ACTA SCIENTIARUM POLONORUM *Acta Sci. Pol., Agricultura 11(3) 2012, 17-29*

EFFECT OF TILLAGE SYSTEMS AND STRAW FERTILIZATION ON THE GRAIN YIELD AND SELECTED INDICATORS OF CEREALS AND PHYSICAL PROPERTIES OF SOIL*

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Abstract. The research has aimed at determining the influence of applying different systems of presowing tillage and fertilization with straw on the grain yield of cereals in crop rotation, selected indices of canopy architecture: leaf area index (LAI) and mean tip angle (MTA), weight of 1000 grains (WTG) and physical properties of soil. There have been presented the results of field experiments carried out in the years 2000-2002 on the fields of the Experimental Station IUNG in Jelcz-Laskowice on grey-brown podzolic soil formed from loamy sand. The highest yields of the studied cereals were obtained in traditional tillage without fertilization with straw. Leaving straw in form of chaff on the field caused decrease in cereal yields in all the research years. No significant influence of tillage was proved on the weight of 1000 cereal grains. Different tillage systems and fertilization with straw had a significant impact on leaf area index (LAI) in oats and mean tip angle (MTA) of winter wheat. That trait appeared to have been only slightly differentiated by the method of straw fertilization. Mean soil humidity over the research period was highest on the plot with zero-tillage and lowest on that with traditional one. Tested tillage techniques and the methods of fertilization with straw were not found to have exerted any significant influence on the soil density. The mean soil compactness was lowest in traditional tillage, and increased along with progressing shallowness of the arable soil layer.

Key words: leaf area index, mean tip angle, penetrometer, reduced tillage, soil density, zero-tillage

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* The study was carried out as part of task 2.4 in the long-term program of IUNG-PIB

INTRODUCTION

Organizational and economical considerations as well as protection of soil and environment require reduction of the traditional tillage system (plough tillage) in favour of zero-tillage system [Kordas 2008]. Decrease in the costs on tillage may cause increase in the profitability of plant production. Reduction in the costs may be obtained through decrease in the depth of tillage or reduction in the number of tillage treatments, up to their complete elimination, as in the case of direct seeding [Roszak *et al*. 1991]. Economical result in tillage is emphasized even more visibly in case of leaving straw on the field after harvesting in the form of chaff [Dzienia *et al*. 1995].

Modern measurement techniques, including the LAI-2000 analyzer, allow for quick and nondestructive measurements of the leaf area index (LAI) and mean tip angle (MTA) of leaves. Mentioned indices define changes occurring in a canopy in a broader way, and allow to determine plant yield in advance [Igras and Kubsik 1999, Czerednik and Nalborczyk 2000, Faber 2000].

According to many authors [Baranowski *et al*. 1988, Dzienia *et al*. 1988, Nowicki and Marks 1994], application of different tillage systems, as well as variants of fertilization with straw, significantly affects the yield structure and physical properties of soil, which in turn may affect plant yield.

The aim of the research was determination of the effect of using different systems of pre- sowing tillage and fertilization with straw on the yield of oat, winter wheat and winter triticale cultivated after one another in crop rotation, on chosen indices of canopy architecture (LAI, MTA), 1000-grain weight (WTG) as well as on physical properties of soil.

MATERIAL AND METHODS

Two-factorial tillage experiments were carried out in the years 2000-2002 on the fields of the Experimental Station of IUNG – PIB in Jelcz-Laskowice (51°1' N; 17°21' E), on grey-brown podzolic soil, formed from sandy loam. The experimental factors included:

I – tillage systems: traditional tillage (UT), based on ploughing with mouldboard plough to the depth of 25-30 cm; reduced tillage (UU) – zero-tillage, consisting in superficial loosening of soil with the use of disk harrow or cultivator to the depth of 10-15 cm; zero-tillage (UZ) – without mechanical tillage treatments with herbicide weed control;

II – fertilization with straw: (1) without straw, (2) straw left on the field in the form of chaff at a rate of 0.4 kg per 1m^2.

In particular years of research cultivation included: oat – cv. Jawor, winter wheat – cv. Elena and winter triticale – cv. Pronto.

The experiment was set up in four replications, with the total area of plots being 360 m^2. The forecrop of oat was maize. Mineral fertilization was applied according to the standard technology for particular plant species. Seeding and plant cultivation was conducted according to the technology practiced at the Experimental Station of IUNG – PIB while keeping optimum agrotechnical dates [Mazurek 1994, Pawłowska 1994, Podolska and Pawłowska 1996]. Harvesting was carried out with a combine harvester at the stage of full ripeness of the grain.

