Soil Redistribution Affected by Tillage in Lower Austrias Farmland

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Abstract: Tillage erosion measurements were conducted in Lower Austrias rolling farmland during the last three years at various slope gradients. Translocation of soil was measured by measuring the movement of aluminum tracers in response to single passes by two tillage implements (moldboard plough, chisel plough). Tillage depth and speed were kept as constant as possible but were varying up to 30 % due to tillage direction and changes in soil conditions. Linear regression equations expressing mean soil displacement as a function of slope gradients were developed and served to calculate tillage erosion coefficients (*k* - values). The *k*-value is defining the erosive capability of one tillage implement for one specific region and implies agrienvironmental conditions as well as tillage specific components. Resulting *k*-values were of the same magnitude for up/downward and contour tillage for each tillage implement but for chisel plough they were only 38 % of those for moldboard plough. The mean soil translocation of all experiments was 0.133 m upwards and 0.325 m downwards for moldboard plough and for chisel plough 0.137 m and 0.238 m, respectively.
Keywords: tillage erosion, soil translocation, tillage implements, soil erosion, tillage

1 Introduction

Recent research has revealed that, besides run-off water and wind activity, there exists a third important erosive agent which contributes significantly to soil erosion appearance on sloping agricultural land. This process which is generally referred to as tillage erosion describes the net downward soil displacement appearing on sloping agricultural land due to agricultural cultivation practices of the soil.

Under extensive European farming conditions, soil translocation by tillage operations is getting more attention. In this field study soil displacement is investigated for (1) different tillage implements (moldboard plough; chisel plough), and (2) different tillage directions (up/downslope, contour).

The experiments were conducted on fields at the agricultural school in Pyhra, Lower Austria. Mean slopes of the sites range between 5% and 20 %. Topsoils (0 cm—30 cm) have a sandy loam to loamy texture.These field investigations are aimed to study effects of key factors on soil movement by tillage including slope gradient, implement type, tillage speed, tillage depth, and tillage direction.

2 Materials and methods

The experiments were conducted on fields at the agricultural school in Pyhra, Lower Austria. Mean slopes of the sites ranged between 5% and 20%. Topsoils (0 cm—30 cm) have a sandy loam to loamy texture.

The methodology used in this study is similar to that used by Van Mysen and Govers (1997) and Govers *et al*. (1994). For each treatment, two strip plots (1 m—1.5 m wide) perpendicular to the tillage direction and on varying slope gradients were established, Fig.1 showes a typical setup of the experimental field. Numbered aluminum cubes with an edge length of 15 mm were used as tracers. On each strip, a series of 11 or 16 holes with a diameter of appr. 2 cm were drilled at intervals of ca. 10 cm, resulting in 55—96 tracers for each strip. Holes were drilled a little bit deeper than tillage depth. In case of a moldboard plough a hole depth of 0.30 m was used, for a chisel plough a depth of 0.25 cm was sufficient. A tracer was then inserted in the hole and its location was precisely recorded using an automatic theodolite. Next, the hole was filled with fine sand over a depth of appr. 4 cm. Another tracer was then inserted and its position was recorded. This procedure was repeated until the hole was completely filled.

Then the experimental field was tilled in the upslope, downslope or contour direction. During tillage, tillage speed and tillage depth were measured and kept as constant as possible but there were variations of up to 30 % due to tillage direction and changing soil conditions. Two tillage implements were used

- moldboard plough: tillage depth 0.23 m, speed 4.5 km • h^{-1}
- chisel plough: tillage depth 0.15 m, speed 8 km • h^{-1}

Immediately after the tillage operation, the plough layer was carefully investigated by means of a metal detector and the location of the displaced tracers were recorded. A recovery rate of the tracers more than 98 % for all strips was obtained. The difference in altitude between non-displaced tracers and the original soil surface served as an estimate for the actual tillage depth.

As each tracer can be identified by its individual number, it is possible to calculate the displacement distances for all tracers, based on the difference in measured coordinates before and after tillage operations.

