The Potential of Mulberry (*Morus alba*) as a Fodder Crop: The Effect of Plant Maturity on Yield, Persistence and Nutrient Composition of Plant Fractions

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ABSTRACT : The forage potential of mulberry (*Morus alba*) was evaluated under Malaysian conditions. The yield and nutrient composition of plant fractions of mulberry (whole plant, leaf and stem fractions) were determined at four harvest stages, namely, 3 (W3), 5 (W5), 7 (W7) and 9 (W9) weeks in a randomized block design. The study was conducted over a 9-month period to assess the persistence of the crop to repeated harvests. Fresh and dry matter (DM) yields of all plant fractions increased significantly ($p<0.01$) with increasing intervals between harvests, with highest DM yields at W9. The leaf to stem ratio declined significantly ($p<0.01$) from 5.2 (W3) to 0.9 (W9), indicating predominance of the stem fraction with advancing maturity. The nutritional composition of plant fractions was also significantly influenced ($p<0.01$) by advancing plant maturity at harvest. Crude protein (CP), ash and the metabolisable energy content of plant fractions declined significantly ($p<0.01$) from W3 to W9, while there was a corresponding significant increase ($p<0.01$) in the acid detergent fibre, neutral detergent fibre and acid detergent lignin. From this study it was concluded that the optimum stage to harvest the whole plant is 5 weeks, which is a compromise between yield, nutrient composition (CP and fibre components), and the annual number of cuts, with good crop persistence to repeated harvests. Fresh mulberry whole plant can provide a valuable supplemental source of nutrients to poor quality basal diets. ***(Asian-Aust. J. Anim. Sci. 2004. Vol 17, No. 12 : 1657-1662)***

Key Words : Mulberry, Harvest Stage, Persistence, Yield, Nutrient Composition

INTRODUCTION

The leaves of the multipurpose perennial shrub, mulberry (*Morus sp*), traditionally used for silkworm rearing, is known for its high protein content with good amino acid profile, high digestibility, high mineral content, low fibre content and very good palatability (Sanchez, 2002). The high biomass yield of the plant together with its low tannin content (Patra et al., 2002; Singh and Makkar, 2002) make it an attractive fodder resource for ruminants particularly, as a supplement to low quality basal diets. There is evidence that mulberry foliage compares favourably to commercial concentrates (Patra et al., 2002), whilst maintaining optimum animal performance (Gonzales and Milera, 2002; Liu et al., 2002; Sanchez, 2002), through improvements in the rumen functions (Singh and Makkar, 2002).

Research conducted on mulberry in different countries (Gonzales and Milera, 2002; Liu et al., 2002), have focused mostly on the utilisation of the leaves, which like most forages, contain greater nutrient concentrations than the whole plant. The whole plant, when harvested during the early growth stages can be a potentially valuable supplemental feed resource to poor quality diets. However systematic and in-depth knowledge on the yield and nutritional composition of mulberry in early growth stages is either not available or poorly defined. Furthermore, there are no reports on the production and nutritional composition of mulberry in Malaysia, with respect to its utilisation as an animal feed.

This study was conducted to determine the yield, persistence and chemical composition of mulberry re-growths at four growth stages and the optimum harvest stage in relation to biomass yield and nutritional composition.

MATERIALS AND METHODS

Experimental site and plot maintenance

The study was conducted on loamy clay soil on the experimental farm of the Department of Animal Science, University Putra Malaysia at Serdang, Selangor, Malaysia. Meteorological data were collected from the meteorological station on the farm throughout the experimental period, from June 2002 to March 2003. Mulberry species, *Morus alba*, was established at a planting density of approximately 20,000 plants/ha (plant spacing of 50×60 cm) and maintained under rain-fed conditions. A maintenance fertiliser rate of 50 kg/ha/yr each of N, P and K (Soo-Ho et al., 1990) was used in split applications over the experimental period. Hand weeding was practised routinely.

Experimental design

The experimental plot was divided into 4 subplots, which were sub-divided into 4 parcels in a randomised complete block design (Gomez and Gomez, 1984), to represent one of the four growth stages, namely, 3 (W3), 5

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Received December 19, 2003; Accepted June 16, 2004

Table 1. Rainfall and temperature during the experiment

	Rainfall (mm)	Temperature (°C)	
		Minimum	Maximum
May	14.7	25.0	34.4
June	4.3	24.2	33.9
July	13.9	24.5	33.6
August	15.2	24.5	33.2
September	17.5	24.2	32.9
October	25.4	24.5	33.7
November	55.1	24.5	32.2
December	35.6	24.7	33.7
January	33.8	24.5	32.8
February	34.8	24.4	34.0
March	7.9	23.8	34.5

(W5), 7 (W7) and 9 (W9) weeks. There were a total of 16 parcels each of 9 m^2.

