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Yield and quality of *Moringa oleifera* under different planting densities and cutting heights in southwest China

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ABSTRACT

Moringa oleifera is a multipurpose plant that is now being promoted as a fodder crop. The aim of this study was to evaluate the effect of different planting densities (0.2 m × 0.2 m, 0.4 m × 0.4 m and 0.8 m × 0.8 m) and cutting heights (15, 30 and 60 cm) on the biomass yield and quality of *Moringa oleifera* in valley areas of southwest China during the period 2010–2012. The results indicated that the highest planting density of 0.2 m × 0.2 m in combination with the intermediate cutting height of 30 cm produced the highest fresh matter (FM) and dry matter (DM) yield throughout the whole evaluation period. The 0.2 m × 0.2 m planting density not only produced the highest FM (8.43–76.41 Mg ha^{-1}) and DM (1.66–12.85 Mg ha^{-1}) yield, but also the highest fine and coarse fractions of the plant over two consecutive evaluation years irrespective of season, i.e., rainy or dry. The 30 cm cutting height resulted in the highest FM (25.18–41.53 Mg ha^{-1}) and DM (5.28–8.27 Mg ha^{-1}) yield in the rainy season, whereas the 15 cm cutting height resulted in the greatest yield in the dry season (4.38–13.16 Mg ha^{-1} FM and 0.82–2.26 Mg ha^{-1} DM). These findings suggest that the lower cutting height could be recommended in the low rainfall area to produce the highest moringa yield. Additionally, the crude protein (CP) content was higher in the rainy season (235.3–257.6 g kg^{-1} DM) than in the dry season (224.1–232.8 g kg^{-1} DM) and was significantly affected by planting density in the rainy season. However, the crude fibre (CF) (up to 192.7 g kg^{-1} DM), neutral detergent fibre (NDF) (up to 293.1 g kg^{-1} DM), acid detergent fibre (ADF) (up to 208.4 g kg^{-1} DM), DM (up to 173.7 g kg^{-1}) and ash (up to 94.5 g kg^{-1} DM) contents were higher in the dry than in the rainy season. Planting density only significantly affected the DM and ash contents in the rainy season, and the CF content in the rainy and dry season. The crude lipid (EE) content (22.9–26.1 g kg^{-1} DM)did not differ significantly between the different planting densities, whereas in vitro DM digestibility (IVDMD) (766.3–853.6 g kg^{-1} DM) was significantly affected by planting density in the rainy season. The cutting height had no significant effect on the CP, IVDMD, EE, NDF, DM and ash contents in either the rainy or dry season, but the CF content in the dry season and the ADF content in the rainy season were significantly affected by cutting height. These data suggest that as a forage crop, moringa is not only a good source of protein but has a balanced fibre component with a high digestion rate for livestock, especially ruminants.

1. Introduction

Many fodder trees contain higher levels of crude protein (CP), minerals and digestible nutrients than other feeds traditionally used in animal feeding, and play a major role in supplementing dietary protein (Benavides, 1994; Topps, 1992; Yahaya et al., 2001). Furthermore, these fodder trees are easily propagated and long-lived; they have the capacity to produce high quantity and quality forage under low cost maintenance, and may enhance the sustainability of the farming system. Thus, their use as a supplement can improve voluntary feed intake, digestibility and animal performance (Aregheore and Yahaya, 2001). *Moringa oleifera* Lam. is one interesting fodder tree species that has received considerable attention during recent years.

Moringa oleifera, which is commonly referred to as the 'drumstick tree' (describing the shape of its pods) or the 'horseradish tree' (describing the taste of its roots), is native to the sub-Himalayan tracts of northwest India. It belongs to the monogeneric family Moringaceae and is distinguished by its usually tripinnate leaves, with leaflets that are 12–18 mm long and petioles that are yellow or white without red streaks (Ramachandran et al., 1980). Moringa is called the "Miracle Vegetable" because it is both a medicinal

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and a functional food (Verma et al., 1976). The leaves are rich in carotene, vitamins A, B, C, and E, essential amino acids, and mineral elements and comprise a rich and rare combination of bioactive secondary metabolites such as glucosinolates, flavonoids and phenolic acids, which have the potential to reduce the risk of cardiovascular diseases and cancer (Anwar et al., 2007; Chawla et al., 1988; Ferreira et al., 2008; Makkar and Becker, 1996; Nouman et al., 2014; Pandey et al., 2011). This tree can be propagated either by seeds or hard stem cuttings and can grow in versatile conditions including hot, humid, dry tropical, and subtropical regions, except under waterlogged conditions (Ramachandran et al., 1980). Moringa has expanded worldwide from northwest India into the tropics and subtropical regions of the globe (Olson, 2002; Pandey et al., 2011) and was introduced into Yunnan province of China in 2001. Approximately 2000 ha of plantations is currently established in southwest China.

