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Soil nitrate N as influenced by annually undersown cover crops in spring cereals

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Cover crops can reduce leaching and erosion, introduce variability into crop rotations and fix nitrogen (N) for use by the main crops. In Finland, undersowing is a suitable method for establishing cover crops in cereals. The effect of annual undersowing on soil nitrate N was studied at two sites. Red clover (*Trifolium pratense* L.), white clover (*Trifolium repens* L.), a mixture of red clover and meadow fescue (*Festuca pratensis* Huds.), and westerwold ryegrass (*Lolium multiflorum* Lam. var. *westerwoldicum*) were undersown in spring cereals during six successive seasons, and a pure stand of cereal was grown in two years after that. In all years, the soil nitrate N was measured in late autumn, and in addition in different times of the season in last four years. The effect of undersowing on soil NO_3-N content was generally low, but in one season when conditions favoured high N leaching, westerwold ryegrass decreased soil NO_3-N. The negligible increase of N leaching risk in connection with undersowing clovers, associated with late autumn ploughing, supports the use of clovers to increase the cereal grain yield. The highest levels of soil NO_3-N were recorded at sowing in spring irrespective of whether a crop was undersown or not. NO_3-N contents were higher in sandy soil than in silt. Undersowing can be done annually in cereal cultivation either to fix or catch N. No cumulative effects on soil nitrate N were associated with undersowing after six years.

Key words: cereals, clovers, cover crops, grasses, intercropping, nitrate nitrogen

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Introduction

Growing cover crops after harvesting a main crop has positive effects on environment and main crops. Cover crops can reduce soil erosion during autumn and winter, improve soil fertility (Carter and Kunelius 1993) and, when legumes are used, fix nitrogen (N) to the benefit of subsequent crops in a rotation (Marstorp and Kirchmann 1991). Besides this, cover crops can decrease or increase soil mineral N (Breland 1996) and by that means affect positively or negatively N leaching. In Finland, reducing N leaching is needed because of eutrophication of coastal waters (Rekolainen et al. 1995) and high risk for lack of oxygen in lakes, which are shallow and covered by ice during long winters. Therefore, more knowledge of the effect of both N catching and N fixing cover crop species on soil NO_3-N is needed.

Undersowing in cereals is a suitable method for establishing a cover crop in northern latitudes (Alvenäs and Marstorp 1993, Jensen 1991). Undersowing enables immediate uptake of residual N by the cover crop after harvest of the main crop (Breland 1996). It therefore follows that if the establishment of the undersown cover crop is successful, it normally reduces N leaching better than sowing the catch crop after the main crop (Beck-Friis et al. 1993). Similarly, when legumes are undersown instead of sowing after the main crop, more mineralisable N is presumably incorporated with the cover crop.

The soil nitrate N content before winter is regarded as an important indicator of N leaching risk in the Nordic countries (Beck-Friis et al. 1993, Wallgren and Lindén 1994, Breland 1996 and Känkänen et al. 1998). Realised N leaching depends on the permanence of soil freezing during winter. During a mild winter downward movement of water in the soil can occur, but in cold winters water conductivity in soil is low due to frost (Turtola and Kemppainen 1998), and large amounts of soil water can drain in the spring when soil and snow melt.

Besides N leaching risk on the grounds of soil nitrate N content before winter, timing of the release of cover crop N was studied. For instance, the net N mineralization can occur too late to be of use to the succeeding crop (Thorup-Kristensen 1996). When grown annually, the effects of cover crops from different years on soil N can also be mixed, because the release of N from plant material takes longer than one growing season (Jensen 1992). Furthermore, N fertilisation and its effect on the growth of both the main and undersown crop are also influencing when the effect of undersown crops on soil N is measured.

Soil type can also greatly affect N leaching. Kolenbrander (1969) reported low leaching from clayey soil and high leaching from sandy soils. Egelkraut et al. (2000) reported that soils with greater clay concentrations mineralised less N from added materials. The soils of the experiment were chosen in accordance with their predominance and difference in tendency to leaching. Two thirds of soils are clayey in southern and south-western part of Finland, where the circumstances for leaching are otherwise favourable. Sandy soil is the second common soil type in Finland and represents soils with high leaching.

The aim of the current study was to investigate how annually repeated undersowing with legume or grass cover crops affected risk of N leaching through measuring soil nitrate N content before winter. During last four years, soil NO_3-N content was measured on different dates in order to determine timing of N mineralisation. Moreover, as N fertilization decreased the yield of clovers and increased the yield of westerwold ryegrass (Känkänen et al. 2001), also effects on soil N was expected, and therefore soil NO_3-N content under different N fertilizer regimes was examined, too.

Grain yields in this study have been published in an earlier paper (Känkänen et al. 2001). Annual undersowing with clovers increased, and undersowing with westerwold ryegrass decreased cereal grain yields. The grain yield was only slightly lower with a mixture of red clover and meadow fescue than with red clover alone. Soil fertility was not notably improved during

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six years of undersowing according to grain yield two years later.

