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Best management practice in Norway to keep good water quality of surface waters in rural areas

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Introduction

In recent years the implementation of the EU "Water Framework Directive" has led to increased focus on water quality and measures to improve the quality. Agriculture is one of the sources influencing water quality, with pollution both from point sources and diffuse runoff from agricultural areas. Even though Norway is not a member of the European Union it is decided to implement the directive (WFD; European Parliament and Council of the European Communities 2000). Classification of the status of water quality has shown that 51% of the Norwegian waterbodies are at no risk with regards to the requirements, 22% at possible risk, 25% at risk and 2% not defined (Snellingen Bye et al. 2010). In the Water Regions there are now a process with planning measures to reduce contributions from agricultural areas and quantifying the costs with the planned measures. This work has high priority and may lead to additional changes and restrictions for agriculture and management practices in future.

In Norway, the work with reduction of pollution from agricultural areas started in the decades before the Water Frame Directive. In the seventies, the focus was on pollution from point sources like leakage from storage of manure, runoff from silage, spreading of manure during winter time. During the eighties the focus was shifted more towards diffuse runoff from agricultural areas and especially on phosphorus losses. During that period research on soil erosion started and also "The National Agricultural Environmental Monitoring Programme" – JOVA was established to document runoff from agricultural areas. By the end of the eighties there were also an algae disaster (algae blooming) in The North Sea. The countries surrounding the North Sea made a political agreement – The North Sea Declaration – to reduce the runoff of nitrogen and phosphorus by 50% compared to the loadings of 1985. Research in Norway about agricultural activities and environmental effects have led to the introduction of several kinds of payments in the early 1990s to encourage more sustainable agricultural production. Since the policy changed e.g. soil erosion has been reduced. Thus, farmers' behaviour and soil erosion in Norway is strongly influenced by agricultural and environmental policy. The work related to the Water Frame Directive is therefore not new in Norway, but is a continuation of earlier work started in the eighties and nineties. It is the same kind of measures needed, but the differences lies in the regulations, political instruments, economical incentives and the time frame set by the WFD to achieve better water quality.

The purpose of this article is to describe the best management practices used for agricultural areas in Norway and give an overview of their implementation and the regulations and incentives in use to implement the changes. Since most of the economic support in Norway is given to reduce erosion and thereby phosphorus losses to waters we have focused on erosion in this article. The recent focus on climate change and effects on agricultural production systems and adaptations may also lead to changes in future in the work with agriculture and environment.

Agricultural production systems

Total agricultural area in Norway was in 2009 1.02 million hectares, 3% of the total land area. Cereals and oil seed constitute 30% of total cultivated land in use, cultivated grassland 65%, potatoes, and root crops, green fodder, fruit and berries constitute about 5% of the cultivated area (Snellingen Bye et al. 2010).

Grain production is mainly focused in the south-eastern part of Norway and in the middle part of Norway, located to the marine sediments. Milk and meat production is located to the western and northern parts of the country and in districts. 25% of all nitrogen and 50% of all phosphorus used in agriculture comes from manure. This equal 855 000 calculated animal manure units. (One calculated animal manure unit is equal to 1 dairy cow or 14 kg phosphorus. This P-amount must be spread on 0.4 ha). The livestock density is highest in the western part of the country with e.g. 1.90 and 2.70 livestock units/ha compared to only 0.21 livestock units/ha in the eastern part.

Soil mapping in Norway

After the "North Sea Agreement" the work with the soil mapping programme was intensified and gave the basis for production of erosion risk maps. Erosion risk maps are produced based on soil and slope characteristics and the USLE (Universal Soil Loss

Equation) adapted to Norwegian conditions (Hole 1988; Lundekvam 1990; Arnoldussen 1999).

The soil mapping activity has been concentrated in the grain production areas in the southern and southeastern parts of the country, and in the Trondheimsfjord area in Mid-Norway. These areas with cereal production and marine sediments are most prone to erosion. Today approximately 4400 km^2 agricultural area has been mapped, which is about 40% of the total agricultural area in Norway. However, most of the area which is drained to the North Sea is mapped (Øygarden et al. 2003). This includes most of the area assumed to have erosion risk.

Four erosion risk classes are distinguished on the erosion risk maps. 22% of the soil mapped area falls in the low erosion risk class (<0.5 ton·ha^{-1}), 54% in the medium class (0.5–2 ton·ha^{-1}), 18% in the high risk class (2–8 ton·ha^{-1}) and 6% in the very high erosion risk class (>8 ton ·ha^{-1}). The soil erosion risk maps are used directly by farmers, advisory services, authorities for planning of soil erosion measures and as a basis when deciding on subsidies. Farmers get subsidies when they e.g reduce tillage and the level of subsidy is often related to the erosion risk class of the land. In some areas, there can be requirements of e.g. buffer zones or control with surface runoff on areas with high erosion risk before e.g. tillage for winter wheat is allowed. These maps are now under revision for better adaptation to topography and local climatic conditions.

Water erosion

Soil erosion in Norway mainly occurs in autumn and spring. In autumn, heavy rainfall on a nearly saturated soil can cause soil loss through surface runoff. In spring, erosion is caused by heavy snowmelt, sometimes in combination with a frozen (sub) soil (Njøs and Hove 1986; Lundekvam and Skøien 1998; Øygarden 2000; Lundekvam 2002). However, in mild winters with unstable weather, erosion can be very high even in December, January and February which normally have little erosion because of cold weather and snow cover (Lundekvam and Skøien 1998; Øygarden 2000).

Both water and wind erosion occur in Norway, but water erosion is the most important. Water erosion is also a problem related to the pollution and eutrofication of rivers and lakes. Only water erosion has been measured in Norway and will be dealt with in the following.

Farming practices influence directly on the occurrence of erosion connected to the soil surface (sheet, rill and gully erosion) but also the internal erosion and nutrient loss through the drainage system.

