In: *Prediction and Reduction of Diffuse Pollution, Solid Emission and Extreme Flows from Rural Areas – case study of small agricultural catchment* (ed. by K. Banasik, L. Øygarden & L. Hejduk), 153–169. Wydawnictwo SGGW, Warszawa – PL, 2011.

10

Erosion studies in plot field experiments with different tillage systems in Norway

TROND BØRRESEN

Norwegian University of Life Sciences, Department of Plant and Environmental Sciences, P.O. Box 5003, NO-1432 Aas, Norway, trond.borresen@umb.no

Background

The mechanisation of the agriculture and the increased production lead to a change in land use in Norway during the 1950ies and 1960ies. The government decided to support grain production in south-eastern Norway and reduced the subsidies for milk production in this area compared with other parts of Norway. This caused more monoculture grain production in south-eastern Norway, but also land levelling and cultivation of new land. This was partly also happening in middle part of Norway however not to the same extent as in south-eastern Norway. The levelling of steep land was allowing mechanisation of areas which has been used for grazing before. Especially the land levelling led to very visible erosion by heavy rilling and gullying. It thus became clear that parts of the agricultural area in Norway had erosion problems and this led to the start of erosion research during the late 1970ies.

The annual precipitation in south-eastern Norway varying from 700–800 and increases from May to November and so it declines. The monthly variation is high and can some years be 2–3 times higher than the average. Especially when high precipitation is occurring in late autumn the agricultural areas are very susceptible to erosion. Intense showers in the growing season happen but are rare. The temperature during winter (December to March) is in average below zero. However, even if some winters can be very cold, other can be very mild and the precipitation will be in the form of rain. Even in mild winters there will be cold periods and the surface layer will be frozen. These events can have a dramatic effect on soil erosion and surface runoff. Under normal winter condition there will be snow melting periods in March and early April. The snow melting contributes significantly to soil erosion (Øygarden 2000)

However, the first measurements of soil erosion in Norway on cultivated land were done in a plot field experiment started 1971 by Uhlen (1978). The main purpose of this experiment was to study nutrient losses, but soil losses were also measured. More comprehensive studies of soil erosion in plot experiments especially on levelled soils were started around 1979 by Njøs and Hove (1986). They measured very high soil losses from levelled soils, especially by autumn ploughing and advised several ways to reduce these losses by better plant or residue cover, application of organics etc. Due to the fact that up to 40% of the agricultural area in some communities was levelled and erosion risk on levelled land could be 3–10 times higher than on not levelled land, soil losses therefore increased dramatically in many communities in south-eastern Norway.

These measurements were continued by Skøien (1988) and expanded by Lundekvam (1990, 1997 and 2007), Lundekvam and Skøien (1998). Since about 1990 and to 2007, associate professor Helge Lundekvam was responsible for the erosion experiments at Department of Plant and Environmental Sciences. His studies have been very important for the Norwegian authorities in their work to reduce soil erosion from agricultural areas. The text and results in this paper is based on different publications and notes written by Helge Lundekvam.

Runoff and erosion from plots were measured at five sites within 60 km from Oslo. Two of the field experiments (Bjørnebekk and Syverud) are still running by Department of Plant and Environmental Sciences. Two sites (Øsaker and Hellerud) have been run by Bioforsk since 2002 (Grønsten et al. 2007). One site (Askim) is closed down in 2009. Bjørnebekk and Syverud are located at Ås (30 km south of Oslo). Øsaker is the southernmost site (60 km south of Oslo), and Hellerud is the farthest north (20 km north of Oslo). Askim is situated about 30 km east of Ås. Within the area winters are 2–3°C colder in the north than in the south. At all fields the soil contain more than 20% clay.

The surface runoff and drainage water are collected by a pipe system and the runoff is measured by tilting bucket (Figure 10.1). The number of tilts is recorded both by a mechanical counter and electronic sensors sending their signals to a data logger (Campbell CR10). Time resolution is 5 minutes, but zeros are not stored. Water sampling is volume proportional by storing a small volume of water from every second tilt in a plastic container. There are two containers for every plot so that both small runoff episodes (1–2 mm of runoff), and larger episodes (up to 50 mm of runoff) may be sampled. All five sites are equiped with the measuring and sampling system as shown in Figure 10.1, but only two sites, Syverud and Askim are recording both surface and drainage runoff.

Precipitation is recorded automatically by a tilting bucket device and also by a manually read pluviograph. The air temperature and wind speed is recorded and stored every hour.

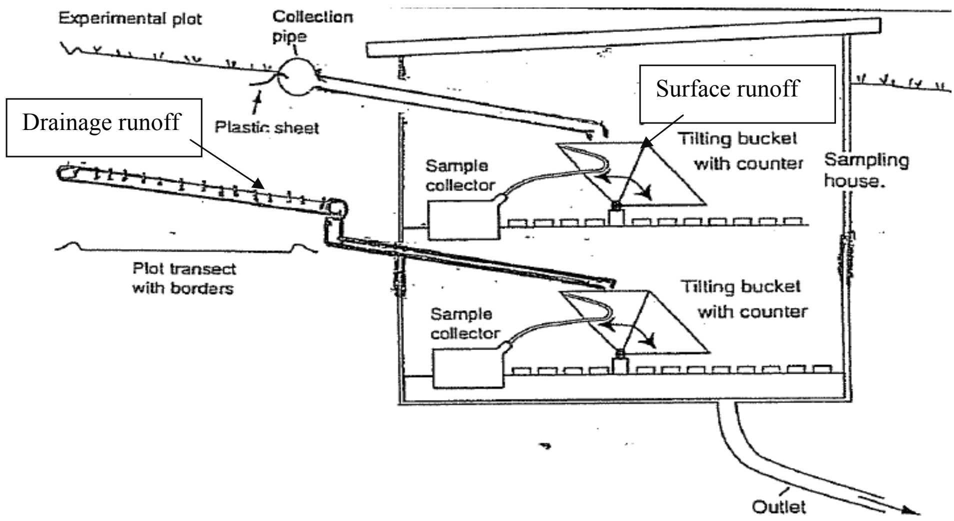

FIGURE 10.1. Runoff measurement and sample collection shown in a sampling house dug into the ground

Surface water from upslope and from the sides of the plots is cut off by furrows and small ridges. The surface runoff from the plots themselves is collected in the lower end using a plastic pipe sliced in the side. To prevent leakage under the pipe, a plastic sheet was attached to the pipe and dug about 15 cm into the soil. In this way some water flowing on the plough pan may be recorded as surface runoff, but since this water usually is highly polluted, it is considered most correct to include it.

