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Full Length Research Paper

Alternative methods of harvesting and storage of grass biomass in a semi-arid region

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Biomass is considered a potential feedstock for many renewable energy production systems and interest especially in grass production has increased markedly in the last two decades. The present work focuses on grass biomass in the semi arid regions of sub-Saharan Africa and includes the study of two different methods of harvesting and baling as well as two different bale storage methods. The results indicated an average dry matter yield of 22600 kg ha^{-1}. The average harvesting rate and fuel consumption were 1.57 h ha^{-1} and 6.23 ℓ ha^{-1}, respectively. The baling rate was 0.80 h ha^{-1} while diesel consumption during baling was 2.69 ℓ ha^{-1}. Manual harvesting using scythes varied extensively depending on time of day and the quality of the handmade bales though acceptable could at times fall below standards. The open barn storage method and open barn plus tarpaulin cover storage method could be used to store bales for a period of up to 5 months with minimum changes in neural detergent fibre (NDF) and acid detergent fibre (ADF) of biomass. The average fuel energy required to both harvest and bale, the biomass constituted less than 1% of the energy that could be recovered from the biomass if used as a fuel.

Key words: Biomass, grass, harvesting, yield, rate, storage, quality.

INTRODUCTION

The rainy season in the semi-arid regions of Botswana spreads from October to March resulting in an annual mean of 520 mm in Gaborone (Zhou et al., 2005). After this season there is normally no rainfall at all for a period of 5 to 6 months. During the rainy season, grass grows very fast and it is possible to harvest a given type of grass or forage crop several times within this growing period. Harvesting can also be continuous throughout the year if the land was under irrigation (McLennan, 2002; Titterton et al., 1999). Controlling the harvesting and storage of hay can offer considerable advantages when compared to pasture grazing practices where only a small portion of the available biomass is consumed and the rest left standing in the field (Burgess, 2002; Enoh et al., 2005). Biomass is a renewable green energy resource that if properly used can reduce the use of fossil fuels and therefore slow down global warming. Straw can be compacted to increase its energy density as well as improve its combustion characteristics (Samson et al., 2007). Murphy and Power (2009) have put a good argument for the use of grass biomass for biogas generation while Schmer et al. (2008) discusses the production of fuel bio-ethanol from switch grass. Prochnow et al. (2009) have also given an in depth review of bioenergy from permanent grasslands. Studies on biomass production costs and yields are many (Schmer et al., 2008; Marti and Gonzalez, 2009; Mulky et al., 2008). However, studies in an arid environment (such

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as in Botswana) and under conditions where production inputs are lacking or minimal also need to be pursued. It is necessary to study the grass harvesting and hay making methods and practices in potential arid regions in a coordinated and systematic way in order to establish both the harvesting and storage technology that gives us a high final product quality at minimum cost. This is only possible if the study is carried out under controlled conditions and the present study is part of this broader objective.

The overall objective of this research was to evaluate various grass harvesting, baling and bale storage methods. The specific objectives were to: 1) determine both the rate and efficiency of both manual and motorized harvesting of grass; 2) determine the rate of baling and quality of bales for both manual and motorized baling and 3) evaluate the effect of different storage methods and durations of storage on hay quality.

MATERIALS AND METHODS

The buffel grass (*Cenchrus ciliaris L*) already established at the research site was used in these experiments. The land was nearly level, measured over 7 ha in area and is located at Sebele at the outskirts of Gaborone city. Grass was allowed to grow naturally and there was no application of commercial or farmyard fertilizer (Enoh et al., 2005). However, weeds were manually removed after every four weeks from the onset of rainfall. The natural pastures were then monitored and harvested when approximately 50% of the heads had emerged (Humphreys and O'kiely, 2006). The maturity state was determined by harvesting some grass stalks from three randomly selected locations from the test area and then calculating the percentage of emerged heads from the harvested stalks. The experimental area was demarcated into twelve plots each measuring 100 m long 50 m wide and completely random design was used to determine how to harvest each plot. After establishing that the grass had reached the correct maturity for harvesting, eight of these plots were harvested using a 1.8 m wide disc mower mounted on an 82 HP rated Massey Ferguson farm tractor that operated the mower through it power take off (PTO). Before beginning the mowing operation the tractor was positioned on a level ground adjacent to the field and topped up with fuel. The tractor was again returned to the same spot after completion of the mowing of each plot and this time topped using a container which held a known quantity of fuel. The volume of fuel that remained after topping-up the tractor was then measured using a measuring cylinder. This allowed the amount consumed during the mowing exercise to be computed (PCARRD, 2001). The time taken to complete the mowing of each plot (100 × 50 m) was measured using a digital stopwatch.

