Int. Agrophysics, 2006, 20, 141-146

INTERNATIONAL
Agrophysics
www.ipan.lublin.pl/int-agrophysics

Maize response to different straw management and tillage systems under cereal crop rotation

J. Pabin[1], *J. Lipiec*[2]*, *S. Włodek*[1], *and A. Biskupski*[1]

[1]Institute of Soil Science and Plant Cultivation, 55-230 Jelcz-Laskowice, Poland
[2]Institute of Agrophysics, Polish Academy of Sciences, Doświadczalna 4, P.O. Box 201, 20-290 Lublin, Poland

Received July 24, 2005; accepted August 22, 2005

A b s t r a c t . The aim of this study was to determine the effect of various straw management and tillage systems on the emergence, grain yield and cob characteristics of maize (*Zea mays* L.) under different cereal rotations on two soils (Orthic Luvisols) of loamy sand and sandy loam textures. The study was conducted in 1999, 2002 and 2003 in a micro-plot (1x1 m) experiment. Concrete walls, 120 cm deep, separated each plot of 1x1 m (five replicates). Straw management systems included: removed straw (RS) and left straw (LS) in the amount of annual straw yield. The retained straw was chopped and spread by hand. Under each straw management system the three following tillage systems were applied: conventional tillage (CT), reduced tillage (RT), no-tillage (NT) with sowing to the uncultivated soil and chemical weed control. Each treatment had five replicates giving a total of sixty micro-plots. The preceding crops of maize were rye, winter wheat or maize, depending on the soil and year. The same maize varieties were used in both soils (Antares in 1999-2000 and Matilda in 2003). There was a tendency towards poorer maize emergence in plots with retained straw compared to removed straw under no-tillage system compared to conventionally tilled system in both soils. The results indicated that the reduced tillage systems in combination with chopped straw can be applied on the studied soils without any significant decrease in maize grain yield.

K e y w o r d s: straw management, tillage systems, maize yield, cereal rotation

INTRODUCTION

The high economic importance of maize and the availability of new hybrids more and more adapted to soil and climate conditions result in increasing sown area of the crop in Poland (GUS, 2002). Growth requirements of maize in respect to soil type are not very stiff but the most favourable growth takes place on fertile, well-drained soils with high water holding capacity.

Preceding crops of maize are often cereals which dominate in crop rotation of many countries of the world, including Poland (FAOSTAT, 2004). As a result, a problem of straw surplus appears, especially in areas without animals. Proper straw management only can resolve this and for this reason crop residue management practices have been included in farm plans in many countries (Børresen, 1999; Karlen *et al.*, 1994).

It was shown that retaining or adding crop residue can improve several soil biological, chemical, and physical characteristics (Ferrero *et al.*, 2005; Karlen *et al.*, 1994), affect the quantity of rainwater entering the soil and evaporation (Pabin *et al.*, 2003), promote soil stability, and reduce soil erosion and runoff (Karlen *et al.*, 1994; Sharratt *et al.*, 1996). On the other hand, straw residues in the proximity of the seed may present a physical barrier to moisture uptake under dry conditions, or it may aggravate problems of anaerobism (such as the accumulation of phytotoxins) under wet conditions (Riley *et al.*, 1994; Szymankiewicz, 1995).

Straw effects on plant growth are related with tillage system, crop rotation and soil type. Many researchers have reported that a reduction in tillage intensity leads to reduced production costs and to increased soil organic matter (SOM) and to accumulation of crop residue (Lal *et al.*, 1994; Reicosky *et al.*, 1995). Moreover, those tillage practices lead to improved aggregation (Pranagal *et al.*, 2004) and to greater macroporosity (Karlen *et al.*, 1994; Mc Garry *et al.*, 2000) and amount of continuous and interconnected pores (Mc Garry *et al.*, 2000; Wiermann and Horn, 2000). Long-term use of reduced tillage can be favourable from the

*Corresponding author's e-mail: lipiec@demeter.ipan.lublin.pl

point of view of environmental protection (Lipiec and Stępniewski, 1995; Tebrügge and Düring, 1999).

