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ISTRO–2000

15TH CONFERENCE of the INTERNATIONAL SOIL TILLAGE RESEARCH ORGANIZATION

FORT WORTH, TEXAS, USA

2–7 JULY 2000

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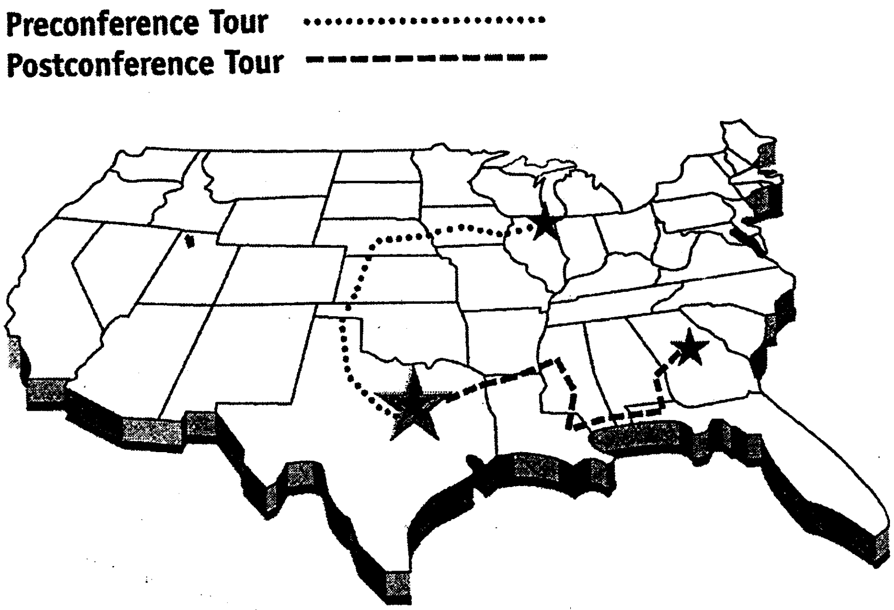

An Integrated Tillage System to Prevent Pulverization and Wind Erosion of Sandy Soils

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Contribution from USDA, ARS in cooperation with Kansas Agric. Exp. Sta, Contribution No. 00-342-A

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ABSTRACT

Wind erosion often occurs near the times of sowing of both spring and fall crops on the intensively-cultivated, sandy soils that occupy large areas in Poland. The objectives of this study were to design and evaluate an integrated tillage system that could reduce the erosion hazard on these low-porosity, loamy sand soils. To achieve the first objective, an integrated tillage system was developed that performed plowing, presowing, and sowing operations in a single tractor pass. Then this system was compared to other tillage systems to determine its relative effects on tillage energy distribution, crop yields, fuel consumption, soil structure, and potential wind erosion. Crop yields and fuel consumption were compared for sugar beets and barley using three tillage systems: conservation, integrated, and conventional multipass tillage. The highest average yields were obtained with the integrated tillage system. In comparision, average yields with the conventional and conservation systems were 88 and 59 percent, respectively, for barley and 84 and 76 percent, respectively, for sugar beets. Fuel consumption was lowest with the conservation tillage system. In comparision, fuel consumptions with the integrated and conventional systems were 127 and 187 percent, respecively, for barley and 119 and 174 percent, respectively, for sugar beets. Finally, the integrated system modified the soil structure. Compared to the conventional tillage system, it produced a larger fraction of non-erodible aggregates that had higher dry-aggregate stabilities at the soil surface. These changes in the surface soil structure created by the integrated system reduced the potential wind erosion in spring by more than 85 percent and nearly eliminated the fall erosion hazard that occurs with the conventional tillage system. Based on these research results, adoption of the integrated tillage system is recommended for loamy sand soils with low natural porosities, because it increases crop yields and reduces both fuel consumption and potential wind erosion compared to the conventional tillage system.

INTRODUCTION

Large regions of sandy soils in Poland are vulnerable to wind eroison when conventional, intensive tillage systems are used for seedbed preparation and sowing of both spring and fall crops. Previous research (Podsiadlowski, 1995) has indicated several reasons for the susceptibility of the loamy sand soil to wind erosion. These reasons include:

- the aggregate structure of these soils has generally low mechanical stability,
- conventional methods of tillage of loamy sands transfers a great amount of unitary tillage energy (kJ/m^2) to the weak aggregates near the soil surface, and
- this large input of unitary tillage energy deteriorates the soil aggregate structure and pulverizes the surface soil, especially under conditions of low soil moisture.

Another challenge in managing these sandy loam soils is that they typically have low natural porosities that range from about 30 to 35 %. In fact, Poland possesses only small areas of soil with high natural porosities (Fig. 1).

