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The Effects of Management (Tillage, Fertilization, Plant Density) on Soybean Yield and Quality in a Three-Year Experiment under Transylvanian Plain Climate Conditions

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Abstract: The regional agroecological conditions, specific to the Transylvanian Plain, are favorable to soybean crops, but microclimate changes related to global warming have imposed the need for agrotechnical adaptive measures in order to maintain the level of soybean yield. In this study, we consider the effect of two soil tillage systems, the seeding rate, as well as the fertilizer dosage and time of application on the yield and quality of soybean crops. A multifactorial experiment was carried out through the A × B × C × D − R: 3 × 2 × 3 × 3 − 2 formula, where A represents the year (a1, 2017; a2, 2018; and a3, 2019); B represents the soil tillage system (b1, conventional tillage with mouldboard plough; b2, reduced tillage with chisel cultivator); C represents the fertilizer variants (c1, unfertilized; c2, one single rate of fertilization: 40 kg ha^{-1} of nitrogen + 40 kg ha^{-1} of phosphorus; and c3, two rates of fertilization: 40 kg ha^{-1} of nitrogen + 40 kg ha^{-1} of phosphorus (at sowing) + 46 kg ha^{-1} of nitrogen at V3 stage); D represents the seeding rate (1 = 45 germinating grains (gg) m^{-2}; d2 = 55 gg m^{-2}; and d3 = 65 gg m^{-2}); and R represents the replicates (r1 = the first and r2 = the second). Tillage had no effect, the climate specific of the years and fertilization affected the yield and the quality parameters. Regarding the soybean yield, it reacted favorably to a higher seeding rate (55–65 gg m^{-2}) and two rates of fertilization. The qualitative characteristics of soybeans are affected by the fertilization rates applied to the crop, which influence the protein and fiber content in the soybean grains. Higher values of protein content were recorded with a reduced tillage system, i.e., 38.90 g kg^{-1} DM in the variant with one single rate of fertilization at a seeding rate of 45 gg per m^{-2} and 38.72 g kg^{-1} DM in the variant with two fertilizations at a seeding rate of 65 gg m^{-2}.

Keywords: soybean; tillage system; fertilization; seeding rate; yield; quality

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1. Introduction

Although the effects of agriculture on global climate change have been frequently studied [1–4], it has also been established that agriculture is one of the sectors most vulnerable to climate change [5–7]. Fossil fuel use and intensive agricultural practices are the main agricultural technologies that are having a major impact on climate change [8]. Thus, practices to reduce energy consumption and adaptive measures to reduce aggressive technologies are common goals of conservative agriculture [9,10].

Conservative agriculture aims at achieving productivity equal to or close to conventional agriculture, with optimized economical and energy efficiencies, while at the same time reducing the impact on the environment [11]. In Romania, conservative agriculture has been applied to almost 10% of the arable land and includes the following complementary agricultural practices [9]: (i) Minimum tillage systems (through a reduced soil tillage system or direct sowing in the stubble) to preserve soil structure, fauna, and organic matter; (ii) permanent soil cover (cover crops, waste, and mulch) to protect the soil and contribute to weed removal; (iii) rotation of different crops and combinations to stimulate soil microorganisms, and therefore control pests, weeds, and plant diseases.

Conservative agricultural practices have been adopted [12] for the agrotechnical aspects (to combat drought and control soil erosion), the economic benefits (efficiency), the protection of the environment (soil greening), and the compatibility with the Common Agricultural Policy of the European Union.

Soybean has a special economic importance due to its many uses, and the fact that the grains are rich in protein (34–39 g kg^{-1} DM), fat (19–20 g kg^{-1} DM), vitamins (A, D, and E), etc. The content of soybean grains is affected by the variety cultivated, the soil and climatic conditions, and the technologies applied [13–15]. In Romania, similar to other countries in Europe, there has been an effort to increase the amount of original plant-based protein. Recently, the area of land cultivated for soybean crops has expanded significantly, for example, from 2013 to 2019, the area increased from 67.7 to 179 thousand ha. During the same period, the average production of soybean grains per ha^{-1} varied from 2045 to 2754 kg ha^{-1}, according to the most common crop techniques applied and the climatic conditions specific to each agricultural year [16].