The purpose of the erosion plot experiment were to measure surface and drain runoff and losses of soil particles, phosphorus and nitrogen under different cropping systems, especially different tillage methods. The Øsaker and Hellerud erosion experiments were in the period 2002 to 2007 used to study the effect of winter wheat cropping after different tillage system. The last 7 to 8 years losses of pesticide are also measured both in surface and drainage water (Askim, Bjørnebekk and Syverud). Another purpose is to provide data for calibrating hydrology and erosion models.

The Syverud Erosion Plot Experiment

Climate, soil and topography

The normal precipitation at Ås is 785 mm/year and yearly mean temperature is 5,3°C, and –3,4°C in December/March. After 1988 we have had more of mild winters than normal, but still the soil usually has been frozen in periods every winter. On this experiment surface runoff has mainly occurred during snowmelt on frozen soil.

Before the experiment was established the area was used for meadow and pasture for many years which resulted in a good soil structure with high infiltration capacity and saturated hydraulic conductivity as well as very high aggregated stability. Some after effects on nitrogen release and low erodibility was to be expected. The drainage system was installed about 1970, but the first period it was used for study loss of nutrient losses from meadow (manure and silage effluent). From 1990 the field experiment is used for erosion and runoff measurements.

The surface layer (0–20 cm) consists of 23% clay, 49% silt and 28% sand (loam/silt loam). The C-tot is 3,2% in the surface layer but is reduced to 0,8% at about 50 cm. The texture is not changing very much down to 65 cm. The soil structure is still very good and the aggregate stability tested with rain simulation is as high as 80 to 90%.

Experimental plan and layout

The experimental layout is shown in Figure 10.2. The main crops have been spring grain (barley and oats). One plot has been used with grass/meadow. The tillage treatment has since 1994 been: Autumn ploughing, autumn harrowing, spring ploughing, spring harrowing in combination with straw or removed straw. The ploughing depth is 20 cm both for autumn and spring ploughing. The harrowing depth is 7–8 cm. Secondary tillage is done by harrowing to about 5 cm depth. Fertilizing has been 100 kg N, 19 kg P and 48 kg K pr hectare as compound fertilizer. The plots are about 30 meter long and 7 meter wide and the slope is about 13%.

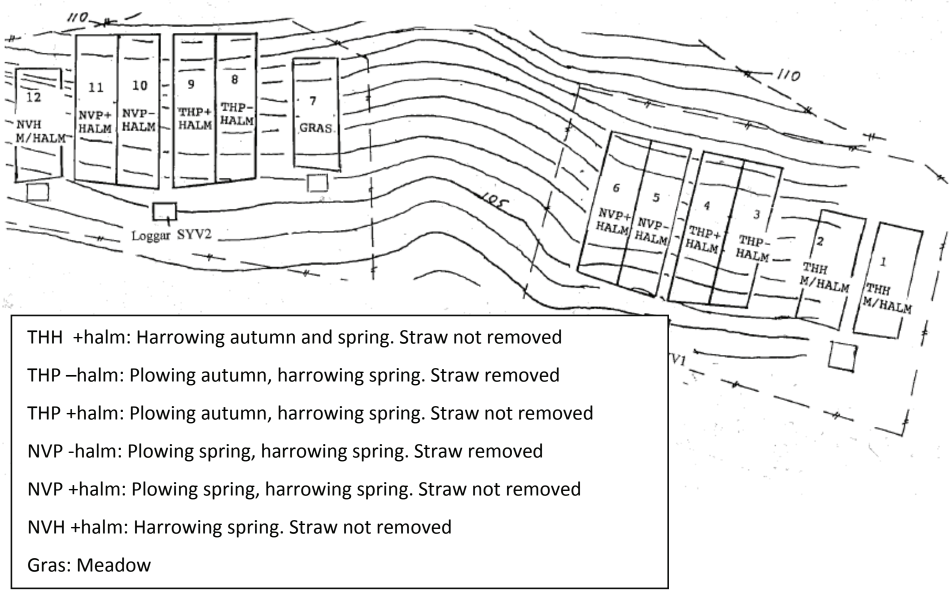

FIGURE 10.2. Experimental layout and treatments for the Syverud erosion plot experiment

Results

Figure 10.3 shows runoff (mm) and soil loss (kg/daa) (1 daa = 1/10 ha) for surface and drainage water from 1994 to 2000. The soil loss on this experiment is very low and about 75% of the runoff is drainage water. The total runoff is quite similar for spring and autumn ploughing. However surface runoff has been higher after spring ploughing but the soil loss has been higher after autumn ploughing.