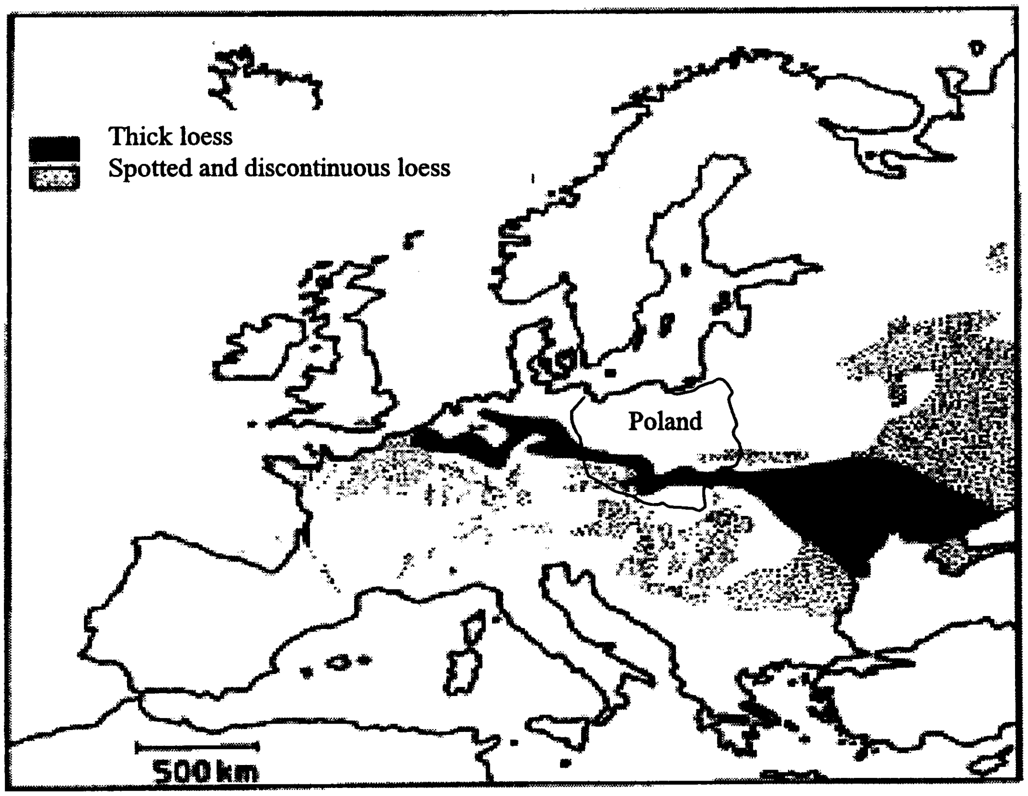

Fig. 1 . Distribution of soils with high natural porosities (loess) occurrences in Europe (Goossens, 1999)

Minimum tillage systems that preserve crop residues have been tested on these loamy sand soils. However, because of the low natural porosities, minimum soil cultivation lowers production of many of the crops traditionally grown on these soils, such as potatoes, sugar beets and barley (Podsiadlowski, 1995).

The objectives of this research were to design and evaluate an integrated tillage system that maintains high crop productivity but reduces the potential amount of wind erosion on these low porosity, loamy sand soils.

DESIGN OF THE INTEGRATED TILLAGE SYSTEM

The first design goal for the proposed tillage system was to minimize the soil-aggregate pulverization from the input of unitary tillage energy (kJ m^{-2}) that leads to the subsequent wind erosion. A second design goal for the tillage system was to provide sufficient soil porosity in the tillage layer for optimum crop growth. Previous research (Podsiadlowski, 1995) showed that, before tillage, the stability of the aggregates typically increased with depth below the surface in the tillage zone. Hence, a soil inversion tool, such as a moldboard plow, can both increase soil porosity and bring the aggregates with the highest mechanical stability to the surface.

To achieve the design goals, an integrated tillage system for cultivation of sandy soils was developed to perform plowing, presowing, and sowing operations simultaneously during a single tractor passage (Fig. 2).

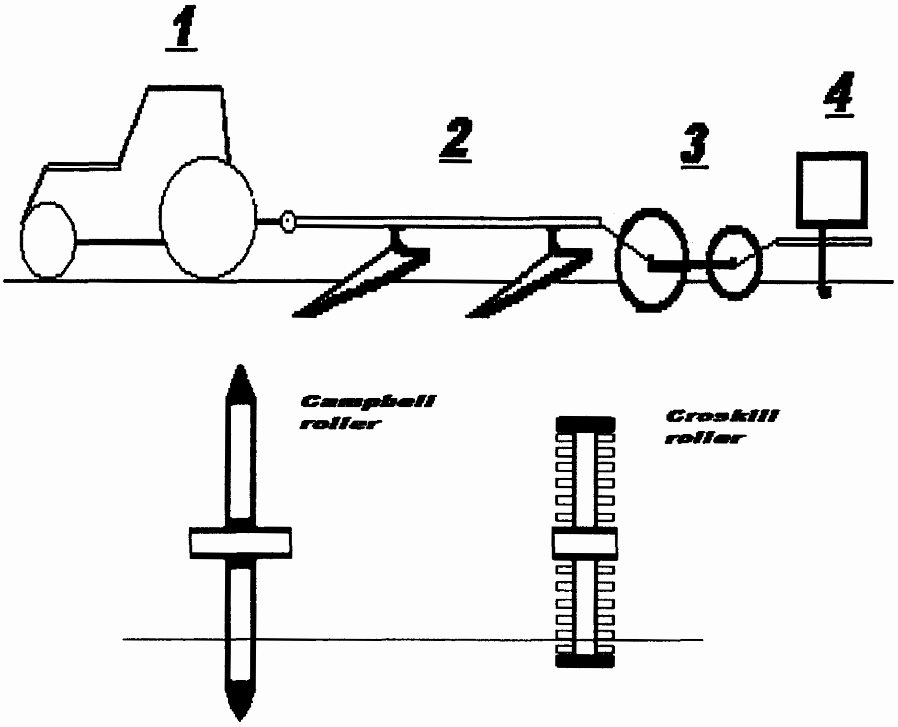

Fig. 2. The components of the integrated tillage system; 1-tractor, 2-moldboard plow, 3-rollers (Campbell + Croskil), and 4-sowing machine.

