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Original Article

Moringa oleifera leaf production as affected by different row to row and plant to plant spacing

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ABSTRACT

A field experiment was conducted at the Institute of Plant Introduction (IPI) Farm, Saleh Muhammad village, Malir, Southern Zone Agriculture Research Center, Karachi (24°25.11'N, 67°14.89'E), Pakistan, during 2018-2019 using a randomized complete block design with two factors: plant spacing (20 x 20 cm, 40 x 40 cm, and 60 x 60 cm) and three successive cuttings. The objective was to determine the optimum plant population for maximum leaf production. Results showed significant differences in M. oleifera leaf yield based on spacing and cutting time. For spacing treatments, the highest green leaf yield per acre was recorded at 40 x 40 cm spacing with 4292.2 kg, followed by 60 x 60 cm and 20 x 20 cm spacing, yielding 2821.1 kg and 2492.7 kg respectively. Similarly, the highest dry leaf yield per acre was also at 40 x 40 cm spacing with 583.67 kg, compared to 436.78 kg and 385.44 kg for 60 x 60 cm and 20 x 20 cm spacing respectively. Among the cuttings, the third cutting resulted in the highest green and dry yields per acre at 6189.8 kg and 874.11 kg respectively, followed by the second cutting (2311.9 kg and 369.11 kg) and the first cutting (1104.3 kg and 162.67 kg). These results indicate that an intermediate spacing of 40 x 40 cm optimizes leaf yield per acre, while subsequent cuttings enhance overall production. This study provides valuable insights for optimizing Moringa leaf production in similar agro-ecological conditions

INTRODUCTION:

M. oleifera, a member of the family Moringaceae, is a highly valued tree native to the sub-Himalayan regions of India, Pakistan, Bangladesh, and Afghanistan. This fast-growing, drought-resistant tree thrives in semi-arid tropical and subtropical climates, particularly in hot and dry sandy soils, including coastal areas. Moringa is renowned for its remarkable nutritional properties, making it one of the most useful trees globally. Almost every part of the plant is utilized for food, medicinal purposes, and various industrial applications (Thapa et al., 2019; Napoleao et al., 2019; .Walia et al., 2022)

India is the leading producer of M. oleifera, with an annual production of 1.2 million tons of fruits and approximately 16,000 tons exported during 2014-2016. The production of Moringa has been increasing by 26-30% annually due to its rising popularity and numerous health benefits. Moringa leaves are particularly rich in nutrients, containing over 90 nutrients and 46 different antioxidants. The leaves provide essential nutrients, amino acids, antioxidants, anti-aging, and anti-inflammatory properties, making them an excellent source of nutrition for both humans and livestock (Sarode .et al., 2023; Soni and Sharma, 2022)

According to recent research, it has been found that dry Moringa leaves are packed with an impressive array of nutrients. They boast a vitamin C content that is seven times higher than oranges, while their vitamin A content surpasses that of carrots by ten times. In terms of calcium, Moringa leaves outshine milk by a whopping seventeen times, and when it comes to potassium, they leave bananas in the dust with a fifteen-fold advantage. Additionally, Moringa leaves contain twenty-five times more iron than spinach and nine times more protein than yogurt, making them a true powerhouse of nutrition (Mahato et al., 2022). Recognizing its nutritional value, the World Health Organization has named Moringa the "Mother's Best Friend" and "Miracle Tree," promoting its use as a remedy for malnutrition (Suganthi et al., 2019; Srivastava and Singh, .2021)

Moringa leaf extract is rich in zeatin and cytokinin, potent plant growth enhancers (Jain et al., 2020). The leaves could significantly benefit populations with limited access to protein-rich foods, particularly in rural and peri-urban areas. Moringa's potential in combating malnutrition is evident in Senegal, where NGOs have utilized it to treat malnourished infants successfully (Singh et al., .2018; Hussein, 2020)

