

Soil Losses Caused by Chicory Root and Sugar Beet Harvesting in Belgium: Importance and Implications

Jean W.A. Poesen*, Gert Verstraeten, Leen Seynaeve and Ruben Soenens

ABSTRACT

The impacts of land use and land use changes on soil erosion processes have received and still receive considerable attention, e.g. in the framework of Global Change projects. Land use changes typically affect the rates of water, wind, and tillage erosion. Field observations point to an additional significant soil degradation process, which has hitherto never been considered in assessments of soil erosion rates: i.e. Soil Losses due to Root crop Harvesting (SLRH). The objectives of this study were 1) to assess SLRH for two commonly grown root crops in Belgium, i.e. chicory root and sugar beet, 2) to investigate some factors controlling the spatial and temporal variation of SLRH, and 3) to evaluate the impacts of this soil degradation process on overall soil loss in the study area. Mean soil losses are 11.8 ton ha⁻¹ harvest⁻¹ for witloof chicory root, 8.1 ton ha⁻¹ harvest⁻¹ for inuline chicory root and 9.5 ton ha⁻¹ harvest⁻¹ for sugar beet. Assuming that root crops are grown once in two years in the study area, mean annual SLRH equals 5.0 ton ha⁻¹ year⁻¹. However, important spatial and temporal variability in SLRH data is observed, depending in part on soil texture and on soil moisture at harvest time. Given the importance of SLRH, in comparison with other processes causing soil loss in the study area, this soil degradation process needs to be incorporated in future assessments of soil degradation processes and of sediment budgets.

INTRODUCTION

The impacts of land use and land use changes on soil degradation processes have received and still receive considerable attention, for instance in the framework of Global Change studies (e.g. Ingram et al. 1996, Poesen et al. 1996a, Bouma et al. 1998). In the past, studies looking at anthropogenic soil erosion only focused on water and wind erosion and mass movements as soil degradation processes causing significant on site soil losses as well as off site problems (e.g. Oldeman et al. 1991). More recently, tillage erosion has also been identified as an important soil degradation process in a range of intensively cultivated hilly environments (e.g. Govers et al. 1994, Poesen et al. 1997, Turkelboom et al. 1997).

Land use changes typically affect the rates of water erosion, mass movements, wind erosion, and tillage erosion. However, field observations in central Belgium point to an additional significant soil degradation process which has

hitherto rarely been considered in assessments of soil erosion rates: i.e. soil losses due to root crop harvesting (SLRH). When harvesting root crops such as chicory root (*Cichorium intybus* L.) and sugar beet (*Beta vulgaris* L.) in Belgium, significant soil losses do occur in addition to soil losses caused by water erosion (interrill, rill, and ephemeral gully erosion) and tillage erosion.

In the soil degradation literature, very few data have been published on this process. Maier and Schwertmann (1981) and Auerswald and Schmidt (1986) estimate that mean soil losses due to sugar beet harvesting in Bavaria (southern Germany) ranges between 4.5 and 7 ton ha⁻¹ yr⁻¹. Vandenberghe & Gulinck (1987), studying ¹³⁷Cs losses in a catchment located in central Belgium, report that dirt tare (mass of wet soil sticking to the root / gross root yield) associated with sugar beet harvest causes maximal yearly soil losses of about 5 ton ha⁻¹ year⁻¹. Frost & Speirs (1996) state that harvesting root crops such as potato or carrot in Scotland commonly removes 1 ton of soil/ha. Within their study area, this would be a more significant cause of soil loss on 94 % of the study area than the soil loss due to water erosion triggered by a severe rain storm with a return period in excess of 20 years. Little or no data on spatial and temporal variation of SLRH exist. Some data on dirt tare can be found in the literature dealing with agronomic aspects of root crops or with machinery used to harvest root crops (e.g. Brunotte and Isensee 1994, Duval 1988, Hoogerkamp 1993, Theurer 1994, Vandergeten et al. 1995). However, from an extensive literature research, we concluded that very few studies have attempted to quantify these soil losses when assessing soil degradation rates in agricultural lands.

