks decreased with increased harvesting heights. Accordingly, by harvesting height, the highest crude protein ratio in the stalks was 12.12% in plants harvested at 30 cm, while the lowest ratios were 5.96% and 5.69% in plants harvested at 150 cm and at the PMS, respectively. In the second study year, by variety, the highest crude protein ratio was 6.64% in Topper-76 followed by the M81-E variety at 5.08%, while the lowest ratios were 4.46% and 4.33% in Nutrima and Nutri Honey, respectively. The highest two-year average crude protein ratio in stalks by variety was 7.43% in the Topper-76 variety, while the lowest was 5.88% in the Nutri Honey variety. The average crude protein content of the stalks decreased up to 20% in the second study year (Table 10).

Leaf crude ash ratio: Variance analysis results of the crude ash contents of leaves are given in Table 11. During the first year of the study, the sorghum cultivars with the highest average crude ash contents in their leaves were Topper-76 with 11.50% and Nutri Honey with 11.35%, while the lowest ratios of crude ash were found in the leaves of the M81-E variety at 10.80% and in Nutrima at 9.80%. Sorghum sudangrass hybrid (SSH) cultivars had the highest average crude ash contents in their leaves in the second year of the study, with the highest crude ash ratios in Nutrima and Nutri Honey varieties at 12.24% and 12.19%, respectively, followed by M81-E with 11.42% and Topper-76 with 11.06%. By harvesting height, the highest crude ash ratios (13.14%) were recorded in the leaves of plants harvested at their PMS, while the lowest values were 11.15%, 11.32% and 11.32% in plants harvested at 90 cm, 120 cm, 30 cm and 60 cm, respectively. By variety, the highest two-year average ratio of crude ash in the leaves was 11.77% in the Nutri Honey variety, followed by Topper-76 with 11.28%, M81-E with 11.11% and Nutrima with 11.02%. By harvesting height, the crude ash content of the leaves was 11.36% in plants harvested at 30 cm and 10.94%, 10.96% and 12.05% in plants harvested at 90 cm, 120 cm and PMS, respectively, and there was significant difference. The average crude ash content of leaves was 10.86% in the first year, which increased to 11.73% in the second study year (Table 11).

Stalk crude ash ratio: Variance analysis results of the crude ash contents of stalks are given in Table 12. In the first year of the study, the variety with the highest crude ash content in the stalks (9.36%) was the Nutrima variety, with the crude ash content varying from 8.62-8.79% in the stalks of all other varieties. In both study years, the crude ash ratios of the stalks decreased as harvesting heights increased. In the first year of the study, the highest crude ash content was 10.17% in the stalks of plants harvested at a height of 30 cm, while the lowest crude ash content was 7.26% in the stalks of crops harvested at the PMS. In the second year of the study, the SSH varieties had the highest crude ash ratios at 8.49% and 8.45% in the Nutri Honey and Nutrima varieties of SSH, respectively, while the crude ash ratios of the stalks of the SS Topper-76 and SS M81-E varieties were 7.46% and 8.03%, respectively. SSH cultivars also had higher two-year average crude ash content than the SS cultivars, with averages of 8.90% and 8.61% in the Nutrima and Nutri Honey cultivars of SSH, respectively, while the lowest crude ash content (8.04%) was recorded in the Topper-76 cultivar of SS. In the second year of the study, by harvesting height, the highest crude ash ratio was recorded at 9.82% in the stalks of crops harvested at 30 cm, while the lowest ratio of crude ash was observed as 6.49% in the stalks of crops harvested at the PMS. When combining cultivars with harvesting heights, the highest crude ash ratio was 10.33% in the stalks of Nutrima variety plants harvested at a height of 30 cm, while the lowest ratios of crude ash were 6.00%, 6.21% and 6.64% in Nutri Honey, Topper-76 and M81-E cultivars harvested at their PMS, respectively. The average crude ash content of the stalks decreased approximately 8% in the second year of the study (Table 12).

Leaves crude fat ratio: Variance analysis results of the crude fat contents of leaves are given in Table 13. In both study years, crude fat content decreased with increased harvesting heights. Crude fat contents of leaves varied between 2.70-2.83% by variety and between 2.19-3.51% when combining variety with harvesting height. In the second year of the study, the average crude fat content of the cultivars varied between 2.67-2.81%. The highest two-year crude fat ratio (3.39%) was found in the leaves of plants harvested at the lowest height (30 cm), while the lowest value (2.24%) was obtained from the leaves of plants harvested at the highest height (PMS). In the second study year, the average crude fat ratios of leaves varied between 2.71-2.82% by variety and between 2.22-3.49% when combining variety with harvesting heights (Table 13).

Stalk crude fat ratio: Variance analysis results of the crude fat contents of the stalks are given in Table 14. As with the crude fat content of leaves, the crude fat content of the stalks decreased as the plants matured. In the first year of the study, the highest crude fat content was 2.26% in the stalks of plants harvested at a height of 30 cm, while the lowest crude fat content was recorded as 1.34% in plants harvested at their PMS. SS cultivars (M81-E and Topper-76) generally accumulated more crude fat in their stalks than SSH cultivars (Nutri Honey and Nutrima). In the second year of the study, by harvesting height, the highest crude fat ratio was recorded at 2.16% in the plants harvested at the shortest height (30 cm), while the lowest crude fat content was 1.26% in plants harvested at the highest height (PMS). M81-E (1.90%) and Topper-76 (1.73%) had the highest crude fat ratios in the second study year, while Nutri Honey (1.62%) and Nutrima (1.55%) had the lowest crude fat ratios. The average crude fat ratios of the stalks were similar between the first (1.76%) and second (1.71%) years of the study (Table 14).

Discussion

Most crops follow a similar growth pattern, beginning with slow growth followed by rapid growth before slowing down again towards the end of their growth cycle (Altın et al., 2011). Since there are fewer chloroplasts at the beginning of the growth cycle there are also fewer assimilation products. But as growth progresses, the number of chloroplasts increases, which increases photosynthetic processes, producing more organic mass. Vegetative growth continuously increases until the generative period. During the generative period, the products of photosynthesis are transferred to generative organs instead of vegetative tissues such as the roots, shoots or leaves (Altın et al., 2011). This limits the forage yield at this stage of development (Chattha et al., 2017). Because of this, the dry forage yields increased regularly and continuously between harvesting heights of 30 cm to the PMS of the crop in this experiment. Previous studies have found differing yield values in experiments carried out with sorghum in Türkiye. For example, Aydınoğlu and Çakmakçı (2018) found an average fresh forage yield between 46,000.0-81,880.0 kg/ha and dry forage yield between 11,870.0-20,370.0 kg/ha. A separate study conducted with 13 different sorghum cultivars in Bingöl found an average fresh forage yield of 73,230.0 kg/ha and an average dry forage yield of 13,080.0 kg/ha (Özmen, 2017). Other studies conducted in different regions found average fresh forage yields between 146,410.0-190,300.0 kg/ha in Konya (Acar et al., 2002), 22,890.0-47,170.0 kg/ha in Çanakkale (Semerci and Baytekin, 2017), 67,300.0 kg/ha (Sürmen and Kara, 2022) and 46,500.0-62,600.0 kg/ha in Aydın (Çelik and Türk, 2021). Studies have also found average dry forage yields varying between 13,080.0 kg/ha (Özmen, 2017), 61,00.0-11,830.0 kg/ha (Tosunoğlu, 2014), 16,540.0 kg/ha (Çeçen et al., 2005), 8,100.0-21,100.0 kg/ha (Kara et al., 2019), 13,500.0-28,400.0 kg/ha (Kır and Şahan, 2019) and 14,800 kg/ha (Sürmen and Kara, 2022). Forage yields differ because different varieties have different genetic structures and react differently to environmental factors. Differences in forage yield by variety was also observed in this study, with the SS Topper-76 variety yielding significantly less than other varieties (Table 4).

The carbon and nitrogen contents of plants vary by species and varieties, and even between different organs of the same species (Yao et al., 2015; Suhui et al., 2018; Zhang, He, et al., 2018). The nitrogen content of plants is closely related to photosynthesis and plant respiration meaning plants have high nitrogen content at the beginning of the growth cycle because there is more photosynthesis and respiration activity in the leaves, and nitrogen and carbon content decreases as the growth cycle continues (Zhang, He, et al., 2018; Zhang et al., 2020). In this study, the carbon ratios of leaves and stalks of different sorghum cultivars differed depending on plant height, with the carbon ratio of the leaves decreasing as plant height increased and the carbon ratio of the stalks increasing as plant height increased. The carbon ratio in the leaves decreased by approximately of 6% from the beginning to the end of the growth cycle, while the carbon ratio of the stalks increased by 4% during the growth cycle. Conversely, the nitrogen ratios in both the leaves and stalks decreased-by 47% in leaves and by 87% in stalks-from the beginning to the end of the growth cycle. The nitrogen content of a plant is closely related to its carbon ratio. High nitrogen concentration in the plant results in higher photosynthetic capacity, which leads to higher respiration (Chapin et al., 1987; Lambers et al., 1989). Accordingly, more nitrogen is used in photosynthesis and more carbon in respiration (Poorter and Remkes, 1990).

The photosynthetic capacity of plants is higher in earlier growth stages compared to late stages because the number of leaves is higher in the earlier stages, and leaves have high photosynthetic capacity and more nitrogen and nutrient content than the stalks and roots (Poorter et al., 1990). The position of the leaves, the age of the plant and certain environmental factors affect a plant's photosynthetic capacity (Aighewi and Ekanayake, 2004; Hgaza et al., 2009).

