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EFFECT OF TILLAGE SYSTEMS ON YIELD, WEED INFESTATION AND SEED QUALITY ELEMENTS OF SOYBEAN

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Abstract. Soybean cultivation is becoming more and more popular in many countries, including Poland, due to the high nutritional value of its seeds, its resistance to diseases and pests, as well as lower propensity to lodging compared to other legumes. Under the climatic conditions of Poland, soybean yield is largely dependent on weather conditions in a particular growing season, primarily temperature and rainfall. Studies on the effect of tillage systems used for soybean cropping under the climatic conditions of Poland are scarce. This proves the need to continue such research. The aim of this study was to compare the effect of conventional tillage (CT) and no-tillage (NT) on yield, weed infestation and seed qualitative composition of the 'Mazowia' soybean cultivar grown under the conditions of the Lublin Upland. A field experiment was carried out in the period of 2009-2012 at the Czesławice Experimental Farm (51°18′23″N 22°16′2″E). In 2010 the soybean plantation was terminated due to adverse weather conditions and related inhibited plant emergence. The experiment was set up on loess-derived grey-brown podzolic soil as a split-block design in four replicates. The present study showed that the soybean seed yield obtained under conventional tillage conditions was higher by 14.6% compared to that obtained under no-tillage. A higher plant density after emergence and before harvest as well as a higher plant height were found in the conventional tillage treatment. The protein, oil and fibre content in soybean seed was significantly affected only by weather conditions in particular growing seasons. A higher weed weight and richer floristic composition of weeds were found under no-tillage conditions in relation to conventional tillage.

Keywords: *Glycine max* L., tillage systems, seed yield, weed infestation, chemical composition of seed

INTRODUCTION

Soybean is a plant with particularly high commercial values. Its seed contains about 40% of protein, 20% of oil, and valuable mineral nutrients, among others calcium, phosphorus, and potassium. It is also a plant that improves soil fertility and structure. It is possible to popularise soybean cultivation due to, among others, the breeding of cultivars adapted to specific climatic conditions and with a higher nutritional value and lower lodging propensity in comparison to other legumes (Abbasi Surki *et al.* 2010). Its high resistance to diseases and pests also makes an argument for growing soybean. Under the conditions of Poland, currently the above-mentioned agricultural pests do not pose a great threat to soybean. However, weed infestation is a factor that significantly reduces the productivity of this crop (Vollmann *et al.* 2010). Under our climatic conditions, soybean yield is largely dependent on weather conditions in a particular growing season, primarily temperature and rainfall. In areas with low levels of rainfall, it is very important to prepare the soil in a way that will ensure retention of the highest possible amount of rainwater. Agronomic practices involving the replacement of the plough with implements that do not turn the soil over or the complete abandonment of mechanical tillage (no-tillage) offer this possibility. As a result of the use of no-tillage, there are changes in soil density and compactness, while the moisture and nutrient content in the soil upper layers increase (Martinez *et al.* 2008). Obtaining frequently lower yields under no-tillage conditions does not necessarily mean lower profitability and does not need to make an argument for the abandonment of this tillage system. Higher labour productivity and lower energy inputs on direct drilling may compensate for losses arising from lower yields of this crop (Dzienia *et al.* 2006).

The aim of the present study was to compare the effect of conventional tillage (CT) and no-tillage (NT) on yield, weed infestation and seed qualitative elements composition of the 'Mazowia' soybean cultivar grown under the conditions of the Lublin Upland.

MATERIAL AND METHODS

A field study was carried out over the period of 2009-2012 at the Czesławice Experimental Farm (51°18′23″N 22°16′2″E), belonging to the University of Life Sciences in Lublin. In 2010 the soybean plantation was terminated due to adverse weather conditions and related inhibited plant emergence.

The experiment was set up on a loess-derived grey-brown podzolic soil as a split-block design in four replicates. The soil was characterised by slightly acidic pH (in 1 mole KCl = 6.2), high phosphorus and potassium availability, as well as medium magnesium availability. The humus content was 1.2%. The area of each experimental plot was 96 m^2. The 'Mazovia' soybean cultivar was grown in the experiment.

The study factors were the following tillage systems:

1. Conventional tillage (CT) – skimming, double harrowing, autumn ploughing to a depth of 25 cm. Spring: harrowing, cultivating, harrowing, sowing (plot seeder for direct sowing of 9 disc coulters, working width 180 cm).

