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Dynamics in nutritional characteristics of natural pasture hay as affected by harvesting stage, storage method and storage duration in the cooler tropical highlands

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This study was conducted to generate information on the dynamics in nutritional qualities of natural pasture hay as affected by harvesting stage, storage method and storage duration at Holetta representing cool tropical environment in the central highlands of Ethiopia. The study was designed with a factorial combinations of four harvesting stages/times (mid-October, late-October, mid-November, late-November), two storage methods (open-air, shelter shade) and five storage durations (zero, two, four, six and eight months). Crude protein (CP), *in vitro* OM digestibility (IVOMD), metabolizable energy (ME), neutral detergent fiber (NDF), acid detergent fiber (ADF) and lignin contents in the hay were significantly ($P < 0.05$) affected by harvesting stages, storage methods and storage durations. The mean CP content was reduced by 30.2%, while both IVOMD and ME contents were reduced by 17.8% each with the delay in harvesting time from mid-October (full heading stage of the pasture) to late-November (one and half months past the full heading stage). On the other hand, the mean of NDF, ADF and lignin contents were increased by 13.8, 21.6 and 36.0%, respectively with the delay in harvesting time within the specified periods. Harvesting during late-October resulted in higher yields of DM (6.83 t/ha), CP (0.48 t/ha) and digestible OM yield (3.77 t/ha) than the other harvests suggesting that late-October is the ideal harvesting time for producing large quantity of better quality hay from natural pasture in the area. The nutritional qualities of the hay also showed considerable dynamism during the eight months storage period both under shade and in open air storage methods. However, the regression analysis indicated that daily rates of changes in nutritional qualities (the rates of decline in CP content and IVOMD, and the rates of increase in the fiber fractions) during storage were higher when the hay was stored in open air than under shade. The result generally showed that in terms of contents of the important nutritional parameters (CP, IVOMD, ME, NDF, ADF and lignin), hay-based feeding could be detrimental to the nutrition of dairy cattle with the delay in harvesting beyond the late-October. Substantial reductions in nutritional qualities were also observed during storage with higher rates of nutrient losses when the hay was stored in open-air than under shade. Therefore, current findings should be supported by further animal performance studies in order to establish proper supplementation schemes considering harvesting stage, storage method and storage duration in hay-based feeding system of dairy cattle in the highlands of Ethiopia.

Key words: Native pasture hay, harvesting stage, hay storage, nutritional qualities, cool highlands.

INTRODUCTION

Among the various constraints hampering livestock production in general and dairy production in particular, feed shortage in terms of both quantity and quality constitutes the major problem in developing countries like Ethiopia. Smallholder dairy production in the tropical highlands mainly depends on natural pasture as the main source of basal diet. According to Abera (2006), the natural pasture available in the cooler highlands of Ethiopia contributes the lion share of the total feed supply for ruminants in the country. The urban and peri-urban dairy, feedlots and small scale fattening operations mainly rely on the hay produced in these areas as source of roughage feed (Berhanu et al., 2009). Hence, the improvement in roughage feed supply for dairy production mainly depends on adequate understanding and applications of management practices that would result in the production of large quantity of better quality hay from natural pasture.

Hay quality can be affected by a number of factors including soil fertility, the stage of maturity at harvest, the moisture available during the growing condition, the general field management such as fertilization, harvesting conditions, field drying and storage. Generally, losses in hay quality can occur during hay making, storage and feeding. The major causes of quality loss during hay making and storage include late cutting, natural respiratory processes, leaching, leaf shattering, microbial activity and bleaching by the sun (Carter, 1960; McGechan, 1989; Rotz et al., 1989; Smith and Brown, 1994; Barr et al., 1995). Storage system is also an important factor affecting hay quality. Hay stored under open air is subjected to wetting and drying cycles and will develop a fibrous, weathered layer; which also commonly develops moldy layer on the exterior and bottom surfaces of the hay (Lemus, 2009). The highest nutrient loss in hay due to weathering is caused by leaching and removal of nutrients by the passage of rain water over the surface of hay whereby the more soluble/digestible nutrients (carbohydrates, lipids, fatty acids, etc) are washed out of the forage. The loss of nutrients in this way causes the fiber component of the forage to represent a larger proportion of the dry matter with the consequent reduction in total digestible nutrients, voluntary intake and consequently results in low livestock performance in hay based feeding systems. In many tropical conditions including the tropical highlands, hay from natural pastures is made following the main rainy season. Seasonal exclusion of grazing lands from livestock for about 3 months during the rainy season is the common strategy of farmers for hay production. Since hay is only produced once a year following the main rainy season, its contribution in the annual livestock feed supply depends on proper harvesting, curing and conservation.

Majority of smallholder dairy farmers in the central highlands of Ethiopia conserve hay under open air (outside) and use it as roughage feed to their cows for about 8 months per year and such practice is common in most extensive livestock production systems in the tropics (Authors, unpublished data). Understanding the dynamics in nutritional characteristics of the hay in the process of production, conservation and utilization in the different agro-ecological conditions and production systems will help in designing appropriate conservation and management strategies, and in turn contribute for efficient utilization of this scarce resource. Moreover, such information is very crucial in order to provide evidence to extensionists, advisors and farmers about proper management and utilization of hay for feeding livestock, especially on the supplementation schemes in hay based feeding systems. Therefore, the objective of this study was to assess the effects of harvesting stage/time, storage method and storage duration on the dynamics in nutritional characteristics of natural pasture hay in the tropical highlands of Ethiopia.

MATERIALS AND METHODS

Description of the experimental site

The study was conducted at Holetta Agricultural Research Center located 34 km west of Addis Ababa in the central highlands of Ethiopia (2400 m above sea level, 38.5°E longitude and 9.8°N latitude). The area has a bimodal rainfall distribution. Over 70% of the rain occurs during the main rainy season (June to September) and about 30% of the rain occurs during the short rainy season (March to May). Forty-three years (1969 to 2012) meteorological data of the center indicates that the area receives an average total annual rainfall of 1038 mm. The long-term average annual minimum and maximum temperatures of the area were 6.2 and 22.4°C, respectively with a mean of 14.3°C. During the experimental period, the total annual rainfall was 976 mm which was lower than the long-term figure, but the average temperature (14.1°C) was very much closer to long-term average figure. Figure 1a and b indicate the long-term and experimental period temperature trends in the area. The major soil type of the area is a red-brown clay loam nitosol having a pH of 5.1, total N content of 0.2%, P content of 12.4 ppm, organic matter (OM) content of 2.2% and cation exchange capacity (CEC) of 17.0 meq/100 g soil (Fekede et al., 2008). However, most grazing lands are characterized by poorly drained seasonally waterlogged vertisols.