Sheet and rill erosion have been measured in plot experiments over many years (Njøs and Hove 1984; Lundekvam and Skøien 1998; Lundekvam 2007) and in small agricultural catchments (Lundekvam 1997; Øygarden 2000) on different soil types and under different cultivation systems. This research showed that surface runoff and erosion risk on agricultural areas in south-east Norway was generally highest during late autumn, winter and spring due to surface runoff because of frost in the soil and/or water saturated soil. This seasonal distribution of soil erosion risk over the year, which affects all types of erosion, implies that no tillage will decrease soil losses compared to tillage in autumn. Actions against this type of erosion are thus based on solid scientific evidence. This was also the basis for governmental support for no autumn tillage. In plot studies soil losses have varied between 0.11 and 4.36 t·ha^{-1}. An overview of the most important erosion field plot experiments in Norway is given in chapter 11 (Børresen 2011) in this book.

There are no measurements of soil erosion covering all of Norway and it is not possible to quantify all the different erosion processes. But there is no doubt that in agricultural areas the erosion is important and that erosion has been greatly increased by land levelling.

Field scale (0.35–3.2 ha) measurements of erosion during a six years period in the Akershus county (Table 12.1) showed great variations in soil losses. For the smallest fields, erosion was only occurring in winters with frozen soils. The highest losses occurred after a combination of rainfall and snowmelt on partly frozen soil (Øygarden 2000).

TABLE 12.1. Surface runoff (mm) and soil loss (t·ha^{-1}) measured at field scale in Ullensaker community, Akershus county in the period 1987–1992 (Øygarden 2000). Mean precipitation = = 825 mm

Field No	Area (ha)	Slope length (m)	gradient (%)	Soil type	Land use	Surface runoff (mm)	Soil los (t·ha^{-1})
1	0.36	100	12	Si.clay loam	Cereals	31–172	0.07–1.5
2	3.25	175	3–14	Si.clay loam	Cereals	29–128	0.03–1.6
3	0.41	113	12	Si.clay loam	Cereals	10–161	0.01–0.1
4	0.35	75	14	Si.clay loam	Cereals	9–77	0.08–0.1
6	0.86	155	4–9	Si.clay loam	Cereals	158–292	0.20–2.6
8	0.44	113	6–16	Silt loam	Cereals	130–327	0.20–5.2

In the National Agricultural Environmental Monitoring Programme (JOVA) soil erosion and losses of nutrients and pesticides are monitored in agricultural catchments. Soil losses are measured at the outlet of agricultural catchment areas of some square kilometres in the JOVA-Programme and reported annually (e.g. Bechmann et al. 1999 and 2001; Vandsemb et al. 2002; Rød et al. 2009). These measurements include all erosion processes (Table 12.2 and 12.3). The catchments Grimestad and Hotran have considerable erosion in the stream channels. The catchments Skuterud, Mørdre, Kolstad, Grimestad and Volbu are all situated in the eastern part of southern

TABLE 12.2. Catchment characteristics for catchments in the Agricultural Environmental Monitoring Programme, JOVA. Measurement periode (Vandsemb et al. 2002; Rød et al. 2009). Soil types: Si = silt, sa = sand, cl = clay, lo = loam

Catchment	Community	Area (ha)	Cultivated (%)	Precip. (mm)	Soil type	Production	Period
Skuterud	Aas	449	61	785	Si-cl-lo	Grain	1993–2009
Mørdre	Nes	680	65	665	Si and cl	Grain	1991–2009
Kolstad	Ringsaker	308	68	585	Sa-lo	Grain	1985–2009
Grimestad	Stokke	185	43	1029	Sa	Grain/grass	1993–2002
Hotran	Levanger	1940	80	892	Si-lo, si-cl	Grain/grass	1992–2009
Naurstad	Bodø	146	35	1020	Sa, peat	Grass	1994–2009
Volbu	Ø. Slidre	168	41	575	Si-sa	Grass	1992–2009
Vasshag	Grimstad	65	62	1230	Sa	Grain/ /vegetables	1992–2009

TABLE 12.3. Measured soil loss (t·ha^{-1}) and phosphorus loss (kg·ha^{-1}) in agricultural catchments in the Agricultural Environmental Monitoring Programme, JOVA. Losses of suspended solids given as t·ha^{-1} for the total catchment area and for the agricultural area for the monitoring period 1991–2010 (Rød et al. 2009)

	Soil loss (t·ha^{-1} year^{-1})		**Total phosphorus** (kg·ha^{-1})	
Catchments	Mean (1991–2010) Total catchment area	Mean (1991–2010) agricultural area	Mean (1991–2010) Total catchment area	Mean (1991–2010) agricultural area
Skuterud	0.71	1.16	1.37	2.21
Mørdre	1.01	1.63	1.18	1.88
Kolstad	0.12	0.17	0.34	0.48
Hotran	1.58	2.74	2.28	3.90
Naurstad	0.30	0.85	1.39	3.84
Skas-Heigre**	0.10	0.11	1.03	1.22
Volbu	0.04	0.11	0.18	0.32
Time***	0.11	0.13	1.36	1.47
Vasshaglona	0.88	1.36	4.05	6.24

*Problem runoff measurement. **SS analysed from 2003/2004. *** Total eight years.

Norway, Vasshaglona at the southern coast, and Hotran in Mid-Norway and Naurstad in Northern Norway.

These catchments include different management systems, crops and tillage and should be representative of production systems in different regions. The catchments Skuterud and Mørdre represent areas with marine sediments and cereal production, assumed to be high risk erosion areas.

By use of the ERONOR model (Lundekvam 2002) the climatic erosion risk for sheet and rill erosion has been estimated in four regions in Norway where relative values compared to Aas (south-east Norway) were: Aas 1, Mjøsa region 0.25, Jæren (south-west Norway) 1.9, and Mid-Norway 0.77. However, due to differences in soil types and agricultural practices the resulting erosion rates in these areas using the ERONOR model and the EcEcMod modelling system (Vatn et al. 2002) were estimated to be: Aas 0.94, Mjøsa region 0.19, Mid-Norway 0.54, Jæren 0.11 $t \cdot ha^{-1} \cdot y^{-1}$ for the period 1976–1997.