In Europe, the area of land cultivated for soybean crops has continuously increased over the last 10 years and the total soybean production has also increased from 764 thousand tons in 2008 to 2.7 million tons in 2017. Additionally, in 2017, the total area of land cultivated for soybean was 0.97 million ha and the average production was 2.8 tons ha^{-1}, with variations according to the country [17].

By the end of the 21st century, soybean yields in China, under the slowest climate warming scenario, are predicted to decrease by 5–10% and decrease by 8–22% under the fastest climate warming scenario [18]. There is already a climate warming trend in Transylvania, and agricultural technologies must take this into account to mitigate the impact of this warming as much as possible.

The evolution of soybean production in Transylvania has been directly influenced by annual climate variations in the research area. The same conclusion has been reported by studies on other areas where soybean is cultivated [19].

Soybean is not significantly affected by the process of soil loosening and good results have been reported by applying reduced tillage or direct sowing [20–22]. However, a soil tillage system modifies the temperature and humidity of soil [23], influencing the activity of symbiotic bacteria, and therefore plant density and fertilization are important when soil minimum tillage systems are applied to soybean crops [24]. These new elements of technology affect the final soybean production as well as the quality and content of protein, fat, and fiber in the soybean grains [25].

Soybean production is affected by soil fertility and soil water content in relation to the soil tillage system [26–28], and the quality of soybean production is affected more by fertilization and climatic factors [29].

For farmers to counteract the effects of climate change, soybean crop technologies must be adapted to the new climate conditions, especially in a pedoclimate area such as in the Transylvanian Plain. Abiotic stresses such as drought, excessive rain, extreme temperature, and low light can significantly reduce crop yields [30].

The purpose of this study is to quantify the effect of management factors (tillage, fertilization, and plant density) and the climate (year) on soybean production and to highlight the interacting effect of these factors on the quality components of the soybean grains, according to the crop conditions in the Transylvania Plain.

2. Materials and Methods

2.1. Site Description

For this study, the data were gathered, according to the climate conditions in the Transylvanian Plain (longitude 23°47′, latitude 46°35′, altitude 427 m), at the Agricultural

Research and Development Station Turda (ARDS Turda) on chernozem soil [31], specific to the layer of soils from this physical-geographical area.

The properties of the soil from the experimental site, at a depth of 0–20 cm, are as follows: Clay content (<0.002 mm) 56.07%, fine dust (0.002–0.05 mm) 19.15%, dust (0.05–0.02 mm) 9.15%, fine sand (0.02–0.2 mm) 14.9%, coarse sand (0.2–2.0 mm) 0.73%, texture clayey loam, bulk density 1.13 g cm^{-3}, total porosity 58%, humus content 3.73% and pH of 6.81, total nitrogen content 0.205 mg kg^{-1}, mobile phosphorus 35 mg kg^{-1}, and mobile potassium 320 mg kg^{-1}. The soil samples for the chemical analyses were sampled at a depth of 0–20 cm. The potentiometric method was used to establish the pH, for humus the Walkley-Black method was used; total nitrogen was established using the Kjeldhal method; phosphorous and the content of potassium was established through the Egner-Riehm-Domingo extraction method.

The multiannual average temperature of the study area is 9.2 °C and the multiannual rainfall is 531.4 mm (for the last 63 years). One characteristic of the soil in the area is that it rapidly compacts with repeated passes of heavy farm machinery or when agricultural work is done under conditions of high humidity, with a soil moisture content of 24–25% which is high enough to produce surface compaction.

Climate conditions have evolved over the 63 years of monitoring at ARDS Turda (1957–2019) and from the data collected one can see a warming trend that has been more pronounced since 2007 [32,33]. The multiannual average (MA) of temperatures from 1957 to 2017 (63 years) is 9.2 °C. The annual average temperature values have been below 9 °C for 25 out of 63 years, between 9 and 10 °C for 25 out of 63 years, and over 10 °C for 13 out of 63 years, especially during the last 8 years (2012–2019). The highest values of the annual average temperature were in 2014 (11.1 °C), 2018 (11.2 °C), and 2019 (11.4 °C). The multiannual rainfall was 531.4 mm; the annual rainfall was under 500 mm for 24 years, over 500 mm for 22 years, over 600 mm for 13 years, and over 700 mm for 4 years; the highest rainfall of 81.8 mm was in 2016.

