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# Reduced tillage: Influence on erosion and nutrient losses in a clayey field in southern Finland

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Reduced tillage was compared with traditional ploughing in terms of erosion and phosphorus (P) and nitrogen (N) losses in an experimental field in southern Finland. One part of the field has been ploughed (treatment PF) and the other part harrowed (treatment NPF) every autumn since 1986. Flow volume and water quality data was collected separately from surface runoff and subsurface drainage waters during 1991–1995 (surface runoff volume since 1993). Erosion was higher in PF (on average 234 kg $ha^{-1}yr^{-1}$ in drainage flow and 479 kg $ha^{-1}$ $yr^{-1}$ in surface runoff) than in NPF (158 kg $ha^{-1}yr^{-1}$ in drainage flow and 160 kg $ha^{-1}yr^{-1}$ in surface runoff). Total N loss in drainage flow was also higher in PF (7.2 kg $ha^{-1}yr^{-1}$) than in NPF (4.6 kg $ha^{-1}yr^{-1}$). Total P losses did not differ much; approximately 0.7 kg $ha^{-1}yr^{-1}$ was transported from both fields. Dissolved reactive P loss in surface runoff was higher in NPF (0.21 kg $ha^{-1}yr^{-1}$) than in PF (0.05 kg $ha^{-1}yr^{-1}$). This was probably attributable to the higher accumulation of P in the surface soil in NPF. The differences between the treatments were largely similar to those found in previous studies.

*Key words*: erosion, nitrogen, phosphorus, losses from soil, tillage, water

## Introduction

Reduced tillage with a protective cover of crop residues left on the soil surface has many advantages over conventional cultivation. Soil with a reduced tillage is found to have higher and longer-lasting moisture (Blevins et al. 1983, Kladivko et al. 1986, Unger and Fulton 1990, Patni et al. 1996) which, in boreal conditions is also affected by slower frost thawing (Kivisaari 1979). Additionally, because of the higher amount of organic matter in the surface soil, the stability of soil aggregates is increased and the structure of the soil improved (Jessen 1984, Kivisaari 1985). Cultivation without ploughing is also economically beneficial, because energy- and time-consuming ploughing work is replaced by lighter tillage. However, this benefit is sometimes diminished, because a field worked

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with reduced tillage may need to be harrowed several times in order to achieve an adequate sowing depth, a proper particle structure and a smooth seed bed (Rydberg 1987). Another disadvantage of reduced tillage is weeds, especially couch grass (*Elytrigia repens*) (Pitkänen 1994). This reduces the environmental value of reduced tillage by increasing the amounts of herbicides needed.

Environmental benefit obtained by reduced tillage usually appears in the form of lower erosion and thus a reduced loss of sediment-bound nutrients (Mannering and Fenster 1983, Potter et al. 1995, Puustinen 1999). With regard to nitrogen (N) leaching, studies performed in Canada (Patni et al. 1996), in the northern USA (Angle et al. 1989, Varshney et al. 1993), and in Finland (Puustinen 1999) suggested nitrate (NO3-N) concentrations being lower in the drainage and runoff waters from no-tillage or reduced tillage fields than from conventionally (moldboard ploughing) cultivated ones. On the other hand, reduced tillage has often not decreased dissolved phosphorus (P) losses (Mostaghimi et al. 1988, Schreiber and Cullum 1998, Puustinen 1999).

In recent decades, P and N loads caused by agriculture have become the most important factor causing eutrophication in surface waters in Finland (Valpasvuo-Jaatinen et al. 1997). This trend is due both to more efficient treatment of municipal and industrial wastewaters and to more intensive cultivation, which included increased use of fertilisers until the late 1980s (Kemira 1992). Measures to mitigate agricultural water pollution are needed, and reduced tillage may offer one alternative. Ploughing was applied in 94% of the 1065 farms included in a Finnish nationwide survey made during 1989–1992 (Puustinen et al. 1994). After the Finland's accession to the EU in 1995, part of the farmers' income became bound to the fulfilment of several environmental stipulations (Valpasvuo-Jaatinen et al. 1997). Because reduced tillage was accepted as one of the measures that farmers can apply to fulfil the stipulations, its use has increased in recent years. However, autumnal moldboard ploughing was still used in more than 50% of the Finnish field-plots in 1999 (Palva et al. 2001).

The aim of this study was to compare the effects of reduced tillage and moldboard ploughing on erosion and N and P losses, and thereby add to the knowledge obtained from other experiments of the same kind. The comparison was based on the data collected in an experimental field divided in two differently cultivated plots in southern Finland during 1991–1995. The experiment was started in 1986 and the results of the first 5-year period have only been presented in a dissertation (Paajanen 1993). Part of these earlier results was included in this study as an additional information.

# Material and methods

## Experimental field

The experimental field (the Kotkaniemi Experimental Station, owned and maintained by Kemira Agro Oy), is in the municipality of Vihti about 45 km north-west of Helsinki. The field (3.2 ha) was divided into two parts of approximately equal size (Fig. 1). The drainage pipes have been laid at a depth of 1.2–1.5 m and the inside diameter of the collector pipes is 50 mm at the top and 65 mm at the bottom. The pipe drainage was first carried out in early 1960s. In 1984, when the division into two plots was made, the drainage was renewed to separate the waters to collector wells. The slope of the north-eastern plot varied from 4.0% to 5.3% and that of the south-western plot from 3.7% to 5.7%. According to the FAO classification (FAO 1988), the soil was tentatively classified as fine-textured Gleyic Cambisol. The soil texture of the plough layer is clay loam and the subsoil is also clayey. Particle size fractions of the plough layer soil are presented in Table 1.