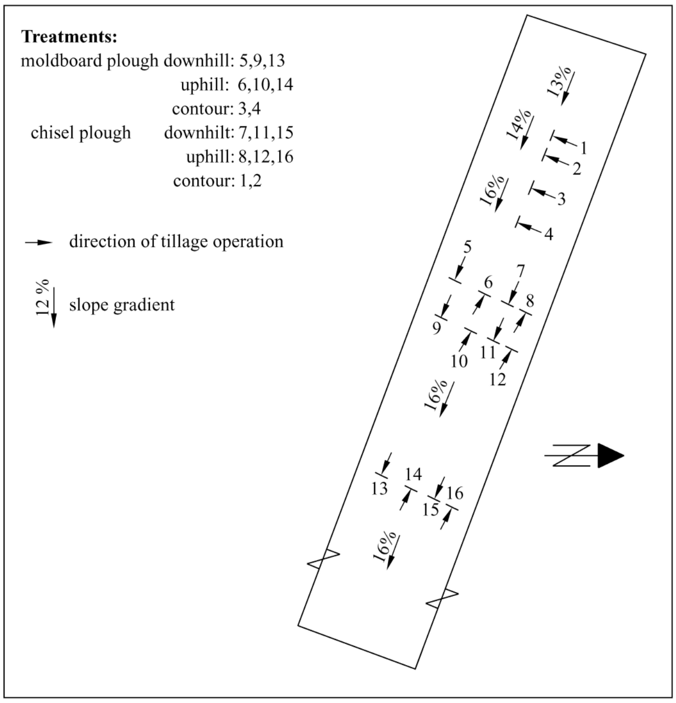

Fig.1 Setup of experiments in September 1999

3 Calculations

From the obtained data, individual horizontal displacement distances of the tracers as well as the mean displacement distance in the direction of tillage and perpendicular to it were calculated for each transect. Only those tracers that were situated in the plough layer were used in these calculations as these were the only ones which were subject to movement during a tillage pass. Tracers situated below the plough layer were excluded from the analysis. No corrections were made for lost tracers.

Soil redistribution by tillage on a hillslope section of infinitesimal length and unit width may be described using the continuity equation for sediment movement on a hillslope (Govers *et al*., 1994)

$$\rho_d \frac{\partial h}{\partial t} = \frac{\partial Q_s}{\partial x} \tag{1}$$

Where ρ_d is bulk density of soil, t is time, h is the height at a given point of the hillslope, Q_s is the flux of soil in the x-direction per unit width, and x is the distance in the horizontal direction.

Displacement distances were calculated in all tillage directions (upslope, downslope, along contour). Soil fluxes, Q_s, per tillage operation (mass of soil that passes a vertical plane along a unit length of contour line, in kg • m^{-1}) in the direction of the steepest slope were calculated from the mean displacement distance d of all tracers (in m), from the tillage depth *D* (in m), and from the soil bulk density ρ_d (kg • m^{-3}) according to the equation (Poesen *et al*., 1997):

$$Q_s = d \bullet D \bullet \rho_d \tag{2}$$

For upslope, downslope and contour tillage, displacement distances occur in both up- and downslope direction. Therefore, an average net soil flux Q_{snet} was calculated from the mean upslope (d_{up}) and the mean downslope displacement distance (d_{down}) using following equation (Poesen *et al*., 1997)

$$Q_{snet} = (d_{down} - d_{up})/2 \bullet D \bullet \rho_d \tag{3}$$

Based on the relationship between slope gradient and mean soil translocation distance in tillage direction, Govers *et al*. (1994) developed a diffusion-type model to calculate the net unit soil transport rate and soil erosion rates along a hillslope profile due to a single tillage operation (Lindstrom *et al*., 2000). This enables to calculate a tillage erosion coefficient, *k*, as a measure of the intensity of tillage erosion for a single tillage operation under given agrienvironmental conditions. Therefore, the unit soil transport rate, Q_s, at a specific point in the field can be calculated with the following equation:

$$Q_s = k \bullet S \tag{4}$$

Where *S* is the slope gradient (m m^{-1}), and *k* is the tillage erosion coefficient (kg • m^{-1} per tillage operation).The tillage erosion coefficient *k* is then defined as:

$$k = \rho_d \bullet D \bullet B \tag{5}$$

Where *B* is the slope of the linear regression equation of the relationship between soil displacement and slope gradient (a single linear regression for up- and downslope tillage; Van Muysen *et al*., 1999).

4 Results

Fig.2—5 contain results from tillage experiments performed in Mai and September of 1999, 2000 and 2001. Bulk density ranged from 1,378 to 1,681 kg • m^{-3} and soil water contents of plough layer at tillage were varying from 12% to 28% due to intensive rainfalls shortly before tillage operations in September 1999 and a very dry weather period in spring 2000. This affected soil dislocation and may be one reason for the great variation of the measurements.