Soil losses through tile drains have been measured by Lundekvam (1997) and Øygarden et al. (1997). Tillage practices, soil type, conditions at the time of drainage and drainage equipment, time since drainage are the main factors that affect these losses. Øygarden et al. (1997) have shown how surface water and soil particles quickly can find their way through macro pores to tile drains on levelled soil. Measured losses have been between 0.03 and $1 \cdot t\ ha^{-1} \cdot year^{-1}$ through drainage systems. Soil and phosphorus losses through drainage system is now being focused for several watersheds e.g. Vestre Vansjø (Bechmann et al. 2006) and has led to ongoing research on use of sedimentation ponds and effect of filter material around drainage pipes to reduce such losses.

Erosion in deeper rills and gullies has been observed several times, but only individual studies document processes and erosion amounts. Lundekvam (1997) found in a 2.7 ha agricultural catchment on levelled soil in south-eastern Norway that erosion due to concentrated flow in valley depressions constituted 40% of total erosion in autumn ploughed fields used for grain production. Under no-till in autumn, this kind of erosion almost disappeared.

During an extreme erosion event in the winter 1990 severe erosion with rills and gullies was observed widespread in the eastern part of Norway. In a field survey (25 fields) in three counties (Akershus, Østfold and Telemark) rills and gullies were measured (Øygarden 2000 and 2003). The combination of frozen subsoil, saturated soil with low strength, snowmelt and intense rainfall led to gully development. Gullies developed to the depth of the drainpipes, which equals soil losses of more than 100 $tons \cdot ha^{-1}$. Such soil losses were measured in all three counties. Locations with low clay content and high silt/sand content had highest erosion. Human activity had a significant influence on the soil losses where there was lack of surface water control. Autumn- tilled soil, winter wheat and harvested early potatoes had high erosion, while adjacent stubble fields had no visible erosion.

In the Skuterud and Mørdre catchments in Akershus county, a field inventory of erosion with detailed measurement of rills has been performed from 1990 to 2002 (Øygarden et al. 2003). Erosion patterns are dependent on management practices, topography and soil type. Rills up to 1.5 m width and 0.70 m depth have been measured. The field inventory also documented erosion around hydrotechnical equipment, bank side erosion and erosion in waterways which can contribute significantly to the total soil losses at the catchment scale. This kind of erosion can be reduced by managing concentrated flow by, e.g., grassed waterways or inlet tanks for surface water combined with no-till in the bottom of the small valleys in fields where water concentrates. These, and similar findings form the basis for subsidies given by government to reduce erosion and for recommendations by advisors to farmers.

In some cases erosion in watercourses may be considerable. Bogen et al. (1993) investigated this type of erosion in a catchment of 659 km^2 at Romerike in south-eastern Norway. About 58% of that area is below the Marine Limit of 205 m. Thirty five percent of the area was cultivated land of which 20% had been artificially levelled. Most of the smaller streams had not established a stable slope, and were scouring the bottom and banks. Frequently, bank segments slid into the creeks. Bogen found that this natural erosion was of the same order of magnitude as erosion from agricultural land in this district. In some cases reestablishment of damaged vegetation zones may stabilize the banks of rivers and creeks, but scouring and slides also occurred in forested areas with little or no human activity. Consequently, only limited control can be exerted on this natural process. Skarbøvik et al. (2009) reported of special events during winter 2008 from the Vansjø-Hobøl catchment (Morsa) were bank erosion and landslides along streams resulted in erosion of 5–15 000 ton suspended solids to Lake Vansjø and totally damaging the fields. These events influenced water quality for a long period, both in the stream but also in the lake Vansjø receiving the transported erosion material.

Erosion rates will differ over time as a result of changes in land use, climatic change and so on. Bogen et al. (1993) measured sedimentation rates on flood plains in the lower part of the River Leira catchment in south-east Norway. The rates were 2.4 cm·year^{-1} for 1954–1985 and 4.3 cm·year^{-1} for 1986–1990. Land levelling, more autumn ploughing and more severe floods in the last period were the most obvious reasons for the increase in sedimentation rates.

Erosion rates in glacial rivers from five glaciers in the period 1967–1976 amounted to 1.9–27.4 tons·ha^{-1}·year^{-1} (Otnes and Ræsted 1977). In contrast to this, erosion rates in rivers from woodland with till soils seldom go beyond 0.06 tons·ha^{-1}·year^{-1}, and in no-glaciated mountain areas seldom beyond 0.1 t·ha^{-1}·year^{-1} (Bogen and Nordseth 1986). However, in catchments below the Marine Limit with clayey and silty soils with agriculture and land levelling erosion rates may be high. In the River Leira, Bogen et al. (1993) measured rates of 2.15 tons·ha^{-1}·year^{-1} from the area below the Marine Limit for the period 1983–1992.

In Norway the winter and the snowmelt period Figure 12.1 have many years been the most important period for runoff and soil loss (Lundekvam and Skøien 1998; Øygarden 2000). Different runoff conditions can occur during the winter period:

- snowmelt on unfrozen soil,
- snowmelt on frozen soils,
- rainfall and snowmelt on frozen or unfrozen soil,
- rainfall on frozen or unfrozen soil.

FIGURE 12.1. Winter period with frozen soil and snowmelt can be the most important erosion period

During snowmelt, thawing in the daytime and freezing at night result in a diurnal runoff pattern. If snowmelt occurs on unfrozen soil, a major part of the runoff can infiltrate and give small surface runoff amounts (Øygarden 2000). For the smallest fields in Table 12.3 surface runoff did not occur in years when snowmelt occurred on unfrozen soils. Annual surface runoff in such years varied between 10–242 mm. Surface runoff and erosion only occurred on fields with valley depressions or on levelled soil. The winter season contributed between 47–100% of annual runoff for these fields.