The north-eastern plot of the field was cultivated traditionally, i.e. it was ploughed with a moldboard plough parallel with the field slope to a depth of 25 cm in every autumn after har-

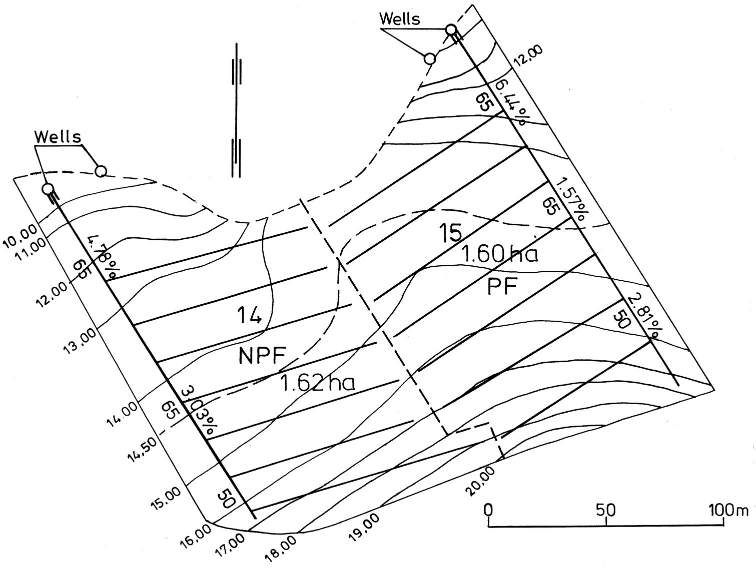

Fig. 1. The Kotkaniemi experimental field. PF and NPF refer to ploughed and non-ploughed fields, respectively.

vesting (treatment PF). The south-western plot has only been worked with a Scandinavian rotary spade harrow to a depth of 5 cm in every autumn since 1986 (treatment NPF). Otherwise, both plots were treated as similarly as possible (Table 2). The straw was not removed after harvesting from either plot. P status of the top soil (0–25 cm) was determined after autumn cultivation for the whole experimental field in 1979, and for the two plots separately in 1986, 1987, annually in 1989–1994, and in 1997. Additionally, P status was determined from three 10-cm layers of the top soil of both plots before the preparation of their seed-beds in spring 1991. All P status determinations were made as acid ammonium acetate extraction (pH 4.65, soil to solution ratio 1:10). This extraction method (described by Vuorinen and Mäkitie 1955) is commonly used in agricultural P status assessments in Finland. Soil samples for the P analyses were taken from 4 spots representing the plots, and each sample was composed of 5 subsamples.

## Determination of losses

Drainage flow was measured for both plots separately using water height gauges installed in the wells at the bottom of the collector drainage pipes. Drainage flow data consisted of daily mean values collected in 1991–1995. Surface runoff was measured for both plots separately using water height gauges installed in the wells at the bottom of the ditches that collected all surface water. Teflon-covered walls were used in order to conduct the surface water into the wells. Although water sampling from surface runoff was started already in 1991, the surface runoff volume was measured only during 1993–1995.

Table 1. Soil texture classes as indicated by particle size fractions (%) in the plough layer of the Kotkaniemi experimental field.

| | Clay<br>< 0.002 mm | Fine silt<br>0.002–0.02 mm | Coarse silt or coarser<br>> 0.02 mm |
|---|---|---|---|
| PF | 38 | 27 | 35 |
| NPF | 40 | 28 | 32 |

PF and NPF refer to ploughed and non-ploughed fields, respectively.

Water samples were collected manually in plastic bottles and delivered immediately to the laboratory in cool bags. In order to catch peak flows sampling was started whenever an increase

Table 2. Cropping pattern, fertilising, the use of pesticides, and the grain yields in the Kotkaniemi experimental field in 1991–1995.

| | 1991 | 1992 | 1993 | 1994 | 1995 |
|---|---|---|---|---|---|
| Crops | Wheat | Oat | Barley | Canola | Barley |
| Sowing rate (kg ha$^{-1}$) | 280 | 280 | 230 | –[1] | –[1] |
| Fertilizer application rate | | | | | |
| N[2] (kg ha$^{-1}$) | 130 | 90 | 110 | 110 | 130 |
| P[2] (kg ha$^{-1}$) | 39 | 16 | 22 | 22 | 26 |
| K[2] (kg ha$^{-1}$) | 39 | 23 | 44 | 44 | 52 |
| Active ingredients of the used pesticides (g ha$^{-1}$) | MCPA (400)<br>Dichloroprop-P (800)<br>Chlormequat chloride (375) | Tribenuron-methyl (7.5)<br>Cypermethrin (40) | MCPA (540)<br>Dichloroprop-P (1080) | Trifluralin (960)<br>Setoxydim (1490)<br>Cypermethrin (40) | MCPA (590)<br>Dichloroprop-P (460)<br>Ioxynil (95)<br>Bromoxynil (60)<br>Chlormequat chloride (375)<br>Dimethoate (200) |
| Sowing date | 10 May | 18 May | 11 May | 13 May | 28 May |
| Harvesting date | 2 September | 13 August | 8 September | 2 September | 25 August |
| Grain yield (kg ha$^{-1}$) | | | | | |
| PF | 4170 | 1615 | 3740 | 1680 | 2580 |
| NPF | 4200 | no yield[3] | 4000 | 1734 | 4550 |

PF and NPF refer to ploughed and non-ploughed fields, respectively.

