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DEVELOPMENT OF A TILLAGE SYSTEM TO PREVENT SOIL PULVERIZATION AND WIND EROSION

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ABSTRACT. **In the Wielkopolska Region of Poland, the sandy loam soils are often subject to wind erosion when conventional, intensive, tillage systems are used. Erosion usually begins during the time of pre-sowing tillage and may continue through crop emergence for both spring and fall crops. Hence, a need exists to develop tillage systems that both control wind erosion and are compatible with current farm operations. In this study, changes in soil surface conditions were compared for a conventional (multi-pass) and an integrated (single-pass) system for soil preparation and sowing of crops. The effects of the resultant surface conditions on simulated wind erosion were also compared. The integrated tillage created a surface with a much lower fraction of wind-erodible soil aggregates, but with higher surface roughness and dry aggregate stabilities compared with conventional tillage. Magnitude of the simulated erosive wind energy was much lower for the integrated tillage, because the wind speeds needed to initiate erosion were higher compared with conventional tillage. When wind erosion did occur, the simulated surface saltation and creep transport capacity was decreased and the distance to reach transport capacity was increased with integrated tillage compared with conventional tillage. Thus, the initial results show application of integrated tillage has the potential to significantly reduce wind erosion on sandy loam soils in Poland.**

KEY WORDS: wind erosion, soil tillage, conservation tillage

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INTRODUCTION

In the Wielkopolska Region of Poland, the area of individual fields has been increasing and the number of both roadside and field shelterbelts decreasing. Coupled with intensive tillage, these trends have increased the wind erosion hazard, particularly on sandy soils. Based on field experiments started in 1986, measured annual soil losses from wind erosion typically vary from 5 to 20 mt/ha (PODSIADŁOWSKI 1997).

Wind erosion on cropland generally occurs during two periods; each begins near the time of pre-sowing tillage and may continue until crop emergence provides shelter to the field surface. The first period occurs in late March and April during the spring planting season. Erosion is typically severe in only one of three years in spring, because adequate surface soil moisture reduces erosion in other years. The second period occurs in August and September during tillage for sowing rye or winter wheat. Soil loss is lower during this period than in spring but occurs every year.

Wind erosion pollutes the air and water, fills road ditches, damages seedlings, and degrades the soil. Hence, a need exists to develop tillage systems for Poland that control wind erosion and are compatible with current farm operations. This paper reports initial results on changes in soil surface conditions for an integrated tillage system compared with a conventional tillage system. The effects of the resultant surface conditions on simulated wind erosion were also compared for the conventional and integrated tillage systems

METHODS AND PROCEDURES

Field surface conditions

A 3-year field study was designed and initial field measurements were obtained in spring 1997 near Poznań, Poland. The soil is a sandy loam with 77% sand, 9% silt, 14% clay, and 1.2% organic matter. A range of surface conditions from the period before spring tillage to post-sowing of a small grain crop were measured (Table 1).

Field conditions compared included the after-winter pre-tillage surface, after--plowing surface, and after-sowing surface for two different tillage systems. One after-sowing surface was created by an integrated tillage system using a moldboard plow, a packer, and a drill to both prepare and sow the seedbed in a single pass of the tractor. The second was a conventional system using four passes of the tractor – the sequence included moldboard plow, harrow twice, and then sow.

Table 1

Field surface conditions near Poznań, Poland

Surface	Roughness [mm]			Erodible fraction	Ratio	Coefficient of abrasion
	random	oriented	Zo	(< 0.84 mm)	(< 0.10/ < 0.84)	(1/m)
Pre-tillage	13.4	20.6	4.0*	0.50*	0.45	
Plow	17.6	27.5	5.3*	0.14		
Integrated:						
plow + pack + sow	12.4	18.7	3.7*	0.25	0.35	0.030*
Conventional:						
plow + 2 harrow + sow	10.3	17.5	3.6*	0.62	0.35	0.033*

*Values calculated from measurements.

To determine threshold wind speeds at which erosion begins, both the surface aerodynamic roughness (Zo) and erodible soil cover fraction are needed (HAGEN 1995). For the tillage ridges in this study, Zo is less than 10% of ridge height (HAGEN and ARMBRUST 1992). Hence in this case, random roughness (SZ_{rr}) dominates creation of aerodynamic roughness, and Zo was calculated as:

$$Zo = 0.3\ SZ_{rr} \tag{1}$$

The erodible soil fraction (< 0.84 mm diameter) was obtained from sieving soil samples on flat sieves. The ratio of the suspension-size (< 0.1 mm diameter) fraction to the erodible fraction of loose soil also was measured. However, the mean pre-tillage erodible fraction was estimated using measured soil texture properties and a regression equation reported by FRYREAR et al. (1994).

