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THE EFFECT OF SET-ASIDE ON SOIL NITRATE LEVELS, MIDDLEGROUNDS FARM, SLAPTON, SOUTH DEVON.

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ABSTRACT

Nitrate-nitrogen levels were measured in soils under different land uses in September 1992. Land that had been set-aside from agricultural production in 1990–1991 showed levels comparable to those in woodland and grassland soils and in the 18–26 months since the last application of fertiliser already showed levels an order of magnitude lower than land retained under arable use. This indicates a rapid loss of nitrate in the set-aside fields under conditions of permeable, rapidly draining soils, low in organic matter.

INTRODUCTION

In the last few years, farmers have been offered the opportunity to set-aside land, that is to take it out of agricultural production, in order to reduce EC surpluses. Under the voluntary scheme (MAFF, 1988), no crops are allowed to be grown and it also follows that fertiliser is not used. In return for taking at least 20% of their land out of production farmers receive compensation and the scheme covers all main arable crops. Farmers may put land set-aside to fallow but land must not be left bare. By 1990 about 650,000 hectares had been set-aside in the UK (Nychas, 1990). As well as the reduction of food surpluses, set-aside has also been of interest in terms of the assumption that decreased fertiliser application will lead to the reduction of nitrate levels in inland waterways (MAFF, 1989; NRA, 1992; Burt, Heathwaite & Trudgill, 1993, esp. Ch. 11 & 12, especially pp. 354–456).

THE SLAPTON STUDY AREA

Slapton is situated in an area of southwest England known as the South Hams between Exeter and Plymouth and, since the establishment of a Field Studies Council Field Centre in 1959, the area has been a focus for a considerable amount of research activity, including long-term monitoring of nitrate levels. Much of the relevant information was summarised by Burt (1993). The soils are freely draining loams, commonly with a 30–40% silt content, developed on Devonian slates but locally, around Slapton village, they are developed on Permian sandstones and breccias and are consequently coarser textured (Trudgill, 1983). Except on the steeper slopes (which can reach angles of up to 24°) the soils are deep with up to 1–2m of permeable fractured slate bedrock locally known as ‘shillet’.

The area used in the present study is shown in Fig. 1, with the land use as it was in September 1992. Table 1 records land use details, indicating when nitrate fertiliser was last applied: 18 months before the measurement period in September 1992 for set-aside field 1, 26 months for field 2 and 23 months for field 3.

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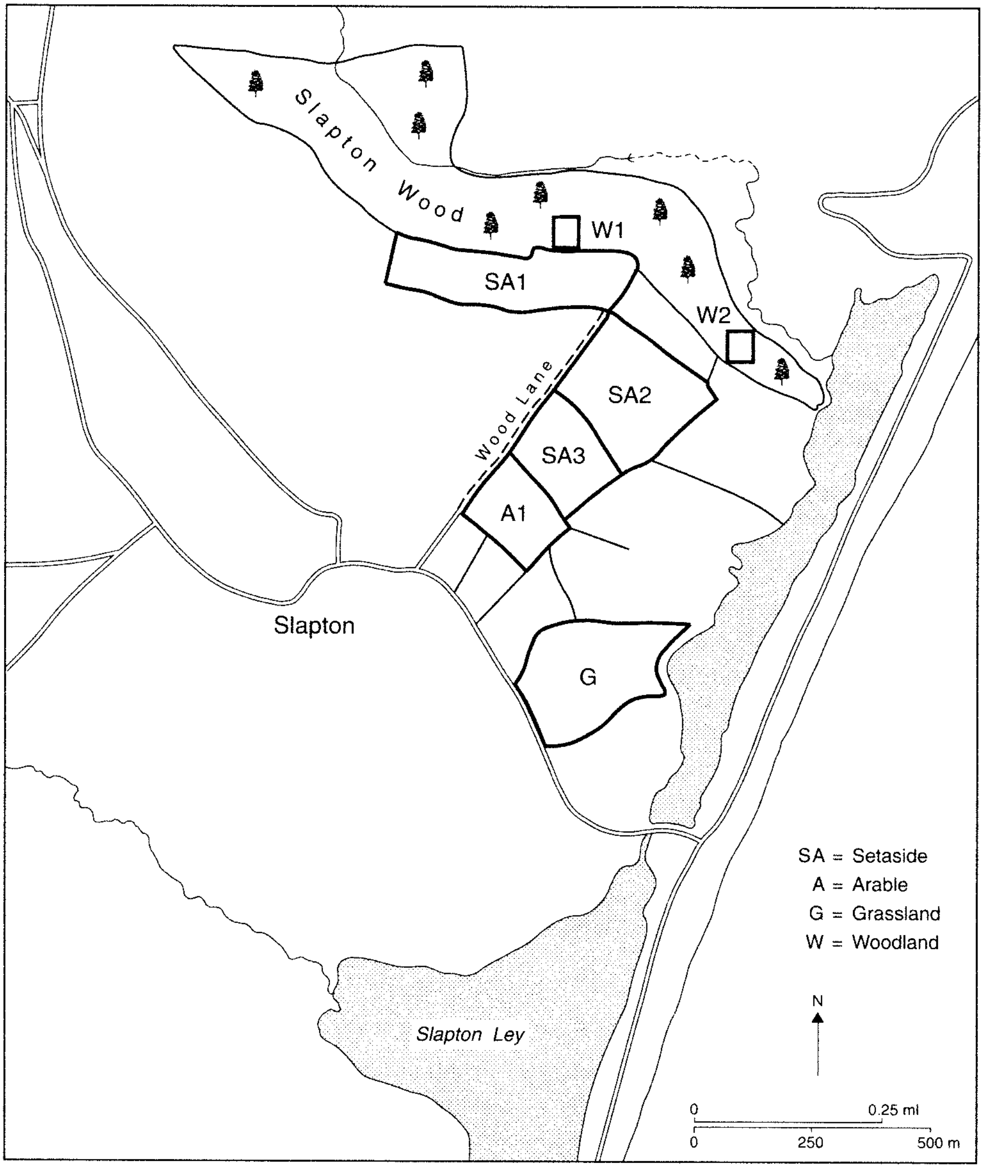