[1] data not available

[2] as elements

[3] crop failure due to a drought in early summer 1992

Table 3. Number of water samples taken in the Kotkaniemi experimental field in 1991–1995.

| Year | Drainage flow | | Surface runoff | |
|---|---|---|---|---|
| | PF | NPF | PF | NPF |
| 1991 | 27 | 29 | 9 | 11 |
| 1992 | 18 | 17 | 5 | 4 |
| 1993 | 7 | 6 | 8 | 8 |
| 1994 | 11 | 12 | 3 | 3 |
| 1995 | 16 | 17 | 1 | 1 |
| Total | 79 | 81 | 26 | 27 |

PF and NPF refer to ploughed and non-ploughed fields, respectively.

in flow was detected. The annual number of samples taken during 1991–1995 is presented in Table 3. The variables determined by analysing the water samples were: total suspended solids (TSS), total P (TP), dissolved reactive P (DRP), total N (TN) and nitrate N (NO3-N). The determinations were made according to the standard methods described by Erkomaa et al. (1977) and National Board of Waters (1982). All filtrations were made with Nuclepore polycarbonate membranes (0.4 µm pore size).

Before the experiment with ploughless cultivation was started in 1986, drainage flows from both plots were measured separately during a calibration period between spring 1984 and spring 1986 in order to find out whether the drainage flow of the two sides was equal enough to be used for reliable comparison of cultivation methods. Moreover, 38 water samples from the drainage flows of the two sides were taken during the calibration period and analysed for TP and TN in order to find out the differences with regard to water quality.

Erosion and nutrient losses were calculated using the following formula:

$$L = \sum_{i=1}^{n} c(t_i) * q(T_i) \quad (1)$$

where L is the loss during the examined period, $c(t_i)$ is the instantaneous concentration at time $t_i$, $q(T_i)$ is the drainage flow or surface runoff during period $T_i$ and n is the number of samples taken during the examined period. $T_i$ is the time from the midpoint of the sampling interval to the midpoint of the next sampling interval.

The division of years into two seasons was made as follows: spring is from 1 January to 30 June, and autumn is from 1 July to 31 December.

### Statistical significance test for the differences

Statistical significance of the differences between the treatments was tested by non-parametric Wilcoxon signed rank test, which was chosen instead of paired t-test because the measured variables were not normally distributed. The Wilcoxon test was performed for monthly values that proved to be free of autocorrelation. The significance level used was 0.05.

## Results and discussion

### Calibration period

During the calibration period (spring 1984 through spring 1986), the drainage flow in the PF side of the experimental field was 93% of that in the NPF side. However, closer examination of the flow diagrams (data not presented) revealed that 8 of the 10 highest daily flow peaks were higher in the PF side. Because the highest flow peaks are crucial with regard to annual material losses (Rekolainen et al. 1991), this finding suggested that the inherent sensitivity to material losses via the drainage systems would tend to be higher in the PF side than in the NPF side. The flow-weighted mean TP concentrations somewhat supported this suspicion, but an opposite difference was found for TN (Table 4). In all, we concluded that the inherent difference between the plots was small enough to allow reliable comparison between the treatments.

### Water flow

Drainage flow was significantly ($p = 0.03$) higher in the PF than in the NPF. Except for very dry spring 1993, drainage flow in spring was higher in the PF in all years of the study. This reflects the water's quicker access to the drainage pipes via the ploughing furrows and the macropores (Bengtsson et al. 1992) and the faster frost thawing (Kivisaari 1979) in ploughed soil. These reasons are in line with our finding that occasional drainage flow peaks detected in the PF in winter were usually not seen in the NPF. In autumn, drainage flow was generally at the same level in both plots, except for 1994, when it was higher in the PF (Fig. 2). This was probably related to the high precipitation (110 mm) in September 1994, i.e., after autumn tillage when ploughing had made the conditions more favourable for water flow into the drainage pipes in the PF. Even higher monthly precipitation was recorded in August 1991 and in August 1993 (147 and 133 mm, respectively), i.e., before autumn tillage. In

Table 4. Flow-weighted mean concentrations of TP and TN in drainage flow during the calibration period (spring 1984 – spring 1986) in the Kotkaniemi experimental field.

| Side of the field | TP | TN |
|---|---|---|
| | $\mu g\ l^{-1}$ | |
| PF side | 112 | 4210 |
| NPF side | 97 | 4440 |

PF and NPF refer to the sides of the experimental field that – during the study period – were to be ploughed and non-ploughed, respectively.
TP = total phosphorus
TN = total nitrogen

