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Biomass production and chemical composition of *Moringa oleifera* under different management regimes in Nicaragua

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Abstract

The effects of different planting densities (250,000, 500,000 and 750,000 plants ha^{-1}) and cutting frequencies (45, 60 and 75 days) on the biomass production and chemical composition of *Moringa oleifera* was studied in a completely randomised split plot design with four blocks, in Managua, Nicaragua, located geographically at 12°08′15″ N and 86°09′36″ E. The 75 day cutting frequency produced the highest fresh matter yield, 100.7 and 57.4 Mg ha^{-1} $year^{-1}$, and dry matter (DM) yield, 24.7 and 10.4 Mg ha^{-1} $year^{-1}$, during the first and second year, respectively. All planting densities produced the highest DM yield at 75 day cutting frequency. In the first year, the density of 750,000 plants ha^{-1} produced the highest fresh matter yield, 88.0 Mg ha^{-1} and highest DM yield, 18.9 Mg ha^{-1}, but in the second year the density of 500,000 plants ha^{-1} gave the highest yields, 46.2 Mg ha^{-1} and 8.1 Mg ha^{-1}, respectively. During the first year, DM (22.8%), neutral detergent fibre (NDF) (30.8%) and ash (9.14%) contents were highest and *in vitro* DM digestibility (IVDMD) (68.2%) was lowest in the longest cutting interval, while contents of crude protein (CP) (22.8%) and acid detergent fibre (ADF) (22.8%) were not affected significantly by cutting frequency. In the second year, DM and CP contents and IVDMD were not significantly affected by cutting frequency, whereas NDF, ADF and ash contents were lowest in the 60 day cutting frequency. Planting density had no significant effect on chemical composition or IVDMD. These data suggest that *Moringa* forage could be an interesting protein supplement for ruminants.

Introduction

The incorporation of tree and shrub species in animal production systems can be a viable alternative to improve the utilization of land and at the same time improve the diet of ruminants. Some trees and shrubs are easily propagated and do not require a high level of management input. In addition, some forage shrubs contain levels of crude protein (CP) that are higher than other feeds traditionally used in animal feeding (Benavides 1994), which improves intake of roughage by ruminants. Shrubs may have good access to water that percolates through the topsoil and infiltrates into the subsoil (30–150 cm) and have the capacity to produce high quantity and quality forage in sites with prolonged dry periods (Knoop and Walker 1985). Some shrub species are long-lived, require low maintenance and may enhance the sustainability of the farming system.

Moringa oleifera Lam (synonym: *Moringa pterygosperma* Gaertner), commonly referred to as the 'drumstick tree', is a member of the Moringaceae family, which grows throughout most of the tropics and is native to the sub-Himalayan tracts of north-western India, Pakistan, Bangladesh and Afghanistan (Makkar and Becker 1997). In Nicaragua *Moringa* was introduced and naturalised in the first 20 years of the 19th century as an ornamental tree and was also used as a live fence and windbreak (Morton 1991). The tree has a height of 7–12 m up to the crown (Makkar and Becker 1997). The leaves are twice or thrice pinnate and spirally arranged. The flowers are bisexual, white or cream coloured with yellow stamens, and the fruit is a three sided or nearly cylindrical capsule. The seed is round, dark chestnut-coloured, and with 3 white wings that facilitate spreading by the wind in natural conditions. *Moringa* can be propagated either by using seeds or cuttings (Morton 1991). Fruits, seeds, leaves and flowers are consumed by humans as nutritious vegetables in some countries (Makkar and Becker 1997).

Moringa can grow in all types of soil, from acid to alkaline (Duke 1983) and can tolerate up to 6 months of dry season reasonably well. The tree grows well at altitudes from 0 to 1800 m a.s.l. and rainfall between 500 and 1500 mm per year. It is therefore useful for semi-arid areas. However, a prolonged period of stress caused by lack of water will result in loss of leaves. The total dry matter (DM) production is high, from 4.2 to 8.3 Mg ha^{-1} with harvesting every 45 days, and fresh leaves contain between 19.3% and 26.4% CP in DM (Makkar and Becker 1996, 1997; Foidl et al. 1999; Aregheore 2002). Moringa leaves have a negligible content of tannins, a saponin content similar to that of soybean meal and no trypsin and amylase inhibitors or cyanogenic glucosides (Makkar and Becker 1996, 1997).

Moringa has a high growth rate and capacity to produce large quantities of fresh biomass even at high planting densities. High densities (1 million plant/ha) can cause competition between plants and the lack of light can cause loss of seedlings (20–30% per cut with the 45 days interval) producing high loss of productive material. The reaction to the cut is negative when the diameter of the stems (at the moment of cut) is small (5–10 mm), indicating that the capacity for producing regrowth is limited (Foidl et al. 1999).