When snowmelt occurs on frozen soils, infiltration is restricted and the amount of surface runoff increases. All the above mentioned fields had surface runoff and erosion in the years when snowmelt occurred on frozen soil. Runoff during the winter period and snowmelt are also dependent of soil moisture conditions the previous autumn. Low saturation of the soil at the onset of the freezing period and low snowmelt rate can result in higher infiltration and a smaller amount of surface runoff. Detailed studies by Lundekvam and Skøien (1998) from plot and catchment studies in the same areas as these fields showed low surface runoff and high drainage runoff due to infiltration. They also found that for winters with frozen soils and little snow, low permeability gave high surface runoff.

Unstable winter conditions with several freezing and thawing cycles are most favourable for erosion. Frozen soil restricts infiltration and rainfall or snowmelt gives high surface runoff. The topsoil might be saturated, aggregate stability and soil shear strength are reduced and the combination of rainfall and snowmelt gives little stability and high soil losses in surface runoff. Especially on silty soil freezing reduces aggregate stability (Kværnø and Øygarden 2003). The combination of rainfall and snowmelt on frozen soil has given the highest soil losses and can also cause extreme events. The above mentioned soil losses from gullies of more than 100 tons·ha^{-1} were caused by such an extreme event. During such snowmelt events there can be very high variations in runoff and soil losses on a daily basis. In a field of 3.2 ha the combination of snowmelt and rainfall in January 1990 resulted in surface runoff of 111 mm during a 2 day event. During the first day almost clear melt water ran off with a soil loss of 0.002 tonn·ha^{-1}. The following day 77 mm surface runoff resulted in a soil loss of 3 tons·ha^{-1} (Øygarden 2000). This event has given the highest soil losses measured in erosion research in Norway, for plot, field and small catchment studies (Lundekvam and Skøien 1998; Bechmann et al. 1999; Øygarden 2000 and 2003; Lundekvam 2002).

In recent years, the use of winter wheat has increased as a cropping system with a highly variable effect on soil erosion. The focus on tillage methods for growing winter cereals has therefore increased. Surface runoff and loss of nutrients were measured on two plot experiments with tillage practice for winter cereals in south-eastern Norway in the period 2002–2007 (Grønsten et al. 2007). Erosion from winter wheat with autumn ploughing was even higher than from traditionally autumn ploughing for spring cereals (Figure 12.2). Light autumn harrowing reduced soil loss with 66% (silt loam) and 79% (clay) compared to traditionally ploughed winter cereals. Direct drill-

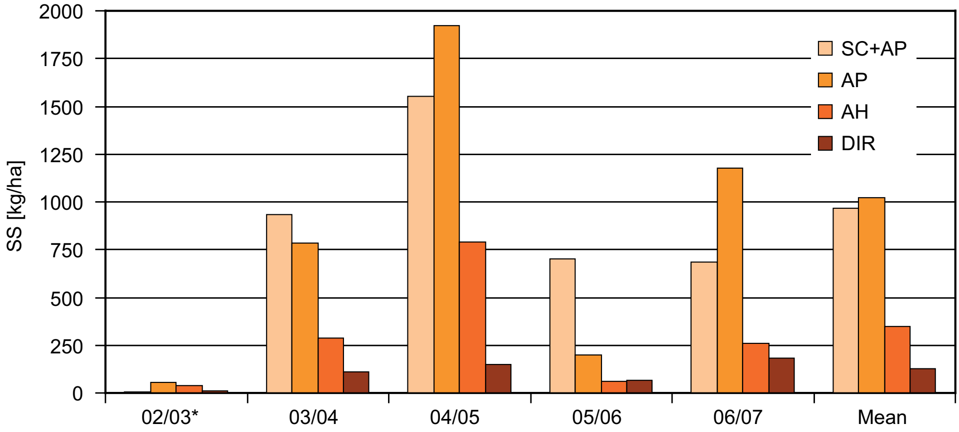

FIGURE 12.2. Soil loss (kg·ha^{-1}) 2002–2007 for plots with SC+AP: Spring cereals with autumn ploughing compared with winter wheat with different soil tillage: AP = Autumn ploughing, AH: Autumn harrowing, Dir: Direct drilling

ing or no-tillage reduced the soil losses with 88%. Runoff event in autumn before the crop had established a proper plant cover (Figure 12.3) gave especially high soil losses (Figure 12.4). Winter wheat gives higher yield than spring cereals and is therefore economically beneficial for farmers. Climate change is expected to give longer cropping season and this might lead to extended area for growing winter wheat. It is also expected more rainfall during autumn and more extreme rainfall events, this might increase erosion risk during autumn. Soil tillage methods for winter wheat that can

FIGURE 12.3. Erosion in field with winter wheat

FIGURE 12.4. Water samples from plots with winter wheat from rainfall event (16 Sept. – – Oct. 5) in 2004. Sowing date for winter wheat was 10 September. Left bottle; Autumn harrowed plot, SS – 1100 mg/l, Middle bottle, Direct Drilling plot SS – 5 mg/l and Right bottle: Autumn ploughing plot SS – 5820 mg/l, SS = suspended solids

reduce erosion during autumn have to be solved. Direct drilling reduced the yield of winter wheat from 10 to 30% while harrowing had far less negative effect on the yields compared to autumn ploughing (Bakkegard et al. 2007).

Conservation tillage in Norway and soil erosion

Serious soil erosion from arable land over the last 25 years has been a major concern in relation to the pollution of inland and coastal waters. Measurements of the effects of various tillage systems on soil erosion have been conducted in Norway in field experiments since 1980 (Lundekvam and Skøien 1998) and modified by later experiments and model evaluations (Lundekvam 2002 and 2007). On the basis of these studies, the tillage systems have been ranked according to their relative erosion risk (Table 12.4). Ploughing in autumn was used as the reference because it has traditionally been the most common tillage practice in Norway. The studies have shown that the best way to prevent soil erosion is to avoid any tillage operation in autumn. Winter wheat cropped on ploughed soil has a variable effect on soil erosion, depending on the degree of crop development in autumn. Direct drilling of winter wheat normally gives low erosion risk.