2. No-tillage (NT) – without mechanical tillage. In the spring, only Roundup Energy 450 SL (active ingredient (a.i.) – glyphosate) was applied at a rate of 3 l ha^{-1}.

Mineral fertilisation was applied in whole in soybean crops before sowing at the following rates: N – 50 kg ha^{-1}, P – 35 kg ha^{-1}, K – 83 kg ha^{-1}. Mineral fertiliser rates were determined based on the nutritional requirements of soybean and soil nutrient availability.

Each year, soybean was sown at the turn of April and May in a field after winter wheat. The row spacing was 20 cm, seeding depth 3 cm, and planned plant density 100 plants per 1 m^2.

Before sowing, soybean seeds were inoculated with Bradyrhizobium japonicum bacteria (Nitragina vaccine – IUNG PIB Puławy) and the seed dressing Vitavax 200 FS (a.i. carboxin, thiuram) was applied at a rate of 400 ml/100 kg seed with water added at a 1:1 proportion. Immediately after sowing, a mixture of the herbicides Afalon Dyspersyjny 450 SC (a.i. linuron) + Dual Gold 960 EC (a.i. S-metolachlor) was applied at an amount of 1 l + 1.8 l ha^{-1}.

Each year, the soybean crop was harvested (plot combine harvester Wintersteiger) in the first 10-day period of September.

Plant density after emergence and before harvest was estimated in two rows along a length of 2.5 m. The yield traits were determined based on a sample consisting of 30 randomly selected plants from each plot. The seed yield was weighed separately for each plot (12 m^2) and the results obtained were expressed on a per hectare basis. Weed infestation of the soybean crop was determined using the dry-weight-rank method at the pod and seed maturation stage (BBCH 81/82), on all experimental treatments. The evaluation involved the determination of the botanical composition of weeds, their density and air-dry weight. The sampling area was delineated with a 1 m × 0.5 m rectangular frame in two randomly selected places in each plot.

The content of protein, oil and fibre in soybean seed was determined at the Department of Agricultural Ecology of the University of Life Sciences in Lublin on an Omega Analyzer G spectrophotometer, produced by Bruins Instruments, Germany.

The results obtained in the years 2009, 2011, and 2012 were statistically analysed by analysis of variance and the significance of differences was evaluated by Tukey's test at $\alpha = 0.05$. The statistical analysis was presented using Statgraphics 5.0 software.

In the first year of the study (2009), the average air temperature in individual months of the growing season was generally higher than the long-term mean (Fig. 1).

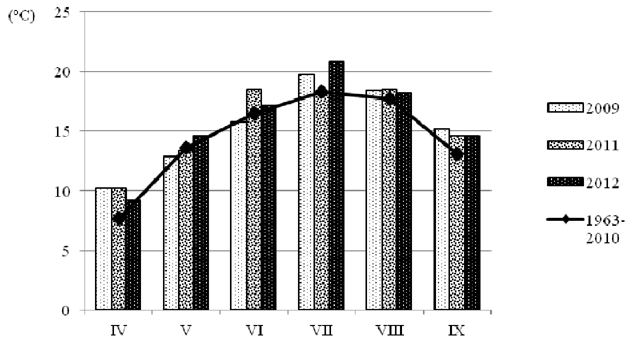

Fig. 1. Mean monthly air temperature (°C) at the Czesławice Meteorological Station in 2009-2012

The temperature values were lower only in May and June. The rainfall in 2009 exceeded the long-term mean only in May and June (Fig. 2). The year 2011 turned out to be favourable for soybean growth in terms of thermal conditions. In particular months of the growing season, higher or similar (May, July) temperatures were generally recorded, compared to the long-term mean. Lower than average rainfall was recorded during the initial period of soybean growth (April and May) as well as during maturation and harvest (August and September). The last year of the study (2012) was very warm and quite dry. A higher than average temperature was recorded in all the months. The total rainfall exceeded the long-term mean in June and July.