The management of fodder trees for maximum production of edible DM depends upon several factors, such as time of the initial cut, frequency and intensity of defoliation, cutting pattern prior to the onset of the dry season (Paterson et al. 1998) and the density of the trees (Knoop and Walker 1985).

Moringa has been evaluated to a limited degree in the Latin American tropics and consequently research is needed to get information about the effects of plant density, height and frequency of cutting, age at first cut and quality when used as animal feed.

The objective of the present experiment was to determine the effects of three cutting frequencies and three plant densities on biomass production, nutritive value and digestibility of leaves, petioles and stems of *Moringa oleifera* in the dry tropics in Nicaragua with the soil and climatic characteristics of the chosen site.

Material and methods

Location of experimental area

The study was conducted at the farm of the National University of Agriculture (UNA) in Managua, Nicaragua, located geographically at 12°08′15″ N and 86°09′36″ E at an altitude of 56 m a.s.l. This corresponds to an ecological zone of dry tropical forest, with average annual rainfall of 1403 mm and a relative humidity of 72% (INETER 2003). There is a dry season between November and April and a wet season between May and October. Mean annual temperature is 27.3 °C, with the highest temperatures occurring towards the end of the dry season. Fieldwork for the present study was conducted from July 2001 to November 2003. During the experiment, there was very low rainfall in the months December–March and the highest rainfall in the months May, June and September (150–450 mm per month). The temperature reached a maximum in April and a minimum in November of 29.6 and 26.4 °C, respectively.

The soil of the experimental area belongs to the series of Sabana Grande of flat topography. It is of volcanic origin with pH 7.3 and classified as slightly alkaline, with low percentages of organic matter (1.97%) and nitrogen (0.09%). It contained 17.33 ppm available phosphorus, 1.96 meq/100 g soil of available potassium and 11.0 meq/100 g of exchangeable calcium. Available phosphorus and potassium were determined by Olsen's method (Olsen and Sommers 1982) and calcium was extracted with ammonium acetate at pH 7. The soil of the experimental plots was classified as class II according USA system (USDA 2003) and texturally as a sandy loam with 17.5% clay, 22.5% silt and 60% sand, with good drainage and appropriate for agriculture. The main constraints are wind erosion and low fertility.

Soil preparation and sowing

Soil preparation was done by conventional tillage using a tractor and mechanical tools to clean the land from plant debris, and by disk ploughing followed by two disk harrowing and furrowing. Seeds of *Moringa* were used for propagation. The seeds were sown on the study site in July 2001 at 2 cm depth in the soil and with 2 seeds per drill. However, after 2 months germination, the stand was thinned and only one healthy plant was kept. Irrigation was not applied and the plot was fertilised at the rate of 90 kg N ha^{-1} as urea and 30 kg P ha^{-1} (P_2O_5) and 30 kg K ha^{-1} (K_2O) on two occasions, one after sowing and the other after the uniform cut. Control of weeds was done manually 30 days after germination and every 2 and 3 months, during the rainy and dry seasons, respectively. Pest and disease incidence was not observed during the experiment.

Experimental design and sampling procedures

A completely randomised split plot design with four blocks was used. The blocks were divided into three main plots and three plant densities (250,000, 500,000 and 750,000 plants ha^{-1}) were randomised over each main plot. Cutting frequencies of 45, 60 and 75 days were randomly split over the main plot. The experiment was set up in a field of 1440 m^2, with 720 m^2 for planting (36 sub plots) and the remaining 720 m^2 a border area (2 m wide alley between blocks and 1 m between sub plots) to facilitate management of the experiment and agronomic labour. The individual sub plot size was 20 m^2 and the net area 12 m^2 to eliminate the edge effect.

At the start of the study, in October 2001, the whole plantation was uniformly cut at a height of 20 cm above ground and all foliage was removed. Harvesting of the regrowth was done for two subsequent years starting from November 2001. Harvesting of the regrowth was made with a machete at a height of 25 cm above ground uniformly throughout the experimental period, according to the decided cutting frequency. The fresh matter of each replication in each treatment was harvested, weighed and registered to estimate fresh matter yield. The material obtained was separated into two fractions: a fine fraction, which included leaves, petioles and stems of a diameter smaller than 5 mm, and a coarse fraction of stems with diameters larger than 5 mm. Samples of the fine fraction was taken for later chemical analysis. Evaluated variables were total yield of fresh matter, fine fraction of fresh matter, coarse fraction of fresh matter, total yield of DM and fine fraction of DM, in Mg ha^{-1}, plant height (cm) and growth rate (kg DM ha^{-1} day^{-1}).

