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Planting Density and Seasonal Variability Effects on Yield of Mung Bean (*Vigna radiata*) as a Novel Crop in Tennessee

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Abstract

Mung bean (*Vigna radiata* (L.) R. Wilczek) is a short-season, Asian pulse grain legume potentially suited to USA agricultural crop rotations that could be of interest to Southeastern farmers. This legume boasts high seed nutritional value and drought tolerance. The climate of the East Asian region of origin of mung bean closely parallels the Southeast region of the United States, making it a candidate for testing as a novel crop. The objective of this study was to evaluate the overall performance and adaptability of available varieties of mung bean to the environmental conditions of West Tennessee. For this, we conducted a three-year study with varieties Berken and OK2000 planted in typical delta soils from 2022 to 2024. Different planting densities and dates were used as variables in the planting of the bean varieties. Planting was at three seeding rates: 150,000, 200,000, and 250,000 seeds per 0.4 ha (1 acre), with 19 cm row width (7.5 inches) in randomized complete block design with 6 repetitions. Trait measurements included plot weight, seed moisture content, and total yield. Results varied between the three years: yield was low in the August 2022 planting but higher in the July 2023 and June 2024 plantings, with mean yields averaging over 1,600 kg ha^{-1} across varieties and densities for those two years. Herbicides were very effective for weed control in the latter two seasons. These findings provide a basis for understanding the potential of mung beans in the agronomic settings and environmental conditions of the Mid South region of the United States.

Keywords

Environmental Stress, Planting Density, Southeastern USA, Yield Potential

1. Introduction

Worldwide pulse production has shown relatively little increase over recent decades compared with cereal crops [1]. Integrating pulse grain legumes into cropping systems is increasingly important due to their agronomic and environmental benefits. Legumes enhance soil quality through symbiotic nitrogen fixation [2], reduce greenhouse gas emissions [3], mobilize soil phosphorus, increase organic matter, and improve soil water retention. In addition, rotational inclusion of legumes has been associated with increased yields in subsequent cereal crops, particularly in regions dominated by cereal monoculture systems [4]. As rotational crops, legumes contribute to nutrient cycling, agroecosystem biodiversity, and pest suppression [5] [6].

Several Asian legumes remain underutilized in United States agriculture but hold considerable promise. Among these, mung bean (*Vigna radiata* (L.) R. Wilczek) is notable for rapid germination, high nutritional value, broad adaptability [7], and positive impacts on soil nitrogen status [8]. Mung bean seeds contain approximately 22% - 24% protein and functional starches that are valuable for food and industrial applications [9]. Their high digestibility further supports their use as a protein source and meat substitute.

As a potential novel crop for Tennessee, mung bean offers multiple advantages. Its short growth cycle of approximately 90 days allows flexibility in planting dates and potential double-cropping. The crop is heat tolerant and can grow during the warmest part of the growing season, while its drought tolerance makes it suitable for rainfed systems. Together, these traits make mung bean a promising rotational option following winter wheat in Mid-South cropping systems. In addition to agronomic benefits, mung bean represents a potential alternative income source for farmers [10]. Previous research suggests that planting density strongly influences mung bean productivity [11], emphasizing the need to identify optimal seeding rates for mechanized row-crop systems.

Existing research highlights the importance of row spacing and planting density for grain legumes. Studies on dry bean report yield benefits at moderate row spacing [12], while narrow rows in mung bean improve light interception, biomass accumulation, and yield. Higher plant density promotes uniformity, faster canopy closure, and improved weed suppression [13]. Earlier research conducted in the southeastern United States demonstrated increased biomass production under closer intra-row spacing, though those studies relied on hand planting and non-commercial row widths [14] [15].

The objective of the present study was to evaluate mung bean adaptation to southeastern U.S. cropping systems using mechanical seeding in narrow rows (19 cm). Specifically, we assessed the effects of three planting densities and two released varieties (Berken and OK2000) across three growing seasons. The overarching goal was to identify agronomic practices that support the development of mung bean as a viable summer rotation legume for Mid-South agriculture.

2. Materials and Methods

Two genotypes were used in this study with both from the plant breeding program of Oklahoma State University (OSU). The first variety was Berken, initially developed by W.E Berkenbile, a pioneer mung bean grower in Oklahoma and released in 1963 (OSU Production Guide) and known for medium sized seed with good green color. The second variety was OK2000, released in 1999 for sprouting and is also medium sized seeded for mung bean. While Berken has no shattering; OK2000 has better resistance to lodging. Each year, the two varieties were sourced and purchased from the OSU Seed foundation (Stillwater OK), where stocks are maintained as certified seed.