The pasture in the area is dominantly composed of *Andropogon spp.*, *Festuca* spp., *Hyparrhenia spp. and Pennisetum spp*. among grasses, and different native annual *Trifolium species* among legumes. Hay is produced after a 3 month rest period, beginning from the peak rainy season around mid July until mid October when harvesting of hay started under normal conditions. The whole process of harvesting, curing, collection and storage of hay can extend from mid October to late November or beyond when

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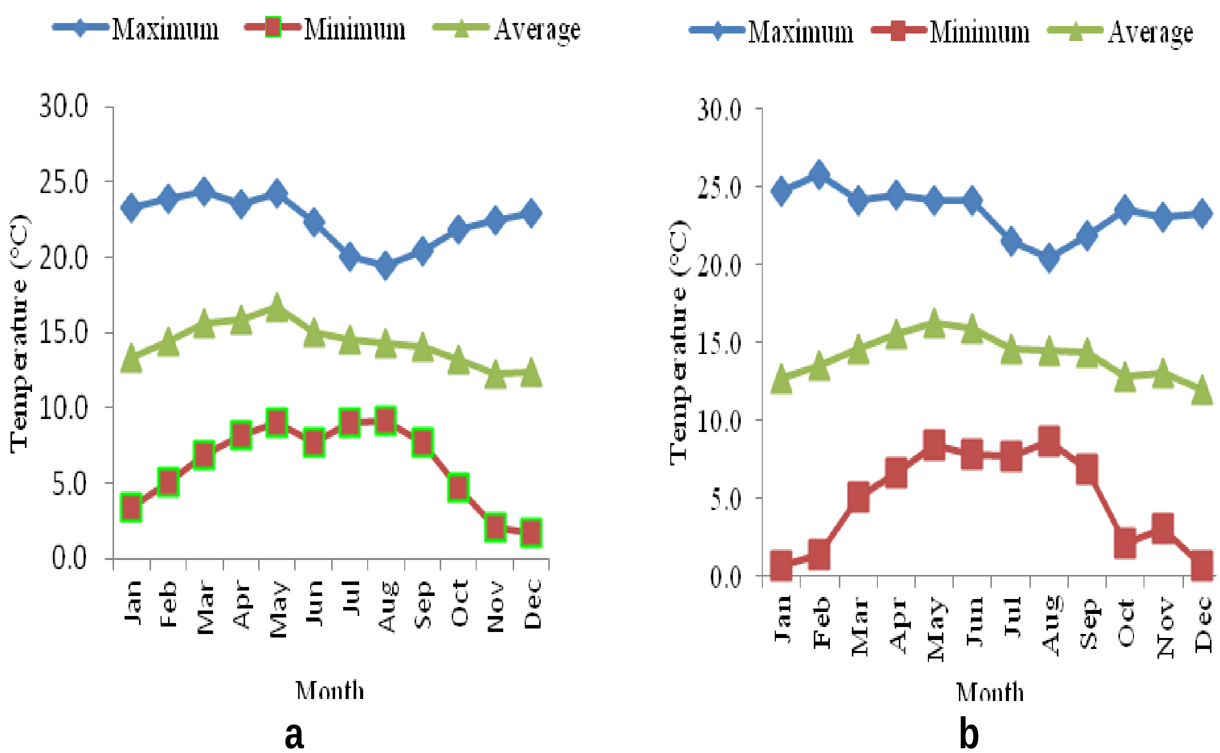

Figure 1a. Long-term (43 years) monthly temperature trends at Holetta; b. Monthly temperature trend during the experimental period at Holetta.

operations are disrupted by untimely rains.

The experimental setup and management

For this study, three blocks of representative pasture fields were delineated during the peak rainy season in mid July 2011 from a native pasture land maintained for grazing and seasonal hay-making at Holetta Agricultural Research Center. Each block was subdivided randomly into four sub plots (5 × 12 m^2 each), which were subjected to four harvesting times/stages in three replicates. The delineated pasture blocks were closely monitored for any management interferences during the pasture growing period of four and half months until all the plots were harvested. Harvesting of every three randomly assigned plots (one per each block) was made at 15 days interval beginning from full heading stage of the pasture in mid October until late November, 2011 (that is, the four harvesting times were mid October, late October, mid November and late November 2011 which correspond to 3, 3.5, 4 and 4.5 months, respectively after delineation and protection of the pasture from livestock). Before each harvest, samples for pasture yield determination were taken by placing 0.5 m^2 quadrates in five randomly selected corners in each of the plots. The respective plots were manually harvested at about 5 cm above the ground during the different harvests. Fresh samples of 500 g were taken from each plot immediately during each harvest and the rest of the biomass was wilted on the field for five days. At the end of fifth day of wilting, the biomass harvested from each plot was composited for uniformity within a plot and samples of 500 g were also taken from the sun dried biomass. Both the fresh and dry samples were dried in air-forced draft oven at 65°C for 72 h to prepare them for subsequent laboratory analysis.

The wilted biomass per each of the plots were then divided into two parts in such a way that one half of the biomass per each plot was stored under open air (outdoor) and the other half under a corrugated iron sheet roofed and well aerated shade. In both storage methods, loose hay was piled on raised wooden beds to avoid contact with the ground in line with the management practice adopted by most smallholder dairy farmers in the highlands of Ethiopia. Subsequent samples were taken after two, four, six and eight months of storage to study the effects of storage methods and storage durations on the dynamics in nutritional characteristics of the hay. The whole experimental process lasted from 15 July, 2011 to 30 July, 2012.