The driver mowed in strips of 100 m length using the headland pattern (PCARRD, 2001) and worked outwards until he completed the marked plot. The time taken at the headlands allowing the tractor to turnaround and start the return trip was considered to be part of the harvesting operation. Upon completion of the harvesting of each plot the fuel consumption was measured as already described earlier. The tractor was then moved to the next plot and the procedure repeated until all the eight plots were mowed.

The remaining four 100 by 50 m blocks were used for manual harvesting using conventional scythes. The work normally started at 08:00 am in the morning when it was generally cool and continued until 13:00 pm. Four people worked on each plot simultaneously with each working from his or her corner. The rate of work of each individual could be measured using the measuring tape and stopwatch (Cooperative Scythe Network, 2010). The area mowed by each of the eight people was measured for the period of 08:00 to 09:00 am, 10:00 to 11:00 am and 12:00 to 13:00 over a period of three weeks.

Baling rates

The harvested grass was allowed to dry in the field while spread out in the manner in which it fell during mowing. The moisture content was monitored by repeating repeated sampling (after every 1 h) using a moisture meter that was already calibrated using the ASAE standard method, S358.2 (ASAE, 1997). In all cases the hay reached the recommended baling moisture of 20 to 25% within 1 day thus making it possible to bale the crop the morning following the day of harvest (Hemming and Wheatson, 1993). Just before baling, dry hay samples were collected for laboratory analysis of dry matter, crude protein (CP), neutral detergent fibre (NDF) and acid detergent fibre (ADF) following the methods outlined under the section on laboratory analysis. For motorized baling, a 1.8 m wide Wagner baling machine was used to make the rectangular bale blocks and the operational movement of the tractor had the same pattern as the one used during harvesting. The same procedure was used to determine the fuel consumption and the rate of baling as the one used during mowing. A wooden box measuring 90 cm long, 60 cm wide and 60 cm high and also having holding handles on each side along its length was constructed for use in manual baling operations (DAR, 2006). The box had an open top through which the hay was fed. Before commencement of the bale making process two twines were raid across the top of the box in a manner that allowed them to wrap around the bale once the hay was pushed into the box. At least two workers were required in order to gather hay from the manually harvested block and feed it into the box. Care was taken to gather the hay systematically by starting at one corner of the plot in order to avoid losses. The box was filled in layers of approximately 30 cm and each layer was followed by trampling until the box was full.

The compressed mass of hay was then tied using the twines already laid across the box before the commencement of the filling procedure. After this the box was overturned and then lifted off the bale by holding on to the handles on either side and shaking as can be seen in Figure 1. After completing the bailing process in each plot, the dimension and masses of ten randomly chosen representative bales were taken using a tape measure and a platform balance (McLennan, 2002). The bales in each plot were also counted. This information was used to determine bale density and hay yield. A sample of hay weighing about 400 to 500 g was taken from bales from each of the 12 plots using a standard hay probe (Ullreys, 1997), put in a sealable plastic bag and transported to the laboratory for analysis. This was done within 1 h of baling. After these field measurements the bales were labeled and transported to the storage area (Quarberg, 1999; Rayburns, 2001; Suttie, 2000).

Laboratory analysis

At the laboratory, approximately 200 g of each sample was withdrawn from the plastic bag, carefully weighed to the nearest 0.1 g and then dried on aluminum pans placed inside an air oven. The remaining sample was refrigerated at 5°C and was used only when there was need to repeat the analysis. The sample for dry matter determination was dried at 103°C for 24 h in accordance with the ASAE standards S358.2 (Lee et al., 2002). Samples for the determination of crude protein were dried at 60°C for 72 h and then ground in a laboratory mill. The ground material was sieved to pass ASTM 1 mm diameter sieve (Humphreys and O'kiely, 2006; Han et

Figure 1. Two workers extracting a hand made bale from a specially designed baling box.

al., 2004) and analyzed for fibre content and nitrogen content using Kjeldahl method (Nielsen, 1994). The nitrogen content was then converted to crude protein (CP) by multiplying nitrogen content by 6.25.