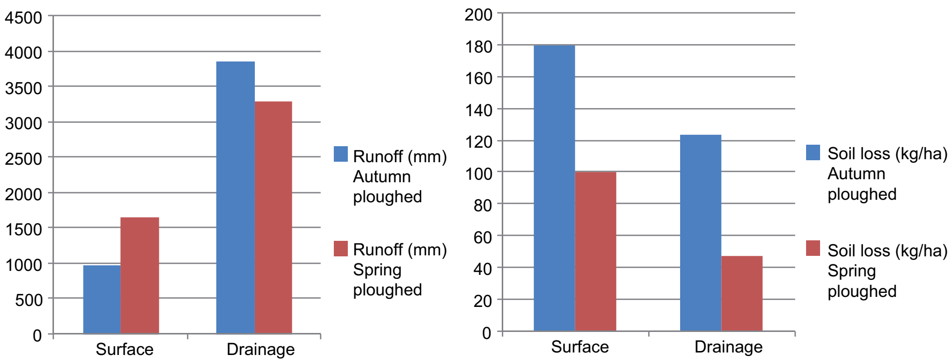

FIGURE 10.3. Water runoff and soil loss by surface runoff and drainage water on a loam soil at Syverud, Ås, Norway 1994–2000

The Bjørnebekk erosion plot experiment

Climate, soil and topography

Climate characteristics: see Syverud erosion plot experiment.

The soil is an artificially levelled silty clay loam, low in organic matter in top of the profile.

Some soil parameters values 0–20 cm are: clay 27%, silt 62%, C-tot 1.4%, N-tot 0.13%, available soil water (pF2–pF4.2) 22%, drainable pores 6%, water stable aggregates: 18%, 24% and 23% for autumn ploughing, autumn harrowing and spring ploughing respectively. At 45–65 cm depth the clay content is 36% and drainable pores only 2%.The low aggregate stability makes the soil vulnerable to silting by rain and crusting and cracking upon drying, and the resistance against erosion is low when the soil is saturated in top. The crop yield potential is relatively low due to the bad physical properties. Cracked soil has a relatively high infiltration capacity, but after wetting and swelling in autumn, infiltration values lower than 1 mm/hour have been measured so that surface runoff may occur even from moderate rain intensities and no frost in soil. The soil usually becomes impermeable even after shallow frost. High surface runoff is thus recorded both in autumn, winter and early spring. Mean surface runoff by autumn ploughing is 50–55% of total runoff at this site.

Experimental plan and layout

The experiment was originally started about 1980, but redesigned in 1989.

The layout of the experiment is shown in Figure 10.4. Spring grain is grown on all plots except on plots 2 and 7 where winter wheat is grown. On spring grain plots, oats and barley are grown every second year. All plots are harrowed before fertilizing and sowing. The last years a horisontally rotating harrow produced by Ferraboli has been used. Additional straw has been put on plots 8 and 10 after harvesting in autumn. Straw was removed from plots 2, 7 and 9 in autumn after harvesting. No straw was added or removed on other plots. Fertilizing has been 100 kg N, 19 kg P and 48 kg K pr hectare as compound fertilizer. Plot length is 21 m and plot width is 8 m and the slope is 13%, except plots 8–11 which are about 18 m long.

1	2	3	4	5	6	7	8	9	10	11
Harrow autumn	Plough autumn Winter Wheat	Plough autumn	Harrow autumn	Plough autumn	Plough spring	Plough autumn Winter Wheat	Harrow spring Straw burnt spring	Harrow spring Straw re- moved	Harrow spring Straw burnt spring	Plough spring

FIGURE 10.4. Experimental layout and treatments for the Bjørnebekk erosion plot experiment

Results

Surface runoff for 4 treatments and 11 years are shown in Figure 10.5. There is considerable yearly variation, and also a rather small difference among treatments. Spring ploughing has altogether reduced surface runoff somewhat compared to the other treatments. Winter wheat has given about 10% higher surface runoff than autumn ploughing. The reason is that winter wheat plots are harrowed and sown in addition to ploughing, resulting in more compaction, reduced surface storage and reduced infiltration rates. Plots that are not tilled in autumn are protected by plant residues against silting, and thus surface runoff is reduced. The soil conditions (ex. wetness) at the time of tillage often has a great influence both on infiltration and erodibility on this soil with low aggregate stability. This explains part of the large yearly variation especially for treatments tilled in autumn.

Soil losses for three cultivating systems for the years 1994–2004 are shown in Figure 10.6. Ploughing in autumn produced soil losses of about 6000 kg/ha/year. This

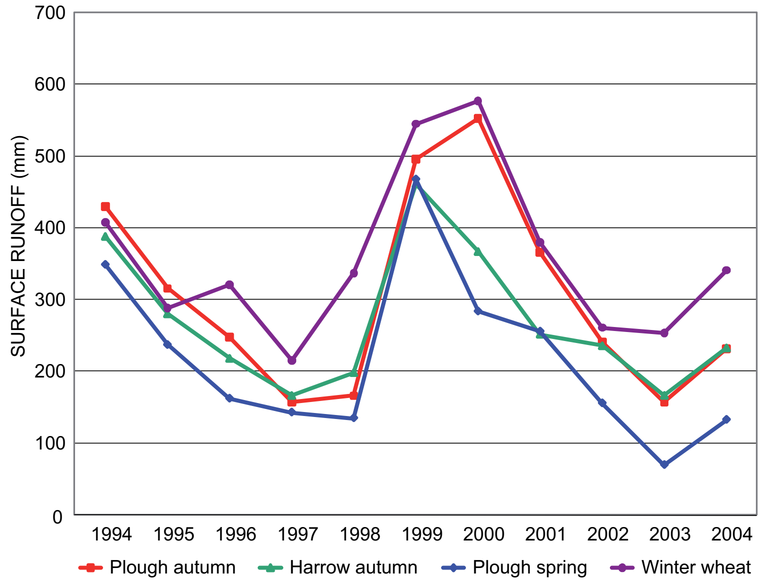

FIGURE 10.5. Surface runoff for three tillage systems for spring cereals and one tillage system for winter wheat in the period 1994–2004