The experiment was conducted at the 400 ha Agricenter International research station in Memphis, Shelby County, Tennessee. Given the large size of the station, the experiment was managed at a fenced in site near the field house facility, which is at the intersection of Smythe Farm Road and the main Agricenter farm road (coordinates 35˚07'33"N and 89˚48'45"W). Plot soils were classified as Falaya-Waverly (https://websoilsurvey.nrcs.usda.gov/), from the series Entisols of the USDA Soil Survey where the soil was a mix of 18.6% clay, 51.6% silt, 29.6% sand that is well-draining. The pH of the site was 6.5 and natural fertility was high.

A randomized complete block design was used for the experiment which was repeated across three summer seasons in years 2022, 2023 and 2024. The design consisted of plots that were 1.8 m (6 ft.) wide and 9.1 m (30 ft.) long. In each plot, there were 9 rows spaced at 19 cm (7.5 inches) between rows and varying in plant density as treatment. The three densities were based on 150,000, 200,000 and 250,000 seeds for the two varieties tested (Berken and OK2000). These densities were computed for the correct number of seeds from lowest to highest density, which were needed per plot. Given that deviation in seed weight between varieties was small, we converted the seeding rates to standard amounts to have an easier measurement to use in planting and reference to farmers. An automated seed counter was used to count out 620, 826, and 1033 seed for the three densities.

All plots were mechanically planted using a no-till drill from Great Plains AG (Sa-lina, KS 67401), with a cone distributor. The planting dates and growing seasons varied in each year with 2022 season spanning from August 3rd to November 22nd, while 2023 season spanned from July 6th to November 17th. The final season of 2024 had a planting date of June 24th and harvest date of November 11th.

In the first year, mung beans were planted without herbicide treatments due to it being a new crop for the site, but in the second two years herbicides were applied. The herbicides included a pre-emergent, Reflex (Syngenta, Greensboro NC 27419, USA) that has fast, effective and long-lasting residual activity, for management of difficult weeds such as glyphosate-resistant Palmer amaranth and ALS-resistant pigweed, grass and sedges. Reflex can be used on a wide range of crops and was registered for grain legumes. The other herbicide was the post-emergent Select Max (Valent, Libertyville, IL 60048 USA) used for control of volunteer corn and other grasses in many row and specialty crops. It has a unique formulation, adjuvant and tank mix flexibility, and excellent crop safety. The plots had a fallow before planting and fertilization was not applied.

Harvesting was mechanical with an Almaco plot combine (Nevada, Iowa 50201) and yield measurement were taken in lbs./acre with moisture content and converted to kg/ha. Agriculture Research Manager (ARM) software (GDM Solutions Inc., Brookings, SD 57006) was used to randomize the varieties, densities and replications into a complete block design (RCBD) as well as for data analysis. The analysis of variance (ANOVA) considered the densities and varieties used as fixed effects while years and replications were random effects. A Tukey's highly significant difference (HSD) test was performed for multiple pairwise comparisons of means and a graph was developed in R Studio software (release 2024.12.1) with compact letter display (CLD) added above the bars.

3. Results

The study examined the impact of planting density, variety, and environmental conditions on mung bean yields over three growing seasons (2022-2024). In each season, we evaluated two varieties across three planting densities. The experiment was planted, maintained and harvested conventionally using no herbicide the first year but two herbicides in the second and third. This allowed us to see how mung bean performed on a large scale with and without chemical weed control. The planting densities per hectare (ha) were equivalent to 16.815 kg, 22.420 kg and 28.025 kg/ha, assuming similar seed weights for each variety and based on the estimate seeds per acre density treatments. The germination rate of Berken was 90 percent, while OK2000 had a germination rate of 88 percent.

Results showed that plant density significantly influenced yield, with higher densities producing better results. For example, at the highest density of 250,000 seeds per acre, the average yield exceeded 1680 kg/ha (1500 lbs./acre) in 2023 and 2024 (**Figure 1**). Comparatively lower yields were recorded with 150,000 seeds per acre than with 200,000 or with 250,000 seeds per acre. Another primary driver of yield differences was the yearly environmental conditions across each season rather than the specific variety planted or the density. Yields were lower in the first season due to the lack of weed control. However, yields were higher in the second two seasons, when herbicides were applied, and the crop had a longer time to mature without weed competition.

