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Optimizing crop geometry and cutting height for enhancing yield, quality, and energy use efficiency in perennial forage moringa (*Moringa oleifera*) production

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ABSTRACT

To optimize the agronomic practices for *Moringa oleifera* production as a perennial forage crop experiments were conducted at ICAR- Central Institute for Research on Goats, Makhdoom for three consecutive years (2021 to 2023). The study focused on evaluating the effects of three crop geometries (30 cm × 15 cm, 45 cm × 15 cm, and 60 cm × 15 cm) and four cutting heights (15, 30, 45, and 60 cm) on dry fodder yield, fodder quality, and energy use efficiency. The experiment was laid out in a split-plot design with three replications. Results showed that among the crop geometries, the 30 cm × 15 cm spacing produced the highest dry fodder yield (44.75 t /ha), total crude protein yield (8356 kg/ha), net energy returns (605146 MJ/ha), energy productivity (0.79 kg/MJ) and energy profitability (10.66). Among the cutting heights, harvesting at 30 cm from ground level resulted in the highest dry fodder yield (43.01 t/ha), total crude protein yield (7567 kg/ha), net energy returns (579828 MJ/ha), energy productivity (0.76 kg/MJ) and energy profitability (10.28). However, the values for 30 cm and 45 cm cutting heights were statistically comparable across these parameters. It inferred that both cutting heights are equally effective for optimizing yield and energy efficiency in moringa forage production.

Key words: Crude protein yield, Cutting height, Energy intensity, Energy productivity

Perennial forage crops are crucial for sustainable livestock production as they offer a consistent fodder supply throughout the year, particularly during the lean periods. *Moringa oleifera*, traditionally grown as a tree, has gained attention as a viable perennial forage crop due to its high nutritional value and ability to withstand harsh climatic conditions. This adaptability, combined with its ability to provide year-round fodder, makes moringa an attractive alternative to annual forage crops, which are restricted to specific growing seasons and require higher energy inputs for cultivation. The transition from annual to perennial forage systems, offers substantial energy savings, primarily because perennial crops reduce the need for repeated sowing, frequent use of machinery, and high-input farming practices (Erdal *et al*., 2007). In global agricultural systems, food production consumes approximately 15–30% of total primary energy, with the most significant contributors being fossil fuels, farm machinery, and chemical inputs (Crippa *et al.,* 2021; Rosa *et al*., 2021; Kumar *et al.,* 2023). Therefore, moringa not only provides high-quality nutrition for livestock but also enhances the energy efficiency of agricultural production.

The importance of adopting energy-efficient technologies in agriculture cannot be overstated, as they are essential for promoting environmental sustainability. In crop production, energy inputs come from various sources, indirect, renewable, and non-renewable, with the most substantial impacts stemming from fuel, machinery, and nutrient management (Manoj *et al*., 2022; Yadav *et al*., 2023). Hence, it was hypothesized that moringa cultivation can contribute significantly to environmental conservation by reducing energy demands while ensuring the continuous availability of quality fodder. Therefore, the research aims to evaluate the yield, fodder quality, and energetics of moringa grown as a perennial forage crop in the Yamuna ravines, focusing on optimizing agronomic practices for sustainable production.