TABLE 12.4. Relative erosion risk associated with different soil tillage systems. The two numbers for relative erosion risk on one row reflect soils with high erodibility (small numbers) and low erodibility (larger numbers)

Tillage system	Time of sowing	Relative erosion risk
Ploughing in autumn	Spring	1.00
Harrowing in autumn	Spring	0.50–0.70
Ploughing in spring	Spring	0.14–0.35
Harrowing in spring	Spring	0.12–0.30
Direct drilling	Spring	0.11–0.25
Ploughing	Autumn	0.70–1.20
Direct drilled	Autumn	0.20–0.50

Since erosion in Norway is particularly associated with autumn ploughing, which makes the soil especially vulnerable during snowmelt in spring and during rainy periods in late autumn, there has been a widespread public opinion that autumn ploughing should be abandoned. In order to motivate farmers to adopt conservation tillage practises, the agricultural authorities started to give support to those who leave the soil untilled during the winter period. This action was initiated in 1990 and has since then become more differentiated.

Long-term trials have been performed with several forms of conservation tillage on representative soil types under varying climatic conditions. Results of these trials indicate that the time of ploughing (spring versus autumn) has little effect on crop

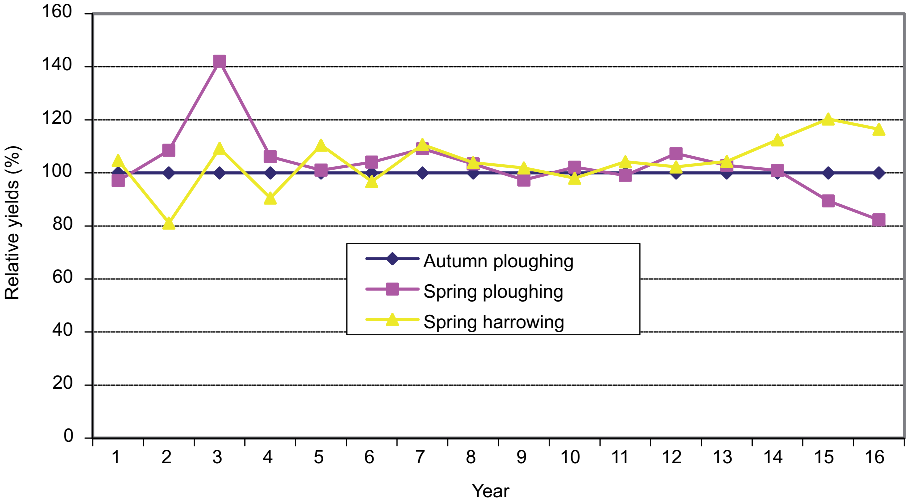

FIGURE 12.5. Annual relative yields of spring sown grain in 16 years from 1990 with spring ploughing and spring harrowing (without ploughing) versus autumn ploughing on a clay loam

yields, even on clayey soils (Figure 12.5). Spring ploughing may, however, delay sowing somewhat and has given higher annual yield variation than autumn ploughing on soil with high clay content (>40%) (Njøs and Børresen 1991).

Ploughless systems are generally successful on well-drained loam and clay soils under the relatively dry conditions in southeast Norway, but have proved to be more problematic under wetter conditions, especially on silty soils. Direct drilling has been investigated in many field experiments. On average for spring sown grain on a loamy soil, direct drilling gave slightly higher yields than autumn ploughing, especially when the straw was left on the surface and when there was an early summer drought. A reduced tillage system in which unploughed soil is harrowed in spring is advantageous compared with direct drilling because it loosens the seedbed before sowing. This allows the use of simpler and cheaper seed-drills. Furthermore, weed infestation is often lower after spring harrowing than after direct drilling (Semb Tørresen 2002). Long-term field experiments on loam soil have shown that the yield fluctuations with such a system, compared to autumn ploughing, are generally small, and that the same average yields may be obtained as with ploughing (Figure 12.5).

A reduced tillage system with harrowing unploughed soil in autumn followed by final seedbed preparation in spring has been investigated in a long-term field experiment on a clay loam since the mid-seventies. This tillage system has given relatively stable relative yields compared with the use of autumn ploughing (Figure 12.6). The results have been found to be somewhat dependent upon weather conditions. There was a tendency for autumn harrowed plots to yield better than autumn ploughed plots in dry years, whilst the reverse was true in wet years. Autumn harrowing is less effec-

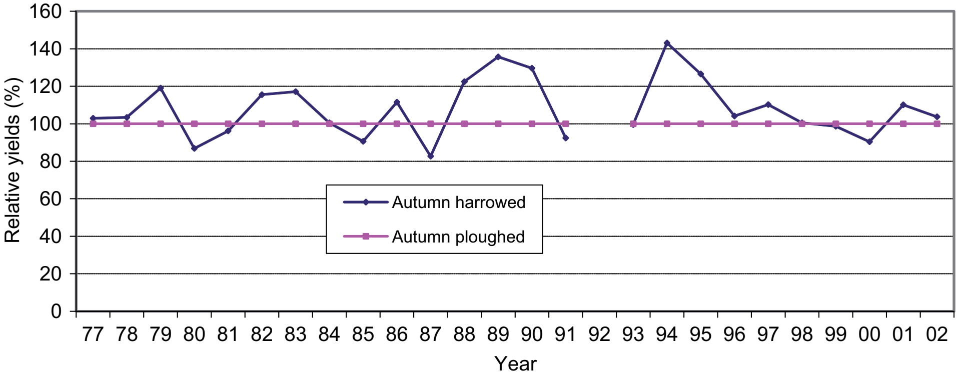

FIGURE 12.6. Annual relative grain yields with autumn harrowing versus autumn ploughing on a clay loam

tive in preventing soil erosion than the omission of all tillage operations in autumn, but it is nevertheless considerably more effective than the use of autumn ploughing.

