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Full Length Article

Effect of Harvesting Time on Yield, Composition and Forage Quality of Some Forage Sorghum Cultivars

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ABSTRACT

Forage sorghum (*Sorghum bicolor* (L.) Moench) is one of the most important fresh fodder and silage sources in the world, and its quality and yield are directly related in the harvesting time. In this study, four forage sorghum cultivars (*Sorghum bicolor* (L.) Moench) were compared to determine effects of delayed harvesting time on the changes in yield and forage quality. Field experiments were conducted during the 2010 and 2011 growing seasons. Four forage sorghum cultivars (Early Sumac, Leotti, Nes, Rox) were harvested at four different growing stages (panicle emergence stage (PE), milky stage (MS), dough stage (DS) and physiologic maturity stage (PM)). Dry matter, fresh forage yield, plant height, dry matter content, panicle proportion, protein yield, lignin content and relative feed value (RFV) tended to increase with advanced plant maturity, while leaf proportion, protein content, neutral detergent fiber content (NDF), acid detergent fiber content (ADF), cellulose content and hemicellulose content tended to decrease. Dry matter contents of all sorghum cultivars harvested during the PE and MS stages were below 247 g kg^{-1}. Among whole plant organs, stem proportion was higher than those of leaf and panicle proportions. Mean dry matter yields of cultivars were ranged from 18.75 t ha^{-1} to 20.15 t ha^{-1}. These findings have shown that suitable harvesting time of forage sorghum is PM stage for high yield and fodder quality, but it may be harvested at DS stage due to increasing lignin content. None of these sorghum cultivars should be harvested before DS stage for ensilage due to low dry matter content. Nes can be preferred because of the high forage and protein yield.

Key Words: Dry matter content; Fodder quality; Maturity stage; Relative feed value

INTRODUCTION

Sorghum is a multipurpose plant that ensures grain and stems as raw material for sugar, alcohol, syrup, fuel and paper production, and for animal feeding as grain, pasture, hay and silage (Dogget, 1988; Cothren *et al*., 2000; Habyarimana *et al*., 2004). It is extensively grown as a forage crops and becoming increasingly importance in many regions of the world (Miron *et al*., 2006; Yosef *et al*., 2009; Glamoclija *et al*., 2011). Many factors such as versatile planting time, resistance to drought, a comparatively short growing season, suitability for second cropping and rotation systems have provided to the wide acceptance of sorghum as grain and forage crop (Cothren *et al*., 2000).

Fodder quality is of great importance as well as higher forage yield. The fodder quality of sorghum depends on many factors such as fertilization, irrigation, genotype, plant density and harvesting time (Pholsen *et al*., 1998; Saeed & El-Nadi, 1998; Cakmakci *et al*., 1999; Pholsen *et al*., 2001; Ayub *et al*., 2002; Zulfiqar & Asim, 2002; Ayub *et al*., 2003; Carmi *et al*., 2006; Miron *et al*., 2006; Glamoclija *et al*., 2011). Maturity stage at harvest is the most important factor determining forage quality, and forage quality decreases with advancing maturity. Also, the maturity of forage crops influence forage digestibility and consumption by animals (Ball *et al*., 2001).

Generally, fiber concentration of the forage crops increases while quality and digestibility decreases as aging prolongs (Ball *et al*., 2001). Acid detergent fiber (ADF), acid detergent lignin (ADL) and neutral detergent fiber (NDF) are commonly used as standard forage testing techniques for fiber analysis. ADF can be used to calculate digestibility, while intake potential is predicted through NDF (Ball *et al*., 2001). Relative feed value (RFV) calculated by using ADF (representing dry matter digestibility) and NDF (showing intake potential) is an index indicating forage quality and RFV decreases with advancing maturity (Rohweder *et al*., 1978; Hackmann *et al*., 2008). Also, sorghum is mainly a silage plant as a result, the dry matter content of sorghum at harvest is one of important factors and its critical level is 247 g kg^{-1} for well ensilage conditions (Castle & Watson, 1973; Miron *et al*., 2006; Carmi *et al*., 2006). All these explanations suggest that determination of the appropriate harvesting time is a crucial factor for a successful forage sorghum production.

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The objective of this research was to compare forage yield, plant morphology, and forage quality of four forage sorghum cultivars harvested at four different maturity stages.

MATERIALS AND METHODS

Site description: Experiments were conducted during the spring-summer months of 2010 and 2011 years in the Research Station of Mustafa Kemal University, Hatay, Turkey, located at 36° 15' N and 36° 30' E. The region has typical Mediterranean climate. Fig. 1 shows meteorological data of the experimental area during the growing season, with monthly average temperature and monthly total rainfall. Soil of experimental area was clay with pH of 7.12, having 6.45% $CaCO_3$, 74.1 kg ha^{-1} phosphorus, and 1.93% organic matter at the depth of 30 cm.

Plant materials and experimental design: Four cultivars of Silage sorghum (Early Sumac, Leotti, Nes, Rox) were grown during two years. Seeds of silage sorghum were obtained from West Mediterranean Agricultural Research Institute, Antalya, Turkey. The study was conducted to investigate the productivity and fodder quality of sorghum cultivars at different harvesting times. To achieve this aim, plants were harvested at four different growing stages; panicle emergence stage (PE), milky stage (MS), dough stage (DS) and physiologic maturity stage (PM). The experimental design was split-plot randomized complete block with harvesting time as the main plot and sorghum cultivars as the subplot with three replicates. A subplot size was 2.8 × 5 m, having 4 rows (with inter-row spacing of 70 cm). Intra-row spacing of 7.5 cm was used in sowing based on planting density 190286 plant ha^{-1}.