In traditional medicine, Moringa has been used for centuries to treat various ailments, including skin infections, anemia, anxiety, asthma, and more (Padayachee and Baijnath, 2020; Meireles et al., 2020). Its oil has significant cosmetic value and is used as a moisturizer and skin conditioner. Recent studies suggest that Moringa supplementation can improve cardiovascular health, glucose metabolism, and potentially offer anticancer .properties (Nova et al., 2020; Ma et al., 2020)

There is a significant contribution made by smallholder farmers to the growth of moringa using agroforestry techniques. A continuous source of feed materials for animals and a steady income stream for farmers over an extended period are both provided by this strategy, which not only ensures sustainable development but also provides a consistent source of livestock feed. Therefore, it is necessary to rely on improved agronomic advice to fulfill the demand for Moringa plant parts in an adequate manner. When it comes to enhanced farming practices, the aspects that have the most significant impact on crop yield are spacing, plant shape, and stand density by far. According to Haque and Sakimin, (2022), these elements have a considerable influence on growth, yield, and yield components. This phenomenon was brought to light by the .authors

There is a dearth of research studies that investigate the influence of population on the production of moringa. According to the findings of a study that was carried out in the southern region of Nigeria by Santos et al., (2021), the most optimal fodder yields of Moringa were obtained from plants that were placed at 30 x 40 cm away from one another, outperforming those with larger spacing. According to the findings of several research (Abdullahi and Maishanu, 2021; Obala, 2023), different planting populations should be used depending on the intended application of the biomass and the origins of the plant. Considering the enormous benefits that are at risk, it is of the utmost importance to conduct an exhaustive analysis of harvesting techniques that maximize the growth of Moringa biomass in a variety of agroecological environments. Several important parameters, like the density at which plants are planted and the frequency with which they are cut, can have a considerable impact on the quantity of biomass generated as .well as the quality of the leaves

According to Aslam et al.'s research from 2020, the species of moringa tree, which is used for fodder, has a remarkable growth rate and the capacity to produce the generation of significant quantities of fresh biomass. Nevertheless, environmental conditions and cutting management procedures have the potential to exert a large amount of influence on the dry matter (DM) production and chemical composition of Moringa. The time of the initial cut, the frequency and height of defoliation, and the density of the trees are some of the elements that need to be taken into consideration to maximize the production of fodder trees (Raj et al., 2023; Perez-Rivera et al., 2021). An extensive amount of study has been carried out to investigate the influence that planting density and cutting frequency have on the dry matter yield of Moringa in the tropical regions of Latin America. This recommendation comes from Perez-Rivera et al., (2021), who state that it is advised to keep the optimal planting density .between 0.75 and 1 million plants per hectare

Despite its many benefits, Moringa remains underutilized in Pakistan. This study aims to determine the optimal planting density and cutting frequency for maximizing Moringa leaf production under the agro-ecological conditions of Malir, Karachi. By identifying the best row-to-row and plant-to-plant spacing, as well as evaluating the impact of successive cuttings on leaf yield, this research seeks to enhance local production and utilization of this "Miracle Tree" for nutritional and economic benefits.

Material and Methods

Experimental Design and Treatments: A field experiment was conducted at the Institute of Plant Introduction (IPI) Farm, Saleh Muhammad village, Malir, Southern Zone Agriculture Research Center, Karachi (24°25.11'N, 67°14.89'E), Pakistan, during 2018-2019 using a randomized complete block design with two factors (Spacing and Cuttings). The study aimed to determine the optimal plant population for maximum leaf production. Three spacing treatments were used: S1 (20 x 20 cm), S2 (40 x 40 cm), and S3 (60 x 60 cm) and three successive cuttings (C1, C2 and C3) with a constant plot size of 3.23 m x 8.0 m (25.84 m²) in three replications. Each treatment had different plant populations: 100,000 plants per acre for S1, 25,000 for S2, and 11,111 for S3.