Bale storage

The two types of bales that had to be stored were; a) bales made using motorized baler, and b) bales made manually using the wooden box. In order to investigate the effect of storage conditions on dry matter, CP, NDF and ADF content, six experimental bales from each of the two types were stored under two storage conditions (Hemming and Wheatson, 2006; Turner et al., 2002). In one method of storage the hay bales were stacked on a wooden platform and placed in an open wall hay barn (HB storage) while under the other storage method the bales were placed on the wooden platform in the same manner and in the same barn as (HB) method but these bales were also covered with a tarpaulin (TP method). There were therefore a total of four hay stacks representing the two bale types and two storage methods. Each stack was made of six core bales that were then surrounded on all sides by other bales that were not used for sampling purposes. Inside each stack three core bales were first placed side by side and the other three core bales placed so as to touch end to end as shown in Figure 2. There was one layer of bales below and one layer above the core bales. Thus, the protective layer on all sides of any core bale was at least one bale deep. Each stack was formed within 2 h of baling. The stacks that were covered with tarpaulin were also covered within 2 h of baling.

Bale sampling

On the second Monday of each month or as close as possible, for the next 5 months after the initiation of storage, all the six core bales in each stack were temporary removed from storage. The mass and dimensions of each bale were taken and then a sample of approximately 20 g was taken from each bale using a standard hay probe . The bales were then returned to their original position in the stack. Under no condition were the bales removed from their storage condition for a period of more than 1 h. The samples of hay obtained from individual bales using the hay probe and for bales that belonged to the same stack were immediately after sampling mixed, put in sealable plastic bags and transported to the laboratory for analysis within the hour. At the laboratory, the procedure for dry matter, CP, NDF and ADF analysis as previously described was followed.

RESULTS AND DISCUSSION

Yield

The average yield from the twelve half hectare plots was 58.67 bales per plot implying an average yield of 117 bales ha^{-1}. After weighing ten bales from each plot it was found that on average the bales weighed 21.01 kg each while the average moisture content at the time of baling was 17.19% (dry basis). The average dimensions of the bales were also found to be 98.4 × 48.7 × 33.8 cm implying an average bale density of 131.04 kg m^{3}. When the moisture content of each of the bales from each of the 12 blocks was taken into consideration during the calculation, the dry matter yield average was calculated as 2261.57 kg ha^{-1}. This value had a standard deviation of 217.68 kg which was equivalent to only 9.63% of the dry matter yield. The average yield in this study is within

