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Effect of one year rotational set-aside on immediate and ensuing nitrogen leaching loss

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Abstract

This paper reports results from a 3-year field experiment which examined Nitrogen (N) leaching loss from land under various set-aside managements. Four treatments were examined: three ploughed plots which were sown with wheat, ryegrass or maintained fallow; the fourth treatment was unploughed and natural weed growth (volunteers) permitted. The l-year set-aside was followed by two winter wheat test crops. Ceramic suction cups were installed at a depth of 90 cm and used to collect drainage water. N leaching loss was calculated by multiplying drainage volume, calculated from meteorological data, by its inorganic N concentration.

Set-aside management significantly affected N leaching loss over the three years. During the set-aside year, the peak nitrate concentration from the unploughed treatment growing volunteer weeds was significantly lower than that from ploughed plots. Of the latter, by the spring, crop (i.e. wheat and ryegrass) assimilation of N significantly reduced N concentration compared to the fallow. The four set-aside treatments had a carry-over effect to the following year (first wheat test crop) resulting in significant differences in N losses. Leaching following the ryegrass treatment was very small and we believe that the grass residues minimised rates of net-N mineralization.

The influence of set-aside management continued to the second wheat test crop where N loss was greater under the all wheat rotation because take-all had reduced yield and therefore crop N uptake.

Introduction

The first EC set-aside programme began in 1988 with the primary aim of taking land out of cereal production and thereby reducing grain surpluses. From the outset it was likely that the widespread use of a long set-aside period (i.e. 5 years) would merely allow farmers to retire their least productive land and would, therefore, have little impact on farm yields. To achieve the desired objective a one-year rotational set-aside was necessary. Uptake of this scheme was initially small but by May 1992, after the implementation of revised regulations, most arable farms in the UK set-aside 15% of their land on a one year rotational basis.

The introduction of this new policy has changed land use, so assessment of its wider impact is required, particularly regarding environment pollution. This paper reports measurements of the leaching of nitrogen (N) as nitrate- and ammonium- N from a 3 year field experiment involving a number of set-aside treatments and the following two winter wheat test crops. Factors directly and indirectly affecting N leaching were examined.

Materials and methods

Site and agronomic treatments

This experiment was carried out at Woburn Experimental Farm, Bedfordshire, in central England (Ordnance Survey map reference SP98 36). The soil was a sandy clay loam (21% clay and 23% silt in the Ap horizon) and classified as Oakington series, a gleyic, ferruginous brown earth over chalky boulder clay. The occurrence of surface run off was minor as the slope is < 2% and the conductivity of the soil is good enough to

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make surface standing water a rarity. The lateral flow through the soil to a depth of 90 cm was presumed small as this zone was well penetrated with roots and some worm channels and is above the clay rich layer. Prior to this experiment winter oats (1989) and winter wheat (1990) were grown. The preceding crop was harvested on 7 August 1990 and had an average grain yield of 7.6 t ha^{-1} (85%DM).

In the autumn of 1990 six set-aside land management treatments, together with a winter wheat control were established in triplicate, each on plots 24 m × 6 m. During the following two seasons (1991-92 and 1992-93) winter wheat was grown on all plots and they were managed in an identical way. Each plot was subdivided into 8 subplots (3 m × 6 m) which, in 1992, received a range of spring nitrogen dressings. Work described in this paper focused on 4 treatments (see Table 1) and only on the sub-plots receiving 0 and 160 kg N ha^{-1}. Including all treatments would have necessitated an unmanageable number of suction cups (see below). Measurements of crop development during the set-aside year were not made. However from observation, plant growth was generally hindered by dry autumn weather but greatest plant cover in mid-November was on the volunteer weed treatment (WT). This was presumably because these plants had a longer period to establish themselves (see Table 1).

Measurement of nitrogen leaching loss

One ceramic suction cup (of pore size 1 μm) was inserted during October 1990 to a depth of 90 cm in each sub-plot that was designated to received zero or 160 kg N ha^{-1}. (I.e. there were 6 cups per treatment). Cup details and the method of insertion were similar to those described by (Webster et al., 1993). When evacuated to 50 kPa, the cups collected about 30 mL of the surrounding soil solution which was assumed to represent water draining through the soil at a depth of 90 cm. This assumption was validated at another field on this farm on a similar soil type (Webster et al., 1993). As this work was concerned with N leaching loss, sampling ceased when there was a sizable soil moisture deficit. The collected solution was analyzed for nitrate and ammonium using a Tecator FIAStar 5010 flow injection analyzer. Nitrite (NO_2) was not measured as measurement in an earlier study (Webster et al., 1993) showed it made a negligible contribution to total N leaching loss. Once installed, the ceramic cups remained in place throughout the experiment. One of the 24 cups failed to collect samples in each of the first two years and were replaced.