The Analysis of variance (**Table 1**) showed that year effects were highly significant ($P < 0.001$) followed by planting density effect ($P = 0.037$). Meanwhile, variety effects were not significant ($P = 0.162$) across the entire experiment; however, the interaction effect of Variety × Year was very close to significance ($P = 0.053$). Other interactions were not significant. Evidently the three years' environmental conditions heavily influenced yields. Plant density effects were most notable in the middle season but less so in the initial and final seasons. Weed pressure reduced yields in 2022, while better weed control in 2023 and 2024 led to higher yields. Year-to-year variation in the ANOVA was found to be significant.

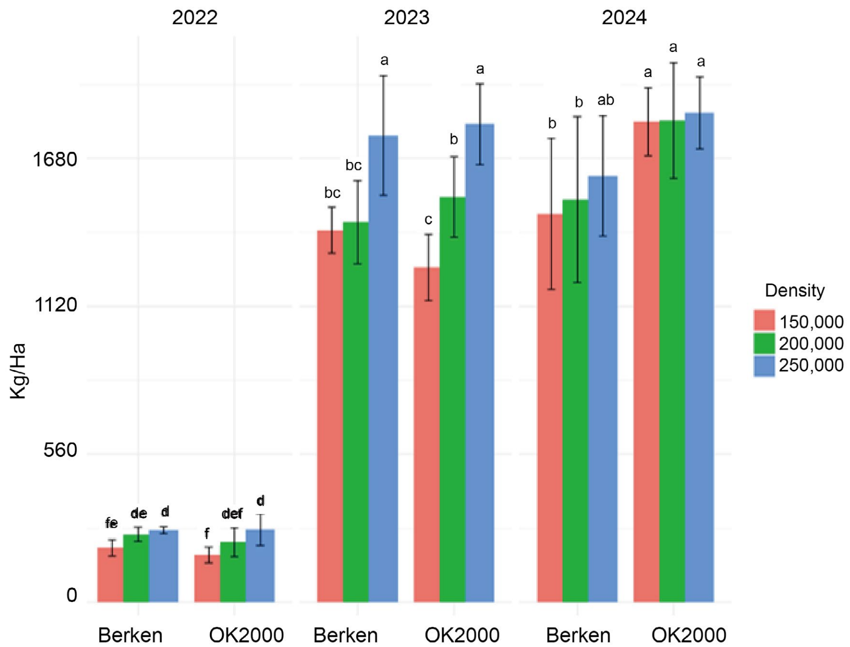

Figure 1. Yield (kg·ha^{-1}) of mung beans (Berken and OK2000) in Tennessee across summer seasons spanning three years (2022, 2023 to 2024) and three planting densities per 0.4 ha (150,000, 200,000 and 250,000 seed) as color coded by the legend to right. Compact letter display above error bars represents significant differences at P < 0.05 based on Tukey's HSD test.

In 2022, yields for mung bean were low across all planting densities and varieties, reflecting the weed stress. Maximum yields barely surpassed 250 kg/ha, with small significant difference among varieties Berken and OK2000. Both genotypes exhibited a dramatic improvement in yield across densities in the following seasons of 2023 and 2024, due to better weed control. At the highest density of 250,000 seeds, yields exceeded 1680 kg/ha, showing a strong response to the use of herbicides as improved management practice.

Table 1. Analysis of variance for the mung bean density experiment in Memphis, Tennessee across summer seasons in three years (2022, 2023, and 2024) with two varieties (Berken and OK2000).

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Variety	1	183183.5	183183.5	1.985943	0.162
Density	2	628620.4	314310.2	3.407525	0.037*
Year	2	30048302	15024151	325.762	<0.001**
Variety × Density	2	13824.82	6912.407	0.074939	0.93
Variety × Year	2	353108.1	176554.05	3.828143	0.053
Density × Year	2	1929.65	964.8229	0.01046	0.99
Variety × Density × Year	4	12340.32	3085.08	0.066892	0.94

[1]*P < 0.05 significance, **P < 0.01 high significance.

When comparing weather data for the seasons (Suppl. **Figure 1**), 2022 had a long and harsh period of drought even though overall the precipitation rate was high at beginning and end of the season. A large drought occurred in October and temperatures recorded a maximum of 102˚F/38.9˚C. The 2023 season had good initial precipitation in the early stages but overall rainfall was much lower for this season with temperatures like the previous year. The 2024 season was slightly less hot with a high only reaching 37.8˚C/100˚F. Planting dates varied for each year and certainly affected the productivity of the mung bean crop. Due to planting date differences, development stages varied between the three years, fitting weather patterns during critical growth periods. More favorable weather conditions in 2023 and 2024 were associated with earlier planting while in 2022 the planting coincided with an extended hot period.