The objectives of this study were 1) to assess SLRH for two commonly grown root crops in central Belgium: i.e. chicory root (both witloof chicory and inuline chicory) and sugar beet, 2) to investigate some factors controlling SLRH spatial and temporal variation, and 3) to evaluate the impacts of this soil degradation process on overall soil loss in the study area.

STUDY AREA

The study area in central and northern Belgium is characterized by a temperate humid climate: mean annual air temperature is 9.5°C and annual precipitation ranges between 700 and 850 mm. Precipitation depth is well distributed over the year but rain erosivity is highest in July-August and lowest from November until April. The northern lowland plain has sandy and clayey soils. The central plateau soils have a loamy sand, sandy loam, and silt loam (loess)

*Jean W.A. Poesen, Gert Verstraeten, Leen Seynaeve and Ruben Soenens, Laboratory for Experimental Geomorphology, K.U.Leuven, Redingenstraat 16, B-3000 Leuven. *Corresponding author: jean.poesen@geo.kuleuven.ac.be.

texture. A large part of the land in this region has been under intensive cultivation for several centuries and is now mainly used for the production of winter wheat and barley (autumn sown), sugar beet, chicory, potato, and maize (spring sown). In 1998, the area under cultivation in Belgium-Luxemburg for chicory root production equaled 12,649 ha and for sugar beet 92,980 ha (FAOSTAT, 1999). These areas represent 62.7 % and 1.3 % respectively of the world area for these crops.

MATERIALS AND METHODS

Witloof chicory

Dirt (soil) tare for witloof chicory root is not measured on a regular basis. Therefore, 43 witloof chicory root samples were taken in the field when root were harvested with machines in the autumn of 1996 (9 samples) and 1997 (34 samples). The chicory fields were selected in such a way that they represented a range of soil textures whereas the timing of sampling was such that the topsoil had a range of soil water contents at harvest time.

Each witloof chicory root sample was collected in a 10 liter plastic bag and contained a number of randomly sampled roots varying between 20 and 50, depending on the root size. At the time of root sampling, one soil sample at 8 cm depth in the plow layer was also taken for gravimetric soil water content (SWC) and soil texture (sieve-pipette method) determinations. Total number of chicory root per ha was also assessed in the field; this parameter ranged between 150,000 and 300,000 roots ha^{-1} . Next, the root + dirt tare were weighed, washed and weighed again and mean oven-dry soil mass sticking to each individual root (Ms) of a given sample was calculated, taking SWC at harvest time into account. This figure was then converted into total soil loss per ha of chicory root (SLRH).

Inuline Chicory

Factories processing chicory root for the production of inuline measure dirt tare of chicory root produced by the farmers. To calculate soil losses due to chicory root harvesting, the following data for the period 1990 – 1996, provided by an inuline producing factory (i.e. Raffinerie Notre-Dame/Orafti s.a., Oreye, eastern Belgium), were used: gross root yield (total mass of roots, including mass of toppings, mass of soil and mass of soil water), top tare (mass of toppings/gross root yield) and dirt tare (total mass of soil and soil water/gross root yield). This factory processes chicory roots grown in an area of approximately 2000 ha. In order to calculate oven-dry soil losses, it was assumed that mean gravimetric moisture content of the soil sticking to the root at the time the root were delivered to the factory ranged between 0.10 and 0.20, which is a realistic soil water content range during the harvesting season (Govers and Poesen 1986). The calculated annual SLRH data represent a spatial (ca. 2,000 ha) and temporal (i.e. within the harvesting season) mean value.

