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Biomass production and nutritional quality of *Moringa oleifera* as a field crop

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Abstract: Dairy and meat production are very complex in dry regions due to shortages and the low quality of fodder, especially in dry months. Livestock scientists are enthusiastic to explore and investigate good quality fodder that can boost milk and meat production in an economical way. *Moringa oleifera* is known as one of the best fodder crops for dry regions with scanty amounts of water. Hence, the present study was designed to evaluate the potential of *Moringa oleifera* as a field crop by harvesting at different cutting heights (30, 90, and 150 cm). The nutritional quality (minerals like P, K, Ca, and Mg, and crude protein) was determined along with antioxidant (SOD, CAT, POD, total phenolic contents) activities. The findings show that a *Moringa* crop gave maximum biomass (472 g plant^{-1}) with higher mineral content in its leaves when harvested at 30-cm cutting height in August, while the minimum biomass (113.54 g plant^{-1}) was recorded when plants were harvested at 150-cm cutting height. Higher antioxidants, total phenolics content, and photosynthetic pigments were recorded in the hot rainy season (July and August). The seasonal variability affects mineral content in moringa leaves. The highest mineral content was found in August, followed by July. It is concluded that the moringa tree, due to its higher mineral content and antioxidant activities, can be cultivated as a field crop as a good alternate for livestock fodder.

Key words: Antioxidant, cutting levels, minerals, total phenolic contents, pigments

1. Introduction

Forage trees and shrubs are an important component of agroforestry systems, especially with respect to livestock fodder production and fuel wood. Tree species are easy to grow and maintain at later stages due to their low demands on postplanting care and protection as compared to agricultural annual fodder crops. Forage trees are capable of producing more foliage with high contents of digestible protein and other essential minerals in their leaves, providing high quality forage for livestock earlier than agricultural crops. In the dry season, most of the agronomic fodder becomes unavailable due to the hot weather, harsh sunlight, and shortage of water. The fodder shortage results in reduced milk production, weight loss, decrease in reproduction, and increase in mortality rates of livestock (Nuru 1988; Saleem 1994; Tarawali et al. 1999). Forage trees have the ability to retain their leaves in dry seasons (Tripathi et al. 1992), along with other numerous benefits like increased farm income and sustainability by providing timber and firewood for domestic and industrial purposes, green manure, fruits, and vegetables (Cobbina et al. 1990; Kang et al. 1990). Some important forage tree species being used as livestock fodder in different countries are *Acacia* spp., *Sesbiana sesbane*, *Delbergia sissoo*, *Moringa oleifera* etc.

M. oleifera belongs to mono-genus family Moringaceae, which has 12 other species. *M. oleifera* is the only species of the family Moringaceae that is cultivated as a crop (Veeraragava 1998). It is native to India and Pakistan, but is now being planted in many parts of the world (Booth and Wickens 1988; Morton 1991; Makkar and Becker 1996). It can be grown for different purposes (biomass production, livestock fodder, green manure biogas, plant growth enhancer, medicines, biopesticides, etc). As livestock fodder, it gives a high dry matter (DM) yield (4.2–8.3 t ha^{-1}) with a 40 day cutting frequency (Sanchez et al. 2006). It is a highly nutritious plant with CP contents up to 292 g kg^{-1} of dry matter (Mendieta-Araica et al. 2011) with all amino acids required according to FAO reference protein (Makkar and Becker 1996). Besides high

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nutritional quality, moringa leaves have exceptionally small amounts of antinutritional factors as well. These leaves have remarkable amounts of minerals and lower amounts of harmful compounds like tannins and phytates (12 and 21 g kg^{-1} of DM, respectively) (Udom and Idiong 2011). Other fodder trees' leaves, like *Sesbania sesban, Acacia angustissima,* and *Acacia cyanophylla,* contain 31, 66 and 38 g kg^{-1} tannin content, respectively (Kaitho 1997; Salem et al. 1999). Therefore, moringa leaves are a good and healthy nutritious source for livestock. Sanchez et al. (2006) and Newton et al. (2006) optimized the cutting frequency of moringa for getting maximum biomass under Nicaraguan and Ghanaian conditions, but there is a need to find out the optimum cutting height at which the farmers can have maximum biomass under local conditions. Stur et al. (1994) suggested carrying out studies to understand the relationship between cutting height, biomass, and number of shoots. The present study was aimed at investigating the effect of cutting height on moringa biomass and physiological and mineral changes taking place with special reference to weather conditions.

2. Materials and methods

2.1. Seed collection

M. oleifera seeds were collected from Punjab Forest Research Institute (PFRI), Faisalabad, Pakistan. The seeds were immediately sown in polythene bags (23 × 15 cm) after harvesting from trees. The polythene bags were filled with clay, sand, and plant compost (1:1:1). At 3 months of age, uniform seedlings were transplanted to the field at the Agronomy Research Farm Area, University of Agriculture, Faisalabad, Pakistan in August 2008. The soil of the farm was sandy clay having EC 0.34 dS m^{-1}, pH 7.6, 0.96% organic matter, and 0.097% N content. P, exchangeable K, B, Zn, and Fe contents were 6, 162, 0.79, 1.30, and 6.84 mg kg^{-1}, respectively. Mean weather data were collected during the field trial (August 2008 to August 2009) from a local weather station located 5 km from the experimental area (Table 1).

2.2. Crop husbandry

The experimental area (144 m^2) was plowed 3 times and leveled. Holes were dug at 30 × 45 cm planting distance (Palada and Chang, 2003) and 3-month-old uniform moringa seedlings were transplanted in the afternoon into each subplot (12 m^2). Border row plants were considered a nonexperimental area and were ignored during data collection. Basal fertilizer was applied at 90:80:90 N:P:K kg ha^{-1} using DAP and NPK once as a single basal dose. The field was irrigated (with no standing water in the field) immediately after seedling transplantation to promote early root development. Then moringa seedlings were irrigated twice a month during the trial period. The plants were staked with sticks until they got firm.

