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Response of precision-planted soybean morphology, seed quality and yield to varying seeding rates under Central European conditions

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Abstract: In Central Europe, soybeans are typically sown in narrow rows (125 mm), whereas wide-row (500 mm) precision planters offer more accurate within-row spacing and greater flexibility for inter-row cultivation and targeted applications. We evaluated whether soybeans established with a precision planter respond to changes in seeding rate. A two-year on-farm strip trial (2023–2024) was conducted in Czechia with two determinate cultivars, Satelia and Tertia, at four target seeding rates (20, 40, 60 and 80 germinating seeds/m^2). Plant morphology, seed yield, and seed composition were assessed. Branch number (3.1–1.0 pcs/plant for Satelia, 2.4–1.1 pcs/plant for Tertia), pod number (54.2–22.6 pcs/plant for Satelia, 53.4–28.0 pcs/plant for Tertia), and fertile nodes (11.6–9.3 pcs/plant for Satelia, 12.2–10.0 pcs/plant for Tertia) all decreased linearly with increasing seeding rate in both tested cultivars, indicating strong morphological compensation at low plant densities. Dry matter seed yield and seed composition were not significantly affected by seeding rate within the tested range, while year and cultivar effects were more pronounced for several seed quality components. These results suggest that soybean yield and quality are largely buffered against variation in plant population.

Keywords: *Glycine max* (L.) Merr.; yield structure; wide rows; field emergence; plant density

Optimising row spacing and seeding rate of soybean [*Glycine max* (L.) Merr.] is a critical agronomical component in European production systems. Because these factors determine plant architecture and yield formation, defining the optimal plant density is essential for achieving both agronomic and economic gains (Colet et al. 2023). Lower soybean crop density can help reduce inter-plant competition for water, nutrients, and sunlight, and increase intercepted radiation and biomass production (De Luca et al. 2014). On the other hand, higher density helps reduce weed pressure, as such soybean stands show lower weed biomass (Chauhan and Opena 2014).

In North American environments, the interactions between seeding rate and yield are well documented. According to Schmitz et al. (2020), seeding rates between 35 and 50 seeds/m^2 did not produce significant yield differences in North Dakota, but lower seeding rates are more suitable for maximising partial net profit when seed costs are considered. Cox

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Figure 1. A field trial was established at a 500 mm row spacing of soybean cultivation used in this field study

and Cherney (2011) found the highest soybean seed yield in New York at 42 seeds/m^2, compared with 32, 37 and 47 seeds/m^2. De Bruin and Pedersen (2008) showed that although maximum yield was achieved at a final population of 46 plants/m^2, more than 95% of this yield was attained with populations as low as 26 plants/m^2. Coelho et al. (2024) showed that uniform plant spacing improves soybean yield and profitability, highlighting the importance of precise seed placement and proper planter adjustment. In a two-year study in Brazil comparing seeding rates from 9 to 35 seeds/m^2, optimal seed yield occurred at 26 seeds/m^2, while maximum profitability was achieved at a seeding rate 6.5% lower. However, according to Ribeiro et al. (2017), in Brazil, regardless of the soybean cultivar, plant densities from 30 to 60 per m^2 do not affect seed yield, plant height, or number of seeds per pod. According to Basso et al. (2021), soybeans can compensate for different intra-row plant spacing by adjusting pods per plant and the number of nodes per plant on lateral branches with no reduction in the final soybean yield.

In Poland, no significant effect of soybean seeding rate (70, 90 and 110 seeds/m^2) on seed yield was found (Prusiński and Nowicki 2020, Jańczak-Pieniążek et al. 2021); instead, seed yield was determined solely by the weather conditions of the respective years. On the other hand, in Germany, Sobko et al. (2019), comparing seeding rates of 30–90 seeds/m^2, found that seed yield increased with the seeding rate.

This study aimed to quantify the responses of soybean plant morphological traits, seed yield and seed quality components to four seeding rates in two early-maturing soybean cultivars under Czech conditions, with wide row spacing (Figure 1), using farm-scale equipment that has not been documented in previous studies. Specifically, we tested the hypotheses that seed yield and quality remain stable over a wide range of seeding densities. Because precision planters are still rarely used for soybeans in Central Europe, our results provide a practical basis for adjusting seeding rates in precision-planting systems.

MATERIAL AND METHODS

Location and weather conditions. Field experiments were conducted from 2023 to 2024 at a single location in Czechia (Zizice; 50.252°N, 14.164°E, 262 m a.s.l.) at a commercial farm. Chernozem was the prevailing soil type, characterised by 43 mg/kg P, 400 mg/kg K, 5 117 mg/kg Ca, and a pH of 7.41.

The average monthly precipitation and temperature for the growing seasons are presented in Figure 2.