Sugar beet

A procedure identical to the one for inuline chicory root was used to calculate the SLRH data for sugar beet. Here, data for the whole of Belgium (i.e. more than 90,000 ha

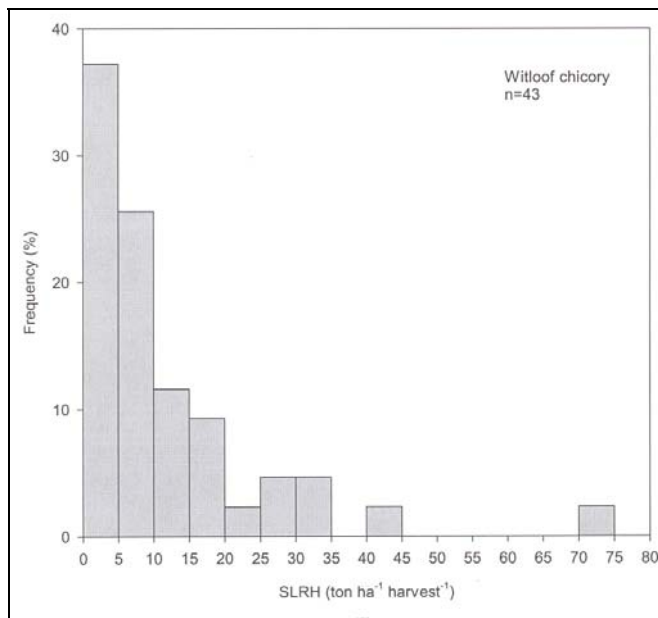


Figure 1. Frequency distribution of soil losses caused by witloof chicory root harvesting (SLRH), calculated from 43 root samples taken in central and northern Belgium at harvesting time.

under sugar beet) were provided by the Belgian Beet Growers Association (CBB). Thus, the calculated annual SLRH data represent a spatial (ca. 90,000 ha) and temporal (i.e. within the harvesting season) mean value.

RESULTS AND DISCUSSION

Witloof chicory

Mean, minimum, and maximum Ms values were respectively 56.6, 5.0 and 321.0 g root $^{-1}$. Fig. 1 depicts the frequency distribution of SLRH for witloof chicory root. Mean SLRH amounts to 11.8 ton ha^{-1} harvest $^{-1}$ (minimum SLRH = 1.7 ton ha^{-1} harvest $^{-1}$, maximum SLRH = 70.5 ton ha^{-1} harvest $^{-1}$). These figures corroborate data published by Lips (1993) who reported dirt tare data for witloof chicory root varying between 5 and 30 ton ha^{-1} harvest $^{-1}$.

In order to explain the observed variation in Ms and SLRH data, relations with % clay, % silt, % (clay + silt), % sand and SWC were investigated and more details can be found in Poesen et al. (2001). The range of these parameters for the 43 witloof chicory root samples is as follows: % clay (0.2 – 48.6), % silt (7.4 – 92.5), % (clay + silt) (14 – 95), % sand (5 – 86) and SWC (%), 11.7 – 33.7). Overall, correlations between these soil parameters and Ms were better than with SLRH. The highest coefficient of determination between Ms and soil properties was found for % sand ($r^2 = 0.43$) followed by % (clay + silt) ($r^2 = 0.38$), % silt ($r^2 = 0.34$), SWC ($r^2 = 0.19$) and % clay ($r^2 = 0.003$). Multiple regression equations containing two or more of these soil parameters were not significant.

The best predictive equations for witloof chicory root were:

$$Ms \text{ (g root}^{-1}\text{)} = 664.2 (\% \text{ sand})^{-0.795} \quad (1)$$

$$r^2 = 0.43$$

and

$$SLRH \text{ (ton ha}^{-1} \text{ harvest}^{-1}) = 106.1 (\% \text{ sand})^{-0.736} \quad (2)$$

$$r^2 = 0.35$$

The negative relation between Ms or SLRH and sand content is explained by a decreasing cohesion (stickiness) with increasing sand content.