Table 1. Weather data recorded during field trial.

Year	Months	Observations					
		Minimum temperature (°C)	Maximum temperature (°C)	Average temperature (°C)	Relative humidity (%)	Rainfall (mm)	Sunshine (h)
2008	August	35.1	26.8	30.9	65	204.5	7.5
	September	34.4	23.7	29.0	59.3	28.8	8.2
	October	33.1	20.2	26.7	57.6	0.0	8.0
	November	27.3	12.2	19.7	58.9	0.0	8.0
	December	21.9	9.1	15.5	68.9	14.6	6.0
2009	January	19.6	7.3	13.5	68.0	13.5	6.1
	February	22.1	9.9	16	64.1	2.2	7.3
	March	27.5	14	20.8	53.5	14.0	7.8
	April	33.5	19.1	26.3	41.7	22.9	9.2
	May	40.1	24.8	32.4	31.4	9.1	10.4
	June	40.7	27.0	33.8	33.6	9.6	9.4
	July	38.0	27.9	32.9	59.0	43.5	9.0
	August	36.6	27.6	32.1	65.8	116	8.4

When moringa plants attained maximum height/ level (150 cm), a uniform cut was applied in April 2009 (8 months after transplantation) to maintain 3 cutting levels: 30, 90, and 150 cm. All the plants were harvested manually with a budding knife at 30-day intervals to evaluate biomass production, physiological attributes, and nutritional quality for 4 consecutive months (May–August), while 6 plants were randomly selected from each replication at each cutting interval to observe the following parameters during data collection.

2.3. Above ground biomass

The number of shoots (<5 mm diameter) was counted and fresh biomass, including fragile shoots and leaves, was weighed immediately after harvesting. The fresh biomass was shade dried, followed by oven drying at 70 ± 2 °C until the samples reached a constant dry weight. Dry weight was determined by subtracting oven dry weight from total fresh weight multiplied by 100.

2.4. Photosynthetic pigments

Chlorophyll *a* and *b* and β-carotene content in moringa leaves were determined after every harvest except the uniformity cut by using the protocol devised by Nagata and Yamashta (1992). One gram of moringa leaves were ground in 10 mL of 80% acetone and filtered through Whatman's filter paper No. 1. The filtered extract was transferred in a cuvette and absorbance was noted at 663, 645, 505, and 453 nm using a UV-spectrophotometer (UV-4000, O.R.I. Germany). Chlorophyll *a* and *b* and β-carotene content were calculated according to following formulae:

Chlorophyll $a = 0.999\ A_{663} - 0.0989\ A_{645}$

Chlorophyll $b = -0.328\ A_{663} + 1.77\ A_{645}$

β-Carotene $= 0.216\ A_{663} - 1.22\ A_{645} - 0.304\ A_{505} + 0.452\ A_{453}$

2.5. Total phenolic contents (TPCs)

TPCs in moringa leaves were quantified following the Singleton and Rossi (1965) method revised by Waterhouse (2001). Folin-Ciocalteu Reagent (2N) and Na_2CO_3 were used as reagents and gallic acid was used as standard (100, 150, 250, and 500 mg L^{-1} gallic acid) for making a standard curve. The absorbance by gallic acid standards and moringa samples was noted at 760 nm by using a UV-spectrophotometer (UV-4000, O.R.I. Germany). The results were reported as gallic acid equivalent (GAE).

2.6. Antioxidant assay

Fresh leaves (0.5 g) were homogenized in 5 mL of 50 mM cooled phosphate buffer (pH 7.8) and filtered through Whatman's filter paper No. 1. The filtered mixture was centrifuged at 15,000 rpm for 20 min at 4 °C, and then the supernatant was separated. The extracted supernatant was used to determine superoxide dismutase (SOD) (EC 1.15.1.1) activity at 560 nm by using a UV spectrophotometer (UV-4000, O.R.I. Germany) following the method devised by Giannopolitis and Ries (1977). One unit of SOD was defined as the amount of enzyme required to cause 50% inhibition of the rate of NBT reduction at 560 nm in comparison with tubes lacking the enzyme extract. Catalase (CAT) (EC 1.11.1.6) and peroxidase (POD) (EC 1.11.1.7) activities were determined by Chance and Maehly's (1955) method with minor modifications. The absorbance was read at 240 nm for 5 min after every 30 s to determine CAT activity, while for determining POD activity the absorbance was read at 470 nm for 5 min after every 20 s. CAT activity was measured as units (μmol of H_2O_2 decomposed per min) per mg of protein. For POD activity, one unit was defined as the change of 0.01 absorbance unit per min per mg of protein. The enzyme protein was quantified by following the protocol devised by Bradford (1976) to express specific activity of SOD, POD, and CAT. POD and CAT activities were calculated with the following formula:

$$A = \frac{lc\varepsilon}{mg\ (Protein)}\ ,$$

where

A = Absorbance

l = Distance that light travels through the body (usually 1 cm)

c = Concentration of absorbing species in the sample

ε = Molar extinction coefficient (2.47 $mmol^{-1}\ L\ cm^{-2}$ and 36 $mol^{-1}\ L\ cm^{-2}$ for POD and CAT, respectively)

2.7. Crude protein analysis

The Chapman and Pratt (1961) method was used for N digestion, distillation, and quantification. Five grams of dry moringa leaves were ground, passing through a 2 mm sieve, and digested in sulfuric acid in the presence of a mixture of K_2SO_4, $CuSO_4$, $FeSO_4$ (10:05:01) using a micro Kjeldahl apparatus to determine N content. Crude protein was calculated by multiplying N content by the factor 6.25.