The integrated tillage system was expected to achieve the following advantages:

- the farm tractor generally would move only on soil with a coherent/homogenous structure and, thus, minimize the destructive effects of compaction energy transmitted by the tractor wheels; moreover, any surface aggregates pulverized by the tractor wheels would be moved to the bottom of the tillage layer by the plow;
- the overall porosity created in the tillage layer could be near the optimum value for most crops, especially during germination and emergence;
- the unitary tillage energy required for crop production could be significantly lower than that in the conventional tillage system;

- both the soil fraction and mechanical stability of nonerodible aggregates would be higher in the near-surface soil than those with the conventional tillage system.

The latter result would be achieved by utilizing the soil moisture and stability gradients present in the untilled soil, reducing the number of tractor passes, and minimizing the energy expended on the soil. Previous research indicated that the mechanical stability of aggregates at the soil surface was greatest immeditely after primary tillage (Podsiadłowski 1995). As time passed and additional cultivation operations were performed, the aggregate stability decreased to about 20% of the initial value. The weakening of the aggregate structure was recognized as being one of the factors contributing to soil pulverization and wind erosion of sandy soils that occurs with traditional multipass tillage systems.

METHODS AND PROCEDURES

Experimental Site

The research was carried out on a field located 14 km northeast of the centre of Poznań (52°29'11"N, 17°24'06"E) near the village of Milno in an area of a flat moraine resulting from the Vistulian (Würm) Glaciation. Soils lesivées (Typic Hapludalfs - Soil Survey Staff 1975, Orthic Luvisols - FAO), which are common in the Polish Plain, have developed on its loamy sands and sandy loams. The crop rotation practiced on the experimental field is typical of loamy sand areas in Poland: potatoes or maize - grains (barley or rye) - lupine or rape - grains. The soil is cultivated using tractors with power ratings of up to 63 kW. The preplanting tillage traditionally used causes breaking and pulverizing of aggregates in the topmost soil layer (0 - 3 cm), which has been shown to accelerate wind erosion.

The field at Milno, which is situated in a W-E oriented "corridor" between two patches of woodland, is particularly susceptible to wind erosion (Fig. 3). Since1986, measurements of aeolian transport have been carried out on the field using dust traps. The mean intensity of this process equalled 8.9 ± 8.1 kg m^{-1} $year^{-1}$ (±1 SD). The minimum and maximum annual totals were 1 kg and 29 kg m^{-1} $year^{-1}$, respectively (Podsiadlowski, 1995). Wind erosion was usually most intense in early spring (March - April) during the preplanting treatment and sowing periods (Hagen, Podsiadlowsi, and Skorupski, 1999).

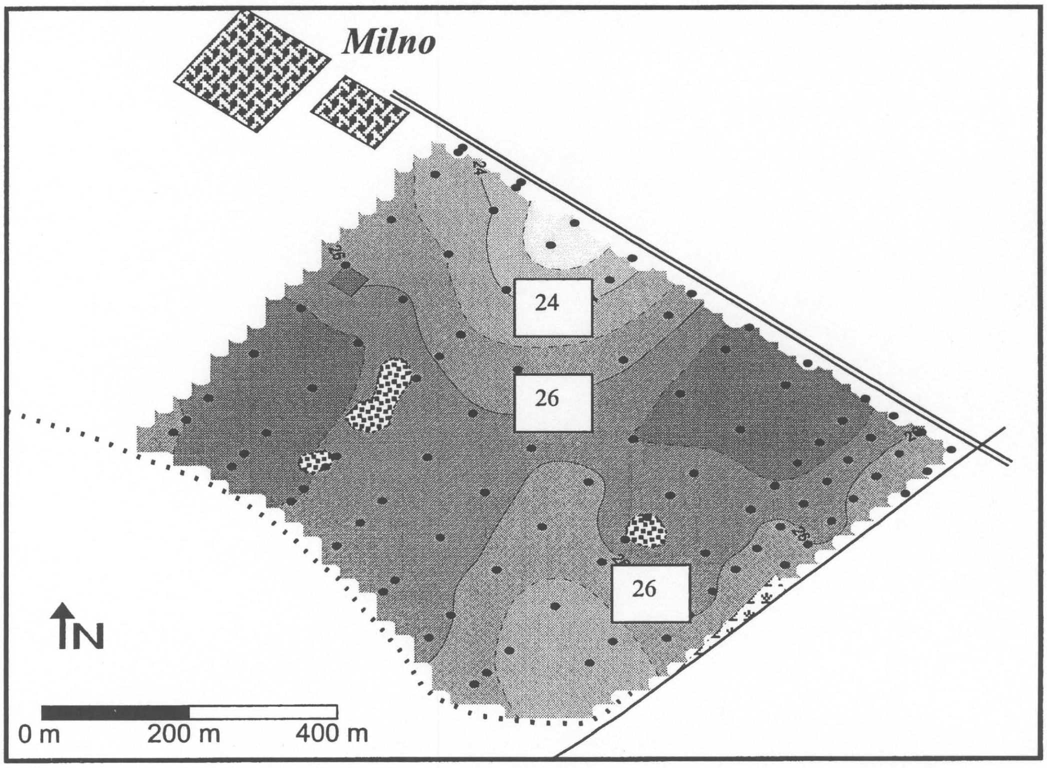

Fig. 3. Spatial variability of silt content in the ploughed layer (Stach and Podsiadlowsi, 1998)

The spatial variability of soils on the Milno field was studied by analyzing soil samples taken from a regular grid in an area of some 64 ha (Stach and Podsiadlowski, 1998). The mechanical composition of the primary particles was determined using the standard Casagrande areometric method as modified by Bouyoucos and Proszynski. After analysis of the soil spatial variability, we chose to conduct tillage investigations on two areas within the field with soil properties as listed in Table 1.