Inuline chicory

Over a 7 year period mean SLRH value equals 8.43 ton ha⁻¹ harvest⁻¹ assuming SWC = 0.10 and 7.73 ton ha⁻¹ harvest⁻¹ assuming SWC = 0.20 (Fig. 2). However, important variations in annual SLRH figures can be observed: i.e. SLRH ranges between 3.1 – 3.4 ton ha⁻¹ harvest⁻¹ in 1995 and 12.2 – 13.2 ton ha⁻¹ harvest⁻¹ in 1992. Part of this variation can be explained by total rain amount recorded during the harvest season (1 September – 31 December) at a nearby rain station, which may reflect top soil water content during harvest (Fig. 2).

Sugar beet

Mean long-term (1968 - 1996, 29 years) SLRH value is 9.12 ton ha⁻¹ harvest⁻¹ assuming SWC = 0.10 and 8.36 ton ha⁻¹ harvest⁻¹ assuming SWC = 0.20 (Fig. 3). Maximum and minimum annual SLRH-values equal 18.7 – 20.4 ton ha⁻¹ harvest⁻¹ (1974) and 4.2 – 4.6 ton ha⁻¹ harvest⁻¹ (1969) respectively. For individual deliveries of sugar beet to the factory, SLRH-values can range between even more extreme values: i.e. 1 – 100 ton ha⁻¹ harvest⁻¹.

Almost half of the variation in annual SLRH can be explained by total rain amount recorded during the harvest season (P) (Fig. 3).

$$SLRH \text{ (ton ha}^{-1} \text{ harvest}^{-1}) = 0.034 P(\text{mm}) + 0.082 \quad (3)$$

$$r^2 = 0.47$$

where SLRH is calculated assuming SWC = 0.10.

The positive relation between P and SLRH can be explained by a positive relation between soil water content during harvest and SLRH as indicated in Fig. 4 (based on data published by Duval, 1988). The remaining scatter is caused by, amongst other factors, the temporal distribution of rain within the harvest season and the exact timing of harvest.

Mean long-term rain amount during harvest season in central Belgium (Ukkel) equals 278 mm. Using equation 3, this corresponds to a mean annual SLRH for sugar beet of 9.5 ton ha⁻¹ harvest⁻¹.

Although this study presented some data on the spatial and the temporal variation of SLRH, significant research efforts are needed to quantify the factors controlling spatial and temporal variation of SLRH.

IMPLICATIONS

Mean SLRH for both witloof chicory and inuline chicory as well as for sugar beet indicate that these soil losses are far from negligible.

Given its importance, SLRH should also be considered as a significant soil degradation process in future assessments of land use impacts on soil degradation. In the past, when confronting overall soil losses with soil loss tolerance levels (e.g. Morgan 1995) this process was not considered. One of the agronomic measures to control mean long-term soil losses due to water erosion is crop rotation.

For each crop, soil losses by water erosion are quantified in order to calculate total long-term soil loss. If root crops are included in the crop rotation scheme, the SLRH should also be taken into account. As an example, Table 1 compares mean annual long-term SLRH and annual soil losses caused by other soil degradation processes in central Belgium.