Average height of the plants was estimated by measuring heights of five different plants in each net sub-plot of each treatment (Toledo and Schultze-Kraft 1982). The measurements were made between the plant base (soil) to the highest tip of the leaves. Growth rate, the daily biomass production (kg DM ha^{-1} day^{-1}) during each cutting frequency, was estimated by the following formula: Growth rate = DM yield (kg ha^{-1} cut^{-1})/ cutting frequency (days).

Chemical analyses

All samples were dried in a forced draft oven at 65 °C for 48 h. Dried samples were ground to pass through a one mm sieve for quality evaluation. DM was determined by oven drying samples at 105 °C for 6 h and ash determination was done at 550 °C for 8 h. Total N was determined by the semi-micro Kjeldahl procedure (Kass and Rodríguez 1993) and CP calculated as N $\times$ 6.25. Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined by the procedure proposed by Goering and Van Soest (1970). *In vitro* DM digestibility (IVDMD) was determined by the two stage digestion technique, but using only 24 h for the pepsin digestion phase (Kass and Rodríguez 1993).

Statistical analyses

An analysis of variance was conducted to determine effect of plant density and cutting frequency on the variables measured by using the General Linear Model in the Minitab Statistical Software Version 12.0 (Minitab 1998). Tukey's pairwise comparison procedure was used when the differences between means were significant ($p < 0.05$). The mathematical model used was $Y_{ijk} = \mu + B_i + D_j + (BD)_{ij} + F_k + (DF)_{jk} + \epsilon_{ijk}$ where μ was the overall mean, B_i the random effect of block, D_j the random effect of plant density, BD_{ij} interaction effect between block and density, F_k the random effect of cutting frequency, DF_{jk} interaction effect between plant density and cutting frequency and ϵ_{ijk} the random residual error.

Results

Biomass yield

The effects of different cutting frequencies on biomass production, growth rate and average height of the *Moringa* plants are shown in Table 1. The total yield of fresh matter, coarse fraction of fresh matter, total yield of DM, growth rate and height during the first and second year increased significantly ($p < 0.05$) as the cutting interval was prolonged from 45 to 75 days. The fine fractions of fresh matter and DM were not significantly different between cutting frequencies in the first year. However, in the second year fine fraction of both fresh matter and

Table 1. Biomass yield, growth rate and average height[1] of *Moringa oleifera* at different cutting frequencies during the first and second year after planting, in Managua, Nicaragua.

Variable	Cutting frequency (days)			
	45	60	75	SE
Number of cuts per year	8	6	5	
First year (2001–2002)				
Fresh matter yield (Mg ha^{-1})				
Total	71.4^{b}	75.3^{b}	100.7^{a}	3.49
Fine fraction	52.2^{a}	50.1^{a}	46.3^{a}	2.11
Coarse fraction	19.0^{c}	25.2^{b}	54.4^{a}	1.94
Dry matter yield (Mg ha^{-1})				
Total	13.5^{b}	15.2^{b}	24.7^{a}	0.77
Fine fraction	8.1^{a}	8.1^{a}	8.3^{a}	0.35
Growth rate (kg DM ha^{-1} day^{-1})	37.4^{b}	42.2^{b}	65.9^{a}	3.51
Height (cm)	84.5^{c}	103.2^{b}	142.6^{a}	4.60
Second year (2002–2003)				
Fresh matter yield (Mg ha^{-1})				
Total	26.7^{b}	39.4^{b}	57.4^{a}	3.23
Fine fraction	19.9^{b}	27.5^{a}	28.8^{a}	1.90
Coarse fraction	7.4^{c}	12.2^{b}	28.6^{a}	1.55
Dry matter yield (Mg ha^{-1})				
Total	4.7^{c}	6.8^{b}	10.4^{a}	0.52
Fine fraction	3.6^{b}	4.7^{a}	5.1^{a}	0.33
Growth rate (kg DM ha^{-1} day^{-1})	13.1^{c}	19.2^{b}	27.4^{a}	1.45
Height (cm)	78.3^{c}	99.8^{b}	150.5^{a}	2.50

[1]Least squares means and standard error (SE).
[a,b,c]Means in the same row with different superscripts differ significantly ($p < 0.05$).

DM were substantially greater ($p < 0.05$) for the long cutting interval (75 days) than for the more frequent cuttings.