Land Preparation and Sowing: The soil of the experimental site was coarse-textured (Hilly Sand) with an EC of 0.40 dS/m and an average pH of 7.8. Irrigation was provided by a dug well with 3558 ppm total soluble salts. Land preparation involved standard practices, and all plots were managed properly through randomization of treatments. Moringa seeds were hydro-primed overnight and sown by hand at a depth of 2 cm in the designated spacing on 12-04-2018. Inter-culturing operations and weed management were conducted through hand weeding, with irrigation applied as needed, typically three times a month.

Harvesting and Data Recording: The first cutting of Moringa was done after 70 days, on 22-06-2018, when the plants reached a height of 2.5 feet. Subsequent cuttings were made at 40-day intervals on 04-08-2018 and 14-09-2018. The study included three cuttings, with data recorded each time. Harvesting involved cutting the plants one foot above the ground, with the remaining height left for future growth. Green leaves from each treatment plot were harvested, weighed, washed, and dried in the shade for 4-5 days before recording the dry weight.

Statistical Analysis: Statistical analysis was conducted using statistical package; STATISTIX® Version 8.1 Analytical software (Inc. Tallahassee, FL, USA) for analysis of variance to assess significant differences among variables. Mean differences for different spacing and cuttings, as well as their interactive effects, were analyzed at a 0.05% probability level (Steel, 1997).

RESULTS

Plant Height (cm): The data indicated that plant height of Moringa planted at different plant-to-plant and row-to-row spacing was statistically non-significant (Figure 1). This lack of significant difference is attributed to the uniformity in cutting practices, which were performed when the plants reached a height of approximately 2.5 feet across all treatments.

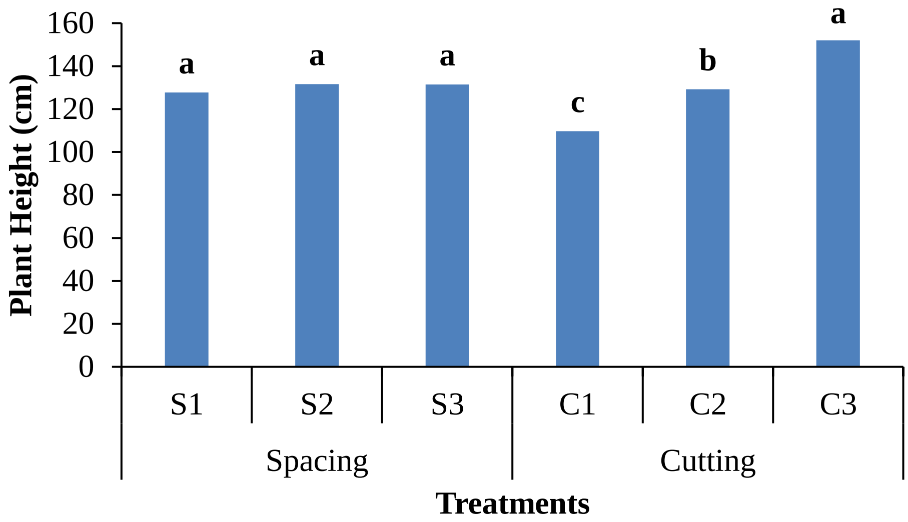

Figure 1. Effect of different spacing and successive cuttings on Moringa plant height. Whereas S1 (20 x 20 cm), S2 (40 x 40 cm), and S3 (60 x 60 cm) and three successive cuttings (C1, C2 and C3).

Green Yield per Plant (g): The study revealed that the maximum green leaves yield per plant (86.06 g) was recorded from the treatment with the widest spacing (60 x 60 cm), followed by the spacing of 40 x 40 cm (84.44 g). The narrowest spacing (20 x 20 cm) produced the minimum green yield per plant (26.57 g). The mean values for the treatments were statistically non-significant (Figure 2).

