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Seed Yield, Seed Protein, Oil Content, and Agronomic Characteristics of Soybean (*Glycine max* L. Merrill) Depending on Different Seeding Systems and Cultivars in Germany

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Abstract: Soybean (*Glycine max* L. Merrill) is one of the most important crops worldwide. In several European countries such as Germany, soybean cultivation is not traditional and as such remains to be optimized. One option to increase soybean production is to adapt and improve the seeding system. To investigate the effects of different seeding systems on seed yield, seed protein, and oil content, plant characteristics were assessed using a two-factorial (two seeding systems and four cultivars) field trial over two years (2017–2018) at two locations in southeast Germany. The seeding systems were drill (row spacing 14 cm) and precision seeding (row spacing 28 cm), and the cultivars were Viola 000, Lissabon 000, ES Mentor 00, and Orion 00. Depending on the seeding system, a seed yield of 3.8 t ha⁻¹ dry matter (DM), 40.9% protein content (DM), and 18.8% oil content (DM) was achieved by drilling, and 3.6 t ha⁻¹ yield (DM), 40.1% protein content (DM), and 19.1% oil content (DM) with precision seeding (average across four cultivars, two locations, and two years). No significant effects of the seeding system on all seed and plant characteristics were observed. As drilling and precision seeding did not affect the seed yield, seed protein, oil contents, and plant characteristics of soybean in this study, farmers are able to choose the seeding system which fits best into their farms and is economically most viable.

Keywords: soybean; seed yield; drill seeding; precision seeding; seed ingredients

1. Introduction

Soybean (*Glycine max* L. Merrill) is considered a globally strategic crop because it has become the main supplier of plant oil and protein [1]. Soybean grains contain 30–45% high quality protein with essential amino acids and 15–22% oil with a favorable proportion of linoleic to linolenic acid of 6–7 [2]. The global area cultivated with soybeans in 2017 was 123.6 million ha, providing 352.6 million t of grain at an average yield of 2.8 t ha⁻¹ [3]. Domestic demand for soybean for food and feed is driving an increase in its acreage in Germany [4]. The German soybean area was 19,000 ha in 2017, with an average yield of 3.2 t ha⁻¹ DM and total production of 61,000 t. The increase in soybean growing area in Germany is being driven, at least in part, by climate change: more areas of the country are becoming suitable for crops, such as soybean, that are adapted to warm regions. Successful plant breeding in recent years has supported the increase in soybean production [5].

Domestic soybean production can be further increased by expanding its growing area and by increasing the yield per area through optimized agricultural practices. Important parameters that cannot be modified are precipitation, temperature, and solar radiation [6]. Optimizing soybean cultivation technology, including breeding, is therefore an option for increasing and stabilizing yields. Seeding density, seeding time and seeding methods are important for crop establishment and provide the foundation for a high yield [4,7]. A seeding system is defined by the key factors of row spacing and seeding method: these are inseparable due to their technical interactions [2], as the type and availability of seeding equipment defines them [8]. The choice of seeding system must also take into account region, soil properties, weeds, pests, seeding time, characteristics of the crop, and its use [9] in addition to economic considerations. The choice of seeding system is intended to achieve optimal emergence conditions in order to guarantee optimal vegetative development of the soybean plants and thus their high productivity in quantity (seed yield) and in quality (protein and oil content/yield) [10].

Precision seeding provides for the precise placement of seeds in depth and distance from each other. There is the same space between the grains and plants in a row, in contrast to drill seeding, thus enabling homogeneous emergence and plant stand [11]. As homogeneous plant density and spacing affects the choice of phenotype and projected yield of soybean [7,12], sowing density can be reduced by 10–15% [13]. Precision seeders are known for technical problems when planting at higher sowing rates (approx. 70 seeds m⁻²), but this high crop density is recommended for early maturing (000) cultivars [13]. For the other maturity groups, low sowing densities are conceivable, up to 30 seeds m⁻² [14]. Drill seeders, on the other hand, enable high sowing densities, have large seed tanks [13], and are robust and multi-purpose with the capacity for variable row spacing [15]. As a disadvantage, drill seeders do not easily achieve exact depth control by grain placement, and thus can result in heterogeneous plant emergence and development [13].