Figure 1 shows the total DM yield in the different months of the year in each cutting frequency. Harvesting in months followed by dry or

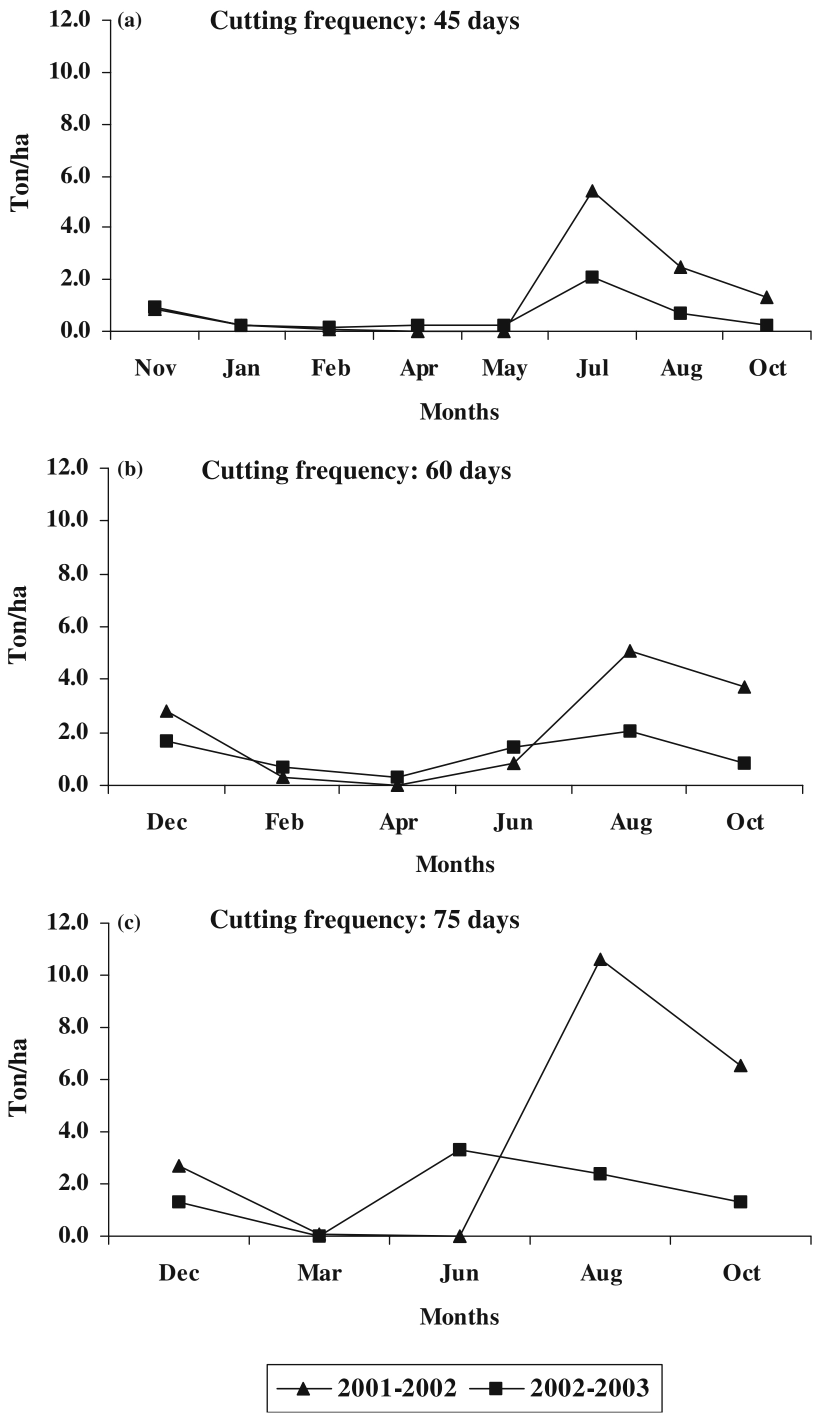

Figure 1. Effect of harvesting month during the first (2001–2002) and second (2002–2003) year on total dry matter yield of *Moringa oleifera* at cutting frequencies 45, 60 and 75 days, in Managua, Nicaragua.

Table 2. Biomass yield, growth rate and average height[1] of *Moringa oleifera* at different planting densities during the first and second year after planting, in Managua, Nicaragua.