As a fodder tree species, moringa has a high growth rate and the capacity to produce large quantities of fresh biomass (Sánchez et al., 2006). However, environmental factors and cutting management practices have important effects on the dry matter (DM) yield and chemical composition of moringa. The management of fodder trees for maximum production depends on several factors, such as the timing of the initial cut, the frequency and height of defoliation, and the density of the trees (Nouman et al., 2014; Knoop and Walker, 1985; Paterson et al., 1998). The influence of planting density and cutting frequency on the DM yield of moringa has been well documented for the Latin American tropics, and 750,000–1 million plants ha^{-1} is recommended as the optimum planting density (Foidl et al., 2001; Sánchez et al., 2006). However, the valley climate of southwest China is mainly characterized by high temperatures, high irradiance, and dry and rainy seasons. Thus, the DM yield and nutritive value of moringa may vary considerably in response to the prevailing season as reported by Melesse et al. (2012). To date, there is no documented information available on the effects of season, planting density and cutting height of moringa on forage yield and quality in this area. In addition, although high densities are positively correlated with high DM yields, the high amount of labour needed and difficulties during harvesting make high densities impractical for small- and medium-scale farmers (Mendieta-Araica et al., 2013). Therefore, studies on lower densities that meet the practical needs of farmers are necessary.

The specific objectives of this study were to determine the effects of three planting densities and three cutting heights on (1) biomass yields, (2) nutrient contents and digestibility of *Moringa oleifera* under different growing seasons, and (3) to identify the management regimes that result in the maximum biomass production for the dry and rainy seasons in the valley areas of southwest China.

2. Materials and methods

2.1. Study area

Our study was conducted over two consecutive years in the valley area of Yuanmou River, Yunnan province, southwest China. The site is located at Laocheng township in Yuanmou county, Yunnan province (101°53′E, 25°37′N, 1100 m above sea level) with a typical subtropical monsoon climate. The climate is characterized by a mean annual air temperature of 21.9 °C and mean annual rainfall of 630.7 mm, which falls in the rainy season from May to October; the dry season occurs from November to April. The fieldwork for this study was conducted from February 2010 to April 2012 in an area that was previously fallow land. During the experiment, Year one spanned the period from May 2010 to April 2011, while Year two ran from May 2011 to April 2012. There were considerable variations in precipitation and temperature during the two consecutive years (Fig. 1). There was much lower rainfall from November–March in Year one (less than 5 mm per month) than in Year two (more than 11 mm per month). The temperature reached a maximum in June 2011 and a minimum in December 2010, i.e., 26.7 and 13.7 °C, respectively.

The soil of the experimental areas was classified as xerothermic soil (Long et al., 2008), with 19.4% clay, 21.7% silt, 58.9% sand and a pH value of 6.6. The percentages of organic matter and nitrogen (N) in the soil were 2.24 and 0.19%, respectively. The soil in the experimental plots contained 7.84 mg/kg of available phosphorus and 185 mg/kg of available potassium, with good drainage, and combined with drip irrigation, is appropriate for agriculture.

2.2. Plant material and growth conditions

Soil preparation was completed by conventional tillage using a tractor and mechanical tools to clear the land of plant debris, and by disk ploughing followed by two disk harrowing and furrowing procedures. Untreated seeds of *Moringa oleifera* were used for propagation. The seeds were sown in the experimental plot in February 2010 at a soil depth of 2 cm with 2 seeds per hole. After 2 months of growth, the stand was thinned and only one healthy plant was retained. During the experiment, the same crop was observed for two years and all plots received irrigation and NPK compound fertilizer (K_2SO_4-type, 16N–16P_2O_5–16 K_2O) at a rate of 30 kg ha^{-1} after each uniform cut. Pest and disease incidence was not observed during the experiment.

2.3. Experimental design and data collection

The experiment was designed as a split-plot with three randomized complete blocks. The blocks were divided into three main plots and three planting densities (D1:0.2 m × 0.2 m, D2:0.4 m × 0.4 m and D3:0.8 m × 0.8 m) were randomized in each main plot. Cutting heights of 15 cm (H1), 30 cm (H2) and 60 cm (H3) were randomly split over the main plot. The experiment was set up in a field that covered an area of 1400 m^2, with 1080 m^2 for planting (including 27 sub-plots). The remaining 320 m^2 comprised the border (including a 1.2 m wide alley between blocks and 0.8 m between sub-plots) to facilitate management of the experiment. The individual sub-plot size was 40 m^2 and the net area used for harvesting was 32 m^2 to eliminate edge effects.

The regrowth of moringa was harvested throughout the two subsequent years, starting from 1 May 2010, i.e., every 30 or 31 days, the regrowth was harvested using a machete according to the specified cutting height. Twelve cuts per experimental year (Year one and Year two) were performed starting with the first regrowth harvest, with Cuts 1–6 taking place in the rainy season (May–October) and Cuts 7–12 in the dry season (November–April). One month before the start of the experiment on 1 April 2010, the whole plantation was uniformly cut at a height of 15 cm above ground and all foliage was removed but not weighed.

The fresh matter (FM) of each replication in each treatment was harvested, weighed and recorded to estimate the FM yield. According to Sánchez et al. (2006), the material obtained from each plot was separated into two fractions: the fine fraction, which included leaves, petioles and fragile shoots with a diameter less than 5 mm, and the coarse fraction (stems with diameters greater than 5 mm); however, only samples from the fine fraction were collected for subsequent chemical analysis.

The variables evaluated in this study were as follows: the total FM yield, fine fraction of FM, coarse fraction of FM, total DM yield and fine fraction of DM (Mg ha^{-1}), average length of new branches (cm) and growth rate (kg DM ha^{-1} day^{-1}). The average length of the new branches was estimated prior to each harvest by ran-