2.8. Mineral analysis

Moringa leaves were oven dried at 60 °C to obtain the constant weight and ground to pass through a 2-mm sieve. The samples were digested using concentrated HNO_3 and $HOCl_4$ (2:1), following the procedure adapted by Rashid (1986). The presence of P content was recorded in a UV-spectrophotometer (UV-4000, O.R.I. Germany) at 410 nm. Color was developed with ammonium molybdate and ammonium vandate solutions. A flame photometer (Jenway PEP-7) was used to determine K content in diluted extracts of plant material by using a K filter (Chapman and Pratt 1961). Ca and Mg were determined by an atomic absorption spectrophotometer (Model: Z-8200).

2.9. Statistical analysis

Randomized completely block design (RCBD) with 4 replications was used in the present experiment. The data were computed and analyzed using MSTAT-C Program (MSTAT Development Team, 1989). An LSD test at 5%

level of probability was used to test the differences among mean values (Steel et al. 1997).

3. Results

Cutting levels (cutting height) and harvesting months affected fresh and dry biomass, photosynthetic pigments, total phenolic contents, and antioxidant (SOD, CAT, POD) activities significantly ($P < 0.05$). Maximum biomass, photosynthetic pigment concentration, TPC, antioxidants, and nutritional quality were recorded in August (harvesting month) at 30-cm height in moringa plants, except dry matter (DM), P, Ca, and Mg. Maximum fresh biomass and number of shoots per plant were recorded when the plants were cut at 30-cm height and at 90-cm height, while maximum dry weight was recorded from the plants at 150-cm cutting height (Table 2). The peak value of chlorophyll *a* content was recorded in August when the plants were harvested at 30-cm height and at 90-cm height in the same month (Table 3). Chlorophyll *b* contents were not significantly affected by cutting height or interaction, but harvesting month affected it significantly ($P < 0.05$) (Table 3). Similarly, maximum β-carotene content was found in August but these were not significantly affected by cutting height, harvesting month, or their interaction (Table 3).

Total phenolic contents (TPC) were not affected by cutting levels (Table 4). Maximum CAT and POD activities were recorded in August when the plants were harvested at 30-cm cutting height, followed by the same cutting height in July, while 90- and 150-cm-high plants were statistically on par with each other for POD (Table 4). Cutting height and the interaction between harvesting months and cutting heights affected SOD activity significantly, while harvesting month had no distinct effect. Maximum SOD activity was found in plants when harvested at 30-cm height in August, followed by 150-cm height in August (Table 4). In the case

Table 2. Effect of different cutting heights on fresh biomass, number of shoots, and dry weight of *M. oleifera* as field crop.

	Fresh biomass (g plant^{-1})			No. of shoots			Dry weight (%)		
	Cutting heights			Cutting heights			Cutting heights		
Harvesting months	30	90	150	30	90	150	30	90	150
Uniformity cut	218.54 ± 16.17 cd	143.13 ± 31.27 ef	113.54 ± 28.08 f	20.50 ± 0.91 c	13.5 ± 0.91ef	10.00 ± 1.29 gh	30.60 ± 1.48 abc	29.70 ± 1.29 abc	31.46 ± 0.58 ab
May	352.92 ± 29.24 b	209.58 ± 16.54 cde	151.25 ± 19.14 def	16.75 ± 1.57 d	9.50 ± 0.92 ghi	6.75 ± 1.06 i	24.69 ± 1.10 e	25.55 ± 0.66 de	30.56 ± 0.56 abc
June	426.04 ± 23.01 a	305.42 ± 15.84 b	186.67 ± 25.75 cde	24.75 ± 1.95 b	12.00 ± 1.29 efg	7.75 ± 0.89 hi	28.54 ± 0.58 abcd	28.34 ± 0.92 bcd	31.74 ± 0.65 a
July	453.75 ± 10.06 a	329.37 ± 16.54 b	206.04 ± 17.08cde	28.00 ± 1.29 a	14.50 ± 0.91 def	10.00 ± 1.00 gh	28.57 ± 1.03 abcd	27.55 ± 0.39 cde	31.57 ± 0.72 ab
August	472.71 ± 39.11 a	342.29 ± 18.65 b	226.25 ± 25.91 c	30.25 ± 1.77 a	14.75 ± 1.21 de	11.50 ± 0.91fg	27.69 ± 1.26 cde	28.42 ± 0.58 bcd	31.77 ± 0.76 a
LSD 5%		67.657			3.1795			3.2511	

Means showing different letters are significantly different in a column at a 5% probability level

Table 3. Effect of different cutting heights on chlorophyll *a* and *b,* and β-carotene contents of *M. oleifera* leaves as field crop.

	Chlorophyll *a* (μg g^{-1})			Chlorophyll *b* (μg g^{-1})			β-Carotene (μg g^{-1})		
	Cutting heights			Cutting heights			Cutting heights		
Harvesting months	30	90	150	30	90	150	30	90	150
May	28.39 ± 0.47 abcd	25.54 ± 2.22 d	26.33 ± 2.58 cd	11.41 ± 0.74 ab	11.18 ± 0.81 ab	10.02 ± 0.55 b	2.79 ± 0.10	2.93 ± 0.19	2.27 ± 0.16
June	27.61 ± 0.54 abcd	26.90 ± 0.35 bcd	27.36 ± 0.85 abcd	14.20 ± 1.06 ab	11.52 ± 1.71 ab	11.90 ± 0.94 ab	2.96 ± 0.20	2.60 ± 0.13	2.66 ± 0.29
July	33.62 ± 2.73 abc	32.34 ± 3.23 abcd	30.10 ± 0.93 abcd	16.62 ± 0.49 a	15.67 ± 0.63 ab	13.09 ± 1.03 ab	3.50 ± 0.32	3.16 ± 0.19	3.15 ± 0.36
August	34.87 ± 2.13 a	34.60 ± 3.70 ab	32.85 ± 2.87 abcd	15.62 ± 1.62 ab	12.67 ± 1.29 ab	13.09 ± 1.03 ab	3.85 ± 0.40	3.68 ± 0.26	3.32 ± 0.36
LSD 5%		0.7743			0.5774				

Means showing different letters are significantly different in a column at a 5% probability level

Table 4. Effect of different cutting heights on SOD, POD, CAT, and TPC of *M. oleifera* leaves as field crop.