During the 3 years that were taken into account in this study (i.e., 2017-2019), there was an unequal distribution of rainfall, with drought periods, followed by prolonged pedological droughts, and then torrential rain was recorded (see Tables 1 and 2).

Table 1. Thermal regime from 2017 to 2019 at the Agricultural Research and Development Station Turda (ARDS Turda).

Year/Months	Temperature—Monthly Average (°C)												Annual Average
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
2017	−6.7	1.5	8.4	9.9	15.7	20.7	20.3	22.3	15.8	11.6	4.9	1.0	10.5
2018	0.2	−0.3	3.3	15.3	18.7	19.4	20.4	22.3	16.7	12.7	6	−0.9	11.2
2019	−2.2	1.7	7.3	11.3	13.6	21.8	20.4	22.1	17.1	13.5	8.9	0.8	11.4
Average 63 years	−3.3	−0.7	4.4	10.0	15.0	18.0	19.8	19.5	15.1	9.8	4.0	−1.3	9.2

Table 2. Rainfall regime from 2017 to 2019 at the ARDS Turda.

Year/Months	Rainfall—Monthly Amount (mm)												Annual Amount
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
2017	2.6	19.2	46.1	65.2	65.4	30.6	110.2	36.1	56.2	49.2	30.8	20.7	532.3
2018	16.7	33.4	40.9	26.2	56.8	98.3	85.7	38.2	29.8	26.8	29.6	58.3	540.7
2019	46	14.7	12.3	62.6	152.4	68.8	35	63.8	19.4	25.6	28.4	14.2	543.2
Average 63 years	21.8	19.8	24.1	46.2	69.6	83.9	77.1	56.1	42.2	35.5	28.5	27.3	531.4

In 2017, it was a warm year with a deviation in the annual average temperature of +1.3 °C as compared with the average over 63 years (i.e., the multiannual average). In addition, it was a normal year, with respect to the amount of rainfall, with just 0.9 mm more than the MA, but with a fluctuant division of it during the vegetative stages of plant growth. This variable distribution of rainfall, i.e., alternating dry periods with rainy periods affected the growth of soybean plants, weeds, and the general hygiene of the soybean crop.

In 2018, it was extremely hot, and the annual average temperature was 2 °C over the MA, but the total amount of rainfall was normal. The rainfall regime was also variable throughout the 12 months.

In 2019, it was a very hot year, with the total rainfall amount close to the MA. The specific months for the beginning of the vegetative stage of soybean (April and May) were rainy, followed by a reduction in rainfall beginning in June. There was a lack of rainfall to the end of the year with the exception of August when rainfall exceeded the MA.

2.2. Experimental Design

The experimental design was carried out using an A × B × C × D − R: 3 × 2 × 3 × 3 − 2 multifactorial experiment, where A represents the year; B, the soil tillage system; C, the fertilizer variants; D, the seeding rate; and R, the repetitions (Table 3). There was a 3-year rotation of soybean, autumn wheat, and maize. The Felix variety, created by ARDS Turda, was used for the soybean crop.

Table 3. The experimental factors with gradations.

Experimental Factors	A Year	B Soil Tillage System	C Fertilization	D Seeding Rate
Gradations of factor	a1, 2017 a2, 2018 a3, 2019	b1, CS (conventional system with moldboard ploughing + preparation of the germinal bed + sowing and fertilization) b2, RT (reduced tillage with chisel cultivator + preparation of the germinal bed + sowing and fertilization)	c1 = UF (unfertilized) c2, one rate of fertilization upon sowing with N40 + P40 (40 kg ha^{-1} of N and 40 kg ha^{-1} of P) * c3, two rates of fertilization: First upon sowing, with N40 + P40 and the second at V3-V5 phenophase ** with N46 (46 kg ha^{-1} of N) ***	d1, 45 germinating grains m^{-2} d2, 55 germinating grains m^{-2} d3, 65 germinating grains m^{-2}

* Granulated complex fertilizer which contain 20% nitrogen (N) and 20% phosphorus (P), achieving N40 (40 kg ha^{-1} of N and P40 (40 kg ha^{-1} of P). ** V3–V5 phenophase = vegetative stages [34]. *** Urea which contains 46% nitrogen, achieving N46 (46 kg ha^{-1} of N).