Table 1. The particle size composition of two soils from the Milno field. Particle size groups (sand, silt, and clay) according to the USDA classification (Soil Survey Staff, 1975).

	Fraction				
Soil	2.0-1.0 mm	1.0-0.1 mm	0.1-0.05 mm	0.05-0.002 mm	<0.002 mm
1 (loamy sand)	4.1%	54.3%	12.7%	24.4%	4.5%
2 (loamy sand)	5.3%	58.8%	14.6%	19.1%	2.2%

1/ The use of trade names in this publication does not imply endorsement of the products.

Experimental Measurements

Before testing of the complete integrated tillage system, a series of tests was conducted to optimize the design of the rollers section. Next, replicated field plot experiments were carried out to compare the effects of a single-pass, integrated tillage system, the conventional, multipass tillage system, and a conservation tillage system for seedbed preparation and sowing. A Ursus U-904 tractor with rated power of 63 kW and 5650 kg mass and equipped with standard tires (front wheels 12.4/11-24, rear wheels 184/15-34) was used in the tillage experiments. The set of integrated tillage implements of 820 kg mass, consisted of: a typical moldboard plow, a rollers section (Campbell + Croskill), and a universal sowing-machine (Fig. 2). The set of implements used for conventional tillage treatments included a moldboard plow, harrow, and sowing-machine. The conservation tillage system consisted of a subsoiler and sowing machine. The inputs of unitary tillage energy, Et, and unitary compaction energy, Ec, were calculated using the computer program, STAPOD, that is based on the algorithm presented by Krysztofiak and Podsiadlowski (1998).

Principle soil characteristics were determined according to methods generally accepted in soil science. Flat sieves were used to measure aggregate size distribution in the surface soil. The geometric mean diameter (GMD) of soil aggregates was then determined according to the method of Campbell (1985). The aggregate abrasion coefficient is a measure of the susceptibility of soil aggregates to break down when impacted by saltating particles during wind erosion (Hagen, 1991; Hagen, Skidmore, and Saleh, 1992). To determine the coefficient of abrasion of the aggregates after sowing for both the conventional and integrated tillage plots, 120 aggregates in the size range 2-3.15 mm were collected from each plot, and their break force was measured using an INSTRON[1/] model 1140.

The various field surface conditions created by the integrated and conventional systems were compared. These included the after-winter pretillage, after-plowing, and after-sowing surfaces. One after-sowing surface was created by the integrated tillage system in a single pass of the tractor. The after-sowing surface for the conventional system used 4 passes of the tractor – the sequence included moldboard plowing, harrowing twice, and then sowing.

The statistical design of the field investigations was a completely randomized block design with 4 blocks and 5 repititions per block for a total of 20 repititions for each treatment combination. Fuel consumption and yields were compared for crops of barley and sugar beets with three tillage systems (conventional, integrated, and conservation tillage).

RESULTS AND DISCUSSION

Tillage System Effects on Tillage Energy Distribution

A major part of the compaction energy inputs, Ec, transferred to the soil during tillage comes from the tractor wheels. This phenomenon cannot be eliminated easily because the axial load of a tractor is one of the main factors controlling the adhesion of wheels to the ground; thus, it also determines the effective traction force of a tractor. Hence, the ratio of unitary tillage energy, Et, to the total unitary tillage energy (compaction plus tillage energy), Etc, must be taken into account in research on protecting soil against excessive compaction and destruction of its structure (Poesse, 1992). This ratio is especially low when shallow, presowing tillage operations are performed with the aid of implements having large widths of work (Fig.4).