Sampling procedure

The plants were initially cut back at approximately 50 cm above ground level one year after establishment. Whole plant samples were cut at approximately 2 cm from the base of the re-growths, from each parcel within an area of 3 m^2 (a total of 6 plants per parcel) to avoid border row effects. Harvests were repeated over a period of 9 months, to assess plant persistency to repeated harvests. Samples were taken and transported to the laboratory within 1 h following harvest for measurements.

Yield measurements

Fresh weight of re-growths and the number of stems were recorded for each plant and later pooled per block before sampling for measurements of stem height, whole plant dry matter (DM). Leaf to stem (L:S) ratio was determined by hand separation of whole plant into leaf (with petiole) and stem. Sub samples of plant fractions (whole plant, leaf and stem) were dried in air-forced oven at 60°C for 48 h for DM determination. Fresh yield was converted to DM yield per plot and per hectare, respectively, according to the equations:

$$\text{DM yield/plot} = \text{weight of fresh material} \times \text{DM \%}$$

$$\text{DM yield/ha} = \text{DM yield/plot} \times \text{Number of plots/ha}$$

Chemical analysis

Oven-dried samples were ground to pass through a 2 mm sieve for chemical analyses. The DM, ash and crude protein (CP) were determined according to the AOAC (1990) procedures. Organic matter (OM) was calculated as 100- % ash. Neutral and acid detergent fibres (NDF and ADF) and acid detergent lignin (ADL) were estimated according to the method of Van Soest et al. (1991). Cellulose content (Cel) was calculated by difference between ADF and ADL and hemicellulose (Hem) by difference between NDF and ADF. Values for metabolisable energy (ME) were derived from appropriate equations (NRC, 1981).

Table 2. Yields (mt/ha/harvest) and L:S ratio at four stages of harvest

Yield	W3	W5	W7	W9	SEM
Whole plant, fresh	1.26^{d}	2.72^{c}	4.78^{b}	7.61^{a}	1.2
Whole plant DM	0.30^{d}	0.86^{c}	1.41^{b}	2.63^{a}	0.38
Leaf DM	0.29^{d}	0.58^{c}	0.83^{b}	1.18^{a}	0.04
Stem DM	0.06^{d}	0.29^{c}	0.58^{b}	1.44^{a}	0.06
L:S ratio	5.19^{a}	1.94^{b}	1.65^{bc}	0.88^{c}	0.23

a-d Means with the different superscripts within rows differ significantly ($p<0.05$).
SEM: Standard error of means pooled across harvest stages.

Statistical analysis

Analysis of variance (ANOVA) for a randomised complete block design (Gomez and Gomez, 1984) was conducted for yield and chemical composition data using the general linear procedure of SAS (1990). Mean values were compared using Duncan Multiple Range test.

RESULTS

Climate

Cumulative rainfall during the experimental period was 258 mm, the driest months being June 2002 and March 2003 with 4.4 and 7.7 mm of rain, respectively (Table 1). Two distinct seasons were observed, a dry period between May and September 2002 and a wet season between October 2002 and February 2003. The low rainfall recorded for March 2003 suggested the start of the next dry season.

Yield

Yields of fresh and DM of whole plant, leaf and stem fractions increased significantly ($p<0.01$) with increasing harvest intervals, while there was a significant decrease ($p<0.01$) in the L:S ratio with advancing maturity (Table 2). The annual fresh and DM yields ranged from 25.9 to 38.1 mt/ha/yr and from 6.2 to 13.1 mt/ha/yr, respectively, from W3 to W9. The estimated annual leaf DM yield was similar at all maturity stages (5.0-5.9 mt/ha/yr), while the annual stem DM yield increased significantly ($p<0.01$) from 1.0 mt/ha/yr at W3 to 7.21 mt/ha/yr at W9. This resulted in a significant decrease ($p<0.01$) in the leaf fraction from 77.8% at W3 to 45.7% at W9.

Advancing maturity was associated with a decrease in the number of stems per plant ($p<0.01$) from 30 at W3 to 19 at W9, and a significant increase in stem height ($p<0.01$) from 21.7 cm at W3 to 90.9 cm at W9. Stem height was positively correlated with DM yield at W3 ($R^2=0.76$), W7 ($R^2=0.79$) and W9 ($R^2=0.84$), respectively.