In this study, the crude protein ratios of sorghum cultivars showed significant variation between the leaves and the stalks. The two-year average crude protein content was 11.42% in leaves and 6.75% in the stalks, meaning the crude protein content in leaves was approximately 40% higher than in the stalks. By variety, the highest crude protein content was found in the leaves of the Nutri Honey and Topper-76 varieties and the stalks of the Topper-76 variety. Crude protein contents of leaves and stalks proportionally decreased, by a total of 64% in leaves and 60% in the stalks of sorghum varieties, with increased plant height. Many factors affect forage quality in forage crops, with nutritional value considered the most important factor. The nutritional value of hay is measured by crude protein content. If the crude protein content of forage plants is 12% or lower, the quality of the hay is considered low. A crude protein content of 15% is considered medium quality hay, and hay with a crude protein content 18% and above is considered to have high nutritional quality (Budak and Budak, 2014; Jerry et al., 2014). Plants contain more crude protein in their leaves because of the higher photosynthesis capacity and the higher nitrogen and nutrient content of leaves compared to the stalks and roots (Poorter et al., 1990). Previous studies have shown that the crude protein ratios of leaves and stalks decrease with an increase in harvesting heights (Keskin et al., 2005; Karataş and Tansı, 2011). The results of this study align with previous studies; the highest crude protein content was observed at the beginning of the growth cycle when sorghum crops were young. In general, plants possess more dividing cells at the beginning of their growth (Taiz and Zeiger, 2008), and these cells have higher levels of physiological activity. All of the biochemical reactions in living things take place under the catalysis of enzymes. Enzymes are made up of proteins, so the protein ratio is always high at the beginning of the growth cycle in plants (Gökkuş et al., 2011). Crude protein ratio also decreases due to the decrease in physiological activity that occurs with plant growth (Towne and Ohlenbusch, 1992). In this study, the average crude protein contents ranged from 10.67-12.49% in leaves and 5.88-7.43% in stems. A separate study recorded the crude protein content of leaves between 14-15% and between 3-4% in stems (Karataş and Tansı, 2011). One previous study on four different sorghum varieties determined that the average crude protein ratio of the whole plant is around 5% (Keskin et al., 2005), while another study conducted on 13 different sorghum cultivars in the Bingöl province of Turkiye recorded the average crude protein content of sorghum cultivars as 4.81% (Özmen, 2017). The average crude protein ratio has been measured in previous studies as 9.5-10.2% (Kozlowski et al., 2006), 7.2% (Marsalis et al., 2010), 7.1-9.7% (Arslan and Çakmakçı, 2011), 7.2-8.8% (Canbolat, 2012) and 8.3% (Tosunoğlu, 2014).

Crude ash (mineral element) contents of different sorghum cultivars showed significant variation in plant leaves and stalks, and by variety and harvesting height. Generally, the macro and micro element contents of the leaves were found to be higher than that of the stalks. Previous studies have determined that the protein, vitamin and mineral contents of leaves are higher than that of the stalks, while cellulose, hemicellulose and lignin contents are lower (Fales and Fritz, 2007; Jung, 2012; Temel and Keskin, 2020). This explains the high crude ash content of the leaves observed in this study. Crude ash contents of sorghum cultivars also differed significantly from each other, likely because of genetic variations in different varieties of sorghum cultivars (Khan et al., 2006; Kering et al., 2011; Özyazıcı and Açıkbaş, 2019). The SSH cultivars generally contained higher crude ash than that of the sudangrass cultivar. This is likely related to the amount of nutrients taken from the soil along with the genetic differences of these varieties (Özyazıcı and Açıkbaş, 2020). Previous studies have found that the ratios of P, K, Ca and Mg significantly differ between sorghum cultivars (Başbağ et al., 2011; Gülümser et al., 2017; Gürsoy and Macit, 2017; Başbağ et al., 2018; Polat and Bayraklı, 2019), and even between different varieties within the same cultivar (Lema et al., 2004; Markovic et al., 2014; Engin and Mut, 2018; Özyazıcı et al., 2018a and 2018b; Turan et al., 2018; Özyazıcı and Açıkbaş, 2019; Tan, 2019; Özyazıcı and Açıkbaş, 2021). In this study, the crude ash content of SSH and SS cultivars decreased with an increase in crop height, meaning mineral element contents decreased based on the physiological maturity of crops. Crops need high levels of crude ash, especially in times of rapid growth. Because most of the crude ash is found in the protoplasm, where physiological activities are intense, and less in the cell wall (Spears 1994), the crude ash content decreases with growth, but the ratio of total organic matter to mineral matter increases because cell wall compounds increase during plant growth. Another reason for the decrease in crude ash content may be the increased amount of dry matter that occurs during plant growth (Kaçar, 2012). Some studies (*Dactylis glomerata* L., *Lathyrus sativus* L.) have reported that decreases in macro and micro element contents are correlated with the ripening process in crops (Schlegel et al., 2016; Can and Ayan, 2017; Özyazıcı and Açıkbaş, 2020). According to a study conducted in rangelands, crude ash content decreases because of the physiological maturity of plants (Gökkuş et al., 2012).

In this study, crude fat ratios were significantly different in leaves and stalks, and by cultivar and harvesting heights. Only the fat content of the stalks differed significantly by cultivar, with the stalks of SS cultivars having 11.4% higher fat content than that of the SSH cultivars. This difference is likely due to the genetic differences of the cultivars (Özyazıcı and Açıkbaş, 2020). In addition to this, the crude fat contents of the stalks and leaves of the crops also differed significantly. Generally, the average crude fat content of the leaves was 37.3% higher than that of the stalks because the metabolic activities in the leaves are faster and more abundant than those in the stalks. A high leaf ratio has been reported to be important to forage quality in forage crops because there are close relationships between leaf ratios and crude protein, digestible crude protein, ratios of mineral substances and digestibility of dry matter (Açıkgöz, 2001). In this study, the crude fat levels of leaves and stalks decreased by approximately 33.9% and 41.2%, respectively, as the plant height increased. Fats are important to the functions and continuity of the biological membranes in crops, the formation of nutrients stored in the seeds, and the stability of the protoplasm. Fats found in the roots, stalks, leaves, flowers and seeds of the crops protect these organs against external factors. The ratio of crude fat can vary by plant organ, variety, species, genotype, and developmental phase/stage (Pallardy, 2008). In similar studies, the average crude fat content of 58 sorghum genotypes and three sorghum cultivars varied between 2.32-5.74% (Kaplan et al., 2016). Other studies have reported average crude fat content of 5.63% in one sorghum variety (Osman et al., 2000), between 1.5-2.23% in three sorghum varieties (Pontieri et al., 2021) and between 2.6-3.1% in sorghum varieties (Canbolat, 2012).

Conclusions

This study aimed to determine the variation in summer main crop forage production, growth process, C-N content and forage quality characteristics of different harvesting heights and different varieties of sweet sorghum (SS) and sorghum sudangrass hybrid (SSH) cultivars. This study was performed in the sowing seasons of 2020 and 2021 at the research area of the Faculty of Agriculture, Çanakkale Onsekiz Mart University, Türkiye. Dry forage yields increased with plant growth, with the amount of forage produced at the end of the growth cycle increasing 172.2% compared to the early growth stages. The M81-E, Nutri Honey and Nutrima varieties had the highest dry forage yields, at 19,840.0 kg/ha, 17,290.0 kg/ha and 17,220.0 kg/ha, respectively, while the lowest value was 15,880.0 kg/ha in the Topper-76 cultivar of SS. The ratio of crude protein in leaves was higher than that of the stalks. Additionally, the crude protein content of the leaves and stems decreased by 50-70% as the plants grew in height. By cultivar, the highest crude protein values were observed in Topper-76 cultivar of SS. The ratios of crude ash increased by 6% in leaves, but decreased by 33.9% in the stalks during the growth cycle of the plant. All sorghum cultivars had similar crude ash ratios. Crude fat ratios were found to be higher in the leaves than in the stalks. Furthermore, the crude fat content decreased by 33.9-41.2% as the plants matured. The highest crude fat ratios were found in SS (M81-E and Topper-76) cultivars. The results of this study also revealed that all tested cultivars had similar forage yield and quality. However, the Nutrima and M81-E sorghum cultivars, harvested three times at heights of 90 to 120 cm, are recommended for the highest yield.

References

Acar R, Akbudak M, Sade B. 2002. The determination of yield and some yield components of Sorghum-Sudangrass hybrid cultivars for silage production in Konya ecological conditions. *Selcuk Journal of Agriculture and Food Sciences*, 16(29): 88-95.

Açıkgöz E. 2001. Forage Crops Uludağ Univ, Agric College, Pub No:182, Bursa.

Aighewi BA, Ekanayake IJ. 2004. In-situ chlorophyll fluoresence and related growth of Guinea yam at different ages. *Tropical Sciences*, 44, 201-206.

Altın M, Gökkuş A, Koç A. 2011. Meadow-pasture management. Vol. 1. T.C. Ministry of Agriculture of Rural Affairs, General Directorate of Agricultural Production and Development; Ankara.

AOAC. 2000. Official Methods of Analysis (15th Ed.). Association of Official Analytical Chemists, Arlington, VA.

Arslan M, Çakmakçı S. 2011. Comparison of corn (*Zea mays*) and sorghum (*Sorghum bicolor*) silages mixed with different plants. *Akdeniz University Journal of the Faculty of Agriculture*, 24(1):47-53.

Avcıoğlu R, Geren H, Tamkoc A, Karadag Y. 2009. Forage Crops, Forage Legume Crops, Vol. II, p. 290-316. Publication of Turkish Agricultural Ministry.

Aydınoğlu B, Çakmakçı S. 2018. Effect of cutting stage on herbage yield and related traits of Sorghum [*Sorghum bicolor* (L.) Moench] plant grown in different locations. *Turk. J. Agric. Res.,* 5(2), 167-175.