Weight of one thousand grains was determined according to the standard PN-68/R--74017. The leaf area index (LAI) and mean tip angle (MTA) were determined while taking measurements with LAI-2000 analyzer (LI-COR, USA) at the stage of the beginning of ear formation. Measurements were taken between 6 and 7 a.m. In order to determine soil moisture and density in spring, samples were taken with the use of cylinders of volume 100 cm^3 from layers 0-5, 10-15 and 25-30 cm after the start of vegetation. Penetrometer resistance (density) in the layer 0-30 cm was determined with an Eijkelkamp penetrometer. All determinations were carried out in four replications.

The results were subjected to statistical evaluation with the use of analysis of variance for two-factorial experiments.

The weather conditions in the years of research were diverse (Table 1). The warmest growing period for plants was the year 2000, in which average temperatures were higher not only compared with the research period, but also with the long-term period. It was particularly visible in spring and at the beginning of summer. Rainfall deficiency occurred in April (only 48% of the mean from the long-term period) and in June (53% of the mean from the long-term period). Growing period of winter wheat was characterized by a favorable distribution of temperature, especially at the initial stage of growing, i.e. in autumn 2000, although moisture conditions in this period were not favorable. Only in November there occurred abundant rainfall, which along with the warmth occurring in that month, improved the state of the plants' vegetation. Further development stage of winter wheat in the growing period 2001 continued under favorable weather conditions, similar to the means in the long-term period. In the third year of research (2002), both the mean temperatures and the rainfall totals had mean values compared with the two previous years. Spring was characterized by a large amount of rainfall, as well as by high temperatures. The month with the highest rainfall was May and August. Such weather conditions were not very favourable for the growth of winter triticale.

RESULTS AND DISCUSSION

Application of a diversified soil tillage significantly affected the quantity of grain yield of the studied species in the first and third year of plants' vegetation (Table 2). The highest grain yield was obtained on plots with traditional tillage without fertilization with straw. Leaving the straw on the field caused decrease in the yield in all years of research. Positive effect in the crop yields, as a result of the lack of simplifications in tillage, was also confirmed by other authors [Ronai 1988, Chamen *et al*. 1992a, b, Reeves *et al*. 1992].

No significant effect of the applied tillage systems was proved on the weight of 1000 cereal grains (Table 3). The method of straw management also only to a lower degree changed this trait. A significant effect of fertilization with straw was proved only in the second year of research.

Leaf area index (LAI) was significantly diversified only in oat (Table 4). The highest LAI was characteristic of oat sown on plots with traditional tillage with straw fertilization (4.93), while the lowest index values were obtained when using zero-tillage and leaving the straw on the field in the form of chaff (3.30).

Table 1. Monthly and yearly mean of air temperature and monthly and yearly sum of precipitation in Jelcz-Laskowice compared with the long-term means 1961-2000

Tabela 1. Średnia miesięczna i roczna temperatura powietrza oraz miesięczne i roczne sumy opadów w Jelczu-Laskowicach na tle średnich wieloletnich 1961-2000

Factor Czynnik*		Month – Miesiąc												Yearly value Wartość roczna
		January styczeń	February luty	March marzec	April kwiecień	May maj	June czerwiec	July lipiec	August sierpień	September wrzesień	October październik	November listopad	December grudzień	
2000														
T		-1.0	3.3	4.7	11.8	15.6	18.1	16.7	18.5	12.8	12.1	6.5	2.0	10.1
O		34.6	33.5	76.9	17.8	76.5	38.1	165.8	45.4	17.3	10.9	47.9	34.8	599.5
2001														
T		0.0	0.9	3.2	7.7	14.8	15.1	19.2	19.4	12.5	12.1	3.4	-2.2	8.9
O		20.7	18.1	60.3	40.9	68.8	71.0	140.8	46.7	79.2	22.5	33.2	31.4	633.6
2002														
T		-0.2	4.3	5.0	8.3	17.2	18.1	20.5	20.4	13.0	7.7	4.8	-4.2	9.6
O		24.0	58.2	15.9	44.5	78.8	53.7	38.2	85.5	32.7	63.3	47.5	19.7	562.0
mean średnia 1961-2000	T	-1.5	-0.3	3.3	8.2	13.4	16.6	18.1	17.6	13.5	8.8	3.7	0.2	8.5
	O	27.9	25.2	31.6	36.9	63.8	71.5	75.4	70.6	47.8	36.9	41.1	35.1	563.7