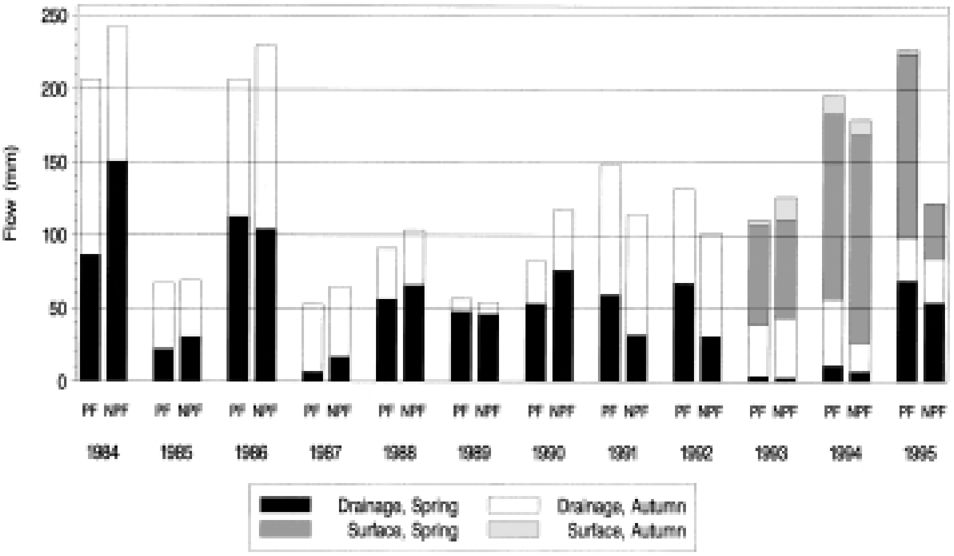

Fig. 2. Water flow (mm) via subsurface drainage and as surface runoff in years 1984–1995 in the Kotkaniemi experimental field. Surface runoff was measured only during 1993–1995. PF and NPF refer to ploughed and non-ploughed fields, respectively.

spite of this, no clear difference between autumn drainage flows attributable to cultivation method was detected in these years. This indicates that the difference is likely to remain negligible during the growing season. Unlike in 1986–1991, the annual drainage flow in 1991–1995 was, on average, lower in the NPF (see Table 5). This trend might indicate that the bulk density of soil below the cultivated layer has increased resulting in reduced porosity and decreasing infiltration of water in the NPF in the course of the experiment years.

For the monthly surface runoff, no significant difference between the two plots was found ($P = 0.38$). Owing to the big difference in 1995 (Fig. 2), the yearly total flow in 1993–1995 was, on average, higher in the PF (178 mm) than in the NPF (142 mm). The most probable reason for the difference in spring 1995 is that the soil was then less frozen than in 1993 and 1994. According to the measurements made at a field located 4 km from the experimental field, the maximum soil frost depth in these three years was reached on the following dates: 36 cm on 12 March 1993, 57 cm on 15 March 1994, and 29 cm on 25 February 1995 (Finnish Environment Institute, unpublished data). Thus, in spring 1995 a larger part of the melt water could percolate into the less frozen soil and the share of surface runoff of the total flow was lower (65% and 41% in the PF and NPF, respectively) than in two other springs when surface runoff comprised more than 90% of the total flow in both plots. Although the huge difference between the plots in spring 1995 (see Fig. 2) may be in part a consequence of measurement errors due to freezing problems, it is probable that more water was stored in top soil in the NPF. This claim was supported by the pF-curves determined in spring 1991 (Paajanen 1993): according to the curves the water storage capacity in the depth of 0–20 cm was higher in the NPF than in the PF.

## Erosion

The difference between the erosion in the two plots was clear (Table 5). Particularly, in the spring surface runoff in 1993 and 1994 erosion from the PF was, on average, more than three-

Table 5. Average seasonal and annual runoff (mm) and erosion (kg ha$^{-1}$) and P and N losses (kg ha$^{-1}$) in the Kotkaniemi experimental field. Data of autumn 1986 through autumn 1991 from Paajanen (1993).

| | | | PF | | | NPF | | |
|---|---|---|---|---|---|---|---|---|
| | Period | Flow path | Spring | Autumn | Annual | Spring | Autumn | Annual |
| Runoff | 1986–1991 | Drainage flow | | | 95 | | | 105 |
| (mm) | 1991–1995 | Drainage flow | 42 | 52 | 94 | 26 | 48 | 74 |
| | 1993–1995 | Surface runoff | 107 | 7 | 114 | 83 | 8 | 91 |
| Erosion | 1986–1991 | Drainage flow | | | 186 | | | 216 |
| (kg ha$^{-1}$) | 1991–1995 | Drainage flow | 76 | 158 | 234 | 29 | 129 | 158 |
| | 1993–1994 | Surface runoff | 465 | 14 | 479 | 140 | 20 | 160 |
| TP | 1986–1991 | Drainage flow | | | 0.25 | | | 0.35 |
| (kg ha$^{-1}$) | 1991–1995 | Drainage flow | 0.10 | 0.18 | 0.28 | 0.05 | 0.20 | 0.25 |
| | 1993–1994 | Surface runoff | 0.38 | 0.02 | 0.40 | 0.39 | 0.05 | 0.44 |
| DRP | 1989–1991 | Drainage flow | | | 0.031 | | | 0.054 |
| (kg ha$^{-1}$) | 1991–1995 | Drainage flow | 0.013 | 0.016 | 0.029 | 0.008 | 0.031 | 0.039 |
| | 1993–1994 | Surface runoff | 0.045 | 0.003 | 0.048 | 0.196 | 0.017 | 0.213 |
| TN | 1986–1991 | Drainage flow | | | 7.1 | | | 4.4 |
| (kg ha$^{-1}$) | 1991–1995 | Drainage flow | 1.8 | 5.4 | 7.2 | 1.6 | 3.0 | 4.6 |
| | 1993–1994 | Surface runoff | 2.7 | 0.2 | 2.9 | 3.6 | 0.3 | 3.9 |
| $NO_3$-N | 1986–1991 | Drainage flo | | | 6.1 | | | 3.7 |
| (kg ha$^{-1}$) | 1991–1995 | Drainage flow | 1.4 | 4.6 | 6.0 | 1.4 | 2.1 | 3.5 |
| | 1993–1994 | Surface runoff | 1.2 | 0.2 | 1.4 | 1.0 | 0.1 | 1.1 |