Worldwide, soybean cultivars are divided into 13 maturity groups ranging from 000 (very early) to X (tropical). In Germany, mainly 00 and 000 cultivars are cultivated [16]. Numerous studies from North and South America with soybean from maturity groups III upward indicate that row spacings between 19 and 38 cm are most suitable for these cultivars and ensure higher seed yields compared to wider row spacings (around 70 cm) [17–23]. The most effective seeding system for early maturity soybean (maturity group 00 and 000) remains a question [12]. Wider row spacing (up to 70 cm) tends to lead to significantly higher protein levels compared to row spacing of 40, 50, and 60 cm, but medium row spacing (50 cm) seems to result in higher oil content [24]. No scientific studies are known to have explicitly examined the influence of seeding system on protein and oil content of soybean. A multi-site comparison of five seeding methods (broadcast, drill, air seeder, planter and no-till drill) in the USA (Arkansas) did not detect significant differences in yield [8]. In contrast to these studies, higher seed yields were reported from drilling compared to air seeding (USA; Iowa) [25]. In Argentina, precision seeding is preferred because the homogeneous distribution of grains in the row facilitates appropriate plant emergence and thus optimal access of each soybean plant to the resources light, water, and nutrient supply [18]. A clear recommendation concerning the optimal seeding system in Germany has not yet been determined. Higher seed yields (+13%) were achieved by drill seeding with row spacing of 13.6 cm compared to precision seeding with row spacing of 50 cm in Bavaria (average over three cultivars and three sowing densities) [26]. According to one survey, almost 60% of all soybean farmers in Germany use drill seeders to sow soybeans and almost 40% use precision seeding systems when this technique is already available on the farms [27]. Soybean growers in Germany could benefit from experimental results of sowing methods for their region in order to base their choice of sowing method on yield data.

The aim of this study was to determine how seed yield, seed composition (protein, oil content), and plant characteristics of soybeans are influenced by two different seeding systems in field trials at two locations and with different cultivars. The results may help to sow soybeans in the most appropriate way for homogeneous crop emergence and rapid development during the critical juvenile

growth stages and thus provide all the requirements for optimal crop development. This could provide the basis of a higher seed yield and the growth of German soybean production.

2. Materials and Methods

2.1. Location and Weather Conditions

The trials were performed at two locations of Saaten Union GmbH research station in 2017 and 2018. The locations were Grünseiboldsdorf (GSD, 48°29' N 11°54' E, altitude of 440 m) and Landshut (LA, 48°34' N 12°9' E, altitude of 398 m) in East Bavaria Germany. They are located at the border of the maritime climate of Western Europe and the continental climate of Eastern Europe in Zone 5, according to the global agroecological zones (FAO, 2019). Weather conditions during the trials were obtained from the agrometeorological station of the German weather service located closest to the trials (Freising; Ergolding and Buerg; Figure 1) [28].

Figure 1. Precipitation (monthly accumulated) and air temperature (monthly averages) during the experimental periods 2017 and 2018 at two locations (GSD = Grünseiboldsdorf and LA = Landshut) in Bavaria, southeast Germany.

Details of cultivation and soil are presented in Table 1. The trial was set up in a split plot design with four replicates at each location. The first factor, ‘seeding system’, consisted of two levels, namely drill seeding and precision seeding, and the second factor was ‘cultivar’ at four levels (Viola 000, semi-determinate; Lisbon 000, determinate; ES Mentor 00, determinate; Orion 00, indeterminate). Plot sizes were 8 m long and 1.8 m width at sowing, and 5.8 m long and 1.8 width at harvest. The sowing density was in all years and at all locations 65 germinable seeds m² in both seeding systems. Sowing time was between mid-April and beginning of May, depending on year and location (Table 1). The sowing depth was 3.5–4.0 cm at both locations and in both years.

For the drill seeding, a tractorseeder INOTEC was used, with a double disc system for seed depot and seed dispenser, and a rubber wheel for soil re-compaction [29]. The precision seeding was operated with a pneumatic precision seeder HEGE 95B, with parallelogram-guided double coulters and skid with trailed depth rollers [30]. The plot with drill seeding consisted of 11 rows with row spacing of 14 cm and by precision seeding of 5 rows and 28 cm row spacing. The working speed for drill seeding was 4.0 km h^{−1} on average and 2.0 km h^{−1} for precision seeding. The seeding of the trials was supported by a GPS guidance system.