* T – temperature – temperatura, O – rainfall – opady

Table 2. Grain yield, Mg·ha^{-1}
Tabela 2. Plon ziarna, Mg·ha^{-1}

Tillage system Sposób uprawy gleby	Oat – Owies			Winter wheat – Pszenica ozima			Winter triticale – Pszenżyto ozime		
	2000			2001			2002		
	without straw bez słomy	straw in the form of chaff – słoma w postaci sieczki	mean średnia	without straw bez słomy	straw in the form of chaff – słoma w postaci sieczki	mean średnia	without straw bez słomy	straw in the form of chaff – słoma w postaci sieczki	mean średnia
Traditional tillage Uprawa tradycyjna	2.85	2.65	2.75	8.49	6.99	7.74	4.11	3.37	3.74
Simplified tillage Uprawa uproszczona	2.72	2.59	2.66	7.00	7.71	7.36	3.17	3.15	3.16
Zero-tillage Uprawa zerowa	2.68	2.32	2.50	7.98	7.07	7.52	3.26	3.03	3.15
Mean – Średnia	2.75	2.52	2.64	7.82	7.26	7.54	3.51	3.18	3.35
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla:									
tillage system – sposobów uprawy		0.162			ns – ni			0.243	
fertilization with straw – nawożenia słomą		0.109			0.311			0.163	
interaction – współdziałania		0.145			0.414			0.218	

ns – ni – non-significant differences – różnice nieistotne

Table 3. Weight of 1000 cereal grains in 2000-2002, g
Tabela 3. Masa 1000 ziaren zbóż w latach 2000-2002, g

Tillage system Sposób uprawy gleby	Oat – Owies			Winter wheat – Pszenica ozima			Winter triticale – Pszenżyto ozime		
	2000			2001			2002		
	without straw bez słomy	straw in the form of chaff – słoma w postaci sieczki	mean średnia	without straw bez słomy	straw in the form of chaff – słoma w postaci sieczki	mean średnia	without straw bez słomy	straw in the form of chaff – słoma w postaci sieczki	mean średnia
Traditional tillage Uprawa tradycyjna	34.4	33.3	33.9	44.9	46.3	45.6	38.2	36.5	37.4
Simplified tillage Uprawa uproszczona	33.7	34.1	33.9	46.2	46.9	46.6	37.7	35.2	36.5
Zero-tillage Uprawa zerowa	33.1	33.9	33.5	45.6	46.9	46.3	36.1	37.6	36.9
Mean – Średnia	33.7	33.8	33.8	45.6	46.7	46.1	37.3	36.4	36.9
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla:									
tillage system – sposobów uprawy		ns – ni			ns – ni			ns – ni	
fertilization with straw – nawożenia słomą		ns – ni			0.94			ns – ni	
interaction – współdziałania		ns – ni			ns – ni			ns – ni	

ns – ni – non-significant differences – różnice nieistotne

Table 4. Leaf area index (LAI) of cereals in 2000-2002
Tabela 4. Wskaźnik powierzchni liści (LAI) zbóż w latach 2000-2002

Tillage system Sposób uprawy gleby	Oat – Owies			Winter wheat – Pszenica ozima			Winter triticale – Pszenżyto ozime		
	2000			2001			2002		
	without straw bez słomy	straw in the form of chaff – słoma w postaci sieczki	mean średnia	without straw bez słomy	straw in the form of chaff – słoma w postaci sieczki	mean średnia	without straw bez słomy	straw in the form of chaff – słoma w postaci sieczki	mean średnia
Traditional tillage Uprawa tradycyjna	4.93	4.50	4.72	2.81	3.12	2.97	2.26	2.24	2.25
Simplified tillage Uprawa uproszczona	4.45	4.20	4.33	2.76	3.80	3.28	2.06	1.97	2.02
Zero-tillage Uprawa zerowa	3.55	3.30	3.43	3.35	2.50	2.93	1.62	1.98	1.80
Mean – Średnia	4.31	4.00	4.16	2.97	3.14	3.06	1.98	2.06	2.02
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla:									
tillage system – sposobów uprawy		0.433			ns – ni			ns – ni	
fertilization with straw – nawożenia słomą		0.258			ns – ni			ns – ni	
interaction – współdziałania		ns – ni			ns – ni			ns – ni	