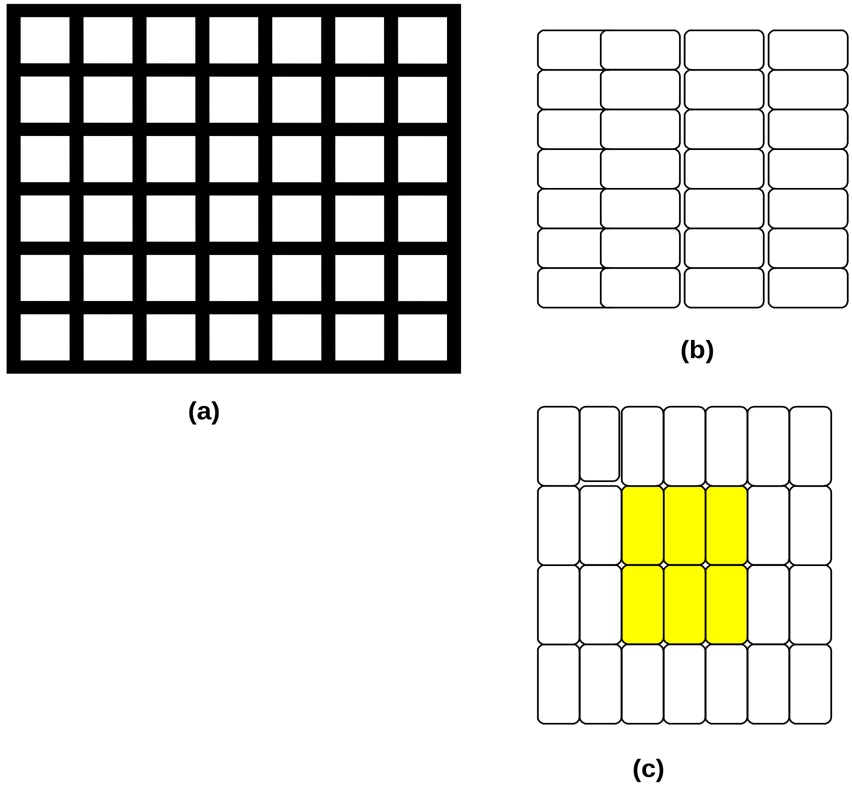

Figure 2. The bales storage top view (not to scale) of: a) the 3 × 3 m wooden platform made of 3 × 2” wooden planks, b) first layer of bales on the platform, c) second layer of bales with test samples in the middle.

Table 1. The harvesting and baling rates of the disc mower as well as the dry matter yield of half hectare experimental plots.

Plot	Harvesting rate		Baling rate			Dry matter yield (kg ha^{-1})
	hrs ha^{-1}	ℓ ha^{-1}	hrs ha^{-1}	ℓ ha^{-1}	Bales, no. per plot	
1	1.91	5.77	0.85	3.80	56	2031.69
2	1.37	6.50	0.81	2.64	66	2509.70
3	1.45	6.30	0.70	2.26	55	2220.96
4	1.48	6.08	0.75	2.08	60	2442.36
5	1.64	6.62	1.03	3.38	62	2376.83
6	1.55	6.12	0.65	1.99	53	1987.90
Average values	1.57	6.23	0.80	2.69	58.67	2261.57
Std.	0.19	0.31	0.13	0.74	4.89	217.68
Std. % of average	12.22	4.95	16.85	27.59	8.33	9.63

the range of values reported by Berdahl et al. (2001) in their study of grass yields with or without fertilization. Murkey et al. (2008) have also reported a dry matter yield of 2406 to 2870 kg ha^{-1} from switch grass when it was grown without application of N fertilizer.

Harvesting and baling rates

The rate of harvesting and baling grass using both the disk mower and the mechanized baler is presented in Table 1. The average harvesting rate was 1.57 h ha^{-1} while the average fuel consumption during harvesting was 6.23 ℓ ha^{-1}. The baling process was relatively easier when compared to harvesting and took a shorter period of time. The average baling duration was 0.80 h ha^{-1} while fuel consumption was 2.69 ℓ ha^{-1}. Although the standard deviation of fuel consumption during baling was high, it was considered to be reasonable especially when considering possible sources of variation such as the

Table 2. The working rates of both men and women when harvesting grass using scythes.

Gender	Time period	ha hr^{-1}	hrs ha^{-1}	% higher than women
	8:00-9:00 am	0.360	2.78	31
Men	10:00-11:00 am	0.150	6.67	38
	12:00-13:00 am	0.086	11.61	34
	8:00-9:00 am	0.274	3.65	-
Women	10:00-11:00 am	0.109	9.16	-
	12:00-13:00 am	0.064	15.62	-