Therefore, combining retaining of straw and reduced tillage results in more sustainable agricultural production practices (Børresen, 1999; Karlen *et al.*, 1994). Reduced labour and machinery costs are economic considerations that are frequently given as additional reasons to use crop residue management practices (Hernanz *et al.*, 1995; Malicki *et al.*, 1997). Some studies conducted in Poland on fine-textured soils (Malicki *et al.*, 1997) have shown that reduced tillage can produce crop yields comparable to those obtained under conventional tillage (using mouldboard plough) at lower production costs and with greater production efficiency.

Despite the practicability of conservation tillage systems, their acceptance by farmers remains low. One main reason is the difficulty in management of high residue rates (Børresen , 1999; Ehlers and Claupein, 1994). Some studies showed, however, that when straw remains as a surface residue or is shallowly incorporated (5 to 7 cm depth), crop establishment and early growth can be severely affected. This may lead to depressed yield compared to ploughing straw down (26-30 cm). However, chopped straw in combination with reduced tillage did not cause significant reduction of crop yields under a temperate climate in Norway (Børresen, 1999).

Crop responses to straw management and reduced tillage can be considerably affected by soil type. Riley (quoted by Børresen, 1999) found similar results for spring cereals on silt and silty clay, but not on morainic loams in Norway. Most studies were conducted on fine textured soils and much less on sandy soils of weak structure and low water holding capacity. Some studies indicated, however, that reduced tillage systems with maize can be used on sandy soils owing to the deep root system and efficient water use by the crop (Borowiecki *et al.*, 1998; Machul, 2003). In addition, the sandy soils can be preferable since they warm up faster in the spring and thereby may have a positive effect under short-season conditions.

Therefore, the aim of this study was to determine the effect of retained chopped straw and reduced tillage on grain yield of maize following cereals on two sandy soils.

MATERIALS AND METHODS

Soil characteristics

The micro-plot experiments were conducted at the research station of the Institute of Soil Science and Plant Cultivation at Laskowice on two soils (Orthic Luvisols), in 1999, 2002 and 2003. Concrete walls to 120 cm depth separated the micro-plots of 1x1 m. Both soils are developed from sandy material but have somewhat different textures. They will be further denoted as loamy sand and sandy loam. Some characteristics of the soils are given in Table 1. The nutrient contents were similar in the upper layer in both soils, and in the deeper layer they were lower in the sandy loam.

Experimental design and treatments

The straw management treatments were as follows: removed (RS) and left straw (LS), in the amounts of annual straw yields. The yields were 0.65, 0.45 and 0.5 kg m^{-2} in 1999; 2002 and 2003, respectively. The retained straw was chopped into pieces approximately 1 cm long and uniformly spread by hand on the surface of the soil. Under each straw management system, the following three tillage systems were applied: conventional tillage (CT) including stubble cultivator (10 cm) + harrowing (3-5 cm) and ploug- hing (25 cm); reduced tillage (RT) with harrowing (3-5 cm); no-tillage (NT) with sowing to the uncultivated soil and chemical weed control using Roundup (5 l ha^{-1}). Hand implements were used to simulate all the tillage operations as much as possible. Using such implements allowed avoiding soil compaction by traffic. The experimental design used randomised blocks with five replicates of micro-plots (1x1 m). The experiments included 60 micro-plots in total.

T a b l e 1. Texture and chemical properties of the soils investigated

Layer (cm)	Particle size distribution (%, dia in mm)			pH in KCl	Content (mg 100 g^{-1} soil)		
	1-0.1	0.1-0.02	<0. 02		P*	K*	Mg
				Loamy sand			
0-30	74	19	7	5.5	4.8	9.0	n.d.
30-60	58	26	16	4.8	4.2	10.0	10.2
				Sandy loam			
0-30	57	24	19	5.8	4.4	10.4	n.d.
30-60	50	44	26	6.9	1.7	7.3	6.3

*According to Egner-Riehm, n.d. - not determined.