ns – ni – non-significant differences – różnice nieistotne

Leaf area index defines plant's ability to absorb PAR, on which photosynthesis depends, and indirectly the increase in the biomass [Lepiarczyk *et al*. 2005]. This index may now be easily determined with a nondestructive method, and used for monitoring crop condition, predicting the grain yield and soil moisture as well as plants' productivity and agricultural yield [Czerednik and Nalborczyk 2000]. However, with the too high values of LAI, the light conditions and CO_2 supply deteriorate, while susceptibility to lodging and to attacks of diseases or pests increases. The effect of the tip angle of leaves on absorbing radiation constitutes a determinant of the course of photosynthesis in the canopy. According to Czerednik and Nalborczyk [2000], the optimum LAI for cereal plants at the stage of earing should be about 4. In author's research, values higher than 4 were obtained for oat, while wheat and winter triticale had lower values.

No significant effect of the tillage system and straw management was observed on the mean tip angle (MTA) of leaves in oat and triticale (Table 5). Significant values of this trait for both factors were proved in the second year of research with the cultivation of winter wheat. Large tip angle of leaves was characteristic of winter wheat growing on plots with traditional tillage, fertilized with straw which was left on the field. It should be emphasized that plants with a large tip angle of leaves were characterized by a lower yield.

A significant diversity in physical properties of soil was observed depending on the used tillage system (Table 6). Mean soil moisture in the period of research was highest on the plot with zero-tillage, and the lowest under conditions of traditional tillage. Among many authors, both national and foreign, opinions on the effect of tillage on soil moisture are diverse. Malicki and Podstawka-Chmielewska [1999], Rasmussen [1999] as well as Mcgarry *et al*. [2000], think that using simplifications in tillage has a favorable effect on accumulation of water in the soil, while results obtained by Flowers and Lal [1999] as well as by Lal and Ahmadi [2000] confirm lack of differences in soil moisture.

Mean density of soil was lowest in traditional tillage (5.0 MPa), and increased along with simplifications in the tillage. Leaving straw on the field significantly increased soil density, when compared with the plot where straw was collected from the field. Similar dependences were obtained by Pabin *et al*. [2000], Vegas and Choudhary [2002] as well as Weber [2004].

Tested tillage techniques as well as methods of fertilization with straw had no significant effect on the condition of soil density. Different results were obtained by Vegas and Choudhary [2002] as well as by Weber [2004], who proved that along with the increase in tillage simplifications, soil density increased as well.

Table 5. Mean tip angle (MTA) of cereals in 2000-2002
Tabela 5. Średni kąt nachylenia liści (MTA) zbóż w latach 2000-2002

Tillage system Sposób uprawy gleby	Oat – Owies			Winter wheat – Pszenica ozima			Winter triticale – Pszenżyto ozime		
	2000			2001			2002		
	without straw bez słomy	straw in the form of chaff – słoma w postaci sieczki	mean średnia	without straw bez słomy	straw in the form of chaff – słoma w postaci sieczki	mean średnia	without straw bez słomy	straw in the form of chaff – słoma w postaci sieczki	mean średnia
Traditional tillage Uprawa tradycyjna	58	60	59	60	62	61	57	58	58
Simplified tillage Uprawa uproszczona	60	61	61	54	58	56	55	60	58
Zero-tillage Uprawa zerowa	57	61	59	55	59	57	52	55	54
Mean – Średnia	58	61	60	56	60	58	55	58	57
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla:									
tillage system – sposobów uprawy		ns – ni			4.8			ns – ni	
fertilization with straw – nawożenia słomą		ns – ni			2.9			ns – ni	
interaction – współdziałania		ns – ni			ns – ni			ns – ni	

ns – ni – non-significant differences – różnice nieistotne

Table 6. Mean soil moisture, bulk density and penetration resistance in the layer 0-30 cm in 2000-2002
Tabela 6. Średnia wilgotność, gęstość i zwięzłość gleby w warstwie 0-30 cm za okres 2000-2002