During erosion, the susceptibility to abrasive breakdown by saltation impacts of the protective clod cover can be represented by the coefficient of abrasion. This coefficient is defined as the mass flux [kg/m^2] abraded from clods/crust for each passing unit mass of saltating abrader [kg/m] (HAGEN 1991).

To determine coefficient of abrasion, aggregate break-force was measured after sowing for both the conventional and integrated tillage plots for 120 aggregates in two size ranges (2 to 3.15 and 5 to 6.3 mm diameter) from each plot using an INSTRON* model 1140.

Average break-forces under conventional tillage were 0.75 N for 5 to 6.3 diameter aggregates and 0.32 N for 2 to 3.15 mm aggregates. For integrated tillage, average break-forces were 1.26 N for 5 to 6.3 mm and 0.62 for 2 to 3.15 mm aggregates.

Next, the break-force measurements were used to estimate crushing energy as (SKIDMORE and POWERS 1982):

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

$$CE = \left(\frac{0.002273 F_{bk}}{d^2}\right)^{0.696}, \quad \frac{F_{bk} \cdot 10^{-5}}{d^2} < 1 \tag{2}$$

where: CE – aggregate crushing energy [J/kg],
F_{bk} – break force [N],
d – aggregate diameter [m].

Finally using CE values, a weighted average of the coefficient of abrasion (1/m) for each tillage treatment was calculated using the regression equation of HAGEN et al. (1992) (Table 1).

Estimated erosive wind energy

The 10-year (1951-1960) annual wind speed classes for Poznań, Poland (Fig. 1) were fitted to a Weibull frequency distribution, and the annual cumulative wind speed distribution was calculated as:

$$F(u) = (1 - F_{\text{calm}})\left[1 - \exp\left(-\left(\frac{u}{c}\right)^k\right)\right] + F_{\text{calm}} \tag{3}$$

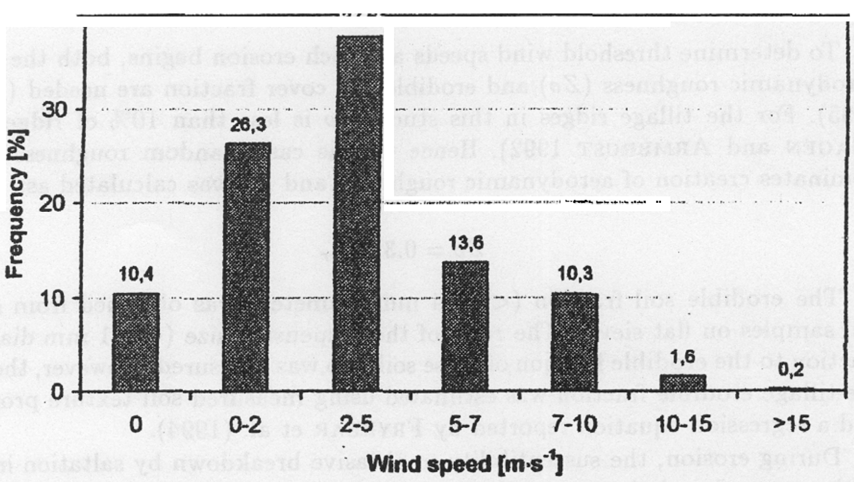

Fig. 1. Frequency of wind speed classes including calm at Poznań, Poland (1951-1960)

where: $F(u)$ – cumulative fraction of time when wind speed is less than u,
F_{calm} – fraction of period with zero wind speed,
u – wind speed at 10 m height [m/s],
c – Weibull scale parameter, 4.34 m/s,
k – Weibull shape parameter, 1.51.

Note that much of central Poland has a wind regime similar to that of Poznań (Fig. 2).