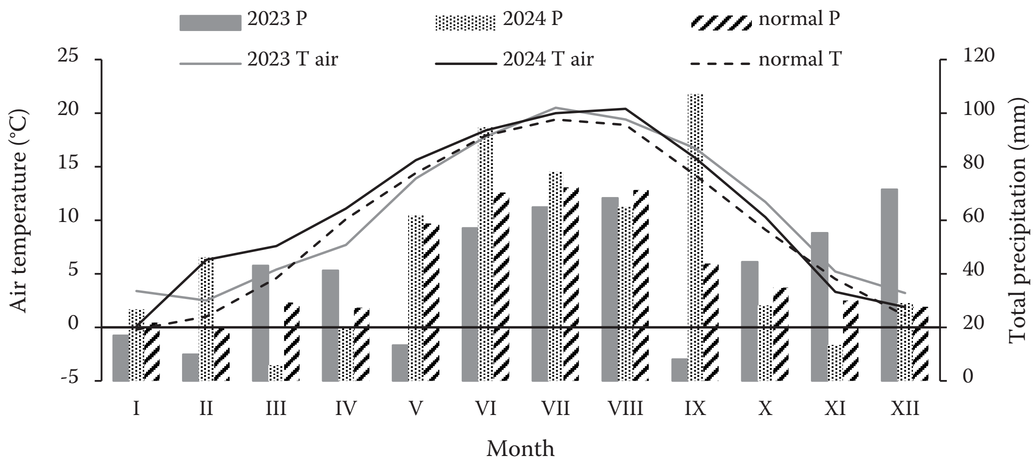

Figure 2. Average monthly cumulative precipitation (P) and monthly average temperature (T) during the vegetative years 2023–2024 in comparison with the standard climatological normal (1991–2020) according to CHMI (2025)

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Table 1. Dates of planting, plant counting, pre-harvest plant analysis and harvest of soybean cultivars

Year	Planting	Plant counting	Plant analysis	Harvest
2023	4 May	11 June	11 September	16 October
2024	26 April	10 June	8 September	21 September

Weather conditions during the trials were obtained from the agrometeorological station of the Czech weather service located closest to the trials.

Agronomic management. The soil tillage practices and data collection (Table 1) were identical across both experimental years, winter wheat [*Triticum aestivum* (L.) Thell.] being the previous crop. The seeding rate variants were established using Tempo V 12 precision planter (Väderstad, Sweden), configured for a 500 mm row spacing.

On the day of planting, all plots were treated with a pre-emergence herbicide, Stomp Aqua by BASF, at a rate of 2.6 L/ha (455 g/L pendimethalin) in 60 L/ha of water. Approximately one month after planting, a post-emergence application of Corum herbicide by BASF (22.4 g/L imazamox + 480 g/L bentazon) was performed at a rate of 1.25 L/ha in 60 L/ha of water. Harvesting was conducted with a Wintersteiger NM ELITE 1993 small plot combine harvester.

Cultivars and experimental design. For this experiment, the early-maturing cultivars Tertia (maturity group 00), owned by Semences Prograin Zia, s.r.o., Czechia and Satelia (maturity group 00), owned by RWA Czechia s.r.o., were chosen.

In each experimental year (2023 and 2024), two cultivars (Satelia and Tertia) were sown at four seeding rates using full-scale machinery. The four planting densities were 20, 40, 60 and 80 germinating seeds per square meter. As the row spacing was 0.5 m, these rates correspond to 10, 20, 30 and 40 seeds per one meter of planted row. The individual seeding rates were implemented in separate 48 m-long planter passes; the order of seeding-rate strips was randomised within the field each year. In each planter pass, both cultivars were sown simultaneously, each using six separate planter units, creating two 3-m-wide strips. Each strip was divided into four consecutive 12 m segments, which were used as sampling units to quantify within-strip variability. The use of a full-scale commercial planter with large distances between passes prevents the implementation of a completely randomised block design independent of field variability.

Data collection. Plant density evaluations were conducted at the V3 phenological stage, following Brown et al. (2021). Approximately 20–30 days before harvest (Table 1), morphological traits were evaluated. For each replication, 10 plants were assessed for the following traits: number of branches per plant, number of pods on branches and main stem, shoot length, first pod height (measured from the soil surface to the apical part of the lowest pod), the average number of seeds per pod per plant and the number of fertile nodes per plant.

The harvest was conducted across the entire length of each replication, using a 1.5 m header width (sampling the centre of each replication), on the dates specified in Table 1. Following the harvest, the moisture content (%), crude protein content (%), and oil content (%) were determined using near-infrared spectroscopy with a Bruins Instruments OmegAnalyzer G™ NIR grain analyser by Bruins Instruments (Puchheim, Germany). Seed yield was calculated as seed yield dry matter (kg/ha). The thousand-seed weight was determined for a representative sample from each experimental unit, measured in two replicates of 500 seeds each.

Statistical analysis. All statistical analyses were performed in R version 4.4.2 (R Foundation for Statistical Computing, Vienna, Austria). For each studied trait, a three-way analysis of variance (ANOVA) was used to assess the main effects and factor interactions. Segment-level observations (four segments per cultivar × seeding-rate strip) were treated as sampling replications within each treatment combination. Data were analysed using ANOVA with Tukey's *HSD* (honestly significant difference) ($P \leq 0.05$) and Pearson correlations.