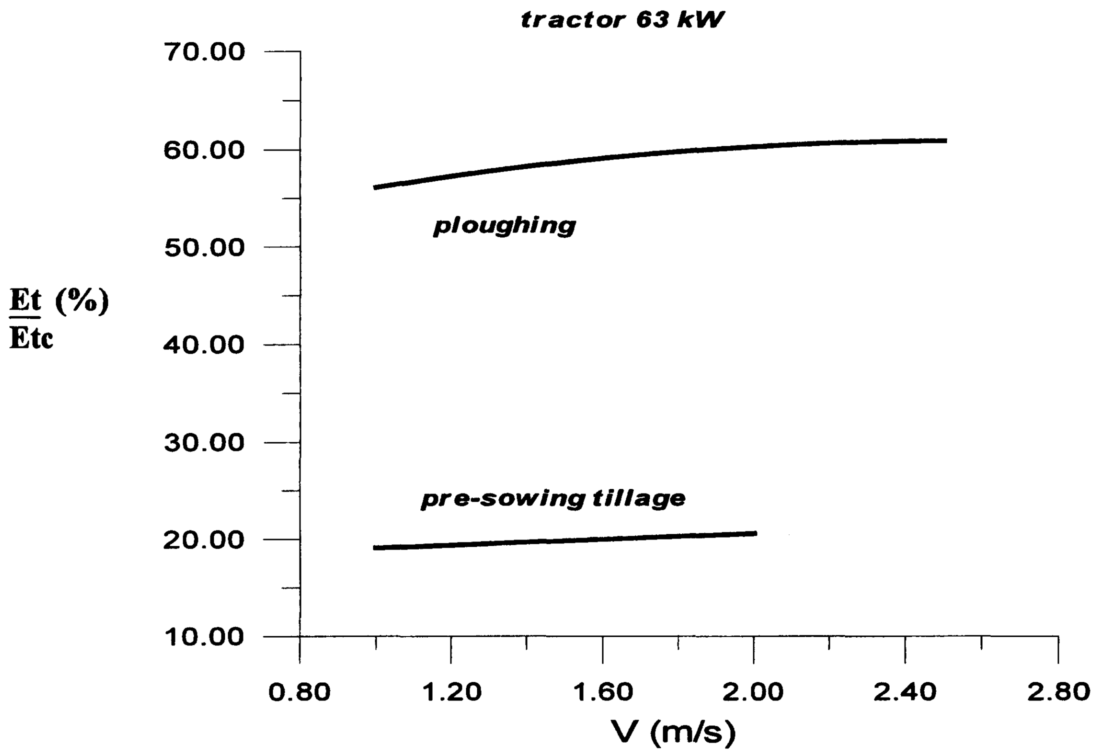

Fig. 4. The ratio of unitary tillage energy Et (kJ m^{-2}) to the total unitary tillage energy Etc (kJ m^{-2}) as influenced by tractor forward speed V (m/s).

In this case, Ec makes up about 80% of the total energy transferred to the soil in the wheel tracks of the tractor and implements. It is also worth mentioning that the total soil coverage of the wheel tracks during the conventional, pre-sowing cultivation usually constitutes more than 30% of the overall working width of a tillage unit. In contrast, plowing at a depth of 25 cm produces an Ec that reaches only 40% of the Etc (Fig. 4). This result stems from the increase in the depth of tillage and the reduction of the working width of a plow compared to implements used after the plow. Another important fact for soil protection is that during plowing, the ground wheels of a tractor move on soil with a cohesive structure that has relatively high mechanical strength. Thus, analysis of the distribution of compaction energy inputs (Fig. 4) indicates that a reduction of this energy is desirable, especially during shallow tillage.

In this study, determination of the specifications for the rollers section also was an initial major focus of the integrated tillage investigation. The design variables included the type, depth, speed of working, and mass of rollers. Tests were conducted to determine the effects of the design variables on the aggregate structure and level of soil compaction. A coefficient of aggregate destruction, expressed as the fractional reduction in the geometric mean diameter (GMD) of the aggregate size distribution, was used to evaluate the quantitative changes in the soil aggregate structure (Fig. 5). The results indicated that the input Et of the rollers section should range from 1 to 2 kJ/m^2 to avoid excessive destruction of the nonerodible aggregates.

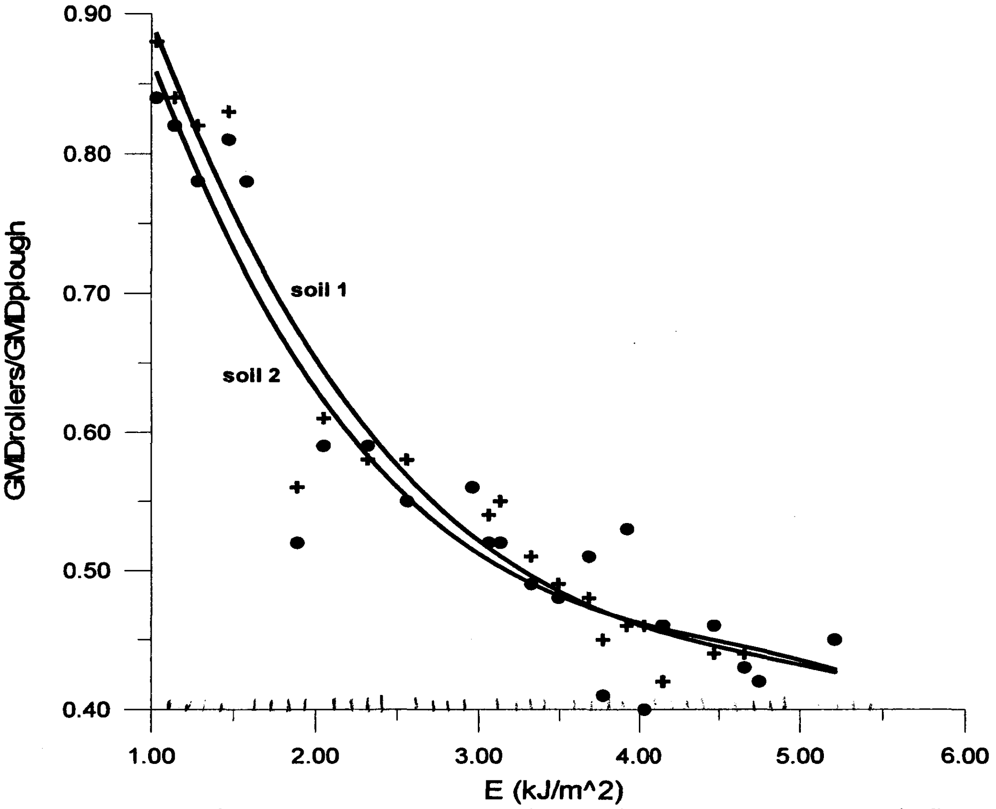

Fig. 5. Changes in aggregate structure of top soil layer (0-10 mm) as influenced by unitary tillage energy of rollers section of the integrated implement set.

A rollers section that included both type Campbell and type Croskill (Fig.2), was selected for use on loamy sands as a result of these investigations. It was further determined that a unitary tillage energy input by the rollers section in the range of 1.45-1.55 kJ/m^2 was sufficient to achieve the desired porosity of the loamy sand seedbed.