In the CS, soil processing occurred in autumn using a plough (Kuhn Master 125 T, Kuhn Farm Machinery, Hamburg, Germania) at a depth of 28 cm and, in spring, the land was worked once with a rotary harrow (HRB 403 D) followed by machine sowing and fertilizing (Gaspardo Directa 400, Maschio Gaspardo, Padova, Italy). In the minimum tillage system with RT, soil was processed, in autumn, using a chisel (Gaspardo Pinocchio, Maschio Gaspardo S. p. A., Padova, Italy) at a depth of 28 cm and, in spring, soil was prepared using a rotary harrow (Kuhn HRB 403 D, Kuhn Farm Machinery, Hamburg, Germania) followed by the sowing and fertilizing machine (Gaspardo Directa 400). The distance between the plant rows was 18 cm and seeds were incorporated in the soil at a depth of 4 cm, in both conventional and minimum tillage systems.

Weed control was done by applying herbicides in two steps: (1) Preemergent application of 600 g l^{-1} metribuzin and 960 g l^{-1} S-metolachlor and (2) postemergent application of 22.4 g l^{-1} imazamox + 480 g l^{-1} bentazone, then, 4 days later 100 g l^{-1} propaquizafop. The following weed species were present in the experimental field: Rough cocklebur (*Xanthium strumarium*), lambs quarters (*Chenopodium album*), bindweed (*Convolvulus arvensis*), black bindweed (*Polygonum convolvulus*), redroot pigweed (*Amaranthus retroflexus*), yellow salsify (*Tragopogon dubius*), quackgrass (*Agropyron repens*), bladder hibiscus (*Hibiscus trionum*), shepherd's purse (*Capsella bursa-pastoris*), yellow foxtail (*Setaria glauca*), common sowthistle (*Sonchus oleraceus*), European dewberry (*Rubus caesius*), common hempnettle (*Galeopsis tetrahit*), creeping thistle (*Cirsium arvense*), whitetop (*Cardaria draba*), black nightshade (*Solanum nigrum*), barnyardgrass (*Echinochloa cruss-galli*), and bristly oxtongue (*Picris echioides*).

Pests were controlled by applying an acaricide, i.e., 570 g l^{-1} propargit, to combat against red spider mite (*Tetranychus urticae*) and a treatment with 240 g l^{-1} tiacloprid, to combat against painted lady (*Vanessa cardui*).

Harvesting was performed using a plot combine (1.5 m cutting width, WinterSteiger™, Austria) during the second week of September in each experimental year.

2.3. Analyzed Parameters

After the soybeans were harvested, samples were taken to measure the moisture content of soybean grains in the lab using a hygrometer (Granomt Perten, Infracont Instruments Ltd., Timișoara, Romania). The production was calculated after standardizing the moisture content of soybeans to 13%, which is the national standard of moisture content (STAS). The composition of soybean grain fat, protein, and fiber was determined using a spectrophotometer (Nir Tango-Bruker Optik GMBH, Gerhardt Analytical Systems device-Gerhardt Koenigswinter, Germany).

2.4. Statistics

The data were analyzed using ANOVA PoliFact Soft, 2015 [35]. A Fisher's protected least significant difference (LSD) test was used to determine the significance of the differences among the variants results and control (*p*-values 0.05, 0.01, and 0.001) for each experimental factor, and the Duncan test for multiple comparisons among the experimental variants for *p*-value of 0.05. ANOVA PoliFact Soft is an USAMV Cluj Napoca property.

3. Results and Discussions

3.1. Soybean Yield in Relation to the Experimental Factors

3.1.1. Climate and Soybean Yield

Climate conditions specific for each cultivating year had the most effect on soybean yield [36]. In 2017, there were favorable conditions of temperature and humidity for the vegetative stages of soybean and yield (Table 4). In contrast, in 2018 and 2019, climate conditions had negative effects and the differences in production as compared with the control year (2017) were statistically significant ($p < 0.01$ in 2019 and $p < 0.001$ in 2018).

Table 4. Effect of the experimental factors on the soybean yield and qualitative characteristics.

