Influence of tillage system and starting N fertilization on seed yield and quality of soybean *Glycine max* (L.) Merrill

P. Fecák[1], D. Šariková[1], I. Černý[2]

[1]*Research Institute of Agroecology, Michalovce, Slovak Republic*
[2]*Slovak University of Agriculture, Nitra, Slovak Republic*

ABSTRACT

This field polyfactorial trial with soybean was performed on gleyey alluvial soil in 2006–2008. Three tillage systems: conventional, reduced (spring shallow cultivation to a depth of 100 mm followed by drilling), no-tillage and two doses of starting N: 50 kg N/ha, 25 kg N/ha were tested in this trial. The trial was organized in a complete randomized block design with four replicates. All data were subjected to ANOVA, LSD method and regression analysis using Statgraphics. Seed yield was highly significantly ($P \leq 0.01$) affected by weather conditions. Weather was the most dominant factor that influenced seed yield. The highest average yield was found in 2008 – 2.77 t/ha, followed by 2.34 t/ha in 2006 and the lowest yield of 1.98 t/ha in 2007. The stage of seed-filling was found as the most sensitive to water stress resulting in a yield reduction. Seed protein and oil were also highly significantly ($P \leq 0.01$) affected by weather. This influence, as compared with tillage system and starting N, was much higher. A negative correlation coefficient $r = -0.96$ was found between protein and precipitation, compared to a positive correlation coefficient $r = 0.81$ between oil and precipitation. Tillage system affected seed yield highly significantly ($P \leq 0.01$). The highest average yield of 2.60 t/ha gave conventional tillage, followed by reduced tillage – 2.39 t/ha and no-tillage – 2.11 t/ha. The results do not support the choice of no-tillage for profitable soybean production on heavy soils. Starting N fertilization had a significant ($P \leq 0.05$) influence on seed yield. The average yield difference between the two starting N treatments was 0.05 t/ha in favour of the dose of 25 kg N/ha. This dose was proven as a rational one.

Keywords: soybean; tillage system; starting N fertilization; weather; seed yield; seed protein and oil

Nowadays growers try to expand the spectrum of traditional cultivated crops by forgotten or new species. One of our so-called forgotten species is undoubtedly soybean *Glycine max* (L.) Merrill. This crop with new early maturing varieties can easily become an excellent cash crop. Soybean is the crop which can be used in many ways; the main use of the seed is in oil industry because of a high content of oil that ranges from 18 to 22% (Javor et al. 2001). The primary product extracted from the seed is high quality oil with a favourable amount of non-saturated fatty acids, mainly essential linoleic acid. Besides oil, soybean meal, a by-product of extraction, is usually used as excellent protein feed. Soybean also contains the highest protein percentage of all legumes, as high as 35–45% of seed protein with a favourable composition of the amino acids (Javor et al. 2001). This is also the reason why soybean is recommended for use in human nutrition as a part of cholesterol-free diets.

Conservation tillage, as a kind of primary tillage for soybean, became very popular and widely practiced in USA and Canada at present. Unger (1994) divided conservation tillage into: (1) reduced tillage, such as mulch tillage, disking, strip tillage, and (2) no-tillage, syn. direct sowing. A prevalent part of arable land in Slovakia as well as in Western Europe is cultivated by conventional tillage, i.e. stubble cleaning followed by autumnal ploughing. In Slovakia, conservation tillage was found profitable just for maize. Conservation tillage used for soybean has not been sufficiently tested so far. Preliminarily, it can be said that reduced tillage is more appropriate for Slovakian soil-climatic conditions than no-tillage. This assumption was confirmed in the field trial performed in the East Slovak Lowland by Šariková (2004) who found that average seed yield under no-tillage was 1.95 t/ha, whereas under conventional tillage as much as 3.57 t/ha, i.e. about 83% higher. Yield variability was highly significantly affected by tillage system. Certain trials on heavy clayey soils revealed that some tillage shortly before sowing is beneficial (Popp et al. 2000). Vyn et al. (1998), based on trials in Southwestern Ontario found that soybean yield was higher on conventional tillage and reduced tillage treatments in comparison with no-tillage treatment. Our trial was focused on confirmation of these trends.