RESULTS AND DISCUSSION

The factors year and cultivar significantly affected seed quality components, whereas morphological traits, branches, pods and fertile nodes per plant responded strongly to seeding rates (Table 2). Shoot length and first pod height were influenced not only by seeding rate but also by year and cultivar, indicating strong environmental and genotypic effects. The number of seeds per pod was controlled primarily by cultivar. A significant year × seeding rate inter-

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Table 2. Analysis of variance for yield and plant properties of soybean for four seeding rates (20, 40, 60 and 80 seeds/m^2), two cultivars (Satelia and Tertia) in the years 2023 and 2024 in Czechia

	Emergence rate	Number of branches	Number of pods on branches	Number of pods per plant	Shoot length	First pod height	Number of fertile nodes	Seeds in pod	Seed moisture	Dry matter seed yield	Dry matter thousand seed weight	Crude protein	Oil
Year					**	***			***	***	***	***	***
Cultivar	***				***	*	*	*	***		***	***	***
Seeding rate		***	***	***		***	***		*				
Year × cultivar									***			***	***
Year × seeding rate				*	**	*	**			*			***
Cultivar × seeding rate					**								
Year × cultivar × seeding rate					*					*			

*P < 0.05; **P < 0.01; ***P < 0.001, blank cells indicate non-significant effects

action suggests that yield responses to seeding rate differed somewhat between years, likely reflecting contrasting weather conditions; however, in neither year did seeding rate produce significant yield differences within cultivars (Table 3).

Number of emerged plants. The number of emerged plants clearly increased with seeding rate (Figure 3). On average, emergence was 74% for Satelia and 63% for Tertia, indicating that seed lot quality and cultivar selection are crucial for optimising plant density and emergence rates. As the field emergence is strongly determined by seed vigour (Egli and TeKrony 1995), the significant effect of cultivar on emergence (Table 2) might be caused by seed lot quality.

In contrast to consistent emergence across seeding rates (Table 3) in our experiment, Sobko et al. (2019) reported unexpectedly higher emergence at low seeding rates (30–50 seeds/m^2) and lower emergence at high seeding rates (70–90 seeds/m^2), which they attributed to seedling competition resulting in poor establishment.

Branches and pods. At the lowest seeding rate, Tertia and Satelia showed 2.4 and 3.1 branches per plant, respectively, which were significantly higher than at higher rates, with values of 0.9 to 1.6 branches per plant (Figure 4A, 4B). Our results align with those of Cox and Cherney (2011), finding approximately 20% more branches at lower densities when comparing seeding rates from 32 to 47 seeds/m^2. Sobko et al. (2019) also reported reduced branching and pod number as seeding rate increased from 30 to 90 seeds/m^2. Ribeiro et al. (2017) found pods per plant decreasing with increasing seeding rate (from 30 to 60 seeds/m^2). Consistent with these studies, for both cultivars our experiment recorded more than 50 pods per plant at the lowest seeding rate, 20 seeds/m^2, whereas at rates of 60–80 seeds/m^2 these values were roughly halved (Figure 4C). Pod number was strongly negatively correlated with plant population (Table 4). In addition, Cox and Cherney (2011) found that pods per plant show a linear response to the seeding rate. These responses reflect the well-established compensatory ability of soybeans to maintain yield through combinations of yield components (Ribeiro et al. 2017). As explained by De Luca et al. (2014), at low plant densities, reduced inter-plant competition for light and space increases leaf area and assimilatory capacity per plant, promoting lateral branching and the development of additional reproductive structures.

Fertile nodes. Both cultivars produced significantly more nodes at the lowest seeding rate of 20 seeds/m^2

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Table 3. Evaluation of morphological traits, seed yield and seed quality components for selected experimental variants of the cultivars Satelia and Tertia across individual years.