Factors	Yield (kg ha^{-1})	Protein (g kg^{-1} DM)	Fat (g kg^{-1} DM)	Fiber (g kg^{-1} DM)
Year				
2017	2838 c *	36.53 a	31.10 b	7.77 a
2018	2149 a	37.95 b	28.02 a	7.69 a
2019	2283 b	37.76 b	28.47 a	7.71 a
Tillage				
CS	2440 a	37.38 a	28.30 a	7.63 a
RT	2407 a	37.44 a	30.10 a	7.82 a
Fertilization				
UF	2197 a	37.08 a	29.21 a	7.74 a
One single rate of fertilization: N40 + P40 upon sowing	2442 b	37.50 b	29.26 a	7.78 a
Two rates of fertilization: N40 + P40 upon sowing + N46 at V3 stage	2632 c	37.70 c	29.13 a	7.66 a
Seeding rate (SR)				
45 gg m^{-2}	2085 a	36.91 a	29.05 a	7.45 a
55 gg m^{-2}	2422 b	37.65 b	29.95 a	7.91 c
65 gg m^{-2}	2764 c	37.73 c	28.60 a	7.69 b

* a, b, c are the mean statistical differences when no common letter is attached to two values for comparison for a *p*-value of 0.05.

Our results indicate a direct relationship between water deficit or variable temperatures and the achievable yield of the soybean (Felix) variety. The amount of rainfall from the sowing to blooming period, together with high temperatures had the greatest effect on the level of the soybean production, which was in accordance with the results obtained by [37,38], who found that there were negative climate effects on soybean yield, due to periods of drought and high temperatures during the growing season. The authors of [39] showed that there was a clear positive response of soybean yield to the increased mean daily maximum temperature, during seed filling, which ranged from 20 to 24 °C. The effects of temperature on soybean yield are complex, in which yield is determined by the growth and partition as well as phenological development and all these responses have different ranges of optimal temperatures. One study reported that the different yields in response to the sowing date and genotype combinations resulted, in part, from the current mean growing season temperature at their experimental site, which was near or below the optimum for soybean yield and yield components [40]. The optimal temperature for reproductive development has been reported to vary between 25.0 and 29.0 °C [41].

In our region, the average temperatures in May, June, July, and August (the defining period for soybean growing and production) are between 10 and 19.8 °C (MA), between 15.3 and 22.3 °C in the warmest experimental year (2018), and between 9.9 and 22.3 °C in the normal year for the area (2017). The maximum daily temperature (31.4 °C) was recorded on 1 June 2018. Compared with the production results obtained in other regions, the variable daily thermal regime is a cause of the lower harvest level (especially variations recorded between monthly fraction temperatures or large day-night temperature differences in the last period).

A low soybean yield results from a reduction in water availability during the reproductive periods, especially during the pod-filling period. This relationship highlights the importance of adjusting the sowing date to the current meteorological scenario in order to optimize production according to the water deficit pattern in the region [36].

In 2018, high temperatures throughout April and May were accompanied by a lack of rainfall and resulted in an increase in spacing with uneven growth and development of plants. Although, in June and July, rainfall exceeded the value of the multiannual average for this period, beginning in August (the phase of grain filling) rainfall was reduced, the pedological drought followed, and the production was less by 668 kg ha^{-1} than that of the previous year. The high temperatures and the non-uniformity of rainfall during June and August in 2019 were the factors affecting the reduction in wheat production by 518 kg ha^{-1}, as compared with the wheat production in 2017.

The significant effect on the reduction in soybean production from the center of Transylvania is attributed to climate variations, especially strong drought or rain showers during blooming. This finding has also been reported by [42] who estimated a linear relation, with different variables in each country and [43] who showed under the United Kingdom Meteorological Office (UKMO) climate scenario that water stress was pervasive throughout the soybean reproductive periods. The probability of water stress increased from Stage R2 (full bloom) to Stage R3 (beginning pod development), and generally declined thereafter to Stage R7 (beginning maturity).