Başbağ M, Çaçan E, Aydın A, Sayar MS. 2011. Determination forage quality traits of some vetch species collected from native flora Southeastern Anatolia. International Participation I. Ali Numan Kirac Agricultural Congress and Fair. April 27-30. Eskisehir, Turkey.

Başbağ M, Çaçan E, Sayar MS. 2018. Determining feed quality values of some grass species and assessments on relations among the traits with biplot analysis method. *Biotech Studies*, 27, 092-101.

Bayram G, Turgut İ. 2015. The Importance and production of sweet sorghum (Sorghum bicolor ssp. saccharatum) for Bioethanol Source. *Journal of Agricultural Faculty of Uludag University*, 29(1), 147-155.

Bremner MJ. 1960. Determination of nitrogen in soil by the Kjeldahl method. *The Journal of Agricultural Science*, 55(1), 11-33.

Budak F, Budak F. 2014. Quality on forage plants and factors effecting forage quality. Türk Bilimsel Derlemeler Dergisi, 7(1): 1-6.

Can M, Ayan İ. 2017. Some feature and yield changes depending on growth periods on cocksfoot (*Dactylis glomerata* L.) populations. *KSU J. Nat. Sci*., 20(2): 160-166, 2017.

Canbolat Ö. 2012. Comparison of in vitro gas production, organic matter digestibility, relative feed value and metabolizable energy contents of some cereal forages. *Kafkas Uni. Vet. Fak. Derg*., 18(4), 571-577.

Casler MD, Vogel KP, 1999. Accomplishments and impact from breeding for increased forage nutritional value. Crop Sci., 39(1):12-20.

Casler MD, Buxton DR, Vogel KP, 2002. Genetic modification of lignin concentration affects fitness of perennial herbaceous plants. Theor. Appl. Genet., 104(1):127–131.

Çeçen S, Öten M, Erdurmuş C. 2005. Assesment of sorghum (*Sorghum bicolor* L.), sudangrass (*Sorghum sudanense* L.) and corn (*Zea mays* L.) as second crop in the coastal region of west Mediterranean belt of Turkey. *Mediterr. Agric. Sci*., 18(3), 337-341.

Çelik B, Türk M. 2021. The Determination of forage yield and quality of some silage sorghum cultivars in ecological conditions of Uşak province. *Turkish Journal of Range and Forage Science*, 2(1): 1-7.

Chapin FS, Bloom AJ, Field CB, Waring RH. 1987. Plant responses to multiple environmental factors. *BioScience*, 37, 49-57.

Chattha MU, Iqbal A, Hassan MU, Chattha MB, Ishaque W, Usman M, Ullah MA. 2017. Forage yield and quality of sweet sorghum as influenced by sowing methods and harvesting times. *Journal of Basic and Applied Sciences*, 13, 301-306.

Engin B, Mut H. 2018. Variation of some nutrient contents with relative feed value according to cutting order in alfalfa (Medicago sativa L.) varieties. *Journal of Tekirdag Agricultural Faculty,* 15(02), 119-127.

Fales SL, Fritz JO. 2007. Factors Affecting Forage Quality. Forages. Ed. Barnes, R. F., Nelson, C. J., Moore, K. J. and Collins, M. 6.th Edition Vol. II Chapter 37, A Blackwell Publishing, pp. 569-580.

Gökkuş A, Özaslan Parlak A, Baytekin H, Hakyemez BH, Parlak M. 2012. Change of Mineral Composition of Herbaceous Species at the Mediterranean Shrublands. *Journal of Tekirdag Agricultural Faculty,* 10(1), 1-10.

Gülümser E, Mut H, Doğrusöz MÇ, Başaran U. 2017. The Effect of sowing rates on quality traits of legumes + cereals mixtures. *Selcuk J. Agr. Food Sci*., 31(3): 37-45.

Gürsoy E, Macit M. 2017. Determination of mineral contents of some legume and cereal forages grown as naturally in pastures of Erzurum province. *Alınteri Journal of Agricultural Sciences*, 32(1): 1-9.

Hgaza VK, Diby LN, Ake S, Frossard E. 2009. Leaf growth and photosynthetic capacity as affected by leaf position, plant nutritional status and growth stage in *Dioscorea alata* L. *Journal of Animal & Plant Sciences*, 5(2): 483-493.

İptaş S, Brohi AR, Aktaş A. 2001. Effect of nitrogen fertilizer and cutting height on forage yield and quality of sorghum x sudangrass hybrid (Sorghum vulgare Pers. x Sorghum sudanense (Piper) Stapf.). *Journal of Agricultural Sciences*, 7(2): 69-74.

Jerry H, Cherney Marvin H, Hall. 2014. The Pennsylvania State University, 201 Willard Building, University Park, PA16802-2801.

Jung HG. 2012. Forage Digestibility: The Intersection of Cell Wall Lignification and Plant Tissue Anatomy. Available at: https://tls.tc/YhEbA.

Jung HJG, Samac DA, Sarath G, 2012. Modifying crops to increase cell wall digestibility. Plant Sci., 185–186:65–77.

Kaçar B. 2012. Plant Nutrition. Nobel Press, Ankara.

Kaplan M, Yılmaz S, Kökten K, Temizgül R, Karaman K. 2016. Determination of antioxidant activities, total phenolic materials, and amino acid quantities in local Sorghum (Sorghum bicolor L) populations. T.C. Erciyes University Scientific Research Projects Final Report.

Kaplan M, Kara K, Unlukara A, Kale H, Buyukkilic Beyzi S, Varol IS, Kizilsimsek M, Kamalak, A. 2019. Water deficit and nitrogen affects yield and feed value of sorghum sudangrass silage. Agricultural Water Management, 218, 30-36.

Kara E, Sürmen M, Erdoğan H. 2019. The Effects of solid biogas residue applications on forage yield and quality in sorghum and sorghum x sudanense hybrid plants. *International Journal of Agriculture and Wildlife Science*, 5(2): 355-361.

Karataş Z, Tansı V. 2011. A research on the effects of the different harvest times on herbage yield and quality components of some sorghum x sudangrass hybrids as doubled crop under Çukurova conditions. *Cukurova University Journal of the Faculty of Engineering*, 26-3, 107-117.
Kering MK, Guretzky J, Funderburg E, Mosali J. 2011. Effect of nitrogen fertilizer rate and harvest season on forage yield, quality, and macronutrient concentrations in midland Bermuda grass. *Commun Soil Sci Plant Analysis*, 42, 1958–1971.
Keskin B, Yılmaz İH, Akdeniz H. 2005. Yield and yield component of forage sorghum hybrid (*Sorghum bicolor* x *Sorghum sudanense* Stapf.) as influenced by varieties and maturity. *Atatürk University Journal of Agricultural Faculty*, 36(2); 145-150.
Khan MA, Iqbal Z, Sarwar M, Nisa M, Khan MS, Lee WS, Lee HJ, Kim HS. 2006. Urea treated corncobs ensiled with or without additives for buffaloes: ruminal characteristics, digestibility and nitrogen metabolism. *Asian-Aust. J. Anim. Sci*., 19(5): 705-712.
Kır H, Şahan BD. 2019. Yield and quality feature of some silage sorghum and sorghum-sudangrass hybrid cultivars in ecological conditions of Kırşehir province. *Turkish Journal of Agricultural and Natural Sciences*, 6(3): 388-395.
Kirsten W. 1983. Organic elemental analysis: ultramicro, micro, and trace methods. Academic Press, Harcourt Brace Jovanovich, New York.
Kozłowski S, Zielewicz W, Oliwa R, Jakubowski M. 2006. Biological and chemical properties of *Sorghum saccharatum* from the point of view of possibilities of its cultivation in Poland. *Grassland Science in Poland*, 9: 101- 112.
Küçüksemerci O, Baytekin H. 2017. Effect of plant density on yield and quality parameters of sweet sorghum in Çanakkale ecological conditions. *Turkish Journal of Agricultural and Natural Sciences*, 4(1): 95–100.
Lambers H, Freijsen N, Poorter H, Hirose T, Van der Werf A. 1989. Analyses of growth based on net assimilation rate and nitrogen productivity. Their physiological background. In H Lambers, ML Cambridge, H Konings, TL Pons, eds, Causes and Consequences of Variation in Growth Rate and Productivity of Higher Plants, SPB Academic Publishing, The Hague, pp 1-17.
Lang B. 2001. Sudan/Sorghum Forage Management. Iowa State Unıv. Ext., Fact Sheet BL-50, 6p.
Lema M, Cebert E, Sapra V. 2004. Evaluation of small grain cultivars for forage in North Alabama. *Journal of Sustainable Agriculture*, 23(4): 133-145.
Liu N, Yu P, 2011. Molecular clustering, interrelationships and carbohydrate conformation in hull and seeds among barley cultivars. J. Cereal Sci., 53(3):379–383.
Li X, Zhang Y, Hannoufa A, Yu P, 2015. Transformation with TT8 and HB12 RNAi constructs in model forage (*Medicago sativa*, alfalfa) affects carbohydrate structure and metabolic characteristics in ruminant livestock systems. J. Agric. Food Chem., 63(43):9590–9600.
Mahmood A, Honermeier B. 2012. Effect of row spacing and cultivar on biomass yield and quality of *Sorghum bicolor* L. Moench. *J. Für Kulturpflanzen*, 64(7): 250-257.