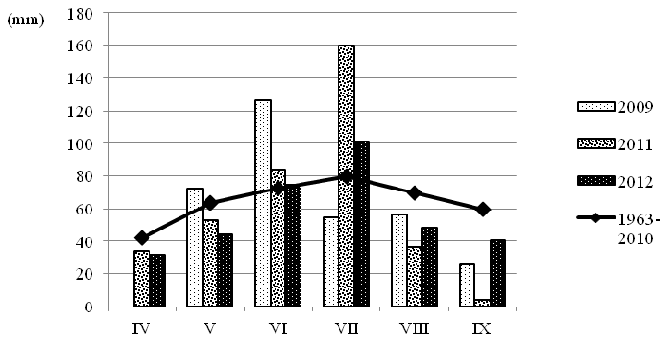

Fig. 2. Total rainfall and rainfall distribution (mm) at the Czesławice Meteorological Station in 2009-2012

RESULTS

On average for the three-year study, the tillage systems caused significant variations in soybean yield (Tab. 1). Under conventional tillage conditions, the soybean seed yield was higher by 14.6% compared to that obtained under no-tillage. Substantial differences were found in soybean productivity, depending on the tillage system, in particular in the first year of the study in which the use of no-tillage caused a decrease in yield by 0.97 t ha^{-1} in relation to conventional tillage. The year 2011, characterised by favourable thermal conditions throughout the entire growing season and a low level of rainfall during seed maturation, proved to be most favourable for soybean yield. Nevertheless, the differences in soybean yield throughout the experimental period were not statistically significant.

Table 1. Yield, plant density and selected characteristic of soybean morphological parameters

TS*	Years	Yield	Plant density		Plant height	First pod height
			after emergence	before harvest		
		(t ha^{-1})	(pcs. m^{-2})		(cm)	(cm)
CT	2009	2.99	51.0	45.8	91.3	9.9
	2011	2.58	99.3	95.3	91.5	10.2
	2012	2.44	44.8	39.5	76.7	8.0
	Mean	2.67	65.0	60.2	86.5	9.4
NT	2009	2.02	40.5	34.3	78.7	8.4
	2011	2.61	92.8	88.5	83.2	13.3
	2012	2.36	31.5	35.3	68.9	6.7
	Mean	2.33	54.9	52.7	76.9	9.5
Y	2009	2.51	45.8	40.1	85.0	9.2
	2011	2.60	96.1	91.9	87.4	11.8
	2012	2.40	38.2	37.4	72.8	7.4
$LSD_{(0.05)}$						
TS		0.184	6.26	5.36	6.58	NS
Y		NS	9.32	7.98	9.79	2.35
TS x Y		0.483	NS	NS	NS	4.14

*TS – Tillage system, CT – Conventional tillage, NT – No tillage, Y – years

As far as the soybean yield and yield components are concerned, the tillage systems used significantly modified only the plant density after emergence and before harvest as well as the plant height (Tab. 1). In the conventional tillage treatment, the average plant density after emergence and before harvest was higher by 18.4 and 14.2%, respectively, in relation to that found under direct drilling of soybean. Under plough tillage conditions, higher plants (by 12.5%) were also observed. The values of the above-mentioned yield components were the highest in the second year of the experiment (2011).

The tillage systems did not have any major effect on the first pod height, 1000 seed weight, number of seeds per pod, number of pods per plant, as well as on the number and weight of seeds per plant (Tabs 1, 2).

Table 2. Some of characteristic of soybean yield components and number and weight of weeds in soybean canopy

TS*	Years	Number of pods per plant	Number of seeds per pod	Number of seeds per plant	Weight of seeds per plant	Number of weeds	Weight of weeds	1000 seeds weight
		(pcs.)	(pcs.)	(pcs.)	(g)	(pcs. m^{-2})	(g m^{-2})	(g)
CT	2009	21.4	2.0	43.6	6.4	10.8	28.0	147.3
	2011	18.4	1.6	29.4	5.7	29.0	31.5	182.7
	2012	23.5	1.7	40.0	5.8	6.2	29.4	142.6
	Mean	21.1	1.8	37.7	6.0	15.3	29.6	157.5
NT	2009	24.1	2.1	50.3	7.5	21.0	86.1	148.5
	2011	13.7	1.5	20.5	3.8	31.5	75.4	185.5
	2012	32.7	1.8	58.7	8.2	12.5	63.0	136.5
	Mean	23.5	1.8	43.2	6.5	21.7	74.8	156.8
Y	2009	22.8	2.1	47.0	7.0	15.9	57.1	147.9
	2011	16.1	1.6	25.0	4.8	30.3	53.5	184.1
	2012	28.1	1.8	49.4	7.0	9.4	46.2	139.6
LSD(0.05)								
TS		NS	NS	NS	NS	NS	20.89	NS
Y		7.52	0.24	14.97	NS	16.88	NS	18.12
TS x Y		NS	NS	NS	NS	NS	NS	NS