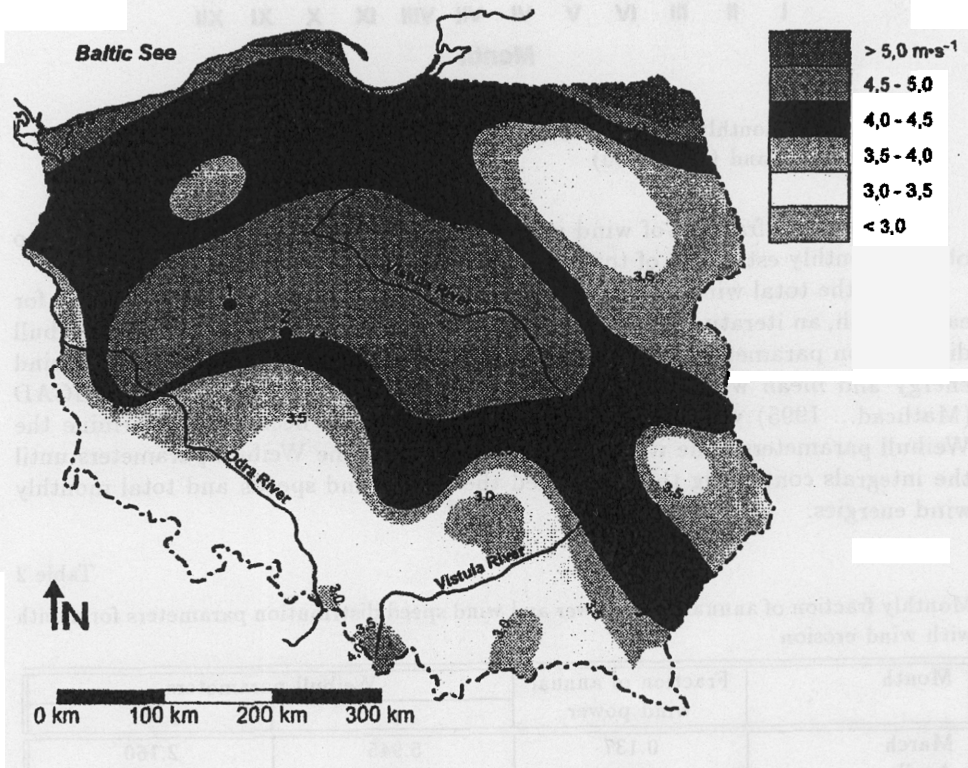

Fig. 2. Areal distribution of average annual wind speeds in Poland; location 1 is Poznań, location 2 is Parzew

Next, the fraction of total wind power occuring in each month was estimated from mean monthly wind speed (Fig. 3) as:

$$FP_i = \frac{u_i^3}{\sum u_i^3} \tag{4}$$

where: FP_i – estimated fraction of annual wind power in ith month,
u_i – mean wind speed in ith month [m/s].

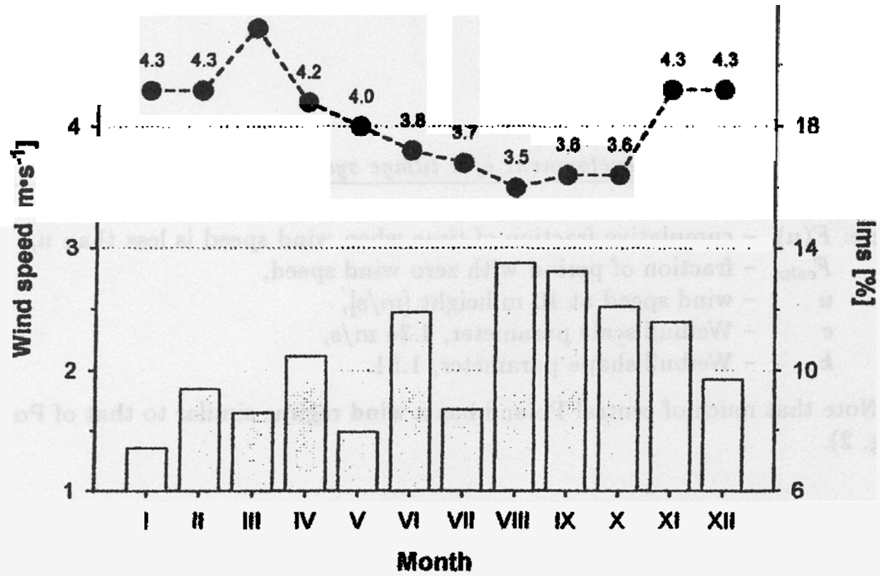

Fig. 3. Mean monthly wind speeds (circles) and percentage of calm periods (bars) at Poznań, Poland (1951-1980)

The monthly fraction of wind power was multiplied by annual wind power to obtain monthly estimates of total wind power.