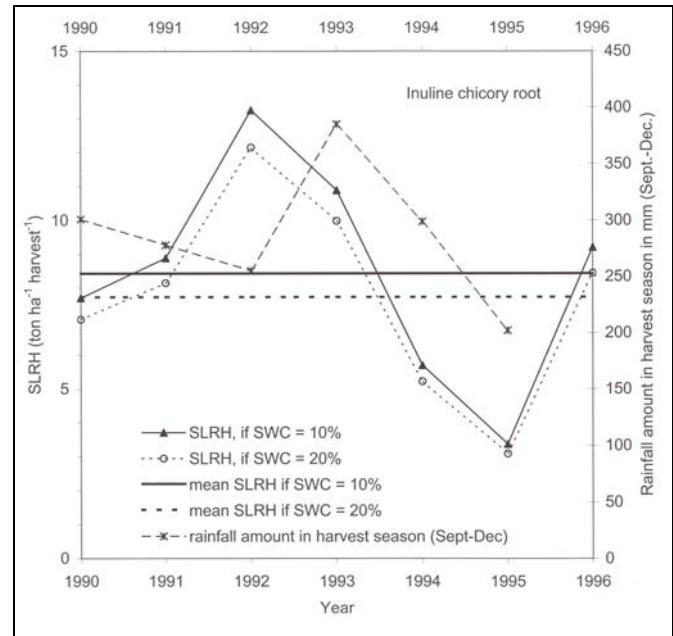


Figure 2. Evolution of mean annual soil losses due to harvesting of inuline chicory root (SLRH). SLRH was calculated using data provided by Raffinerie Notre-Dame/Orafti s.a. (Oreye, Belgium) and assuming two gravimetric soil water contents (SWC): i.e. 10 % and 20 %. Total rain amount recorded during harvest season at a nearby station (Waremmme) is also shown.

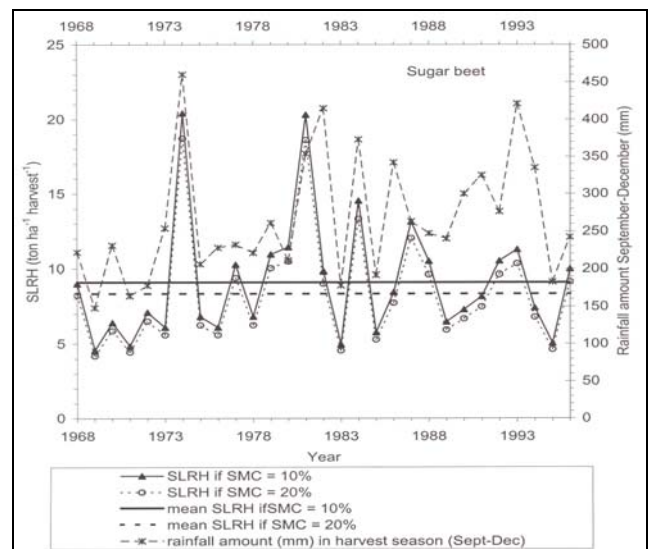


Figure 3. Evolution of mean annual soil losses due to sugarbeet harvesting in Belgium. SLRH was calculated using data provided by the Confederation of Belgian Sugar Beet Growers and assuming two gravimetric soil water contents (SWC): i.e. 10 % and 20 %. Total rain amount recorded during harvest season in central Belgium (Ukkel) is also shown.

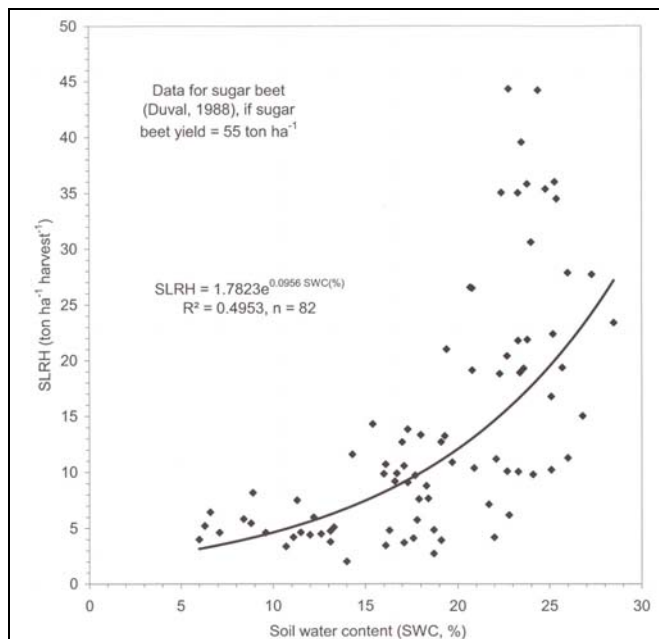


Figure 4. Relation between gravimetric moisture content of the top soil and soil losses caused by harvesting sugar beet (SLRH). SLRH was calculated based on dirt tare data published by Duval (1988) and assuming a mean net sugar beet yield of 55 ton ha⁻¹.