	SOD (unit mg⁻¹ protein)			POD (unit mg⁻¹ protein)			CAT (unit mg⁻¹ protein)			TPC (GAE)		
	Cutting heights			Cutting heights			Cutting heights			Cutting heights		
Harvesting months	30	90	150	30	90	150	30	90	150	30	90	150
May	498.36 ± 27.88bcde	397.26 ± 17.57 de	465.54 ± 27.12 cde	1486.91 ± 222.59 ab	817.80 ± 141.76 ab	1149.89 ± 180.42 ab	64.62 ± 5.50 bcd	45.95 ± 3.09 cd	29.04 ± 4.46 d	26.05 ± 0.19 d	26.48 ± 0.48 d	26.000.17 d
June	450.55 ± 33.80 cde	386.72 ± 33.39 e	467.91 ± 31.51 cde	1460.00 ± 127.24ab	832.79 ± 113.61ab	441.28 ± 33.79 b	66.06 ± 5.44abcd	53.29 ± 4.44 bcd	30.69 ± 4.12 d	58.50 ± 0.18 c	58.64 ± 0.20 c	58.57 ± 0.27 c
July	697.70 ± 39.03 abc	556.17 ± 39.23 abcde	651.76 ± 37.96 abcd	2081.67 ± 247.90 ab	1144.92 ± 99.47 ab	667.35 ± 111.90 ab	90.47 ± 7.70 ab	64.32 ± 4.16 bcd	40.65 ± 6.24 cd	67.17 ± 0.33 b	67.26 ± 0.30 b	67.01 ± 0.20 b
August	797.37 ± 44.61 a	635.62 ± 51.49 abcde	744.87 ± 43.39 ab	2379.05 ± 145.07 a	1308.49 ± 125.83 ab	839.83 ± 59.47 ab	103.40 ± 3.88 a	73.51 ± 4.32 abc	46.46 ± 7.13 cd	84.73 ± 0.16 a	84.86 ± 0.18 a	84.71 ± 0.12 a
LSD 5%		256.34			1754.5			38.485			0.4877	

Means showing different letters are significantly different in a column at a 5% probability level

of cutting height, maximum SOD activity was recorded in 30-cm-high plants, which were statistically on par with 90-cm-high plants. Data revealed that harvesting months did not affect SOD activity significantly, but maximum activity was noted in August, which was statistically on par with July.

Crude protein content was not influenced by cutting heights, harvesting months, or their interactions (Figure 1). Cutting height did not alter the mineral content (K, Ca, Mg, and P) of moringa leaves, but harvesting months and their interaction with different cutting heights showed pronounced effects (Figures 2–5). In the case of harvesting months, maximum P and K content was recorded in August, which was statistically on par with those of July. In the case of cutting heights, maximum K content was found in 30-cm-high plants, followed by 90-cm cutting height. Ca and Mg content also exhibited a similar trend and were maximum when the plants were harvested in August at 90-cm cutting

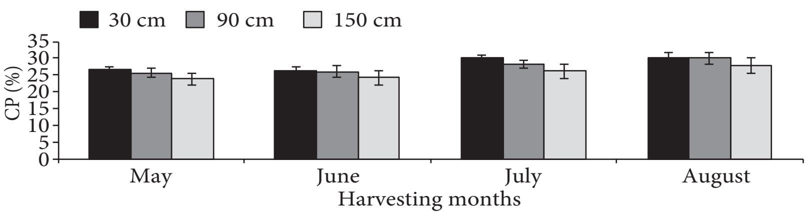

Figure 1. Effect of different cutting heights on crude protein contents (%) of *M. oleifera* as field crop. Means showing different letters are significantly different ($P < 0.05$) from each other. ± vertical bars represent standard errors. Data were computed from 4 replications consisting of 6 plants in each replication.

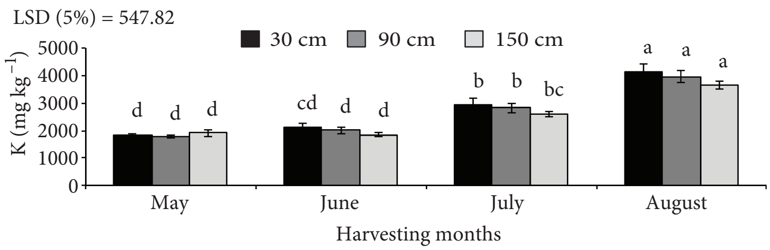

Figure 2. Effect of different cutting heights on potassium contents (mg kg⁻¹) of *M. oleifera* as field crop. Means showing different letters are significantly different ($P < 0.05$) from each other. ± vertical bars represent standard errors. Data were computed from 4 replications consisting of 6 plants in each replication.

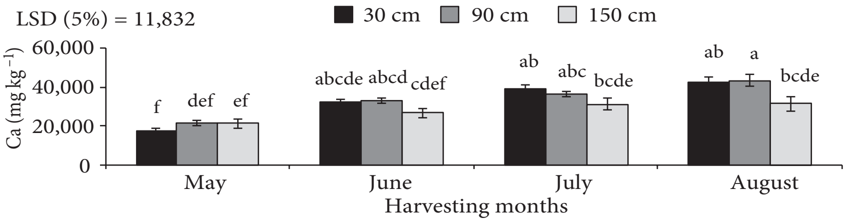

Figure 3. Effect of different cutting heights on calcium contents (mg kg^{-1}) of *M. oleifera* leaves as field crop. Means showing different letters are significantly different ($P < 0.05$) from each other. ± vertical bars represent standard errors. Data were computed from 4 replications consisting of 6 plants in each replication.