4. Discussion

The study across the three years (2022–2024) demonstrates the variable yield potential for mung bean. The first growing season with a later planting date was particularly hit by weed pressure and drought. This drought coincided with crucial stages of plant development, particularly flowering and pod setting, and resulted in very low yields. Devasirvatham et.al., and Haeften *et al*. observed similar effects on yield varying depending on the stage in which the drought occurs across various legumes [16] [17]. Temperature trends showed sustained periods of high heat, with maximum temperatures above 90˚F/32.2˚C for over half of the season. These conditions likely compounded the drought's effects by inducing heat stress in plants, significantly reducing productivity. In addition, weed control was difficult in the first year, without a set of herbicides applied during that season. The maximum yields during 2022 only reached 250 kg·ha^{-1}, highlighting the detrimental impact of these combined environmental and biotic challenges to mung bean productivity.

The 2023 experiment was planted in July, earlier than the previous year, and benefited from more favorable weather conditions and the implementation of herbicides. While precipitation was lower compared to other years, the weed control might have reduced water stress. As a result, yields were dramatically higher across all planting densities and varieties, reaching over 1,680 kg·ha^{-1}. The improved agronomic conditions continued in 2024 when an earlier planting date in June enabled greater crop productivity, although with less effect of planting density than in 2023. We can postulate that June would be an ideal planting date that would allow for better flower pollination and pod set as well as a longer period of pod filling. However, July would still provide enough time for pod fill. Timing of flowering for cooler and rainier periods of the year is known to be important in grain legumes. For example, chickpea studied under heat stress versus cooler season had higher pollen sterility [16].

Although the Variety × Year interaction was not statistically significant at α = 0.05 the observed proximity to significance (P = 0.053), it suggests that Berken and OK2000 may have responded differently to variable environmental patterns. Given the strong main effect of year in coordination with yield, this indicates that varietal performance was not consistent across growing seasons. Such responses are common in short-season legumes and may reflect differences in sensitivity to temperature, moisture availability, or planting time. These results emphasize the importance of multi-year evaluations when assessing varietal adaptation and stability for mung bean production.

In terms of variety effects, OK2000 had significantly higher yields under the higher planting density during 2023 but not in 2024. The use of two mung beans was with the plan of developing varieties suited to Tennessee agricultural systems and seeing if they interacted with planting density. The study unveiled significant plasticity and yield adaptability for genotypes, highlighting the crop's potential within the state. While each season was planted about one month apart, previous studies conducted at Tennessee State University showed that planting date had minimal effect on the productivity of mung beans, which were more affected by plant density than by earlier planting [15].

This outcome suggests that the impact of planting density on enhancing mung bean productivity is more important when drought is intermittent. Bhardwaj *et al.* found that drought was a major factor affecting mung bean yield, with improved performance associated with irrigation and higher soil moisture. The study also identified weed management as a major challenge across all replications, pointing to an essential area for future mung bean cropping improvements [18].

The results from the three growing seasons demonstrate the variable yield potential of mung bean under different management conditions. The 2023 and 2024 seasons particularly highlighted the crop's good yield potential with conventional herbicide use and associated farming practices. The contrasts between the 2022, 2023, and 2024 seasons were also attributed to environmental factors such as rainfall or temperature differences between years and weed competition during the first year.

While mung beans tend to be a heat-tolerant crop, the stage at which the species is disrupted by high temperatures is crucial in determining yield [19] [20]. Like many other plant species, including groundnut and common bean, mung bean reproductive organs are highly sensitive to heat stress [21]. In comparison, peanuts compensate for heat stress by increasing lipid saturation within cell tissues, helping to sustain flowering and fruit set [22]. In addition to heat tolerance, mung bean is noted as a drought-tolerant crop [20], allowing irrigation to be kept to a minimum. The use of herbicides also improved varietal performance in this study, consistent with findings from mung bean systems in India [23].

5. Conclusion

Mung bean demonstrated strong yield potential under Mid-South conditions when planted early and managed with effective weed control. Planting density and environmental conditions had a significant effect on yield, while varietal differences were secondary. These results support the inclusion of mung bean as a viable summer legume in southeastern U.S. cropping systems and provide a foundation for future agronomic optimization.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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