Material and methods

Experimental sites

The experiments were established in 1991 at the Häme Research Station in Pälkäne (61˚20'N, 24˚13'E) and at the Laukaa Research and Elite Plant Station (62˚25'N, 26˚15'E). The soils were classified at two points, which were at the extreme ends of the trial areas (the topsoil classifications and the conventional abbreviations of the Finnish names are given in parentheses). At Pälkäne the soil was an Aquic Eutrocryept, (fine sandy loam, KHt) and an Oxyaquic Cryopsamment (loamy sand, KHt). At Laukaa the soil was a Typic Cryaquept or Typic Cryaquent (silt loam, Hs) and a Typic Cryaquent or Typic Cryaquept (silt loam, Hs) (Yli-Halla et al. 2000).

At Pälkäne, soil in deeper layers varied, changing from silty clay at the extreme end of the first replicate to sandy in the second and third replicates. The greatest variation was in the first replicate, where the content of sand in the 60 to 90 cm soil layer was 14 and 90% in one corner and in the middle of the replicate, respectively.

Experimental design

The experiments were designed as split-plots with N fertiliser application rates as the main plots (size 6 m × 20 m and 7.5 m × 20 m at Pälkäne and Laukaa, respectively), arranged in a randomised complete block design with three replicate blocks. The split-plot treatments (five undersowings) were randomised among the subplots (6 m × 4 m and 7.5 m × 4 m at Pälkäne and Laukaa, respectively) within each main plot.

Sowing of cereals was done between 17 and 31 May when the soil moisture was adequate for sowing spring cereals. The seedbed was prepared with an S-tine harrow to 4–5 cm and 3–4 cm depth at Pälkäne and Laukaa, respectively. Spring barley (*Hordeum vulgare* L.) was sown in 1991 and 1994, spring wheat (*Triticum aestivum* L.) in 1992 and 1995 and oats (*Avena sativa* L.) in 1993 and 1996, using a combined drill adjusted to those depths. The seed rates for barley, wheat and oats were as normally used in Finland, 450, 500–650 and 500 seeds per m^2 respectively. Undersowing was done across the cereal rows to about 2 cm depth at Pälkäne and 1 cm at Laukaa using a combined drill at Pälkäne and an Oyjord experimental sower at Laukaa. Undersowing was done after cereal sowing on the same day or on the following day, except at Pälkäne in 1993 and 1995 where it was done five and four days later respectively. The plots that were not undersown remained undisturbed during this phase. The row distance of cereals and undersown crops was 12.5 cm. The trial areas were rolled with a continental Cambridge roller before and after undersowing.

Red clover (*Trifolium pratense* L.), white clover (*Trifolium repens* L.), a mixture of red clover and meadow fescue (*Festuca pratensis* Huds.) (R.C. & M.F.) and westerwold ryegrass (*Lolium multiflorum* Lam. var. *westerwoldicum*) were undersown in spring cereals in the same plots during six successive seasons, 1991–1996. A treatment without undersowing represented the control. In 1997 and 1998 a pure stand of spring barley was grown on all plots to measure the residual effect of long-term undersowing. The seed rates for red clover, white clover and westerwold ryegrass were 6, 6 and 10 kg ha^{-1} of viable seed respectively. In the mixture the seed rates for red clover and meadow fescue were 3 and 6 kg ha^{-1}, respectively.

All cover crop treatments were combined with N treatments at 0, 30, 60 or 90 kg N ha^{-1}. Fertiliser N was applied with a combined drill at a depth of 7–9 cm at the same time with cereal sowing, and the subplots kept the same N treatment across experimental years. Phosphorus and potassium were applied separately to the entire trial area before sowing the cereal, according to recommendations.

After harvesting the cereal crop with a combine harvester in August or September, when the crop was at growth stage 92 (Zadoks et al. 1974), straw residues were collected from the trial area. The cereal crop was harvested, leaving the stubble as high as possible, to ensure minimal damage to the undersown crop.

Soil was ploughed in 1991–1996 in late October to ensure a sufficiently long growing season for the undersown crops. In 1992 at Laukaa ploughing was not done until 7 December, after early snow cover had melted. In 1997 ploughing was done in late September, the normal ploughing time in Finland.