Soybean has an important ability to fix atmospheric nitrogen by means of a symbiotic nodulating bacterial species *Bradyrhizobium japonicum*. Harper (1987) reported that soybean is able to use more than 50% of fixed N and the rest is taken from the soil. Marečková and Sýkora (1980) found a negative influence of an increasing amount of soil inorganic N on a number and dry matter content of the nodules. Also Baker and Sawyer (2005) stated that N application before sowing or at early growth stages could suppress the process of N fixation. Similarly, Ham et al. (1975) claimed that no matter what kind of nitrogen fertilizer is used, fertilization decreased N fixation by plants, a number of the nodules and their weight per plant. As a matter of fact, soybean is totally dependent on soil N from the stage of emergence to the stage of two true leaves and this time is the so-called hunger period. Javor et al. (2001) suggest a dose of 40–60 kg N/ha to overcome the hunger period; Starling et al. (1998) and Racz (2003) stated that a dose of 50 kg N/ha applied before sowing is reasonable on soils with a low amount of inorganic N. Our research was aimed at testing two different starting N doses to find the rational one.

There is no question that protein and oil are the most important soybean seed constituents. Kolařík et al. (1980), based on the results of the field trial with seven varieties in two different environments, namely maize and sugar beet growing regions, concluded that seed protein was highly significantly affected by weather and locality; the term environment refers to a weather × locality interaction. Simply said, weather is characterized by a temperature × precipitation interaction; a locality is characterized by the duration of a growing season. Environments influenced seed protein by 72.5%, from which 70.2% was a weather influence and 29.1% was a locality influence, whereas genotype had the lowest influence on seed protein. The content of seed oil is also mainly affected by environment (Purseglove 1987). Kolařík et al. (1980) found that the effect of environment on seed oil was 51.7%, from which 99.9% was the influence of weather; genotype had, again, the lowest influence. Šariková and Fecák (2007), in conditions of the East Slovak Lowland, reported that weather influence on seed protein was as high as 98.0%, on seed oil it was also fairly high – 48.3%. Kolařík and Marek (1981) found a highly significant negative correlation between seed protein and oil; in a dry and warm year, the content of protein was the highest and the content of oil the lowest, conversely, in a year with sufficient precipitation, the content of oil enormously increased whereas the content of protein decreased. Drier and warmer weather encourages protein synthesis, whereas humid and colder weather encourages oil synthesis. Wilcox and Shibles (2001) detected a strong negative correlation between protein and oil with a highly significant correlation coefficient $r = -0.88$. To test the relation between protein and oil in the seed was our objective as well.

MATERIAL AND METHODS

This field polyfactorial trial with soybean (variety Quito) was performed at the research site of the Research Institute of Agroecology in Milhostov (altitude: 101 m, average temperature: 9.0°C, sum of precipitation: 559 mm) on gleyey alluvial soil in 2006–2008. Soil pH/KCl ranged from 6.3 to 6.6 (slightly acid – neutral soil reaction) during the trial period. Temperatures and sums of precipitation during the growing seasons were evaluated according to Kožnarová and Klabzuba (2002) and are presented in Tables 1 and 2. Two-rowed barley was a preceding crop. A seeding amount of 650 000 viable seeds/ha and a row spacing of 180 mm were used. Seed was not inoculated. Three tillage systems: conventional tillage (stubble cleaning followed by mouldboard ploughing in autumn and seedbed preparation followed by drilling in spring), reduced tillage (spring shallow cultivation by a stubble cultivator to a depth of 100 mm followed by drilling) and no-tillage, and two starting doses of nitrogen: 50 kg N/ha and 25 kg N/ha applied before drilling, were tested in the trial. The doses of PK fertilizers were estimated on the basis of soil tests and also applied before drilling. The trial was organized in a complete randomized block design with four replicates. A plot seed yield, harvested from the area of 1.5 × 23 m, was adjusted to moisture of 14% and expressed in t/ha. Some supplementary data such as a number of pods per plant and TSW (thousand seed weight) were also collected. The total N of the seed was determined using the Kjeldahl distil-