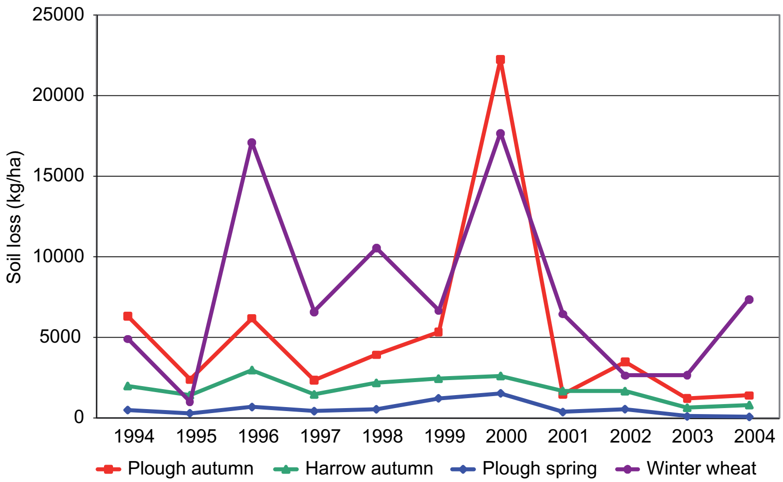

FIGURE 10.6. Soil loss for three tillage systems for spring cereals and one tillage system for winter wheat in the period 1990–2004

was reduced by 60% when only harrowing was done in autumn and by 88% with no tillage in autumn but ploughing in the spring. This clearly shows that straw cover, but also soil consolidation during summer reduced the possibility of soil detachment. The year 2000 was special. Ploughing in autumn was done when soil was rather wet, and the autumn was unusually wet and mild with no frost until December 18. This led to low infiltration and high surface runoff and great soil losses especially on autumn ploughed plots but also on winter wheat plots. The grain was not harvested in a normal way this year, only cut, resulting in a rather dense stand of new plants emerging from the nonharvested grain seeds. This was especially so on the autumn harrowed plots, so that the effect of this treatment was unusually high, and the results this year should not be used. Normally the reduction in soil loss was about 50% by harrowing autumn compared to ploughing autumn on this soil.

Soil losses increase with increasing harrowing intensity reducing residue cover. Both straw yield and harrowing intensity influence the resulting residue cover. Residue cover ought to be at least 40% to have a good effect. The system with winter wheat increased soil losses by 30% (mean values 1994–2004) compared to autumn ploughing. The plant cover usually has not been enough to counter the negative effect of tilling operations. Little autumn rain and a good plant cover are necessary if winter wheat should have an effect.

By no tillage in autumn, doubling the amount of straw compared to removing the straw reduce relative soil losses from 14% to about 9% compared to ploughing autumn. In summary: Relative soil losses compared to autumn ploughing when year 2000 is excluded are: Autumn ploughing (1.0), harrowing autumn (0.51), no tillage autumn with spring ploughing (0.14), no tillage in autumn with double straw burned in spring and spring harrowed (0.09), winter wheat (1.3).

The Askim erosion plot experiment

Climate, soil and topography

The normal precipitation at Askim is 829 mm/year and yearly mean temperature is 4,9°C, and –3,7°C in December/March. The experiment was established on levelled area and rather poor soil structure with low infiltration capacity and low hydraulic conductivity as well as aggregated stability. The drainage system was installed to a depth of 1 m. The surface layer (0–20 cm) consists of 29% clay, 61% silt and 10% sand. The C-tot is 1,1% in the surface layer. The texture is not changing very much down to 65 cm.

Experimental plan and layout

The experiment was originally started 1986. However, the treatments on the plots were changed in 2000. The experiments consisted of six plots wit h a slope about 13%, four of plots were 24,5 meter and two of these had 4 meter and two had 8 meter distance between the drainage pipes, and two of the plots were 44,5 meter long and had 8 meter between drainage pipes. 3 of the plots were only harrowed in spring (no tillage in autumn) and 3 of the plots were ploughed in autumn. From year 2000 autumn ploughing was substituted with autumn harrowing. The crop was always a rotation of barley and oats. Fertilizing has been 100 kg N, 19 kg P and 48 kg K pr hectare as compound fertilizer.

Results

Figure 10.7 shows the surface runoff from autumn ploughed plots and from spring harrowed plots and as expected the variation is high from year to year. However, the effect of the different tillage system is rather small. On average during this period autumn ploughed plots had about 40 mm higher surface run off compared to spring harrowing. The amount of drainage water was on average for all plots 270 mm per year. This is 35 mm more than surface runoff measured as average for all plots. Drainage water can not be given for each tillage treatment because the drainage system gathered water from two and two plots.

The soil loss with surface runoff is all years higher at autumn ploughed plots compared to spring harrowed plots (Figure 10.8). From year 2000 autumn ploughing was substituted by autumn harrowing and for these years the measured value