Laboratory analysis

After oven drying (65°C, 72 h), all the samples were chopped into shorter fiber lengths and milled using Cyclo-Tech Sample Mill (Tecator, Sweden) of 1 mm screen size for chemical analysis. Samples were analyzed for dry matter (DM) (oven-dried at 105°C overnight) and total ash using method 924.05 of AOAC (1990). The Kjeldahl wet digestion procedure (AOAC, 1999; method 954.01) was used to determine the total N content. The crude protein (CP) content was then estimated by multiplying the Kjeldahl N by 6.25. Neutral detergent fiber (NDF), acid detergent fiber (ADF) and Lignin were determined according to the standard procedures (ADF: AOAC, 1995, no. 973.18, expressed without residual ash after incineration at 500°C for 1 h; lignin: Robertson and Van Soest (1981), determined by solubilization of cellulose with sulphuric acid; NDF: Mertens (2002), analyzed with heat stable amylase and expressed without residual ash).

The *in vitro* OM digestibility (IVOMD) was determined according to the two-stage rumen fluid technique described by Tilley and Terry (1963). Rumen fluid was obtained from three rumen-

Table 1. Levels of significance indicating the effects of the main factors and their interactions on nutritional qualities of natural pasture at the time of harvest.

Factor	df	P-value							
		DM	Ash	NDF	ADF	Lignin	CP	IVOMD	ME
HT	3	0.7214	0.0234	<0.0001	<0.0001	<0.0001	0.0003	<0.0001	<0.0001
Samtyp	1	0.0066	0.1558	0.6441	0.0499	0.0900	0.3302	0.0056	0.0058
HT*Samtyp	3	0.2937	0.4353	0.9240	0.0613	0.0116	0.9891	0.4882	0.4903

HT = Harvesting time; Samtyp = Sample type, df = degrees of freedom, DM = dry matter, NDF = Neutral detergent fiber, ADF = Acid detergent fiber, CP = Crude protein, IVOMD = *in vitro* OM digestibility and ME = Metabolizable energy.

cannulated Zebu × Holstein crossbred steers fed on a basal diet of native grass hay and supplemented with 2 kg concentrate. The same natural pasture used in this study was the source of the hay fed to the donor animals. Metabolizable energy (ME) content was estimated from IVOMD according to MAFF (1984):

ME (MJ/kg DM) = 0.015*IVOMD (g/kg DM)

Experimental design and data analysis

The experiment was laid-out in a factorial arrangement of 4 (harvesting stages) × 2 (storage methods) × 5 (storage durations) and was executed using randomized complete block design. The model used for analysis included the main effects of harvesting stage, sample type (fresh and sun dried) and their interaction during the time of harvest. In the case of stored hay, the model included harvesting stage, storage method, storage duration and their two- and three-way interactions. Data analysis was performed using the general linear model procedure of the Statistical Analysis System (SAS, 2002) and the significance of mean differences was tested using the least significance difference (LSD) method. Differences were considered significant when P < 0.05. Regression analysis was also performed to determine the daily rates of changes in the contents of selected nutritional parameters in hay during the eight months storage period under the two storage methods.

The following statistical models were used for the analysis:

Model 1: Harvesting times and sample types as main factors (during harvesting)

$$Y_{ijkl} = \mu + b_i + h_j + s_k + (h*s)_{jk} + e_{ijkl}$$

where, Y = the response variable, μ = the overall mean, b_i = effect of i^{th} block, h_j = effect of j^{th} harvesting time (j = mid-October, late-October, mid-November, late-November), s_k = effect of k^{th} sample type (k = fresh and sun dried simples taken immediately during harvesting and after 4 days of field drying, respectively), $(h*s)_{jk}$ = the interaction effects of harvesting time and sample type and e_{ijkl} = the random error.

Model 2: Harvesting times, storage methods and storage durations as main factors (stored hay)

$$Y_{ijklm} = \mu + b_i + h_j + s_k + d_l + (h*s*d)_{jkl} + e_{ijklm}$$

where, Y = the response variable, μ = the overall mean, b_i = effect of i^{th} block, h_j = effect of j^{th} harvesting time (j = mid-October, late-October, mid-November, late-November), s_k = effect of k^{th} storage method (k = under shelter shade, under open air), d_l = effect of l^{th} storage duration (l = immediately before storage, 2 months, 4 months, 6 months, 8 months), $(h*s*d)_{jkl}$ = the interaction effects of harvesting time, storage method and storage duration and e_{ijklm} = the random error.

RESULTS

Effect of harvesting time on chemical composition and IVOMD

Table 1 presents the effects of harvesting time, sample type and their interaction on nutrient composition of the pasture during harvesting. All the nutritional parameters except the DM content were significantly affected by harvesting time (P < 0.05). Sample type had significant effect (P < 0.05) on DM, ADF, IVOMD and ME contents of the pasture. On the other hand, the interaction of harvesting time and sample type had no significant effect (P > 0.05) on all the nutritional parameters except the lignin content.

The dry matter, total ash, NDF, ADF, Lignin, CP and ME contents, and IVOMD of fresh and sun dried natural pasture during different harvests were shown in Table 2. The mean of DM content in the pasture was comparatively higher during late November harvest. Significantly, higher (P < 0.05) ash content was also recorded during late November harvest. Contents of the fiber fractions (NDF, ADF and lignin) showed significantly (P < 0.05) increasing trend with the delay in harvesting time. On the other hand, CP content, IVOMD and ME contents significantly declined with delay in time of harvest (P < 0.05). The mean of CP content was reduced by 30.2%, while both IVOMD and ME contents were reduced by 17.8% with the delay in harvesting from mid October (full heading stage) to late November. On the other hand, the mean of NDF, ADF and lignin contents were increased by 13.8, 21.6 and 36.0%, respectively between the two harvests. There were no significant difference in contents of the different nutritional parameters in fresh and sun dried/wilted pastures (P > 0.05).

However, fresh pasture had comparatively lower DM and higher CP, IVOMD and ME contents than sun dried pasture. In general, the result showed significant difference (P < 0.05) among the different harvesting times

Table 2. Chemical composition and *IVOMD* of fresh and sun dried natural pasture during different times of harvest.