Variable	Planting density (plants ha^{-1})			
	250,000	500,000	750,000	SE
First year (2001–2002)				
Fresh matter yield (Mg ha^{-1})				
Total	80.2^{b}	79.1^{b}	88.0^{a}	3.20
Fine fraction	49.9^{a}	47.7^{a}	51.2^{a}	1.93
Coarse fraction	30.3^{b}	31.4^{b}	36.9^{a}	1.78
Dry matter yield (Mg ha^{-1})				
Total	17.6^{a}	16.9^{a}	18.9^{a}	0.70
Fine fraction	8.3^{a}	7.7^{a}	8.5^{a}	0.32
Growth rate (kg DM ha^{-1} day^{-1})	48.0^{a}	46.1^{a}	51.4^{a}	1.93
Height (cm)	110.0^{a}	106.0^{b}	115.0^{a}	2.10
Second year (2002–2003)				
Fresh matter yield (Mg ha^{-1})				
Total	41.1^{ab}	46.2^{a}	36.1^{b}	3.02
Fine fraction	25.1^{a}	27.2^{a}	23.5^{a}	1.78
Coarse fraction	16.6^{ab}	19.0^{a}	12.6^{b}	1.44
Dry matter yield (Mg ha^{-1})				
Total	7.6^{ab}	8.1^{a}	6.2^{b}	0.50
Fine fraction	4.6^{a}	4.9^{a}	4.0^{a}	0.31
Growth rate (kg DM ha^{-1} day^{-1})	20.5^{ab}	22.3^{a}	16.9^{b}	1.36
Height (cm)	112.0^{a}	111.0^{a}	106.0^{a}	2.34

[1]Least squares means and standard error (SE).
[a,b,c]Means in the same row with different superscripts differ significantly ($p < 0.05$).

low rainfall conditions (January–May) resulted in stunted regrowth and lower total DM yield, while allowing plants to grow during the rainy season and harvesting in the wet season and start of the dry season (July–December) gave higher total DM yield.

Table 2 shows the effect of different planting densities on biomass production, growth rate and average height of the *Moringa* plants. The total yield of fresh matter and the coarse fraction of fresh matter were significantly ($p < 0.05$) higher for the density of 750,000 plants ha^{-1} in the first year and 500,000 plants ha^{-1} in the second year. The fine fraction of fresh matter and DM were not significantly different between plant densities in any of the years. Total yield of DM was not significantly different between densities in the first year but the density of 500,000 plants ha^{-1} gave a significantly higher DM yield in the second year than 750,000 plants ha^{-1}. The growth rate showed the same pattern.

Interactions effects between planting density and cutting frequency on total yield of fresh matter and DM and fine fraction of DM of *Moringa* during the first year and the second year after planting are presented in Figure 2. The interactions between density and cutting frequency were significantly different ($p < 0.05$) for total yield of fresh matter and total yield of DM in both evaluation years but for the fine fraction of DM only in the second year. All planting densities produced significantly ($p < 0.05$) higher total yield of fresh matter and total yield of DM at 75 days cutting frequency. The fine fraction of DM, however, was slightly higher for the density of 750,000 plants ha^{-1} in the first year and in the density of 500,000 plants ha^{-1} in the second year.

Although biomass yield and growth rate were not compared statistically between evaluation years, it was observed that the production in the second year was lower than in the first year (Tables 1 and 2, Figures 1 and 2).