Green Yield per Acre (Kg): The study illustrated that the maximum green leaves yield per acre (4292.2 kg) was achieved with the 40 x 40 cm spacing, followed by the 60 x 60 cm spacing (2821.1 kg). The narrowest spacing (20 x 20 cm) resulted in the minimum green yield per acre (2492.7 kg). The mean values were significantly different across all treatments (Figure 2).

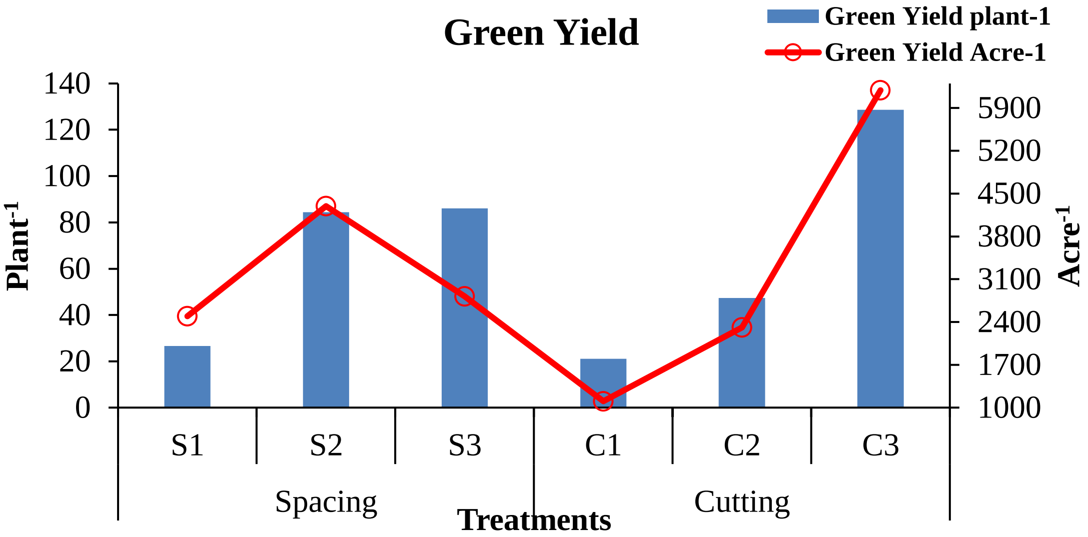

Figure 2. Effect of different spacing and successive cuttings on Moringa green yield. Whereas S1 (20 x 20 cm), S2 (40 x 40 cm), and S3 (60 x 60 cm) and three successive cuttings (C1, C2 and C3).

Dry Yield per Plant (g): The highest dry yield per plant (13.17 g) was recorded from the widest spacing (60 x 60 cm), followed by the 40 x 40 cm spacing (11.41 g). The narrowest spacing (20 x 20 cm) yielded the minimum dry yield per plant (4.01 g). Like green yield, the mean values for dry yield were statistically non-significant. On average, Moringa leaves reduced their weight by up to 85% when properly dried for powder purposes (Figure 3).

Dry Yield per Acre (Kg): The highest dry leaves yield per acre (583.67 kg) was also recorded with the 40 x 40 cm spacing, followed by the 60 x 60 cm spacing (436.78 kg). The narrowest spacing (20 x

20 cm) produced the minimum dry yield per acre (385.44 kg). The mean values for the 40 x 40 cm and 60 x 60 cm treatments were statistically non-significant, but the yield was significantly reduced under the 20 x 20 cm spacing (Figure 3).