Harvesting time	Pasture type	DM (g/kg)	(g/kg DM)						ME (MJ/kg DM)
			Ash	NDF	ADF	Lignin	CP	IVOMD	
	Fresh	924.3	89.5	647.4	400.0	72.7	90.0	588.9	8.83
Mid-October	Dry	930.5	90.0	653.0	435.6	81.3	86.0	563.9	8.46
	Mean	927.4	89.7^{ab}	650.2^{b}	417.8^{b}	77.0^{c}	88.0^{a}	576.4^{a}	8.65^{a}
	Fresh	928.9	85.9	678.8	451.0	88.2	72.4	556.7	8.35
Late-October	Dry	931.9	85.6	670.2	450.6	85.6	67.6	546.7	8.20
	Mean	930.4	85.7^{b}	674.5^{b}	450.8^{b}	86.9^{bc}	70.0^{b}	551.7^{a}	8.28^{a}
	Fresh	922.2	84.0	723.8	472.2	102.5	64.4	515.3	7.73
Mid-November	Dry	933.6	87.3	715.4	513.4	91.1	60.9	473.9	7.11
	Mean	927.9	85.7^{b}	719.6^{a}	492.8^{a}	96.8^{ab}	62.6^{b}	494.6^{b}	7.42^{b}
	Fresh	921.9	90.3	742.0	513.9	109.0	62.2	482.8	7.24
Late-November	Dry	942.0	98.8	737.4	501.8	100.3	60.6	464.7	6.97
	Mean	931.9	94.5^{a}	739.7^{a}	507.9^{a}	104.7^{a}	61.4^{b}	473.8^{b}	7.11^{b}

$^{a-c}$Mean values for the different harvesting stages with different superscripts in a column differ significantly ($P < 0.05$), Fresh pasture – the pasture sample taken immediately at the time of harvest, Dry pasture – the pasture sample taken on the 5th day of field drying just before storage of the hay, The mid October, late October, mid November and late November harvests, respectively correspond to 3, 3.5, 4 and 4.5 months after delineation and protection of the pasture from livestock. DM = dry matter, NDF = Neutral detergent fiber, ADF = Acid detergent fiber, CP = Crude protein, IVOMD = *in vitro* OM digestibility and ME = Metabolizable energy.

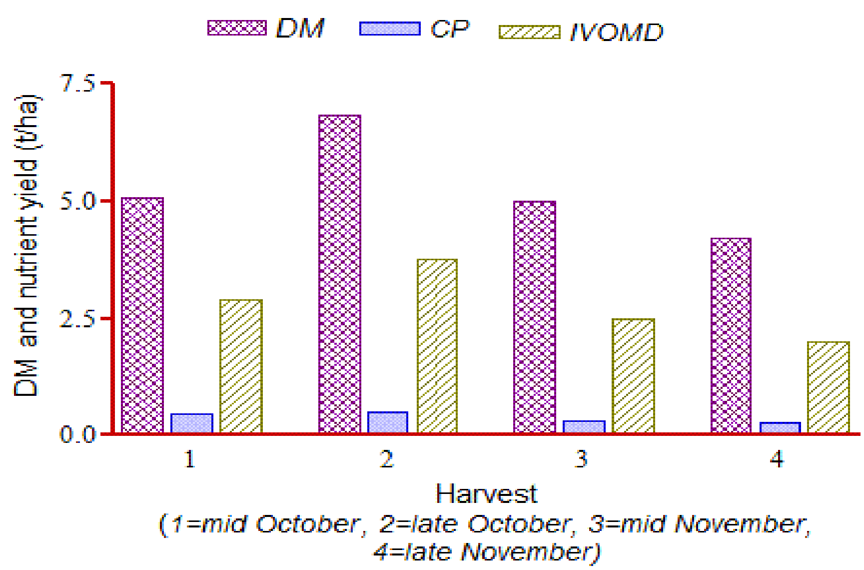

Figure 2. Dry matter and estimated nutrient yields of natural pasture during the different times of harvest (DM = dry matter, CP = Crude protein, IVOMD = *in vitro* OM digestibility, ME = Metabolizable energy).

for most of the parameters and it was noted that delay in harvesting as late as mid November could lead to significant reduction in quality. Figure 2 indicates the DM and estimated nutrient (CP and digestible OM) yields during the different harvests. Harvesting during late October resulted in higher DM yield (6.83 t/ha), CP yield (0.48 t/ha) and digestible OM yield (3.77 t/ha) than the other harvests suggesting that late October is the ideal harvesting time for producing high amount of better quality hay from natural pasture in the area.

Table 3. Levels of significance indicating the effects of the main factors and their interactions on nutritional qualities of hay during storage.

Factor	df	P-value							
		DM	Ash	NDF	ADF	Lignin	CP	IVOMD	ME
HT	3	<0.0001	0.1857	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
SM	1	0.0009	0.0495	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
SD	4	<.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
HT*SM	3	0.8229	0.9172	0.3677	0.0013	0.6190	0.1454	0.0150	0.0153
HT*SD	12	<0.0001	<0.0001	0.3911	<0.0001	0.0001	0.1080	0.0001	0.0001
SM*SD	4	0.0002	0.0557	0.0020	<0.0001	0.0247	0.0003	0.0002	0.0002
HT*SM*SD	12	0.1078	0.8626	0.9398	0.5576	0.8667	0.9941	0.8630	0.8634

HT = Harvesting time; SM = Storage method; SD = Storage duration, df = degrees of freedom, DM = dry matter, NDF = Neutral detergent fiber, ADF = Acid detergent fiber, CP = Crude protein, IVOMD = *in vitro* OM digestibility and ME = Metabolizable energy.