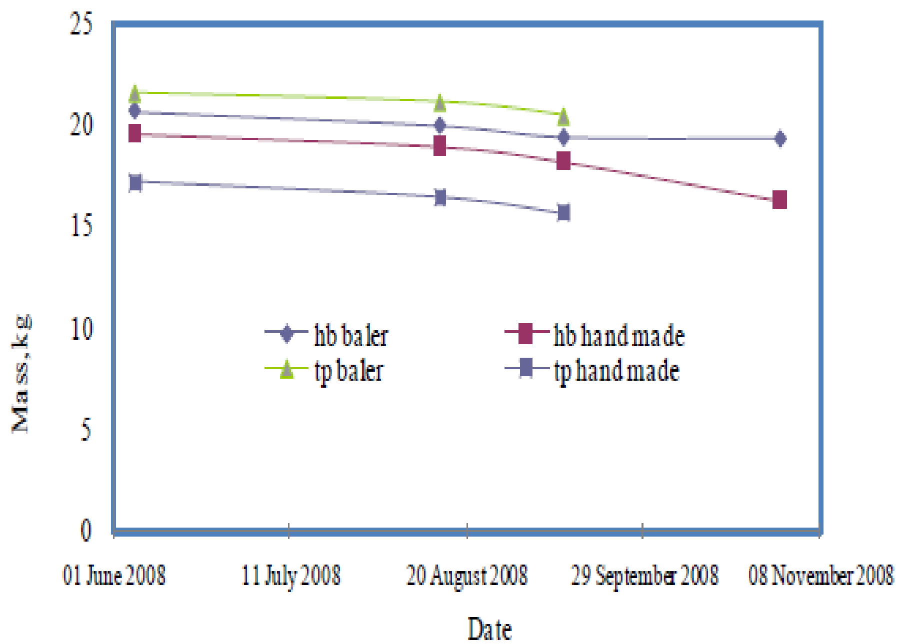

Figure 3. Mass of bales stored under open hay barn (HB) and tarpaulin covered plus hay bam storage (TP).

spatial differences of yield, terrain variations and also the difference in the ease of turning at the headlands of different plots. Assuming that the diesel fuel used by the tractor has an energy heat content of 45 MJ kg^{-1} (Dmytryshyna et al., 2004) and that the dry matter from the hay has an energy heat content of 20 MJ kg^{-1} (Field et al., 2008) and barring any other energy used in the production process, the amount of energy used to do the harvesting and baling is less than 1% of the energy that can be extracted from the harvested biomass.

The grass harvesting rate when using manual methods of harvesting are presented in Table 2. The results show that harvesting of grass using scythes in the early hours of the morning could be as fast as 2.78 and 3.65 h ha^{-1} for both men and women, respectively. However the manual rate of harvesting decreased progressively as the day advanced and it became hotter. The lowest rate of manual harvesting averaged at 11.61 and 15.65 h ha^{-1} for both men and women, respectively, for the period of time between noon and 13:00 h. The men were harvesting at a rate that was at least 30% faster than the women irrespective of the time of day.

Storage quality (mass)

Figure 3 represents the changes occurring in the mass of bales stored in the barn. The handmade bales are lighter than those made using the baling equipment. However, there is a similar decreasing trend in the mass of the bales (whether they are handmade or not) for the period between 6th June and 8th September. This trend is independent of whether the bales are stored under HP or TP storage. The bales stored under TP storage were mistakenly uncovered by an overcautious farm manager following a heavy downpour that occurred on the 17th of

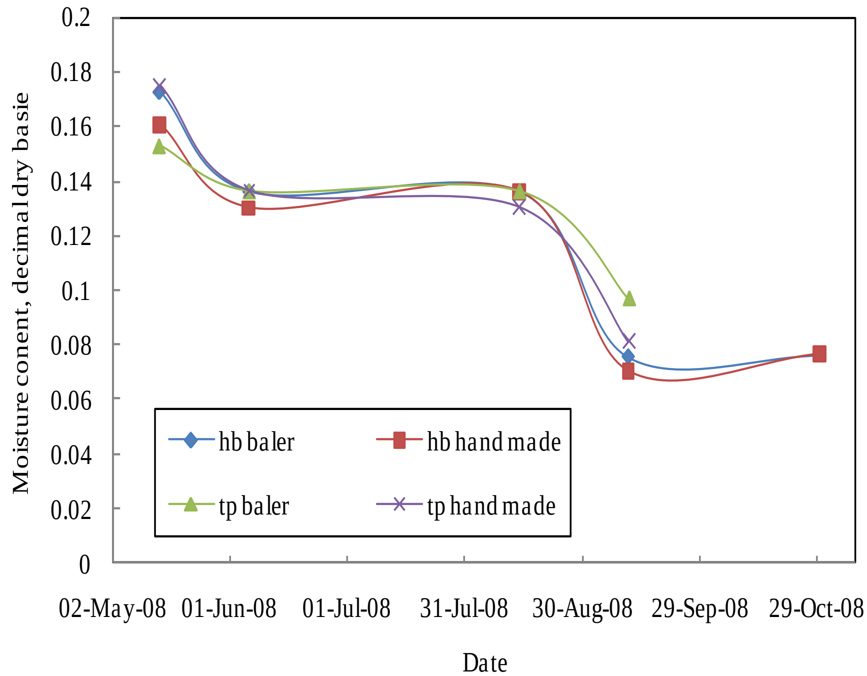

Figure 4. The moisture content of hay bales as a function of storage duration.