Tillage experiments on clay soil (clay content >40%) have shown lower grain yields for direct drilling and spring harrowing compared to autumn ploughing. Oats gave about 10% reduction in yields for direct drilling and 6% for spring harrowing in the period 1998 to 2006 (Riley et al. 2008).

Winter wheat cropped with different tillage system is studied in only a few long term field experiments in Norway, but 41 short term experiments were conducted from 2002 to 2006. A poor establishment and germination has often been seen after direct drilling of winter wheat. Direct drilling reduced the yield of winter wheat from 10 to 30% while harrowing had far less negative effect on the yields compared to autumn ploughing (Bakkegard et al. 2007).

In recent years *Fusarium* spp. has been in focus in Norwegian grain production. *Fusarium* spp. may develop mycotoxins when the grain is at storage and these toxins are dangerous for both human and animal. *Fusarium* spp. is depending on many factors such as climate, rainfall in late growing season, tillage, crop rotation and nitrogen fertilisation. Even if there is a lack of knowledge we must assume higher risk for *Fusarium* spp. if we do not plough the soil.

The effect of different tillage systems on soil structure has been studied in many of our long-term experiments. The changeover from ploughing to a ploughless system is considered to be a more radical change of practise than is varying the timing of tillage operations (e.g. autumn versus spring), with respect to the effect on soil structure. Nevertheless, many of our studies show only relatively small effects of this change on soil porosity, though air-filled porosity generally declines and available water capacity increases slightly (Riley et al. 1994) in ploughless tillage systems. Common to all our studies is that the content of organic matter in the topsoil has increased in the absence of ploughing, with accompanying increases in aggregate stability. The average increases in ignition loss were 0.84% and 0.44% at 0–10 cm and 10–20 cm depth, respectively, after an average period of about 6 years.

Aggregate stability is related to the content of organic matter in the soil, and the importance of increasing soil organic matter has been shown to be greatest on soils with <4% humus (Riley 1983b). Marti (1984) found that reduced tillage (harrowing) increased the average aggregate stability from 58 to 63% in a number of trials on different soils, and his data showed that the increases were greatest on soil low in organic matter. Børresen and Njøs (1993) reported that aggregate stability increased by on average 1% per year over a period of 14 years without ploughing.

Soil conservation and policies to combat erosion and off-site problems

Artificial land levelling in the period 1970–1985 (promoted by subsidies) led to severe erosion problems and increased water pollution. In some municipalities up to 40% of the agricultural area was levelled. Today land levelling is not allowed without special permission. Njøs and Hove (1984) identified the adverse effect of land levelling on soil structure and erodibility. Their findings were later confirmed by Lundekvam and Skøien (1998), Øygarden (2000) and Torri et al. (2004). The effect of levelling on erosion will be greatly affected by how this operation is done. There are, however, no experiments where the effect of levelling has been measured directly. But it is well known that the topsoil is disturbed and more or less mixed with subsoil and compacted, resulting in a lower content of humus, reduced aggregate stability, reduced infiltration capacity and increased erodibility. By combining measurements and model considerations, Lundekvam (2003) estimated a 3–13 times increase in soil erosion (sheet and rill erosion) on areas that were levelled. In addition, the levelling procedure often created longer slopes and more concentrated flow. In the first years after the onset of land levelling concentrated flow was not properly handled resulting in very large increases in erosion with the development of rills and gullies.

Erosion research has resulted in several governmental actions involving subsidies, new regulations, information etc. Subsidies are given for tillage practice with low erosion risk, establishment of buffer zones, catchcrops and grass covered waterways, sedimentation ponds and mending erosion damage on levelled land. The government has set as a priority the reduction of the area under autumn ploughing in regions susceptible to erosion. The amount of compensation is related to the erosion risk level of the respective areas. The regulation has been successful and Norway has nearly fulfilled the reduction of phosphorus but not for nitrogen to North Sea and Skagerak as agreed in the North Sea Declaration (Snellingen Bye et al. 2010, 2000; Eggestad et al. 2001). P-losses from agriculture are reduced by 35% and N-losses by 25%. From 2003 each Norwegian farmer is obliged to have an Environmental Plan for the farm and measures to reduce erosion are a part of it. In exposed watersheds, for example the Morsa watershed, located in Østfold county (south eastern Norway) and used for drinking water for 60.000 people, special regulations are implemented to improve water quality. Farmers are obliged to specific management practices for receiving the general production support. The regulations are especially focused on the need for reducing tillage during autumn period in areas with a high potential erosion risk or exposed to flooding. In such areas farmers are not allowed to do any autumn ploughing, they need to establish buffer zones along open waters. Winter wheat with autumn tillage is only permitted on areas with low erosion risk and the farmer must have control with surface runoff and establish bufferzones. The farmers in these watersheds with strong regulations get higher economic support than in other watersheds.

Payments for no autumn tillage were introduced in 1991 irrespective of the erosion risk. After 1993 these subsidies were targeted on areas with significant erosion risk; the highest rate is given to areas with the highest risk class. In 2009 about 53% of the grain area is tilled only in spring, 42% ploughed in autumn and 5% harrowed in autumn (Snellingen-Bye et al. 2010). Current support is given at rates of 50–180 Euros·ha^{-1} per annum, varied according to erosion risk, with 90% of the support being given on areas with medium to extremely high erosion risk.

Figure 12.7 shows the trend of total area given subsidies for reduced tillage since 2000. There was a quick response to the subsidies for no autumn tillage the first years after introduction of the payment. The subsidies for catch crops were increased in 2000 and led immediately to an increase in area.

In 2005 the national support regime was changed to Regional Environmental Programmes. Each county develop (local authorities, farmers organisations, extension service involved) on their own environmental support program, both what measures should be given support and also the level of support. The programs are approved by the Agricultural Authorities. In 2009 about 1392 million Euro were given as environmental support for measures on 0.2 mill ha agricultural areas. Total area used for grain production was 0.3 mills ha.