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MATERIALS AND METHODS

The field experiment was conducted from 2021 to 2023 at the ICAR-Central Institute for Research on Goats, Makhdoom, Mathura (Uttar Pradesh), to evaluate the effects of different crop geometries and cutting heights on the dry matter yield, forage quality, and energy efficiency of *Moringa oleifera*. The experimental soil was neutral (*p*H 7.0) with an EC of 0.27 dS/m, low in organic carbon (0.29%), medium in available nitrogen (253 kg/ha) and potassium (161 kg/ha), and high in available phosphorus (40 kg/ha). The treatments included three crop geometries (30 cm × 15 cm, 45 cm × 15 cm, and 60 cm × 15 cm) and four cutting heights (15 cm, 30 cm, 45 cm, and 60 cm) from the ground. The experiment followed a split-plot design with three replications, covering 36 plots, each measuring 3.6 m × 4.5 m. Moringa variety 'PKM-2' was sown on July 3, 2021, with seed rates of 75, 50, and 37.5 kg/ha for the respective crop geometries. Seeds were soaked overnight and treated with carbendazim @ 5 g/kg. Harvesting followed the treatment schedule of up to eight cuttings, the first cut was taken 90 days after sowing and the second 57 days later in 2021; the third cut of moringa was taken in the first week of May 2022 (after the completion of the winter season 2021-22) and subsequent fourth, fifth and sixth cuts were taken at the interval of about 60 days during 2022; then seventh cut was taken in the last week of April 2023 (after the completion of winter season 2022–23) and the eighth cut was taken after 60 days of seventh cut. Although moringa can remain in the field for 4–5 years, only eight cuttings were analyzed for this study.

Samples of whole moringa plants were oven-dried, grounded, and subjected to proximate analysis. Energy input and output were calculated by converting various inputs used, *viz.* manpower, seed, water, electricity, fertilizers, etc., and output *viz.* dry fodder yield into energy as suggested by Tuti *et al.* (2012). Further, the total input energy used in moringa production was divided into different categories *i.e.* direct (man-power, diesel fuel, water for irrigation, etc.), indirect (machinery, seed, fertilizers, etc.), renewable (seed, man-power, water for irrigation, etc.) and non-renewable (machinery, fertilizers, diesel fuel, etc.) energy. Different energy use efficiency parameters were estimated by using the following formula:

$$\text{Net energy return (MJ/ha)} = \text{Gross energy output} - \text{Input energy}$$

$$\text{Energy use efficiency} = \frac{\text{Energy output (MJ/ha)}}{\text{Energy input (MJ/ha)}}$$

$$\text{Energy productivity (kg/MJ)} = \frac{\text{Crop yield (kg/ha)}}{\text{Energy input (MJ/ha)}}$$

$$\text{Energy profitability} = \frac{\text{Net energy return (MJ/ha)}}{\text{Energy input (MJ/ha)}}$$

$$\text{Energy intensity in physical term (MJ/kg)} = \frac{\text{Total input energy (MJ/ha)}}{\text{Total crop yield (kg/ha)}}$$

$$\text{Energy intensity in economic term (MJ/₹)} = \frac{\text{Gross energy output (MJ/ha)}}{\text{Cost of cultivation (₹/ha)}}$$

Data were statistically analyzed using the appropriate analysis of variance (ANOVA) method as described by Gomez and Gomez (1984). The replicated means were subjected to ANOVA using MS Excel (2021), and the critical difference (CD) was determined at p=0.05 to identify significant differences.

RESULTS AND DISCUSSION

Dry fodder yield

Different cropping geometries and cutting height had a significant impact on the dry fodder yield (Table 1). The

Table 1. Effect of crop geometries and cutting heights on dry fodder yield of perennial forage moringa

Treatment	Dry Fodder Yield (t/ha)								
	2021		2022				2023		Total
	I Cut	II Cut	III Cut	IV Cut	V Cut	VI Cut	VII Cut	VIII Cut	
Crop geometry									
30 cm × 15 cm	4.34	5.08	4.46	5.73	6.29	6.83	5.72	6.30	44.75
45 cm × 15 cm	3.70	3.41	3.67	4.80	5.63	6.10	4.87	5.71	37.91
60 cm × 15 cm	3.35	3.08	3.32	4.25	5.06	5.42	4.36	5.09	33.94
SEm±	0.11	0.14	0.12	0.17	0.20	0.22	0.18	0.21	1.00
CD (P=0.05)	0.44	0.54	0.47	0.66	0.78	0.85	0.72	0.84	3.92
Cutting height									
15 cm	4.04	3.72	3.56	4.49	5.08	5.33	4.33	4.81	35.36
30 cm	3.93	4.18	4.18	5.36	6.26	7.00	5.63	6.48	43.01
45 cm	3.73	3.95	3.97	5.12	5.90	6.37	5.26	6.09	40.38
60 cm	3.49	3.58	3.55	4.76	5.41	5.77	4.73	5.43	36.72
SEm±	0.10	0.12	0.12	0.15	0.15	0.17	0.16	0.18	0.89
CD (P=0.05)	0.30	0.35	0.36	0.44	0.45	0.50	0.47	0.53	2.66