Effect of storage method and storage duration on chemical composition and IVOMD

Table 3 shows the effects of the main factors and their interactions on nutrient content of hay during storage. Harvesting time had significant effect ($P < 0.05$) on all the parameters except the ash content. All the nutritional parameters were also significantly affected by storage method and storage duration ($P < 0.05$). Only ADF, IVOMD and ME contents were significantly affected by the interaction of harvesting time and storage method, while most of the parameters except the NDF and CP contents were significantly affected by the interaction of harvesting time and storage duration ($P < 0.05$). The interaction of storage method and storage duration had significant effect on all the nutritional parameters ($P < 0.05$). On the other hand, effect the 3-way interactions of harvesting time, storage method and storage duration was not significant on all the parameters ($P > 0.05$).

The dry matter, ash, CP, IVOMD, ME and the fiber fractions of natural pasture hay harvested at different times and stored for different durations under shelter shade and in open air are presented in Tables 4 and 5. The DM content showed increasing trend with harvesting time under both storage methods, but there were no consistent trend in DM content with storage durations within the harvests (Table 4). Similarly, the ash content was found to be stable and did not show consistent trends across the harvests, storage methods and storage durations. On the other hand, the mean CP content, IVOMD and ME contents showed decreasing trend with the delay in harvesting time under both storage methods. Moreover, the three parameters undergo significant reduction ($P < 0.05$) with prolonged storage duration in all the harvests and storage methods, except CP for the hay harvested in mid October and stored under shelter shade. The reductions in CP, IVOMD and ME contents with prolonged storage durations were higher in the hay stored in open air than under shade for all the harvests. The three parameters showed considerable reductions beginning from six months after storage under shade and beginning from four months after storage in open air. When averaged across the different harvests, the mean CP content, IVOMD and ME content in the hay showed decreasing trend with the delay in harvesting time under both storage methods.

In contrary to CP, IVOMD and ME contents, the fiber fractions showed increasing trend with prolonged storage durations under the two storage methods for all the harvests (Table 5). However, the effect of storage duration on the contents of the fiber fractions was significant ($P < 0.05$) when hay was stored in open air for all harvests. In the case of storage under shade, only ADF and lignin contents increased significantly ($P < 0.05$) with prolonged storage durations for the hay harvested in mid October. The results indicated that the fiber contents in the hay were considerably increased beginning from four months after storage mainly under open air storage method. When averaged across the harvests, contents of the fiber fractions in the hay were higher when the hay was stored in open air than under shade. Moreover, the effect of harvesting stage was also reflected on fiber contents of hay in storage with the mean values increasing with delayed harvesting time in the order mid October harvest < late October harvest < mid November harvest < late November harvest under both storage methods. Exception to the above was the lignin content which was comparatively lower in the late October harvest than the mid October harvest.

Table 6 shows the regression coefficients indicating the daily rates of changes in contents of the major nutritional parameters (CP, IVOMD, NDF, ADF and lignin) in the hay during eight months storage period under shade and in open air. For all the harvests, considerable changes were noticed in nutrient composition of the hay on daily basis (a decline in CP content and IVOMD, and an increase in fiber fractions) during the eight months storage under both storage methods. But, the rates of changes were much higher in open air than under shade storage. On average, there was a loss in CP content of0.07 and 0.11 g/day under shade and in open air storage methods, respectively. Storage in open air

Table 4. Dry matter, total ash, CP and ME contents, and IVOMD of natural pasture hay harvested at different times and stored under shelter shade and in open air for different durations.

Harvesting time	Storage duration	Storage under shelter shade					Storage under open air				
		DM (g/kg)	(g/kg DM)			ME	DM (g/kg)	(g/kg DM)			ME
			Ash	CP	IVOMD	(MJ/kg DM)		Ash	CP	IVOMD	(MJ/kg DM)
Mid-October	0	927.4^{b}	89.8^{b}	88.0	576.4^{a}	8.65^{a}	927.4^{a}	89.8^{b}	88.0^{a}	576.4^{a}	8.65^{a}
	1	943.1^{a}	82.3^{b}	81.9	536.9^{ab}	8.05^{ab}	936.3^{a}	91.6^{b}	80.4^{ab}	522.0^{ab}	7.83^{ab}
	2	943.1^{a}	84.3^{b}	80.7	451.0^{b}	6.77^{b}	939.3^{a}	79.6^{b}	79.7^{ab}	447.2^{bc}	6.71^{bc}
	3	932.3^{b}	86.3^{b} *	73.2	447.7^{b}	6.72^{b}	933.0^{a}	89.5^{b} *	64.4^{bc}	438.5^{bc}	6.58^{bc}
	4	876.7^{c}	112.0^{a}	65.6	441.1^{b}	6.62^{b}	865.4^{b}	117.5^{a}	57.5^{c}	427.9^{c}	6.42^{c}
	Mean±SE	924.5±12.3	90.9±5.4	77.9± 3.9	490.6±27.7	7.36±0.42	920.3±13.9	93.6±6.3	74.0±5.6	482.4±28.8	7.24±0.43
Late-October	0	930.4^{ab}	85.8	70.0^{a}	551.7^{a}	8.28^{a}	930.4^{b}	85.8^{b}	70.0^{a}	551.7^{a}	8.28^{a}
	1	946.4^{a}	85.2	66.6^{a}	544.8^{a}	8.17^{a}	948.6^{a}	84.0^{b}	64.2^{a}	521.8^{b}	7.83^{b}
	2	948.9^{a}	84.6	60.1^{ab}	488.9^{b}	7.33^{b}	948.8^{a}	85.1^{b}	56.6^{b}	442.0^{c}	6.63^{c}
	3	945.9^{a}	83.7	58.8^{ab} *	471.0^{b}	7.06^{b}	950.6^{a}	87.2^{b}	51.3^{bc} *	416.9^{cd}	6.26^{cd}
	4	895.2^{b}	108.3	51.9^{b}	467.0^{b}	7.00^{b}	870.2^{c}	121.8^{a}	45.9^{c}	402.0^{d}	6.03^{d}
	Mean±SE	933.4±10.1	89.5±4.7	61.5±3.2	504.7±18.2	7.57±0.27	929.7±15.3	92.8±7.3	57.6±4.3	466.9±29.6	7.01±0.44
Mid-November	0	927.9^{bc}	85.7^{ab}	62.7^{a}	494.6^{a}	7.42^{a}	927.9^{bc}	85.7^{bc}	62.7^{a}	494.6^{a}	7.42^{a}
	1	950.5^{ab}	79.8^{b}	60.7^{ab}	473.1^{ab}	7.10^{ab}	951.7^{ab}	83.0^{c}	54.7^{ab}	458.9^{ab}	6.89^{ab}
	2	958.3^{a}	92.9^{a}	58.1^{ab}	456.5^{ab}	6.85^{ab}	955.5^{a}	86.8^{bc}	49.7^{bc}	420.7^{ab}	6.31^{ab}
	3	949.6^{ab}	92.2^{ab}	56.2^{ab} *	442.2^{ab}	6.64^{ab}	941.0^{ab}	101.7^{a}	44.1^{cd} *	383.6^{b}	5.75^{b}
	4	918.2^{c}	90.7^{ab}	52.3^{b} *	439.4^{b}	6.60^{b}	910.1^{c}	96.3^{ab}	40.2^{d} *	377.8^{b}	5.67^{b}
	Mean±SE	940.9±7.6	88.3±2.5	58.0±1.8	461.2±10.3	6.92±0.15	937.2±8.3	90.7±3.5	50.3±4.0	427.1±22.3	6.41±0.33
Late-November	0	932.0^{c}	94.5	61.4^{a}	473.8^{a}	7.11^{a}	932.0^{b}	94.5	61.4^{a}	473.8^{a}	7.11^{a}
	1	952.9^{ab}	99.8	56.2^{ab}	460.9^{a}	6.91^{a}	953.4^{a}	96.1	52.4^{ab}	438.7^{ab}	6.58^{ab}
	2	939.6^{bc}	89.5	54.4^{abc}	447.9^{a}	6.72^{a}	942.1^{ab}	88.8	45.1^{bc}	406.2^{b}	6.09^{b}
	3	961.9^{a}	87.8	49.5^{bc}	391.1^{b} *	5.87^{b} *	957.2^{a}	91.0	39.2^{cd}	334.0^{c} *	5.01^{c} *
	4	934.7^{c}	90.3	45.8^{c}	388.6^{b}	5.83^{b}	927.3^{b}	96.5	33.5^{d}	332.2^{c}	4.99^{c}
	Mean±SE	944.2±5.7	92.4±2.2	53.5±2.7	432.5±17.9	6.49±0.27	942.4±5.8	93.4±1.5	46.3±4.9	397.0±28.2	5.96±0.42