At the beginning of the 1990 s research on the effects of vegetative buffer zones and sedimentation ponds was initiated in Norway. It was a normal procedure to do autumn ploughing and other kind of tillage as near the streams as possible. Trees and other vegetation near the stream banks were often removed. Because of visible erosion on agricultural land and joint efforts to implement measures to reduce erosion, a new focus was placed on retention areas in the landscape. Sedimentation ponds have shown to be effective in reducing sediment transport (Braskerud 2001). Ponds with a size of less than 0.1% of the catchment area have reduced sediment transport by 50–60%. A major reason for the effectiveness is that particles are often transported as

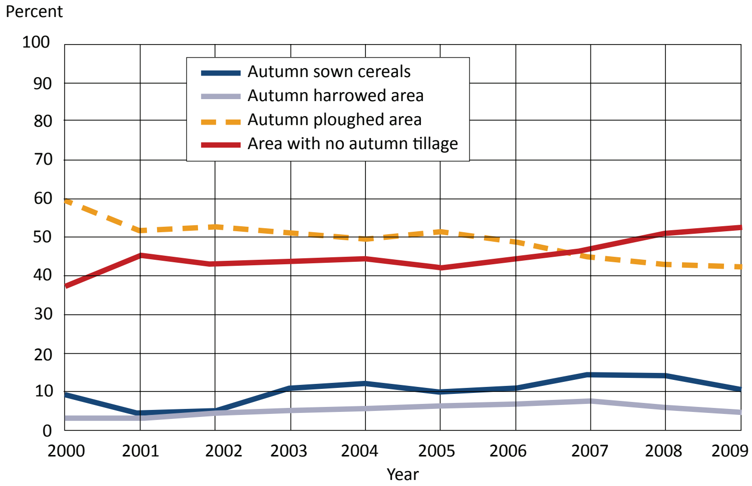

FIGURE 12.7. Development of the area with autumn sown crops, spring tillage, autumn ploughed for the period 2000–2008

aggregates. Establishment of several smaller ponds along the streams have therefore proved to be more effective than larger ponds at the outlet of a larger stream.

Farmers have been given 70% of cost in economic support for establishment of such constructed wetlands. From 2000–2002 the number increased from 39 to 100. In the period 1994 until 2009 (Figure 12.8) a total of 834 sedimentation ponds and wetlands have been given support. It is also given support for maintenance and cleaning of sedimentation ponds when filled up by sediments. For 2009 it was given such support to 69 sedimentation ponds. New research activities are focused on using sedimenta-

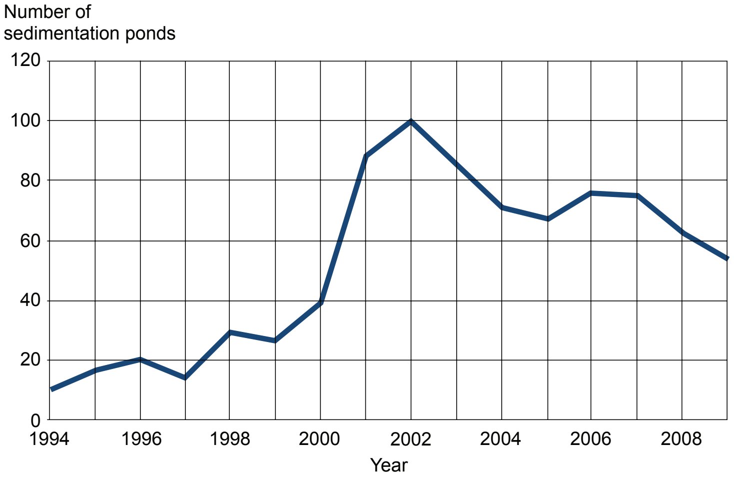

FIGURE 12.8. The number sedimentation ponds receiving financial support between 1994 and 2008

tion ponds for retention of particles and phosphorus losses from drainage pipes. There is ongoing research on design of sedimentation ponds and use of different kind of filter materials for reducing phosphorus losses from runoff by the outlet of the dams.

Buffer (Figure 12.9) zones have shown to be effective in encouraging deposition during winter periods and snowmelt (Syversen 2002). Buffer zones 5–15 m wide reduced sediment transport from surface runoff by between 55 and 95%. During periods with high surface runoff larger particles and aggregates are transported and they sediment more easily in the buffer zone. Because of these results, farmers got 70% subsidies for the establishment of buffer zones and sedimentation (Figure 12.10) ponds when there was a national supporting scheme. It was recommended to use 5–10 m wide buffer zones. This support is continued through the Regional Environmental Programs. Some counties have made local rules for support e.g. for 20 meter buffer-zones along watercourses and also grass on areas with high erosion risk. The motivation for wider zones that are being harvested is that farmers then can utilize the grass production economically. In 2009 it was given support to 393 km grassed waterways, 1022 km buffer zones and 4600 ha other areas covered by gras for environmental purposes.

FIGURE 12.9. Buffer zone

FIGURE 12.10. Sedimentation pond

Establishment of buffer zones is in most areas a voluntary option, but in some heavily polluted watersheds there are special regulations where farmers need to establish such zones to get the general production support. Examples: Morsa catchment (Øygarden et al. 2010)

Evaluation of Regional Environmental Programs (RMP) showed (Øygarden et al. 2008) that the changes not had reduced the calculated environmental effects. It was high variation among counties both in different measures in their programmes and in the different subsidy rates. In some regions subsidies were differentiated according to erosion risk while in other counties the same amount of subsidy was given for all erosion risk classes. The highest changes were found in areas where special restrictions and regulations were implemented in addition to higher subsidy level. One example from the Østfold and Akershus counties can illustrates this. In the Årungen catchment (Akershus county) subsidy level for reduced tillage like autumn harrowing, direct drilling or stubble during winter period were higher than in the rest of the county. In the Morsa catchments (Akershus and Østfold county) there were also higher subsidies for these management practices, but in addition there were specific regulations on management practices. A special law regulated that if the farmers should receive any production support then soil in erosion risk class 3 and 4 or flooded areas must be in stubble during winter. It must be grassed buffer zones of 10 meter or stubble 20 meter along all water courses. For areas used for winterwheat surface runoff must be controlled e.g. with grassed waterways. Therefore the Morsa catchment had more area with reduced tillage than Årungen without special regulations. The procedures with developing regional environmental programmes had a positive effect in involving cooperation between farmers organisations, extension service, environmental and agricultural local authorities.