The preceding crop was rye (*Secale cereale* L.) in 1999 and 2002 and maize (*Zea mays* L.) in 2003 on the sandy loam, with winter wheat (*Triticum aestivum* L.) in 1999 and 2002 and maize in 2003 on the medium textured soil. Crop rotation before the experiment was as follows: winter rye (1995), maize (1996), oats (*Avena sativa* L.) (1997), winter rye (1998) on the loamy sand and winter wheat (1995), maize (1996), oats (1997) and winter wheat (1998).

Maize was fertilized with 60 kg N ha^{-1}, half of that in autumn and another half in spring before sowing, 80 kg N ha^{-1} after sowing, half in mid of May and another half in mid June, and 30.6 kg P ha^{-1} and 124.5 kg K ha^{-1} in spring before sowing. All plots were fertilized with magnesium lime equivalent to 920 kg of Ca and 399 kg Mg ha^{-1}. The liming was repeated in 2000 applying 1073 kg Ca and 465 kg Mg ha^{-1}. The same maize varieties were used in both soils, sowing 9 seeds with one seed in one point. The varieties used were Antares in 1999 and 2000 and Matilda in 2003. Plant density at emergence growth phase was recorded in all the years and, additionally, the length and diameter of cobs in 2003. Statistical analysis was determined with Tukey's test.

The experimental years (1999, 2002, 2003) were characterized by scarce and uneven distribution of rainfalls during the growing season. The period of vegetative growth between germination and flowering (May – mid July) was characterized by certain excess of precipitation, whereas during generative growth since flowering (mid July – mid August) a shortage of rainfalls was observed in all the years. Air temperature was favourable in all the growing seasons of maize. The course of temperature and rainfalls during growing season is given in Table 2.

RESULTS AND DISCUSSION

There was a tendency towards poorer maize emergence in plots with left straw compared to removed straw under no-tillage system when compared to conventionally tilled system in both soils. The effects of the straw management and tillage systems treatments were not significantly different from each other (Table 3).

In most cases the effect of straw management and tillage systems on grain yield of maize was small (Tables 4 and 5). Significantly higher yield was observed only in 2002 on straw left vs. removed straw plots on coarse textured soil. These results indicate a high tolerance of maize yield to reduced tillage and post harvest straw management systems. Woźnica *et al.* (1995) reported similar results showing the

T a b l e 2. Mean half-month and annual air temperatures (°C) and half-month and annual precipitation (mm)

Parameter	Term*	Month								Annual value
		IV	V	VI	VII	VIII	IX	X	XI	
					1999					
Temperature	1	9.9	12.3	16.5	20.5	19.2	16.2	11.0	4.4	
	2	9.4	15.6	16.6	19.4	16.3	16.8	7.3	0	9.4
Precipitation	1	7.5	22.8	35.3	178.8	5.6	11.6	18.7	30.9	
	2	48.9	12.8	43.8	4.8	11.8	21.9	56.0	5.4	631.0
					2002					
Temperature	1	5.6	17.7	16.2	20.7	20.2	15.6	7.2	2.9	
	2	11.1	16.7	20.0	19.0	20.6	10.4	8.1	6.6	9.6
Precipitation	1	22.0	31.8	47.9	26.2	30.2	18.0	22.7	18.1	
	2	22.5	47.0	5.8	12.0	55.3	14.7	40.6	29.4	562.0
					2003					
Temperature	1	3.6	15.4	20.9	17.5	21.2	13.6	9.4	3.3	
	2	11.3	16.0	18.4	21.8	18.5	14.3	1.9	6.9	8.8
Precipitation	1	11.7	36.1	15.0	36.9	17.3	16.3	41.5	2.2	
	2	7.9	21.6	12.7	40.8	39.2	11.2	9.1	25.1	444.7
					1961-2000					
Temperature	1	7.0	12.5	16.3	17.9	18.6	14.7	10.6	5.1	
	2	9.4	14.2	17.0	18.3	16.6	12.3	7.1	2.3	8.5
Precipitation	1	16.2	31.5	35.3	40.2	32.7	27.9	1.2	21.9	
	2	20.6	32.4	36.2	39.3	33.7	19.7	19.8	16.4	563.5

*1 – first half of month, 2 – second half of month.