Cultivation practice: Sowing was performed by hand on 6 May in the both years. Before seeding, 80 kg ha^{-1} each of N and P_2O_5 was applied. Additionally, nitrogen was top dressed at the rate of 70 kg ha^{-1} when the plants attained 40–50 cm height. If necessary, weeds were controlled by hand and harrowing. Depending on climatic conditions, plots were irrigated every 10 – 14 days from June to each harvesting time when consumed nearly half of the available soil water.

Measurement and sampling procedures: At each harvesting time, harvest and sampling procedures were made at the center two rows of each plot. Plant heights were measured of ten plants randomly selected before harvest. Plants were cut to a stubble height of approximately 5 cm. After measuring fresh forage weights, five plants selected randomly from each plot at harvest. Five of these sample plants were divided into leaves, stem and panicle; all plant fractions were dried in a forced-draft oven to constant weight at 80°C for their percentage. The other five sample were chopped in to 2–3 cm by a shredder (Bosch AXT 25D shredder, Germany) and a 500 g sub-sample taken from chopped samples was dried in a forced-draft oven to constant weight at 65°C for dry matter (DM) content. Dried samples were ground in a mill to pass a 1 mm screen for chemical analysis. Another 250 g sub-sample taken from chopped samples was dried 105°C and used for calculation of dry matter content.

Forage quality analysis and calculations: Crude protein, NDF, ADF and ADL were determined for all samples. Nitrogen concentrations were determined by the Kjeldahl procedure and crude protein concentration was calculated by the formula of N concentration × 6.25. NDF, ADF and ADL were analyzed according to the sequential method of Van Soest *et al*. (1991) by adding α-amylase without sodium sulfite and using the ANKOM filter bag system with A220 fiber analyzer (ANKOM Technology, Fairport, NY), and expressed as exclusive residual ash. Cellulose (ADF - ADL) and hemicellulose (NDF - ADF) and lignin (ADL) were calculated from the organic matter of the detergent fiber fractions.

Relative feed value (RFV) calculated by using ADF (related dry matter digestibility) and NDF (related intake potential) is an index indicating forage quality. Relative feed value (RFV) is identified and formulated by Rohweder *et al*. (1978) and Van Dyke and Anderson (2002) as below:

$$DDM = 88.9 - (0.77 \times ADF\%)$$
$$DMI = (120/NDF\%)$$
$$RFV = DDM\% \times DMI\% \times 0.775.$$

Where, DDM was digestible dry matter as % of dry matter, and DMI was dry matter intake as a % of body weight.

Statistical analysis: Data were analyzed by using the MSTAT-C computer software program. A combined analysis of variance over 2 years was performed. The ANOVA was performed by using split plot design with the 4 main plot treatments and 4 sub-plot treatments replicated three times. Treatment mean differences were separated and tested by Fisher's protected least significant difference (LSD) at P = 0.05 significance level.

RESULTS

Fresh forage yield: The effects of harvesting times were significant in terms of fresh forage yields, which were 60.87, 75.40, 84.69 and 91.90 t ha^{-1} for PE, MS, DS and PM, respectively (Table I). Fresh forage yields ranged from 76.16 to 81.27 t ha^{-1} among the silage sorghum cultivars (Table I). Fresh forage yield of Rox was significantly higher than other cultivars. Fresh forage yields obtained from PE and MS stages of Rox were higher than that of Early Sumac and Nes. Delayed harvesting time from MS to PM stage increased fresh forage yields of Early Sumac Nes and Rox by 34%, 22% and 12%, respectively.

Dry matter yield: The effect of harvesting time was significant for dry matter yield. Dry matter yields obtained at PE, MS, DS and PM stages were 10.26, 16.23, 21.05 and 30.01 t ha^{-1}, respectively (Table I). During plant maturation from PE to PM stage, dry matter yield tended to increase.

Table I: Effect of harvesting time on fresh forage yield and dry matter yield of four forage sorghum cultivars

Cultivars	Fresh forage yield (t ha^{-1})					Dry matter yield (t ha^{-1})				
	Harvesting time					Harvesting time				
	PE	MS	DS	PM	Mean	PE	MS	DS	PM	Mean
E. Sumac	$59.30\pm2.77^{h+}$	70.29 ± 1.81^{fg}	88.38 ± 5.78^{bc}	94.78 ± 5.06^{a}	$78.19\pm3.56^{B\dagger}$	$9.65\pm0.38^{h+}$	15.00 ± 0.55^{f}	20.91 ± 0.51^{bc}	30.08 ± 0.75^{a}	$18.91\pm1.57^{B\dagger}$
Leotti	59.30 ± 1.22^{h}	74.19 ± 2.97^{ef}	82.65 ± 4.49^{d}	88.51 ± 3.98^{ab}	76.16 ± 2.81^{B}	9.63 ± 0.31^{h}	15.64 ± 0.44^{ef}	19.74 ± 0.56^{c}	29.99 ± 0.33^{a}	18.75 ± 1.53^{B}
Nes	55.96 ± 2.55^{h}	75.94 ± 4.36^{e}	84.83 ± 3.83^{cd}	92.60 ± 1.37^{ab}	77.29 ± 3.23^{B}	10.17 ± 0.35^{h}	16.67 ± 0.84^{de}	21.75 ± 0.52^{b}	30.32 ± 1.24^{a}	19.73 ± 1.56^{A}
Rox	68.91 ± 2.91^{g}	81.18 ± 1.08^{d}	83.05 ± 1.16^{d}	91.71 ± 1.71^{ab}	81.21 ± 1.90^{A}	11.58 ± 0.50^{g}	17.60 ± 0.82^{d}	21.78 ± 0.49^{b}	29.63 ± 0.88^{a}	20.15 ± 1.38^{A}
Mean	$60.87\pm1.58^{D++}$	75.40 ± 1.63^{C}	84.69 ± 2.14^{B}	91.90 ± 1.76^{A}		$10.26\pm0.25^{D++}$	16.23 ± 0.40^{C}	21.05 ± 0.31^{B}	30.01 ± 0.43^{A}	
$LSD_{0.05}$		HT:4.295** C: 2.467** HT×C: 4.933**					HT: 1.122** C: 0.669** HT×C: 1.337*			