Using the total wind energy estimate, mean wind speed, and fraction calm for each month, an iterative computer program was used to solve for monthly Weibull distribution parameters (c and k) (Table 2). The integrals to compute total wind energy and mean wind speed were coded in a 'solve' routine, and MATHCAD (Mathcad... 1995) was used to perform the iterations needed to determine the Weibull parameters. The iteration procedure varied the Weibull parameters until the integrals containing them returned the mean wind speeds and total monthly wind energies.

Table 2

Monthly fraction of annual wind power and wind speed distribution parameters for month with wind erosion

Month			
March	0.137	5.945	2.160
April	0.092	5.287	2.221
August	0.053	4.576	2.483
	0.058	4.699	2.454

Next, information on threshold friction velocities developed in the WEPS project (Fig. 4) was used to calculate threshold friction velocities for each surface tested (HAGEN 1995).

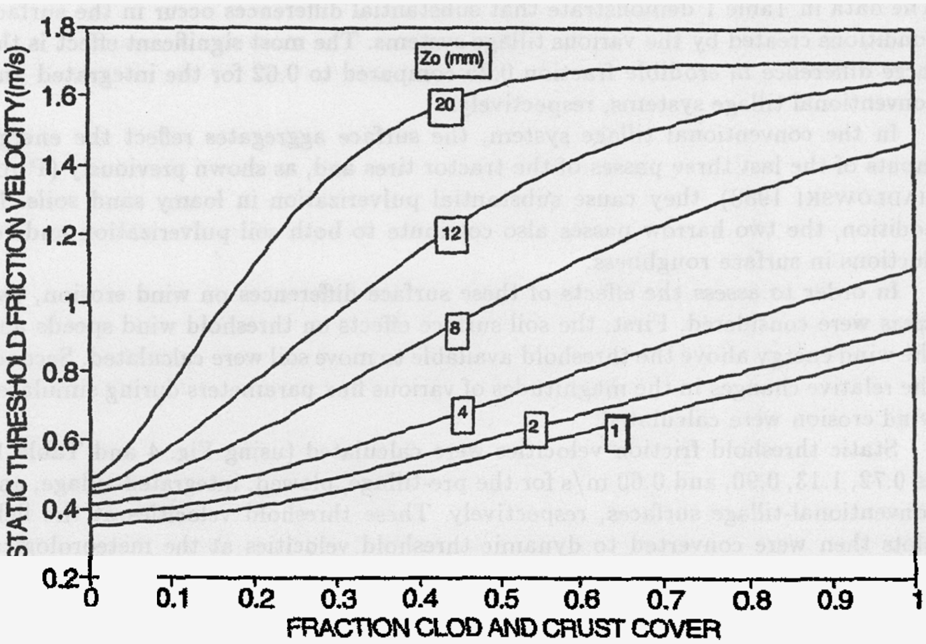

Fig. 4. Static threshold friction velocities needed to initiate wind erosion as a function of both non-erodible clod and crust cover and surface aerodynamic roughness (Zo) on dry, bare fields

The tested surfaces had smaller aerodynamic roughness values than the surface at the Poznań meteorological station, so threshold velocities at the station were adjusted for the station roughness. An aerodynamic roughness of 25 mm was assumed for the meteorological station, and the corresponding station friction velocities were calculated as (PANOFSKY and DUTTON 1984):

$$u_{\mathrm{sta}} = u_* \left(\frac{Zo_{\mathrm{sta}}}{Zo_{\mathrm{field}}} \right)^{0.067} \qquad (5)$$

where: u_{sta} – friction velocity at meteorological station [m/s],
u_* – friction velocity at the field surface [m/s],
Zo_{sta} – aerodynamic roughness at meteorological station [mm],
Zo_{field} – aerodynamic roughness at the field surface [mm].