Interaction: Nonsignificant

highest dry fodder yield was consistently observed across three years, i.e. 2021 (I cut: 4.34 t/ha, II cut: 5.08 t/ha), 2022 (III cut: 4.46 t/ha, IV cut: 5.73 t/ha, V cut: 6.29 t/ha, VI cut: 6.83t/ha), and 2023 (VII cut: 5.72 t/ha, VIII cut: 6.30 t/ha) with a total yield of 44.75 t/ha when moringa was sown with a spacing of 30 cm × 15 cm. This crop geometry resulted in significantly higher total dry fodder yield than spacings of 45 cm × 15 cm and 60 cm × 15 cm by 18.04% and 31.85%, respectively. The increased yield at 30 cm × 15 cm spacing is likely due to the higher plant population. These findings align with those of Adegun and Ayodele (2015); Zheng *et al.* (2016) and Mabapa *et al.* (2017). Additionally, the cutting height influenced the dry fodder yield. Harvesting of moringa at 30 cm above ground level resulted in the highest dry fodder yield in 2021 (II cut: 4.18 t/ha), 2022 (III cut: 4.18 t/ha, IV cut: 5.36 t/ha, V cut: 6.26 t/ha, VI cut: 7.00 t/ha), and 2023 (VII cut: 5.63 t/ha, VIII cut: 6.48 t/ha), with a total yield of 43.01 t/ha. While the highest yield in 2021 at the I cut was recorded at a 15 cm cutting height, however, both 15 cm and 30 cm heights produced similar yields at the I cut. At 45 cm and 30 cm cutting heights, the dry fodder yields were comparable for all cuts except the VI cut in 2022. The increased yield at a 30 cm cutting height could be due to harvesting more side branches. These results are consistent with the findings of Siddharth *et al.* (2022) who reported that the harvesting height significantly influenced the yield of moringa, cutting height of 30 cm above the ground level has the greatest yield followed by 45 cm and 60 cm. A similar finding was also reported by Zheng *et al.* (2016).

The yield of proximate chemicals constitutes

The yield of crude protein, ether extract, and total ash was significantly influenced by different crop geometries and cutting heights (Fig. 1). The highest total yields of crude protein (8356 kg/ha), ether extract (1417 kg/ha) and ash (5021 kg/ha) were recorded with the 30 cm × 15 cm crop geometry, followed by the 45 cm × 15 cm spacing. Among the different cutting heights, forage moringa harvested at 30 cm, recorded 7567 kg/ha, 1286 kg/ha, and 4596 kg/ha of crude protein, ether extract, and ash yields, respectively, followed by 45 cm from the ground level. The higher yields with the 30 cm × 15 cm spacing and 30 cm cutting height are likely due to the higher values of crude protein, ether extract, and ash content along with the increased dry matter yield in these treatments. Velayudham *et al.* (2011) reported that the crude protein yield of the bajra napier hybrid was significantly influenced by different crop geometries.

Agro-energetics

The cultivation of perennial fodder moringa at a crop geometry of 30 cm × 15 cm recorded the highest input energy, while the lowest input energy was observed at a crop geometry of 60 cm × 15 cm. This difference is primarily due to the higher seed rate required for the 30 cm × 15 cm spacing compared to the 60 cm × 15 cm spacing. However, cutting heights did not affect the input energy, as the input values remained the same across all treatments (Table 2). Among the different inputs, electricity for irrigation and irrigation water represented the highest input