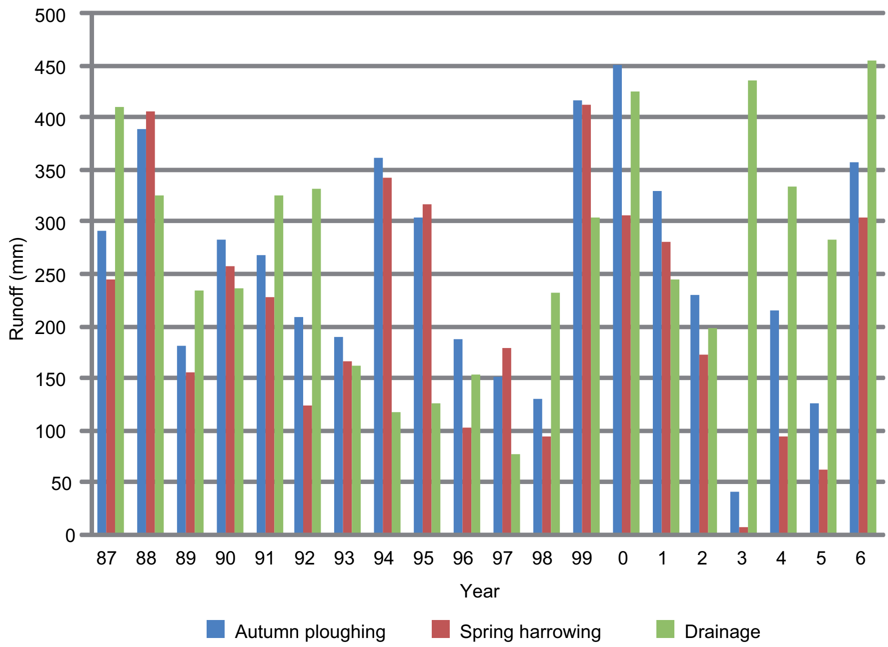

FIGURE 10.7. Surface runoff on autumn ploughed (from year 2000 this treatment is autumn harrowing) and spring harrowed soil and drainage water sampled from both tillage treatments on a silty clay loam soil at Askim, Norway 1987–2006

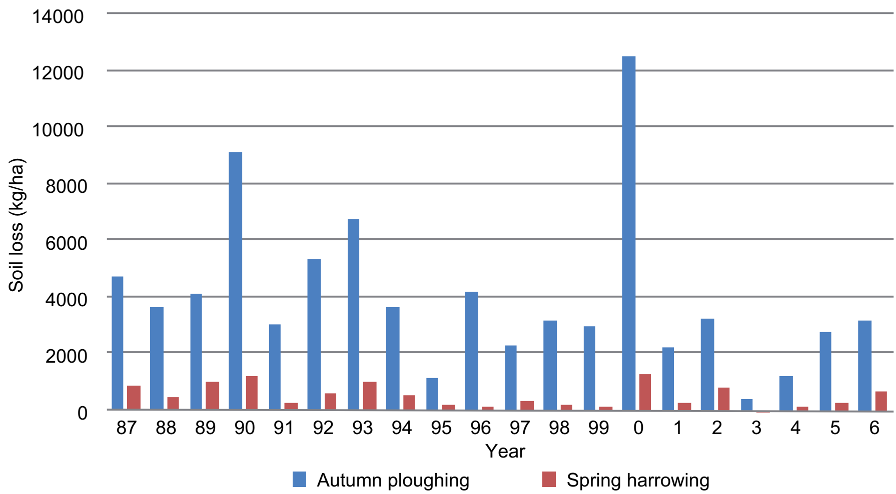

FIGURE 10.8. Soil loss on a silty clay loam soil at Askim, Ås, Norway 1987–2006. The figures for autumn ploughing in the period 2000–2006 are calculated from soil loss measurements for autumn harrowing

for soil loss for this treatment is multiplied by 1,7 to give an estimate for autumn ploughing. As measured on average for both treatment soil losses through drainage water is in many years close to the soil loss by surface runoff from spring harrowed plots, but some years it is a bit higher. However the soil loss in drainage water is always lower than the soil loss by surface runoff from autumn ploughed plots.

The Øsaker erosion plot experiment

Climate, soil and topography

The normal precipitation at Øsaker is 853 mm/year and yearly mean temperature is 6,1°C, and –2,3°C in December/March. The surface layer (0–20 cm) consists of 44% clay, 42% silt and 14% sand. The C-tot is 2,2% in the surface layer. The texture is not changing very much down to 100 cm. The available soil water volume (pF2–pF4.2) is 21% and the drainable pore volume is 12%.

Experimental plan and layout

The experiment was originally started 1979. However, the experiment was redesigned in 1989 and 2002. The experiments consisted of eight plots. The plots are 22 meter long and 6 meter wide and the slope is about 13%. The treatments in the period 1989–2002 have been Autumn ploughing, Autumn ploughing and winter wheat, Autumn harrowing and Direct drilling. Since the autumn 2002 the winter wheat was introduced as the main crop. The treatments were Autumn ploughing, Autumn ploughing and winter wheat, Autumn harrowing and winter wheat and Direct drilling and winter wheat. Fertilizing has been 100 kg N, 19 kg P and 48 kg K pr hectare as compound fertilizer.

Results

Average annal soil loss at Øsaker has varied between 170–1430 kg/ha (Grønsten et al. 2007). Winter wheat sawn on autumn ploughed soil resulted in the highest soil loss most years, but it should be mentioned that one of the two plots with this treatment had extremely high soil loss (Figure 10.9). Autumn harrowing (reduced tillage) and direct drilling of winter wheat gave consistent reduction in soil loss. Autumn ploughing in a cropping system with spring sown cereals gives most years low soil loss. This is due the stable structure and high aggregate stability on this soil. This is consistent with the soil loss measurements done at Øsaker from 1979 to 2000 which indicate a very low erosion risk on this soil even when it is ploughed in autumn. To sow winter wheat after ploughing on this soil will increase the erosion risk drastically.