Measurements

Plant samples (from 0.25 m^2 per plot), including above-ground material of the undersown crop, were taken before autumn ploughing. Plants were cut with scissors at the base. Root samples from the 0–25 cm soil layer were taken immediately before autumn ploughing. The root samples were taken manually with a steel box and a spade (25 cm × 25 cm surface area) during the first three years and mechanically with a tractor borer (12.5 cm × 12.5 cm surface area) in later years. Roots were washed manually during the first three years and in later years with a hydropneumatic root washer (Smucker et al. 1982). Organic matter was separated with forceps. Shoot and root samples were dried in an oven (2 hours at 105˚C and overnight at 60˚C), and dry matter, N concentration (%) and yield (kg ha^{-1}) were measured. Measured above-ground material included only biomass from undersown crops, but root biomass from plants other than cover crops was not separated from root samples. Shoot and root samples were taken in all undersowing years, except at Pälkäne in 1992 because of early snow cover and in 1993 because of almost total failure to establish a cover crop.

The effect of undersowing on soil NO_3-N concentration before winter was studied by taking annually repeated measurements from each subplot in four experimental phases: 1) the first year of undersowing, 2) additional years of undersowing 3) the first year after the last undersowing year and 4) the second year after the last undersowing year. The experimental phases were chosen in order to bring out the different implication of undersown crop in each phase. In Phase 1 only the cover crop of that year affected, in Phase 2 the effect of current and previous cover crops were mixed, and in Phase 3 only previous cover crops affected. The Phase 4 represents long-term effects after annually undersown cover crops. The soil samples (Table 1) were taken near the beginning of soil frosting, from late October to early December in different years, except earlier in autumn in the last year.

Until 1995, samples were taken manually by mixing 16 cores from topsoil or six cores from subsoil samples. Because of difficulties in carrying out complete sampling, the statistical analysis included only a few years in Phase 2 (Table 1). From 1995, samples were taken mechanically by mixing 16 cores from topsoil or ten cores from subsoil samples. Using a machine for sampling after the start of soil frosting assisted in getting the planned samples.

From 1995 samples were taken in early spring before soil thowing (Time 1), before sowing in spring (Time 2), at cereal harvest (Time 3), before autumn ploughing (Time 4) and before winter, near the start of soil frost (Time 5). These samples were taken from 0 and 90 N treatments from control plots and plots containing white clover and westerwold ryegrass. Because of small amount of observations per each sampling time, there was a disagree between the statistical analysis and the actual situation on field, and results are studied graphically.

Soil samples were extracted with 2 M KCl. The nitrate (NO_3-) nitrogen contents of the extracts were analysed with a autoanalyser (air segmented flow analyser, photometric detection) and converted into kg ha^{-1} (Esala 1991).

Information on weather conditions during the experimental years is given in detail by Känkänen et al. (2001).

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Table 1. Soil samples for NO_3-N analysis taken before winter during four different phases when red clover, white clover, a mixture of red clover and meadow fescue and westerwold ryegras were undersown in spring cereals during six successive seasons at Pälkäne and Laukaa experimental sites.

		First year of undersowing		Additional years of undersowing			First year after discontinuation of undersowing		Second year after discontinuation of undersowing	
Site	Soil layer (cm)	Crops[a)]	N fertilisation (kg ha^{-1})	Crops[a)]	N fertilisation (kg ha^{-1})	Years	Crops[a)]	N fertilisation (kg ha^{-1})	Crops[a)]	N fertilisation (kg ha^{-1})
Pälkäne	0–30			1–5	0,30,60,90	95,96	1–5	0, 90	1–5	0,30,60,90
	30–60			1,3,5	0, 90	95,96	1,3,5	0, 90	1,3,5	0, 90
	60–90			1,3,5	0, 90	95,96	1,3,5	0, 90	1–5	0, 90
Laukaa	0–30	1–5	0,30,60,90	1–5	0,30,60,90	92,93,96	1–5	0, 90	1–5	0,30,60,90
	30–60			1–5	0, 90	96	1–5	0, 90	1,3,5	0, 90
	60–90			1–5	0, 90	96	1–5	0, 90	1,3,5	0, 90

a) 1 = no undersowing, 2–5 = spring cereals undersown in six years with 2 = red clover, 3 = white clover, 4 = mixture of red clover and meadow fescue, 5 = westerwold ryegrass.

Statistical methods

Soil nitrate N concentration was analysed using a mixed model:

$$Y_{ijkl} = \mu + b_i + F_j + e_{ij} + U_k + FU_{jk} + f_{ijk} + P_l + g_{il} + FP_{jl} + h_{ijl} + UP_{kl} + FUP_{jkl} + s_{ijkl}$$

where Y_{ijkl} is the response for block i, fertiliser rate j, undersowing k and period l; μ is the overall mean; b is the random block effect; F, U and P are the fixed effects of fertiliser, undersowing and period, respectively; FU, FP and UP are the two-factor interactions of the fixed effects and FUP is the three-factor interaction; e, f, g, h and s are the random error terms. The random variables b_i, e_{ij}, f_{ijk}, g_{il}, h_{ijl} and s_{ijkl} are assumed independent and normally distributed with zero means and constant variances. Furthermore, the error vectors $s_{ijk} = (s_{ijk1},\ldots,s_{ijkL})$ for soil nitrate N were assumed to be independent and multivariate normal with zero means and unstructured covariance matrices Σ. The models were fitted by using the residual maximum likelihood (REML) estimation method. The degrees of freedom were approximated through the method introduced by Kenward and Roger (1997). Accordances of the data with the distributional assumptions of the models were checked graphically. The residuals were checked for normality using box plots (Tukey 1977). In addition, the residuals were plotted against the fitted values. The PROC MIXED procedure (Littell et al. 1996) of SAS/STAT software was used.