For moldboard plough soil displacement distances for 9.1% to 17.1% slopes ranged from 0.149 m to 0.504 m in downslope direction, and from 0.010 m to 0.269 m in upslope direction. Corresponding values for chisel plough ranged between 0.169 m and 0.363 m downslope and between 0.017 m and 0.193 m upslope, respectively.

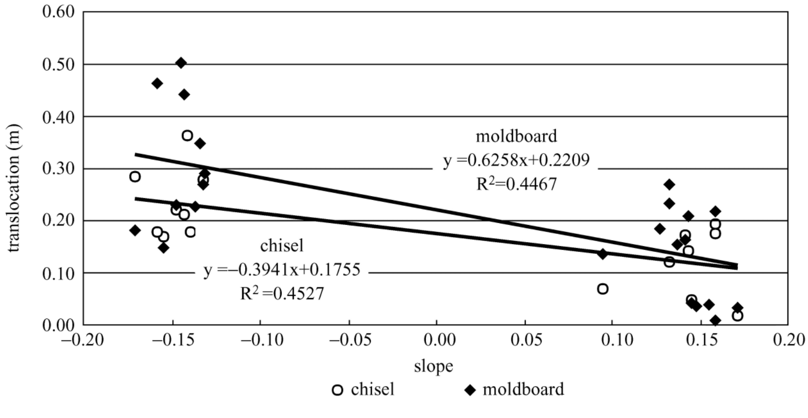

Fig.2 Mean translocation distances [m] in tillage direction for moldboard and chisel ploughing up/downslope

For contour tillage with moldboard plough (turning soil upwards) soil displacements were between 0.362 m and 0.550 m perpendicular to tillage direction i.e. upslope. Chisel ploughing resulted in a downslope movement between 0.000 and 0.122 m. Displacement in tillage direction ranged from 0.137 m to 0.499 m with moldboard and from 0.063 m to 0.584 m with chisel plough at contour ploughing.

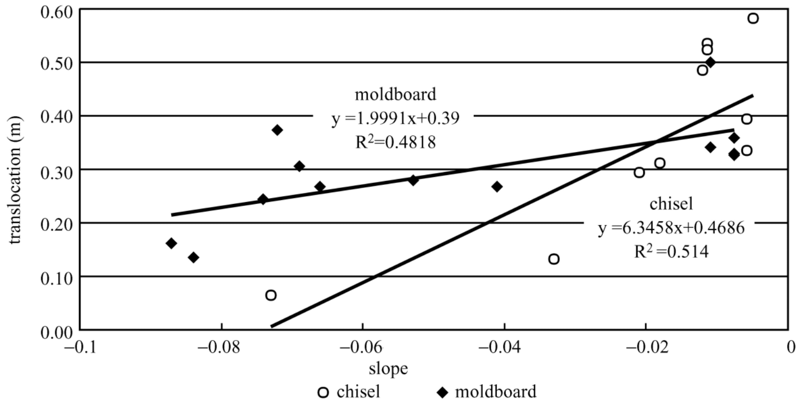

Fig.3 Mean translocation distances [m] in tillage direction for moldboard and chisel ploughing along contour

Translocation distances for moldboard plough perpendicular to tillage direction ranged from 0.025 m to 0.513 m tilling upslope and from 0.413 m to 0.634 m downslope. Chisel ploughing resulted in 0.005 m to 0.176 m and 0.004 m to 0.061 m of perpendicular translocation in up- and downslope tilling. The measured soil displacement distances are compareable to those published by van Muysen *et al.* (1999), Lindstrom *et al.* (1992), Quine *et al.* (1999), and Montgomery *et al.* (1999).