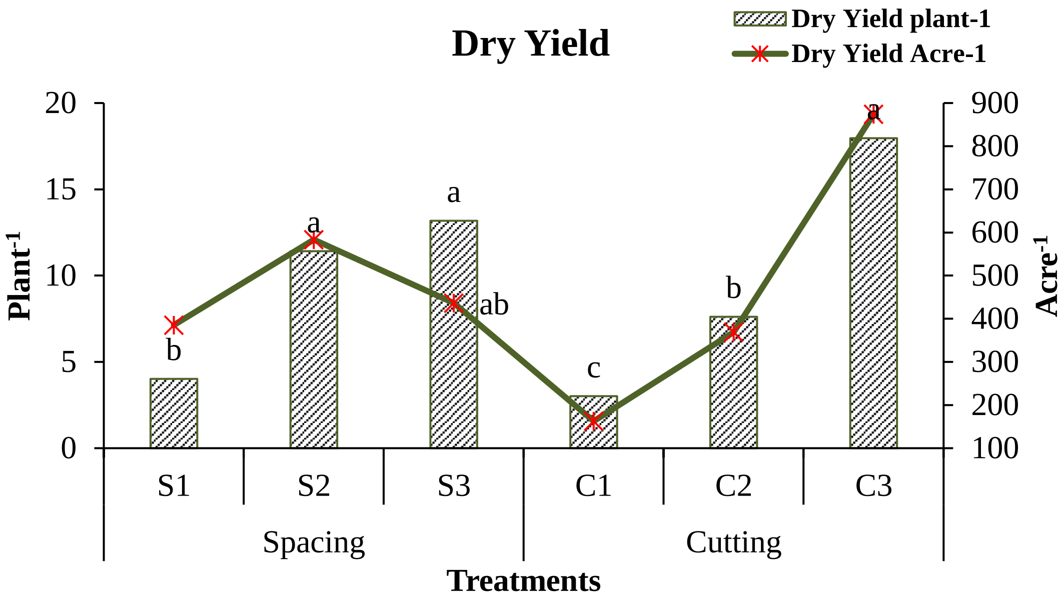

Figure 3. Effect of different spacing and successive cuttings on Moringa dry yield. Whereas S1 (20 x 20 cm), S2 (40 x 40 cm), and S3 (60 x 60 cm) and three successive cuttings (C1, C2 and C3).

Spacing Interaction with Cuttings: The analysis of variance revealed significant interactions between different spacing and cutting treatments. The data in Table 1 showed that the maximum dry yield of Moringa leaf per acre (1066.0 kg) was noted from the third cutting with a spacing of 40 x 40 cm, followed by the same cutting at a spacing of 60 x 60 cm (831.0 kg). The minimum yield per acre was observed from the first cutting at the 60 x 60 cm spacing, likely due to the lower plant population and early cutting.

Cuttings	Spacing	Dry leaf (kg) per acre
C_3	S_2	1066.0 a
C_3	S_3	831.0 ab
C_3	S_1	725.3 bc
C_2	S_2	503.7 cd
C_2	S_3	338.7 de
C_2	S_1	265.0 de
C_1	S_2	181.3 e
C_1	S_1	166.0 e
C_1	S_3	140.7 e

Six Treatments: S_1 (20 x 20 cm), S_2 (40 x 40 cm), and S_3 (60 x 60 cm) and three successive cuttings (C_1, C_2 and C_3).

Table 1. Interaction of different spacing with different cuttings of Moringa crop.

Six Treatments: S1 (20 x 20 cm), S2 (40 x 40 cm), and S3 (60 x 60 cm) and three successive cuttings (C1, C2 and C3).

DISCUSSION

The results of this study provide valuable insights into the impact of plant-to-plant and row-to-row spacing, as well as successive cuttings, on the yield of M. oleifera. The data indicated that plant height was statistically non-significant across different spacing, likely due to the uniform cutting height of approximately 2.5 feet, which was maintained across all treatments. This suggests that under the studied conditions, plant height is not a limiting factor for biomass production when uniform cutting practices are employed.

The green yield per plant showed significant variation with different spacing, with the highest yield recorded at the widest spacing (60 x 60 cm) and the lowest at the narrowest spacing (20 x 20 cm). These results are consistent with the notion that wider spacing allow for better light penetration and reduced competition for resources, thus enhancing individual plant productivity. However, the statistical non-significance of the mean values suggests that while trends are observed, they are not strong enough to be conclusive under the given experimental conditions.