Results

Biomass of undersown cover crops

Growth of undersown crops varied between years because of variable weather conditions, and among sites and treatments. In 1993 at Laukaa the dry matter yield of red clover, white clover and the mixture of red clover and meadow fescue was only 100–200 kg ha^{-1} before autumn ploughing, when high N fertilisation was used. However, generally undersowing was a successful means of establishing a cover crop, which yield was normally ≥ 1000 kg ha^{-1}. The yield of red clover, white clover and the mixture of red

Table 2. Average yield and N-% of above ground (shoots) and root dry matter of crops undersown annually in spring cereals during 1991–1996 at Pälkäne and Laukaa experimental sites.

		Pälkäne				Laukaa			
Undersown crop	N fertilisation (kg ha^{-1})	shoots (kg ha^{-1})	roots (kg ha^{-1})	shoots (N-%)	roots (N-%)	shoots (kg ha^{-1})	roots (kg ha^{-1})	shoots (N-%)	roots (N-%)
Red clover	0	1000	1860	3.05	2.21	920	1370	3.18	2.62
	30	580	1400	3.09	1.80	820	1150	3.10	2.84
	60	600	1250	3.12	1.69	530	780	3.29	2.83
	90	460	1100	3.42	1.96	380	600	3.35	2.70
White clover	0	1780	2170	3.19	1.97	1230	590	3.58	2.48
	30	1460	1850	3.14	1.77	860	420	3.42	2.61
	60	1500	1350	3.31	1.88	660	290	3.52	2.78
	90	1240	1620	3.45	1.86	540	400	3.58	2.58
Red clover & meadow fescue	0	700	2090	2.85	1.97	780	1110	3.20	2.47
	30	560	1350	2.97	1.27	670	840	3.02	2.70
	60	760	1700	2.80	1.57	430	500	2.95	2.47
	90	310	1410	3.00	1.44	400	700	2.81	2.14
Westerwold ryegrass	0	800	1610	2.09	0.91	310	320	1.78	1.10
	30	1190	2030	1.99	0.91	320	210	1.78	1.08
	60	1340	1940	2.23	0.94	390	200	1.89	1.06
	90	1190	2060	2.54	1.09	470	420	1.87	1.13

clover and meadow fescue decreased, and that of westerwold ryegrass slightly increased, with increasing N fertilisation. The above ground and root biomass N contents were highest for red and white clover and lowest for ryegrass. The root N concentrations were somewhat higher at Laukaa than at Pälkäne (Table 2).

Soil NO_3-N before winter

At Pälkäne, the undersown crop did not have a significant main effect on soil NO_3-N content before winter at 0–30 cm, but the effect varied between experimental phases (Table 3). In the 30–60 cm soil layer, differences associated with undersown crops were established ($F_{2, 8.73} = 4.14$, $P = 0.054$), and there was also a statistically significant interaction between phase and undersown crop (Table 3). No statistically significant differences were found among samples from the 60–90 cm layer. There was no statistically significant interaction between N fertilisation and undersown crop at any soil layer or in any phase.

At Laukaa, the undersown crop affected (a statistically significant main effect, $F_{4, 26.7} = 5.61$, $P = 0.002$) the NO_3-N content in the 0–30 cm soil layer, but the effect depended on the experimental phase (Table 3). No significant effects were found at deeper soil layers. There was no statistically significant interaction between N fertilisation and undersown crop at any layer or for phase.

For each case of a main effect of the undersown crop there was an interaction between experimental phase and undersown crop, too. Consequently, the effect of the undersown crop is not detailed at main effect level, but differences in each phase are expressed.

In experimental Phase 1 samples were taken only at Laukaa from the 0–30 cm soil layer. Soil NO_3-N content was quite low, 4.5 kg ha^{-1} (standard error of means, SEM 0.71) without undersowing. Westerwold ryegrass decreased soil

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Table 3. Statistical significances of N fertiliser level x crop, crop x experimental phase and N level x crop x experimental phase interactions on soil nitrate N content (kg ha^{-1}) before winter, when red clover, white clover, a mixture of red clover and meadow fescue and westerwold ryegras were undersown in spring cereals during six successive seasons at Pälkäne and Laukaa experimental sites.