FIG.1.
The Slapton study area, with land use as at September 1992

METHODS

Within each of the 8 study sites (3 set-aside fields, 2 arable fields, one grassland field and 2 woodland plots), two 20m x 20m plots were laid out at an upper and lower slope position, making 16 plots in all, and samples were taken from 8 random points within each plot. At each point, a topsoil sample was taken from 0–30 cm depth using a 5 cm diameter soil auger and a subsoil sample from 30–60 cm depth using a smaller 3.5 cm

TABLE 1. *Land use in the study area. (See Fig. 1 for the location of field numbers)*

Land-use	Site No.	Last fertilised	Last crop	Last cut
Set-aside	1	April 1991	Oil seed rape	Aug. 1991
	2	Nov. 1990	Winter wheat	March 1991
	3*	Feb. 1991	Potatoes	July 1991
			Current crop	
Arable	1	May 1992	Potatoes	July 1992
	2	May 1992	Spring Barley	Sept. 1992
Grassland		March 1992	Grassland	March 1992**
Woodland***	1			
	2			

*Site 3 had a dense cover of (nitrogen fixing) red clover (*Trifolium pratense*).

**On the coarser textured soils developed on Permian bedrock (see text).

***Dominantly sweet chestnut (*Castanea sativa*) woodland.

diameter auger, placed within the hole made by the 5 cm auger. The different diameter augers were used in order to minimise any contamination of the subsoil sample with the surface soil during its withdrawal (Trudgill *et al.*, 1991). Soil samples were analysed on the day of collection. 25g of fresh soil was shaken for 30 minutes with 100 ml of distilled water and filtered through a Whatman GF/C filter paper under vacuum. The filtrate was analysed using an EIL Nitrate specific Ion Electrode, with fresh standards prepared each day and allowing a 5 minute meter response time. Results are expressed as mg g^{-1} NO_3-N (milligrams of nitrate nitrogen per gram) of dry soil, the weight of dry soil being established by drying a separate subsample.

Dry bulk density was measured for surface soils at 8 points within the plots by the insertion of a standard volume sampling tin into the soil, excluding surface litter, and drying the sample overnight at 105°C, cooling in a desiccator. The results were expressed as dry weight per volume of the tin in g cm^{-3} (grams per cubic centimetre)

RESULTS

The arable soils, fertilised in May 1992 and sampled in September 1992 had soil nitrate levels an order of magnitude higher than the other sites (Fig. 2). The overall mean values for all data for each land use type (including both upslope and downslope plots and topsoil plus subsoil) were in the order arable > woodland > grassland (Table 1). For the set-aside fields, the overall means were higher than the grassland but lower or overlapping with the woodland. Since the current arable fields had means of 0.1–0.2 mg g^{-1} NO_3-N and the set-aside 0.02–0.04, the immediate implication is one of rapid loss of fertiliser nitrate in the 1 or 2 years since the conversion from arable to set-aside but this conclusion needs further careful consideration after a more detailed analysis of the available data.