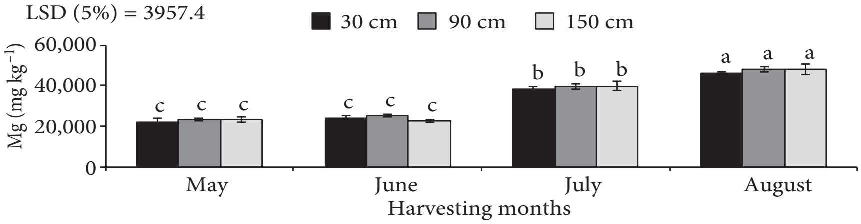

Figure 4. Effect of different cutting heights on magnesium contents (mg kg^{-1}) of *M. oleifera* leaves as field crop. Means showing different letters are significantly different ($P < 0.05$) from each other. ± vertical bars represent standard errors. Data were computed from 4 replications consisting of 6 plants in each replication.

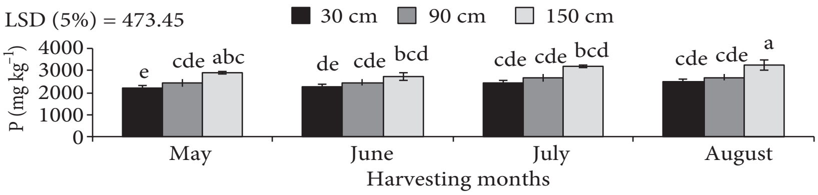

Figure 5. Effect of different cutting heights on phosphorous contents (mg kg^{-1}) of *M. oleifera* as field crop. Means showing different letters are significantly different ($P < 0.05$) from each other. ± vertical bars represent standard errors. Data were computed from 4 replications consisting of 6 plants in each replication.

height. Interestingly, all 3 cutting heights were statistically on par with each other regarding magnesium contents.

In reference to weather conditions, fresh biomass, mineral concentration in moringa leaves, and antioxidant activities were positively correlated with temperature and rainfall (Tables 5 and 6). In hot wet seasons, moringa plants exhibited maximum mineral accumulation in leaves and antioxidant activity, which resulted in enhanced fresh biomass.

4. Discussion

Cutting of leaves and branches is a good practice, especially in summer and rainy seasons, to obtain maximum foliage in tropical countries (Stur et al. 1994). In this experiment, the moringa plants were cut at different levels to evaluate the growth behavior, biomass production, and nutritional quality of moringa plants. It was found that maximum fresh biomass was obtained in the hot rainy season (August and July, respectively) when the plants were harvested at 30-cm cutting level. Without a doubt, fresh biomass is partially correlated with temperature and rainfall averaged over time, mostly per annum (Tables 4 and 5). However, the present study was conducted in July–August, when maximum rainfall occurred and the temperature was extreme. Similar observations have also been reported in the cases of Lucerne and mulberry (Benavides 1986; Baatar 2008), but Kadin and Kreil (1990) reported high biomass yield at higher cutting levels. Kadin and Kreil (1990) reported that if the leaf stem ratio was higher, then thicker branches cannot be used as palatable foliage. In the present study, only the leaves and fragile shoots (<5 mm girth) were considered as fresh biomass. Boschini (2000) suggested studying the relationship between leaf to stem ratio and cutting levels to find out about the effects of cutting levels/heights on biomass production. It has

Table 5. Correlation matrix between monthly temperature and moringa growth behavior, physiological activities, and mineral concentration.

	β-Carotene	CAT	CP	Ca	Chl *a*	Chl *b*	Fresh weight	K	Mg	N	P	POD	TPC	SOD
CAT	0.7725													
CP	0.9214	0.8636												
Ca	0.8350	0.7622	0.8661											
Chl *a*	0.9332	0.6895	0.9234	0.8280										
Chl *b*	0.6263	0.7403	0.6897	0.6320	0.6322									
Fresh weight	0.6114	0.9543	0.7401	0.6736	0.5190	0.7417								
K	0.9150	0.6025	0.8321	0.7853	0.9351	0.4253	0.4084							
Mg	0.8528	0.4227	0.7610	0.7052	0.9179	0.4252	0.2195	0.9401						
N	0.9214	0.8636	1.0000	0.8661	0.9234	0.6897	0.7401	0.8321	0.7610					
P	0.0104	−0.558	−0.187	−0.1524	0.1416	−0.2455	−0.695	0.2347	0.4661	−0.187				
POD	0.6552	0.9512	0.7432	0.6024	0.5800	0.6993	0.9179	0.4987	0.3000	0.7432	−0.558			
TPC	0.7918	0.4266	0.6848	0.8007	0.8307	0.4479	0.3026	0.8788	0.8789	0.6848	0.3476	0.2624		
SOD	0.8399	0.5267	0.7126	0.5746	0.8651	0.5566	0.3409	0.8585	0.8713	0.7126	0.3813	0.5119	0.7593	
Temp	0.6154	0.3385	0.5362	0.7643	0.6585	0.5083	0.2982	0.6502	0.6829	0.5362	0.2712	0.1575	0.9256	0.5712

Table 6. Correlation matrix between monthly rainfall and moringa growth behavior, physiological activities, and mineral concentration.

	β-Carotene	CAT	CP	Ca	Chl *a*	Chl *b*	Fresh weight	K	Mg	N	P	POD	TPC	SOD
CAT	0.7725													
CP	0.9214	0.8636												
Ca	0.8350	0.7622	0.8661											
Chl *a*	0.9332	0.6895	0.9234	0.8280										
Chl *b*	0.6263	0.7403	0.6897	0.6320	0.6322									
Fresh weight	0.6114	0.9543	0.7401	0.6736	0.5190	0.7417								
K	0.9150	0.6025	0.8321	0.7853	0.9351	0.4253	0.4084							
Mg	0.8528	0.4227	0.7610	0.7052	0.9179	0.4252	0.2195	0.9401						
N	0.9214	0.8636	1.0000	0.8661	0.9234	0.6897	0.7401	0.8321	0.7610					
P	0.0104	−0.558	−0.187	0.1524	0.1416	−0.245	−0.695	0.2347	0.4661	−0.187				
POD	0.6552	0.9512	0.7432	0.6024	0.5800	0.6993	0.9179	0.4987	0.3000	0.7432	−0.558			
TPC	0.7918	0.4266	0.6848	0.8007	0.8307	0.4479	0.3026	0.8788	0.8789	0.6848	0.3476	0.2624		
SOD	0.8399	0.5267	0.7126	0.5746	0.8651	0.5566	0.3409	0.8585	0.8713	0.7126	0.3813	0.5119	0.7593	
Rainfall	0.8359	0.4397	0.7152	0.6520	0.8598	0.2535	0.2336	0.9747	0.9294	0.7152	0.3698	0.3407	0.8583	0.832