Markovic J, Dinic B, Terzic D, Andjelkovic S, Milenkovic J, Blagojevic M, Celjaj B. 2014. Macroelements in red clover (*Trifolium pratense* L.) relative to cow requirements. Fifth International Scientific Agricultural Symposium "Agrosym 2014", October 23-26, Jahorina, pp. 863-867.
Marsalis MA, Kirksey RE, Flynn R, O'Neill MK, Lauriault LM, Place M. 2010. Corn and sorghum performance tests. New Mexico State University, Las Cruces.
Müftüoğlu NM, Türkmen C, Çıkılı Y. 2012. Soil and plant fertility analysis. Nobel, Ankara
Osman RO, Abd El Gelil FM, El-Noamany HM, Dawood MG. 2000. Oil content and fatty acid composition of some varieties of barley and sorghum grains. *Grasas y Aceites*, 51(3): 157-162.
Özmen S. 2017. Determination of yield and quality features of different sorghum species in bingol conditions. Bingöl University, Institute of Science and Technology, Department of Field Crops, M.Sc., 63p.
Özyazıcı MA, Açıkbaş S. 2019. Phosphorus, potassium, calcium and magnesium content of roughage and importance on animal nutrition. ISPEC International Conference on Agriculture, Animal Science and Rural Development-III, December 20-22, Van, Turkey, s. 553-568.
Özyazıcı MA, Açıkbaş S. 2021. Effects of different salt concentrations on germination and seedling growth of some sweet sorghum [*Sorghum bicolor* var. saccharatum (L.) Mohlenbr.] Cultivars. *Turkish Journal of Agricultural Research*, 8(2): 133-143.
Özyazıcı MA, Açıkbaş S, Turan N, Kara MA. 2018a. Evaluation of some common chickling (*Lathyrus sativus* L.) genotypes in terms of hay quality and some mineral contents. International Conference on Agriculture, Forest, Food, Veterinary Sciences and Technologies (ICAFOF-2018), 2-5 April, Çeşme-İzmir/ Turkey, p. 215.
Özyazıcı MA, Eliş S, Özyazıcı G, Açıkbaş S, Turan N. 2018b. Some macronutrient content of silages obtained from different cultivars of branched millet (*Panicum virgatum* L.). 1st International Battalgazi Multidisciplinary Studies Congress, Congress Full Text Book, Malatya –Türkiye.
Pallardy SG. 2008. Physiology of Woody Plants (3rd Ed). Elsevier Inc., 454 p.
Polat H, Bayraklı F. 2019. Nutrient content and crude protein of some plants in natural rangeland in Konya region. *Journal of Bahri Dagdas Crop Research*, 8(1): 132-147.
Pontieri P, Troisi J, Calcagnile M, Bean SR, Tilley M, Aramouni F, Boffa A, Pepe G, Campiglia P, Del Giudice F, Chessa AL, Smolensky D, Aletta M, Alifano P, Del Giudice L. 2021. Chemical composition, fatty acid and mineral content of food-grade white, red and black sorghum varieties grown in the Mediterranean environment. *Foods,* 11, 436.
Poorter H, Remkes C. 1990. Leaf area ratio and net assimilation rate of 24 wild species differing in relative growth rate. *Oecologia*, 83, 553-559.
Poorter H, Remkes C, Lambers H. 1990. Carbon and nitrogen economy of 24 wild species differing in relative growth rate. *Plant Physiol*., 94, 621-627.

Reddy MSS, Chen F, Shadle G, Jackson L, Aljoe H, Dixon RA, 2005. Targeted down-regulation of cytochrome P450 enzymes for forage quality improvement in alfalfa (*Medicago sativa* L.). Proc. Natl. Acad. Sci., 102(46):16573–16578.

Salman A, Budak B. 2015. A study on yield and yield properties of different varieties of hybrid sorghum x sorghum sudan grass (*Sorghum bicolor* x *Sorghum sudanense* Stapf.). *Journal of Adnan Menderes University Agricultural Faculty,* 12(2): 93-100.

Sanderson MA, Jones RM, Ward J, Wolfe R. 1992. Silage sorghum performance trial at Stephen Ville. Forage research in Texas. Report PR-5018. Stephenville, USA: Texas Agricultural Experimental Station.

Schlegel P, Wyss U, Arrigo Y, Hess HD. 2016. Mineral concentrations of fresh herbage from mixed grassland as influenced by botanical composition, harvest time and growth stage. *Animal Feed Science and Technology*, 219, 226-233.

Spears JW. 1994. Minerals in Forages. In: Fahey G.C., Ed. Forage Quality, Evaluation, and Utilization, ASA, CSSA, SSA, Wisconsin, 281-317.

Suhui M, Feng H, Di T, Dongting Z, Zhengbing Y, Yulong Y, Tiancheng Z, Kaiyue H, Haihua S, Jingyun F, 2018. Variations and determinants of carbon content in plants: a global synthesis. Biogeosciences, 15, 693–702.

Sürmen M, Kara E. 2022. Forage yield and quality performances of sorghum genotypes in Mediterranean ecological conditions. *Journal of Adnan Menderes University Agricultural Faculty,* 19(2): 331-339.

Taiz L, Zeiger E. 2008. Plant Physiology. 5th Edition, Sinauer Associates Inc., Sunderland, 782 p.

Tan M. 2019. Macro and micromineral contents of different quinoa (*Chenopodium quinoa* Willd.) varieties used as forage by cattle. *Turkish Journal of Agriculture and Forestry*, 43, 1-8.

Temel S, Keskin B. 2020. The effect of morphological components on the herbage yield and quality of quinoa (*Chenopodium quinoa* Willd.) grown in different dates. Turk J. Agric. For. 44(5): 533-542.

Tosunoğlu S. 2014. Determination of sorghum, sudangrass and sorghumxsudan grass hybrid varieties as the main and second crop in the Yozgat province. Bozok University Graduate School of Natural and Applied Sciences, Department of Field Crops, M.Sc., 75p.

Towne G, Ohlenbusch DP. 1992. Native Hay Meadow Management. Coop. Ext. Serv., Kansas State Univ., MF-1042, 2p.

Turan N, Özyazıcı MA, Açıkbaş S, Seydoşoğlu S. 2018. The determining of some macro element contents in genotypes of vetch species. UMTEB III. Gaziantep, Türkiye, s. 3705-3712.

Undersander D. 2003. Sorghums, sudangrasses, and sorghum-sudan hybrids. *Focus on Forage*, 5(5): 2.

Yao FY, Chen YH, Yan ZB, Li P, Han WX, Fang JY. 2015. Biogeographic patterns of structural traits and C:N:P stoichiometry of tree twigs in China's forests, Plos One, 10, e0116391.

Yücel C, İlker İ, Gündel F, Yücel D, Aktaş A, Karaağaç HA, Hatipoğlu R, Dweikat İ. 2017. The determining silage quality parameters of sap of sweet sorghum extraction for bioethanol production. *KSU J. Nat. Sci.,* 20 (special issue), 144-148, 2017.
Zhang J, He N, Liu C, Yang H, Meiling L, Guirui Y, Wilcox K, Yu Q, He N. 2018. C:N:P stoichiometry in China's forests: From organs to ecosystems. Functional ecology, 32(1): 50-60.
Zhang, J.H., He, N.P., Liu, C, Xu L, Chen Z, Li Y, Wang R, Guirui Y, Sun W, Xiao C, Chen HYH, Reich PB, 2020. Variation and evolution of C:N ratio among different organs enable plants to adapt to N-limited environments. Glob. Chang. Biol., 26, 2534–2543.

Legends:

Figure 1:

Meteorologic data for the Canakkale province including long-term averages and data from the study years.

Table 1:

Soil properties of the research area.

Table 2:

Sorghum cultivars used in this study and their characteristics.

Table 3:

Deterministic statistics and mean square values of SSH and SS in 2020 and 2021 and two-year average forage yields and quality.

Table 4:

Dry forage yields of SSH and SS varieties (kg/ha) in 2020 and 2021 and the two-year averages.

Table 5:

Carbon ratios in the leaves of SSH and SS varieties (%) in 2020 and 2021 and the two-year averages.

Table 6:

Carbon ratios in the stalks of SSH and SS varieties (%) in 2020 and 2021 and the two-year averages.

Table 7:

Nitrogen ratios in the leaves of SSH and SS varieties (%) in 2020 and 2021 and the two-year averages.

Table 8:
Nitrogen ratios in the stalks of SSH and SS varieties (%) in 2020 and 2021 and the two-year averages.

Table 9:
Crude protein ratios in the leaves of SSH and SS varieties (%) in 2020 and 2021 and the two-year averages.

Table 10:
Crude protein ratios in the stalks of SSH and SS varieties (%) in 2020 and 2021 and the two-year averages.

Table 11:
Crude ash ratios in the leaves of SSH and SS varieties (%) in 2020 and 2021 and the two-year averages.

Table 12:
Crude ash ratios in the stalks of SSH and SS varieties (%) in 2020 and 2021 and the two-year averages.

Table 13:
Crude fat ratios in the leaves of SSH and SS varieties (%) in 2020 and 2021 and the two-year averages.

Table 14:
Crude fat ratios in the stalks of SSH and SS varieties (%) in 2020 and 2021 and the two-year averages.