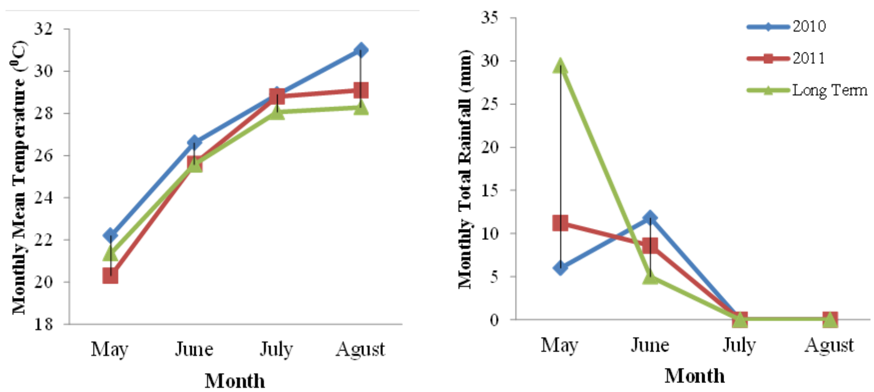
*significant at $p < 0.05$, **significant at 0.01

+) Values with the different small letter are significantly different according to the LSD test at P<0.05

++) Means of harvesting time with the different capital letter (within a line) are significantly different at P<0.05

†) Means of harvesting time with the different capital letter (within a column) are significantly different at P<0.05

Fig. 1: Monthly mean temperature and total rainfall during the study and long term data



Cultivar and cultivar × harvesting time interaction were also significant on the dry matter yields. Mean dry matter yields of cultivars ranged from 18.75 to 20.15 t ha^{-1}. There was approximately three-fold increase in dry matter yield of each cultivar, when harvesting time was delayed from the PE to PM stage.

Plant height: Plant height values are presented in Table II. The effect of harvesting time was significant in terms of plant height. At the all harvesting time, plant heights were over 230 cm. The highest plant height was obtained from the latest harvesting time with 269.3 cm, while the lowest was obtained from the first harvesting time with 230.2 cm measured during the maturation from PE to PM stage. Significant differences were detected among four sorghum cultivars on plant height. Plant heights of the four sorghum cultivars ranged between 245.7 cm and 266.1 cm. The highest plant height was obtained from Leotti (266.1 cm), while the lowest was obtained from Nes (245.7 cm). Plant heights of Early Sumac and Rox were statistically similar.

Dry matter content: Dry matter contents of the sorghum plants, harvested at four stages of growth, were illustrated in Table II. The effect of harvesting time, cultivar and cultivar x harvesting time interaction were significant for dry matter content. Dry matter contents were 169.3, 216.2, 250.5 and 329.1 g kg^{-1} for PE, MS, DS and PM stages, respectively. During plant maturation from the PE to PM stage, dry matter yield continuously tended to increase. The highest value was obtained from Nes, while the lowest was obtained from Early Sumac. Dry matter content was higher in Rox as compared with Early Sumac and Leotti, but similar with that of Nes.

Composition of plant organs: The distributions of dry matter among whole plant organs (leaves, stems & panicles) were shown in Table III and IV. Leaf contents of dry matter were 269.5, 179.7, 143.1 and 100.4 g kg^{-1} at the PE, MS, DS and PE stages, respectively. Proportion of leaves was continuously decreased depending on advancement in maturity. The effects of cultivars were insignificant in terms of leaf proportion, but the effects of cultivar x harvesting time interaction was significant. At DS and PM stages, proportions of leaves were similar for all cultivars, but it was different at PE and MS stages. At PE stage, Early Sumac had higher proportion of leaves as compared other cultivars. However, leaf proportions of Rox and Early Sumac were similar at MS (195.7 & 186.8 g kg^{-1}, respectively), while in Leotti and Nes, it was reduced to 160.8 and 175.6 g kg^{-1}, respectively. Stem content of total dry matter was higher than proportion of leaves and panicle. Stem contents of dry matter ranged from 552.9 to 663.1 g kg^{-1} for all treatments. The results of statistical analysis showed that the effect of cultivar on proportion of stems was also significant. Stem contents of dry matter ranged from 586.8 to 648 g kg^{-1} among the silage sorghum cultivars. Proportion of stem of Leotti was significantly higher than those of others and stem proportion of the each cultivar was significantly different from each

Table II: Effect of harvesting time on plant height and dry matter content of four forage sorghum cultivars