3.1.2. Tillage and Soybean Yield

Soybeans react positively to a minimum tillage system (chisel), resulting in a yield close to that of a conventional system (with ploughing), with no statistically significant difference between these two systems. The two tillage systems are used in the Transylvania Plain. However, the choice of minimum tillage system supports sustainability of the land and a reduction in fossil fuel use. Regarding the beneficial effect of the conventional system on soybean yield, the results obtained in Poland [44] showed that the yield was higher by 10.3% with the conventional system, as compared with the no tillage system. Similar to our results of favorable ecological conditions for soybean production, a study Turkey by [45] determined that the highest yield from a conventional system (2036 kg ha^{-1}) was comparable to the yield with reduced tillage (2015 kg ha^{-1}) with a difference of only 21 kg ha^{-1}, and a low yield with a no tillage system (1881 kg ha^{-1}). Similar results were obtained by a study from 2010 to 2012 with soybeans on heavy soil (the content of clay more than 53%) in East Slovakia [19]. They studied the effect of three tillage systems (conventional, minimum tillage, and no tillage) and reported that the higher yields were achieved with conventional and minimum tillage variants, with no significant difference in the yield between these variants, but the soybean yield in the no tillage variant was significantly lower.

3.1.3. Fertilizers and Soybean Yield

The fertilizer application, especially nitrogen (N) fertilization for soybean crops, continues to be a controversial subject, and determining the plant conditions specific to each cultivation area is very important. The soybean production response to N fertilization appears to be dependent on the concentration of soil nitrate at the time of planting. Nitrogen applied during plant reproductive stages has been reported to be the most reliable application time for increasing yields, but yield decreases were also observed when N was applied at reproductive stages (RS) [46].

The evolution of average soybean yield, during the 3 experimental years, according to the fertilization system applied is not exceptional, even if crop bonuses are statistically ensured. As compared with an unfertilized experimental variant (control) with a yield of 2197 kg ha^{-1}, for the variant with one fertilization of N40 (40 kg ha^{-1} of N) + P40 (40 kg ha^{-1} of P) applied at the time of sowing, there was a statistically significant increase in the average soybean yield recorded, even if the growth was not very high. Soybean plants reacted very well to additional fertilization when N40 was applied at the stage of three to four trifoliate leaves (V_3), with a greater difference in yield as compared with the unfertilized control. Thus, the impact of thermal and hydric stress on the vegetative stages of soybean was reduced by applying mineral fertilizers during the vegetative stages, in reduced doses, which were essential factors for the increased yield.

3.1.4. Soybean Density and Yield

The sowing density had an effect on the average yield of soybean over the 3 experimental years. There were different yields of soybean (Felix) variety depending on the sowing density, i.e., the highest yield was achieved at a sowing density of 65 gg m^{-2}, which was a statistically significant difference, as compared with the control variant (45 gg m^{-2}). An increase in the sowing density, even by 10 gg m^{-2}, led to a significant increase in the seed yield (Table 4).

A study conducted for 9 years in the USA and Canada showed that the soybean seed yield variability was mainly explained by the yield environments, followed by planting dates, relative maturity of the variety, and row spacing factors [47]. There were no interactions observed between soybean plant density and the application of N on yield, yield components, or oil and protein concentrations [48,49]. The results of [50] and others indicated that soybean planted in narrow rows of 19 cm had higher yield potential, as compared with soybean planted in wider rows. They reported that soybean yield responded to the seeding rate with the maximum yield obtained at a seeding rate of 506,500 seeds per ha^{-1} with no significant interaction between the row spacing and seeding rate.

The higher sowing density of the soybean (Felix) variety also improved the crop yield (Table 5). The highest production was achieved by the combination of maximum density of 65 gg per m^{-2} (d3) and two fertilizations (c3, N40 + P40 + N46) for both tillage systems.

Table 5. Synthesis of yield comparisons by technological factors.

No.	Factors Combination *	Yield (kg ha^{-1})	Duncan Classification **
1	d1 b2 c1	1865.67	A
2	d1 b1 c1	2028.83	B
3	d1 b2 c2	2065.50	BC
4	d1 b1 c2	2118.00	BCD
5	d2 b2 c1	2144.67	BCD
6	d1 b1 c3	2211.67	CD
7	d1 b2 c3	2217.17	D
8	d2 b1 c1	2227.83	D
9	d2 b2 c2	2434.83	E
10	d3 b2 c1	2450.00	E
11	d3 b1 c1	2467.33	E
12	d2 b1 c2	2491.00	EF
13	d2 b2 c3	2611.83	FG
14	d2 b1 c3	2624.00	FG
15	d3 b1 c2	2725.83	GH
16	d3 b2 c2	2816.83	H
17	d3 b2 c3	3059.67	I
18	d3 b1 c3	3066.33	I

* b1, CS; b2, RT; c1, UF; c2, N40 + P40, one single rate; c3, N40 + P40 at sowing + N46 at V3 stage, two rates; d1, 45 gg m^{-2}; d2, 55 gg m^{-2}; d3, 65 gg m^{-2}. ** A–I, all the different letters between two variants mean statistical significance, *p*-value of 0.05.