	Layer (cm)	N level x crop		Crop x phase		N level x crop x phase	
		F-value and DF	P-value	F-value and DF	P-value	F-value and DF	P-value
Pälkäne							
	0–30	$F_{12, 32.3} = 0.83$	0.620	$F_{8, 40} = 2.95$	0.011	$F_{24, 40.1} = 1.02$	0.464
	30–60[a, b)]	$F_{2, 7.0} = 1.13$	0.377	$F_{4, 8.9} = 5.58$	0.016	$F_{4, 4.9} = 1.90$	0.250
	60–90[a, b)]	$F_{2, 8.5} = 1.27$	0.330	$F_{4, 8.2} = 1.43$	0.307	$F_{4, 8.2} = 2.20$	0.157
Laukaa							
	0–30	$F_{12, 25.3} = 0.52$	0.884	$F_{12, 33} = 2.14$	0.042	$F_{36, 44.3} = 1.21$	0.269
	30–60[b)]	$F_{4, 17.1} = 0.37$	0.826	$F_{4, 16.7} = 0.74$	0.581	$F_{4, 16.7} = 0.29$	0.882
	60–90[b)]	$F_{4, 16.8} = 0.73$	0.584	$F_{4, 12.4} = 1.10$	0.398	$F_{4, 9.9} = 1.61$	0.248

[a)] No undersowing, white clover and westerwold ryegrass included.
[b)] 0 N and 90 N included.
DF = degrees of freedom
At Pälkäne phases 2, 3 and 4, and at Laukaa in 0–30 cm all phases and in 30–60 cm and 60–90 cm phases 2 and 3 are included. Phase 1 = the first year of undersowing, Phase 2 = additional years of undersowing, Phase 3 = the first year after the last undersowing year, Phase 4 = the second year after the last undersowing year.

NO_3-N content by 1.8 kg ha^{-1} as compared with no undersowing (Table 4).

In experimental Phase 2, soil NO_3-N content without undersowing at Pälkäne was 5.2, 7.4 and 5.5 kg ha^{-1} and at Laukaa 2.4, 2.5 and 1.5 kg ha^{-1} in soil layers 0–30, 30–60 and 60–90 cm, respectively. At Pälkäne in two upper soil layers westerwold ryegrass decreased soil NO_3-N content (Table 4). In the 60–90 cm layer at Pälkäne and the 30–90 cm layer at Laukaa there were no differences associated with different crops.

In experimental Phase 3, soil NO_3-N content without undersowing at Pälkäne was 8.7, 8.8 and 7.8 kg ha^{-1} and at Laukaa 10.0, 5.0 and 2.1 kg ha^{-1} in soil layers 0–30, 30–60 and 60–90 cm, respectively. At both sites there were signs of increased soil NO_3-N contents after white clover, but all differences were small and only once statistically significant (Table 4).

In experimental Phase 4, soil NO_3-N content without undersowing at Pälkäne was 7.6, 4.3 and 2.4 kg ha^{-1} and at Laukaa 7.2, 6.1 and 2.5 kg ha^{-1} in soil layers 0–30, 30–60 and 60–90 cm, respectively. At Laukaa a mixture of red clover and meadow fescue increased soil NO_3-N content by 3.1 kg ha^{-1} at 0–30 cm (Table 4). Otherwise there were no differences associated with different crops.

Soil NO_3-N in different dates during final years

Sampling time greatly affected the NO_3-N content of soil. The content was often clearly highest before sowing in spring (Time 2), especially in 1996 at both sites and in 1997 at Pälkäne (Fig. 1). This was regardless of soil layer or N fertilisation. Almost without exception there was more NO_3-N with white clover than with westerwold ryegrass. However, when compared with no undersowing, the effect of an undersown crop varied among sampling dates. N fertilisation did not greatly affect the soil NO_3-N. Only at Pälkäne there was 1–5 kg NO_3-N ha^{-1} higher content per soil layer at 90 N than at 0 N on dates other than at sowing. However, the effect of an undersown crop was similar at both N rates.

Table 4. The differences and P values between estimated means of soil nitrate N (kg ha^{-1}) before winter, when cereal cropping without undersowing is compared with using different undersown crops, in cases where the crop x experimental phase interaction had a statistical significance (P<0.05). Standard error of difference (SED) is presented for each comparison.