Total N leached was calculated as the product of drainage volume multiplied by N concentration. Drainage volume was calculated by assuming that, with a zero soil moisture deficit (SMD), drainage equalled rainfall less evapotranspiration. Daily evapotranspiration from all treatments was assumed to equal a value for cut grass which was calculated using the Penman equation (see French and Legg, 1979) and data from the Woburn farm meteorological station. Between November and March the equation gave very similar values for cut grass and bare earth and therefore actual differences between treatments in their overwinter evapotranspiration were probably small. The date that the soil reached zero SMD was calculated by first subtracting the profile water content (0-90 cm), measured in October from that of soil sampled in January when it was at field capacity. This gave the SMD for the October sampling. A short run of rainfall and evapotranspiration data was then used to determine the date soil attained a zero SMD.

The suitability of this approach was verified in an earlier study (Webster et al., 1993) when, over 3 consecutive years, the annual volume of drainage from monolith lysimeters was accurately predicted. However the precision in this study will have been less. In the first year there was little difference between treatment SMDs and the mean value was used. In the second and third years, autumn SMDs will have varied between treatments due to their different crops and N fertiliser rates. Extensive soil sampling was not possible and values from the WW were used for all treatments. As a consequence, estimates of treatment N leaching loss during the second and third seasons were subject to greater error. The yield of grain was measured at each harvest and diseases were assessed in spring and summer (Gutteridge et al., 1987).

Results

Rainfall during the period August-March for the first two winters of this study (306 and 328 mm respectively) was well below the long-term average (425 mm). Thus the total drainage volume (103 mm in 1990–91 and 101 mm in 1991–92) was about half that typically experienced. During the final season August to March rainfall (550 mm) and drainage volume (296 mm) were more typical for this region. The mean inorganic N concentration in water draining through a depth of 90

Table 1. Summary of agronomic treatments used in this experiment[a]

1990–91 Set-aside year	1991–92 First wheat test crop	1992–93 Second wheat test crop
Winter wheat (WW) ploughed 23.8.90 Sown 25.9.90, with var. Mercia Harvested 20.8.91 200 kg N ha^{-1} spring top dressing		
Plough fallow (PL) ploughed 23.8.90, weeds killed during winter with glyphosate, Rotary cultivated during summer 1991	All four treatments ploughed 18.9.91 Mercia drilled 2.10.91 N dressing[b] applied on 9.4.92 Harvested 10.9.92	All plots ploughed 8.10.92 Mercia drilled 14.10.92 All plots dressed with : - 41.4kg N ha^{-1} on 26.3.93, 159kg N ha^{-1} on 6.5.93. (No sub-plots this year) Harvested 18.8.93
Ryegrass (RG) Ploughed 23:8.90, sown 6.9.90. Grass topped during spring + summer		
Volunteer weeds (WT) Not ploughed Weeds topped in spring and summer		

[a] The previous wheat crop was harvested on 7 August 1990
[b] N.B. This study only involved sub-plots receiving 0 and 160 kg N ha^{-1}. Diseases were controlled by good standard farm practice.

cm under each treatment, as captured by ceramic cups, is shown in Figure 1. Concentrations are plotted as a function of the cumulative drainage volume on the date that they were collected. A monthly time scale is also indicated on the x-axis. Ammonium-N concentrations were always small, thus inorganic N and nitrate-N concentration are effectively synonymous. Samples from the same treatments showed considerable variation, resulting in large Least Significant Differences (LSD) shown in Figure 1. In the set-aside year the nitrate concentration in the non-ploughed volunteer weeds (WT) treatment was consistently smaller than the others but the difference was only occasionally significant see Figure 1A. The greatest nitrate concentrations measured from the 3 ploughed treatments was found at the onset of drainage. Thereafter crop N assimilation (WW and RG) had, by early spring, significantly reduced values compared to the uncropped PL

At the beginning of the second year (1991–92), the nitrate concentration of all treatments closely resembled that at the end of the previous spring (cf. Figs 1A and B). With the exception of the PL treatment, concentrations increased before falling sharply during the spring, (see Fig.1B). Because the different rates of fertilizer were applied to the first test winter wheat crop after drainage had ceased (see Table 1), they clearly had no effect on N leaching in the 1991–92 season, so results from each N rate are combined in Figure 1B. Inter-treatment variability was less than in 1990–91, and on most sampling occasions N leached from the PL treatment was significantly greater than from the continuous wheat. The clearest feature of the second years' results is the very small N loss from the RG