Figure 1

Meteorologic data for the Canakkale province including long-term averages and data from the study years

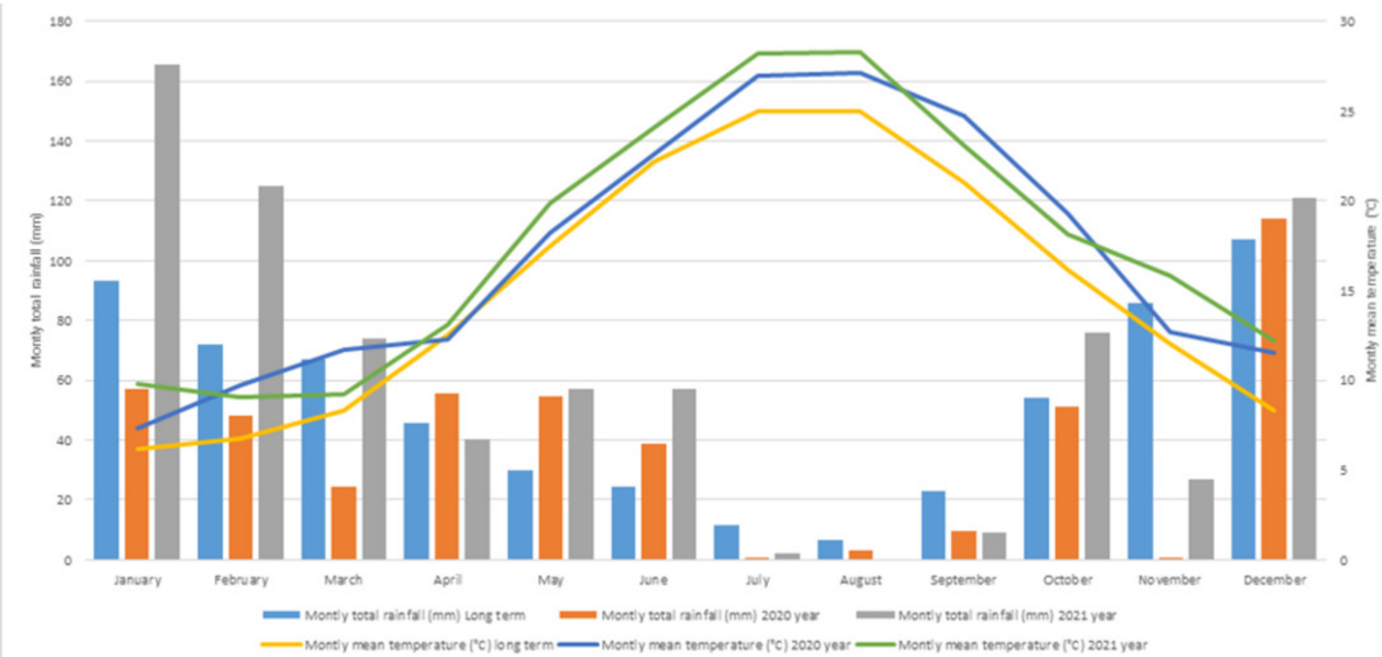

Table 1 (on next page)

Soil properties of the research area

	Soil properties (%)	pH	E.C. (mS/cm)	Lime (%)	Soil organic carbon content (%)	P (mg/kg)	K (mg/kg)
Sample 1	70	7.50	0.85	8.65	1.89	66.08	358.8
	Clay-loamy	Slightly alkaline	Saltless	Medium chalky	Poor	Poor	Poor
Sample 2	65	7.35	0.88	7.69	1.95	54.88	337.9
	Clay-loamy	Neutral	Saltless	Medium chalky	Poor	Poor	Poor
Sample 3	68	7.31	0.95	9.16	1.78	69.44	385.5
	Clay-loamy	Neutral	Saltless	Medium chalky	Poor	Poor	Poor
Mean	67.7	7.39	89.3	8.50	1.87	63.39	360.7
	Clay-loamy	Neutral	Saltless	Medium chalky	Poor	Poor	Poor

Table 2(on next page)

Sorghum cultivars used in this study and their characteristics

Species	Cultivars	Organization name	Purpose of production	Maturity
Sweet sorghum	Topper-76	Nebraska University	Syrup, ethanol	Mid late
Sweet sorghum	M81-E	Nebraska University	Syrup, ethanol, silage	Late
Sorghum x sudangrass	Nutri Honey	Alfa Seed	Forage and grazing	Mid early
Sorghum x sudangrass	Nutrima	Royal AgriLife	Fresh forage, silage, grazing	Late

Table 3 (on next page)

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Deterministic statistics and mean square values of SSH and SS in 2020 and 2021 and two-year average forage yields and quality

Mean Square	DHY	LC	LN	SC	SN	LCP	SCP	LCA	SCA	LCF	SCF
Year (Y)	153385.00	36.73	39.85	11.17	19.79	745.20	1160.21	82.31	65.04	0.000734	0.103469
Varieties (V)	456284.00	8.61	3.71	44.44	1.44	306.33	156.50	36.75	43.30	0.271096	2.481722
Y*V	905792.00	14.98	2.59	12.45	2.70	396.02	204.05	116.91	12.06	0.095603	0.036475
Harvesting Height (HH)	42121497.00	169.07	27.09	74.90	48.95	1967.98	2765.20	42.41	424.75	20.239297	13.550272
Y*HH	60884.00	16.08	4.41	15.04	2.19	42.92	27.32	35.21	7.61	0.089009	0.039331
V*HH	7964635.00	65.94	2.76	58.83	6.60	154.39	203.06	58.17	51.72	0.321532	0.241861
Y*V*HH	687806.00	32.15	5.64	16.25	6.10	70.69	193.81	43.90	94.76	0.631341	0.106625

Deterministic statistics of variables for two years

Mean±Standart deviation	DHY	C	N	CP	CA	CF
Stalk	1680.8±608.5337	38.807±1.424	1.248±0.886	6.917±2.883	8.341±1.533	1.732±0.357
Leaf		41.243±1.615	2.332±0.813	11.782±3.339	11.007±0.970	2.759±0.422

*: P<0.05, **: P<0.01, ns: not statistically significant, DHY-Dry Forage Yield; LC-Leaf Carbon; SC-Stalk Carbon; LN-Leaf Nitrogen; SN-Stalk Nitrogen; LCP-Leaf Crude Protein; SCP-Stalk Crude Protein; LCA-Leaf Crude Ash; SCA-Stalk Crude Ash; LCF-Leaf Crude Fat; SCF-Stalk Crude Fat, C: Carbon, N: Nitrogen, CP: Crude protein, CA: Crude ash, CF: Crude fat.

Table 4(on next page)

Dry forage yields of SSH and SS varieties (kgha) in 2020 and 2021 and the two-year averages

Harvesting Heights	Sorghum-Sudangrass (SSH)		Sweet Sorghum (SS)		Average
	Nutri Honey	Nutrima	M81-E	Topper-76	
2020 year					
30 cm	10420.0^{l}	11800.0^{k}	7490.0^{m}	7600.0^{m}	9332.0^{E}
60 cm	11690.0^{k}	13660.0^{hi}	12280.0^{k}	12450.0^{jk}	12520.0^{D}
90 cm	12520.0^{ijk}	13570.0^{hu}j	13780.0^{h}	12450.0^{jk}	13080.0^{D}
120 cm	19980.0^{de}	17560.0^{g}	18510.0^{fg}	17360.0^{g}	18350.0^{C}
150 cm	19270.0^{ef}	22450.0^{c}	19360.0^{def}	18890.0^{ef}	19990.0^{B}
PMS	21710.0^{c}	20530.0^{d}	34550.0^{h}	25700.0^{b}	25620.0^{A}
Average	15930.0^{C}	16590.0^{B}	17660.0^{A}	15740.0^{C}	**16480.0^{B}**
Significant	PV:0.0001, PHH: 0.0001, PV*HH: 0.0001.				
2021 year					
30 cm	12390.0^{ij}	11480.0^{jk}	7720.0^{l}	7660.0^{l}	9810.0^{E}
60 cm	15720.0^{ef}	15510.0^{efg}	10630.0^{k}	13280.0^{hi}	13780.0^{D}
90 cm	14450.0^{fgh}	14380.0^{gh}	14550.0^{fgh}	12710.0^{ij}	14010.0^{D}
120 cm	23510.0^{c}	18810.0^{d}	16610.0^{e}	14540.0^{fgh}	18370.0^{C}
150 cm	23410.0^{c}	23430.0^{c}	15110.0^{fg}	19480.0^{d}	20360.0^{B}
PMS	22450.0^{c}	23500.0^{c}	31490.0^{a}	28450.0^{b}	26470.0^{A}
Average	18660.0^{A}	17850.0^{B}	16020.0^{C}	16020.0^{C}	**17140.0^{A}**
Significant	PV:0.0001, PHH: 0.0001, PV*HH: 0.0001.				
Two-years average (2020-2021)					
30 cm	11410.0^{j}	11640.0^{j}	7600.0^{k}	7630.0^{k}	9570.0^{E}
60 cm	13710.0^{hi}	14580.0^{gh}	11450.0^{j}	12860.0^{ij}	13150.0^{D}
90 cm	13480.0^{hi}	13960.0^{hi}	14160.0^{hi}	12580.0^{ij}	13550.0^{D}
120 cm	21750.0^{c}	18190.0^{de}	17560.0^{ef}	15950.0^{fg}	18360.0^{C}
150 cm	21340.0^{c}	22940.0^{j}	17240.0^{ef}	19190.0^{d}	20180.0^{B}
PMS	22080.0^{c}	22020.0^{c}	33020.0^{a}	27080.0^{b}	26050.0^{A}
Average	17290.0^{A}	17220.0^{A}	19840.0^{A}	15880.0^{B}	
Significant	PY: 0.0003, PV:0.0001, PY*V: 0.0001, PHH: 0.0001, PY*HH: 0.3467, PV*HH: 0.0001, PY*V*HH: 0.0001				

*: P<0.05, **: P<0.01, ns: not statistically significant, Y: Years, V: Varieties, HH: Harvesting Height, PMS: Physiological Maturity Stage

Table 5(on next page)

Carbon ratios in the leaves of SSH and SS varieties (%) in 2020 and 2021 and the two-year averages