Like green yield, the dry yield per plant was highest at the widest spacing and lowest at the narrowest spacing. The findings that the mean values were statistically non-significant align with the patterns observed in green yield, further supporting the conclusion that wider spacing may enhance individual plant productivity. On average, the reduction in weight (moisture) by up to 85% during drying highlights the substantial loss in biomass due to moisture content.

Contrary to the per plant yields, the per acre yields were highest at the intermediate spacing of 40 x 40 cm for both green and dry biomass. This intermediate spacing appears to offer a balance between plant population density and resource availability, optimizing overall productivity per unit area. These results are in line with previous studies, such as those by Aslam et al., (2020), who recommended an optimum planting density of 0.25 M plants ha^{-1} for achieving significant fresh and dry biomass yields. Similar conclusions were drawn by Balakumbahan et al., (2023), Perez-Rivera et al., (2021), and Amissah et al., (2024), who noted that higher plant densities can enhance biomass production.

The analysis of different cuttings revealed significant impacts on all yield parameters of Moringa leaf production. The third cutting produced the maximum dry leaf yield per acre, followed by the second cutting, while the first cutting yielded the minimum dry biomass. These results corroborate the findings of Tetteh et al., (2021), who reported maximum biomass production when Moringa leaves were harvested after 40 days in Ghana. The increase in yield with successive cuttings can be attributed to the cumulative biomass accumulation over time and possibly enhanced regrowth dynamics (Obala, 2023; Santos et al., 2021; Santoso and Parwata, 2020).

The interaction between spacing and cutting treatments showed interesting patterns. The maximum dry yield per acre was recorded from the third cutting at the 40 x 40 cm spacing, followed closely by the same cutting at the 60 x 60 cm spacing. The minimum yield was observed from the first cutting at the widest spacing, likely due to the lower plant population and early cutting timing. These findings suggest that while wider spacing enhance individual plant yield, an intermediate spacing combined with strategic cutting schedules can optimize overall productivity. This recommendation aligns with Eshete et al., (2022) and Hamore et al., (2022), who suggested an optimum planting density for maximizing biomass yields.

The study highlights the importance of optimizing both planting density and cutting frequency to maximize the yield of M. oleifera. While wider spacing benefit individual plant productivity, intermediate spacing can optimize total yield per unit area, particularly when combined with appropriate cutting schedules. These insights can inform agronomic practices aimed at enhancing Moringa cultivation for both nutritional and economic benefits.

Conclusion:

This study provides significant insights into the effects of planting density and cutting frequency on the yield of M. oleifera, a crucial fodder tree species with high potential for sustainable agricultural practices. The findings underscore that while plant height remains uniform due to standardized cutting practices, both green and dry yields per plant are optimized at wider spacing (60 x 60 cm), though these trends are not statistically significant. In contrast, the highest per acre yields are achieved at an intermediate spacing of 40 x 40 cm, which balances plant population density and resource availability. Successive cuttings notably enhance yield, with the third cutting providing the maximum dry leaf yield per acre. This highlights the importance of strategic cutting schedules in optimizing biomass production. The interaction between spacing and cutting further emphasizes that intermediate spacing combined with appropriate cutting intervals can significantly boost overall productivity.

For smallholder farmers and agroforestry practitioners, adopting an intermediate spacing of 40 x 40 cm and employing successive cuttings can significantly enhance the yield of M. oleifera. These practices not only improve biomass production but also support sustainable agricultural development by providing continuous feed materials and income streams over multiple years. Future research should further explore the long-term impacts of these practices across different agroecological conditions to refine and validate these recommendations.

Conflict of interest: The Authors declare that there is no conflict of interest.

Author's Contribution Statements: AFS conceived the idea, supervision of experiment, AAK and NAS executed the field research and statistical analysis, IK helped in writing the article and IA proofread the article, polished the results, finalize the graphical representation of the data and prepare the article according to the journal.

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