The seeds of all four soybean cultivars were inoculated with liquid formulated Rizoloq Top S[®] (Buenos Aires, Argentina) (1 × 10¹⁰ KBE m^{−1} *Bradyrhizobium japonicum* SEMIA 5079 and SEMIA 5080; 300 mL ha^{−1}). The inoculation was performed immediately before sowing together with the bacterial protection Premax[®] (Buenos Aires, Argentina) (100 mL ha^{−1}). In both growing seasons and at both

locations, insects and diseases (low infection of bacterial blight (*Pseudomonas syringae* pv. *glycinea*) were not controlled chemically (the damage threshold was not exceeded). Harvesting was performed by a plot harvester (HALDRUP C-85) with a 1.8-m cutting unit.

Table 1. Cultural practices and environmental data for location Grünseiboldsdorf GSD and Landshut (LA) in two trial years (2017 and 2018).

Location	2017		2018	
	GSD	LA	GSD	LA
soil typ	luvisol	histosol	luvisol	luvisol
N _{min} 0–90 cm content in Early spring, kg/ha ^{−1}	36	145	35	28
Preceding Crop	winter wheat (<i>Triticum aestivum</i>)	corn (<i>Zea mays</i>)	spring barley (<i>Hordeum vulgare</i>)	corn (<i>Zea mays</i>)
Pre-Preceding Crop	corn (<i>Zea mays</i>)	winter wheat (<i>Triticum aestivum</i>)	winter wheat (<i>Triticum aestivum</i>)	winter wheat (<i>Triticum aestivum</i>)
Primary tillage	soil inversion tillage by a mouldboard plough (25 cm depth)			
Seedbed preparation	rotary harrow (28 March)	rotary harrow (18 April and 06 May)	rotary harrow (2 April and 16 April)	rotary harrow (12 April)
Seeding	24 Apr.	06 May	17 April.	13 Apr.
Herbicide and application time	Centium 36 C 0.25 l/ha + Sencor WG 0.3 kg/ha + Spektrum 0.8 l/ha			
	17 May	17 May	21 April.	18 April.
Harvesting date	26 September., 05 October.	29 September.	13 September.	29 August.

2.2. Data Collection

Crop density was determined at development stage V5 (fifth unrolled trifoliate leaf) [31] by counting one running meter in a randomly selected row in each soybean plot [32]. The leaf area index (LAI) was measured at growth stage R2 (at flowering/full bloom) and at the beginning of maturity (R7). Values were determined using the plant canopy analyzer LAI-2000 from LI-COR (Lincoln, NE, USA) [31,33].

At R2, six plants per plot were carefully removed by digging (20 × 20 × 25 cm soil volume), roots were washed, and the number of nodules was determined. All nodules were divided into primary (at the tap root) and secondary nodules (at lateral roots). At full seed stage (R6), the plant heights of 10 randomly selected plants per plot were measured. All soybean plants in an area of 0.25 m² per plot were cut at development stage R7 at the soil surface and dried at 100 °C for 72 h for dry matter determination. After measuring the height of the first pod, the harvested material was separated into grains, pods, and stem with remaining leaves. The height of the first pod, the number of pods per plant, the number of seeds per pod, and the number of side branches were determined. The harvest index was calculated as dry grain mass/(dry grain mass + dry mass of soybean). Just before machine harvesting of the entire plot (R8 + 10 to 12 days), plant lodging was evaluated by rating from 1 (no lodging) to 9 (total plant lodging).

Samples of freshly threshed soybean were taken (ca. 500 g per plot) and immediately examined for oil and protein content by Near Infrared Reflectance Spectroscopy (NIRS) with appropriate calibration from Polytec PSSSHA03–2.1 (Waldbronn, Germany) [34]. After seeds were cleaned, thousand kernel mass (TKM) was determined by a Marvin seed analyzer.

2.3. Statistics

Statistical analysis was conducted with application of PLABSTAT, system version 3A [35]. Homogeneity of the data was checked graphically. A linear model for balanced data set was chosen to exclude the effects of the two factors seeding system and cultivar, and of their interaction. Year and location were included as random factors in the model, and their interaction and interactions between seeding system, cultivar, and year-by-location were also assessed. According to results from ANOVA and *F*-tests, simple multiple *t*-tests were performed to carry out the least significant differences (LSD) and standard errors (SE).

3. Results

3.1. Analysis of Variance

Effects of the seeding system were not statistically significant for any of the assessed plant properties. TKM, height of the first pod, lodging, plant height, and sum of nodules were significantly affected by cultivar. Only one trait—seed yield was significantly affected by the interaction of seeding system and cultivar. The random factors (year, location, their interaction, and interactions between seeding system, cultivar, and year-by-location) had little effect on the analyzed soybean properties (Table 2).