*– Explanations as in Table 1

The experimental factor did not result in differences in the quality elements of soybean seed (Tab. 3). The percentage content of protein, oil and fibre in seed differed significantly depending on the year of the study. The weather conditions in the year 2011, characterised by high temperatures in all months of the growing season and low rainfall during soybean maturation (VIII-IX), promoted seed protein accumulation, but adversely affected the oil content. The highest oil and fibre content in soybean seed was found in the year 2012 which was characterised by high temperatures and moderate rainfall throughout the entire growing season of soybean.

On average for the three-year study period, the tillage systems were not found to significantly influence the number of weeds in the soybean crop (Tab. 2). However, an increasing trend in the value of this trait was observed under no-tillage conditions. The weather conditions in the particular growing seasons had a proven effect on the number of weeds. The highest number of weed individuals was found in the year 2011, characterised by high rainfall in June and July, while in June also by the highest air temperature throughout the study period.

The experimental factor caused significant differences in the air-dry weight of weeds per 1 m^2 of the soybean crop (Tab. 2). In the conventional tillage treatment, the weed weight was lower by as much as 60.4% compared to that found under no-tillage.

Table 3. Selected seed quality elements in seeds soybean

TS*	Years	Protein (%)	Fat (%)	Fibre (%)
CT	2009	34.6	17.4	5.0
	2011	36.8	16.2	4.9
	2012	30.7	18.4	5.4
	Mean	34.0	17.3	5.1
NT	2009	34.8	17.3	5.0
	2011	35.6	16.5	5.0
	2012	31.7	18.0	5.3
	Mean	34.0	17.3	5.1
Y	2009	34.7	17.4	5.0
	2011	36.2	16.4	5.0
	2012	31.2	18.2	5.4
$LSD_{(0.05)}$				
TS		NS	NS	NS
Y		0.52	0.28	0.06
TS x Y		0.92	0.50	0.11

*– Explanations as in Table 1

In all experimental treatments, Elymus repens was the dominant weed species (Tab. 4). Both under conventional tillage and no-tillage, the following annual weed species occurred in greatest numbers: Echinochloa crus-galli, Chenopodium album, and Galinsoga parviflora. The use of plough tillage reduced the numbers of most weeds, in particular Echinochloa crus-galli and Galinsoga parviflora, and eliminated from the soybean crop 8 weed species that occurred in the no-tilled plots.

DISCUSSION

The soybean is a plant very sensitive to environmental stresses such as low and high temperature or drought. In cold climate countries, low temperatures are the factor that determines the production of this crop (Vollmann *et al*. 2000, Ohnishi *et al*. 2010). In the present experiment, a higher soybean yield under no-tillage conditions, compared to conventional tillage, was obtained in the year 2011 which proved to be favourable for soybean growth, because it was characterised by low rainfall during the maturation period and favourable thermal conditions throughout the entire growing season. Likewise, according to De Vita *et al*. (2007), benefits arising from the use of no-tillage can be observed in warm years with lower rainfall. Those authors achieved better production effects under no-tillage relative to conventional tillage in years with an amount of rainfall below 300 mm. This was associated with higher water accumulation in the soil caused by lower evaporation and changes in soil water permeability in the absence of mechanical tillage (Martinez *et al*. 2008). The adverse weather conditions in 2009 had a negative effect on the yield of soybean grown under no-tillage. Compared to plough tillage, the seed yield was then lower by as much as 32.4%. Rainfall in the months of May and June was the yield-limiting factor in this growing season. Excessive rainfall at the initial growth stages of soybean disturbed the water and air relations and caused soil crusting and related uneven emergence. According to Włodek *et al*. (2012), under no-tillage conditions both an excess and a shortage of rainfall cause a decrease in crop yield.