Cultivars	Plant height (cm)					Dry matter content (g kg^{-1})				
	Harvesting time					Harvesting time				
	PE	MS	DS	PM	Mean	PE	MS	DS	PM	Mean
E. Sumac	230.8±5.58^{gh+}	250.3±3.02^{e}	257.7±4.80^{d}	264.5±4.25^{c}	250.8±3.43^{B†}	163.4±3.49^{g+}	214.8±11.5^{e}	241.2±12.7^{d}	322.8±18.8^{b}	235.5±13.4^{C†}
Leotti	226.8±7.46^{h}	272.8±4.37^{b}	278.0±4.58^{b}	286.8±7.41^{a}	266.1±5.64^{A}	162.4±3.54^{g}	211.7±5.52^{e}	240.9±7.14^{d}	342.8±15.4^{a}	239.4±14.2^{BC}
Nes	227.7±3.07^{h}	244.3±2.70^{f}	250.2±2.47^{e}	260.5±2.40^{cd}	245.7±2.77^{C}	182.6±4.07^{f}	220.4±4.13^{e}	257.7±7.64^{c}	327.1±10.9^{b}	247.0±11.5^{A}
Rox	235.3±4.50^{g}	249.5±2.05^{ef}	259.5±1.50^{cd}	265.3±1.57^{c}	252.4±2.69^{B}	168.9±6.47^{g}	217.8±12.6^{e}	262.4±5.84^{c}	323.6±10.8^{b}	243.2±12.6^{AB}
Mean	230.2±2.78^{D++}	254.3±2.74^{C}	261.3±2.76^{B}	269.3±308^{A}		169.3±2.81^{D++}	216.2±4.64^{C}	250.5±4.81^{B}	329.1±7.37^{A}	
$LSD_{0.05}$		HT: 2.389**	C: 2.884**	HT×C: 5.769**			HT: 6.259**	C: 6.495**	HT×C: 12.99**	

$^{**)}$ significant at 0.01
$^{+)}$ Values with the different small letter are significantly different according to the LSD test at P<0.05
$^{++)}$ Means of harvesting time with the different capital letter (within a line) are significantly different at P<0.05
$^{†)}$ Means of harvesting time with the different capital letter (within a column) are significantly different at P<0.05

Table III: Effect of harvesting time on leaves content and stem content of four forage sorghum cultivars

Cultivars	Leaves content (g kg^{-1})					Stem content (g kg^{-1})				
	Harvesting time					Harvesting time				
	PE	MS	DS	PM	Mean	PE	MS	DS	PM	Mean
E. Sumac	252.0±6.50^{b+}	186.8±9.44^{cd}	151.8±6.27^{fg}	96.5±4.48^{h}	171.8±12.0	630.3±8.03^{bc+}	621.4±10.3^{cd}	592.7±11.3^{efg}	663.1±5.99^{a}	626.9±6.88^{B†}
Leotti	274.4±8.57^{a}	160.8±11.9^{ef}	137.3±9.40^{g}	101.7±5.54^{h}	168.6±14.0	610.3±12.5^{c-f}	670.3±18.3^{a}	652.6±5.16^{ab}	662.6±7.84^{a}	648.9±9.83^{A}
Nes	280.0±5.19^{a}	175.6±6.19^{de}	140.4±8.00^{g}	104.4±5.50^{h}	175.1±13.8	601.5±7.53^{def}	607.5±11.2^{c-f}	583.8±10.9^{fg}	619.5±7.94^{cd}	603.1±5.33^{C}
Rox	271.5±5.10^{a}	195.7±8.49^{c}	143.1±8.17^{fg}	99.2±5.00^{h}	177.3±13.5	606.2±4.35^{c-f}	552.9±13.1^{h}	574.2±23.9^{gh}	613.9±13.5^{cde}	586.8±9.19^{D}
Mean	269.5±3.90^{A++}	179.7±5.33^{B}	143.1±4.17^{C}	100.4±2.64^{D}		612.1±4.86^{B++}	613.0±10.91^{B}	600.8±11.34^{B}	639.7±6.63^{A}	
$LSD_{0.05}$		HT: 7.583**	C: ns	HT×C: 19.04*			HT: 14.43**	C: 13.04**	HT×C: 26.08**	

*significant at $p < 0.05$, **significant at 0.01, ns: not significant
$^{+)}$ Values with the different small letter are significantly different according to the LSD test at P<0.05
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$^{†)}$ Means of harvesting time with the different capital letter (within a column) are significantly different at P<0.05

Table IV: Effect of harvesting time on panicle content and protein content of four forage sorghum cultivars

Cultivars	Panicle content (g kg^{-1})					Protein content (g kg^{-1})				
	Harvesting time					Harvesting time				
	PE	MS	DS	PM	Mean	PE	MS	DS	PM	Mean
E. Sumac	117.8±4.66^{h+}	191.7±11.6^{f}	255.5±9.30^{bc}	240.5±6.52^{c}	201.4±11.8^{C†}	81.3±1.07^{cd+}	77.0±4.22^{ef}	83.9±4.33^{bc}	67.7±4.04^{hi}	77.5±2.22^{A†}
Leotti	115.3±9.30^{h}	169.1±8.43^{g}	210.1±7.4^{ef}	235.7±5.46^{cd}	182.6±10.8^{D}	78.8±1.06^{de}	70.6±1.19^{gh}	84.3±6.99^{bc}	64.9±3.96^{i}	74.7±2.55^{B}
Nes	118.5±7.09^{h}	218.6±11.1^{de}	272.5±12.6^{ab}	269.5±10.2^{ab}	219.8±14.0^{B}	92.5±1.41^{a}	87.0±1.37^{b}	73.7±2.56^{fg}	57.1±1.52^{j}	77.6±2.93^{A}
Rox	122.3±5.50^{h}	251.4±19.2^{bc}	282.7±17.4^{a}	287.0±11.0^{a}	235.8±15.4^{A}	81.2±1.22^{cd}	66.1±1.74^{i}	65.7±1.42^{i}	64.1±2.08^{i}	69.3±1.63^{C}
Mean	118.5±3.47^{C++}	207.7±9.11^{B}	255.2±9.25^{A}	258.2±6.25^{A}		83.4±1.24^{A++}	75.2±2.01^{B}	76.9±2.69^{B}	63.5±1.75^{C}	
$LSD_{0.05}$		HT:15.21**	C: 10.68**	HT×C: 21.35**			HT:2.038**	C:1.809**	HT×C:3.617**	