Year	Cultivar	Seeding density	Plants per m^2 (pcs.)	Emergence	Number of branches per plant (pcs.)	Number of pods on branches (pcs.)	Number of pods per plant (pcs.)	Shoot length (cm)	1st pod height (cm)	Number of fertile nodes (pcs.)	Number of seeds per pod (pcs.)	Moisture (%)	Dry matter seed yield (kg/ha)	Thousand seed weight (g)	Crude protein (%)	Oil (%)
2023	Satelia	20	15.0^{d}	0.8^{a}	2.8^{a}	28.4^{a}	52.3^{a}	61.9^{a}	5.1^{b}	11.5^{a}	2.7^{a}	12.9^{a}	2 730^{a}	143.6^{a}	35.6^{a}	19.5^{a}
		40	30.5^{c}	0.8^{a}	1.7^{b}	9.0^{b}	29.5^{b}	61.3^{a}	9.3^{ab}	10.4^{ab}	2.6^{a}	12.7^{a}	2 442^{a}	148.7^{a}	35.4^{a}	19.5^{a}
		60	47.1^{b}	0.8^{a}	0.9^{b}	3.6^{b}	19.7^{b}	60.7^{a}	11.5^{a}	8.8^{b}	2.9^{a}	12.6^{a}	2 183^{a}	143.3^{a}	34.5^{a}	20.0^{a}
		80	59.3^{a}	0.7^{a}	0.9^{b}	2.3^{b}	19.1^{b}	59.7^{a}	11.1^{a}	8.8^{b}	2.7^{a}	12.0^{a}	2 348^{a}	146.7^{a}	35.3^{a}	19.5^{a}
	Tertia	20	12.5^{d}	0.6^{a}	2.1^{a}	22.6^{a}	51.4^{a}	72.3^{a}	5.8^{a}	12.1^{a}	2.5^{a}	11.7^{a}	2 411^{a}	165.5^{a}	35.7^{a}	18.9^{a}
		40	25.6^{c}	0.6^{a}	1.4^{ab}	9.8^{b}	39.3^{ab}	69.2^{a}	7.9^{a}	11.9^{a}	2.8^{a}	11.6^{a}	2 632^{a}	163.6^{a}	35.5^{a}	19.0^{a}
		60	36.8^{b}	0.6^{a}	1.2^{ab}	4.3^{b}	28.9^{bc}	66.8^{ab}	8.1^{a}	10.5^{ab}	2.7^{a}	11.7^{a}	2 929^{a}	165.2^{a}	35.2^{a}	19.5^{a}
		80	50.8^{a}	0.6^{a}	0.7^{b}	2.2^{b}	20.4^{c}	59.7^{b}	8.4^{a}	8.9^{b}	3.0^{a}	11.4^{a}	2 332^{a}	155.6^{a}	35.0^{a}	19.3^{a}
2024	Satelia	20	14.3^{c}	0.7^{a}	3.3^{a}	26.0^{a}	56.1^{a}	52.8^{b}	5.0^{a}	11.7^{a}	2.5^{ab}	11.6^{a}	1 850^{a}	132.3^{a}	31.8^{a}	21.8^{a}
		40	30.4^{b}	0.8^{a}	1.4^{b}	8.0^{b}	30.2^{b}	57.3^{ab}	5.9^{a}	10.0^{b}	2.8^{a}	11.4^{ab}	1 766^{a}	129.7^{a}	31.9^{a}	21.7^{a}
		60	44.9^{a}	0.7^{a}	0.8^{b}	4.7^{b}	26.8^{b}	60.1^{a}	7.6^{a}	9.7^{b}	2.3^{b}	11.4^{ab}	1 981^{a}	133.0^{a}	32.3^{a}	21.5^{a}
		80	51.4^{a}	0.6^{a}	1.1^{b}	6.6^{b}	26.0^{b}	57.6^{ab}	6.2^{a}	10.0^{b}	2.6^{ab}	11.2^{b}	2 123^{a}	132.7^{a}	32.0^{a}	21.6^{a}
	Tertia	20	13.4^{d}	0.7^{a}	2.7^{a}	24.8^{a}	55.3^{a}	67.0^{a}	6.4^{a}	12.3^{a}	2.8^{a}	11.5^{a}	1 912^{a}	156.6^{a}	33.8^{a}	20.3^{a}
		40	25.4^{c}	0.6^{a}	1.2^{b}	4.6^{b}	26.8^{bc}	66.4^{a}	5.8^{a}	10.4^{ab}	3.0^{a}	11.3^{a}	1 895^{a}	151.5^{ab}	33.4^{a}	20.4^{a}
		60	36.4^{b}	0.6^{a}	0.9^{b}	2.3^{b}	19.2^{c}	59.5^{b}	6.3^{a}	8.9^{b}	2.6^{a}	11.3^{a}	1 940^{a}	148.8^{b}	33.8^{a}	20.2^{ab}
		80	51.5^{a}	0.6^{a}	1.4^{b}	8.7^{b}	35.6^{b}	69.3^{a}	4.9^{a}	11.1^{a}	2.9^{a}	11.2^{a}	2 230^{a}	144.7^{b}	33.4^{a}	19.9^{b}

Different superscript letters within columns for individual years indicate statistically significant differences between means of selected parameter across seeding rates within the cultivar (ANOVA, Tukey's *HSD* (honestly significant difference), $P \leq 0.05$)

than at 60 and 80 seeds/m^2 (Figure 4F). Differences among 40–80 seeds/m^2 were small and not significant. When averaged over cultivars, significant differences between 11.9, 10.7 and 9.5 fertile nodes per plant for seeding rates 20, 40 and 60 seeds/m^2, respectively, were documented. At a rate of 80 seeds/m^2, there were 9.7 fertile nodes per plant, which did not differ significantly from the values at rates of 40 and 60 seeds/m^2. Comparable trends in viable nodes under wider spacing were reported by Basso et al. (2021).