3.2. Soybean Quality

In [51], the authors showed that quadratic regression supported observations that protein concentration decreased with an increase in temperature between 14 and 20 °C and protein concentration increased with an increase in temperature above 25 °C, agreeing with our observations that protein concentration increases at high temperatures. In our experiment, the maximum amount of protein from soybean grains was registered in 2018, which was the warmest year and, in particular, the year with the highest temperatures from June to August (Table 4).

In soybean, drought stress during seed maturation decreases the seed fat and protein contents by reducing biosynthesis and promoting degradation.

As compared with 2017 when the rainfall regime was normal during the filling and ripening of soybeans (July to September), in the other 2 years, diminished values of the average fat content were obtained, with variations depending on technological factors. The average fat content decreased by 2.63–3.08 g kg^{-1} DM, as compared with that in 2017.

In the Transylvanian Plain, the effect of climate on the protein content of soybeans is statistically significant during the experiment. In 2018 and 2019, the protein content of soybean was higher than it was in 2017. A statistically significant variation was achieved in total fat content too between 2017 and the next 2 years of experiment. It significantly decreased in 2018 and 2019 compared to 2017. Only the fiber content was stable with the climatic variations (Table 4).

According to the quality analyses in relation to the technological factors (Tables 6–8), the fat percentage from the soybean seeds (Table 6) was higher (33.78 g kg^{-1} DM) in the RT system with a sowing density of 55 gg m^{-2} and one single rate of fertilization (N40 + P40), as compared with the CS in which the highest value of fat percentage in the grain seeds was 30.24 g kg^{-1} DM% with a sowing density of 65 gg m^{-2} and two fertilizations (N40 + P40 + N46). The lowest fat percentage value (24.53 g kg^{-1} DM) was reached with a sowing density of 45 gg m^{-2} and UF in the CS with ploughing. With respect to the protein content (Table 7), higher values were recorded with the RT system and the following variants: 38.90 g kg^{-1} DM with one single rate of fertilization (N40 + P40) and a sowing density of 45 gg m^{-2} and 38.72 g kg^{-1} DM with two fertilizations (N40 + P40 + N46) at a sowing density of 65 gg m^{-2}. This shows good adaptability of the soybean (Felix) variety in a minimum tillage system with a higher sowing density. With respect to the percentage of fiber (Table 8), higher values were recorded with the CS and a sowing density of 55 gg m^{-2} and two fertilizations (8.09 g kg^{-1} DM), as well as with the minimum tillage system and the same level of fertilization, but a sowing density of 65 gg m^{-2} (8.03 g kg^{-1} DM).

Table 6. Synthesis of soybean fat content (g kg^{-1} DM) comparisons by technological factors (Duncan classification of the average values for 2017–2019).

No.	Factors Combination *	Fat (g kg^{-1} DM)	Duncan Classification **
1	d1b1c1	24.53	A
2	d2b1c3	26.67	AB
3	d3b2c2	27.08	ABC
4	d3b1c1	27.58	ABCD
5	d1b1c2	27.61	ABCD
6	d3b1c2	27.74	ABCD
7	d2b1c2	27.86	ABCDE
8	d2b1c1	28.18	ABCDE
9	d2b2c3	28.21	ABCDE
10	d3b2c3	29.14	BCDE
11	d2b2c1	29.56	BCDE
12	d3b2c1	29.78	BCDE
13	d1b1c1	29.8	BCDE
14	d3b1c3	30.24	BCDEF
15	d1b2c3	30.61	CDEF
16	d1b2c1	31.11	DEF
17	d1b2c2	31.57	EF
18	d2b2c2	33.78	F

* b1, CS; b2, RT; c1, UF; c2, N40 + P40, one single rate; c3, N40 + P40 at sowing + N46 at V3 stage, two rates; d1, 45 gg m^{-2}; d2, 55 gg m^{-2}; d3, 65 gg m^{-2}. ** A–F, all the different letters between two variants mean statistical significance, *p*-value of 0.05.