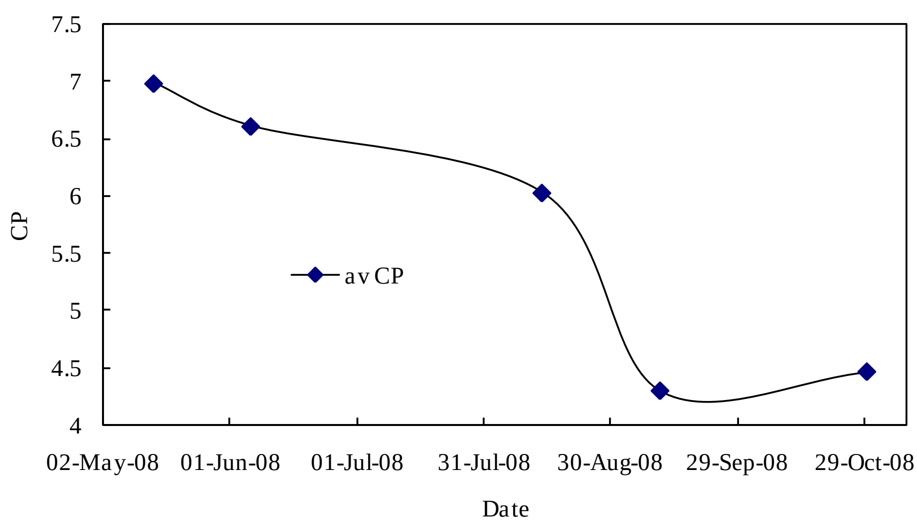

Figure 5. The average crude protein (CP) of hay either stored in an open hay barn or stored in an open hay barn and then covered with tapaulin.

September. Only the data for the HB storage is available for the remaining storage period and the rainfall appears to have slowed the rate of decrease in mass with increase in storage duration for bales made using motorized method. This is perhaps because the downpour resulted in an increase in air humidity. The effect on the high density bales was not duplicated in the low density handmade bales. In these bales the rate of decrease in mass continued unabated.

Hay quality

The average moisture content of bales was 17.19% (dry basis) and it ranged from a low of 15.3% to a high of 17.5% (dry basis) at the time of putting the bales into the store. Thereafter the moisture content of the bales changed with the duration of storage as presented in Figures 4 and 5. It can be observed that the four stacks of bales behaved in a similar manner implying that the

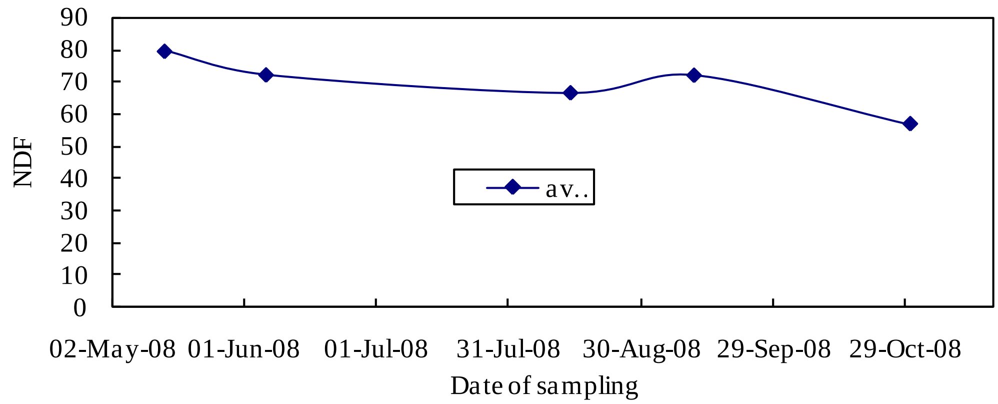

Figure 6. Average values of neutral detergent fibre (NDF) of stored hay bale as a function of date of sampling.