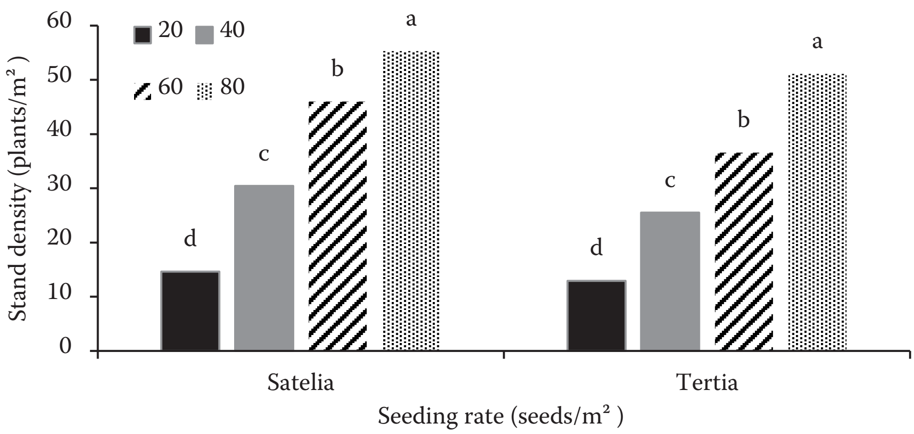

Figure 3. Emerged plants of soybeans with four different seeding rates (20, 40, 60, 80 seeds/m^2) and two cultivars (Satelia, Tertia); means over two years (2023 and 2024)

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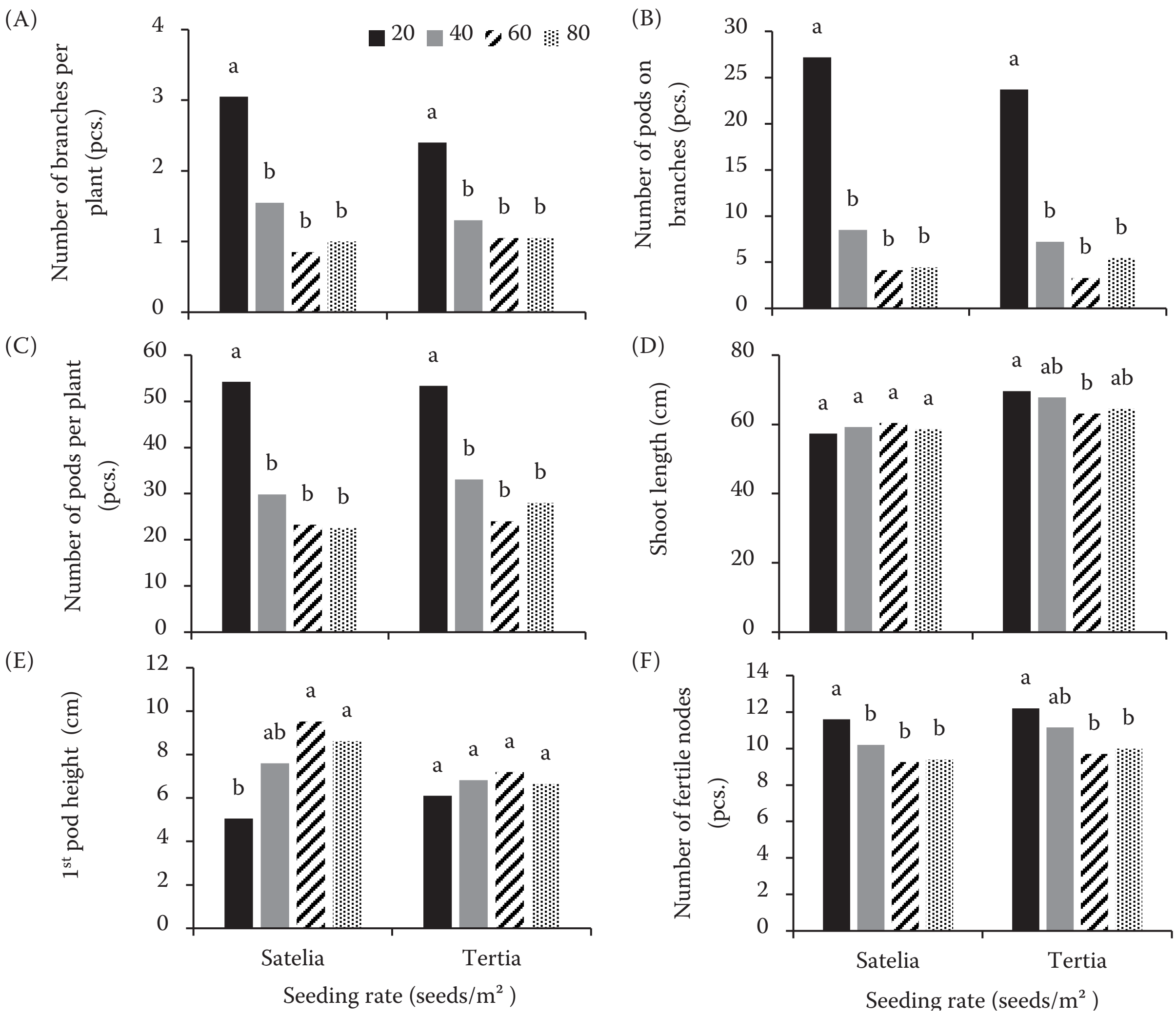