Tillage System Effects on Crop Response

Measurements of tillage effects from replicated plots, summarizing both average crop yields and fuel consumptions for two crops and three tillage systems, are illustrated in Table 2.

In every experiment, the highest crop yields were obtained with the integrated tillage system. The favorable soil conditions created by that system also were manifested in the tallest crop heights. In contrast, both the lowest crop heights and lowest yields occurred with the conservation tillage system. The crop performance results for conservation tillage were caused by both uneven germination and emergence of the barley and sugar beets. The integrated tillage system used over 30% less fuel than the conventional tillage. Although the conservation tillage system was characterized by the lowest crop yields, it required 15 to 21% less fuel than the integrated tillage system.

Table. 2. Comparison of average crop yields and fuel consumptions among three tillage systems.

Crop and Variable	Integrated Tillage Average	Integrated Tillage Std. Dev	Conventional Tillage Average	Conventional Tillage Std. Dev	Conservation Tillage Average	Conservation Tillage Std. Dev
Barley						
Yield (kg ha^{-1})	5835 a♣/	1225	5112 b	1278	3428 c	959
Fuel (l ha^{-1})	32 a	4.8	47 b	10.2	27 c	4.2
Sugar beets						
Yield (kg ha^{-1})	65163 d	11208	54870 e	11311	49673 f	12397
Root mass (g)	680.7	406.3	612.0	425.5	523.2	398.1
Max diameter of root (cm)	10.6	2.7	9.5	3.3	8.2	2.6
Length of root (cm)	19.0	4.1	20.4	5.6	18.8	4.5
Fuel (l ha^{-1})	38 d	7.23	56 e	16.54	30 f	5.71

♣/ Means for crop yields and fuel consumption values followed by different letters are significantly different at the P = 0.05 level.

Tillage System Effects on Soil Structure and Potential Wind Erosion

Substantial differences occurred in soil structure conditions created by the various tillage systems. In some cases, these differences persisted over the entire growing season .

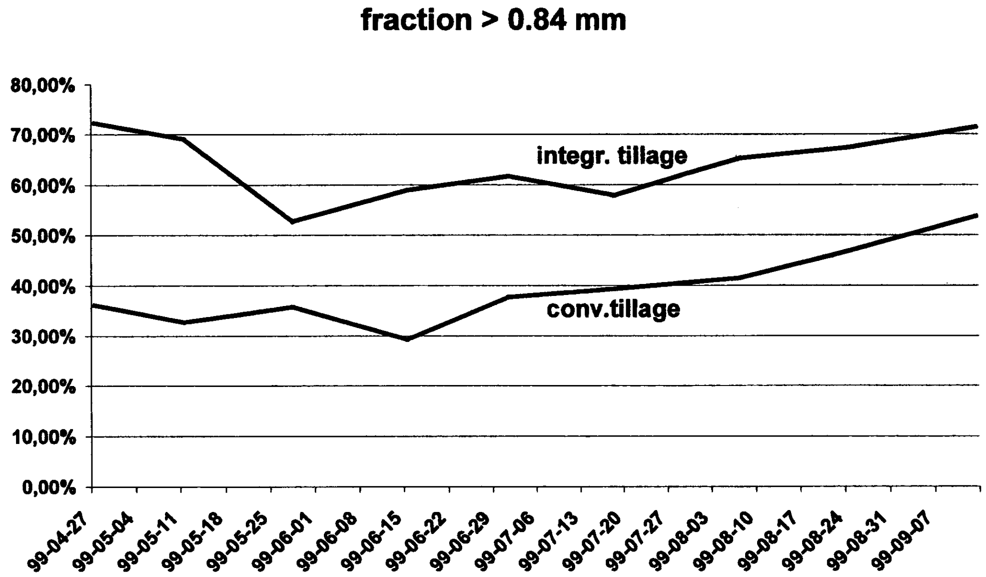

Fig. 6. Temporal changes in the nonerodible soil aggregate fraction (>0.84 mm) in the topsoil layer (0-10 mm) of soil 1 with a sugar beet crop from April to September, 1999.

The data in Fig. 6 illustrate that the integrated tillage system provided a significantly higher level of nonerodible aggregates at the surface compared to the conventional tillage system in a sugar beet cropping system during 1999. The increased fraction of nonerodible aggregates in the integrated tillage system not only increased the threshold wind speed needed to initiate erosion but also decreased the rate of erosion for wind speeds above the threshold (Hagen, Podsiadlowski and Skorupski ,1999).

The increased fraction of nonerodible aggregates in the integrated tillage system also was accompanied by an increase in the break force of these aggregates (Fig. 7). However, with both the integrated and conventional tillage systems, increasing the levels of tillage energy tended to decrease the break force and, consequently, the aggregates' resistance to abrasion impact during wind erosion. Nevertheless, significant differences were evident between the two systems.

Measurements of roughness and the mass fraction of nonerodible aggregates at the surface can be combined to estimate both the aerodynamic roughness, Zo, and the threshold velocities at which wind erosion begins (Hagen, Podsiadlowski, and Skorupski, 1999). Mean values of roughness and nonerodible fractions sampled before and after the various tillage systems in the initial 2 years of this 3-year study are given in Table 3.