**significant at 0.01
$^{+)}$ Values with the different small letter are significantly different according to the LSD test at P<0.05
$^{++)}$ Means of harvesting time with the different capital letter (within a line) are significantly different at P<0.05
$^{†)}$ Means of harvesting time with the different capital letter (within a column) are significantly different at P<0.05

other. At DS and PM stages, panicle contents of whole plant were significantly higher than PE and MS stages. The panicle proportions of cultivars varied during growing periods. Panicle proportions of Leotti and Rox continued to increase after DS stage, while that of Early Sumac and Nes decreased. Mean panicle proportions of the four sorghum cultivars ranged between 182.6 and 235.8 g kg^{-1}. Proportions of panicles obtained from the Early Sumac, Leotti, Nes and Rox were 201.4, 182.6, 219.8 and 235.8 g kg^{-1}, respectively.

Crude protein content and yield: Crude protein contents and yields of four forage sorghum cultivars observed during the four harvesting times were shown in Table IV and V. The effect of harvesting time, cultivar and cultivar x harvesting time interaction were significant for crude protein content and yield. Protein contents were 83.4, 75.2, 76.9 and 63.5 g kg^{-1} for PE, MS, DS and PM stages, respectively. During plant maturation from PE to PM stage, crude protein content continuously tended to decrease, but the protein contents were similar at MS and DS stages.

Crude protein yields obtained in PE, MS, DS and PM stages were 855.2, 1213.9, 1619.5 and 1897.1 kg ha^{-1}, respectively, and mean protein yield of each harvesting times significantly differed. Mean crude protein contents of the four sorghum cultivars ranged between 69.3 and 77.6 g kg^{-1}. Crude protein contents obtained from the Early Sumac, Leotti, Nes and Rox were 77.5, 74.7, 77.6 and 69.3 g kg^{-1}, respectively. Crude protein content of Early Sumac and Nes was significantly higher than that of others. The results of statistical analysis showed that the effect of cultivar on protein yield was also significant. Crude protein yields ranged from 1355.2 to 1429.4 kg ha^{-1} among the investigated sorghum cultivars. Crude protein yield of Rox was significantly lower than that of Early Sumac and Nes.

Table V: Effect of harvesting time on NDF content and protein yield of four forage sorghum cultivars

Cultivars	Protein yield (kg ha^{-1})					NDF content (g kg^{-1})				
	Harvesting time					Harvesting time				
	PE	**MS**	**DS**	**PM**	**Mean**	**PE**	**MS**	**DS**	**PM**	**Mean**
E. Sumac	783.0±24.3^{h+}	1141.4±28.1^{f}	1762.2±125.2^{c}	2030.5±114.3^{a}	1429.4±109.7^{A†}	666.7±4.29^{b+}	607.1±7.09^{d}	585.1±10.0^{e}	484.5±11.8^{h}	585.8±13.9^{A†}
Leotti	757.3±17.9^{h}	1104.6±36.9^{f}	1681.9±177.9^{cd}	1943.3±116.1^{ab}	1371.8±109.6^{AB}	671.8±8.24^{ab}	583.9±5.35^{e}	563.5±10.7^{f}	470.3±9.24^{hi}	572.4±15.4^{C}
Nes	939.3±25.1^{g}	1451.5±82.8^{e}	1605.8±76.7^{d}	1720.9±46.3^{cd}	1429.4±68.5^{A}	656.6±8.64^{b}	608.6±10.3^{d}	551.7±9.63^{f}	511.2±4.87^{g}	582.0±1.2^{AB}
Rox	941.3±47.5^{g}	1158.3±42.4^{f}	1427.4±12.5^{e}	1893.9±54.0^{b}	1355.2±75.6^{B}	686.3±12.2^{a}	634.5±12.2^{c}	518.3±10.9^{g}	462.3±10.1^{i}	575.3±18.9^{BC}
Mean	855.2±23.3^{D++}	1213.9±38.4^{C}	1619.5±63.1^{B}	1897.1±50.1^{A}		670.4±4.63^{A++}	608.5±5.90^{B}	554.6±4.47^{C}	482.1±6.32^{D}	
$LSD_{0.05}$	HT:87.61** C:59.61** HT×C:118.6**					HT:13.85** C:9.257* HT×C:18.51**				

*significant at $p < 0.05$, **significant at 0.01

$^{+)}$ Values with the different small letter are significantly different according to the LSD test at P<0.05

$^{++)}$ Means of harvesting time with the different capital letter (within a line) are significantly different at P<0.05

$^{\dagger)}$ Means of harvesting time with the different capital letter (within a column) are significantly different at P<0.05

Table VI: Effect of harvesting time on ADF content and lignin content of four forage sorghum cultivars