Figure 4. Morphological traits represented by (A) number of branches per plant; (B) number of pods on branches; (C) number of pods per plant; (D) shoot length; (E) first pod height, and (F) number of fertile nodes of soybeans with four different seeding rates (20, 40, 60, 80 seeds/m^2) and two cultivars (Satelia, Tertia); means over two years (2023 and 2024). Different lowercase letters for individual columns indicate statistically significant differences between means of selected parameter across seeding rates within the cultivar (ANOVA, Tukey's *HSD* (honestly significant difference), $P \leq 0.05$); pcs. – pieces

Shoot length and first pod height. Shoot length and first pod height responses were mostly genotype-specific. Tertia showed greater sensitivity of shoot length to seeding rate, whereas Satelia exhibited clearer responses in first pod height with higher insertions (9.5 and 8.6 cm) at greater densities (Figure 4D, 4E), suggesting cultivar-dependent plasticity. While Sobko et al. (2019) demonstrated that increasing seeding rates led to taller plants and a higher first pod height, Prusiński and Nowicki (2020) found no effect of density on shoot length. Our results align more closely with the latter, suggesting that environmental conditions may override density effects on plant height. Jańczak-Pieniążek et al. (2021) compared seeding rates of 70–110 seeds/m^2 in row spacings of 150 and 300 mm. They found significantly higher first pod height at a seeding rate of 110 seeds/m^2 than at 70 seeds/m^2, which corresponds to the trend observed for the Satelia cultivar in our study. On the other hand, Tertia showed no significant differences in first pod height among seeding rates, which agrees with the conclusions of Basso et al. (2021), who observed no significant response of first pod height to intra-row spacing. First pod height plays a critical role in harvest quality for minimising harvest losses. Ribeiro et al. (2017) state that a substantial increase in the height of the first pod insertion may be disadvantageous, leading to plants with poor

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Table 4. Pearson's correlation matrix between the studied parameters for different seeding rates from two-year data (n = 8) for cultivars Satelia (above diagonal) and Tertia (below diagonal) separately

	Plants/m^2	Number of branches per plant	Number of pods on branches	Number of pods per plant	Shoot length	1st pod height	Number of fertile nodes	Number of seeds per pod	Moisture	Dry matter seed yield	Thousand seed weight	Crude protein	Oil
Plants/m^2		–0.91**	–0.90**	–0.92**	0.28	0.69	–0.91**	0.02	–0.28	–0.06	0.14	0.06	–0.11
Number of branches per plant	–0.77*		0.97***	0.97***	–0.43	–0.66	0.93***	–0.07	0.24	0.13	–0.07	–0.02	0.06
Number of pods on branches	–0.76*	0.97***		0.98***	–0.29	–0.72*	0.93***	–0.10	0.27	0.23	–0.08	0.02	0.03
Number of pods per plant	–0.73*	0.96***	0.97***		–0.42	–0.78*	0.96***	–0.21	0.13	0.08	–0.21	–0.13	0.18
Shoot length	–0.51	0.63	0.64	0.77*		0.49	–0.38	0.16	0.64	0.74*	0.68	0.76*	–0.76*
1st pod height	0.18	–0.36	–0.34	–0.31	–0.39		–0.83*	0.33	0.37	0.22	0.66	0.55	–0.58
Number of fertile nodes	–0.69	0.86**	0.84**	0.94***	0.89**	–0.29		–0.28	0.09	0.09	–0.23	–0.16	0.21
Number of seeds per pod	0.50	–0.34	–0.40	–0.34	–0.23	0.06	–0.23		0.42	0.14	0.31	0.34	–0.37
Moisture	–0.58	0.40	0.44	0.51	0.49	0.48	0.54	–0.56		0.80*	0.86**	0.90**	–0.88**
Dry matter seed yield	0.16	–0.18	–0.14	0.00	0.31	0.60	0.14	–0.24	0.68		0.82*	0.89**	–0.88**
Thousand seed weight	–0.52	0.29	0.35	0.40	0.41	0.56	0.43	–0.49	0.98***	0.70		0.97***	–0.97***
Crude protein	–0.21	–0.01	0.15	0.18	0.25	0.62	0.19	–0.43	0.83*	0.77*	0.89**		–1.00***
Oil	0.02	0.05	–0.13	–0.19	–0.35	–0.45	–0.22	0.32	–0.66	–0.77*	–0.71*	–0.93***	

*P < 0.05; **P < 0.01; ***P < 0.001; otherwise non-significant

stem utilisation, which subsequently reduces the production potential of the stand.