Table 1. Average monthly temperatures in °C during the growing seasons of 2006–2008 in comparison with the long-term average of 1951–1980 (LA)

Month	LA	2006	ΔLA		2007	ΔLA		2008	ΔLA	
IV.	9.7	11.3	1.6	W	11.2	1.5	N	10.7	1.0	N
V.	14.6	14.8	0.2	N	17.5	2.9	VW	15.0	0.4	N
VI.	18.2	18.8	0.6	N	20.7	2.5	VW	19.3	1.1	N
VII.	19.6	22.5	2.9	EW	22.5	2.9	EW	19.7	0.1	N
VIII.	18.9	18.8	–0.1	N	21.7	2.8	EW	20.1	1.2	W
IX.	14.8	16.3	1.5	W	13.6	–1.2	C	14.0	–0.8	N
∅ IV.–IX.	16.0	17.1	1.1	W	17.9	1.9	VW	16.5	0.5	N
∅ I.–XII.	9.0	9.6	0.6	W	11.0	2.0	EW	10.2	1.2	W

ΔLA – deviation of long-term average; C – cold; N – normal; W – warm; VW – very warm; EW – extremely warm

lation method and seed protein was estimated as N × 6.25 and expressed in %; the oil content of the seed was determined using the Soxhlet extraction method and was also expressed in %. All data were subjected to ANOVA, LSD method and regression analysis using Statgraphics.

RESULTS AND DISCUSSION

Seed yield, seed protein and oil as influenced by weather. Seed yield was affected highly significantly ($P \leq 0.01$) by weather conditions (Table 3). Furthermore, weather was the most dominant factor that influenced seed yield. The highest average yield was found in 2008 – 2.77 t/ha, followed by 2.34 t/ha in 2006 and the lowest yield of 1.98 t/ha in 2007 (Table 4). In 2007, the yield was negatively affected by very warm May and June and extremely dry April and normal May, but with 28% less precipitation than the long-term average; the amount of 44 mm represented only 48% of the long-term average for April plus May. This serious shortage of precipitation resulted in the smallest number of pods per plant from all trial years, namely only 14 pods. In addition, not only April and May, but also July 2007 was the month with extremely warm (average monthly temperature of 22.5°C) and dry weather with total precipitation of 36 mm, only 47% of the long-term average; yet July is the month of the seed-filling stage. Altogether, the lack of precipitation at the beginning of the growing season as well as during July 2007 was responsible for the lowest average yield of 1.98 t/ha of all trial years. In 2006, even though the highest number of pods per plant was found – 21 pods, extremely warm and very dry July (average monthly temperature of 22.5°C and total precipitation of 18 mm, only 24% of the long-term average) caused the lowest TSW of 167 g and finally, the yield (2.34 t/ha) was also affected by these unfavourable weather conditions. These results are in accordance with the findings of Momen et al. (1979) and Brevedan and Egli (2003) who concluded that the stage of seed-filling is the most sensitive to water stress resulting in a yield reduction. In comparison of the

Table 2. Monthly sums of precipitation in mm during the growing seasons of 2006–2008 in comparison with the long-term average of 1951–1980 (LA)

Month	LA	2006	LA(%)		2007	LA(%)		2008	LA(%)	
IV.	39	49	126	N	6	15	ED	48	123	N
V.	53	83	157	W	38	72	N	40	76	N
VI.	78	96	123	N	72	92	N	61	78	N
VII.	76	18	24	VD	36	47	D	140	184	VW
VIII.	63	151	240	EW	29	46	D	53	84	N
IX.	41	5	12	VD	147	359	EW	34	83	N
∑ IV.–IX.	348	402	116	N	328	94	N	376	108	N
∑ I.–XII.	559	556	99	N	543	97	N	554	99	N

LA (%) – percentage of long-term average; ED – extremely dry; VD – very dry; D – dry; N – normal; W – wet; VW – very wet; EW – extremely wet

Table 3. Analysis of variance of the influence of the tested factors on seed yield, seed protein and oil