Cultivars	ADF content (g kg^{-1})					Lignin content (g kg^{-1})				
	Harvesting time					Harvesting time				
	PE	**MS**	**DS**	**PM**	**Mean**	**PE**	**MS**	**DS**	**PM**	**Mean**
E. Sumac	351.2±10.3^{cde+}	350.0±4.96^{de}	343.9±4.62^{de}	281.4±15.1^{h}	331.6±7.58	39.2±0.80^{i+}	44.2±1.55^{g}	46.2±0.76^{def}	50.7±1.72^{b}	45.1±0.97^{C†}
Leotti	362.9±14.9^{bc}	344.3±5.39^{de}	327.1±5.00^{f}	285.6±9.16^{h}	330.0±7.51	39.5±0.93^{i}	47.2±0.90^{cde}	48.0±0.38^{c}	53.0±2.35^{a}	47.0±0.93^{AB}
Nes	339.6±5.11^{e}	353.4±3.48^{cd}	342.4±4.26^{de}	304.6±8.03^{g}	335.0±4.64	44.9±1.43^{fg}	46.9±0.89^{cde}	47.6±1.77^{cd}	50.5±1.49^{b}	47.5±0.78^{A}
Rox	365.9±10.5^{ab}	377.9±6.08^{a}	324.4±6.97^{f}	273.8±7.40^{h}	335.5±9.21	42.0±0.66^{h}	45.5±0.45^{efg}	46.2±1.92^{def}	52.2±2.09^{ab}	46.5±0.91^{B}
Mean	354.9±5.78^{A++}	356.4±3.64^{A}	334.4±3.21^{B}	286.4±5.67^{C}		41.4±0.64^{D++}	46.0±0.69^{C}	47.0±0.8^{B}	51.6±0.98^{A}	
$LSD_{0.05}$	HT:7.893** C:ns HT×C:12.27**					HT:0.801** C: 0.910** HT×C:1.820**				

**significant at 0.01, ns: not significant

$^{+)}$ Values with the different small letter are significantly different according to the LSD test at P<0.05

$^{++)}$ Means of harvesting time with the different capital letter (within a line) are significantly different at P<0.05

$^{\dagger)}$ Means of harvesting time with the different capital letter (within a column) are significantly different at P<0.05

Quality properties of forage: The effect of harvesting time was significant for NDF and ADF content (Table V & VI). NDF contents of sorghum cultivars were 670.4, 608.5, 554.6 and 482.1 g kg^{-1} at PE, MS, DS and PM stages, respectively, while ADF contents were 354.9, 356.4, 334.4 and 286.4 g kg^{-1} at PE, MS, DS and PM stages, respectively. NDF content of the each harvesting times were significantly differed from each other, but ADF contents were similar in the PE and MS stage. Generally, NDF and ADF contents tended to decrease with delayed harvesting time. Lignin contents continuously increased depending on advancement in maturity in the present study. The highest lignin content was 51.6 g kg^{-1} for the latest harvesting time, while the lowest lignin content was 41.4 g kg^{-1} for the first harvesting time, and lignin content of the each harvesting times were significantly differed from each other (Table VI). Cellulose contents were similar at PE and MS stages (312.0 g kg^{-1} & 308.5 g kg^{-1}, respectively), while cellulose contents at the DS and PM stages were lower than at the PE and MS stages (Table VII). In general, cellulose contents were higher than hemicellulose contents during advancing growth stage (except PE stage). The effects of cultivars were significant for NDF, lignin and hemicellulose contents, while insignificant for ADF and cellulose contents (Table V, VI & VII). NDF contents ranged from 572.4 to 585.8 g kg^{-1} among the silage sorghum cultivars. NDF content of Early Sumac was significantly higher than that of Rox and Leotti while similar with that of Nes. The highest lignin content was obtained from Nes, while the lowest value was obtained from Early Sumac. Lignin contents were higher in Nes and Leotti as compared with Early Sumac and Rox. Mean hemicellulose contents of the four sorghum cultivars ranged between 239.9 and 254.2 g kg^{-1}. Hemicellulose content of Early Sumac, Leotti, Nes and Rox were 254.2, 242.4, 247.0 and 254.2 g kg^{-1}, respectively. RFV were significantly increased depending on advancement in maturity (Table VIII). RFV were 85.2, 93.7, 105.8 and 129.2 at PE, MS, DS and PM stages respectively. The highest RFV was estimated from the latest harvesting time, while the lowest RFV was estimated the first harvesting time. Calculated values at the DS and PM stages were higher than reference value of RFV, while lower at PE and MS stages. RFV ranged from 101.6 to 105.1 among the silage sorghum cultivars (Table VIII). RFV of Leotti and Rox were significantly higher than that of others.

DISCUSSION

Results indicated that investigated yield and quality properties of forage sorghum were influenced by harvesting time. During plant maturation from PE to PM stage, both fresh forage yield and dry matter yield tended to increase. There was approximately three-fold increase in dry matter yield of each cultivar, when harvesting time was delayed from the PE to PM stage. On the contrary, Miron *et al.* (2006) found that dry matter yield of forage sorghum varieties decreased with delayed harvesting time from the early head to soft dough stage. Miron *et al*. (2006) explained this phenomenon with the depletion of water-soluble carbohydrate for plant sustenance under conditions of

Table VII: Effect of harvesting time on cellulose content and hemicellulose content of four forage sorghum cultivars