Seeds per pod. The number of seeds per pod remained stable across seeding rates, confirming its low sensitivity to plant population. These findings are consistent with those of Cox and Cherney (2011) and Prusiński and Nowicki (2020), who also reported limited or no influence of seeding rate on this trait. In a study testing four soybean cultivars, Sobko et al. (2019) observed a tendency for seeds per pod and harvest index to decline with increasing plant density; however, these trends were not statistically significant. In our multi-factor analysis, the number of seeds per pod was not influenced by year but was significantly affected by cultivar (Tertia averaged 2.8 seeds per pod compared with 2.6 in Satelia), indicating a stronger genetic than environmental control. Similar cultivar- and year-specific differences were reported by Borowska and Prusiński (2021), supporting the conclusion that this parameter is primarily genotype-dependent and shows limited sensitivity to plant density.

Harvested seed yield. Seed yield was not significantly affected by seeding rate in either cultivar

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(Figure 5). On average across the two years, Satelia yielded 2 178 kg/ha dry matter and Tertia 2 285 kg/ha dry matter, with no consistent trend along the density gradient. Our results most closely resemble those of Sobko et al. (2019), who found no yield differences among densities of 50, 70, and 90 seeds/m^2, although yield at 30 seeds/m^2 was significantly lower in their case. Souza et al. (2016) also found no significant yield differences across seeding rates of 25–45 seeds/m^2. We expected seed yield to show a quadratic response, as found in the study by Cox and Cherney (2011), which examined rates from 32 to 47 seeds/m^2 across various row spacings; this was not confirmed in our study. Prusiński and Nowicki (2020) investigated the effects of different seeding rates (70, 90, and 110 seeds/m^2) with row widths of 160 and 320 mm on seed yield. In their experiments, averaged across three years, no statistically significant effect of seeding density on the yield of soybean sown in wide rows was found. Jańczak-Pieniążek et al. (2021) compared row spacings from 150 to 300 mm and seeding rates of 70, 90, and 110 seeds/m^2, and found only the growing season factor to influence seed yield. Optimal seeding rate seems to depend strongly on row spacing and environmental context. Under high-yielding conditions, Devlin et al. (1995) reported maximum yields at 28 seeds/m^2 in 760 mm rows, while narrower 200 mm spacing required higher densities of 50–57 seeds/m^2. Under moisture-limited conditions, seeding rate had no measurable effect on yield.

Seed quality components. The ANOVA results (Table 2) indicate that seed composition was driven largely by genotype and year, rather than plant density. Tertia produced significantly higher crude protein (34.5%) and a greater thousand-seed weight (156.4 g) than Satelia (33.6% and 138.8 g, respectively). A slight non-significant trend towards lower harvest moisture at higher densities was observed in both cultivars (Table 3). The absence of a seed rate effect on crude protein content within the tested range confirms the results of Sobko et al. (2019), who tested similar seeding rates. On the other hand, Bellaloui et al. (2015) and Jańczak-Pieniążek et al. (2021) showed that a higher plant density per unit area resulted in an increase in the crude protein content in harvested soybeans. Our findings confirmed the conclusions of Borowska and Prusiński (2021), who observed significant differences in crude protein content amongst the tested cultivars. Popović et al. (2012) reported that the environment is a dominant factor determining protein content in soybean grain. They reported a non-significant positive correlation between oil and seed yield; however, we found a significant negative correlation (Table 4). Several authors (Bellaloui et al. 2015, Sobko et al. 2019 and Jańczak-Pieniążek et al. 2021) confirmed no significant influence of seeding rate on oil content, as stated also in our study. The research by Sobko et al. (2019) confirmed a negative correlation between protein and oil content (R = –0.88), as also described by Popović et al. (2012) and De Luca et al. (2014), whereas our value was –0.97.

In conclusion, our findings indicate that soybeans compensate for low plant density primarily through increased branching, fertile node formation, and pod production per plant. Although architectural traits showed genotype-specific responses, these modifications did not translate into significant differences in yield across the tested density range. These findings suggest that soybean seed yield and quality are often buffered against variation in plant population through morphological adjustments.

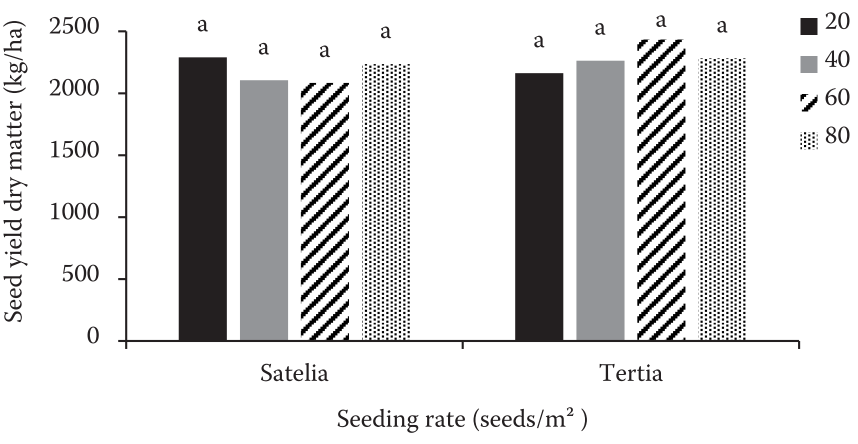

Figure 5. Seed yield dry matter of soybeans with four different seeding rates (20, 40, 60, 80 seeds/m^2) and two cultivars (Satelia, Tertia); means over two years (2023 and 2024). Different lowercase letters for individual columns indicate statistically significant differences between means across seeding rates within the cultivar (ANOVA, Tukey's *HSD* (honestly significant difference), $P \leq 0.05$)