Mean annual SLRH equals 5.0 ton ha⁻¹ year⁻¹ and is calculated using an average figure based on the SLRH data obtained in this study and assuming that roots and tubers crops (chicory, sugar and fodder beet or potato) are grown once every two years. This figure corresponds quite well with average data published by Maier and Schwertmann (1981) and Auerswald and Schmidt (1986) for southern Germany and by Vandenberghe and Gulink (1987) for central Belgium.

In central Belgium, SLRH represents on average 21.5 % of total soil loss. However, in flat areas, the contribution of SLRH to total soil loss can be as high as 100 %. Therefore, SLRH needs to be incorporated in sediment budgets.

Water erosion and tillage erosion are quite intense in central Belgium at specific topographic positions in the landscape: i.e. on steep and long slopes as well as in planform concavities for water erosion, and on hillslope convexities and upper parts of field plots for tillage erosion (Van Oost and Govers 1998). However, although not yet studied, it is very likely that SLRH are less dependent from topography, unless topography has a strong control on soil texture and soil water content at harvesting time.

When interpreting processes leading to soil profile truncation, SLRH need to be considered too. For central Belgium, roots and tubers are grown for over 200 years. Assuming a mean annual denudation rate of 0.33 mm (5 ton ha⁻¹ year⁻¹, Table 1) this results in an overall soil profile truncation of 66 mm.

Given the importance of SLRH, these soil losses should be reduced where possible in order not to exceed soil loss tolerance levels. This could be achieved by, for instance, reducing the area where root crops are grown, by providing

Table 1: Mean annual soil losses due to various soil degradation processes in central Belgium. SLRH is calculated assuming that once in two years a root or tuber crop is grown in the study area.

Process	Soil loss (ton ha ⁻¹ year ⁻¹)	Source
Water erosion		Poesen et al. (1996b)
- interrill and rill erosion	6.9 (29.6 %)	
- ephemeral gully erosion	5.4 (23.2 %)	
Tillage erosion	6.0 (25.7 %)	Van Oost & Govers (1998)
Soil Loss by Root crop Harvesting (SLRH)	5.0 (21.5 %)	This study
Total:	23.3 (100 %)	

financial incentives for root crop growers in order to encourage low SLRH or by charging environmental taxes for large SLRH.

ACKNOWLEDGEMENTS

The authors thank the following persons who provided background information or data on yield and dirt tare of various root crops: Dr. K. Auerswald (T.U. München), Dr. J. Boiffin, Dr. Y. Duval and Dr. J. Guérif (INRA, Laon, France), Mr. D. Du Ville (Confederation of Belgian Sugar Beet Growers, Brussels), Mr. J. Fockedeey (Warcoing Industrie s.a.), Dr. F. Kwaad (University of Amsterdam), Mr. G. Legrand and Mr. J.P. Vandergeten (KBIVB, Royal Institute for the Improvement of the Sugar beet, Tienen), Mr. G. Paternoster (Raffinerie Notre-Dame/Orafti s.a., Oreye) and Mr. Rob Sarrazyn (Provinciaal Voorlichtingscentrum West-Vlaanderen)