The last years there has been increased focus on the recommendations of phosphorus fertilizing to minimize the risk of runoff losses. The recommendations for P-application to cereals, gras/meadow and potatoes have been reduced by 30%, 24% and 22%. It is established new recommendations for P-fertilizing related to the phosphorus level in soil, the P-Al value. When P-Al level is between 5–7 it is recommended for cereals and gras to apply the same amount of P as removed by harvest, so called balanced-fertilizing. If the P-AL ≥ 14 it is recommended not to apply any phosphorus at all. Recommendations for cereals are now 14–17.5 kg P/ha while for vegetables the norm is between 30 and 60 kg P/ha and for potatoes 30–35 kg/ha. (www.bioforsk.no/gjodslingshandbok).

In the monitoring programme JOVA, 20% of the agricultural area in the catchment with intensive husbandry (Time catchment) and the catchment with vegetables (Vasshaglona catchment) had P-Al values (Figure 12.11) higher than 25 (Rød et al. 2009). This is the result of intensive Phosporus- fertilizing to vegetables and also areas with application of manure and mineral fertilizer over many years.

Another example of the focus of reduced phosphorus fertilizing is from a special project in the Vestre–Vansjø catchment (Øgaard and Bechmann 2010) dominated by high fertilization to vegetables. A mean value for phosphorus in soil is 14.6 mg P-AL/100 g and 75% of the area has a P-AL value above 8. By special agreements (contracts) with the farmers phosphorus fertilizing has been reduced by 47%. Monitoring of water quality has shown a reduction in phosphorus losses in the same period. In addition to reduced fertilization also reduced soil tillage and establishment of buffer zones have contributed to less phosphorus losses.

In 2009 the Ministry for Agriculture and Food presented a Governmental White Paper to the Parliament: "Climate Change and Agriculture – agriculture part of the solution" (Stortingsmelding 39, 2008– 2009). Agriculture as well as other sectors has to reduce emissions of Greenhouse gases (GHG). According to official statistics

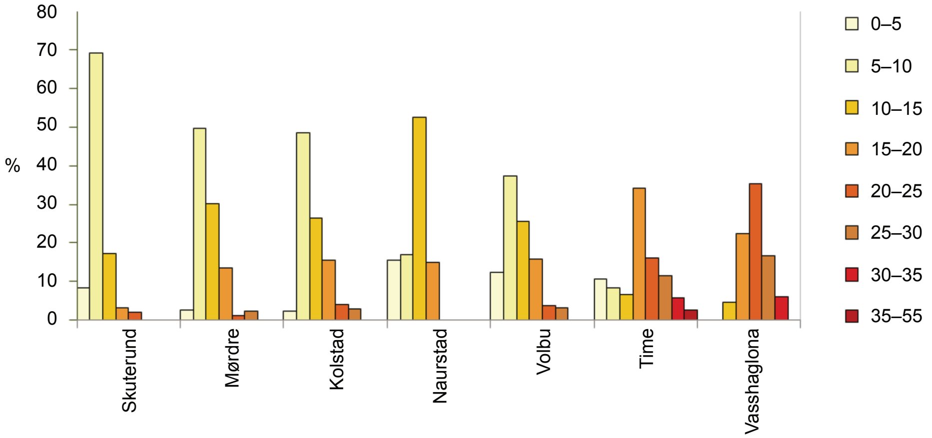

FIGURE 12.11. Percent contribution of phosphorus level (P-AL = mg P/100 g soil) in the monitored catchments

Agriculture contribute to about 9% or 4.5 mill tonnes CO_2 of emissions in Norway (SSB 2010). Agriculture contributes to 63% of emissions of nitrous oxide, mainly derived from manure and commercial fertilizers. It is expected that in the future, the work with agriculture and environment will focus more on production systems/farming activities that will reduce losses both to water and to air. In Norway measures to reduce losses from agricultural areas have been targeted on reducing phosphorus losses. For reduction of greenhouse gases measures to reduce nitrogen losses are important and this requires different measures.

The White Paper presents possibilities to reduce greenhouse gas emissions by 1.3 million tonnes CO_2 by increased carbon storage, using manure for biogas production and reduction of nitrogen fertilizer.

In 2010 the report "Climate Cure 2020" (State Pollution Control 2010) was delivered to the Ministry of Environment with a list of possible options of measures to reduce emissions of greenhouse gases. The report gives an overview of all sectors and for the agricultural sector possible measures were calculated to 1.2 million tonnes CO_2. The measures with highest effect potential were increased carbon storage by producing biochar from straw residues and possibilities of using 30–60% of all manure for biogas production. Other measures included stopping new cultivation of peatland and restoration of existing peatland. For reducing emissions of nitrous oxide it was examined how nutrients could be utilized more efficiently such as through improved fertilizer management. It was suggested to improve fertilizer planning and a plan to fertilize for mean yields and not maximum yields seldom accievable. A special focus was given to improving animal manure application techniques. It is a common practice to use broadspreading technique for manure. Changing from broadspreading on the field surface to direct injection, strip injection and adding water before spreading can reduce emissions. Also improved drainage and less soil compaction can lead to better utilization of nutrients. All these measures are calculated with effects and costs in the Climate Cure report. In 2011it is expected that the politicians (Norwegian Parliament) will follow up the suggestion and this may lead to new restrictions, laws, regulations or new support systems. All the measures to reduce emissions and improve utilization of nutrients will also lead to less risk of losses to water. It is also expected that Regional Environmental Programs in future will include support for measures that reduce both losses to water and to air.

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