Table 4. Density (pcs. m^{-2}) of weed species in soybean (mean of 3 years)

Species	Conventional tillage (CT)	No tillage (NT)
I. Short-term		
Amaranthus retroflexus L.	–	0.1
Capsella bursa-pastoris (L.) Medik.	0.1	0.3
Chenopodium album L.	2.0	2.1
Conyza canadensis (L.) Cronquist	–	0.5
Echinochloa crus-galli (L.) P. Beauv.	2.4	3.1
Galeopsis tetrahit L.	0.2	0.1
Galinsoga ciliata (Raf.) S. F. Blade	–	0.5
Galinsoga parviflora Cav.	1.0	2.7
Geranium pusillum Burm. f. ex L.	0.1	0.4
Gnaphalium uliginosum L.	–	0.4
Lamium amplexicaule L.	–	0.2
Poa annua L.	–	0.3
Polygonum lapathifolium L.	1.0	0.7
Senecio vulgaris L.	–	0.2
Solanum nigrum L. emend. Mill.	0.1	–
Stellaria media (L.) Vill.	–	0.4
Veronica arvensis L.	0.1	–
Viola arvensis Murray	0.5	0.8
Total of short-term weeds	7.5	12.8
II. Perennial		
Cirsium arvense (L.) Scop.	0.8	0.4
Elymus repens (L.) Gould	6.7	5.9
Equisetum arvense L.	0.3	0.9
Plantago major L.	–	0.2
Taraxacum officinale (L) F. H. Wigg.	–	1.5
Total of perennial weeds	7.8	8.9
Total number of species	13	21

In the experiment under discussion, on average for the study period, a higher soybean seed yield was obtained under conventional tillage conditions. Similar results were obtained in the studies by Bujak *et al*. (2004), Amini (2005), Monsefi *et al*. (2014), Rokosz and Podsiadło (2015), who found a significant decrease in yield under no-tillage, compared to conventional tillage. The research conducted by Gawęda *et al*. (2014) showed that also other soybean cultivars (‘Aldana’ and ‘Augusta’) grown under the same agronomic, climatic and soil conditions as the presented ‘Mazowia’ cultivar, respond negatively to no-tillage compared to conventional tillage. Korzeniowska and Stanisławska-Glubiak (2009) also observed a decrease in yields of legumes (faba bean and field pea) as a result of replacement of conventional tillage by direct drilling. Pikul *et al*. (2001) showed that any modifications in tillage for sowing soybean negatively affect its yield potential and yields can be lower even by a dozen or so percent. Opposite results were obtained by Houx *et al*. (2014) who proved a significant increase in soybean seed yield (by 4.8%) under no-tillage on loamy soil in relation to that obtained under conventional tillage conditions.

A decrease in crop yield under the no-tillage system can be associated, among others, with specific physicochemical soil properties. According to Pabin (2002), under no-tillage conditions only the upper part of the humus layer accumulates a larger amount of organic matter and some fertiliser nutrients (phosphorus and potassium), while topsoil acidification, the proportion of large diameter pores (above 30 mm), and water infiltration increase. Carter (2005) demonstrates that in no-tillage treatments the organic C content in the soil under soybean is higher only in the 0-10 cm layer, whereas the N content is lower in the entire layer investigated (0-60 cm) in comparison to conventional tillage. Studies of many authors reveal that deteriorating soil physical conditions, involving its excessive compaction, are a negative aspect of no-tillage (Carter 2005, Botta *et al*. 2007, Fernandez *et al*. 2007, López-Garrido *et al*. 2014). The results presented in this paper show a lower plant density of soybean under no-tillage conditions. It can therefore be presumed that the reason for this could have been the higher compaction of the upper soil layer, resulting in inhibited plant emergence and lower yields. A lower plant density under no-tillage conditions contributing to a significant reduction in yield was also observed by Ciesielska and Rzeźnicki (2007).

Under conventional tillage, higher soybean plants were found than under no-tillage. However, Monsefi *et al*. (2014) showed tillage system to have a significant effect on plant height only during the initial period of plant growth, whereas the soybean plant height before harvest was similar under no-tillage and conventional tillage.

In the present study, tillage system did not cause variations in the protein, oil and fibre content in soybean seed. The results of the research by Houx *et al*. (2014) also reveal that the use of no-tillage does not modify significantly the seed protein and oil content. However, Gao *et al*. (2009) obtained an increase in oil yield per hectare under no-tillage. In this study, the weather conditions had a proven effect on the protein, oil and fibre content in soybean seed. In the year 2011, characterised by low rainfall during soybean maturation (VIII-IX), the lowest seed oil content was obtained. The study on white mustard conducted by Paszkiewicz-Jasińska (2005) also found drought to have an adverse effect on seed oil accumulation.