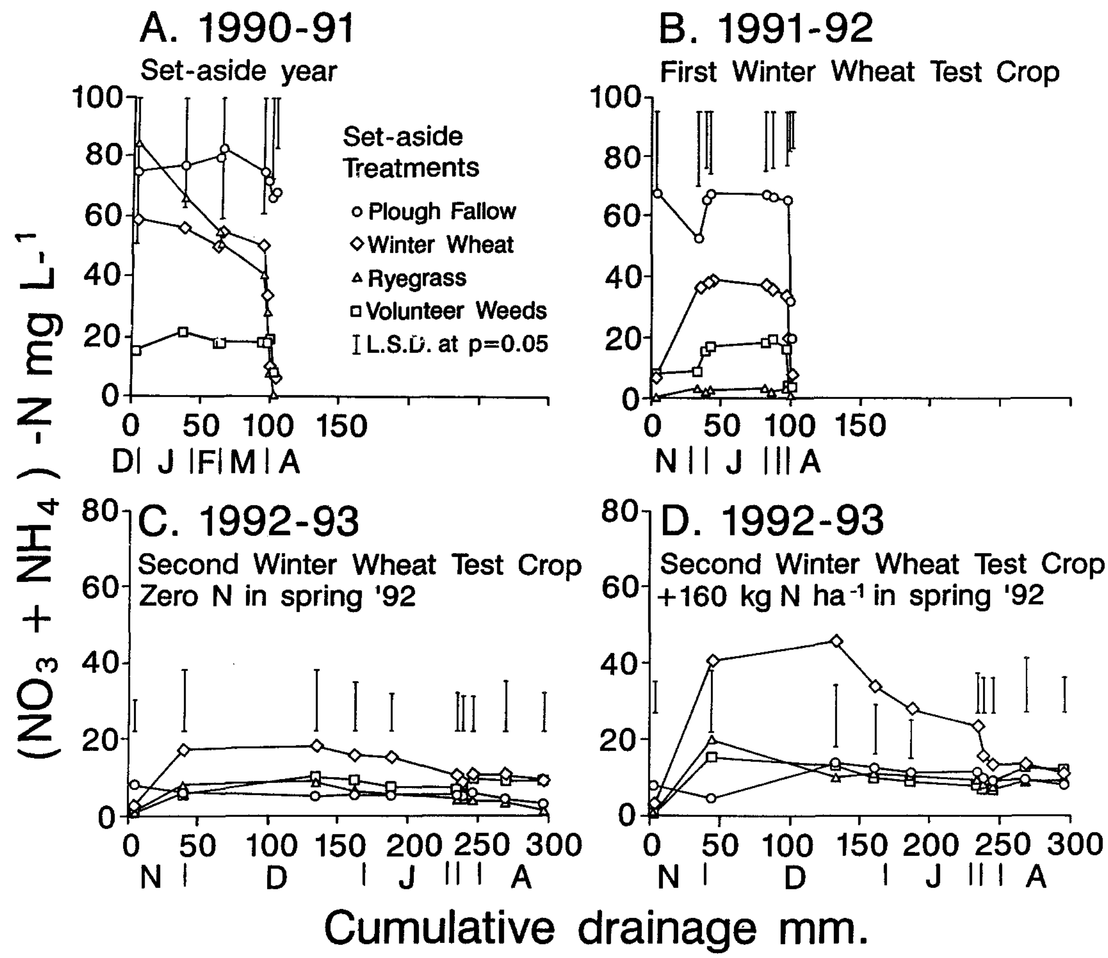

Fig. 1. The inorganic N concentration in drainage from a set-aside experiment over 3 years. Some L S D bars have been omitted for clarity. A monthly time scale is included on the x-axis, N= November, D= December etc.

treatment which was significantly less than from the WW.

During the third season (1992–1993) the sub-plots which had received the 160 kg N ha^{-1} top dressing in the spring of 1992 had greater nitrate concentrations in their drainage than those receiving no N. However only where the wheat test crops followed the winter wheat (WW) control was the difference significant (Fig. 1C, D and Table 2).

The total quantity of nitrogen leached over the 3 years is given in Table 2. Despite the uncertainty introduced by calculating drainage volumes, four points are noteworthy: Firstly, the combination of ploughing and the resulting shorter period for plant establishment and growth appears to promote N leaching loss, although the only treatments significantly different from one another were the WT and PL. Secondly, poor plant cover during the set-aside on the PL not only resulted in the greatest N losses during the first year, but had a carry-over effect, with significantly greater N losses in the second year. Thirdly, N leached under the first wheat test crop after the RG treatment was very small. Fourthly N leaching was considerable from the second WW test crop which received the spring N top dressing in 1992.