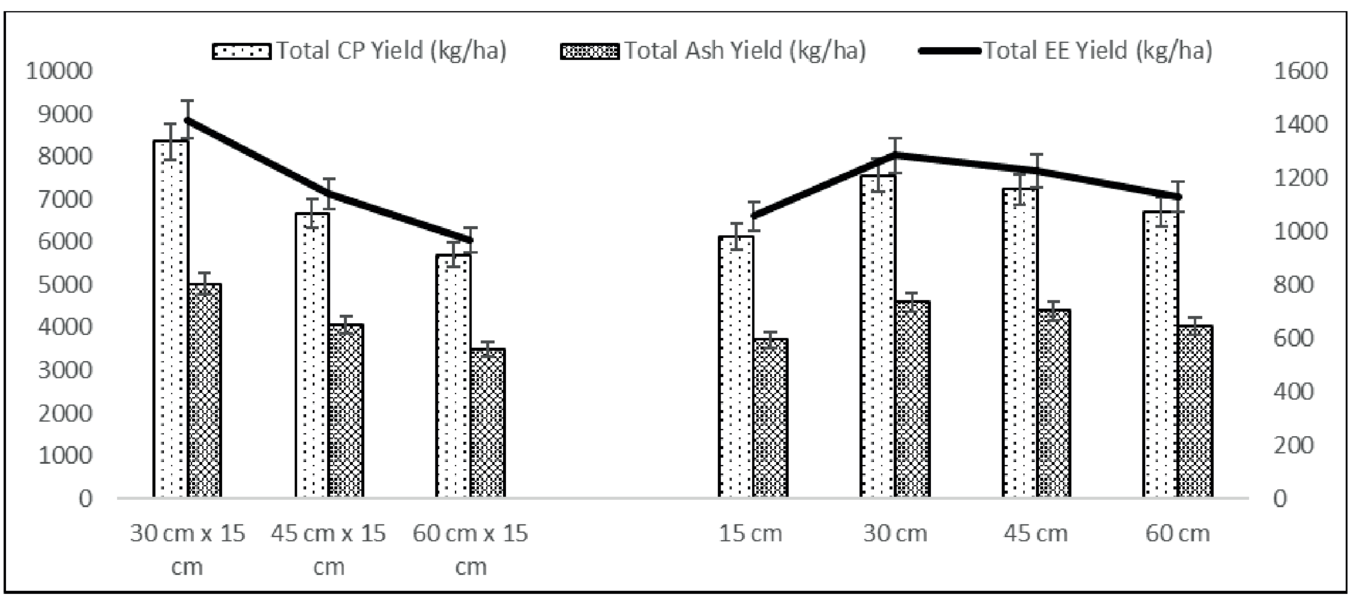

Fig. 1. Effect of crop geometries and cutting heights on total yield of proximate chemical constituents of forage moringa

Table 2. Effect of crop geometries and cutting heights on energy input, output, and different energy indices of perennial fodder moringa production

Treatment	Energy Input (MJ/ha)	Energy Output (MJ/ha)	Net Energy Returns (MJ/ha)	Energy Use Efficiency	Energy Productivity (kg/MJ)	Energy Profitability	Energy Intensity in physical terms (MJ/kg)	Energy Intensity in economic term (MJ/₹)
Crop geometry								
30 cm × 15 cm	56,751	6,61,897	6,05,146	11.66	0.79	10.66	1.28	3.78
45 cm × 15 cm	56,279	5,60,751	5,04,472	9.96	0.67	8.96	1.50	3.59
60 cm × 15 cm	56,043	5,02,008	4,45,964	8.96	0.61	7.96	1.68	3.42
SEm±	-	14,767	14,767	0.26	0.02	0.26	0.04	0.10
CD (P=0.05)	-	57,982	57,982	1.03	0.07	1.03	0.14	NS
Cutting height								
15 cm	56,358	5,23,020	466,662	9.27	0.63	8.27	1.62	3.27
30 cm	56,358	6,36,182	579,824	11.28	0.76	10.28	1.33	3.98
45 cm	56,358	5,97,245	540,887	10.59	0.72	9.59	1.42	3.74
60 cm	56,358	5,43,095	486,737	9.63	0.65	8.63	1.57	3.39
SEm±	-	13,216	13,216	0.23	0.02	0.23	0.03	0.08
CD (P=0.05)	-	39,268	39,268	0.70	0.05	0.70	0.10	0.25