Harvesting Height	Sorghum-Sudangrass (SSH)		Sweet Sorghum (SS)		Average
	Nutri Honey	Nutrima	M81-E	Topper-76	
2020 year					
30 cm	41.92^{ef}	42.57^{cde}	40.43^{ij}	42.21^{ef}	41.78^{B}
60 cm	42.05^{ef}	43.43^{ab}	42.95^{bcd}	41.16^{gh}	42.40^{A}
90 cm	42.31^{de}	43.19^{abc}	42.94^{bcd}	41.53^{fg}	42.49^{A}
120 cm	42.27^{de}	43.76^{a}	42.57^{cde}	40.83^{ghi}	42.36^{A}
150 cm	41.53^{ef}	42.49^{cde}	42.23^{ef}	40.80^{hi}	41.76^{B}
PMS	39.76^{j}	40.40^{ij}	38.68^{k}	39.97^{j}	39.70^{C}
Average	41.64^{B}	42.64^{A}	41.63^{B}	41.08^{C}	**41.75^{A}**
Significant	PV:0.0001, PHH: 0.0001, PV*HH: 0.0001.				
2021 year					
30 cm	41.92^{bc}	42.33^{ab}	40.19^{fgh}	41.74^{bcd}	41.54^{AB}
60 cm	41.58^{b-e}	41.30^{b-f}	43.40^{a}	42.01^{bc}	42.07^{A}
90 cm	40.95^{c-g}	39.95^{gh}	43.20^{a}	40.73^{d-h}	41.21^{B}
120 cm	39.88^{gh}	40.00^{gh}	39.99^{gh}	41.45^{b-e}	40.33^{C}
150 cm	41.98^{bc}	39.76^{h}	42.41^{ab}	40.49^{e-h}	41.16^{B}
PMS	38.26^{i}	40.07^{gh}	36.04^{j}	38.07^{i}	38.11^{D}
Average	40.76	40.57	40.87	40.75	**40.74^{B}**
Significant	PV:0.6309, PHH: 0.0001, PV*HH: 0.0001.				
Two-year average (2020-2021)					
30 cm	41.92^{b-e}	42.45^{abc}	40.31^{g}	41.97^{a-e}	41.66^{AB}
60 cm	41.82^{c-f}	42.37^{abc}	43.18^{a}	41.58^{c-f}	42.23^{A}
90 cm	41.63^{c-f}	41.57^{c-f}	43.07^{ab}	41.13^{d-g}	41.85^{AB}
120 cm	41.08^{efg}	41.88^{b-e}	41.28^{c-g}	41.14^{d-g}	41.34^{B}
150 cm	41.76^{c-f}	41.12^{d-g}	42.32^{a-d}	40.65^{fg}	41.46^{B}
PMS	39.01^{h}	40.23^{g}	37.36^{i}	39.02^{h}	38.91^{C}
Average	41.20	41.60	41.25	40.92	-
Significant	PY: 0.0001, PV:0.0001, PY*V: 0.0001, PHH: 0.0001, PY*HH: 0.0001, PV*HH: 0.0001, PY*V*HH: 0.0001				

*: $P<0.05$, **: $P<0.01$, ns: not statistically significant, Y: Years, V: Varieties, HH: Harvesting Height, PMS: Physiological Maturity Stage.

Table 6(on next page)

Carbon ratios in the stalks of SSH and SS varieties (%) in 2020 and 2021 and the two-year averages

Harvesting Height	Sorghum-Sudangrass (SSH)		Sweet Sorghum (SS)		Average
	Nutri Honey	Nutrima	M81-E	Topper-76	
2020 year					
30 cm	38.21^{e-k}	39.79^{bc}	38.34^{e-j}	38.30^{e-j}	38.65^{B}
60 cm	37.35^{ijk}	38.76^{c-g}	38.55^{c-i}	37.29^{jkl}	37.99^{C}
90 cm	37.90^{g-k}	39.57^{cd}	38.39^{d-j}	36.12^{l}	37.99^{C}
120 cm	37.85^{g-k}	38.62^{c-h}	37.49^{h-k}	37.02^{kl}	37.75^{C}
150 cm	37.53^{h-k}	39.40^{cde}	39.56^{cd}	37.97^{f-k}	38.62^{B}
PMS	39.17^{c-f}	40.83^{b}	42.71^{a}	38.05^{f-k}	40.19^{A}
Average	38.00^{B}	39.49^{A}	39.17^{A}	37.46^{C}	**38.53^{B}**
Significant	PV:0.0001, PHH: 0.0001, PV*HH: 0.0003.				
2021 year					
30 cm	38.77^{f-j}	39.15^{c-i}	36.89^{k}	39.31^{c-h}	38.53^{CD}
60 cm	37.99^{h-k}	38.65^{f-j}	40.19^{b-e}	39.10^{d-j}	38.98^{BC}
90 cm	38.22^{g-k}	37.75^{j-k}	37.84^{ijk}	37.95^{ijk}	37.94^{D}
120 cm	40.50^{bc}	40.29^{bcd}	38.91^{e-j}	38.26^{g-j}	39.49^{B}
150 cm	39.56^{b-g}	39.69^{b-f}	39.66^{b-f}	37.85^{ijk}	39.19^{BC}
PMS	40.14^{b-e}	40.68^{ab}	42.00^{a}	38.78^{f-j}	40.40^{A}
Average	39.20^{A}	39.37^{A}	39.25^{A}	38.54^{B}	**39.09^{A}**
Significant	PV:0.0193, PHH: 0.0001, PV*HH: 0.0001.				
Two-year average (2020-2021)					
30 cm	38.49^{d-h}	39.44^{cde}	37.61^{hi}	38.80^{c-g}	38.59^{B}
60 cm	37.67^{hi}	38.71^{c-h}	39.37cde	38.20^{fgh}	38.49^{BC}
90 cm	38.06^{f-i}	38.66^{c-h}	38.11^{f-i}	37.03^{i}	37.97^{C}
120 cm	39.17^{c-f}	39.44^{cde}	38.20^{fgh}	37.64^{hi}	38.61^{B}
150 cm	38.54^{c-h}	39.55^{cd}	39.61^{c}	37.91^{ghi}	38.90^{B}
PMS	39.66^{bc}	40.76^{b}	42.36^{a}	38.41^{e-h}	40.30^{A}
Average	38.60^{B}	39.43^{A}	39.21^{A}	38.00^{C}	-
Significant	PY: 0.0001, PV:0.0001, PY*V: 0.0004, PHH: 0.0001, PY*HH: 0.0005, PV*HH: 0.0001, PY*V*HH: 0.0537				

*: P<0.05, **: P<0.01, ns: not statistically significant, Y: Years, V: Varieties, HH: Harvesting Height.

Table 7 (on next page)

Nitrogen ratios in the leaves of SSH and SS varieties (%) in 2020 and 2021 and the two-year averages

Harvesting Height	Sorghum-Sudangrass (SSH)		Sweet Sorghum (SS)		Average
	Nutri Honey	Nutrima	M81-E	Topper-76	
2020 year					
30 cm	3.58^{a}	3.23^{a-e}	2.93^{c-h}	3.42^{abc}	3.29^{A}
60 cm	3.37^{a-d}	3.38^{abc}	3.02^{b-f}	2.92^{c-h}	3.17^{A}
90 cm	2.71^{e-h}	2.89^{c-h}	1.88^{ij}	3.15^{a-f}	2.66^{C}
120 cm	3.48^{ab}	3.22^{a-e}	2.41^{hi}	3.00^{b-g}	3.03^{AB}
150 cm	3.20^{a-e}	2.82^{e-h}	2.67^{fgh}	2.85^{d-h}	2.88^{BC}
PMS	2.49^{gh}	1.92^{ij}	1.61^{j}	2.62^{fgh}	2.16^{D}
Average	3.14^{A}	2.91^{B}	2.42^{C}	2.99^{AB}	**2.87^{A}**
Significant	PV:0.0001, PHH: 0.0001, PV*HH: 0.0450.				
2021 year					
30 cm	2.46^{bc}	2.53^{ab}	2.26^{b-e}	2.95^{a}	2.55^{A}
60 cm	2.46^{bc}	2.25^{b-e}	1.77^{ghi}	2.34^{bcd}	2.21^{B}
90 cm	1.89^{e-h}	1.79^{ghi}	1.95^{d-h}	2.24^{b-f}	1.97^{C}
120 cm	0.32^{l}	1.43^{ij}	1.55^{hij}	1.88^{e-i}	1.29^{D}
150 cm	2.06^{c-g}	1.80^{f-i}	1.95^{d-h}	1.81^{e-i}	1.91^{C}
PMS	0.94^{k}	1.16^{jk}	0.83^{k}	0.76^{kl}	0.92^{E}
Average	1.69^{B}	1.83^{AB}	1.72^{B}	2.00^{A}	**1.81^{B}**
Significant	PV:0.0061, PHH: 0.0001, PV*HH: 0.0001.				
Two-year average (2020-2021)					
30 cm	3.02	2.88	2.59	3.18	2.92^{A}
60 cm	2.91	2.82	2.40	2.63	2.69^{AB}
90 cm	2.30	2.22	1.92	2.69	2.28^{BC}
120 cm	1.90	2.33	1.98	2.44	2.16^{C}
150 cm	2.63	2.31	2.31	2.33	2.40^{BC}
PMS	1.71	1.54	1.22	1.69	1.54^{D}
Average	2.41	2.35	2.07	2.49	-
Significant	PY: 0.0001, PV:0.0001, PY*V: 0.0001, PHH: 0.0001, PY*HH: 0.0001, PV*HH: 0.0147, PY*V*HH: 0.0001				

*: P<0.05, **: P<0.01, ns: not statistically significant, Y: Years, V: Varieties, HH: Harvesting Height, PMS: Physiological Maturity Stage.