	Source of variation	*df*	*F*-ratio
Seed yield	year (A)	2	421.073**
	tillage system (B)	2	164.162**
	starting N (C)	1	4.307*
	interaction A × B	4	6.490**
	interaction A × C	2	25.519**
	interaction B × C	2	13.104**
Seed protein	year (A)	2	15016.875**
	tillage system (B)	2	43.079**
	starting N (C)	1	121.892**
	interaction A × B	4	112.819**
	interaction A × C	2	75.774**
	interaction B × C	2	145.610**
Seed oil	year (A)	2	700.370**
	tillage system (B)	2	6.724**
	starting N (C)	1	0.344^{ns}
	interaction A × B	4	109.717**
	interaction A × C	2	70.052**
	interaction B × C	2	3.626*

^{ns} $P > 0.05$; * $P \leq 0.05$; ** $P \leq 0.01$

years 2006 and 2008, the average number of pods per plant was 17 in 2008 whereas it was 21 in 2006; however a sufficient amount of precipitation in July 2008 (as much as 140 mm) positively affected TSW which was 216 g, i.e. the highest result of all trial years, and accordingly, the seed yield in 2008 was the highest of all trial years – 2.77 t/ha (Tables 1 and 2). Be that as it may, a negative influence of drought during the critical growth stages, such as seed-filling period, on seed yield can be eliminated only by supplemental irrigation.

Seed protein and oil were highly significantly ($P \leq 0.01$) affected by weather conditions (Table 3). As expected, this influence, as compared with tillage system and starting N, was much higher. The highest protein content of 38.4% was found in 2007, followed by 2008 – 36.4% and 2006 – 29.7% (Table 4). In contrast to seed protein, the highest oil content was found in 2006 – 18.9 %, followed by 2007 – 16.8% and 2008 with the lowest oil content of 16.5% (Table 4). These findings are in agreement with the results of Kolařík et al. (1980), Purseglove (1987), Šariková and Fecák (2007) who also reported the highest influence of weather conditions on seed protein and oil. Based on regression analysis, seed protein was in a negative relationship to seed oil. These results are compatible with those obtained by Kolařík and Marek (1981) or Wilcox and Shibles (2001). A negative correlation coefficient $r = -0.80$ ($P \leq 0.01$) characterized by a strong negative linear relationship between seed protein and oil was detected. These findings are in accordance with the results reported by Wilcox and Shibles (2001) who found a highly significant correlation coefficient $r = -0.88$. This strong negative relationship could be explained by different weather requirements for protein and oil syntheses. Generally speaking, in a dry and warm year, seed protein is usually higher and seed oil lower. On the contrary, in a colder year with a sufficient amount of precipitation, the seed contains more oil and less protein. This was a good reason why regression analyses between the following pairs: protein – temperature, protein – precipitation, oil – temperature and oil – precipitation were performed. Between protein and temperature a positive correlation coefficient $r = 0.76$ ($P \leq 0.01$) was found. In terms of a protein – precipitation relation, a negative correlation coefficient $r = -0.96$ ($P \leq 0.01$) was found. It indicated a strong negative linear relationship with a coefficient of determination $r^2 = 0.92$, i.e. as much as 92% of protein content variability can be explained by precipitation amount variability. The more the precipitation received, the less the protein contained in the seed. As it was predicted, between oil and temperature a negative correlation coefficient $r = -0.45$ was

Table 4. Seed yield, seed protein and oil as influenced by tillage system and starting N during the trial years of 2006–2008

Year	Tillage system	Starting N (kg/ha)	Seed yield (t/ha)	Seed protein (%)	Seed oil (%)
2006	conventional tillage	50	2.40	30.5	18.5
		25	2.62	29.0	19.1
	reduced tillage	50	2.29	29.5	18.0
		25	2.45	29.2	19.6
	no-tillage	50	1.98	29.3	18.9
		25	2.32	30.5	19.1
	year average		2.34	29.7	18.9
2007	conventional tillage	50	2.18	38.2	16.2
		25	2.32	38.8	16.0
	reduced tillage	50	1.85	38.3	16.6
		25	2.02	39.3	16.6
	no-tillage	50	1.82	37.1	17.6
		25	1.67	38.8	17.6
	year average		1.98	38.4	16.8
2008	conventional tillage	50	2.98	36.1	18.1
		25	3.11	35.9	17.1
	reduced tillage	50	2.89	35.6	16.9
		25	2.82	36.0	15.8
	no-tillage	50	2.68	36.8	15.8
		25	2.16	38.2	15.4
	year average		2.77	36.4	16.5