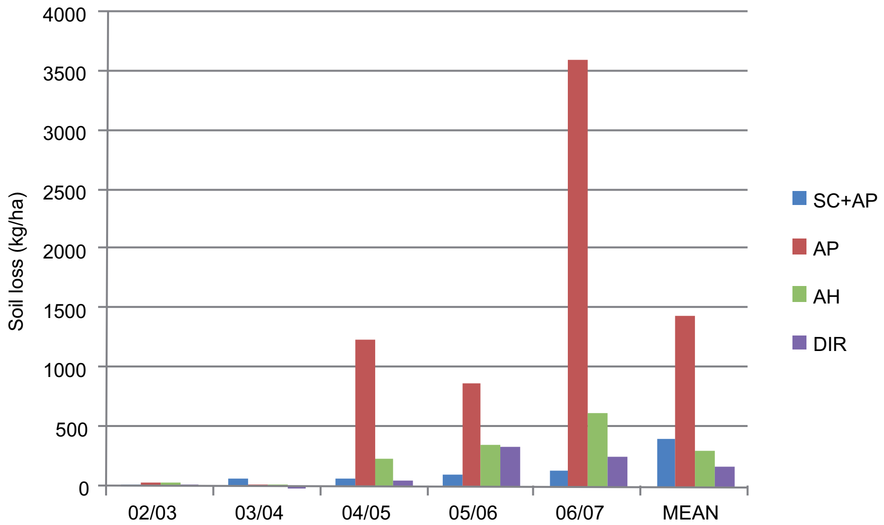

FIGURE 10.9. Soil loss as dry matter (kg/ha) for the different treatments at Øsaker in the period 2002–2007. (Ap: autumn ploughing, AH: autumn harrowing, Dir: direct drilling, Sc: Spring cereals- autumn ploughing) (Grønsten et al. 2007)

The Hellerud erosion plot experiment

Climate, soil and topography

The normal precipitation at Hellerud is 830 mm/year and yearly mean temperature is 4,0°C, and –5,8°C in December/March. The surface layer (0–20 cm) consists of 30% clay, 66% silt and 4% sand. The C-tot is 1,7% in the surface layer. The available soil water volume (pF2–pF4.2) is 27% and the drainable pore volume is 4%.

Experimental plan and layout

The experiment was established in 1991 on the farm to Det Kgl. Selskap for Norges Vel. The field plot experiment consists of 8 plots as shown in Figure 10.10. The plots are 30 to 66 meter long and 6–22 meter wide and the slope is about 12%. As the Figure 10.11 shows one plots is extra wide to do tillage across the slope and one plot is extra long to see the effect of the length of the slope. Since the autumn 2002 the winter wheat was introduced as the main crop. The treatments were Autumn ploughing, Autumn ploughing and winter wheat, Autumn harrowing and winter wheat and Direct drilling and winter wheat. The wide plot and the extra long plot were also ploughed in autumn and sown with winter wheat. Fertilizing has been 100 kg N, 19 kg P and 48 kg K pr hectare as compound fertilizer.

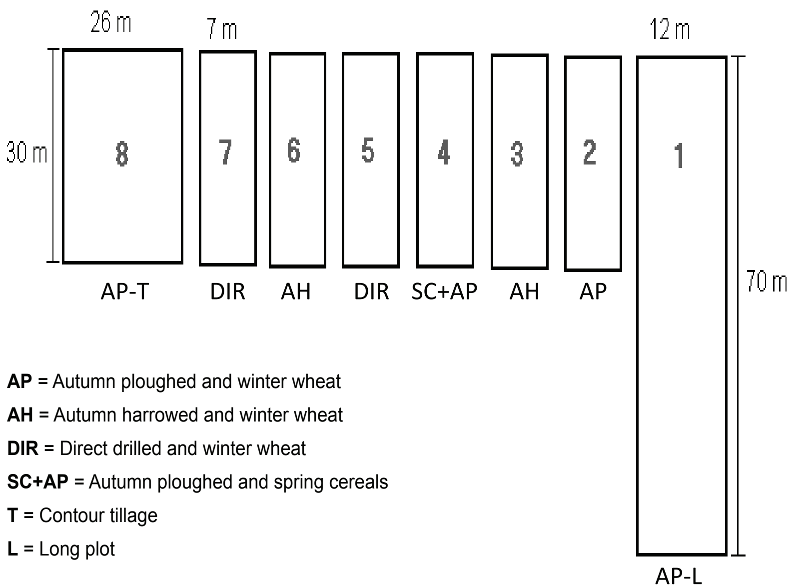

FIGURE 10.10. Experimental design on Hellerud in the period 2002–2007 (Grønsten et al. 2007)

FIGURE 10.11. Plot field experiment at Hellerud at June 23, 2004. Plot1 to plot 8, from right to left. Photo: R.M. Skjevdal

Results

Average soil loss at Hellerud has varied between 130–1020 kg/ha (Grønsten et al. 2007). Autumn ploughed soil showed about the same soil loss for winter and spring sown cereals (Figure 10.12). Autumn harrowing (reduced tillage) and direct drilling of winter wheat gave consistent reduction in soil loss. Contour tillage reduced the soil loss to about 50% compared to the normal tillage direction (up and down the slope) On the extra long plot (70 m) the soil loss increased by 27% compared to the soil loss at the standard plots (30 m).

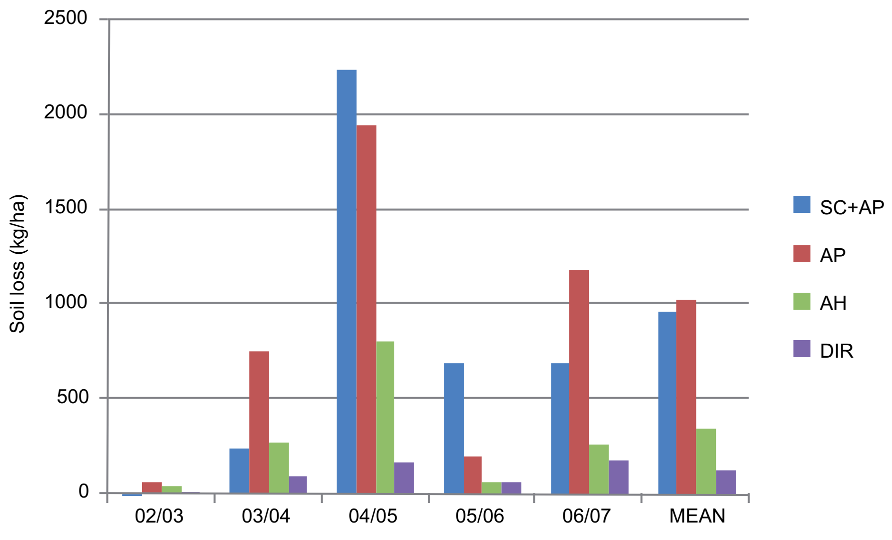

FIGURE 10.12. Soil loss as dry matter (kg/ha) for the different treatments at Hellerud in the period 2002–2007 (Ap: autumn ploughing, AH: autumn harrowing, Dir: direct drilling, Sc: Spring cereals- autumn ploughing) (Grønsten et al. 2007)