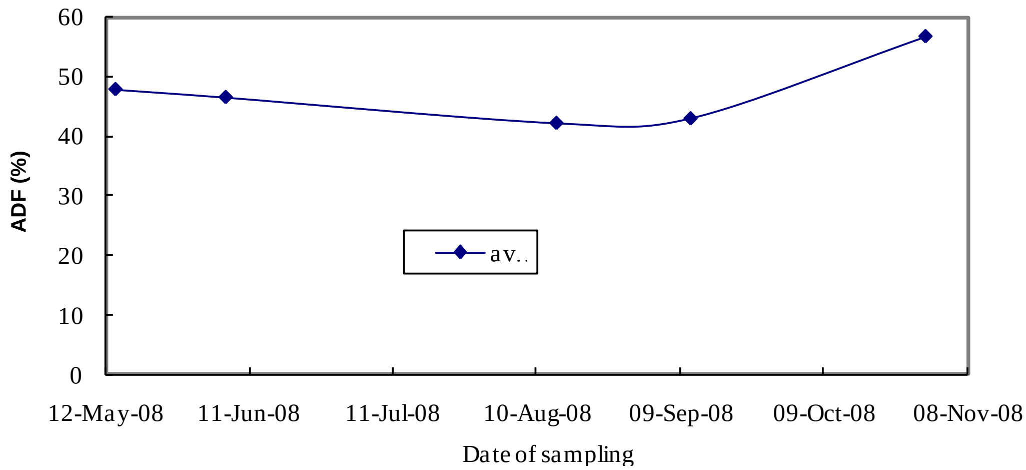

Figure 7. Variation of acid detergent fibre (ADF) with duration of storage of hay bales in an open barn system.

changes in moisture content were not dependent on the way the bales were made. It can also be observed that the change in moisture content was not dependent on the storage method as both the TP and HB bales exhibited similar trends. There was marked decrease in moisture content of the bales soon after storage. This was followed by a period of time when the moisture content remained almost constant. This period represents winter which is the coldest period of the year in Botswana. The moisture content however undergoes a sudden fall between mid August and mid September caused by the temperature increase as the region climbed out of winter. Change in moisture content however decreased in the period of mid September to end of October. The crude protein of hay at harvest was found to be average of 6.99% which is close to the values reported by Ward and Ward (1987) while working on switch grass. The crude protein of hay stored under the hay barn storage method was found not to be significantly different (P>0.1) from that of the hay stored in the hay barn and then also covered with a tarpaulin. Even the changes in crude protein with duration of storage for both storage methods were found to be similar. Consequently, average values for both methods were computed and are presented in form of Figure 5. It was also observed that the trend in the change of crude protein was remarkably similar in shape to that of the change in moisture content as presented in Figure 4.

The average neutral detergent fibre (NDF) and the acid detergent fibre (ADF) are both predictors of hay quality. These values were found to be 79.3 and 47.9% of dry matter at harvest, for NDF and ADF, respectively. Having noted that there is no significant difference (P>0.1) between the NDF and ADF values of hay stored in the two different storage methods for a particular storage duration, the average values were computed for each storage duration and then presented in Figures 6 and 7. The NDF decreases continuously for most of the storage duration except for a slight increase recorded in the period of mid August to mid September. The ADF also has a steady decrease until mid August when it starts to increase with any further increase in duration of storage. Changes in both NDF and ADF that occur after mid August are probably because of temperature changes as the season change from winter to spring.

Conclusion

There are large tracks of unutilized land in arid regions of the world. This land has the potential to produce up to 2 tons of biomass per hectare per season without land degradation if only one harvest per season is practiced. Also the energy required to harvest this biomass represents only a small percentage of the combustible energy that will be recovered from the biomass. The study also shows that grass biomass can be stored safely for up to 5 months in open hay barns.

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REFERENCES

ASAE (1997). ASAE Standards 1997. American society of Agricultural Engineers, St Josephs MI, USA.

Berdahl JD, Karn JF, Hendrickson JR (2001). Dry matter yields of cool-season grass monocultures and grass- alfalfa binary mixtures. Agron. J., 93: 463-467.

Burgess J (2002). FAO Country pasture/forage resource profiles for Botswana, FAO, Rome.

Cooperative Scythe Network (2010). Mowing with ease. Last retrieved in June 2010 from http://www.scytheconnection.com.

DAR (2006). Department of Agricultural Research: Promotion pamphlets. Gaborone, Botswana.

Dmytryshyna SL, Dalai AK, Chaudharia ST, Mishraa HK, Reaney MJ (2004). Synthesis and characterization of vegetable oil derived esters: Evaluation of their diesel additive properties. Bioresour. Technol, 92: 55-64.