T a b l e 3. Effect of straw management and tillage systems on maize emergence (plants m^{-2})

Straw	Tillage	Loamy sand				Sandy loam			
		1999	2002	2003	Mean	1999	2002	2003	Mean
Harvested	CT*	9.0	9.0	7.3	8.4	9.0	9.0	8.3	8.8
	RT	8.4	9.0	7.6	8.7	8.6	8.6	8.3	8.5
	NT	7.4	8.6	6.8	7.6	8.4	8.9	8.4	8.6
	Mean	8.3	8.9	7.2	8.2	8.7	8.8	8.3	8.6
Left	CT	8.2	8.7	7.7	8.2	9.0	8.4	8.2	8.5
	RT	8.8	8.8	6.9	8.2	9.0	8.6	7.8	8.5
	NT	8.0	8.4	7.1	7.8	7.0	7.8	7.7	7.5
	Mean	8.3	8.6	7.2	8.1	8.3	8.3	7.9	8.2
Mean	CT	8.6	8.8	7.5	8.3	9.0	8.7	8.2	8.6
	RT	8.6	8.9	7.2	8.2	8.8	8.6	8.0	8.4
	NT	7.7	8.5	7.0	7.7	7.7	8.4	8.1	8.1
	Annual	8.3	8.8	7.2	8.1	8.5	8.6	8.1	8.4
$LSD_{(0.05)}$:									
Tillage (T)	ns**	ns	ns	ns	ns	ns	ns	ns	ns
Straw (S)	ns	ns	ns	ns	ns	ns	ns	ns	ns
Years (Y)	ns	ns	ns	ns	ns	ns	ns	ns	ns
Interaction	ns	ns	ns	ns	ns	ns	ns	ns	ns

*CT – Conventional Tillage, RT – Reduced Tillage, NT– No Tilllage, **ns – not significant.

T a b l e 4. Effect of straw management and tillage systems on maize grain yield (dag m^{-2}) and cob diameter and length (cm) from loamy sand

Straw	Tillage	Grain yield				Cobs 2003	
		1999	2002	2003	Mean	Diameter	Length
Harvested	CT*	89.6	96.2	116.6	100.8	4.2	15.4
	RT	90.8	94.3	120.0	101.7	4.3	16.0
	NT	88.0	93.8	123.2	101.7	4.3	15.8
	Mean	89.5	94.8	119.9	101.4	4.3	15.7
Left	CT	92.7	109.5	113.4	105.2	4.2	15.2
	RT	89.2	97.0	107.4	97.9	4.1	15.4
	NT	86.8	98.0	120.0	101.6	4.3	16.0
	Mean	89.6	101.5	113.6	101.6	4.2	15.6
Mean	CT	91.2	102.8	115.0	103.0	4.2	15.3
	RT	90.0	95.7	113.7	99.8	4.2	15.7
	NT	87.4	95.9	121.6	101.6	4.3	15.9
	Annual	89.5	98.1	116.8	101.5	4.2	15.6
$LSD_{(0.05)}$:							
Years (Y)			5			–	
Tillage (T)	ns**	ns	ns	ns	ns	ns	ns
Straw (S)	ns	6.5	ns	ns	ns	ns	ns
Interaction:							
(YxT), (TxS)	ns	ns	ns	ns	ns	ns	ns
(YxS)			4.5			–	

*Explanation as in Table 3.

T a b l e 5. Effect of straw management and tillage systems on maize grain yield (dag m^{-2}), cob diameter and length (cm) from sandy loam

Straw	Tillage	Grain yield				Cobs 2003	
		1999	2002	2003	Mean	Diameter	Length
Harvested	CT*	87.4	98.2	120.2	101.9	4.2	16.3
	RT	78.4	88.9	122.0	96.4	4.3	16.7
	NT	86.7	93.5	123.0	101.1	4.3	16.6
	Mean	84.2	93.6	121.7	99.8	4.3	16.5
Left	CT	90.8	90.8	122.4	101.3	4.1	15.8
	RT	88.8	93.1	123.8	101.9	4.3	16.8
	NT	84.8	93.1	120.4	99.4	4.3	17.0
	Mean	88.2	92.3	122.2	100.9	4.2	16.5
Mean	CT	89.1	94.5	121.3	101.6	4.2	16.1
	RT	83.6	91.0	122.9	99.2	4.3	16.7
	NT	85.8	93.3	121.7	100.3	4.3	16.8
	Annual	86.2	93.0	122.0	100.3	4.2	16.6
$LSD_{(0.05)}$:							
Years (Y)			5.7			–	
Tillage (T)	ns**	ns	ns	ns	ns	0.1	ns
Straw (S)	ns	ns	ns	ns	ns	ns	ns
Interaction:							
(TxS)	ns	ns	ns	ns	ns	ns	ns
(YxS), (YxT)			ns			–	