Best tillage practice

Figure 10.13 shows the P- and N-losses in the period 1994 to 2000 for the five plot erosion experiments in Norway for autumn ploughing compared with spring tillage (ploughing or harrowing) for spring sawn cereals. The effect of time for tillage on P-loss is very clear on most of the experiments, but not on Syverud. It is also a significant difference between the experiments. Bjørnebekk, a silt clay loam with low content of organic matter have a higher P- and N-loss than the other experiments.

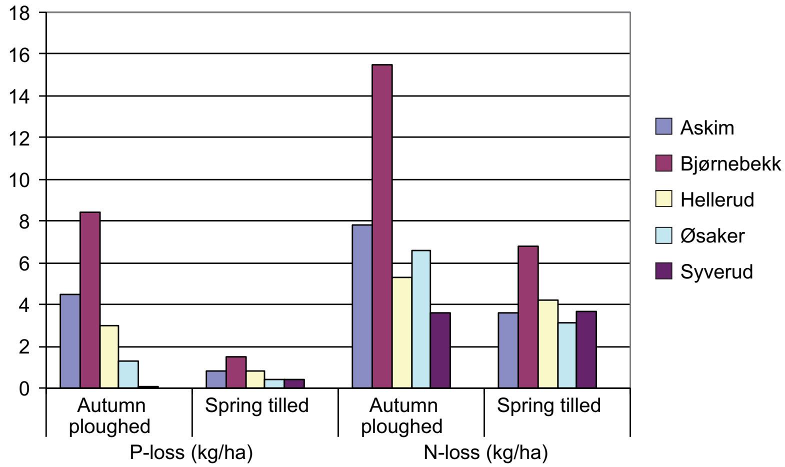

FIGURE 10.13. The effect of time for tillage (Autumn and spring) on P- and N-loss at 5 erosion trails in Norway 1994–2000

Lundekvam et al. (2003) used the data from the five plot field experiments in Norway to estimate the soil loss for different tillage and in combination with different crops on three different erosion risk classes (Figure 10.14). On fields with high risk of erosion the figure shows that is difficult to reach an acceptable level of soil loss even if you change to ley. The figure shows that if you avoid tillage in autumn you reduce the erosion risk significantly on fields with medium and high erosion risk.

The five erosion plot experiments described here and other field experiments with soil tillage have resulted in several governmental actions to reduce soil erosion. Subsidies are given for no till in autumn, light harrowing in autumn, direct drilling of winter wheat in autumn, under sown catch crop in spring grain, change of high erosion risk areas into permanent grassland or pasture, construction of vegetation zones or wetlands, repair of damaged hydrotechnical installations. More information about the change in use of area, change in tillage practices, change in fertilizing and use of pesticides may be found in agricultural statistics e.g. (Snellingen Bye et al. 2010). Lundekvam et al. (2002) discuss the effect of agricultural policy in Norway on soil erosion.

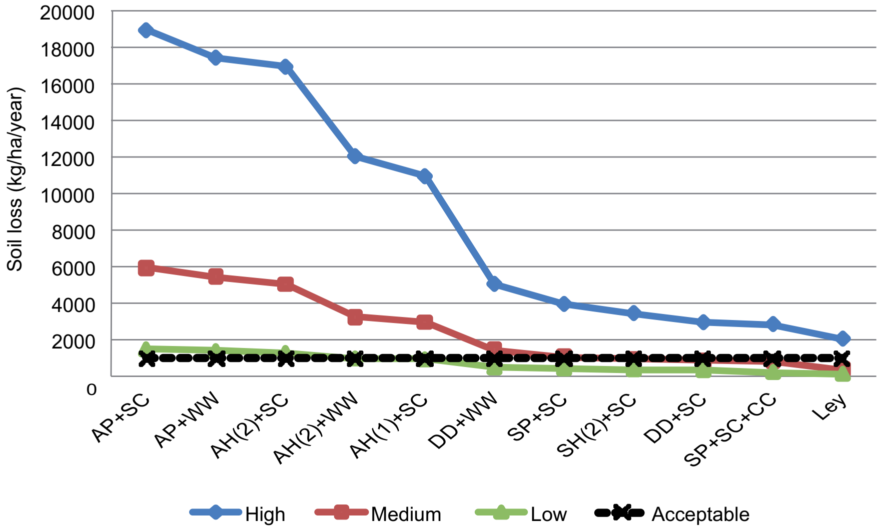

FIGURE 10.14. Estimated soil loss (kg/ha and year) for different soil management on tree different erosion risk classes. Acceptable erosion is set to 1000 kg/ha and year. (High: levelled, <2% organic matter and poor structure; medium: some levelling, 3,5% organic matter and medium structure; Low: No levelling, 5% organic matter, good structure). AP: autumn ploughing, AH: autumn harrowing, SP: spring ploughing, SH: spring harrowing, DD: direct drilling, SC: spring sown crops, WC: autumn sown crops, CC: cover crop, (Lundekvam et al. 2003)

Another important result of the first erosion plot experiments was the strong regulations of land levelling in 1985 which in fact stop new levelling projects and later in 1991 the introduction of subsidies to change tillage practise to reduce erosion. The subsidies have been regulated many times since the introduction in 1991. Table 10.1 show the support in 2010 a farmer growing spring grain could receive depending on the erosion risk of his grain fields.