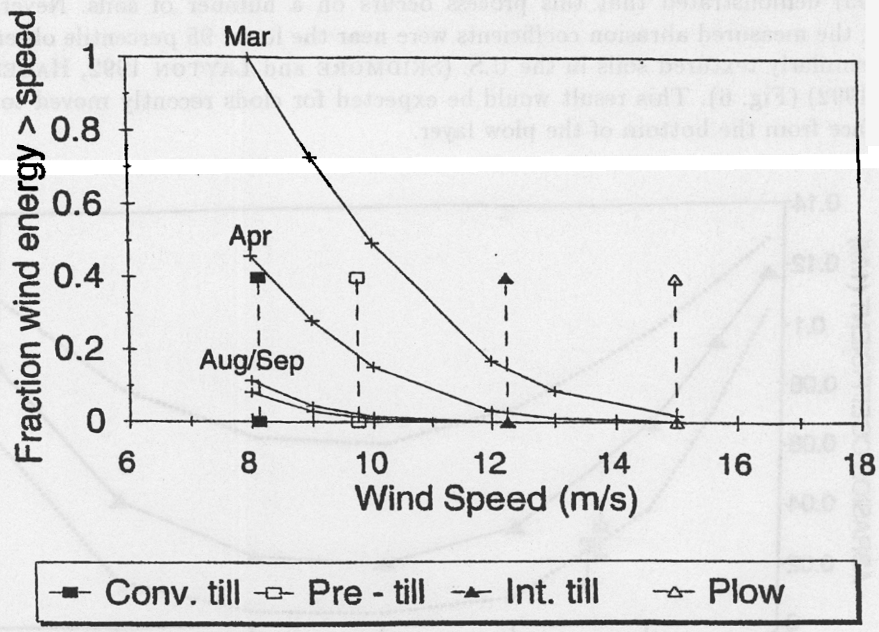

Fig. 5. Fractions of March, April, August, and September wind energies available above various wind speeds relative to the March wind energy available above 8 m/s (solid lines), and calculated dynamic threshold wind speeds at 10 m height at meteorological station for various field surface conditions (dashed lines)

Erosion is generally proportional to the wind energy above the threshold wind speeds. To estimate likely amounts of erosion in any month relative to conventional tillage, wind energies above threshold were normalized to monthly wind energies above threshold of the conventional tillage (Table 3). These results show that integrated tillage significantly reduces erosion in spring. In addition, erosion after integrated tillage in August or September should be controlled, provided the tilled soil conditions are similar to those measured in spring.

Table 3

Fraction of wind energy above threshold wind speeds of other surfaces compared to conventional till

Surface	March	April	August	September
Pre-till	0.56	0.41	0.15	0.18
Plow	0.02	0.002	$2 \cdot 10^{-6}$	$1 \cdot 10^{-4}$
Integrated till	0.15	0.056	0.002	0.004
Conventional till	1.0	1.0	1.0	1.0

Although the major effect of the integrated-tillage system is to prevent erosion by raising the wind speed threshold, it also affects soil flux during wind erosion. First, the soil clods in the integrated-tillage system had an average abrasion coefficient about 91% of those in conventional tillage (Table 1). Thus, clods erode slower during saltation impacts under integrated tillage.

Evidently, surface clods tend to develop stress cracks under repeated tillage, which increases susceptibility to abrasion. In previous work, PODSIADŁOWSKI (1995) demonstrated that this process occurs on a number of soils. Nevertheless, the measured abrasion coefficients were near the lower 95 percentile observed for similarly textured soils in the U.S. (SKIDMORE and LAYTON 1992, HAGEN et al. 1992) (Fig. 6). This result would be expected for clods recently moved to the surface from the bottom of the plow layer.

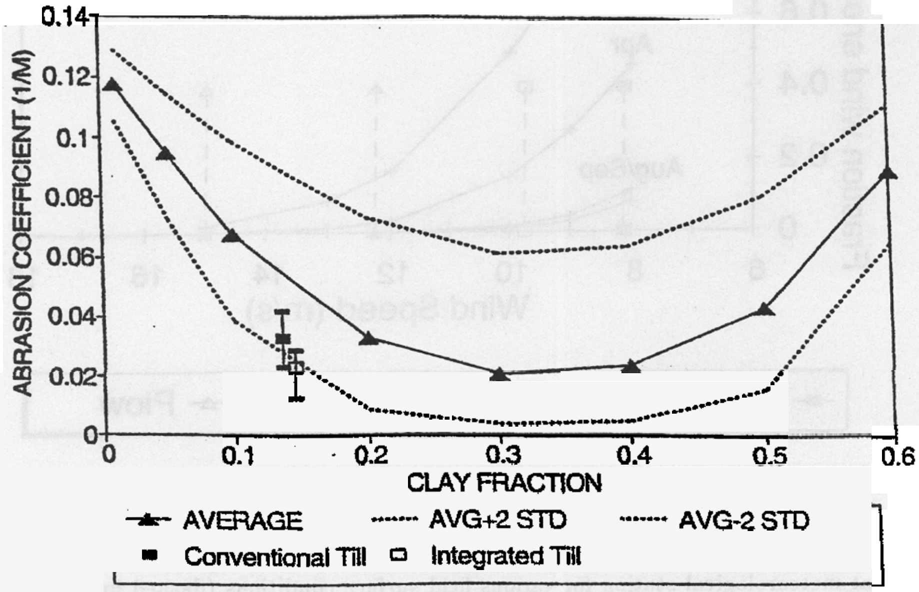

Fig. 6. Calculated mean and standard deviations of clod abrasion coefficients for conventional and integrated tillage on a sandy loam soil in Poland compared to mean and two standard deviations measured in a range of U.S. soils (SKIDMORE and LAYTON 1992, HAGEN et al. 1992)