REFERENCES

- Auerswald, K. and F. Schmidt. 1986. Atlas der Erosionsgefährdung in Bayern. GLA-Fachberichte, München, 1, 74 pp.
- Bouma, J., G. Varallyay and N.H. Batjes. 1998. Principal land use changes anticipated in Europe. *Agriculture, Ecosystems and Environment* 67:103-119.
- Brunotte, J. and E. Isensee. 1994. Nach Mulchsaat weniger Erdanhang? *DLG-Mitteilungen* 3:20-21.
- Duval, Y. 1988. Pour réduire la tare, connaître et observer les sols. *Le Betteravier Français* 531:27, 29.
- FAOSTAT, 1999. Agriculture data. Agricultural production. Available at <http://apps.fao.org>.
- Frost, C.A. and R.B. Speirs. 1996. Soil erosion from a single rainstorm over an area in East Lothian, Scotland. *Soil Use and Management* 12:8-12.
- Govers, G. and J. Poesen. 1986 A field-scale study of surface sealing and compaction on loam and sandy loam soils. Part I. Spatial variability of soil surface sealing and crusting. In Callebaut, F., D. Gabriels and M. De Boodt(eds.) *Assessment of Soil Surface Sealing and Crusting*, University of Ghent, 171-182.

- Govers, G., K. Vandaele, P. Desmet, J. Poesen and K. Bunte. 1994. The role of tillage in soil redistribution of hillslopes. *European Journal of Soil Science* 45:469-478.
- Hoogerkamp, D. 1993. Research on dirt tare in the Netherlands. Proc. 27th Biennial Meeting Agriculture, Anaheim, California, March 3-6, 1993, American Society of Sugar beet Technologists, 113-119.
- Ingram, J., J. Lee and C. Valentin. 1996. The GCTE soil erosion network: a multi-participatory research program. *J. Soil and Water Conservation* 51:377-380.
- Lips, J. 1993. Het rooien van de wortelen. In *Witloofteelt*. Ministry of Agriculture, Brussels, 81-90.
- Maier, J. and U. Schwertmann. 1981. Das Ausmass des Bodenabtrags in einer Lösslandschaft Niederbayerns. *Bayerisches Landwirtschaftliches Jahrbuch*, 58 (2): 194.
- Morgan, R.P.C. 1995. *Soil Erosion and Soil Conservation*. Longman, England.
- Oldeman, L.R., R.T.A. Hakkeling and W.G. Sombroek. 1991. World map of the status of human-induced soil degradation: An explanatory note. *ISRIC Wageningen*, UNEP, Nairobi, 34 p.
- Poesen, J., J. Boardman, B. Wilcox and C. Valentin. 1996a. Water erosion monitoring and experimentation for global change studies. *J. Soil and Water Conservation* 51:386-390.
- Poesen, J., K. Vandaele and B. van Wesemael. 1996b. Contribution of gully erosion to sediment production on cultivated lands and rangelands. *IAHS Publ.* 236:251-66.
- Poesen, J., B. van Wesemael, G. Govers, J. Martinez-Fernandez, P. Desmet, K. Vandaele, T. Quine and G. Degraer. 1997. Patterns of rock fragment cover generated by tillage erosion. *Geomorphology* 18:183-197.
- Poesen, J., G. Verstraeten, R. Soenens and L. Seynaeve. 2001. Soil losses due to harvesting of chicory roots and sugar beet: an underrated geomorphic process? *Catena* 43:35-47.
- Theurer, J.C. 1994. Agronomic comparison of different types of smooth root and "soil free" sugarbeet. *Journal of Sugar Beet Research* 31 (3-4):105-116.
- Turkelboom, F., J. Poesen, I. Ohler, K. Van Keer, S. Ongprasert, and K. Vlassak. 1997. Assessment of tillage erosion rates on steep slopes in northern Thailand. *Catena* 29:29-44.
- Vandenberghe, I. and H. Gulinck. 1987. Fallout ¹³⁷Cs as a tracer for soil mobility in the landscape framework of the Belgian loamy region. *Pedologie* 37-1:5-20.
- Vandergeten, J.P., T. Vreven, and P. Engels. 1995. Les démonstrations de matériel de récolte en 1994. *Le Betteravier*, Février 1995:18-23.
- Van Oost, K. and G. Govers. 1998. Bodemverplaatsing door landbewerking in de Belgische leemstreek: modelleren, kwantificeren en temporele evolutie. *De Aardrijkskunde* 1998 (1-2):91-99.