Cultivars	Cellulose content (g kg^{-1})					Hemicellulose content (g kg^{-1})				
	Harvesting time					Harvesting time				
	PE	MS	DS	PM	Mean	PE	MS	DS	PM	Mean
E. Sumac	$311.4\pm10.9^{bc+}$	305.7 ± 4.32^{cd}	294.0 ± 4.22^{d}	237.5 ± 14.4^{gh}	287.2 ± 7.53	$315.5\pm7.06^{a+}$	257.1 ± 6.34^{b}	241.3 ± 7.33^{bc}	203.1 ± 16.3^{de}	$254.2\pm9.78^{A\dagger}$
Leotti	320.2 ± 15.7^{ab}	296.4 ± 4.80^{d}	276.5 ± 5.14^{e}	241.5 ± 7.62^{g}	283.7 ± 7.54	309.0 ± 4.75^{a}	239.6 ± 4.98^{bc}	236.5 ± 8.10^{c}	184.7 ± 3.42^{f}	242.4 ± 9.44^{B}
Nes	294.4 ± 4.31^{d}	304.4 ± 3.46^{cd}	294.8 ± 4.29^{d}	259.0 ± 8.04^{f}	288.1 ± 4.42	317.0 ± 9.49^{a}	255.2 ± 7.29^{b}	209.3 ± 9.52^{d}	206.7 ± 9.78^{de}	247.0 ± 10.2^{AB}
Rox	322.0 ± 10.2^{ab}	327.5 ± 6.18^{a}	279.9 ± 5.81^{e}	229.2 ± 6.12^{h}	289.6 ± 8.84	320.4 ± 8.77^{a}	256.7 ± 8.63^{b}	193.8 ± 6.14^{def}	188.5 ± 4.25^{ef}	239.9 ± 11.5^{B}
Mean	$312.0\pm5.95^{A++}$	308.5 ± 3.36^{A}	286.3 ± 2.97^{B}	241.8 ± 5.26^{C}		$315.5\pm3.96^{A++}$	252.1 ± 3.78^{B}	220.2 ± 5.60^{C}	195.7 ± 5.27^{D}	
$LSD_{0.05}$	HT:8.058** C:ns HT×C:11.94**					HT:11.16** C:8.962* HT×C:17.92**				

*significant at $p < 0.05$, **significant at 0.01, ns: not significant

+) Values with the different small letter are significantly different according to the LSD test at P<0.05

++) Means of harvesting time with the different capital letter (within a line) are significantly different at P<0.05

†) Means of harvesting time with the different capital letter (within a column) are significantly different at P<0.05

Table VIII: Effect of harvesting time on RFV of four forage sorghum cultivars

Cultivars	Relative feed value				
	Harvesting time				
	PE	MS	DS	PM	Mean
E. Sumac	$85.9\pm1.68^{gh+}$	94.5 ± 1.53^{ef}	98.8 ± 0.93^{e}	129.0 ± 3.78^{b}	$102.1\pm3.48^{B\dagger}$
Leotti	84.3 ± 3.07^{gh}	99.0 ± 1.98^{e}	104.7 ± 1.07^{d}	132.3 ± 4.64^{ab}	105.1 ± 3.86^{A}
Nes	88.6 ± 1.44^{g}	93.9 ± 1.64^{f}	105.2 ± 2.19^{d}	118.9 ± 2.99^{c}	101.6 ± 2.61^{B}
Rox	82.0 ± 1.52^{h}	87.4 ± 2.19^{g}	114.6 ± 3.33^{c}	136.5 ± 4.17^{a}	105.1 ± 4.72^{A}
Mean	$85.2\pm1.13^{D++}$	93.7 ± 1.26^{C}	105.8 ± 1.57^{B}	129.2 ± 2.38^{A}	
$LSD_{0.05}$	HT:3.479** C:2.409** HT×C:4.819**				

**significant at 0.01

+) Values with the different small letter are significantly different according to the LSD test at P<0.05

++) Means of harvesting time with the different capital letter (within a line) are significantly different at P<0.05

†) Means of harvesting time with the different capital letter (within a column) are significantly different at P<0.05

restricted water supply. This result indicated that dry matter accumulation might be continued until the PM stage since water was not a limiting factor (Carmi *et al*., 2006) and forage sorghum harvest can be delayed until PM for high yield. Cultivar influence on dry matter yields closely conforms with previous researches using different sorghum cultivars and growing conditions (Yosef *et al*., 2009; Zhao *et al*., 2009; 2012; Xie *et al*., 2012). Dry matter yields of some studies were lower than that of our findings (Ayub *et al*., 2003; Munir *et al*., 2004; Miron *et al*., 2006, Nabi *et al*., 2006). Although the mean dry matter yields of Leotti and Early Sumac were lower than those of Rox and Nes, the dry matter yields of all cultivars were similar at PM stage. This status indicated that dry matter accumulation of each cultivar varied among plant growth stages.

An increase in plant height was recorded as maturity prolonged for forage sorghum cultivars (Ayub *et al*., 2002; Xie *et al*., 2012). Unlike the result of the present study, Carmi *et al*. (2006) reported that plant height of low type sorghum cultivars were not significantly different after heading. The contradictory results might have been due to variation in genetic traits of plants. Compared with the current study, lower plant heights were also obtained (Ayub *et al*., 1999; Mahmud *et al*., 2003; Carmi *et al*., 2005; Carmi *et al*., 2006; Yosef *et al*., 2009). These differences can be attributed to differences in climatic conditions, fertility status of the soil, cultivation practices, harvesting time, and genetic make-up of the cultivars.