detected, whereas between oil and precipitation correlation coefficient was positive $r = 0.81$ ($P \leq 0.01$). It was a strong positive linear relationship with a coefficient of determination $r^2 = 0.66$, i.e. as much as 66% of oil variability is possible to explain by variability in precipitation amount. The more the precipitation, the more the oil contained in the seed. On the basis of these results and also those of Kolařík and Marek (1981), it is possible to assume that drier and warmer weather during a growing season causes a more active protein synthesis in the seed, whereas a more humid and colder weather causes a more active oil synthesis in the seed.

Seed yield, seed protein and oil as influenced by tillage system. Tillage system affected seed yield highly significantly ($P \leq 0.01$) (Table 3). Seed yields of all tillage system treatments are presented in Table 4. The highest average yield of 2.60 t/ha was reported at conventional tillage, followed by reduced tillage – 2.39 t/ha and no-tillage – 2.11 t/ha. These results confirmed the expected trends of higher yield when more intensive tillage is performed. This is consistent with the results of Vyn et al. (1998), Popp et al. (2000), Šariková and Fecák (2007). These results do not support the choice of no-tillage for profitable soybean production on heavy soils.

Tillage system had a highly significant ($P \leq 0.01$) influence on seed protein (Table 3). Seed protein of all tillage system treatments is shown in Table 4. However, this influence was much lower than those of weather and starting N. The highest average seed protein was detected under no-tillage – 35.1%. It was also highly significantly (LSD, $P \leq 0.01$) higher in comparison with conventional tillage – 34.8% and reduced tillage – 34.7%. The difference between conventional and reduced tillage was non-significant (LSD, $P > 0.05$). As to seed oil, tillage system had a highly significant ($P \leq 0.01$) influence on seed oil, still much lesser than weather (Table 3). Seed oil of all tillage system treatments is displayed in Table 4. The highest seed oil was obtained at conventional tillage – 17.5%, followed by no-tillage – 17.4% and reduced tillage – 17.3%. Only the difference between conventional and reduced tillage treatments was significant (LSD, $P \leq 0.05$).

Seed yield, seed protein and oil as influenced by starting N fertilization. Starting N had a significant ($P \leq 0.05$) influence on seed yield (Table 3). Seed yields of both starting N treatments are presented in Table 4. The average yield difference between the two starting N treatments was 0.05 t/ha (LSD, $P \leq 0.05$) in favour of the dose of 25 kg N/ha. A dose of 50 kg N/ha, recommended by Starling et al. (1998), Javor et al. (2001) and Racz (2003), is rational only on the condition that the amount of soil inorganic N is too low. Soil N of our trial site during the trial period was medium high to high (N_{in} = 17.0–22.3 mg/kg), so the dose of 25 kg N/ha was proven as rational.

Starting N had a highly significant ($P \leq 0.01$) influence on seed protein (Table 3). Seed protein of all starting N treatments is shown in Table 4. The treatment with 25 kg N/ha had 35.08% of seed protein. It was about 0.48% (LSD, $P \leq 0.01$) more compared to the double dose (34.60%). The statement of Marečková and Sýkora (1980), that seed protein with an increasing amount of inorganic N usually decreases, was confirmed partially. Only no-tillage treatments with 25 kg N/ha had consistently higher protein than those with the double dose during the whole trial period. The other treatments had inconsistent percentage of seed protein. Starting N had a non-significant ($P > 0.05$) influence on seed oil (Table 3). Seed oil of all starting N treatments is displayed in Table 4.

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Corresponding author:

Ing. Peter Fecák, Research Institute of Agroecology, Špitálska 1273, 071 01 Michalovce, Slovak Republic
e-mail: pfecak@yahoo.ca