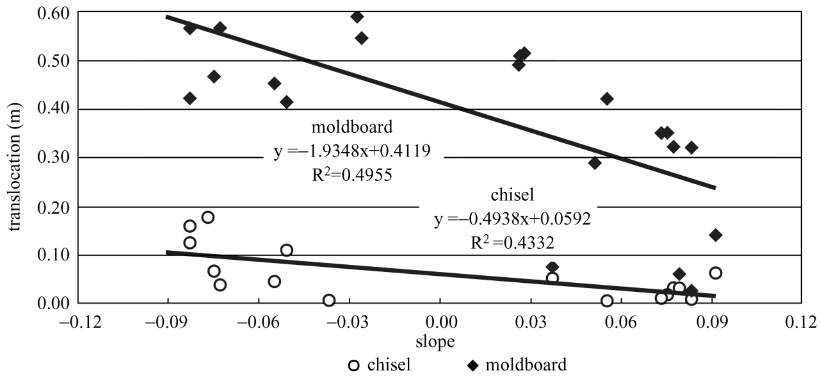

Fig.4 Mean dislocation distances [m] perpendicular to tillage direction for moldboard and chisel ploughing up/downslope

Regression of slope versus translocation leads to a gradient of - 0.6258 for moldboard plough and a gradient of – 0.3941 for chisel plough in up- and downslope tillage. At contour tillage regression gradients are – 0.6639 for moldboard plough and – 0.3561 for chisel plough.

The intensity of the tillage erosion process can be characterised by a single konstant, *k*, which is referred to as tillage erosion coefficient. The *k*-value implies agrienvironmental conditions like bulk density, soil moisture, soil texture and crop rotation as well as tillage specific components like tractor speed, depth and direction of tillage and the applied tillage implement. Therefore the *k*-value is definig the erosive capability of one tillage implement for one specific region. Table 1 showes *k*-values derived from our experimental data which fit well to data from other publications.

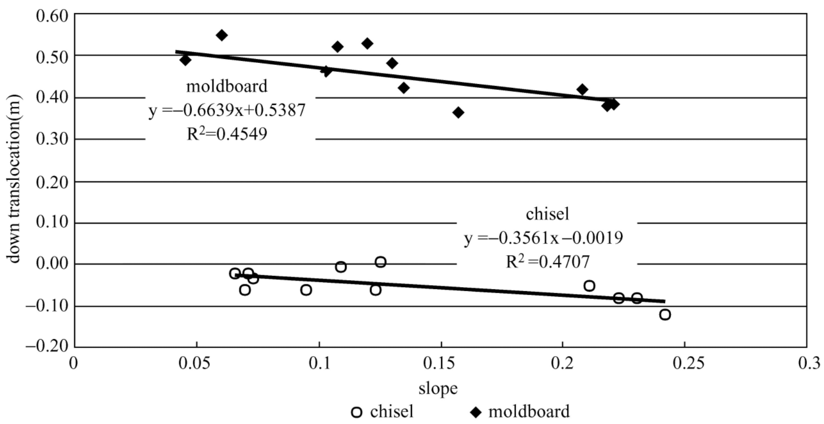

Fig.5 Mean dislocation distances [m] perpendicular to tillage direction for moldboard and chisel ploughing along contour

The mean soil translocation of all experiments was 0.133 m upward and 0.325 m downward for moldboard plough and 0.137 m respectively 0.238 m for chisel plough tilling up/downwards. At contour tillage the upward translocation was 0.453 m with moldboard plough (turning soil upwards) respectively 0,513 m turning soil downwards and with chisel plough it was 0.051 m downwards.

Table 1 Tillage erosion coefficient (*k*) for one single tillage pass

Implement	tillage direction	*k*-value
		[kg • m^{-1}]
Moldboard plough	up/downslope	230
Moldboard plough	Contour (turning soil upwards)	244
Chisel plough	up/downslope	95
Chisel plough	Contour	85

5 Conclusions

During the last three years a total number of 92 tillage experiments (30 contour and 26 up/downslope with moldboard plough, 16 contour and 20 up/downslope with chisel plough) were carried out in different seasons and therefore varying agrienvironmental conditions. The broad distribution of the results and the weak correlation of slope versus translocation show that factors like initial soil conditions and tractor speed influence the soil movement heavily.

Moldboard ploughing in contour direction delivered *k*-values of the same order of magnitude like up/downslope tillage. That shows that the topsoil is moved upwards in the same magnitude by contour tillage as it is moved downwards by up/downslope tillage.

Chisel ploughing generates more or less the same soil translocation at contour tillage and at up/downslope tillage but the soil is always moved downwards. Moldboard ploughing causes 2,6 times higher soil translocation than chisel ploughing.

The study showes that besides water erosion soil translocation by tillage leads to downslope soil dislocation. On a longterm scale this process affects soil quality and fertility especially in upslope positions.

Acknowledgement

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