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REFERENCES

Basso C.J., Pertile W.B., Sangiovo M.J.R., De Souza F.M., Da Silva D.R.O. (2021): Impact of row spacing on soybean morphological parameters and yield. African Journal of Agricultural Research, 17: 998–1002.

Bellaloui N., Bruns H.A., Abbas H.K., Mengistu A., Fisher D.K., Reddy N.K. (2015): Effects of row-type, row-spacing, seeding rate, soil-type, and cultivar differences on soybean seed nutrition under US Mississippi Delta conditions. PLoS ONE, 10: 1–23.

Borowska M., Prusiński J. (2021): Effect of soybean cultivars sowing dates on seed yield and its correlation with yield parameters. Plant, Soil and Environment, 67: 360–366.

Brown A.V., Conners S.I., Huang W., Wilkey A.P., Grant D., Weeks N.T., Cannon S.B., Graham M.A., Nelson R.T. (2021): A new decade and new data at SoyBase, the USDA-ARS soybean genetics and genomics database. Nucleic Acids Research, 49: D1496–D1501.

Chauhan B.S., Opena J.L. (2014): Effect of plant spacing on growth and grain yield of soybean. American Journal of Plant Sciences, 4: 2011–2014.

Coelho A.E., Sangoi L., Sapucay M.J.L.C., Bratti F., Balbinot Junior A.A. (2024): Soybean yield and profitability are affected by the spatial distribution of seeds in rows and seeding rate. Agronomy Journal, 116: 247–259.

Colet F., Lindsey A.J., Lindsey L.E. (2023): Soybean planting date and seeding rate effects on grain yield and profitability. Agronomy Journal, 115: 2286–2297.

Cox W.J., Cherney J.H. (2011): Growth and yield responses of soybean to row spacing and seeding rate. Agronomy Journal, 103: 123–128.

Czech Hydrometeorological Institute (CHMI) (2025): Open Data of the Czech Hydrometeorological Institute. Prague, Czech Republic. Available at: https://opendata.chmi.cz (accessed 15 January 2025)

De Bruin J.L., Pedersen P. (2008): Effect of row spacing and seeding rate on soybean yield. Agronomy Journal, 100: 704–710.

De Luca M.J., Nogueira M.A., Hungria M. (2014): Feasibility of lowering soybean planting density without compromising nitrogen fixation and yield. Agronomy Journal, 106: 2118–2124.

Devlin D.L., Fjell D.L., Shroyer J.P., Gordon W.B., Marsh B.H., Maddux L.D., Martin V., Duncan S.R. (1995): Row spacing and rates of soybean in low- and high-yielding environments. Journal of Production Agriculture, 8: 215–222.

Egli D.B., TeKrony D.M. (1995): Soybean seed germination, vigor and field emergence. Seed Science and Technology, 23: 595–607.

Jańczak-Pieniążek M., Buczek J., Bobrecka-Jamro D., Szpunar-Krok E., Tobiasz-Salach R., Jarecki W. (2021): Morphophysiology, productivity and quality of soybean (*Glycine max* (L.) Merr.) cv. Merlin in response to row spacing and seeding systems. Agronomy, 11: 403.

Popović V., Jaksic S., Glamoclija Đ., Grahorac N., Djekic V., Mickovski Stefanovic V. (2012): Variability and correlations between soybean yield and quality components. Romanian Agricultural Research, 29: 131–137.

Prusiński J., Nowicki R. (2020): Effect of planting density and row spacing on the yielding of soybean (*Glycine max* L. Merrill). Plant, Soil and Environment, 66: 616–623.

Ribeiro A.B.M., Bruzi A.T., Zuffo A.M., Zambiazzi E.V., Soares I.O., Vilela N.J.D., Pereira J.L.A.R., Moreira S.G. (2017): Productive performance of soybean cultivars grown in different plant densities. Ciência Rural, 47: 1–8.

Schmitz P.K., Stanley J.D., Kandel H. (2020): Row spacing and seeding rate effect on soybean seed yield in North Dakota. Crop, Forage and Turfgrass Management, 6: e20010.

Sobko O., Hartung J., Zikeli S., Claupein W., Gruber S. (2019): Effect of sowing density on grain yield, protein and oil content and plant morphology of soybean (*Glycine max* L. Merrill). Plant, Soil and Environment, 65: 594–601.

Souza R., Teixeira I., Reis E., Silva A. (2016): Soybean morphophysiology and yield response to seeding systems and plant populations. Chilean Journal of Agricultural Research, 76: 3–8.

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