Repeated harvests of the plants resulted in significant

Table 3. Chemical composition of plant fractions at 4 stages of maturity

	DM	% DM						
		CP	Ash	NDF	ADF	ADL	Cel	Hem
Whole plant								
W3	25.2^{c}	32.0^{a}	9.7^{a}	33.2^{c}	22.4^{d}	5.2^{c}	17.2^{c}	13.4
W5	30.9^{b}	24.9^{b}	10.1^{a}	39.7^{b}	27.7^{c}	6.7^{c}	20.8^{b}	11.4
W7	30.3^{b}	20.5^{c}	8.5^{b}	41.1^{b}	31.3^{b}	9.7^{b}	21.6^{ab}	12.7
W9	34.4^{a}	17.2^{d}	6.7^{c}	52.4^{a}	37.9^{a}	13.6^{a}	24.4^{a}	13.1
SEM	0.42	0.49	0.17	0.71	0.73	0.51	0.58	0.41
Leaf								
W3	24.9^{c}	35.8^{a}	9.6^{b}	28.3^{b}	17.9	4.8^{a}	13.1^{b}	12.8
W5	31.8^{ab}	30.6^{b}	10.9^{a}	30.9^{a}	18.3	3.4^{b}	14.9^{a}	11.3
W7	30.4^{b}	28.1^{c}	9.9^{b}	28.3^{b}	17.9	4.3^{ab}	13.6^{b}	10.5
W9	32.4^{a}	26.9^{c}	9.2^{b}	30.5^{ab}	18.5	4.6^{a}	13.9^{ab}	11.4
SEM	0.43	0.36	0.14	0.40	0.17	0.18	0.34	0.48
Stem								
W3	30.9^{b}	15.8^{a}	9.5^{a}	61.1^{c}	45.5^{b}	12.8^{b}	32.6	17.5
W5	24.1^{c}	11.1^{b}	7.5^{b}	61.6^{c}	47.7^{b}	16.1^{b}	31.6	14.4
W7	23.7^{c}	8.3^{c}	5.3^{c}	66.9^{b}	49.2^{b}	18.2^{b}	31.1	19.1
W9	36.3^{a}	6.9^{c}	3.9^{d}	72.3^{a}	56.8^{a}	32.0^{a}	24.8	16.4
SEM	0.84	0.39	0.23	0.59	0.76	1.23	1.1	0.78

$^{a-d}$ Means with the different superscripts within each column for each plant fraction differ significantly (p<0.05).

Table 4. Expected CP yield (mt/ha) at different harvest stages

Harvest stage	CP yield/harvest	CP yield/yr
Whole plant		
W3	0.12^{d}	2.0
W5	0.21^{c}	2.1
W7	0.30^{b}	2.1
W9	0.45^{a}	2.3
Leaf		
W3	0.11^{d}	1.8
W5	0.18^{c}	1.8
W7	0.24^{b}	1.7
W9	0.33^{a}	1.6
Stem		
W3	0.01^{d}	0.14^{c}
W5	0.03^{c}	0.33^{b}
W7	0.05^{b}	0.36^{b}
W9	0.11^{a}	0.55^{a}

$^{a-d}$ Means with the different superscripts in each column for each plant fraction differ significantly (p<0.01).

differences (p<0.01) in fresh and DM yields of all plant fractions and the L:S ratio at all harvest stages. However, no significant trend could be established given the wide fluctuations in DM yields between the different harvests for each harvest stage. There was a general declining trend in the number of stems under repeated harvests for all harvest stages while there was a corresponding significant increasing trend in stem height (p<0.01).

Nutrient composition

The DM content of the all plant fractions increased with advancing maturity (p<0.01), with more pronounced differences in the whole plant and stem fraction than in the leaf (Table 3). Highest DM content was obtained at W9 for all fractions.

The overall CP concentration in the leaves (30.8% DM) was greater than in the whole plant (25.1% DM), and stem fraction (10.7% DM), respectively (Table 3). The CP content of the plant fractions declined significantly (p<0.01) with advancing plant maturity from W3 to W9 (Table 3), with more pronounced effects in the whole plant and stem fractions compared to the leaf. Highest CP concentration was recorded in the leaves at W3, while leaf CP concentration at W9 was comparable to that of the whole plant at W5. The CP content of the stem fraction ranged from 7.6 to 14.1%.

The expected CP yield/ha/harvest, calculated from yield data and CP content of the different fractions was significantly different at all harvest stages (p<0.01) and was in the order: W9>W7>W5>W3 (Table 4). However, when expressed on an annual basis, there were no significant differences in the CP yields of the whole plant and the leaf fraction at all harvest stages. The stem, however, yielded lower annual CP yield.