Table 3 shows the grain yields, which will reflect total N off-take from the plots. The set-aside treatments affected yield in a number of ways such as creating different nutrient and disease levels. Of relevance to this paper are the generally poor yields in 1992 following ryegrass incorporation and, for crops given fertilizer N, yields in both 1992 and 1993 were lowest on the

Table 2. Total inorganic nitrogen leached, all values are kg N ha^{-1}

Treatment[a]	1990–91 Set-aside year	1991–92 lst WW test crop	N[b] rate	1992–93 2nd WW test crop
WW	50	34	N0	39
			N3	85
PL	77	59	N0	14
			N3	29
RG	52	3	N0	17
			N3	30
WT	19	14	N0	22
			N3	29
LSD 5%	40.7	20.4		30.3

[a] See Table 1 for treatment details.
[b] N0 = zero N during April 1992. N3 = 160 kg N ha^{-1} on 9.4.92.

Table 3. Grain yield at harvest(t ha^{-1}) (85% DM)

Treatment[a]	1990–91 Set-aside year	N[b] rate	1991–92 lst WW test crop	1992–93 2nd WW test crop
WW	9.26	N0	5.37	4.49
		N3	6.25	5.30
PL	-	N0	7.62	7.00
		N3	7.08	5.74
RG	-	N0	4.26	6.17
		N3	6.91	5.47
WT	-	N0	5.88	7.46
		N3	7.35	7.59
LSD 5%			1.56	3.64

[a] See Table 1 for details.
[b] N0 = zero N April 1992. N3 = 160 kg N ha^{-1} on 9.4.92.

(WW) treatment. This was caused by severe infection with take-all (*Gaeumannomyces graminis*).

Discussion

Ceramic cups are point samplers and their results typically show large variation (Macduff et al., 1990). The degree of variation found in this experiment is, therefore unexceptional, especially as the number of cups per set-aside treatment was only 6 (but only 3 after N was applied) and they were placed in 3 separate replicate plots. However a consequence was that observed differences were not always statistically significant.

Water movement through soil in autumn is complex and only in exceptional circumstances does it occur as a saturated front moving by piston displacement. If a soil contains macropores it allows a route for rapid and deep movement of water often referred to as by-pass flow (Bouma, 1991). In addition, sub-soil matrix suction induces water flux through unsaturated soil. Both these processes can accentuate the downward transport of solutes. Thus the volume of drainage required to elute the peak N concentration is usually less than the water holding capacity of the soil. Despite this, previous studies comparing ceramic cups and lysimeters have shown that ceramic cups give a reasonable measure of the quantity and timing of nitrate leaching (Webster et al., 1993). Most studies (e.g. Kolenbrander, 1969) show that the N concentration in initial drainage following a crop is small, presumably as it reflects the small concentration of inorganic N left in the subsoil by the crop. The inorganic N concentration then typically increases as the recently mineralised N is eluted.

In the first year of our experiment this pattern was not observed; the initial drainage from the ploughed plots contained the greatest N concentration. In addition the N concentration from the unploughed WT treatment was considerably less than from the ploughed treatments. The whole field used in this experiment was uniformly cropped during 1989–90. Therefore, if initial drainage N concentrations reflected post-harvest levels of residual N in the subsoil, all treatments should show similar initial concentrations. Possibly the longer period of plant (i.e. weeds) establishment on the WT treatment allowed them to root deeply and exploit subsoil N. Alternatively or in addition, ploughing has been reported to stimulate net N mineralization (Dowdell et al., 1976; Powlson, 1980) and this process may have had a role. However this explanation additionally requires the rapid transfer of freshly mineralized N from the plough layer to 90 cm by by-pass flow as discussed by Bouma (1991). We are unable to determine whether such flow occurred. Although the summer and autumn were dry, no large scale cracking was observed. The greater N loss from the PL during the set-aside and first test crop years is due to the absence of plant N assimilation during 1990–91 and confirms the desirability of plant cover. Inter-treatment variation was considerable during the first season and probably contributed to the apparent large differences in treatment means.

Only the WW treatment received N fertilizer (200 kg N ha^{-1}) in the spring of 1991 and it was the only treatment to be harvested. As the grain yield was large (Table 3), it is likely that little fertilizer N remained in the soil after harvest as inorganic N (see Macdonald et al., 1989). In other treatments the grass or weed was topped and left in situ.