also been reported that higher cutting levels exhibit more dry matter compared to lower ones (Hairiah et al. 1992; Ncamihigo and Brandelard 1993). Similar observations were recorded in the present study. The effect of cutting levels on dry matter yield is still not clear, as Xavier and Carvalho (1996) reported that cutting level does not affect dry matter yield. Therefore, there is a need to study the relationship between fresh biomass, dry matter yield, leaf area, and branches' diameter (Stur et al. 1994). Higher cutting levels gave more moringa DM yield in rainy seasons (July and August). Similar findings were reported in *Leucaena leucocephala* plants by Karim et al. (1991). In a few previous research reports (Takahashi and Ripperton 1949; Sampet and Pattaro 1987; Gutteridge 1988), no significant effect of cutting levels was found on DM yield, but in all these cases the maximum cutting level was up to 50 cm. This increase in DM may be due to leaf stem ratio (Salerno and Seiffert 1990). The sugar, protein, and amino acid contents move speedily from the roots to develop new leaves, which may cause high DM yield in plants harvested at higher cutting levels (Kitamura et al. 1981).

Since moringa biomass is produced for livestock and human consumption, and emerging use as a crop growth enhancer (Nouman et al. 2012a, 2012b). Therefore, mere biomass is not the only required target; the quality of the biomass is also important. Moringa leaves have been reported as a rich source of proteins, antioxidants, minerals, and other quality parameters. We report the maximum antioxidant activities were recorded in the rainy season (July and August) when the plants were harvested at shorter cutting levels. Yang et al. (2006) observed a positive correlation between temperature, rainfall, and antioxidant activities. The researchers reported that higher antioxidant activity rate in the hot wet season was higher among 120 tropical and subtropical edible plants that were investigated during their study, while Iqbal and Bhanger (2006) reported higher antioxidant activity in December to March and less in the hot season in a study conducted in the Mardan district, Pakistan, which is ecologically different from the present study zone (Faisalabad). The Mardan district receives higher rainfall during the months of May, November, and December, while maximum rainfall in the Faisalabad district occurs in July–August. This climatic information suggests that maximum antioxidant activities occur during hot and rainy months, but these factors vary according to varying ecological zoning. Variations in climatic conditions of different agroclimatic regions also affect the antioxidant activity of aqueous, aqueous methanol, and aqueous ethanol extracts of frozen-dried moringa leaves (Siddhuraju and Becker 2003). The present study also suggests that moringa plants accelerate their antioxidant activity in response to cutting intensity. The researchers are still unclear about the relationship between antioxidant activities and cutting intensity or cutting levels. It may be attributed that under cutting stresses, the plants exhibit nutritional balance and enhance their self-defense mechanisms (antioxidant system) to survive under cutting stress conditions.

Seasonal variability also affected the mineral content of moringa plants significantly ($P < 0.05$), while no significant changes were observed in CP content regarding harvesting month and cutting height. Therefore, farmers can get higher CP-containing fodder (moringa tender shoots) for their livestock both in hot dry and hot rainy seasons. Higher concentrations of Ca, K, and Mg were found in rainy months (July and August). Moreover, a highly positive correlation was found between rainfall–temperature and mineral content, but Ramírez-Lozano et al. (2010) reported higher mineral content in different grasses, shrubs, and trees in the hot rainy season in comparison with spring and dry months. Likewise, Shamat et al. (2009) found higher Ca, P, and K content in wet months than dry months in shrubs and forages.

The present study concludes that moringa leaves have sufficient amount of all the minerals required for livestock. Mg is abundantly present in all green plants (Wilkinson et al. 1990). In the present study, Mg contents were affected by seasonal variability, ranging from 23,058.00 to 47,426.00 mg kg^{-1}, which is higher than the required amount for ruminants (2000 mg kg^{-1}) as reported by Minson (1990). Similarly, the increase in K content in the wet season is in accordance with Reid and Horvath (1980). McDowell (2003) reported that 2300, 2700, and 2800 mg kg^{-1} of P; 6000, 6500, and 4600 mg kg^{-1} of K; 4600, 5100, and 3000 mg kg^{-1} Ca; and 1000, 1500, and 1600 mg kg^{-1} of Mg are sufficient for beef cattle, sheep, and goats, respectively. Jumba et al. (1996) and Minson (1990) related lower mineral contents in summer with higher light intensity and temperature. Likewise, Ramírez et al. (2006) and Guerrero (2009) also reported that plant species exhibit higher mineral contents in hot and wet seasons rather than spring and dry ones.

Moringa is a good alternate for fodder crops, especially in the dry season when no fodder is available. Farmers can get an economical moringa biomass at a 30-day harvesting interval, when cut at a height of 30 cm, in any season, with higher CP content. Moringa leaves have sufficient amounts of minerals required for healthy livestock, but the concentration varies with the seasons. In July and August (hot wet season), moringa plants have high mineral and crude protein content compared to hot dry months. Therefore, farmers should be encouraged to plant moringa as a fodder crop to feed their livestock.

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References

Baatar B (2008) Effects of cutting height and frequency on yield in a Mongolian rangeland. Land Restoration Training Programme Final project 2008 Keldnaholt, 112 Reykjavík, Iceland.