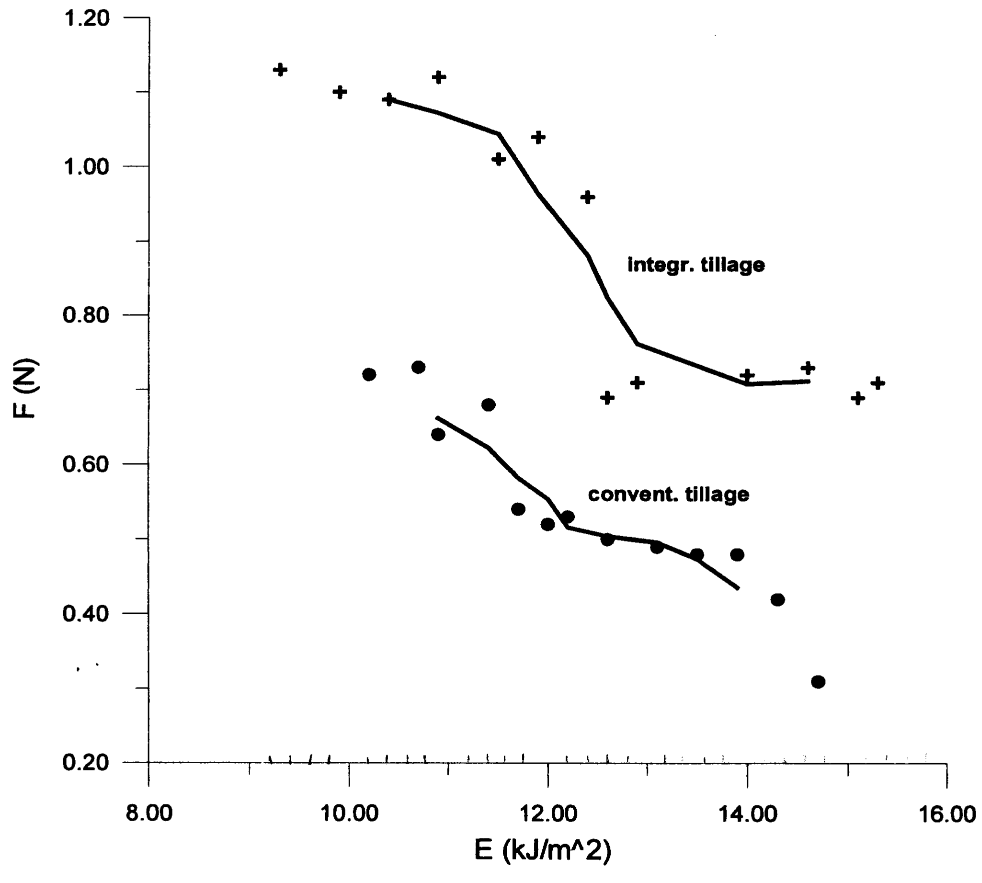

Fig. 7. The aggregate break force of a nonerodible soil fraction (sieve diameter range of 2-3.15 mm) as influenced by unitary tillage energy of soil 1 with a sugar beet crop

To illustrate the effects on potential wind erosion from the various tillage treatments, the wind energy distributions for the months when wind erosion typically occurs were calculated for the meteorological station at Poznan in eastern Poland. To provide a comparison among months, the wind energies above various wind speeds were normalized to that of the total wind energy above 8 m s^{-1} in March (Fig. 8). Next, the erosive wind speed thresholds were plotted on Fig. 8 for each of the tillage system surfaces shown in Table 3. Thus, the fraction of wind energy available for erosion in each month is only the area under each curve that is above the threshold wind speed.