Table 2. Analysis of variance for yield and plant properties of soybean (*Glycine max*) for two seeding systems (drill seeding, precision seeding) and four cultivars at two locations in southeast Germany in the years 2017 and 2018: $p \leq 0.05$ ‘*’ $p \leq 0.01$ ‘**’; SeSy—seeding system; NSB—number of side branches; LAI—leaf area index; PN—number of primary nodules; SN—number of secondary nodules; NN—total number of nodules; HI—harvest index.

	ANOVA								
	Seed Yield	Crop Density	Plant Height	Pods/Plant	Seeds/Pod	TKM	Protein Content	Oil Content	NSB
SeSy	ns	ns	ns	ns	ns	ns	ns	ns	ns
cultivar	ns	ns	*	ns	ns	*	ns	ns	ns
year	ns	ns	ns	ns	ns	ns	ns	ns	ns
location	ns	ns	ns	ns	ns	ns	ns	ns	ns
SeSy × cultivar	ns	ns	ns	ns	ns	ns	ns	ns	ns
SeSy × year	ns	ns	ns	ns	ns	ns	ns	ns	ns
SeSy × location	ns	ns	ns	ns	ns	ns	ns	ns	ns
SeSy × year × location	ns	**	ns	ns	ns	**	**	**	ns
cultivar × year	*	ns	ns	ns	ns	ns	+	ns	ns
cultivar × location	**	ns	ns	ns	ns	ns	ns	ns	ns
cultivar × year × location	ns	ns	**	ns	*	ns	**	**	ns
year × location	*	ns	**	ns	**	**	**	**	ns
	LAI R2	LAI R7	Height 1 st Pod	PN	SN	NN	Lodging	HI	
SeSy	ns	ns	ns	ns	ns	ns	ns	ns	
cultivar	ns	ns	*	ns	ns	*	*	ns	
year	ns	ns	ns	ns	ns	ns	ns	ns	
location	ns	ns	ns	ns	ns	ns	ns	ns	
SeSy × cultivar	ns	ns	ns	ns	ns	ns	ns	ns	
SeSy × year	ns	ns	ns	ns	ns	ns	ns	ns	
SeSy × location	ns	ns	ns	ns	ns	ns	ns	ns	
SeSy × year × location	ns	ns	*	ns	ns	ns	ns	ns	
cultivar × year	ns	ns	ns	ns	ns	ns	ns	ns	
cultivar × location	ns	ns	ns	ns	ns	ns	ns	ns	
cultivar × year × location	ns	**	ns	ns	ns	*	ns	ns	
year × location	**	ns	ns	**	ns	**	ns	ns	

3.2. Seed Yield and Yield Structure

The mean seed yield across all seeding systems, cultivars, and locations was 1.0 t ha^{-1} DM higher in the year 2017 (4.2 t ha^{-1} DM) than in 2018 (3.2 t ha^{-1} DM; data not shown). Across seeding systems, cultivars, and years the yield at both locations was almost the same (3.7 t ha^{-1} DM; data not shown). The seed yield with drill seeding tended to be higher than with precision seeding in each of the tested cultivars (Figure 2). The highest-yielding cultivar in both seeding systems was ES Mentor 00 (4.0 t ha^{-1}) and the lowest-yielding was Viola 000 (3.5 t ha^{-1} ; data not shown).

Figure 2. Seed yield of soybeans (*Glycine max*) with drill seeding (DS) or precision seeding (PS) and four cultivars; means over two locations in southeast Germany and two years (2017 and 2018), no significant differences, comparison within cultivar.

The yield of soybean after drill seeding tended to be higher than after precision seeding, although most of the yield components developed in greater numbers (not significant) with precision seeding (Table 3), except crop density (not significant).

Table 3. Seed yield structure and harvest index of soybeans by different seeding systems, average across four cultivars, two locations in southeast Germany (GSD, LA) and two years (2017, 2018), LSD: least significant difference, $p \leq 0.05$; SE—standard error, NSB—number of side branches, HI—harvest index.

Seeding System	Crop Density, Plant m^{-2} (ns)	Pods/Plant, n (ns)	Seeds/Pod, n (ns)	HI (ns)	NSB, n Plant $^{-1}$ (ns)
Drill Seeding	62.5	20.4	2.2	0.6	1.4
Precision Seeding	44.5	30.0	2.2	0.6	1.9
LSD	31.1	29.3	0.4	0.5	0.6
SE	2.3	1.9	0.03	0.01	0.2

The crop density with drill seeding was $62.4 \text{ plant m}^{-2}$, which was 18 plants m^{-2} more than with precision seeding. A similar tendency was observed for number of pods per plant, with ca. 10 pods per plant more with precision seeding. The number of seeds per pod and harvest index were the same in both seeding systems.