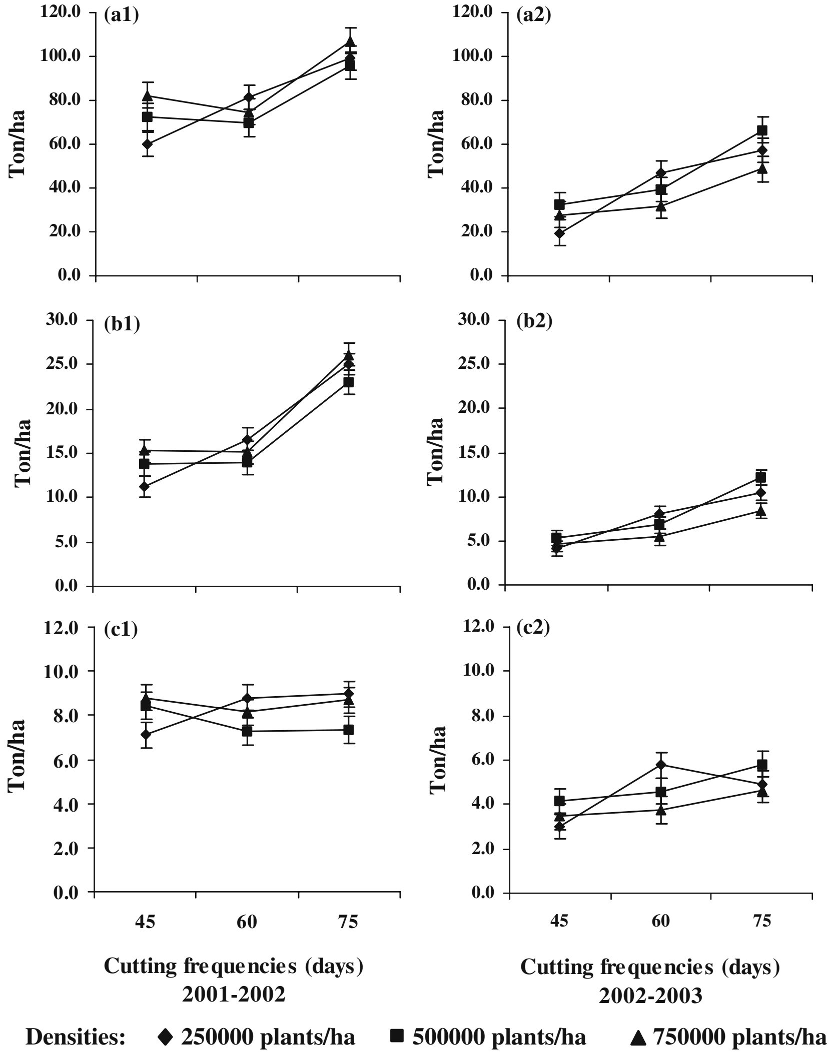

Figure 2. Effect of cutting frequencies and plant densities during the first and second year on total fresh matter yield (a1, a2), total dry matter yield (b1, b2) and dry matter yield of the fine fraction (c1, c2) of *Moringa oleifera*, in Managua, Nicaragua.

Chemical composition and in vitro *dry matter digestibility*

The effect of different cutting frequencies on DM, CP, NDF, ADF and ash contents and IVDMD of *Moringa* are presented in Table 3. During the first year CP and ADF contents were not affected significantly by cutting frequency. DM and ash contents consistently ($p < 0.05$) increased while *in vitro* DM digestibility decreased as cutting interval increased from 45 to 75 days. In the second year DM and CP contents and IVDMD were not significantly different between cutting frequencies, whereas NDF, ADF and ash contents were significantly ($p < 0.05$) lower for the 60 day cutting frequency.

Planting densities had no significant effect on DM, CP, NDF, ADF and ash contents and *in vitro* DM digestibility of *Moringa* during the first or second year of evaluation (Table 4).

Although chemical composition (DM, CP, NDF, ADF, and ash contents) and IVDMD of *Moringa* were not compared statistically between evaluation periods, it was noted that the DM and CP contents and IVDMD were lower, and NDF, ADF and ash content were higher in the first year than in the second year (Tables 3 and 4).

Table 3. Chemical composition and *in vitro* dry matter digestibility[1] of *Moringa oleifera* at different cutting frequencies during the first and second year after planting, in Managua, Nicaragua.

Variable	Cutting frequency (days)			
	45	60	75	SE
Number of cuts per year	8	6	5	
Number of samples	96	72	60	
First year (2001–2002)				
DM (g kg^{-1})	185.4[c]	195.9[b]	228.3[a]	2.21
In g kg^{-1} DM				
Crude protein	226.3[a]	228.9[a]	222.5[a]	2.24
Neutral detergent fibre	321.2[b]	289.0[a]	307.5[ab]	5.47
Acid detergent fibre	227.6[a]	203.1[a]	225.1[a]	5.05
Ash	85.8[b]	90.6[a]	91.4[a]	0.64
In vitro dry matter digestibility	700.9[a]	709.1[a]	681.8[b]	4.28
Second year (2002–2003)				
DM (g kg^{-1})	178.1[a]	179.6[a]	179.4[a]	1.62
In g kg^{-1} DM				
Crude protein	211.1[a]	213.8[a]	215.7[a]	2.49
Neutral detergent fibre	396.8[a]	363.0[b]	380.7[ab]	5.07
Acid detergent fibre	262.1[a]	234.1[b]	253.1[a]	4.21
Ash	96.7[a]	90.8[b]	97.1[a]	1.48
In vitro dry matter digestibility	659.2[a]	667.8[a]	658.2[a]	3.95

[1]Least squares means and standard error (SE).
[a,b,c]Means in the same row with different superscripts differ significantly ($p < 0.05$).

Table 4. Chemical composition and *in vitro* dry matter digestibility[a] of *Moringa oleifera* at different planting densities during the first and second year after planting, in Managua, Nicaragua.

Variable	Planting density (plants ha^{-1})			
	250,000	500,000	750,000	SE
Number of samples	76	76	76	
First year (2001–2002)				
DM (g kg^{-1})	204.7	201.2	203.6	1.80
In g kg^{-1} DM				
Crude protein	226.3	230.1	221.3	3.31
Neutral detergent fibre	302.7	308.1	307.0	8.34
Acid detergent fibre	223.5	208.9	223.5	7.43
Ash	88.7	88.9	90.2	1.03
In vitro dry matter digestibility	696.3	697.6	697.5	4.75
Second year (2002–2003)				
DM (g kg^{-1})	180.0	179.7	177.3	1.75
In g kg^{-1} DM				
Crude protein	210.1	218.7	211.8	2.91
Neutral detergent fibre	380.0	379.9	380.6	6.49
Acid detergent fibre	248.7	250.2	250.4	4.19
Ash	94.8	95.3	94.6	1.91
In vitro dry matter digestibility	663.5	661.5	660.3	4.69

[a]Least squares means and standard error (SE).