$^{a-d}$ Mean values with different superscripts within each harvesting time and storage method in a column differ significantly ($P < 0.05$), *Values for the same parameter differ significantly between the two storage methods within a row ($P < 0.05$), Storage durations (0 = immediately before storage; 1 = two months; 2 = four months; 3 = six months; 4 = eight months); DM = dry matter, NDF = Neutral detergent fiber, ADF = Acid detergent fiber, CP = Crude protein, IVOMD = *in vitro* OM digestibility and ME = Metabolizable energy.

resulted in 0.04 g/day (57.1%) more average loss in CP content as compared to storage under shade. Similarly, the average daily rates of decline in IVOMD during storage were 0.41 and 0.62 g, respectively under shade and in open air storages, with 0.21 g/day (51.2%) more loss in

Table 5. Neutral detergent fiber (NDF), acid detergent fiber (ADF) and Lignin contents of natural pasture hay harvested at different times and stored under shelter shade and in open air for different durations.

Harvesting time	Storage duration	Storage under shelter shade (g/kg DM)			Storage under open air (g/kg DM)		
		NDF	ADF	Lignin	NDF	ADF	Lignin
Mid-October	0	650.2	417.8[c]	77.0[b]	650.2[b]	417.8[c]	77.0[b]
	1	658.3	424.6[c]	79.6[b]	684.7[a]	439.0[bc]	100.0[ab]
	2	664.0	435.8[bc]	83.4[b]	697.4[a]	460.1[b]	101.4[ab]
	3	671.5	475.8[ab]	113.9[a]	693.9[a]	497.5[a]	121.0[a]
	4	689.7	486.4[a]	116.9[a]	708.1[a]	509.1[a]	125.3[a]
	Mean±SE	666.7±6.7	448.1± 13.9	94.2±8.7	686.9±9.9	464.7± 17.2	104.9±8.6
Late-October	0	674.5	450.8	86.9	674.5[b]	450.8[c]	86.9[c]
	1	678.2	458.0	88.3	686.0[ab]	470.3[c]	92.2[abc]
	2	681.4	462.3	91.1	702.2[ab]	501.9[b]	98.1[abc]
	3	690.0	470.6	93.0	718.3[a]	521.7[ab]	103.5[ab]
	4	705.5	476.1	98.7	724.1[a]	526.1[a]	112.2[a]
	Mean±SE	685.9±5.5	463.5±4.5	91.6±2.1	701.0±9.4	494.2± 14.6	98.6±4.4
Mid-November	0	719.6	492.8	96.8	719.6[d]	492.8[b]	96.8[b]
	1	721.5	498.1	99.8	739.1[cd]	509.2[ab]	107.6[ab]
	2	730.5	504.7	104.4	750.1[bc]	524.0[ab]	119.3[ab]
	3	736.9 *	511.9	111.2	767.4[ab] *	543.7[a]	128.4[a]
	4	740.2	516.9 *	113.4	772.5[a]	544.6[a] *	129.1[a]
	Mean±SE	729.7±4.1	504.9±4.4	105.1±3.2	749.7±9.6	522.9± 10.0	116.2±6.2
Late-November	0	739.7	507.9	104.7	739.7[b]	507.9[b]	104.7[b]
	1	743.3 *	510.9	109.8	750.3[ab] *	517.3[ab]	118.2[ab]
	2	745.8	513.8 *	113.0	759.1[ab]	523.1[ab] *	122.7[ab]
	3	749.3	516.7	117.7 *	765.0[a]	529.1[a]	126.8[a] *
	4	752.1	519.6	119.0	772.3[a]	532.0[a]	130.7[a]
	Mean±SE	746.0±2.2	513.8±2.1	112.8±2.6	757.3±5.7	521.9±4.3	120.6±4.5

[a-d]Mean values with different superscripts within each harvesting time and storage method in a column differ significantly (P < 0.05), *Values for the same parameter differ significantly between the two storage methods within a row (P < 0.05), Storage durations (0 = immediately before storage; 1 = two months; 2 = four months; 3 = six months; 4 = eight months), NDF = Neutral detergent fiber, ADF = Acid detergent fiber.

open air. The fiber contents in the hay were increased with varying rates in the different harvests. When averaged over the harvests, the NDF content was increased by 0.10 and 0.19 g/day under shade and in open air storage methods, respectively with 0.09 g/day (90%) more

Table 6. The regression coefficients indicating the rate of change in major nutritional parameters in natural pasture hay harvested at different times and stored for eight months under shade and in open air.