energy in moringa cultivation. This high input energy requirement is attributed to the perennial nature of the fodder moringa, which required about 25 irrigations during the reported period. The lowest input energy was associated with moringa seeds, which accounted for an average of 2% of the total input energy (Fig. 2). Further, out of total input energy, 71% of direct and 29% of indirect energy (Fig. 3a) and 38% of renewable and 62% of non-renewable energy (Fig. 3b) was utilized in perennial fodder moringa cultivation during the experimental period.

Different crop geometries and cutting heights significantly affected energy output and various energy indices of fodder moringa (Table 2). The highest energy output (661897 MJ/kg) was recorded when moringa was sown with a spacing of 30 cm × 15 cm. This higher output energy might be attributed to the increased seed rate and higher biomass yield at this spacing compared to other geometries. Similarly, the highest net energy returns (605146 MJ/kg) and energy use efficiency (11.66) were also observed with the 30 cm × 15 cm geometry. This

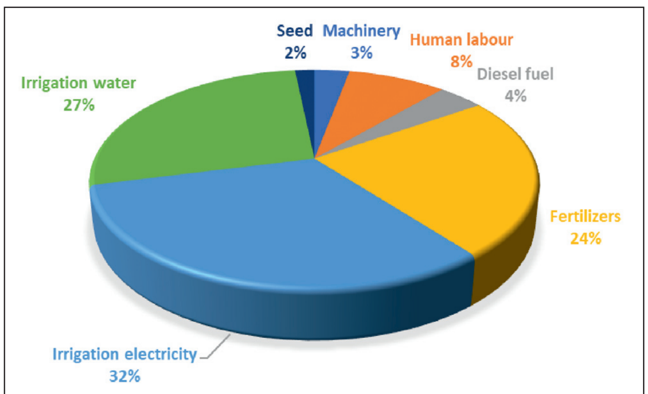

Fig. 2. Share of energy inputs in perennial fodder moringa production

spacing provided 19.96 % and 35.69 % higher net energy returns compared to 45 cm × 15 cm and 60 cm × 15 cm spacings, respectively. These findings align with Priya *et al.* (2019) and Mangal *et al.* (2017). The highest energy productivity (0.79 kg/MJ) and profitability (10.66) were also achieved with the 30 cm × 15 cm spacing, showing 29.51 % and 33.92 % higher energy productivity and profitability compared to the 60 cm × 15 cm spacing. This increased energy productivity and profitability at the 30 cm × 15 cm spacing are likely due to the higher biomass yield, higher net energy returns, and lower input energy requirements. Similar results were also reported by Lorzadeh *et al.* (2011) and Mangal *et al.* (2017) in maize crops. Additionally, the lowest energy intensity in physical terms (1.28 MJ/kg) and the highest energy intensity in economic terms (3.78 MJ/₹) were recorded at the 30 cm × 15 cm spacing. Energy intensity in physical terms is the ratio of total energy input to total biomass yield, while energy intensity in economic terms is the ratio of gross energy input to the cost of cultivation. Therefore, the lowest input energy and cost of cultivation, combined with the highest output energy and biomass yield, explain the lowest and highest energy intensities in physical and economic terms, respectively, for the 30 cm × 15 cm spacing compared to other crop geometries. Priya *et al.* (2019) found that differences in specific energy (physical energy intensity) may result from increased competition for nutrients in narrower spacings compared to wider row spacings. Among the treatments with varying cutting heights, the highest energy output (636182 MJ/kg) was recorded when fodder moringa was harvested at a height of 30 cm from the ground, with statistically at-par values observed at 45 cm. This higher energy output can be attributed to the increased biomass yield at these cutting heights. Similarly,