PF and NPF refer to ploughed and non-ploughed fields, respectively.
TP = total phosphorus
DRP = dissolved reactive phosphorus
TN = total nitrogen

fold of that measured in the NPF even though the surface runoff volume was then slightly lower in the PF. Surprisingly, the difference between the plots in terms of erosion in surface runoff was not found statistically significant (Table 6). This was probably a consequence of the low number of pairs of monthly erosion due to the shortage of surface runoff data. In the light of the TSS concentration results (Fig. 3, Table 6), however, erosion is likely to have been consistently higher in the PF all through the period of the experiment. The lower erosion by surface runoff from the NPF was probably a consequence of the plant residues left in the soil surface reducing the eroding energy of the runoff water (Dickley et al. 1984) and the increased stability of the soil aggregates (Pitkänen 1988).

In drainage flow, both erosion and TSS concentration were found significantly higher in the PF than in the NPF (Table 6). The difference was consistent on both annual and seasonal basis. The higher TSS concentrations in drainage flow in the PF in spring were probably related to the higher concentrations in surface runoff noted above. According to Bengtsson et al. (1992), a great deal of spring drainage flow water in ploughed soil is melt water originating from surface runoff. The bulk of the TSS particles carried by this water were obviously not bound in the soil during the flow through macropores into the drainage pipes. The discrepancy between the periods 1986–1991 and 1991–1995 was due to the somewhat lower drainage flow in the PF than in the NPF during the former period (Table 5).

In this study, the total (drainage flow + surface runoff) material losses could be calculated

Table 6. Statistical significance of the differences between monthly mean concentrations and monthly losses from the PF and the NPF plots in the Kotkaniemi experimental field in 1991–1995. The presented P-values (2-tailed) are based on the Wilcoxon signed rank test. The P-values printed in boldface denote significant ($P < 0.05$) differences.

| Period | Flow path | Eroded material | TP | DRP | TN | $NO_3$-N |
|---|---|---|---|---|---|---|
| | | Concentrations | | | | |
| 1991–95 | Surface runoff | **0.001**[a] | 0.780[a] | **0.002**[b] | 0.279[a] | **0.031**[a] |
| 1991–95 | Drainage flow | **0.012**[a] | 0.875[a] | **0.001**[b] | **0.004**[a] | **0.004**[a] |
| | | Losses | | | | |
| 1993–95 | Surface runoff | 0.086[a] | 0.515[b] | **0.038**[b] | 0.314[b] | 0.051[a] |
| 1991–95 | Drainage flow | **0.000**[a] | 0.476[a] | 0.300[b] | **0.015**[a] | **0.004**[a] |

[a]: erosion or loss higher in the PF than in the NPF
[b]: erosion or loss higher in the NPF than in the PF
PF and NPF refer to ploughed and non-ploughed fields, respectively.
TP = total phosphorus
DRP = dissolved reactive phosphorus
TN = total nitrogen

only for years 1993 and 1994. In these two years, the average erosion in the PF was 582 kg ha$^{-1}$, whereas notably over 1000 kg ha$^{-1}$ yr$^{-1}$ erosion has been measured in sloped fields in intensively cultivated areas in south-western Finland (Mansikkaniemi 1982, Puustinen 1999). The difference was probably not only due to the less steep slope of our experimental field, but also to the short observation period during which the runoff was rather low. As for drainage flow solely, the range of annual erosion in the PF during 1991–1995 (68–541 kg ha$^{-1}$) did not differ much from that measured in ploughed fields during a 4-year period by Turtola and Paajanen (1995): 120–568 kg ha$^{-1}$ yr$^{-1}$.

## P loss

Nor TP concentrations neither TP losses from the plots significantly differed from each other (Fig. 3, Tables 5 and 6). A clear difference was found between the TP concentrations in surface runoff in spring (on average 857 µg l$^{-1}$ in the PF and 412 µg l$^{-1}$ in the NPF), but not in autumn (on average 400 µg l$^{-1}$ in the PF and 448 µg l$^{-1}$ in the NPF). This indicates that particle-bound P was transported from the PF with spring floods more easily than from the NPF whereas in autumn the role of erosion was not so predominant. DRP concentrations and losses from the NPF – particularly in surface runoff – clearly exceeded those from the PF (Fig. 3, Tables 5 and 6).

Given that the average P status in clayey cultivated soils in Finland has increased from 8 to 11 mg P l$^{-1}$ from the early 1970s to early 1990s (Yli-Halla et al. 2001), the soil analyses made in 1979 and 1986 revealed that the pre-experiment P status in the top soil (0–25 cm) of the experimental field was rather low: less than 4 mg P l$^{-1}$. Although the P statuses in both plots seemingly increased from this level during the experiment, no unequivocal difference between the plots has been evolved (Fig. 4). However, according to the layered P status determination made in 1991, i.e. 5 years after the beginning of the experiment, more plant-available P seems to accumulate in the uppermost (0–10 cm) soil layer in the NPF than in the PF (Table 7). Also Pitkänen (1988) and Faulkner et al. (2000) found much higher surface (0–10 cm) soil P concentrations in fields under reduced tillage than in conventionally ploughed fields, and noted that the difference evened out down to 30 cm depth.