Discussion

Effect of cutting frequency on biomass production

In both evaluation years, the highest total yield of DM, growth rate and height of plants were obtained with the longest cutting interval of 75 days, however, biomass yield was higher in the first year than in the second year (Table 1). The increase in production was mainly woody biomass but the longest cutting interval was still the most productive in terms of fine fraction of

DM. According to Ella et al. (1989) the coarse fraction will represent a larger proportion of DM production when the cutting interval increases.

The biomass production was affected by the amount of rainfall during the growing period in both years in all cutting frequencies. Even though plants were allowed to grow for the same length of time their total DM production was different (Figures 1 and 2). Hence, it is not only the length of the growing period, but also the season in a particular year which affects DM yield. This is probably mainly a result of rainfall being higher in the first year than in the second year (Figure 1). During the first year, the rainfall in May, August and September was higher than for the same months in the second year and this was reflected in total DM yields. For the cutting frequencies, 45, 60 and 75 days for the harvests realised in July, August and October, in the first year, the total DM yields were higher than in the second year for the same cutting frequencies at the same months (Figure 1). These results illustrate the possibility of adjusting the length of cutting interval to maximize total DM yield. The results of the first year are higher than values found for *Moringa* by Palada (1996) of 11.2 Mg DM ha^{-1}, whereof 4.5 Mg ha^{-1} DM leaves and 6.8 Mg ha^{-1} DM stem. Palada's reported yields are similar to our results in the second year. Foidl et al. (2001) reported a biomass production up to 99 Mg DM ha^{-1} $year^{-1}$, as a result of eight cuttings after sowing 1 million seeds ha^{-1} and managing the plantation with irrigation and fertilisation. Similar experiments with different forage trees also support the findings that longer cutting intervals increase biomass production (Assefa 1998) and consequently that frequent cutting will decrease biomass production (Nygren and Cruz 1998). DM yield of *Moringa* obtained in this study was also comparable to the DM production of *Calliandra calothyrsus* (17.8 Mg ha^{-1}), *Gliricidia sepium* (17.7 Mg ha^{-1}) and *Leucaena leucocephala* (19.5 Mg ha^{-1}) reported by Catchpoole and Blair (1990) and higher than DM yield of *Sesbania grandiflora* (13.93 Mg ha^{-1}).

Moringa is an extremely fast-growing tree and within 1–3 months trees reach 2.5 m and exhibit the fastest regrowth after pruning (Palada 1996). The average plant height obtained in this study in the longest cutting interval (75 days) was higher than reported in *Moringa* by Manh et al. (2003) of 30, 90 and 145 cm at 60, 90 and 120 days of age, and Tomar et al. (2003) who found an average height of 95 and 219 cm of plants of 1 and 3 years of age. A short time for regrowth decreased the potential of the plant to produce new regrowth and reduced plant height, but this depends on environmental plant adaptation and water availability in the soil.

The growth rate of *Moringa* significantly increased ($p < 0.05$) as cutting interval was prolonged from 45 to 75 days. Defoliation generally affected growth rate. Frequent defoliation takes away the possibility of photosynthesis and inhibits nutrient assimilation and reduces the carbohydrate reserve, which influence the leaf area development and affects the growth rate of the plants.

Effect of planting density on biomass production

For high biomass production, dense stands are a key means of establishing sufficient leaf area for light interception, photosynthesis and consequently maximum crop growth and yield. The present study showed that the total yield of DM during the first evaluation year was similar between different plant densities, with only a slight increase of 12% with 750,000 plants ha^{-1}. In the second year, the density of 500,000 plants ha^{-1} gave the highest yield (Table 2). The results give a clear indication that higher planting densities result in a stand with higher sunlight interception and also higher growth of fine branches. However, yield per plant decreased as total biomass production per unit area increased with increased population density. The decreased yield per plant is more than compensated for by the number of plants, resulting in increasing yield per area as plant population increases (Ball et al. 2000). Naturally, in theory an optimal number of plants for optimal production exists. In the present study, competition between plants did not affect biomass production in the first year, but in the second year biomass production decreased, probably partly due to increased competition between plants. However, production time span is a major question mark in *Moringa* cultivation because in intensive commercial production the life span of the plant is not known.