*Explanation as in Table 3.

highest maize yield for silage when direct drilling of maize seeds in stubble of rye for green silage (nurse crop) was applied on loamy sand.

A substantial effect of weather during the growing season on maize grain yield was observed. The highest yield in both soils was obtained in 2003, with the least total precipitation (Table 2) but favourable distribution during the growing season. As reported by Dubas *et al.* (1995), the most favourable growth of maize takes place when rainfalls during the period corresponding to flowering (mid July – mid August) reach approximately 150 mm. In our study the rainfalls during the growth phase were hardly 10, 30 and 58 mm in 1999, 2002 and 2003, respectively, and were positively correlated with maize grain yield. The data imply a helpful effect of increasing water supply at flowering on maize growth even at relatively scarce precipitations. As indicated in earlier studies, sufficient water at flowering growth phase may diminish the differences in grain yield among different tillage systems (Carter *et al.*, 2002; Dubas *et al.*, 1995).

The data in Table 4 indicate a significant interactive effect of straw management and the weather conditions in the experimental years on the loamy sand. In 1999, a year with the highest annual precipitations (631 mm), the effect of different straw management on maize yield was not different, whereas in 2002 with medium rainfalls (562 mm) and in 2003 with the lowest rainfalls (445 mm) the effect of leaving straw was negative and positive, respectively. For comparison, the long-term mean annual precipitation of the site is 563.5 mm. However, in the case of sandy loam maize yield was similar in all the years. The differences in maize yield responses between the soils can be partly due to different water holding capacity and hydraulic conductivity of variously textured soils, that affect the amount of plant available water and the rate of evaporation (Walczak *et al.*, 2002a and b).

In 2003 we measured also the diameter and length of the maize cobs (Tables 4 and 5). These parameters were similar among the straw management and tillage treatments in both soils (Table 4).

CONCLUSIONS

1. The data of grain yield indicates that maize well tolerates simplified tillage systems including no-tillage with retained annual chopped straw on both loamy sand and sandy loam.

2. This research showed that reduced tillage and no-tillage in combination with straw retaining can be used without any significant decrease in grain yield of maize grown on medium and coarse-textured soils.

REFERENCES

Borowiecki J., Lipski S., Machul M., and Brzóska F., 1988. Tillage and use of fodder maize for grain and CCM (in Polish). IUNG, Puławy, Instruction, 66/98, 58.

B∅rresen T., 1999. The effect of straw management and reduced tillage on soil properties and crop yields of spring-sown cereals on two loam soils in Norway. Soil Till. Res., 51, 91-102.

Carter M.R., Sanderson J.B., Ivany J.A., and White R.P., 2002. Influence of rotation and tillage maize productivity, weed species, and soil quality of a fine sandy loam in cool-humid climate of Atlantic Canada. Soil Till. Res., 67, 85-98

Dubas A., Michalski T., and Sulewska H., 1995. Maize growth in ploughless tillage and direct drilling system after various preceding crops (in Polish). Proc. Conf. Direct Drilling in Theory and Practice, Szczecin-Barzkowice, 71-80.

Ehlers W. and Claupein W., 1994. Approaches toward conservation tillage in Germany. In: Conservation Tillage in Temperate Agroecosystems (Ed. M.R. Carter). Lewis Publishers, CRC Press, Boca Raton, 141-165.

FAOSTAT, **2004**. Agriculture Data.

Ferrero A., Usowicz B., and Lipiec J., 2005. Effects of tractor traffic on spatial variability of soil strength and water content in grass covered and cultivated sloping vineyard. Soil Till. Res., 84, 127-138.