The mean NDF content was highest (p<0.01) in the stem fraction (65.3% DM) compared to the whole plant (40.5% DM) and the leaf (29.4% DM). The variation in NDF in the leaf fraction was however less pronounced than in the whole plant or the stem fraction. The NDF content of plant fractions increased significantly (p<0.01) with plant maturity and was highest at W9. The NDF content of whole plant at W5 and W7 was not significantly different (p<0.01).

The ADF content of whole plant and the stem fraction increased significantly (p<0.01) with plant maturity (Table 3), unlike the leaf, which had similar ADF content at all harvest stages.

Advancing plant maturity was associated with a significant (p<0.01) increase in the ADL content of the

Table 5. Estimated ME[1] (MJ/kgDM) content of plant fractions at different harvest stages

	W3	W5	W7	W9	Mean[2]	SEM
Whole plant	10.8[a]	9.7[b]	8.9[c]	7.5[d]	9.4	0.15
Leaf	11.7	11.7	11.6	11.6	11.7	0.04
Stem	5.9[a]	5.4[a]	5.1[a]	3.5[b]	5.0	0.16

[a-d] Means with the different superscripts in each row differ significantly ($p<0.01$).
[1] ME (MJ/kg DM) = 0.82 × {0.04409 × [102.56 - (ADF % × 1.4)]}
[2] Mean values pooled across all harvest stages.

whole plant and stem (Table 3), the latter having the highest lignin concentration. Although ADL in the leaf showed significant differences between the harvest stages, no particular trend could be observed. The increase in lignification from W3 to W9 was more pronounced in the stem fraction and to a lesser extent in the whole plant.

The overall cellulose and hemicellulose contents of the plant fractions were respectively, 20.6 and 12.6% for the whole plant, 13.9 and 11.4% for the leaf and 30.4 and 16.6% for the stem. Cellulose content of the whole plant increased significantly ($p<0.01$) with plant maturity (Table 3). The leaf cellulose content, although significantly influenced by plant maturity, did not show any consistent trend over the harvest stages. Plant maturity at harvest did not have any significant influence on the cellulose content of the stem and the hemicellulose content of all plant fractions (Table 3).

The ash content of the whole plant, the leaf and stem fractions decreased significantly with maturity (Table 3). The decline in the ash content was more marked in the whole plant and the stem fraction than in the leaves.

The ME content of the whole plant decreased significantly ($p<0.01$) with advancing maturity as follows: W3>W5>W7>W9 (Table 5). The energy content of the leaf was similar at all harvest stages, while that of the stem declined significantly ($p<0.01$) from W7 to W9. The leaves had higher energy concentration than the whole plant and the stem, respectively.

The chemical composition of mulberry of all plant fractions fluctuated over the successive harvests, but no significant trend could be established.

DISCUSSION

Yield

Increasing intervals between harvests significantly increased the fresh and DM yields of all plant fractions, although there was a predominance of the stem with advancing maturity. This trend is in agreement with findings of Boschini (2002) and Rodrigues et al. (1994), cited by Martin et al. (2000) who obtained increases in biomass production with increasing harvest intervals. Yield data obtained in the present study were lower than that reported by some authors (Blanco (1992) cited by Boschini, 2002), for plants harvested at 6, 9 and12 week-intervals. Differences in yield may be due to the influence of many factors such as, plant density, soil conditions, fertilizer application practices and geographical location as reported by Tingzig et al. (1988).

Nutrient composition

Advancing plant maturity resulted in significant changes in the nutritional composition of mulberry, which is reflected in the decline in protein content, and an associated increase in the fibre components, namely, NDF, ADF and lignin. The effects of plant maturity on the fibre components were more marked in the whole plant and stem fraction, compared to the leaves, indicating that the leaves have less structural material than the stem. The decline in CP with advancing plant maturity is also a consequence of the decrease in the L:S ratio and was consistent with reports of Liu et al. (2002), Martin et al. (2002) and Boschini (2002). Although highest CP concentration was obtained in all plant fractions at W3, the plants showed poor persistency to repeated harvests. The CP concentration of mulberry stem is comparable to mature forages such as guinea grass (*Panicum maximum*) in early or full bloom (5.5 and 6.6%, respectively) or Napier grass (*Pennisetum purpureum*) post-ripe (4.1%), (NRC, 1981). At W9, CP content of the stem (6.9%) was well within the range of the critical level of CP (6.5 to 8.5% DM) in forages, to support the activity of the rumen microorganisms (Shayo, 1997). The mean crude protein content of mulberry whole plant (25.1%) is comparable to that of alfalfa (*Medicago sativa*) (14-20%; NRC, 1981). This places mulberry in the same rank as high quality forages. The non-significant effect of plant maturity on the annual CP yield of whole plant and leaf implies that the whole plant can be harvested in the early growth stages. However, given the poor persistence of the plant at W3, harvesting at this stage is not desirable.