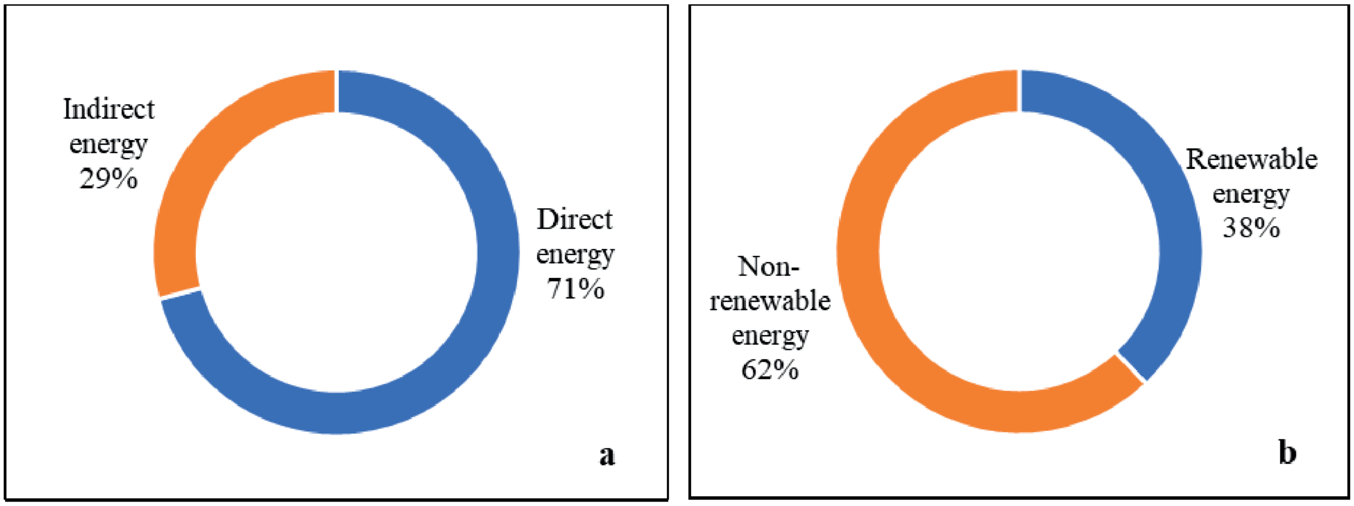

Fig. 3. (a) Utilization of direct and indirect energy and (b) renewable and non-renewable energy in perennial fodder moringa production

the highest net energy returns (579824 MJ/kg) and energy use efficiency (11.28) were also recorded at the 30 cm cutting height, which was statistically comparable to the 45 cm cutting height. Harvesting at 30 cm from the ground showed 24.25 % and 19.12 % higher net energy returns compared to 15 cm and 60 cm cutting heights, respectively. The highest energy productivity (0.76 kg/MJ) and energy profitability (10.28) were recorded at the 30 cm cutting height, with values comparable to the 45 cm cutting height. Harvesting at 30 cm resulted in 20.63 % and 24.30 % higher energy productivity and profitability compared to the 15 cm cutting height. These higher values are likely due to the increased biomass yield, higher net energy returns, and lower input energy at the 30 cm cutting height compared to the 15 cm and 60 cm heights. Additionally, the lowest energy intensity in physical terms (1.33 MJ/kg) and the highest energy intensity in economic terms (3.98 MJ/₹) were recorded at the 30 cm cutting height, with values comparable to the 45 cm cutting height. The lowest input energy and cost of cultivation, combined with the highest output energy and biomass yield, explain the lowest and highest energy intensities in physical and economic terms, respectively, for the 30 cm cutting height. These findings align with Chen *et al.* (2023), who reported that cutting height in forage-food dual-purpose ratoon rice cropping significantly influenced energy output, net energy, energy use efficiency, energy productivity, and energy profitability.

Thus, the findings concluded that moringa should be sown with a row spacing of 30 cm and a plant spacing of 15 cm (30 cm × 15 cm), and harvested at a height of 30 to 45 cm from the ground to achieve maximum dry fodder yield, forage quality, and energy efficiency.

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