Table 8(on next page)

Nitrogen ratios in the stalks of SSH and SS varieties (%) in 2020 and 2021 and the two-year averages

Harvesting Height	Sorghum-Sudangrass (SSH)		Sweet Sorghum (SS)		Average
	Nutri Honey	Nutrima	M81-E	Topper-76	
2020 year					
30 cm	1.94^{cde}	2.72^{a}	2.29^{a-d}	2.29^{a-d}	2.31^{A}
60 cm	2.47^{ab}	1.91^{cde}	1.71^{efg}	2.65^{a}	2.18^{A}
90 cm	1.80^{def}	1.56^{e-h}	2.53^{a}	2.37^{abc}	2.06^{A}
120 cm	1.71^{efg}	1.97^{b-e}	1.16^{hi}	1.69^{efg}	1.63^{B}
150 cm	0.95^{i}	1.11^{hi}	1.36^{f-i}	1.25^{ghi}	1.17^{C}
PMS	0.19^{j}	0.24^{j}	0.02^{j}	1.05^{i}	0.37^{D}
Average	1.51^{B}	1.58^{B}	1.51^{B}	1.88^{A}	**1.62^{A}**
Significant	PV:0.0015, PHH: 0.0001, PV*HH: 0.0001.				
2021 year					
30 cm	1.42	1.19	1.70	1.31	1.40^{A}
60 cm	1.27	1.72	0.56	0.92	1.12^{A}
90 cm	2.15	1.31	0.79	1.25	1.38^{A}
120 cm	1.81	0.97	0.47	0.61	0.97^{A}
150 cm	0.21	0.19	0.45	0.46	0.33^{B}
PMS	0.09	0.13	0.01	0.14	0.09^{B}
Average	1.16	0.92	0.66	0.78	**0.88^{B}**
Significant	PV:0.1298, PHH: 0.0001, PV*HH: 0.4090.				
Two-year average (2020-2021)					
30 cm	1.68	1.95	2.00	1.80	1.86^{A}
60 cm	1.87	1.81	1.14	1.78	1.65^{AB}
90 cm	1.97	1.43	1.66	1.81	1.72^{A}
120 cm	1.76	1.44	0.81	1.15	1.29^{B}
150 cm	0.58	0.65	0.90	0.85	0.75^{C}
PMS	0.14	0.18	0.02	0.60	0.23^{D}
Average	1.33	1.24	1.09	1.33	-
Significant	PY: 0.0001, PV:0.1254, PY*V: 0.0153, PHH: 0.0001, PY*HH: 0.1240, PV*HH: 0.0479, PY*V*HH: 0.0748				

*: P<0.05, **: P<0.01, ns: not statistically significant, Y: Years, V: Varieties, HH: Harvesting Height, PMS: Physiological Maturity Stage.

Table 9 (on next page)

Crude protein ratios in the leaves of SSH and SS varieties (%) in 2020 and 2021 and the two-year averages

Harvesting Height	Sorghum-Sudangrass (SSH)		Sweet Sorghum (SS)		Average
	Nutri Honey	Nutrima	M81-E	Topper-76	
2020 year					
30 cm	17.13	15.02	13.60	15.01	15.19^{A}
60 cm	16.80	14.40	13.64	13.85	14.67^{A}
90 cm	16.07	12.28	11.78	12.68	13.20^{B}
120 cm	15.79	10.00	12.31	13.15	12.81^{B}
150 cm	14.08	9.66	11.97	12.82	12.13^{B}
PMS	12.00	8.14	7.30	5.81	8.31^{C}
Average	15.31^{A}	11.58^{B}	11.77^{B}	12.22^{B}	**12.72^{A}**
Significant	PV:0.0001, PHH: 0.0001, PV*HH: 0.3480.				
2021 year					
30 cm	11.86	13.39	12.96	15.18	13.35^{A}
60 cm	11.07	10.90	10.76	13.76	11.62^{B}
90 cm	10.44	10.28	10.00	12.85	10.89^{BC}
120 cm	9.88	10.38	10.38	12.29	10.74^{C}
150 cm	9.20	8.17	9.30	11.34	9.50^{D}
PMS	5.53	5.38	2.54	5.01	4.61^{E}
Average	9.66^{B}	9.75^{B}	9.32^{B}	11.74^{A}	**10.12^{B}**
Significant	PV:0.0001, PHH: 0.0001, PV*HH: 0.5203.				
Two-year average (2020-2021)					
30 cm	14.49	14.20	13.28	15.10	14.27^{A}
60 cm	13.93	12.65	12.20	13.81	13.15^{B}
90 cm	13.26	11.28	10.89	12.76	12.05^{C}
120 cm	12.83	10.19	11.35	12.72	11.77^{CD}
150 cm	11.64	8.91	10.63	12.08	10.82^{D}
PMS	8.76	6.76	4.92	5.41	6.46^{E}
Average	12.49^{A}	10.67^{B}	10.55^{B}	11.98^{A}	
Significant	PY: 0.0001, PV:0.0001, PY*V: 0.0001, PHH: 0.0001, PY*HH: 0.3118, PV*HH: 0.1284, PY*V*HH: 0.8293				

*: P<0.05, **: P<0.01, ns: not statistically significant, Y: Years, V: Varieties, HH: Harvesting Height, PMS: Physiological Maturity Stage.

Table 10(on next page)

Crude protein ratios in the stalks of SSH and SS varieties (%) in 2020 and 2021 and the two-year averages

Harvesting Height	Sorghum-Sudangrass (SSH)		Sweet Sorghum (SS)		Average
	Nutri Honey	Nutrima	M81-E	Topper-76	
2020 year					
30 cm	12.24^{bc}	14.77^{a}	10.41^{cde}	11.07^{bcd}	12.12^{A}
60 cm	9.45^{def}	12.50^{b}	9.09^{d-g}	9.57^{def}	10.15^{B}
90 cm	8.53^{e-h}	12.52^{abc}	7.32^{f-i}	7.93^{f-i}	9.07^{B}
120 cm	7.01^{g-j}	8.77^{e-h}	6.64^{hij}	6.65^{hij}	7.27^{C}
150 cm	4.43^{jk}	5.15^{ijk}	6.91^{f-j}	7.34^{f-j}	5.96^{C}
PMS	2.90^{k}	5.30^{h-k}	7.81^{d-j}	6.76^{f-k}	5.69^{C}
Average	7.42^{B}	9.84^{A}	8.03^{B}	8.22^{B}	**8.38^{A}**
Significant	PV:0.0007, PHH: 0.0001, PV*HH: 0.0147.				
2021 year					
30 cm	7.97^{cd}	8.48^{bc}	7.52^{cde}	10.27^{a}	8.56^{A}
60 cm	6.30^{fgh}	6.57^{efg}	7.25^{def}	9.50^{ab}	7.41^{B}
90 cm	4.64^{ijk}	4.45^{i-l}	5.32^{hi}	8.42^{bcd}	5.71^{C}
120 cm	3.32^{lmn}	3.70^{klm}	5.56^{ghi}	5.08^{ij}	4.41^{D}
150 cm	2.08^{no}	2.30^{mno}	3.76^{j-m}	4.81^{ijk}	3.24^{E}
PMS	1.70^{no}	1.30^{o}	1.05^{o}	1.79^{no}	1.46^{F}
Average	4.33^{C}	4.46^{C}	5.08^{B}	6.64^{A}	**5.13^{B}**
Significant	PV:0.0001, PHH: 0.0001, PV*HH: 0.0013.				
Two-year average (2020-2021)					
30 cm	10.10	11.63	8.96	10.67	10.33^{A}
60 cm	7.88	9.54	8.17	9.54	8.78^{B}
90 cm	6.58	8.48	6.32	8.18	7.39^{C}
120 cm	5.16	6.23	6.10	5.86	5.84^{D}
150 cm	3.25	3.72	5.33	6.07	4.60^{E}
PMS	2.30	3.30	4.43	4.27	3.57^{E}
Average	5.88^{C}	7.15^{AB}	6.55^{BC}	7.43^{A}	
Significant	PY: 0.0001, PV:0.0001, PY*V: 0.0001, PHH: 0.0001, PY*HH: 0.4951, PV*HH: 0.0064, PY*V*HH: 0.0100				

*: P<0.05, **: P<0.01, ns: not statistically significant, Y: Years, V: Varieties, HH: Harvesting Height, PMS: Physiological Maturity Stage.

Table 11(on next page)

Crude ash ratios in the leaves of SSH and SS varieties (%) in 2020 and 2021 and the two-year averages

Harvesting Height	Sorghum-Sudangrass (SSH)		Sweet Sorghum (SS)		Average
	Nutri Honey	Nutrima	M81-E	Topper-76	
2020 year					
30 cm	11.44^{bc}	11.03^{b-g}	11.34^{bc}	11.40^{bc}	11.30^{A}
60 cm	11.29^{bcd}	10.44^{d-g}	10.29^{e-h}	11.02^{b-g}	10.76^{B}
90 cm	11.76^{b}	10.52^{c-g}	10.02^{fgh}	10.66^{c-g}	10.74^{B}
120 cm	11.24^{b-e}	9.38^{h}	10.58^{c-g}	11.21^{b-e}	10.60^{B}
150 cm	11.66^{bc}	9.97^{fgh}	10.63^{b-g}	11.10^{b-g}	10.84^{AB}
PMS	10.70^{b-h}	7.48^{i}	11.93^{abc}	13.60^{a}	10.93^{AB}
Average	11.35^{A}	9.80^{C}	10.80^{B}	11.50^{A}	**10.86^{B}**
Significant	PV:0.0001, PHH: 0.0481, PV*HH: 0.0001.				
2021 year					
30 cm	11.72	11.84	11.36	10.76	11.42^{C}
60 cm	12.26	11.68	10.87	10.86	11.42^{C}
90 cm	11.58	11.88	10.46	10.67	11.15^{C}
120 cm	11.89	11.94	11.18	10.26	11.32^{C}
150 cm	12.37	12.54	11.42	11.15	11.87^{B}
PMS	13.30	13.58	13.21	12.64	13.14^{A}
Average	12.19^{A}	12.24^{A}	11.42^{B}	11.06^{C}	**11.73^{A}**
Significant	PV:0.0001, PHH: 0.0001, PV*HH: 0.4195.				
Two-year average (2020-2021)					
30 cm	11.58^{cde}	11.43^{c-g}	11.35^{c-h}	11.08^{e-i}	11.36^{B}
60 cm	11.77^{bcd}	11.06^{e-i}	10.58^{ij}	10.94^{f-i}	11.09^{BCD}
90 cm	11.67^{b-e}	11.20^{d-i}	10.24^{j}	10.66^{ij}	10.94^{D}
120 cm	11.57^{b-f}	10.66^{ij}	10.88^{f-j}	10.74^{g-i}	10.96^{CD}
150 cm	12.02^{bc}	11.25^{c-i}	11.03^{d-j}	11.13^{hij}	11.36^{BC}
PMS	12.00^{a-e}	10.53^{gij}	12.57^{ab}	13.12^{a}	12.05^{A}
Average	11.77^{A}	11.02^{B}	11.11^{B}	11.28^{B}	
Significant	PY: 0.0001, PV:0.0001, PY*V: 0.0001, PHH: 0.0001, PY*HH: 0.0001, PV*HH: 0.0001, PY*V*HH: 0.0041				

*: P<0.05, **: P<0.01, ns: not statistically significant, Y: Years, V: Varieties, HH: Harvesting Height, PMS: Physiological Maturity Stage.