Finally, using measured surface conditions for the conventional- and integrated--tillage systems, the WEPS erosion submodel (HAGEN 1995) was used to simulate wind erosion. An example of the simulation results for a uniform field with conventional tillage is illustrated in Figure 7. The results showed that distance to transport capacity of saltation/creep increased from about 120 m for conventional

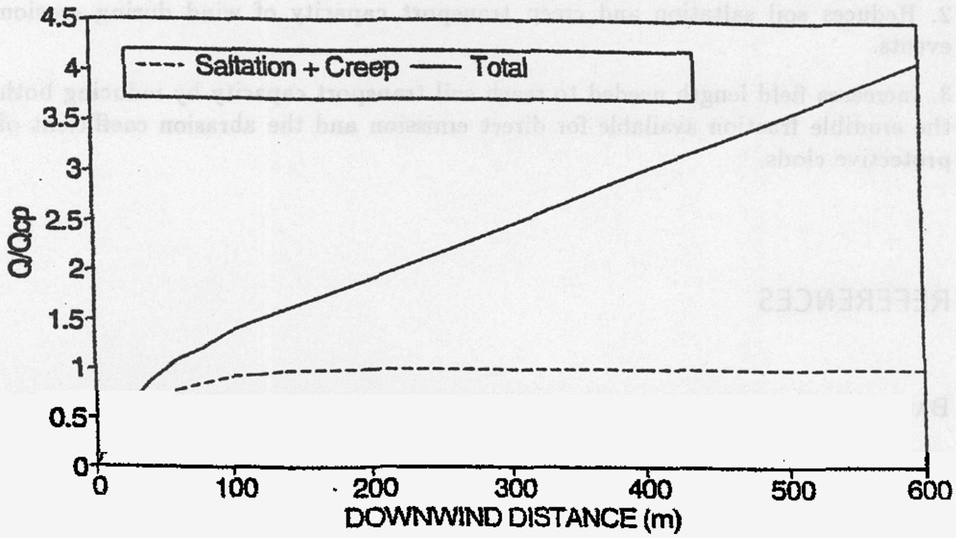

Fig. 7. Simulated saltation and creep downwind horizontal discharge [kg/m] and total downwind horizontal discharge [kg/m] normalized by saltation and creep discharge transport capacity (*Ocp*) as a function of downwind field lenth [m] for a uniform field with conventional-till surface conditions

tillage to about 220 m for conventional tillage to about 220 m under integrated tillage. More importantly, the transport capacity of the integrated-tillage surface was less than 10 and 2% of the capacity of conventional tillage in March and April, respectively.

As erosion proceeds on sandy loam, however, the downwind field surface becomes more erodible. If multiple erosion events occur, erosion from the integrated tillage may eventually become similar to the conventional till near the downwind edge of long fields. Because the downwind areas are potentially subject to large surface changes, using strip cropping or other methods to maintain short field lengths is still important.

The simulation results also showed that the suspension component increased nearly linearly downwind and exceeded the saltation/creep component after about 200 m on uniform fields. This occured because the loose-erodible portion of the sandy loam soils had about 35% suspension component initially (Table 1) and both abrasion of clods and breakage of saltation contributed to further amounts of suspension component. In comparison to saltation/creep component, the suspension component has a very large transport capacity.

CONCLUSIONS

Sandy loam soils often have low natural porosity and are also subject to wind erosion when conventional (multi-pass) tillage system are used. Based on initial data and analyses, an integrated (single-pass) tillage system has the potential to significantly reduce wind erosion in the Wielkopolska region of Poland. The integrated tillage system reduces wind erosion by the following mechanisms:

1. Prevents initiation of erosion by increasing wind speed threshold for wind erosion.

2. Reduces soil saltation and creep transport capacity of wind during erosion events.

3. Increases field length needed to reach soil transport capacity by reducing both the erodible fraction available for direct emission and the abrasion coefficient of protective clods.

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