Enoh MB, Kijora C, Peters KJ, Yonkeu S (2005). Effect of stage harvest on DM yield, nutrient content, *in vitro* and *in situ* parameters and their relationship of native and brachiaria grasses in the Adamawa Plateau of Cameroon. Livestock research for rural development, pp. 4-17 Retrieved May 2010 from http://www.cipav.org.co/lrrd/lrrd17/1/enoh17004.htm

Field CB, Campbell JE, Lobell DB (2008). Biomass energy: The scale of the potential resource. Trends Ecol. Evol., 23(2): 65-72.

Han KJ, Collins M, Vanzant ES, Dougherty CT (2004). Forage grazing lands: Bale density and moisture effects on alfalfa round bale silage. Crop. Sci, 44: 914-919.

Hemming JC, Wheatson HN (1993). Making and storing quality hay. University of Missouri extension services, Retrieved in May 2010 from http://extension.missouri.edu/publications/DisplayPub.aspx?P=G575.

Humphreys J, O'kiely P (2006). Amount and quality of grass harvested for first cut silage for differing spring grazing frequencies of two mixtures of perennial ryegrass cultivars with contrasting heading dates. Grass and Forage Science, 61: 77-88.

Lee WS, Burks TF, Schueller JK (2002). Silage yield monitoring system. ASAE annual meeting 2002: Paper 021165.

Martí BV, Gonzalez EF (2009). Analysis of the process of biomass harvesting with collecting chippers fed by pick up headers in plantations of olive trees. Biosystems Engineering, 104: 184-190.

McLennan N (2002). Livestock nutrition: Production, storing, feeding, and improving native pasture hay. Agency for food fibre science, File no SW0087, State of Queensland (Department of primary industries and fisheries) Queensland Government, Australia.

Mulkey VR, Owen VN, Lee DK (2008). Management of warm season grass mixtures of biomass production in South Dakota USA. Bioresour. Technol, 99: 609-617.

Murphy JD, Power NM (2009). An argument for using biomethane generated from grass as a biofuel in Ireland. Biomass Bioenergy, 33(3): 504-512.

Nielsen SS (1994). Introduction to chemical analysis of foods. Jones and Bartlett Publishers Inc, Boston.

PCARRD (2001). Philippines Agricultural Engineering Standards: Agricultural machinery- Four wheel tractor method of test, Report Number PAES 199, Philippines council of Agriculture, forestry and natural resources research and development.

Prochnow A, Heierman M Plöchl M, Amon T, Hobbs JP (2009). Bioenergy from permanent grassland – A review: 2 Combustion. Bioresour.Technol.100(21): 4945-4954.

Quarberg D (1999). Hay storage management considerations for Alaska: Report number FGV-00145, Alaska cooperative extension service.

Rayburns E (2001). Proper handling and curing of hay. Virginia forage and grassland council meeting of January 11, 2001. Verona, Virginia.

Samson R, Bailey S, Lem CH (2007). Densified grasses for heat related energy. Resource efficient agricultural production – Canada. Retrieved in June 2010 from www.reap-canada.com

Schmer MR, Vogel KP, Perrin RK (2008). Net energy of cellulosic ethanol from switchgrass: Proceedings of the national academy of sciences PNAS) of the United States, 10(2): 464-469.

Suttie JM (2000). Hay and straw conservation for small scale farming and pastoral conditions. FAO, ISBN: 92(5): 104458-9.

Titterton M, Mhere O, Maasdorp B, Kipnis T, Ashbell G, Weinberg Z (1999). Conservation of forage for dry season feeding of livestock in semi arid areas of the tropics. In Proceedings of a joint ZSAP/FAO "Strategies for dry season feeding of animals in central and southern Africa" workshop held in Harare, Zimbabwe on 25th-27th October 1999 Edited by Holmes D H.

Turner JE, Lobtenz WK, Scarbough DA, Coffey KP, Kellogg DW, Mcbeth LJ, Rhein RT (2002). Change in nutritive value of bermudagrass hay during storage. Agron. J., 94:109-117.

Ullreys DE (1997). Hay quality evaluation fact sheet number 001 of July 1997. Michigan State University.

Ward MG, Ward JK (1987). Ammonization of warm-season grass hay for gestating beef cows. J. Anim. Sci., 65: 359-365.

Zhou X, Persaud N, Wang H (2005). Periodicities and scaling parameters of daily rainfall over semi-arid Botswana. Ecol. Model.182: 371-378.