GUS Statistical Yearbook of Poland, **2002**. Warsaw, 762.

Hernanz J.L., Giron V.S., and Cerisola C., 1995. Long-term energy use and economic evaluation of three tillage systems for cereal and legume production in central Spain. Soil Till. Res., 35, 183-198.

Karlen D.L., Wollenhaupt N.C., Erbach D.C., Berry E.C., Swan J.B., Eash N.S., and Jordahl J.L., 1994. Crop residue effects on soil quality following 10-years of no-till corn. Soil Till. Res., 31, 149-167.

Lal R., Logan T., Eckert D.J., Dick W.A., and Shipitalo M.J., 1994. Conservation tillage in the corn belt of the United States. In: Conservation Tillage in Temperate Agroecosystems (Ed. M.R. Carter), Lewis Publishers, CRC Press, Boca Raton, 73-114.

Lipiec J. and Stępniewski W., 1995. Effects of soil compaction and tillage systems on uptake and losses of nutrients. Soil Till. Res., 35, 37-52.

Machul M., 2003. Reduced tillage in maize cultivation (in Polish). Agrochemia, 2003, 9, 31-34.

Malicki L., Nowicki J., and Szwejkowski Z., 1997. Soil and crop responses to soil tillage systems: a Polish perspective. Soil Till. Res., 43, 65-80.

McGarry D., Bridge B.J., and Radford B.J., 2000. Contrasting soil physical properties after zero and traditional tillage of an alluvial soil in semi-arid subtropics. Soil Till. Res., 53, 105-115.

Pabin, J., Lipiec J., Włodek S , and Biskupski A., 2003. Effect of different tillage systems and straw management on some physical properties of soil and on the yield of winter rye in monoculture. Int. Agrophysics, 17, 175-181.

Pranagal J., Lipiec J., and Domżał H., 2004. Changes in pore-size distribution and aggregate stability of two soils under long term tillage systems. Int. Agrophysics, 19, 165-174.

Reicosky D.C., Kemper W.D., Langdale G.W., Douglas Jr., C.L., and Rasmussen P.E., 1995. Soil organic matter changes resulting from tillage and biomass production. J. Soil Water Conserv., 50, 253-261.

Riley H., B∅rresen T., Ekeberg E., and Rydberg T., 1994. Trends in reduced tillage research and practice in Scandinavia. In: Conservation Tillage in Temperate Agroecosystems (Ed. M.R. Carter), Lewis Publishers, CRC Press, Boca Raton, 23-45.

Sharratt B.S., 1996. Tillage and straw management for modifying physical properties of a subarctic soil. Soil Till. Res., 38, 239-250.

Szymankiewicz K., 1995. Effect of different tillage systems on dynamics of water storage, soil fertility and maize yield. Proc. Conf. Direct Drilling in Theory and Practice, Szczecin -Barzkowice, 89-98.

Tebrügge F. and Düring R.A., 1999. Reducing tillage intensity - a review of results from a long-term study in Germany. Soil Till. Res., 53, 15-28.

Walczak R., Ostrowski J., Witkowska-Walczak B., and Sławiński C., 2002a. Spatial characteristic of hydrophysical properties in arable mineral soils in Poland as illustrated by field water capacity (FWC). Int. Agrophysics, 16, 151-159.

Walczak R., Ostrowski J., Witkowska-Walczak B., and Sławiński C., 2002b. Hydrophysical properties of mineral soils of arable soils in Poland (in Polish). Acta Agrophysica, 79, 1-99.

Wiermann C. and Horn R., 2000. Effect of different tillage systems on the recovery of soil structure following a single compaction event. In: Subsoil Compaction - Distribution, Processes and Consequences (Eds R. Horn, J.J.H. van den Akker, J. Arvidsson), Catena, Reiskirchen, 339-350.

Woźnica Z., Pudełko J., Skrzypczak G., and Matysiak R., 1995. Effect of alternative tillage systems on weeding and maize yield. Proc. Conf. Direct Drilling in Theory and Practice, Szczecin-Barzkowice, 109-117.