Parameter	Harvesting time	Rate of decline (g/day) during eight months storage		Difference	% Difference*
		Under shade	Under open air		
CP	Mid-October	0.09	0.13	0.04	44.4
	Late-October	0.07	0.10	0.03	42.9
	Mid-November	0.04	0.09	0.05	125.0
	Late-November	0.06	0.12	0.06	100.0
	Mean	*0.07*	*0.11*	*0.04*	*57.1*
IVOMD	Mid-October	0.60	0.63	0.03	5.0
	Late-October	0.41	0.67	0.26	63.4
	Mid-November	0.24	0.52	0.28	116.7
	Late-November	0.40	0.65	0.25	62.5
	Mean	0.41	0.62	0.21	51.2
		Rate of increase (g/day) during eight months storage		**Difference**	**% Difference**
		Under shade	**Under open air**		
NDF	Mid-October	0.15	0.21	0.06	40.0
	Late-October	0.12	0.22	0.10	83.3
	Mid-November	0.09	0.22	0.13	144.4
	Late-November	0.05	0.13	0.08	160.0
	Mean	0.10	0.19	0.09	90.0
ADF	Mid-October	0.31	0.40	0.09	29.0
	Late-October	0.11	0.34	0.23	209.1
	Mid-November	0.10	0.23	0.13	130.0
	Late-November	0.05	0.10	0.05	100.0
	Mean	0.14	0.27	0.13	92.9
Lignin	Mid-October	0.19	0.20	0.01	5.3
	Late-October	0.05	0.10	0.05	100.0
	Mid-November	0.07	0.14	0.07	100.0
	Late-November	0.06	0.10	0.04	66.7
	Mean	0.09	0.13	0.04	44.4

*Refers to the % difference in the daily rate of change in nutritional quality (decrease or increase) under open air storage over the rate of change noticed when the hay was stored under shade (NDF = Neutral detergent fiber, ADF = Acid detergent fiber, CP = Crude protein and IVOMD = *in vitro* OM digestibility).

rate of increase in open air storage. Similarly, the ADF content was on average increased at the rate of 0.14 g/day under shade and 0.27 g/day in open air, with 0.13 g/day (92.9%) more rate of increase in open air than under shade. The average rates of increases in lignin content were 0.09 and 0.13 g/day under shade and in open air storage methods, respectively with the rate of increase higher by 0.04 g/day (45.9%) in open air as compared to storage under shade. Generally, the result indicated considerable dynamics in nutritional quality features of natural pasture hay during storage, with higher rates of changes (losses in CP and IVOMD; and increases in the fiber fractions) in open air storage system than under shade.

DISCUSSION

Effect of harvesting stage

The stage of plant maturity at the time of harvest is the most important factor affecting the nutritional quality of hay. As a plant matures, its nutritional quality decreases due to an increase in indigestible fiber (more stem fraction) and a decrease in nutrient content (less leaf fraction). Grasses mature faster than legumes, and the drop in nutritional quality with the delay in harvesting stage is faster in grasses than in legumes. The grass dominated pasture in this study showed high reduction in CP, IVOMD and ME contents and an increase in fiber fractions when harvesting was delayed for one and half months after full heading stage of the pasture (mid October harvest). This agrees with Gabrielsen et al. (1990) and Van Soest (1965) who reported that NDF, ADF and lignin concentration increased with maturity while IVOMD and CP declined. Buxton (1989) reported that the proportion of stem in a grass approaching maturity was the main morphological factor determining quality.

Mainly, the CP content and IVOMD undergo considerable changes in reverse order to the lignin content with the delay in harvesting time. This could be attributed to high cell wall lignification and dilution of the CP content by increasing structural carbohydrates at late stage of maturity (Hassen et al., 1990). As pasture gets mature, it is characterized by high content of fiber with a higher grade of lignification and low protein content. Changes of quality during the growing period of grasses are particularly high under tropical conditions due to the physiological differences between temperate and tropical grasses and the higher photosynthesis rate at the increased radiation intensity in the tropics (Nelson and Moser, 1994). Temperature is also one of the environmental factors influencing forage quality. In grasses, both leaf and stem digestibility decline with increasing temperature, but the effect is more pronounced in tropical grasses (Van Soest, 1982). The quantitative effect of temperature on digestibility of grasses have been estimated by partial regression which showed a decline of half a unit of digestibility per degree Celsius increase in temperature when other factors (light, age, maturity and fertilization) were controlled (Deinum, 1968). Minson and McLeod (1970) also reported a decline of 1.14 units in digestibility of temperate and tropical grasses per degree Celsius increase in temperature. The weather data recorded at Holetta during the experimental period indicated that the average temperature was slightly higher (0.2°C) in November than in October which might have partly contributed to the observed differences in nutritional qualities of pasture harvested during different times.

In the field drying process which requires three or more days, plant respiration and rainfall are known to alter the quantity and quality of hay (Gupta et al., 1990; Barr et al., 1995). The respiration process consumes highly digestible carbohydrates and therefore leads to the loss in hay quality. Similarly, occurrence of rainfall during field drying can cause leaf loss and leaching of soluble nutrients such as sugars. Moreover, wet weather prolongs the required period for drying and can cause further losses. Microbial activities and bleaching by the sun are other factors responsible for the loss in hay quality during field drying. The tendencies of decreasing levels of CP, IVOMD and ME, and the increase in fiber fractions in sun dried pasture in this study could be attributed to one or more of the above factors. However, during harvesting and drying processes of the pasture in the current study, there was no incidence of rainfall and solar radiation was also not intense as harvesting was made shortly after the end of the main rainy season. Hence, plant respiration could have been the main factor responsible for the observed changes in nutrient concentration during the field drying process.