Phase	Undersown crop	Pälkäne, 0–30 cm		Pälkäne, 30–60 cm		Laukaa, 0–30 cm	
		estimate	P value	estimate	P value	estimate	P value
1	red clover					0.6	0.203
	white clover					–0.3	0.434
	R.C. & M.F.					0.8	0.093
	westerwold ryegrass					1.8	<0.001
SED						0.43	
2	red clover	0.5	0.231			–0.4	0.197
	white clover	0.2	0.518	–0.2	0.745	–1.1	0.001
	R.C. & M.F.	0.6	0.141			–0.7	0.016
	westerwold ryegrass	1.8	<0.001	3.3	<0.001	0.4	0.139
SED		0.37		0.5		0.27	
3	red clover	–0.5	0.347			–1	0.133
	white clover	–0.8	0.148	–1.8	0.367	–1.5	0.027
	R.C. & M.F.	–0.5	0.309			–1.3	0.052
	westerwold ryegrass	–0.2	0.693	–0.7	0.706	–0.1	0.832
SED		0.53		1.84		0.62	
4	red clover	–0.1	0.885			–1.7	0.115
	white clover	–0.8	0.208	–0.3	0.615	–1.6	0.152
	R.C. & M.F.	–0.7	0.287			–3.1	0.006
	westerwold ryegrass	0.1	0.819	0.7	0.219	0.2	0.844
SED		0.65		0.5		1.06	

Phase 1 = the first year of undersowing, Phase 2 = additional years of undersowing, Phase 3 = the first year after the last undersowing year, Phase 4 = the second year after the last undersowing year. R.C. & M.F. = mixture of red clover and meadow fescue. In cases with no values, no soil sampling was done.

At Pälkäne, the westerwold ryegrass decreased soil NO_3-N content cleary in autumn and winter 1995–1996, after a high ryegrass yield in 1995. The effect was greater at 90 N than at 0 N. The above ground dry matter yield of westerwold ryegrass was 2220 kg ha^{-1} at 0 N and 3640 kg ha^{-1} at 90 N in 1995, but only 120 kg ha^{-1} in 1996 at both N levels. White clover increased the NO_3-N content clearly in 1997 at spring sowing, although the growth of clover was weak in 1996. The above ground dry matter yield of white clover before ploughing was 4020 kg ha^{-1} and 1050 kg ha^{-1} at 0 N, and 2850 kg ha^{-1} and 50 kg ha^{-1} at 90 N, in 1995 and 1996, respectively.

At Laukaa, white clover increased the mean NO_3-N content in 1996 before sowing in spring (Time 2). However, only two replicates were sampled, and the difference was mainly attributable to one of them. The effect of westerwold ryegrass on decreasing soil NO_3-N was recorded in the last year of the experiment when no N fertilisation was given. This was the only marked long term or N fertilisation effect established in this study.

Discussion

Risk for N leaching can be decreased with undersowing with grasses, although effect of west-

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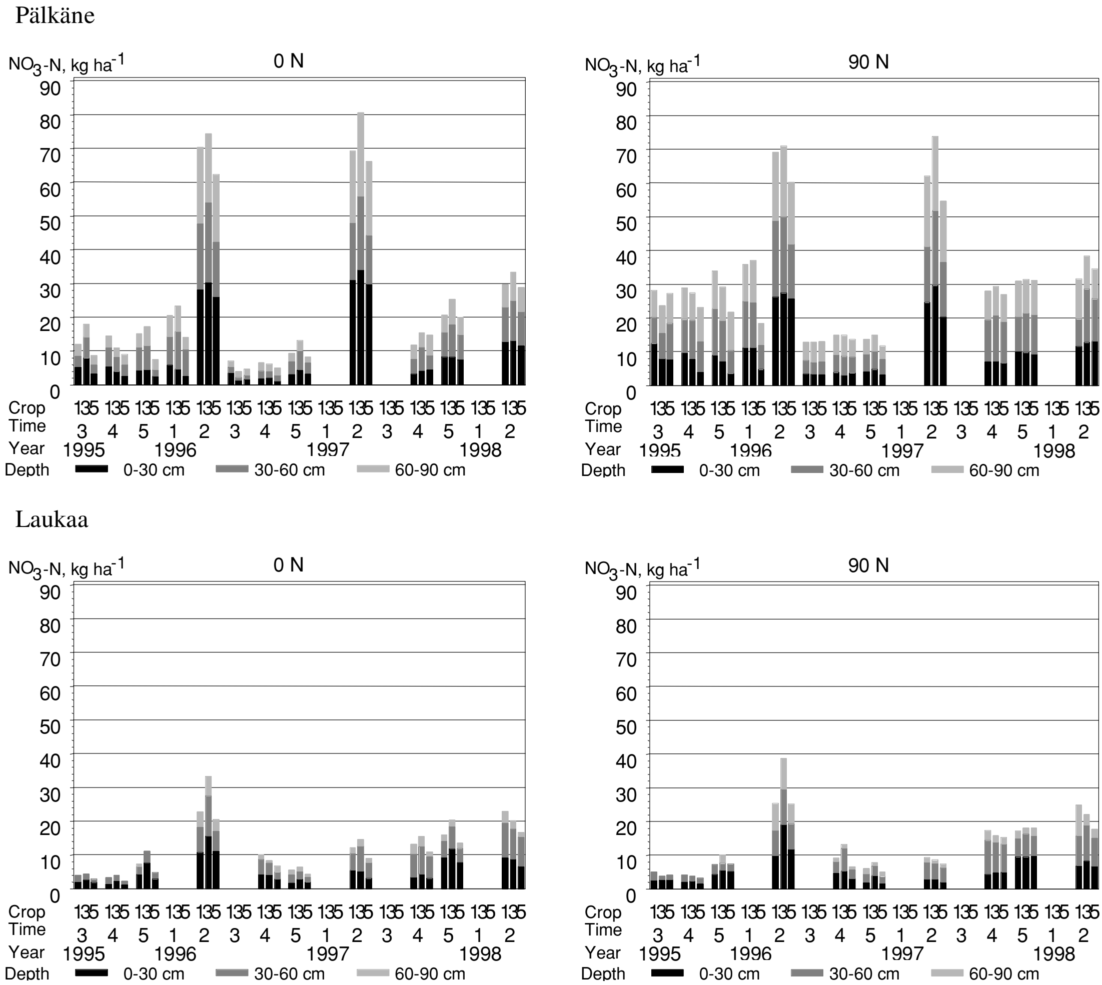