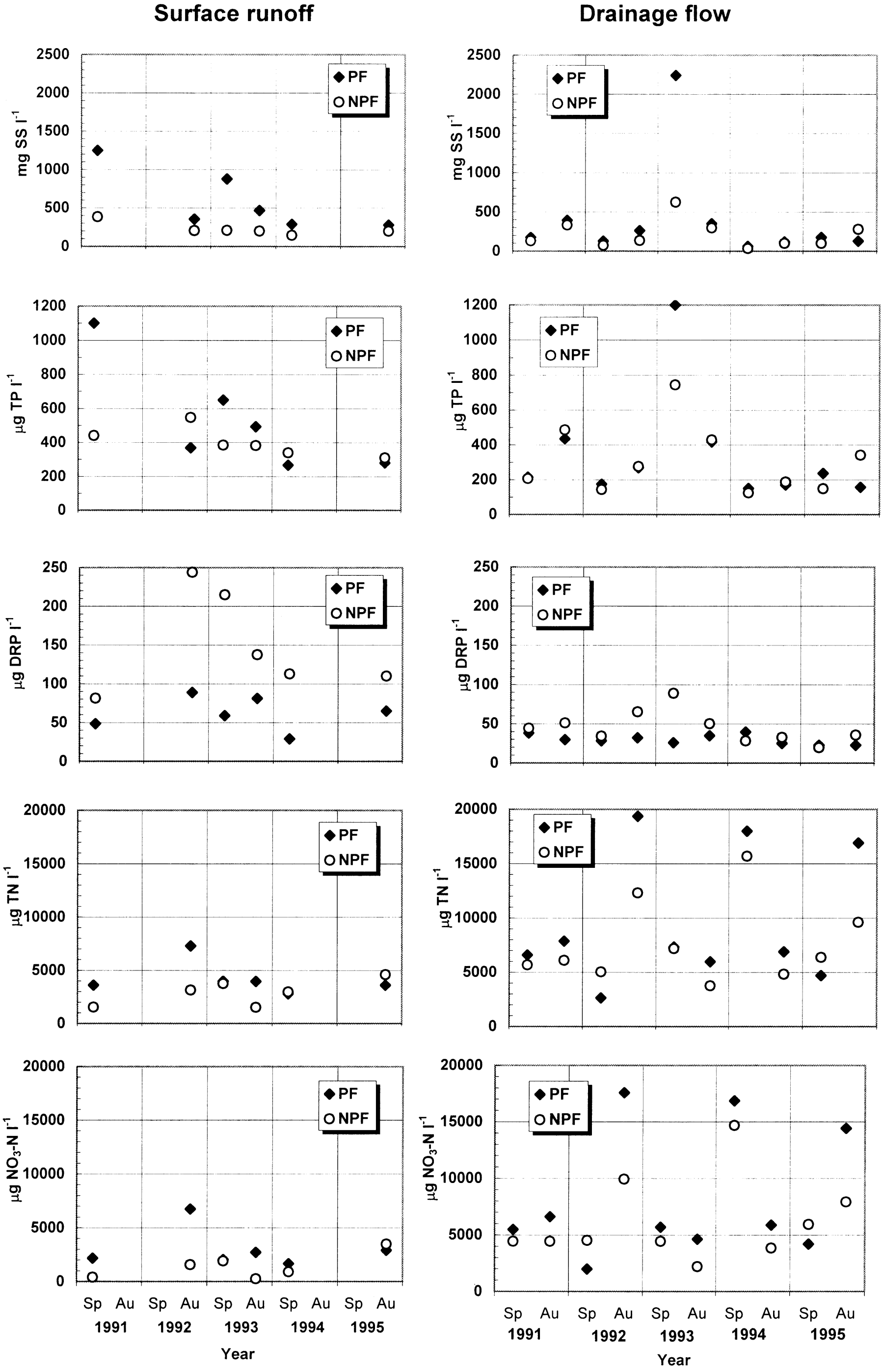

Fig. 3. Arithmetic averages of the observed concentrations (µg $l^{-1}$, except for TSS mg $l^{-1}$) of TSS (total suspended solids), TP (total phosphorus) DRP (dissolved reactive phosphorus), TN (total nitrogen) and $NO_3$-N (nitrate nitrogen) in spring (Sp) and in autumn (Au) for years 1991–1995 in the Kotkaniemi experimental field. PF and NPF refer to ploughed and non-ploughed fields, respectively.

Table 7. Plant-available phosphorus concentration (mg l$^{-1}$) in spring 1991 measured from three layers in the Kotkaniemi experimental field. Data from Paajanen (1993)

| Layer | PF | NPF |
|---|---|---|
| 0–10 cm | 6.5 | 10.0 |
| 10–20 cm | 7.3 | 6.8 |
| 20–30 cm | 6.1 | 3.4 |

PF and NPF refer to ploughed and non-ploughed fields, respectively.

Moreover, Pitkänen (1988) found that the difference was bigger after 12 years than after 6 years of the experiment. Also in this study, it is likely that the difference between the top 10-cm layers in the PF and NPF further increased since 1991 over time up to 1995 because in the NPF only a shallow (5 cm) soil layer was cultivated. Hence, the yearly added P was mixed with a markedly smaller amount of soil than in the PF where the cultivation depth was fivefold (25 cm). Accordingly, Sharpley et al. (1999) attributed the increased P build-up in the uppermost soil in reduced tillage systems to blending of fertilizers only to shallow depths.