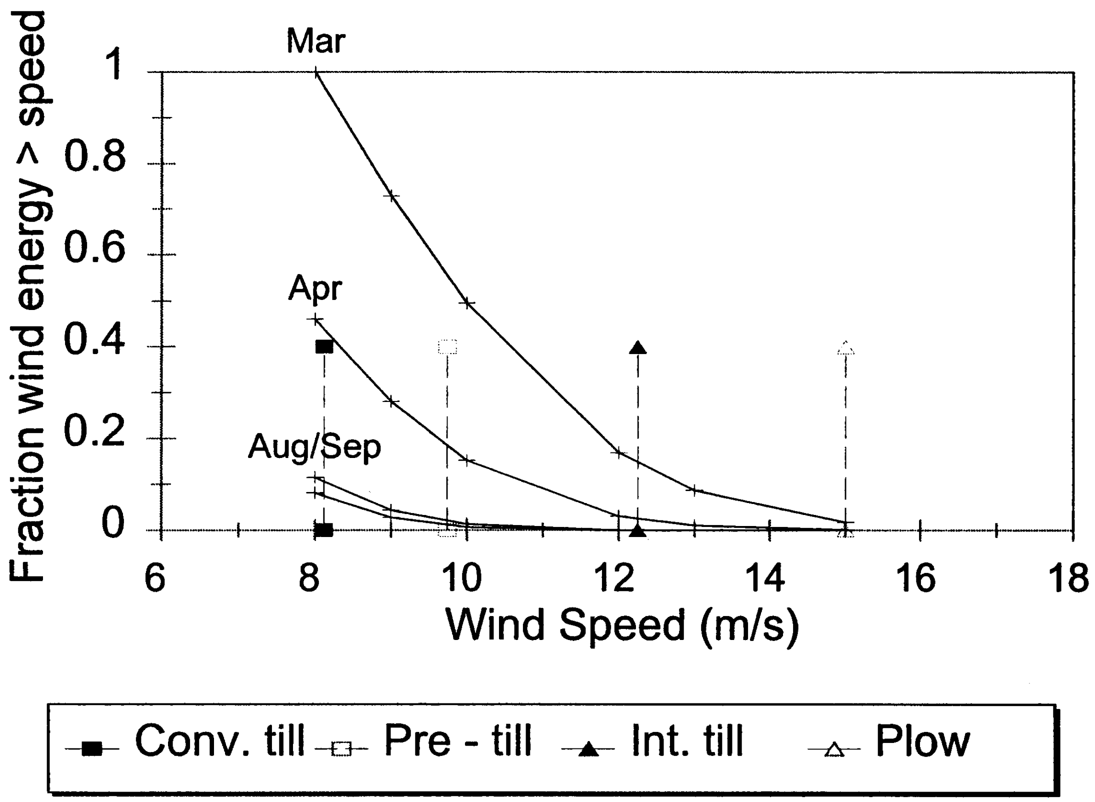

Fig. 8. Fractions of wind energies available in March, April, August, and September above various wind speeds relative to the March wind energy above 8 m/s (solid lines) and calculated dynamic threshold wind speeds at 10 m height at the Poznan meteorological station for various surface conditions (dashed lines).

Table 3. Field surface conditions near Milno, Poland.

Surface	Roughness Random	Roughness Oriented	Zo	Nonerodible Fraction
	(mm)	(mm)	(mm)	(>0.84 mm)
Pretillage	13.4	20.6	4.0♣	0.50
Plow	17.6	27.5	5.3♣	0.86
Integrated tillage	12.4	18.7	3.7♣	0.75
Conventional tillage	10.3	17.5	3.6♣	0.38

♣ Values calculated from measurements

The results in Fig. 8 show that integrated tillage reduced the potential wind erosion in March by about 85 percent and even more in April compared to the conventional tillage system. The integrated tillage system nearly eliminated the August and September erosion hazard. Further, when erosion does occur, the potential soil flux is much less with the integrated tillage system than with the conventional system, because the energy above the threshold speed is less and the aggregates are more resistant to abrasion.

SUMMARY AND CONCLUSIONS

Wind erosion often occurs near the times of sowing on the intensively cultivated, sandy soils that cover large areas in Poland. The objectives of this study were to design and evaluate an integrated tillage system suitable for use on these low-porosity, loamy sand soils. An integrated tillage system was designed that performed plowing, pre-sowing, and sowing in a single tractor pass. Critical to the success of the system was the establishment of the design parameters for the presowing, rollers section to achieve optimum porosity, while minimizing pulverization of the surface aggregates.

Crop yields and fuel consumtion were compared for sugar beets and barley using conservation, integrated, and conventional multipass tillage systems. The highest average yields were obtained with the integrated tillage system. In comparision, average yields with the conventional and conservation systems were 88 and 59 percent, respectively, for barley and 84 and 76 percent, respectively, for sugar beets. Fuel consumption was lowest for the conservation tillage system. In comparision, fuel consumptions with the integrated and conventional systems were 127 and 187 percent, respectively, for barley and 119 and 174 percent, respectively, for sugar beets.

Finally, the integrated system produced a larger fraction of nonerodible aggregates that had higher dry-aggregate stabilities at the soil surface compared to the conventional tillage system. These changes in the surface soil structure created by the integrated system reduced potential wind erosion in spring by more than 85 percent and nearly eliminated the fall erosion hazard that occurs with the conventional tillage system.

Based on these research results, adoption of the integrated tillage system is recommended for loamy sand soils with low natural porosities, because it increases crop yields and reduces both fuel consumption and the wind erosion hazard compared to the conventional tillage system.

REFERENCES

Campbell, G., 1985. Soil physics with BASIC-transports models for soil-plant systems. Dev. Soil Sci. 14.

Goossens, D., 1999. The Belgian loess deposits: An overview. 2nd International Symposium on Tillage Erosion and Tillage Translocation, Leuven, Belgium, 12-14 April 1999. Excursion. Gert Verstraeten, 5-10.

Hagen, L.J., 1991. Wind erosion mechanics: Abrasion of aggregated soil. Trans. Am. Soc. Agric. Eng., 34, 4: 831-834.

Hagen, L.J., Podsiadlowski, S., and Skorupski, D. 1999. Development of a tillage system to prevent soil pulverization and wind erosion. Scientific Papers of Agric. University of Poznan, Poland. Agriculture, 1: 15-27.

Hagen, L.J., Skidmore, E.L., and Saleh, A., 1992. Wind erosion: Prediction of aggregate abrasion coefficients. Trans. Am. Soc. Agric. Eng. 35(6):1847-1850.

Krysztofiak A., and Podsiadlowski, S., 1998. The method of calculating tillage unitary energy expenditure for prediction of aeolian erosion process. Proc. of ESSC Conference, Tenerife.

Podsiadłowski, S., 1995. Rola uprawy mechanicznej w stymulacji procesu erozji eolicznej gleb lekkich (sum.: Influence of mechanical tillage on initiation of wind erosion on light soils). Roczniki Akademii Rolniczej w Poznaniu, Rozprawy Naukowe, 264, 1-47.

Poesse, G.J., 1992. Soil compaction and new traffic systems. Vol. Possibilities offered by New Mechanisation Systems to Reduce Agricultural Production Costs. Commission of the European Communities, pp.78-91.

Soil Survey Staff, 1975. Soil Taxonomy. USDA, Washington, 754 pp.

Stach, A., and Podsiadlowski, S., 1998. The effect of wind erosion on the spatial variability of cultivated soils in the Wielkopolska region (Poland). Proc. Inter. Conf. on Agric. Eng., AgEng-Oslo 98 (CIGR), paper no: 98-C-089.