The findings of the current study were in line with the previous reports on nutritional qualities of natural pasture harvested at different stages in the central highlands of Ethiopia (Zinash et al., 1995; Adane and Birhan, 2007). Lemma (2002) reported CP contents of 81.8 and 59.7 g/kg DM for seasonally stock excluded and year round grazed grasslands, respectively which were harvested during mid-September in the mid altitude vertisols of Ginchi in the Ethiopian highlands. Despite the early harvest, the reported CP content was lower than the figure recorded for natural pasture harvested in mid October in this study. This could be due to the effect of higher temperature which enhances maturity and lead to fast reduction in nutritional quality of the pasture in the mid altitude areas as compared to the cooler highlands. Moreover, the proportion of legumes in the pasture is higher in the cooler highlands than in the mid- and lower altitude areas (Lulseged and Alemu, 1985), which could be another reason for the higher CP content of natural pasture in the cooler highlands.

Similarly, the natural pasture in this study had higher CP and lower fiber fractions than those reported for different grass species during different seasons in semi-arid region of northern Ethiopia (Yayneshet et al., 2009). The variations could be attributed to the differences in climatic conditions, soil factors, pasture species composition, stage of maturity and season. The mean CP content of natural pasture in this study fell below the critical level of 70 g/kg DM required for optimal rumen function and feed intake in ruminants (Van Soest, 1982) as harvesting was delayed beyond late October but was fairly above the 6% threshold value suggested for tropical forages (Minson, 1990) during all the harvests.

Effects of storage method and storage durations

The loss in DM, an increase in fiber contents and reductions in CP content and DM digestibility are a common phenomenon in hay with prolonged storage durations (Guerrero et al., 2010). Storage method is the main factor responsible for nutrient loss or retention during storage. The loss in hay quality is more and faster when hay is stored outdoor due to spoilage resulting from exposure to adverse weather conditions. This was clearly reflected in the observed dynamics in nutritional quality of natural pasture hay stored under shade and in open air in the present study. The CP, IVOMD and ME contents were reduced, while the fiber fractions were increased with prolonged storage duration from the pre-storage period to eight months after storage under both storage methods. But the dynamics in nutritional quality of the hay (the decline in CP and IVOMD; and the increase in fiber fractions determined by the regression coefficients) were considerably higher under open air storage method for all the harvests.

According to Seyoum et al*.* (2007) dry forages and roughages in Ethiopia are on average characterized by 67 g/kg DM CP content, 471 g/kg DM IVOMD and 7.3 MJ ME/kg DM which are not sufficient even to meet the maintenance requirement of dairy cows. In this study, it was learned that contents of the three parameters in the hay were found to be lower than the levels reported above with delayed harvesting time and prolonged storage durations. Had it not been for absence of short rains (March and April), and the delay in the onset of main rains during 2011 to 2012 in the study area, the nutrient losses in the hay could have been greater than the observed figures under open air storage.

Nsahlai et al*.* (1996) classified tropical pastures and roughages as high, medium and low quality roughages based on the CP concentration: roughages with CP contents of 99 to 152, 66 to 91 and 30 to 61 g/kg DM were classified as high, medium and low quality roughages, respectively. The CP content of natural pasture in this study was within the range of medium quality roughages during the mid- and late-October harvests, and fall under poor quality roughages during the mid- and late-November harvests. The CP level in the hay was maintained within the range of medium quality roughage throughout eight months storage period under shade and for six months under open air for the pasture harvested in mid October. Moreover, in the late October harvest, the CP content in the hay was maintained within the range of medium quality roughages for two months when stored under shade. The hay harvested later than late October and stored under both systems was classified under low quality roughage with higher degree of reduction in quality under open air storage. According to Milford and Minson (1966) the critical CP required in a pasture before intake is reduced by nitrogen deficiency has been estimated at between 60 and 85 g/kg DM. As harvesting was delayed beyond late October, CP content in the hay was reduced below the above range and categorized as low quality roughage shortly after storage both under shade and under open air. Regression analysis also showed further losses in CP and IVOMD, and increases in fiber fractions with considerably higher rates of changes per day under open air storage method during the eight months storage period. This has got a significant practical implication and serves as a basis for establishing proper supplementation schemes in hay based feeding dairy systems like the case in the central highlands of Ethiopia where hay is used as a major source of roughage for an average of eight months per year (Fekede, 2013).

Conclusions

The nutritional quality of natural pasture hay was affected by harvesting stage, storage methods and storage durations. Delaying harvesting from mid-October (full heading stage) to late-November led to reductions in CP, IVOMD and ME contents, but an increase in the fiber fractions. Higher DM, CP and IVOMD yields were recorded during the late-October harvest suggesting that this is the ideal harvesting time for producing high amount of better quality hay from natural pasture in the study area. The nutritional qualities of the hay also showed considerable dynamism during the eight months storage period. However, the dynamics in nutritional qualities (the rates of decline in CP content and IVOMD, and an increase in the fiber fractions) were higher when the hay was stored under open air than under shade. Generally, in terms of contents of the important nutritional parameters (CP, IVOMD, ME, NDF, ADF and lignin), hay-based feeding could be detrimental to the nutrition of dairy cattle with the delay in harvesting beyond late-October. This could be further exacerbated by the observed substantial reductions in nutritional qualities during storage, mainly when the hay was stored in open air.

RECOMMENDATION

Feeding trials and animal response studies should be conducted in order to establish proper supplementation schemes while considering harvesting stage, storage method and storage duration in hay-based feeding system of dairy cattle in the highlands of Ethiopia. Moreover, there is a need to sensitize development agents and farmers on the proper harvesting, storage and utilization of hay for feeding dairy cattle in the area.

Conflict of Interest

The authors have not declared any conflict of interests.

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