Effect of interaction between planting density and cutting frequency on biomass yield

The interaction between plant density and cutting frequency for total yield of DM was statistically significant in both years ($p < 0.05$). For the fine fraction of DM in the first year there was no statistical significance. However, the differences between combinations did not rank clearly according to density (Figure 2). In the first year, the highest planting density, 750,000 plants ha^{-1}, in combination with the longest cutting interval, 75 days, produced the greatest total yield of DM and fine fraction of DM. The intermediate density of 500,000 plants ha^{-1} did not rank second in production but the combination of low plant density (250,000 plants ha^{-1}) with longest cutting frequency (75 days) did. In the second year, the medium planting density (500,000 plants ha^{-1}) in combination with longest cutting interval (75 days) produced the greatest total yield of DM and fine fraction of DM, followed by the combination of low plant density (250,000 plants ha^{-1}) with longest cutting interval (75 days) (Figure 2).

Differences in compensation yield, in response to high population density, were evident from the first to second year evaluation. Total DM yield for 250,000, 500,000 and 750,000 was lower in the second year in relation to the first year at the same density. Although biomass yield decreased at different planting densities, the reduction was higher in the density of 750,000 plants ha^{-1} than in the other plant densities (Table 2). This may have been due to lower rainfall in the second year than in the first year (Figure 1) and nutrient deficit in the soil that increased competition among plants and could have reduced plant survival, mainly in the highest plant density, with a consequent reduction in biomass production per unit area.

Effect of cutting frequency and plant density on chemical composition

In both years, the effects of cutting frequency and plant density on CP content and IVDMD were not significant. These results are similar to those reported by Ventura and Pulgar (1997) in that CP content did not show differences between plant densities while total nitrogen and IVDMD (Assefa 1998; Nygren and Cruz 1998) decreased progressively, but not significantly as cutting frequencies increased. Even at longer harvesting intervals, the CP and IVDMD remained high. This can be explained by the fact that N content in the leaves and young stems generally do not decrease with maturity (Miquilena et al. 1995). In the present investigation, CP content and IVDMD of *Moringa* was within the range of 193–264 g CP kg^{-1} DM and 648–790 g kg^{-1} DM, respectively, reported for *Moringa* by other workers (Makkar and Becker 1996, 1997; Foidl et al. 1999; Aregheore 2002; Al-Masri 2003; Manh et al. 2003).

Plant density had no significant effect on the NDF and ADF contents of *Moringa* during the first and second year (Table 4). The same trend was reported by Al-Masri (2003). However, NDF concentrations in both years were affected significantly by cutting frequency, while ADF concentration was only affected during the second year. Young stems are generally of high quality, but the quality decreases faster than in leaves, because epidermis and fibrous cells change into secondary cellular wall and lignin content increases with increased age of the plant. NDF and ADF contents obtained in this study for the different cutting frequencies were within the range of 151–564 g kg^{-1} DM and 92–515 g kg^{-1} DM reported by other researchers (Makkar and Becker 1996, 1997; Foidl et al. 1999; Aregheore 2002; Al-Masri 2003) for NDF and ADF, respectively. Factors, such as differences in agro-climatic conditions, soil type and fertilisation, age of trees, stage of maturity of the leaves, different parts of the plant sampled (leaves, twigs, branch, stems) could have contributed to some of the differences between reported values.

Planting density had no significant effect on ash contents of *Moringa* during the 2 years of evaluation (Table 4). The same trends were reported by Al-Masri (2003), also working with *Moringa*. Ash concentration in both years was, however, affected significantly ($p < 0.05$) by cutting frequency. The ash content in the present study fell within the range of 88–134 g kg^{-1} DM reported by other researchers for *Moringa* (Makkar and Becker 1996, 1997; Al-Masri 2003). Many factors can influence the concentration of mineral elements (ash) in plants, e.g. minerals in the soil and their availability to the plant, soil type and soil pH and stage of growth (Lukhele and Van Ryssen 2003).

Conclusions

The data indicated that for intensive biomass production *Moringa oleifera* could be planted densely (50–75 plants per square meter) and cut every 75 days. Biomass yield was dependent on rainfall, as yield dropped during the dry season, mainly in the second evaluation year when precipitation was lower than in the first year. In addition, for higher quality of forage and higher total DM yield for animal feeding, *Moringa* should be harvested at intervals of 75 days because the nutritive value of *Moringa* forage in terms of CP and IVDMD did not decline under the longer harvesting interval. *Moringa* contained high levels of CP and IVDMD, 220 and 680 g kg^{-1} DM, respectively. These data suggested that *Moringa* forage could be a valuable protein supplement for ruminants fed poor quality grass. Although it was not studied, lack of available nutrients in the soil probably affected biomass yield in the second year. Future studies should include nutrient management (fertilization).

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