Fig. 1. Soil NO_3-N (kg ha^{-1}) at different sampling times from early autumn in 1995 to spring in 1998 when spring cereals were annually undersown in 1991–1996 at Pälkäne and Laukaa. Three soil layers (0–30, 30–60 and 60–90 cm) and two fertiliser N levels (0 and 90 kg ha^{-1}). Crop: 1 = no undersowing, 3 = white clover undersown and 5 = westerwold ryegrass undersown. Time: 1 = in March before soil thawing, 2 = in May before sowing, 3 = between September 13 and 25 after cereal harvest, 4 = in October before autumn ploughing and 5 = in November near soil frosting.

erwold ryegrass on soil NO_3-N content was often small, probably due to poor growth after cereal harvest. However, when the N leaching risk was high in autumn 1995 – spring 1996 at the 90 N level in Pälkäne, the ryegrass grew vigorously in autumn and markedly reduced the amount of NO_3-N in soil. Italian ryegrass, which grows more reliably in autumn than westerwold ryegrass, was shown by Lemola et al. (2000) to reduce N leaching by 27 to 68% depending on soil type. However, the undersown ryegrass can reduce soil mineral N already during main crop growth, as reported by Breland (1996). Consequently, the competitive effect of the undersown crop should be taken into account. In these experiments cereal grain yield was decreased substantially due to westerwold ryegrass (Känkänen et al. 2001).

Drainage runoff and nitrate N leaching in Finland are normally highest in November, December and April (unpublished data from two leaching experiment fields at MTT). It suggests that sampling time in late autumn was acceptable for define N leaching risk, although leaching occurs between cereal harvest and late October, too. In addition, soil N analyses in four last years with increased sampling dates showed, that the amount of nitrate N was often largest in spring. Obviously the mineralisation was high in spring, and nitrate N was found also in deeper layers because of water flow through soil after snow and soil thawing. This suggests, that a cover crop should have capability to catch N also in spring, contrary to westerwold ryegrass, in case of the succeeding crop is late to catch the mineralised N.

When clovers are used for fixing N for subsequent crops, there is a risk for increased N leaching. Also in this study white clover tended to increase the soil NO_3-N content, but did not greatly increase N leaching risk, according to soil NO_3-N measurements taken near soil frosting. Undersown red clover did not increase N leaching risk. The soil NO_3-N contents were similar in a mixture of meadow fescue and red clover as in a pure stand of red clover, although non-leguminous residues in a mixture normally decrease net N mineralisation as compared with pure leguminous residues (Kuo and Sainju 1998). Similar soil NO_3-N content as in pure red clover was however to some extent anticipated, because clover dominated in the mixture. The negligible increase of N leaching risk in connection with undersowing clovers supports the use of clovers to increase the cereal grain yield, as they did here (Känkänen et al. 2001).

Late autumn ploughing probably resulted in fairly low soil NO_3-N after legumes. Känkänen et al. (1998) reported that delaying incorporation of N-rich crops decreased the N leaching risk under Finnish conditions, as also reported by Gustafson (1987) in Sweden and Sanderson and MacLeod (1994) in Canada. In the present study the incorporation took place very late, when the mean air temperature between ploughing and soil frost was near 0°C, and ploughing was often done after the first soil frost. A low mineralisation rate, resulting from late incorporation, is also an obvious reason why higher N yield of legumes at low fertiliser N rates did not lead to more soil NO_3-N.