To target the most erodible areas, subsidies were differentiated on erosion risk classes after 1993 in some counties based on an adaptation of the Universal Soil Loss Equation (USLE) to Norwegian conditions by Lundekvam (1990) and the use of soil map information to construct erosion risk maps. The erosion risk maps were constructed by the Norwegian Institute for Soil and Land Inventory (NIJOS). Algal blooms in the North Sea and increased focus on environmental problems further accentuated actions against soil erosion.

Later Lundekvam (2002) developed erosion models ERONOR/USLENO for Norwegian conditions because foreign models did not predict erosion in Norway properly. As an example Grønsten (2000a and b) tested the American process based erosion model WEPP (Flanagan et al. 1995) but found it not to work under winter conditions or under conditions with saturated surface runoff caused by rainfall of moderate intensity. Unfortunately the new erosion model was not used to update

TABLE 10.1. Government support for 2010 (Euro per hectare) for conservation tillage systems for arable production, according to erosion risk class, and the percentage of area in each class that receives support

Erosion risk class	Conservation tillage system		Percentage of area in each class that receives support
	no autumn tillage	harrowing only	
Extremely high	180	40	10
High	150	40	30
Medium	75	40	50
Low	40	40	10

the erosion risk maps when we still had Helge Lundekvams expertise to make the necessary corrections.

An integrated modelling tool to simulate farmers' behaviour and the resulting effects on economy and several environmental parameters has also been developed (Vatn et al. 2002). Grain cultivation in Norway is especially challenging due to the difficulties in combining sufficient weed control with no tillage in autumn and moderate use of pesticides (Fykse et al. 2002). However, no till in autumn combined with spring ploughing may in many cases by an acceptable compromise (Vatn et al. 2002).

References

Flanagan D.C., Nearing M.A. (eds) 1995. USDA-Water Erosion Prediction Project (WEPP). Technical documentation. NSERL Report No 10. National Soil Erosion Research Laboratory, West Lafayette, Indiana, USA.

Fykse H., Lundekvam H., Romstad E. 2002. Environment and agriculture: the dichotomy of erosion and weed control. [In:] J. Steenworden, F. Claessen and J. Willems (eds). Agricultural Effects on Ground and Surface Waters: Research at the Edge of Science and Society. IAHS Publication no 273: 29–34.

Grønsten H. 2000a. Evaluation of The WEPP Erosion Model, Hillslope Module. Event Simulations under Norwegian conditions. Internal report from Department of Soil and Water Sciences, Agric. Univ. of Norway.

Grønsten H. 2000b. Enkel uttesting av WEPP Watershed versjonen under norske forhold. Internal report from Department of Soil and Water Sciences, Agric. Univ. of Norway.

Grønsten H.A, Øygarden L., Skjevdal R.M. 20007. Jordarbeiding til høstkorn – effekter på erosjon og avrenning av næringsstoffer [in Norwegian]. Bioforsk Rapport, Vol. 2, Nr 60, 70 pp.

Lundekvam H. 1990. Open åker og erosjonsproblem. Foredrag ved konferansen om Landbrukspolitikk og Miljøforvaltning i Drammen 30–31 januar 1990: 31 [in Norwegian].

Lundekvam H. 1997. Spesialgranskingar av erosjon, avrenning, P-tap og N-tap i rutefelt og småfelt ved Institutt for jord- og vannfag. Jordforsk rapport nr 6/97: 69 [in Norwegian].

Lundekvam H., Skøien S. 1998. Soil erosion in Norway. An overview of measurements from soil loss plots. Soil Use and Management 14: 84–89.

Lundekvam H. 2002. ERONOR/USLENO – Empirical erosion models for Norwegian conditions. Report no: 6/2002 from Agricultural University of Norway. ISBN: 82-483-0022-6: 40.

Lundekvam H., Romstad E., Øygarden L. 2003. Agricultural policies in Norway and effects on soil erosion. *Environmental Science & and Policy* 6: 57–67.

Njøs A., Hove P. 1986. Erosjonsundersøkelser. NLVF sluttrapport nr 655, Norwegian Research Council, Oslo [in Norwegian].

Øygarden L. 2000. Soil erosion in small agricultural catchments, south-eastern Norway. Doctor Scientiarum Thesis 2000:8. Agricultural University of Norway. ISBN:82-575-0418-1.

Skøien S. 1988. Virkning av jordarbeiding og plantedekke på erosjon og fosforavrenning. Norsk landbruksforskning 2: 207–218 [in Norwegian].

Snellingen Bye A., Aarstad P.A., Løvberget A.I., Hoem B. 2010. Jordbruk og miljø.Tilstand og utvikling 2010. Statistisk sentralbyrå – Statistics Norway [in Norwegian].

Uhlen G. 1978. Nutrient leaching and surface runoff in field lysimetres on a cultivated soil. I. Runoff measurements, water composition and nutrient balances. Scientific reports of The Agricultural University of Norway, vol. 57, No 27: 26. ISSN 0025-8946.

Vatn A., Bakken L.R., Bleken M.A., Baadshaug O.H., Fykse H., Haugen L.E., Lundekvam H., Morken J., Romstad E., Rørstad P.K., Skjelvåg A.O., Sogn T.A., Vagstad N., Ystad E. 2002. CECMod 2.0: An Interdisciplinary Research Tool for Analysing Policies to Reduce Emissions from Agriculture, Report no 3/2002, Agricultural University of Norway, Ås, Norway.