Dry matter content of forage crops at harvest is one of the most important factors for successful ensilage (Miron *et al*., 2006; Carmi *et al*., 2006) and according to Castle and Watson (1973), minimal dry matter content is 247 g kg^{-1} for suitable ensilage conditions. The present results suggested that all sorghum cultivars harvested during PE and MS stages have risk for the success of ensilage. Therefore, none of these sorghum cultivars should be harvested before DS stage for ensilage. At DS stage, dry matter contents of Nes and Rox were slightly above the critical level, while that of Early Sumac and Leotti were slightly below. Similarly, Miron *at al*. (2006) reported that sorghum plants reached critical dry matter content at soft dough stage. Delaying of harvesting time through PM stage might be useful to ensure that the fermentation of silage. The sorghum plants harvested during PE and MS might be used for direct consumption in the warm summer season with fresh fodder gap (especially, fast-growing cultivars such as Rox; Table II).

Proportion of leaves was continuously decreased depending on advancement in maturity. Similar results were also reported by some researchers (Cakmakci *et al*., 1999; Carmi *et al*., 2005; Carmi *et al*., 2006). This situation might be associated with increasing proportion of panicle during advancement in maturity. Carmi *et al*. (2005) reported that high proportions of leaves needs for good quality sorghum silage and leaves are main contributor of protein in sorghum (Hanna *et al*., 1981; Pedersen *et al*., 1983; Cakmakci *et al*., 1999). Therefore, a high proportion of foliage is a desired feature in sorghum. Proportion of stems was higher in the PM stage as compared with other growth stages. This result might be associated with proportion of leaves was decreased and proportion of panicles was unchanged until from the DS to the PE stage. An increase in proportion of stems with delayed harvesting time was obtained (Carmi *et al*., 2005; Carmi *et al*., 2006). Stems containing higher amount of water soluble carbohydrates such as in sorghum may have higher digestibility rate than the leaves containing lower water soluble carbohydrates (Pedersen *et al*., 1983; Miron *et al*., 2005; Carmi *et al*., 2006). An increase in proportion of panicles with advancement in maturity was reported for forage sorghum (Cakmakci *et al*., 1999; Carmi *et al*., 2005; Carmi *et al*., 2006; Miron *et al*., 2006). Miron *et al.* (2005) suggested that the grain including panicles had the higher dry matter digestibility than other plant parts. Therefore, high panicle content of dry matter was a desirable feature due to that of high digestibility and high starch content.

Crude protein content decreased with the prolonged maturity. Similar results were reported for forage sorghum cultivars by Pedersen *et al*. (1983), Ayub *et al.* (2002), Cakmakci *et al*. (1999), Butler and Muir (2003), Miron *et al*. (2006), Nabi *et al*. (2006). Despite the lower crude protein content of forage sorghum at the advanced maturity stage, the amount of protein produced per unit land area increased with delayed harvesting due to the high dry matter yield per land area. Crude protein contents of the four sorghum cultivars ranged between 69.3 and 77.6 g kg^{-1}. Differences in protein content among sorghum genotypes were also suggested by Zulfiqar and Asim (2002), Carmi *et al*. (2005), Miron *et al*. (2005), Miron *et al*. (2006), Yosef *et al*. (2009). Unlike of crude protein content, crude protein yield continuously increased with delayed harvesting time. Despite the lower dry matter yield, the protein yield of Early Sumac was higher than that of Rox. This was resulted from the higher crude protein content of Early Sumac. Since protein is one of the most costly supplements for livestock, the total amount of protein produced per unit area is one of the most important quality characteristics as suggested by Assefa and Ledin (2001), Lithourgidis *et al*. (2006) and Atis *et al*. (2012).

The effect of harvesting time was significant for all quality properties. Lignin content and relative feed value (RFV) tended to increase with advanced plant maturity, while NDF, ADF, cellulose content and hemicellulose content tended to decrease. The similar results were reported for forage sorghum by Butler and Muir (2003), Carmi *et al*. (2005) and Miron *et al*. (2006). Previous studies observed that higher lignin content was resulted in lower *in vitro* dry matter digestibility (Carmi *et al*., 2006; Miron *et al*., 2006; Yosef *et al*., 2009). Therefore, quality of forage sorghum was adversely affected by plant age, despite higher yields and lower NDF values. Also, Filya (2004) stated that the nutritional value of NDF components decreased with plant age was related to increased lignin content. The synthesis and accumulation of lignin generally appear during the formation and thickening of the secondary cell walls, thus maturity that increases cell wall thickening probably influences lignin content of plant (Carmi *et al*., 2006). In general, cellulose contents were higher than hemicellulose contents during advancing growth stage (except PE stage). This finding is in accord with some previous studies (Filya, 2004; Carmi *et al*., 2005; Miron *et al*., 2006). Relative feed value (RFV) is an estimate of overall forage quality and it is calculated from intake and digestibility of dry matter (Rohweder *et al*., 1978) and reference value of it is 100 that RFV of full bloom alfalfa is value (Moore & Undersander, 2002; Hackmann *et al*., 2008). RFV showed a case in parallel with NDF and ADF contents, due to calculated by using them. In spite of the high values of RFV, lignin contents of sorghum cultivars should be considered at advanced maturity stages. Similar values were also reported in a previous study for RFV of warm- season grass (ranged from 88 to 166) by Hackmann *et al*. (2008).

In conclusion, suitable harvesting time of forage sorghum is PM stage for high yield and fodder quality. Considering the increased lignin content, forage sorghum may be harvested at DS stage, but it should not be harvested before DS stage for suitable ensilage conditions. Among four cultivars, Nes can be preferred because of the high forage and protein yield.

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