The high NDF content of the stem fraction is related to the anatomical structure of the mulberry plant, whereby the fibre resides mostly in the stem for support (Van Soest, 1990). Fluctuations in the NDF content of plant fractions over the successive harvests may be related to fluctuations in temperature, which influence the extent of lignification (Van Soest, 1990).

The relatively low ADF content in mulberry is indicative of its high digestibility. The ADF values obtained in the present study were lower than values reported by Singh and Makkar (2002), Schmidek et al. (2002), Boschini (2002) and Datta et al. (2002). These differences may be due to factors such as rain damage, weathering, high temperatures and weeds (Van Soest, 1990).

The variation in the cellulose content with maturity was significant for the whole plant and leaf fraction only. Datta et al. (2002) reported cellulose values in the range of 10-40% for the leaves, while Singh and Makkar (2002) reported values of 19-25%. Cellulose is the major fibre fraction to be digested and is normally tied up with lignin when the latter is present in high levels, particularly with advancing maturity, hence making it indigestible. With advancing maturity, the increase in the ADF fraction (ADF) was associated with significant increases in both the lignin and cellulose components. However, cellulose predominated the lignin component, even up to W9 for the whole plant and up to W7 in the stem fraction, while at W9 there was a predominance of lignin relative to cellulose in the stem. This implies that the whole plant maintains high digestibility up to W7, beyond which, the digestibility may be reduced due to the formation of lignocellulose.

The concentration of minerals in forages is influenced by plant maturity, soil type and fertility, climate, time of the year, DM yield and harvest conditions (Rayburn, 1997; Polland et al., 2001). Such factors, together with the shift in the L:S ratio with advancing maturity may explain the decrease in ash content over time. Schmidek et al. (2002) reported ash values of 90 day-old leaves to be 9.8%, which is comparable to the range of 9.6 to 9.2% obtained in the present study. Singh and Makkar (2002), on the other hand, reported higher values ranging from 14.3 to 22.9% for the leaves.

The mean ME content of the whole plant and the leaves (9.4 and 11.7 MJ/kg DM, respectively) showed that mulberry is comparable to energy feed such as rice or wheat bran (ME: 10.6 MJ/kg DM, NRC, 1981) and is slightly lower than corn (12.6 MJ/kg DM, NRC, 1981). The mature stem at W9 also provides an additional energy source (3.5 MJ/kg DM) to the animal.

Fresh mulberry can thus provide a good energy source, besides being a good protein and mineral source, hence serving multiple functions appropriate for satisfying the requirements of the rumen microbes.

CONCLUSION

The high protein content and low content of cell wall components (NDF, ADF and ADL) in mulberry are indicators of its good forage quality (Van Soest, 1990). Harvesting at very early growth stages may result in low DM yields and increase the risk of losing the crop if not intensively managed. This was observed in the poor plant persistence when mulberry was harvested at W3. On the other hand, delayed harvesting resulted in higher yields and greater plant persistence, but was also associated with a marked reduction in the L:S ratio and CP content and a corresponding increase in lignification, although the lignin content relative to cellulose was still low.

On the basis of the estimated annual CP yield and the variation in NDF fraction with advancing maturity, it can thus be concluded that the mulberry plant re-growths are best harvested at five week-intervals. At this harvest stage, mulberry provides forage of high digestibility and high protein, energy and mineral sources to ruminants that can improve the efficiency of utilisation of low quality fibrous roughages, such as rice straw. The benchmark analysis for alfalfa for high-producing dairy cows is considered to be 20% CP, 30% ADF, and 40% NDF (OMAF, 2003) and in this respect, mulberry whole plant harvested at 5 week-intervals, is comparable to, if not better than alfalfa. However, being a non-legume, regular fertilisation practices must be observed to maintain vigorous growth of the plant.

ACKNOWLEDGEMENTS

The postgraduate fellowship granted by the Third World Organisation for Women in Science (TWOWS) and the support of the management of the Agricultural Research and Extension Unit (AREU) of the Food and Agricultural Council (FARC), in particular, Mr. S. Naidu, Director, for the grant of study leave are gratefully acknowledged.

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