3.3. Seed Characteristics

Across both seeding systems, the thousand kernel mass varied from approximately 168 to 200 g, protein from 39.4% to 41.0% DM, and oil from 18.8% to 19.4% DM, depending on cultivar (Table 4).

Table 4. Seed characteristics of soybeans of different cultivars, average across two seeding systems (drill seeding and precision seeding), two locations in southeast Germany (GSD, LA) and two years (2017, 2018), LSD: least significant difference, $p \leq 0.05$.

Cultivar	TKM g	Protein Content % DM (ns)	Oil Content % DM (ns)
Viola 000	167.6	40.8	18.9
Lissabon 000	186.4	39.4	19.4
ES Mentor 00	199.9	41.0	18.8
Orion 00	205.1	40.9	18.7
LSD	19.8	2.9	1.5
SE	4.7	0.3	0.3

The highest values of TKM were measured in cultivars from maturity group 00–ES Mentor (199.9 g) and Orion (205.1 g). Only the difference in TKM between Viola and Orion was statistically significant. Cultivars of maturity group 00 had higher protein content than cultivars of 000. There were few differences between the cultivars in oil content across the seeding systems. The protein content across cultivars was 40.9% with drill seeding and 40.1% with precision seeding, with oil content 18.8% and 19.1%, respectively (data not shown).

3.4. Plant Characteristics

Height of the first pod from the soil surface across the seeding systems was similar for the cultivars Viola, Lissabon, and ES Mentor, and significantly lower for the cultivar Orion (Table 5). Plant height and lodging were also higher for cultivar Orion (99.7 cm and 5.2, respectively).

Table 5. Plant characteristics of soybeans of different soybean cultivars, average across two seeding systems (drill seeding and precision seeding) at two locations in southeast Germany (GSD, LA) and two years (2017, 2018), LSD: least significant difference, $p \leq 0.05$.

Cultivar	Height 1 st Pod, cm	Lodging, Rating ¹	Plant Height, cm	Number of Nodules Plant ⁻¹
Viola 000	10.3	2.9	87.5	74.0
Lissabon 000	10.4	1.6	76.4	62.5
ES Mentor 00	10.4	1.1	85.7	78.0
Orion 00	13.4	5.2	99.7	59.6
LSD	2.5	2.3	9.6	7.4
SE	0.6	0.6	2.1	5.6

¹ Rating according to a scale from 1 = no lodging and 9 = total plant lodging.

The highest number of nodules was found on the roots of ES Mentor (78.0). The cultivars Lissabon and Orion formed significantly lower numbers of nodules (62.5 and 59.6).

4. Discussion

The two seeding systems studied differed mainly in the spacing between rows and between plants in each row. With drill seeding, the soybean plants did not have the same individual space in the field, which could have led to competition for solar radiation, nutrients, and water. This aspect has been discussed in other studies from the USA [36]. The doubled width of row spacing with precision seeding compared to drill seeding (28 cm versus 14 cm) and exact grain placement in the row could promote more space for each soybean plant and ensure the development of more side branches [37]. Similar to

our results, studies from the USA [8], India [38], and Russia [39,40] did not find significant differences in yield between different seeding systems (drill, air seeder, planter) with varied row spacing and sowing densities. A study from Argentina [18], however, found that precision seeding of soybean was superior to drill seeding in terms of how carefully the grains were handled during sowing, leading to uniform field emergence and also to higher seed yield. However, accurate placement at the same seeding depth for each seed in a row in precision seeding is difficult to achieve with lightweight models of seeding units such as the HEGE 95B, which was used in our study [13]. This could have led to uneven field emergence because soybean, as a large grain legume with epigenetic germination, needs a lot of force to break through the soil surface. Breaking the soil surface is easiest if all germinating seedlings in a row exert pressure at the same time. If the soybean grains are not placed at the same depth, this simultaneous pressure cannot be applied and only the seedlings with greater germination power will emerge [2,41]. The initial conditions in both trial years were different, and especially in 2018, soybeans were grown under dry conditions, as there was less than 15 mm of precipitation throughout April at both locations (Figure 2). In such conditions, the field emergence of soybean cross-tested cultivars using precision seeding was not equal to drill seeding, resulting in low crop densities, sometimes below 30 plant m² (data not shown).