Table 7. Synthesis of soybean protein content (g kg^{-1} DM) comparisons by technological factors (Duncan classification of the average values for 2017–2019).

No.	Factors Combination *	Protein (g kg^{-1} DM)	Duncan Classification **
1	d2b2c1	35.4	A
2	d1b1c2	36.17	B
3	d2b2c3	36.52	C
4	d3b2c1	36.69	D
5	d2b1c3	36.9	E
6	d1b1c1	37.05	F
7	d2b1c2	37.12	F
8	d3b2c2	37.27	G
9	d1b2c3	37.43	H
10	d3b1c1	37.6	I
11	d2b1c1	37.62	I
12	d3b1c2	37.68	I
13	d2b2c2	37.88	J
14	d1b2c1	38.14	K
15	d1b1c3	38.21	K
16	d3b1c3	38.41	L
17	d3b2c3	38.72	M
18	d1b2c2	38.9	N

* b1, CS; b2, RT; c1, UF; c2, N40 + P40, one single rate; c3, N40 + P40 at sowing + N46 at V3 stage, two rates; d1, 45 gg m^{-2}; d2, 55 gg m^{-2}; d3, 65 gg m^{-2}. ** A–N, all the different letters between two variants mean statistical significance, *p-value* of 0.05.

Table 8. Synthesis of soybean fiber content (g kg^{-1} DM) comparisons by technological factors (Duncan classification of the average values for 2017–2019).

No.	Factors Combination *	Fiber (g kg^{-1} DM)	Duncan Classification **
1	d2b1c3	6.88	A
2	d2b2c3	7.15	AB
3	d2b1c1	7.24	AB
4	d3b1c2	7.32	BC
5	d3b2c2	7.48	BCD
6	d3b1c1	7.69	CDE
7	d3b2c1	7.71	DE
8	d2b2c2	7.72	DE
9	d1b1c2	7.76	DE
10	d2b1c2	7.82	DE
11	d3b1c3	7.85	DE
12	d1b1c1	7.85	DE
13	d1b2c3	7.86	DE
14	d2b2c1	7.9	E
15	d1b2c1	7.93	E
16	d1b2c2	7.99	E
17	d3b2c3	8.03	E
18	d1b1c3	8.09	E

* b1, CS; b2, RT; c1, UF; c2, N40 + P40, one single rate; c3, N40 + P40 at sowing + N46 at V3 stage, two rates; d1, 45 gg m^{-2}; d2, 55 gg m^{-2}; d3, 65 gg m^{-2}. ** A–E, all the different letters between two variants mean statistical significance, *p*-value of 0.05.

The results by [19] indicated that N fertilization would not be an effective means of altering protein and fat concentrations of soybean in Alabama.

4. Conclusions

The June–August droughts in 2018 and 2019 correlated with high or variable temperatures which negatively affected the soybean yield in the Transylvania Plain.

The elements of agro techniques applied under these pedoclimate conditions have different effects on the soybean yield obtained. The effect of the soil tillage system is not significant on the crop formation. However, soybean reacts favorably to the minimum tillage technology with an average production that was comparable to that from the conventional tillage system.

Additional fertilization with N46 in the soybean vegetative phenophases (V3–V5) has a significantly positive and quantity effect on the soybean production.

A sowing density of 55–65 gg m^{-2} also has a significantly positive effect on the quantity of the soybean production.

The fat percentage values in the grains were higher with the reduced tillage system (33.78 g kg^{-1} DM) at a sowing density of 55 gg m^{-2} and one single rate of fertilization. Higher protein content values were recorded with the reduced tillage system as well, i.e., 38.90 g kg^{-1} DM with one single rate of fertilization and a sowing density of 55 gg m^{-2} and 38.72 g kg^{-1} DM with two fertilization rates and at a sowing density of 65 gg m^{-2}. Higher fiber percentage values were recorded with the conventional system at a sowing density of 45 gg m^{-2} and two fertilizations (8.09 g kg^{-1} DM), but a clear conclusion on this soybeans feature was not found, since between 7.69 and 8.09 g kg^{-1} DM the fiber content has no statistical significance (*p*-value of 0.05). In addition, this range of values includes the effect of 13 combinations of technological factors.

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