Table 12(on next page)

Crude ash ratios in the stalks of SSH and SS varieties (%) in 2020 and 2021 and the two-year averages

Harvesting Height	Sorghum-Sudangrass (SSH)		Sweet Sorghum (SS)		Average
	Nutri Honey	Nutrima	M81-E	Topper-76	
2020 year					
30 cm	10.17^{bcd}	10.99^{a}	9.84^{c-f}	9.69^{d-g}	10.17^{A}
60 cm	10.01^{b-e}	10.62^{abc}	9.27^{e-h}	9.03^{fgh}	9.73^{B}
90 cm	9.80^{b-g}	10.82^{ab}	7.86^{jkl}	8.02^{i-l}	9.13^{C}
120 cm	9.08^{e-i}	9.00^{f-i}	8.85^{g-j}	7.83^{jkl}	8.69^{CD}
150 cm	7.63^{kl}	7.64^{kl}	8.88^{f-k}	8.92^{e-k}	8.27^{D}
PMS	5.72^{m}	7.09^{lm}	8.05^{h-l}	8.21^{h-l}	7.26^{E}
Average	8.73^{B}	9.36^{A}	8.79^{B}	8.62^{B}	**8.88^{A}**
Significant	PV:0.0163, PHH: 0.0481, PV*HH: 0.0001.				
2021 year					
30 cm	9.80^{a}	9.67^{ab}	9.31^{abc}	9.12^{bcd}	9.47^{A}
60 cm	9.16^{a-d}	9.22^{abc}	8.77^{c-f}	9.07^{b-e}	9.06^{B}
90 cm	8.71^{c-f}	8.20^{fg}	8.37^{ef}	8.46^{def}	8.43^{C}
120 cm	8.67^{c-f}	8.42^{def}	9.06^{b-e}	6.89^{i}	8.26^{C}
150 cm	8.30^{efg}	7.99^{fgh}	7.45^{ghi}	7.03^{hi}	7.69^{D}
PMS	6.28^{ij}	7.19^{ghi}	5.23^{jk}	4.21^{k}	5.72^{E}
Average	8.49^{A}	8.45^{A}	8.03^{B}	7.46^{C}	**8.11^{B}**
Significant	PV:0.0001, PHH: 0.0481, PV*HH: 0.0002.				
Two-year average (2020-2021)					
30 cm	9.98^{ab}	10.33^{a}	9.58^{bcd}	9.40^{cde}	9.82^{A}
60 cm	9.58^{bcd}	9.92^{abc}	9.02^{def}	9.05^{def}	9.39^{B}
90 cm	9.25^{c-f}	9.51^{b-e}	8.11^{h-k}	8.24^{ghi}	8.78^{C}
120 cm	8.87^{efg}	8.71^{fgh}	8.95^{d-g}	7.36^{jkl}	8.47^{C}
150 cm	7.96^{h-k}	7.82^{ijk}	8.17^{g-k}	7.98^{h-k}	7.98^{D}
PMS	6.00^{m}	7.14^{j-m}	6.64^{lm}	6.21^{m}	6.49^{E}
Average	8.61^{AB}	8.90^{A}	8.41^{B}	8.04^{C}	
Significant	PY: 0.0001, PV:0.0001, PY*V: 0.0315, PHH: 0.0001, PY*HH: 0.3462, PV*HH: 0.0011, PY*V*HH: 0.0001				

*: P<0.05, **: P<0.01, ns: not statistically significant, Y: Years, V: Varieties, HH: Harvesting Height, PMS: Physiological Maturity Stage.

Table 13(on next page)

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Crude fat ratios in the leaves of SSH and SS varieties (%) in 2020 and 2021 and the two-year averages

Harvesting Height	Sorghum-Sudangrass (SSH)		Sweet sorghum (SS)		Average
	Nutri Honey	Nutrima	M81-E	Topper-76	
2020 year					
30 cm	3.51	3.34	3.31	3.38	3.39^{A}
60 cm	3.26	2.94	3.12	3.01	3.02^{B}
90 cm	2.87	2.77	2.73	2.72	2.77^{C}
120 cm	2.76	2.51	2.62	2.68	2.64^{C}
150 cm	2.33	2.47	2.54	2.47	2.46^{D}
PMS	2.25	2.19	2.26	2.22	2.23^{E}
Average	2.83	2.70	2.76	2.75	**2.76**
Significant	PV:0.3990, PHH: 0.0481, PV*HH: 0.9590.				
2021 year					
30 cm	3.20	3.32	3.67	3.38	3.39^{A}
60 cm	3.06	2.90	3.04	2.91	2.98^{B}
90 cm	2.86	2.86	2.87	2.69	2.82^{C}
120 cm	2.75	2.62	2.58	2.52	2.62^{D}
150 cm	2.69	2.54	2.38	2.31	2.48^{D}
PMS	2.23	2.25	2.30	2.22	2.25^{E}
Average	2.80	2.75	2.81	2.67	**2.76**
Significant	PV:0.0873, PHH: 0.0481, PV*HH: 0.2169.				
Two-year average (2020-2021)					
30 cm	3.36	3.33	3.49	3.38	3.39^{A}
60 cm	3.16	2.92	3.08	2.96	3.03^{B}
90 cm	2.86	2.82	2.80	2.70	2.80^{C}
120 cm	2.75	2.56	2.60	2.60	2.63^{D}
150 cm	2.51	2.51	2.46	2.39	2.47^{E}
PMS	2.24	2.22	2.28	2.22	2.24^{F}
Average	2.82	2.73	2.79	2.71	
Significant	PY: 0.8966, PV:0.1068, PY*V: 0.5319, PHH: 0.0001, PY*HH: 0.8389, PV*HH: 0.9364, PY*V*HH: 0.4876				

1 *: P<0.05, **: P<0.01, ns: not statistically significant, Y: Years, V: Varieties, HH: Harvesting Height, PMS: Physiological Maturity Stage

Table 14(on next page)

Crude fat ratios in the stalks of SSH and SS varieties (%) in 2020 and 2021 and the two-year averages

Harvesting Height	Sorghum-Sudangrass (SSH)		Sweet sorghum (SS)		Average
	Nutri Honey	**Nutrima**	**M81-E**	**Topper-76**	
2020 year					
30 cm	2.25	2.05	2.46	2.29	2.26^{A}
60 cm	1.99	1.86	2.20	2.05	2.03^{B}
90 cm	1.76	1.62	2.01	1.75	1.78^{C}
120 cm	1.52	1.53	1.86	1.60	1.63^{D}
150 cm	1.51	1.37	1.71	1.47	1.52^{D}
PMS	1.31	1.24	1.50	1.30	1.34^{E}
Average	1.72^{B}	1.61^{C}	1.96^{A}	1.75^{B}	**1.76^{A}**
Significant	PV:0.0001, PHH: 0.0481, PV*HH: 0.9983.				
2021 year					
30 cm	2.02	1.92	2.41	2.83	2.16^{A}
60 cm	1.85	1.76	2.27	2.03	1.98^{B}
90 cm	1.71	1.60	2.02	2.72	1.76^{C}
120 cm	1.58	1.53	1.82	1.55	1.62^{D}
150 cm	1.39	1.29	1.66	1.48	1.46^{E}
PMS	1.19	1.19	1.32	1.32	1.26^{F}
Average	1.62^{C}	1.55^{C}	1.92^{A}	1.73^{B}	**1.71^{B}**
Significant	PV:0.0001, PHH: 0.0481, PV*HH: 0.2036.				
Two-year average (2020-2021)					
30 cm	2.14	1.98	2.44	2.29	2.21^{A}
60 cm	1.92	1.81	2.23	2.04	2.00^{B}
90 cm	1.74	1.61	2.02	1.74	1.77^{C}
120 cm	1.55	1.53	1.84	1.58	1.62^{D}
150 cm	1.45	1.33	1.69	1.48	1.49^{E}
PMS	1.25	1.22	1.41	1.31	1.30^{F}
Average	1.67^{C}	1.58^{D}	1.94^{A}	1.74^{B}	
Significant	PY: 0.0223, PV:0.0001, PY*V: 0.5999, PHH: 0.0001, PY*HH: 0.8440, PV*HH: 0.6417, PY*V*HH: 0.9842				

*: P<0.05, **: P<0.01, ns: not statistically significant, Y: Years, V: Varieties, HH: Harvesting Height, PMS: Physiological Maturity Stage