Existing research demonstrates that weeds are a factor that strongly reduces soybean productivity (Norsworthy 2003, Vollmann *et al*. 2010). Gibson *et al*. (2005) report that in soybean and maize crops weeds are a greater problem than diseases, nematodes and insects. In the opinion of Singh and Jolly (2005), a decrease in seed yield of this crop under the influence of weed infestation can be as much as 58%. The study presented in this paper also reveals higher weed infestation and a lower soybean yield under no-tillage. When plough tillage was abandoned, the lower plant density and related impeded competitiveness of soybean against weed plants probably contributed to higher weed infestation of the soybean crop.

Blecharczyk *et al*. (2010) observed a similar number of weed species in a field pea crop under no-tillage and conventional tillage systems. Contrary to this, in the study presented in this paper no-tillage was characterised by much richer floristic composition of weeds.

CONCLUSIONS

1. Under conventional tillage (CT) conditions, the soybean seed yield was higher by 14.6% compared to that obtained under no-tillage (NT).

2. A higher plant density after emergence and before harvest as well as a higher plant height, by 18.4, 14.2 and 12.5%, respectively, were found in the conventional tillage treatment in comparison to no-tillage.

3. The tillage system did not cause variations in the protein, oil and fibre content in soybean seed.

4. The weather conditions in the year 2011, characterised by high temperatures in all months of the growing season and low rainfall during soybean maturation (VIII-IX), promoted seed protein accumulation, but adversely affected the oil content in relation to the other experimental years.

5. On average for the three-year study, an insignificant, statistically unproven, increase in the number of weeds was found in the soybean crop under no-tillage.

6. In the conventional tillage treatment, the weed weight was significantly lower, by as much as 60.4%, compared to that found under no-tillage.

7. In the non-tilled plots, the study found richer floristic composition of weeds and an increase in the numbers of most of the weeds.

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WPŁYW SYSTEMÓW UPRAWY ROLI NA PLONOWANIE, ZACHWASZCZENIE I ELEMENTY JAKOŚCIOWE NASION SOI

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S t r e s z c z e n i e. Uprawa soi w wielu krajach, jak i w Polsce staje się coraz bardziej popularna ze względu na dużą wartość odżywczą nasion, odporność na choroby i szkodniki oraz mniejszą skłonność do wylegania w porównaniu z innymi roślinami strączkowymi. Plonowanie soi w warunkach klimatycznych Polski jest w dużym stopniu uzależnione od przebiegu warunków pogodowych w danym sezonie wegetacyjnym, głównie temperatury i opadów. Badania dotyczące wpływu sposobu uprawy roli pod soję prowadzone w warunkach klimatycznych Polski są nieliczne. Świadczy to o potrzebie dalszej ich kontynuacji. Celem niniejszej pracy było porównanie wpływu konwencjonalnej uprawy roli (CT) oraz siewu bezpośredniego (NT) na plonowanie, zachwaszczenie i skład jakościowy nasion soi odmiana Mazowia, uprawianej w warunkach Wyżyny Lubelskiej. Badania polowe przeprowadzono w latach 2009-2012 w Gospodarstwie Doświadczalnym Czesławice

(51°18′23″N 22°16′2″E). W 2010 roku ze względu na niesprzyjające warunki atmosferyczne i wynikające z nich utrudnione wschody plantację soi zlikwidowano. Eksperyment założono na glebie płowej wytworzonej z lessu, metodą split-block w czterech powtórzeniach. Przeprowadzone badania wykazały, że w warunkach uprawy płużnej (CT) plon nasion soi był wyższy o 14.6% w porównaniu do uzyskanego w siewie bezpośrednim (NT). Na obiekcie z uprawą płużną (CT) stwierdzono również większą obsadę roślin po wschodach i przed zbiorem oraz wysokość roślin. Na zawartości białka, tłuszczu i włókna w nasionach soi wpływał istotnie jedynie przebieg warunków pogodowych w poszczególnych sezonach wegetacyjnych. W warunkach siewu bezpośredniego soi (NT) stwierdzono znacznie większą masę chwastów oraz bogatszy skład florystyczny chwastów w porównaniu do uprawy tradycyjnej (CT).

Słowa kluczowe: *Glycine max* L., systemy uprawy roli, plon nasion, zachwaszczenie, skład chemiczny nasion