Because high amounts of inorganic N on soils with continuos cereals are found only sometimes (Esala 2002), like here in 1995–1996 in Pälkäne, also the decreasing effect of a grass cover crop on N content of soil is only occasionally substantial. Problem is how to identify the situation, when N cathing cover crop should be used. Soil type is a significant factor in decision making. It was found by Lemola et al. (2000), that silt, similar to Laukaa in this study, has very low tendency to NO_3-N leaching compared with sand and peat soils. Also the regional need for inhibit eutrophication of waters (Rekolainen et al. 1995) or protect drinking water should be taken into account. On the other hand the results suggest, that undersowing clovers is safe, if only avoided in situations mentioned above. Moreover, the significance of soil NO_3-N content varies according to the risk of leaching and the changing requirements of main crops during the year. The highest amounts of soil NO_3-N were found at sowing, indicating establishment of conditions for high use of mineralised N by the succeeding crop (Esala 2002).

Hiitola and Eltun (1996) found greater decrease of soil mineral N at 120 N as compared with at zero N fertilisation for undersown Italian ryegrass, but here the effect of westerwold ryegrass was normally similar independent of N fertilisation rate. However, the highest N fertilisation level (90 N) in our study did not exceed the recommended amount for a cereal crop (Esala 1991), which decreased residual N in the soil after harvest and the need for N catchment in autumn.

Hansen et al. (2000) reported increased leaching after long-term (24 years) undersowing with perennial ryegrass, but no increase in soil NO_3-N contents was found in the present study. The

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six-year undersowing period was probably too short for increased mineralisation. On the contrary, when no N fertilisation was given, the soil NO_3-N at Laukaa in the last year of the experiment was lower after westerwold ryegrass than after no undersowing. This is in agreement with the findings of Schröder et al. (1997), who reported that ploughing unfertilised Italian ryegrass immobilized soil mineral N.

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SELOSTUS

Aluskasvien toistuvan käytön vaikutus maan nitraattityppeen viljan viljelyssä

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Viljan aluskasveja käytetään sekä typen huuhtoutumisen estämiseen että typen tuottamiseen. Ensin mainittuun tarkoitukseen sopivia ovat heinät ja jälkimmäiseen ilmakehästä typpeä sitovat apilat. Tutkimuksessa selvitettiin, miten toistuva aluskasvien käyttö vaikuttaa herkästi huuhtoutuvan nitraattitypen määrään maassa kahdella huuhtoutumisherkkyydeltään erilaisella maalajilla. Aluskasvien merkitystä typen huuhtoutumisriskin kannalta arvioitiin myöhäissyksyllä otettujen maanäytteiden avulla. Lisäksi tutkimuksen loppuvuosina maan nitraattitypen muutoksia seurattiin ottamalla näytteitä typen huuhtoutumisen ja käytön kannalta kriittisinä ajankohtina.

MTT:n Laukaan ja Pälkäneen tutkimusasemilla viljeltiin puna-apilaa, valkoapilaa, puna-apilan ja nurminadan seosta sekä westerwoldin raiheinää kuusi vuotta toistuvasti kevätviljan aluskasvina. Nitraattitypen määrä maassa loppusyksyllä ei yleensä ollut suuri, eikä myöskään aluskasvien vaikutus siihen. Vaikka valkoapila usein lisäsi ja westerwoldin raiheinä vähensi nitraattitypen määrää, niiden merkitys typen huuhtoutumisriskin kannalta oli normaalisti vähäinen. Raiheinä kuitenkin vähensi nitraattitypen määrää selvästi silloin, kun olot sekä heinän kasvun että huuhtoutumisen kannalta olivat edulliset.

Aluskasvimenetelmään liittyvä myöhäinen syyskyntö oli ilmeisesti osasyy siihen, että apiloiden typpi ei ehtinyt vapautua huuhtoutumiselle alttiiseen muotoon ennen talven tuloa. Yleensäkin nitraattitypen määrä oli suurimmillaan kevätkylvön aikaan, eli typpi mineralisoitui lähellä optimaalista ajankohtaa viljan käytön kannalta. Toisaalta nitraattitypen määrän voimakas kasvu roudan sulamisen ja kylvön välillä voi merkitä myös huuhtoutumisriskiä. Typen keräämisen kannalta voisikin herkästi huuhtoutuvilla mailla olla enemmän hyötyä talvehtivasta heinäkasvista kuin yksivuotisesta raiheinästä. Pitkäaikaisvaikutuksia ei kuusi vuotta kestäneestä aluskasvien käytöstä havaittu.

Vaikka typen huuhtoutuminen Suomen oloissa on usein pientä verrattuna eteläisempiin viljelyalueisiin, on täälläkin tilanteita, jolloin huuhtoutuminen on merkittävää. Huuhtoutumisen riskiä voidaan pienentää viljelemällä heinää viljan aluskavina. Apiloita voidaan toistuvastikin viljellä aluskasveina sitomaan viljojen käyttöön typpeä ilman että typen huuhtoutumisen riski oleellisesti kasvaa aluskasvittomaan viljelyyn nähden. Syyskyntö on silloin tehtävä niin myöhään kuin maan rakennetta vaarantamatta on mahdollista.