Benavides JE (1986) Efecto de diferentes niveles de suplementación con follaje de Morera (*Morus sp.*) sobre el crecimiento y consumo de corderos alimentados con pasto (*Pennisetum purpureum*). En: Resumen de las investigaciones realizadas con rumiantes menores, cabras y ovejas en el Proyecto de Sistemas de Producción Animal. CATIE. Turrialba, Costa Rica. Serie Técnica. Informe Técnico No 67. pp. 40–42.

Booth FEM, Wickens GE (1988) Non-timber uses of selected arid zone trees and shrubs in Africa. FAO conservation guide. Food and Agriculture Organization, Rome, Italy, p. 176.

Boschini CF (2000) Establishment and Management of Mulberry for Intensive Forage Production. FAO Electronic Conference on mulberry for animal production (Morus1-l).[Online] http://ict.udg.co.cu/FTPDocumentos/Literatura%20Cientifica/Maestria%20Nutricion%20Animal/6.%20EVENTOS%20RELEVANTES/Sistemas%20Agroforestales%20Pecuarios/Morus1/Boschini.htm. Accessed on November 18, 2010.

Bradford MM (1976) A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein–dye binding. Anal Biochem 72: 248–254.

Chance M, Maehly AC (1995) Assay of catalases and peroxidases. Meth Enzymol 2: 764–817.

Chapman HD, Pratt PF (1961) Methods of Analysis for Soils, Plants and Water. University of California, Berkeley, California, USA.

Cobbina J, Atta-Krah AN, Meregini AO, Duguma B (1990) Production of some browse on acid soils of South-Eastern Nigeria. Trop Grassl 24: 41–45.

Giannopolitis CN, Ries SK (1977) Superoxide dismutase occurrence in higher plants. Plant Physiol 59: 309–314.

Guerrero CM (2009) Valor nutricional de forrajes nativos del norte de México. Tesis de doctorado. Facultad de Ciencias Biológicas, Universidad autónoma de Nuevo León. pp. 77–81.

Guteridge RC (1988) Alley cropping Kenaf (*Hibiscus cannabinus*) with *Leucaena leucocephala* in South-Eastern Queensland. Australian J Exp Agric 28: 481–484.

Hairiah K, Noordwijk M, Santoso B, Syekhfani MS (1992) Biomass production and root distribution of eight trees and their potential for hedgerow intercropping on an ultisol in southern Sumatra. Agrivita 15: 54–68.

Iqbal S, Bhanger MI (2006) Effect of season and production location on antioxidant activity of *Moringa oleifera* leaves grown in Pakistan. J Food Compos Analys 19: 544–551.

Jumba IO, Suttle NF, Wandiga SO (1996) Mineral composition of tropical forages in the Mount Elgon region of Kenya. 1. Macrominerals. Trop Agric 73: 108–112.

Kadin H, Kreil W (1990) Optimum use and management of reed canarygrass swards. Archiv. Fuer. Acker. Pflanzenbau. Bodenkunde. 34: 489–495.

Kang BT, Reynolds L, Atta-Krah AN (1990) Alley farming. Adv Agron 43: 315–359.

Karim AB, Rhodes ER, Savill PS (1991) Effect of cutting height and cutting interval on dry matter yield of *Leucaena leucocephala* (Lam.) de Wit. Agrofor Syst 16: 129–137.

Kaitho RJ (1997) Nutritive value of browses as protein supplement(s) to poor quality roughages. PhD Thesis. University of Wageningen, Wageningen, Netherlands.

Kitamura Y, Samejina M, Abe J (1981) Vegetative regrowth, nodule development and nitrogen fixation of a tropical legume after harvest. J Japan Soc Grass Sci 27: 227–284.

Makkar HPS, Becker K (1996) Nutritional value and antinutritional components of whole and ethanol extracted *Moringa oleifera* leaves. Anim Feed Sci Technol 63: 211–228.

McDowell LR (2003) Minerals in Animal and Human Nutrition. 2nd ed., Elsevier, The Netherlands, pp. 256–315.

Mendieta-Araica B, Sporndly R, Sanchez NR, Sporndly E (2011) Moringa (*Moringa oleifera*) leaf meal as a source of protein in locally produced concentrates for dairy cows fed low protein diets in tropical areas. Livestock Sci 137: 10–17.

Minson DJ (1990) Forage I ruminant nutrition. Academic Press Inc., London, United Kingdom.

Morton JF (1991) The horseradish tree, *Moringa pterygosperma* (Moringaceae). A boon to arid lands? Econo Bot 45: 318–333.

MSTAT Development Team (1989) MSTAT User's Guide: A Microcomputer Program for the Design Management and Analysis of Research Experiments. Michigan State University, East Lansing, Michigan, USA.

Nagata M, Yamashta I (1992) Simple method for simultaneous determination of chlorophyll and carotenoids in tomato fruit. J Japan Soc Food Sci Technol 39: 925–928.

Ncamihigo O, Brandelard P (1993) Effects of cutting heights and cutting frequencies on the annual yield of Leucaena and Calliandra hedges. In: Proceedings of the XVII International Grassland Congress, Vol. 1, New Zealand and Queensland, Australia, pp. 2131–2132.

Newton AK, Timpo GM, Ellis WO, Bennett RN (2006) Effect of spacing and harvest frequency on the growth and leaf yield of moringa (*Moringa oleifera* Lam), a leafy vegetable crop. In: Proceedings of "Moringa and other highly nutritious plant resources: Strategies, standards and markets for a better impact on nutrition in Africa". Accra, Ghana.

Nouman W, Siddiqui MT, Basra SMA (2012a) *Moringa oleifera* leaf extract: An innovative priming tool for rangeland grasses. Turk J Agric For 36: 65–75.

Nouman W, Siddiqui MT, Basra SMA, Afzal I, Rehman H (2012b) Enhancement of emergence potential and stand establishment of *Moringa oleifera* Lam. by seed priming. Turk J Agric For 36: 227–235.

Nuru S (1988) Research and development in pastoral production system in Nigeria: Past, present and future. In: National conference on Pastoralism in Nigeria, NAPRI, A. B. U., Zaria.