When using the data of Table 5 it can be calculated that the particles in surface runoff contained almost twice more P in the NPF (1419 mg P kg$^{-1}$) than in the PF (735 mg P kg$^{-1}$). The higher P concentration both in the uppermost soil and in the detached particles well explain the higher DRP loss from the NPF because the uppermost soil layer is readily exposed to the impacts of rainfall and snow melting, and thus crucial with regard to P losses. As reported by Sharpley et al. (1981) and Yli-Halla et al. (1995), DRP loss increases as the P content of soil – or that of detached particles – increases. Increased DRP concentrations have also been attributed to P release from plant residues (Ulén 1984, Schreiber and Cullum 1998). This may further explain the high difference between the DRP losses from the plots because reduced tillage left apparently more crop residue in the soil surface in the NPF than did the moldboard ploughing applied in the PF.

The high DRP loss from the NPF offset the advantage gained by the lower erosion and thereby lower particle-bound P loss. This character of reduced tillage calls its environmental benefit into question, because DRP is reported to be a relatively good approximation of the amount of P that, at least, is algae-available and hence highly contributing to eutrophication of surface waters (Ekholm 1998). P concentrations were, unlike those of N, on average higher in surface runoff than in drainage flow in both plots (Fig. 3). Therefore, regardless of cultivation method, minimising the proportion of surface

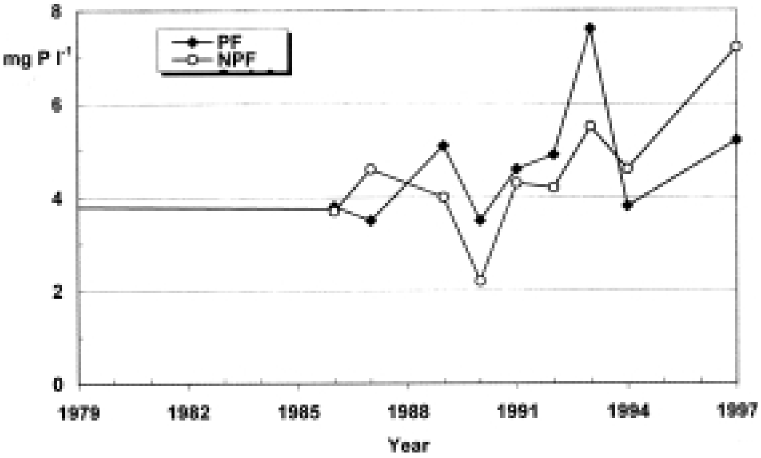

Fig. 4. Plant-available phosphorus concentration (mg l$^{-1}$) after autumn cultivation in 1979, in 1986–1994, and in 1997 measured from 0–25 cm depth in the Kotkaniemi experimental field. PF and NPF refer to ploughed and non-ploughed fields, respectively.

runoff by taking care of the functioning of subsurface drainage seems to make a useful contribution to reducing P loss. The latter was also recommended by Turtola and Paajanen (1995).

Due to the reasons discussed in the case of erosion, the total TP losses obtained in this study (0.52 kg ha$^{-1}$ yr$^{-1}$ both in 1993 and in 1994) remained below the range 0.9–1.8 kg ha$^{-1}$ yr$^{-1}$ that, according to Rekolainen (1989), represents the average TP loss in Finnish arable areas. However, in drainage flow the ranges of annual P losses from the PF during 1991–1995 (0.10–0.60 kg ha$^{-1}$ yr$^{-1}$ for TP and 0.01–0.05 kg ha$^{-1}$ yr$^{-1}$ for DRP) were quite similar to those measured in ploughed fields during a 4-year period by Turtola and Paajanen (1995): 0.10–0.51 kg ha$^{-1}$ yr$^{-1}$ for TP and 0.01– 0.05 kg ha$^{-1}$ yr$^{-1}$ for DRP. On the other hand, the highest annual DRP loss in this study (0.27 kg ha$^{-1}$ yr$^{-1}$ transported by surface runoff in the NPF in 1994) was clearly lower than that measured by Puustinen (1999) for a 1–year period in 1993–1994 in south-western Finland in two fields under reduced tillage treatments: on average 0.65 kg ha$^{-1}$ yr$^{-1}$.

## N loss

N concentrations were generally higher in the PF than in the NPF (Fig. 3, Table 6). In surface runoff the difference was clear both in spring (NO3-N on average 2100 µg l$^{-1}$ in the PF and 800 µg l$^{-1}$ in the NPF) and in autumn (NO3-N on average 5000 µg l$^{-1}$ in the PF and 1200 µg l$^{-1}$ in the NPF). In drainage flow, the difference emerged distinctly in autumn: in spring the N concentrations between the plots did not differ much (Fig. 3).

TN and NO3-N losses in drainage flow were significantly higher in the PF than in the NPF (Tables 5 and 6). In surface runoff the difference was, due to the shortage of flow data, not as undeniable. Nonetheless, the N concentration results (see Fig. 3 and Table 6) support the assumption that more N, at least $NO_3$-N, was leached from the PF in surface runoff as well. One reason for the higher $NO_3$-N loss from the PF could come from the difference in terms of aerobia. It is likely that, due to the deeper cultivation, more aerobic conditions prevailed in the PF than in the NPF where water content of soil was obviously higher. As reported by Burt et al. (1993), aerobia correlates positively with mineralisation rate and negatively with denitrification rate. The stronger the mineralisation and the weaker the denitrification, the higher the amount of easily leachable $NO_3$-N in soil at the end of the growing season.