By trend, the plants sown with precision seeding had more side branches, more pods per plant could be produced compared to drill seeding (Table 3). Competition between plants was therefore low, so all were able to form more pods on their side branches, as also shown by other studies [42,43]. The increase in these two yield components, more side branches and lower competition, usually leads to an increase in seed yield [36]. The yield, however, tended to be unexpectedly lower with precision seeding than with drill seeding, perhaps due to potentially uneven field emergence in our study. The tested cultivars belong to different maturity groups and have different habitus properties. Cultivars of late maturity groups usually form more side branches, as shown by studies from North and South America with maturity groups from IV to VIII [43,44]. These differences are not found between the much earlier maturity groups (00 and 000).

For increasing soybean productivity, the genetics of cultivars also play a major role. Since the tested cultivars had different genetic backgrounds and therefore different growth types, the latter resulted in temporal shifts in vegetative and reproductive development of the studied soybean plants. The temperature sum (crop heat units (CHU)) during the growing season affects soybean growth and development [45]. Cultivars from maturity group 00 (ES Mentor, determinate, and Orion, indeterminate) had higher heat requirements than those from maturity group 000 (Viola, semi determinant, and Lissabon, determinant) for transitioning from one growth phase to another and to maturing [45,46]. ES Mentor and Orion, as 00 cultivars, have the genetic potential to develop more above-ground biomass and thus intercept more solar radiation; this could in turn contribute to higher photosynthetic rates and possibly higher plant heights than in early maturing cultivars [37]. Due to its determinate growth type, lodging was the lowest of all cultivars in ES Mentor. For the other cultivars, the well-known relationship between plant height and lodging was confirmed: the higher the plant height, the higher the lodging [47]. As lodging causes harvest losses, successful breeding has been done to develop more stable cultivars even at high crop densities [48]. Plant height and lodging were also higher for cultivar Orion (99.7 cm and 5.2, respectively). Another potential contributor to harvest losses is low distance of the first pods from the ground surface. Previous results have indicated that drastic harvest losses occurred at a height of first pod below 7.5 cm [49]. All cultivars assessed in our study developed the first pod at a stem height > 10 cm and therefore had a low risk of harvest loss due to distance of first pods from the soil surface.

Soybean can supply up to 80% of its nitrogen needs through symbiosis with rhizobia and subsequent fixation of N₂ from the air [2]. According to Smit et al., 1992 [50], the success of root infection with rhizobia and subsequent symbiosis between the soybean plant and bacterium depends on compatibility of the genes of both plant and bacterium. This interaction, together with environmental and soil factors, determines not only the quantity, but also the efficacy of the nodulations [2].

Therefore, different genetic backgrounds of the tested cultivars resulted in the sum of the nodules for each cultivar to differ (Table 3).

Seed characteristics, such as protein and oil content, did not depend on the seeding system (Table 4). The higher number of side branches and, consequently, more pods per plant, with precision seeding compared to drill seeding did not lead to an increase in protein or oil content in soybean. However, an increase in crop density tends to lead to higher protein content [51,52] and since the two, i.e., protein and oil content, correlate negatively [53], oil content also increases with decreasing crop density by trend [54]. Our results showed that neither drill nor precision seeding reduced or increased protein content and oil content.

To achieve the full potential of soybean plant development with respect to a particular cropping system in Germany, the seeding system can be adapted to the phenotype of the cultivars. Cultivars with a higher number of side branches (for example ES Mentor) can be sown in a precision seeding system with greater row spacing (28 cm and more) as they can make a good use of the initial space and nutrients for each individual plant to increase yield via side branches. The cultivar types with low branching capacity (such as Viola) can be sown by drill seeding and can produce good seed yields with narrow row spacing. The cultivation of the indeterminate cultivar types is more likely to benefit from precision seeding. The determinate cultivar types can be sown by drill seeding with lower row spacing and make good use of solar radiation for efficient photosynthesis during the critical period of grain formation and filling, as has been demonstrated in other scientific studies [55].

5. Conclusions

As neither tested seeding system for soybean resulted in significant differences in seed yield, seed composition, seed composition (protein and oil contents), and plant characteristics, farmers have the opportunity to decide on any of the seeding systems, depending on their farm management, farm structure, and the economics of their machinery and labor requirements.

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