Palada MC, Chang LC (2003) Suggested Cultural Practices for Moringa. International Cooperator's Guide, Asian Vegetable Research and Development Center, Shanhua, Taiwan.

Ramírez-Lozano RG, González-Rodríguez H, Gómez-Meza MV, Cantú-Silva I, Uvalle-Sauceda JI (2010) Spatio-temporal variations of macro and trace mineral contents in six native plants consumed by ruminants at northeastern Mexico. Trop Subtrop Agroecosys 12: 267–281.

Ramírez RG, González-Rodríguez H, Ramírez-Orduña R, Cerrillo-Soto MA, Juárez-Reyes AS (2006) Seasonal trends of macro and micro minerals in 10 browse species that grow in northeastern Mexico. Anim Feed Sci Technol 128: 155–164.

Rashid A (1986) Mapping Zinc Fertility of Soils Using Indicator Plants and Soil Analyses. PhD Thesis. University of Hawaii, Hawaii, USA.

Reid RL, Horvath DJ (1980) Soil chemistry and mineral problems in farm livestock. A review. Anim Feed Sci Technol 5: 95–167.

Saleem MMA (1994) Evaluation of Stylosanthes for pasture development: an overview of ILCA's experience in Nigeria. In: Stylosanthes as a forage and fallow crop. In: Proceedings of the Regional Workshop on the Use of Stylosanthes in West Africa (Eds. De Leeuw PN, Mohammed S.MA, Nyamu AM) Kaduna, Nigeria, pp 17–23.

Salem HB, Nefzaoui A, Salem LB, Tisserand JL (1999) Different means of administering polyethylene glycol to sheep: effect on the nutritive value of *Acacia cyanophylla* Lindl. foliage. Anim. Sci 68: 809–818.

Salerno AR, Seiffert NF (1990) Cultivars of *Leucaena* tested in Santa Catarina. Agropecuaria-Catarinense 3: 16–18.

Sampet C, Pattaro V (1987) *Sesbania grandiflora, Gliricidia maculata* and *Leucaena leucocephala* as fodder crop. Thai J Agric Sci 20: 303–313.

Sanchez NR, Spörndly E, Ledin I (2006) Effect of feeding different levels of foliage of *Moringa oleifera* to creole dairy cows on intake, digestibility, milk production and composition. Livestock Sci 101: 24–31.

Shamat AM, Babiker IA, Mukhtar AMS, Ahmed FA (2009) Seasonal and regional variations in mineral content of some important plants species selected by camels (*Camelus dromedarius*) in arid and semi-arid lands (ASAL) of sudan. J App Sci Res 5: 1676–1684.

Siddhuraju P, Becker K (2003) Antioxidant properties of various solvent extracts of total phenolic constituents from three different agroclimatic origins of drumstick tree (*Moringa oleifera* Lam.) leaves. J Agric Food Chem 51: 2144–2155.

Singleton VL, Rossi JA (1965) Colorimetry of total phenolics with phosphomolybdic- phosphotungstic acid reagents. Amer J Enol Vitic 16: 144–158.

Steel RCD, Torrie JH, Deekey DA (1997) Principles and procedures of statistics a biometric approach. 3rd ed. McGraw-Hill Book Co. Inc. New York, pp. 400–428.

Stur WW, Shelton HM, Gutteridge RC (1994) Defoliation management of forage tree legumes. In: Forage Tree Legumes in Tropical Agriculture (Eds. Gutteridge RC, Shelton HM). CAB International, Wallingford, United Kingdom.

Takahashi M, Ripperton JC (1949) Koahaole *(Leucaena glauca),* its establishment, culture, and utilization as a forage crop. University of Hawaii Agricultural Experimental Station, Bulletin 100, p. 59.

Tarawali SA, Peters M, Schultz KR (1999) Forage legumes for sustainable agriculture and livestock production in sub-humid West Africa. ILRI, Nairobi.

Tripathi BR, Psychas PJ (1992) The AFNETA alley farming training manual - Volume 1: Core course in alley farming. Alley Farming Network for Tropical Africa. International Institute of Tropical Agriculture, Ibadan.

Udom GN, Idiong NB (2011) Nutrients and anti-nutritional factors of mixed fodder diets for goats in southeastern Nigeria. Electr J Environ Agric Food Chem 10: 2272–2278.

Veeraragava TD (1998) Drumstick (*Moringa oleifera* Lam.). In: Veeraragava Thatham D.; Jawaharlal M.; Seemanthini R. (eds) A guide on vegetable culture. Suri Associates, Coimbatore, India, pp. 139–143.

Waterhouse AL (2001) Determination of total phenolics in current protocols. In: Food and Analytical Chemistry, 11.1–11.1.8.Wrolstad, R.E. Wiley.

Wilkinson SR, Welch RM, Mayland HF, Grunes DL (1990) Magnesium in plants: Uptake, distribution, function and utilization by man and animal. In "Metal Ions in Biological Systems, Vol. 26, Compendium on Magnesium and Its Role in Biology, Nutrition and Physiology" (Eds. Sigol H, Sigel A). Marcel Dekker, New York, USA, pp. 3–56.

Xavier DF, Carvalho MM (1996) Evaluación agronómica de *Cratylia argentea* en zonas de Mata de Minas Gerais, In: Pizarro, E.A. y Coradin, L. (eds). *Potencial de Cratylia como leguminosa forrajera.* EMBRAPA, Cenargen, CPAC y CIAT. Memorias del taller sobre *Cratylia*, 19–20 Julio 1995, Brasilia, Brasil. pp. 29–39.

Yang RY, Chang LC, Hsu JC, Weng BBC, Palada MC, Chadha ML, Levasseur V (2006) Nutritional and functional properties of moringa leaves from germplasm to plant, to food, to health. In: Proceedings of "Moringa and other highly nutritious plant resources: Strategies, standards and markets for a better impact on nutrition in Africa". Accra, Ghana.