The average annual TN losses presented in this study (Table 5) were below the range representing typical TN losses in Finnish arable areas (10–20 kg ha$^{-1}$yr$^{-1}$, Rekolainen 1989). On the other hand, with regard to drainage flow, the range of annual TN losses in the PF (2.3–12.4 kg ha$^{-1}$yr$^{-1}$) quite well corresponded the range (0.6–14.8 kg ha$^{-1}$yr$^{-1}$) measured by Turtola and Paajanen (1995) in ploughed fields. As for the surface runoff in the NPF, the average TN loss (3.9 kg ha$^{-1}$yr$^{-1}$) was similar to that measured by Puustinen (1999) during 1993–1994 in south-western Finland in two field plots under reduced tillage treatments (on average 4.0 kg ha$^{-1}$yr$^{-1}$).

## Use of the results

The main findings of this study were quite clear. They were in good agreement with many previous studies (see Introduction) and hence not surprising. However, modelling of the environmental impacts of different agricultural practices is chronically in need of empirical experiences from various conditions. The information offered by this study – together with other field-studies – are of value for the modelling activities, because it is very important to find out how the effects of management practices (like tillage systems) respond to varying circumstantial factors of fields (slopes, soil P statuses, soil textures, etc.). Moreover, with respect to drainage flow this study offers readily available information on the amounts of water, soil, and nutrients transported to bodies of water via a field drainage system typical of Finnish farms. As for surface runoff, the losses were based on a two-year, drier-than-normal period. Thus, the total material loss estimates – calculated by summing the losses in drainage flow and surface runoff – probably underestimate the average losses from commensurate fields in Finland.

## Conclusions

Reduced tillage is an efficient means when the aim is to reduce erosion and N loss from fields. In single years, we found erosion even 400 kg ha$^{-1}$ yr$^{-1}$ and NO$_3$-N loss almost 6 kg ha$^{-1}$ yr$^{-1}$ less from the field cultivated with lighter method than from a conventionally ploughed field. Thus, considerable reductions are achievable in proportion to the amounts typical of Finnish arable areas (Mansikkaniemi 1982, Rekolainen 1989, Turtola and Paajanen 1995). Regardless of the efficiency in erosion control, reduced tillage has little effect on TP loss, and DRP output is markedly increased. DRP concentration seems to be particularly high in surface runoff from a non-ploughed field. Therefore, reduced tillage should be combined with minimising the portion of surface runoff by means of efficient sub-surface drainage.

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# SELOSTUS

## Aurattoman viljelyn vaikutus eroosioon ja ravinnehuuhtoumiin eteläsuomalaisella, savimaalla sijaitsevalla pellolla

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Aurattoman viljelyn ja perinteisen syyskynnön vaikutuksia eroosioon sekä typen ja fosforin huuhtoutumiseen verrattiin eteläsuomalaisella, savimaalla sijaitsevalla koekentällä. Vaikka koe aloitettiin jo syksyllä 1986, tässä artikkelissa esitetään lähinnä vuosien 1991–1995 tuloksia. Koekenttä oli jaettu kahteen lähes samansuuruiseen lohkoon, joista toinen kynnettiin 25 cm syvyyteen ja toinen äestettiin lapiorulläkeellä 5 cm syvyyteen joka syksy. Eroosio oli suurempi kynnetyltä lohkolta (keskimäärin 234 kg ha$^{-1}$ v$^{-1}$ salaojavalunnassa ja 479 kg ha$^{-1}$ v$^{-1}$ pintavalunnassa) kuin kyntämättömältä (keskimäärin 158 kg ha$^{-1}$ v$^{-1}$ salaojavalunnassa ja 160 kg ha$^{-1}$ v$^{-1}$ pintavalunnassa). Niinikään typpihuuhtoumat olivat suurempia kynnetyltä lohkolta, josta kokonaistyppeä huuhtoutui salaojavalunnassa keskimäärin 7,2 kg ha$^{-1}$ v$^{-1}$, kun vastaava määrä kyntämättömältä lohkolta oli 4,6 kg ha$^{-1}$ v$^{-1}$.

Kokonaisfosforihuuhtoumissa ei havaittu eroa lohkojen välillä: huuhtoutunut määrä oli molemmilta lohkoilta osapuilleen 0,7 kg ha$^{-1}$ v$^{-1}$. Ero havaittiin sen sijaan liuenneen reaktiivisen fosforin huuhtoumissa, jotka olivat kyntämättömältä lohkolta selvästi suuremmat, esim. pintavalunnassa keskimäärin 0,21 kg ha$^{-1}$ v$^{-1}$, kun kynnetyltä lohkolta huuhtoutui vastaavasti 0,05 kg ha$^{-1}$ v$^{-1}$. Tulokset vahvistavat aiempia käsityksiä aurattoman viljelyn eduista eroosion ja nitraattihuuhtoumien vähentämisessä. Ympäristölle koituvaa hyötyä kuitenkin vähentää liuenneen ja samalla leville suoraan käyttökelpoisen fosforin kuormituksen kasvu, jolla on vesistöjä rehevöittävä vaikutus.