Tillage system Sposób uprawy gleby	Current soil moisture – Wilgotność aktualna gleby, % s.m.			Bulk density of soil – Gęstość gleby $g \cdot cm^{-3}$			Soil density – Zwięzłość gleby MPa		
	without straw bez słomy	straw in the form of chaff – słoma w postaci sieczki	mean średnia	without straw bez słomy	straw in the form of chaff – słoma w postaci sieczki	mean średnia	without straw bez słomy	straw in the form of chaff – słoma w postaci sieczki	mean średnia
Traditional tillage Uprawa tradycyjna	6.5	6.9	6.7	1.66	1.63	1.65	4.9	5.2	5.0
Simplified tillage Uprawa uproszczona	6.9	7.1	7.0	1.63	1.64	1.64	5.9	6.2	6.0
Zero-tillage Uprawa zerowa	7.3	7.8	7.6	1.64	1.67	1.66	6.7	6.9	6.8
Mean – Średnia	6.9	7.3	7.1	1.64	1.65	1.65	5.8	6.1	6.0
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla:									
tillage system – sposobów uprawy		0.64			ns – ni			0.24	
fertilization with straw – nawożenia słomą		ns – ni			ns – ni			0.14	
interaction – współdziałania		ns – ni			ns – ni			ns – ni	

ns – ni – non-significant differences – różnice nieistotne

CONCLUSIONS

1. The quantity of grain yield of studied cereal species depended on the used tillage systems and weather conditions in the period of plants' vegetation. The yield-forming effect of fertilization with straw was negative for most analyzed variants.

2. No significant effect of the used tillage simplifications was observed on the weight of 1000 grains of oat, winter wheat and winter triticale. Fertilization with straw significantly diversified the weight of 1000 grains only for winter wheat, and it was higher on plots with reduced tillage and zero-tillage.

3. Diverse tillage systems and fertilization with straw significantly affected the leaf area index (LAI) in oat and mean tip angle (MTA) in winter wheat. Higher LAI was observed in traditional tillage without fertilization with straw, while the leaf tip angle was greater on plots with straw.

4. Using simplifications in tillage caused a significant increase in the mean moisture and density of soil, however it did not significantly diversify the bulk density of soil.

5. Leaving straw in the form of chaff on the field (zero-tillage), relatively mixed with the surface layer of the soil (reduced tillage), did not prevent negative changes in the physical condition of soil.

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WPŁYW SPOSOBÓW UPRAWY ROLI I NAWOŻENIA SŁOMĄ NA PLON ZIARNA I WYBRANYCH WSKAŹNIKÓW ROŚLIN ZBÓŻ ORAZ WŁAŚCIWOŚCI FIZYCZNE GLEBY

Streszczenie. Celem badań było określenie wpływu stosowania różnych sposobów przedsiewnej uprawy roli i nawożenia słomą na plon ziarna zbóż w zmianowaniu,

wybrane wskaźniki architektury łanu: wskaźnik powierzchni liści (LAI) i kąt ich nachylenia (MTA), MTZ oraz właściwości fizyczne gleby. W pracy przedstawiono wyniki badań polowych przeprowadzonych w latach 2000-2002 na polach Stacji Doświadczalnej IUNG w Jelczu-Laskowicach na glebie płowej wytworzonej z piasku gliniastego mocnego. Najwyższe plony badanych gatunków zbóż uzyskano po zastosowaniu uprawy tradycyjnej w wariancie bez nawożenia słomą. Pozostawienie słomy w postaci sieczki na polu powodowało obniżkę plonów zbóż we wszystkich latach badań. Nie wykazano istotnego wpływu uprawy roli na masę 1000 ziaren zbóż. Zróżnicowane systemy uprawy roli oraz nawożenie słomą wpływały istotnie na wskaźnik powierzchni liści (LAI) u owsa i ustawienia liści (MTA) pszenicy ozimej. Sposób nawożenia słomą również w niewielkim stopniu różnicował tę cechę. Średnia wilgotność gleby w okresie badań była najwyższa w obiekcie z uprawą zerową, a najmniejsza w uprawie tradycyjnej. Testowane techniki uprawy roli oraz sposoby nawożenia słomą nie miały istotnego wpływu na stan gęstości gleby. Średnia zwięzłość gleby była najmniejsza w uprawie tradycyjnej i zwiększała się wraz ze spłycaniem warstwy ornej gleby.

Słowa kluczowe: kąt nachylenia liści, penetrometr, uprawa uproszczona, uprawa zerowa, wskaźnik powierzchni liści, zwięzłość gleby

Accepted for print – Zaakceptowano do druku: 13.08.2012