The change in drainage N concentrations during the second year was more typical of other research (Kolenbrander, 1969). With the exception of WT, the initial drainage contained smaller concentrations than in the first year and peak N concentrations appeared after 30–50 mm of drainage. The relatively small and large N losses from the RG and PL treatments respectively, compared to the WW treatment were found in similar set-aside experiments carried out at a number of sites by ADAS (Froment and Grylls, 1992). However, they did not confirm our finding of consistent (but non-significant) smaller N leaching loss from the WT treatment.

The ability of ryegrass leys to minimise net mineralization has been widely reported. Gasser (1968) found that the degree of immobilisation was related to the residue N content, with greater immobilisation from unfertilized 3-year ryegrass leys than from those which were fertilized. This tying up of N has been found to result in a poor yield of the first arable crop following a grass ley (Widdowson and Penny 1970). The low crop N uptake from the unfertilized RG treatment in this experiment (Table 3) is also consistent with these findings.

During the final drainage season the significantly greater N loss from the fertilized WW treatment was probably due to poor crop performance. Disease assessment (Dr R J Gutteridge pers. commun.) showed that this treatment was most heavily infected with take-all (*Gaeumannomyces graminis*) during the second and third years. Thus the WW had the smallest yield of all fertilized treatments (Table 3), assimilated the least amount of N and left the most inorganic N in the soil after harvest. This was then subject to leaching in the winter of 1992–93.

Conclusions

- In this experiment, ploughing and the sowing of ryegrass (RG) was no better at conserving N than the simple topped volunteer weeds (WT) during the set-aside year.
- However, N leaching was very small under the first wheat test crop following ryegrass. This phenomenon has been observed before and is worthy of further investigation.
- The absence of plant N assimilation on the ploughed and fallowed PL treatment resulted in this treatment having the greatest N leaching loss both in the set-aside and first test crop year.
- Set-aside policy may be incorporated into a disease control programme and thereby indirectly assist in minimising N leaching loss. However, in other circumstances, set-aside can increase the severity of take-all by breaking a continuous sequence of wheat crops and this may result in increased N leaching.

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References

Bouma J 1991 Influence of soil macroporosity on environmental quality. *In* Advances in Agronomy, Vol. 46. Ed. D L Sparks. pp 1–39. Academic Press, San Diego, USA.

Dowdell R J, Crees R and Cannell R Q 1976 A field study of the effects of contrasting methods of cultivation on nitrate content during autumn, winter and spring. J. Soil Sci. 34, 367–379.

French B K and Legg B J 1979 Rothamsted irrigation 1964–76. J. Agric. Sci., Camb. 70, 323–329.

Froment M A and Grylls J 1992 Changes in soil mineral nitrogen during set-aside and effect of rotational fallows on the yield and N-optima of subsequent cereal crops. *In* Set-aside, BCPC Monograph No 50. Ed. J Clarke. pp 23–28. BCPC Publications Sales, Farnham, UK.

Gasser J K R 1968 Mineralizable-N in the soil under various leys and its effect on the yield of the following wheat. J. Agric. Sci., Camb. 70, 323–329.

Gutteridge R J, Bateman G L and Hornby D 1987 Comparison of the effects of spring applications of ammonium chloride and other nitrogen ferilizers on take-all in winter wheat. J. Agric. Sci., Camb. 108, 567–572.

Kolenbrander G J 1969 Nitrate content and nitrogen loss in drainwater. Neth. J. Agric. Sci. 17, 246–255.

Macdonald A J, Powlson D S, Poulton P R and Jenkinson D S 1989 Unused fertilizer nitrogen in arable soils - its contribution to nitrate leaching. J. Sci. Food Agric. 46, 407–419.

Macduff J H, Jarvis S C and Roberts D H 1990 Nitrates: leaching from grazed grassland systems. *In* Nitrates - Agriculture - Eau. Ed. R Calvert. pp 405–410. Institut National Agronomique, Paris - Grignon, France.

Powlson D S 1980 Effect of cultivation on the mineralization of nitrogen in soil. Plant and Soil 57, 151–153.

Webster C P, Shepherd M A, Goulding K W T and Lord E 1993 A comparison of methods for measuring the leaching of mineral nitrogen from arable land. J. Soil Sci. 44, 49–62.

Widdowson F V and Penny A 1970 The effects of three crops and of the N fertilizer given to them on the yield of the following barley. J. Agric. Sci., Camb. 74, 511–522.

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