STATISTICAL ANALYSES

Comparison of mean values can be misleading unless the data spread is limited and, thus, the mean is representative of the whole sample population; with a greater spread of data there is more deviation from the mean and mean values are less useful. Fig. 3 shows that there is widespread deviation from the mean in the arable soils and Fig. 4 shows that the smaller arable values overlapped with those for the other land uses. These two figures show the data plotted on common axes which are relative to the highest (arable) value and thus the standard deviations and ranges for the smaller value sites are not well displayed. For illustrative purposes, Fig. 5 (a)–(d) plots the amalgamated upslope and downslope topsoil data together for selected sites on vertical axes which have a maximum value appropriate to each site rather than to the highest (arable) value: (a) arable 1, (b) set-aside field 2, (c) grassland and (d) wood plot 2. This readily shows the wide range for the arable site but also that the smaller values for set-aside, grassland and woodland also show considerable variation, though there is a central portion of data which are more consistent with each other, especially for the set-aside and the grassland.

While, in these two latter cases, the mean is liable to be more representative, it is more appropriate to compare the data as a whole using analysis of variance (AOV). This assesses whether the variation within data sets is greater or lesser than the variation between them. If the variation between the sets is greater than the variation within, the sets can be said to be significantly different. AOV calculates a critical value of F (F_{crit}) based on sample size and, if this is less than a value of F calculated from the data (F_{calc}), the data sets can be said to be significantly different at given levels of significance (in this study, both the 1% and 5% levels are given) (see Gregory, 1971, Ch. 9).

Slope position

Given that the fields did not always occupy the same slope position and, thus, that the sites on different land uses may not be directly comparable, the use of two plots, upslope and downslope, in the fields gives the possibility of assessing whether slope position is a significant factor. It could be assumed that leaching into throughflow waters moving laterally downslope would yield higher nitrate levels in the lower slope position. Equally, however, with a deep and permeable soil profile extending well below the maximum sampling depth of 60 cm before less permeable bedrock is reached, it is also possible that the samples were taken within the zone of vertical percolation, well above any such lateral flow. Slope position would then make no difference to nitrate distribution in the top 60 cm of soil.

One-way analysis of variance between upslope and downslope positions in fact yielded no significant differences between these positions for the sites, as shown in Table 2. Only the subsoil (30-60 cm) for set-aside site 2 yielded a significant difference at the 5% level but not at the 1% level, with upslope and downslope means of 0.047 and 0.062 respectively. This tends to refute the significant of any downslope leaching in the 0-60 cm depth of soil sampled. For subsequent analyses, the data sets were therefore amalgamated and both the downslope and upslope sites are treated as samples from the same population.

This procedure increases sample size to 16 for each depth for each site. This can be compared with the results of Trudgill *et al.*, (1991) who found that, because of the spatial variability of nitrate data, and using the approach adopted by Curtis & Trudgill

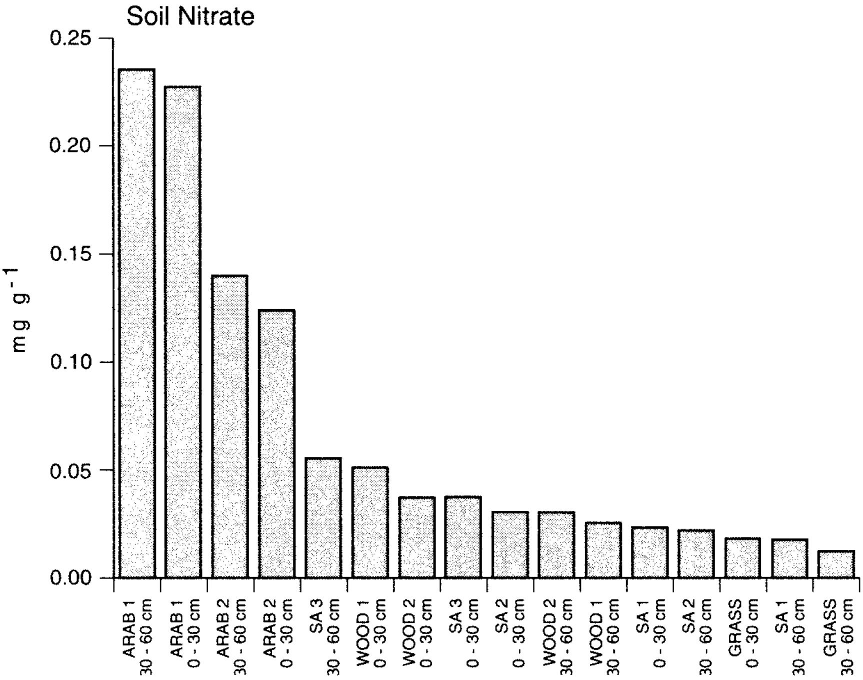

FIG. 2.
Soil nitrate data for the different land use sites, ranked in order of mean value of soil NO_3-N, mg g^{-1}

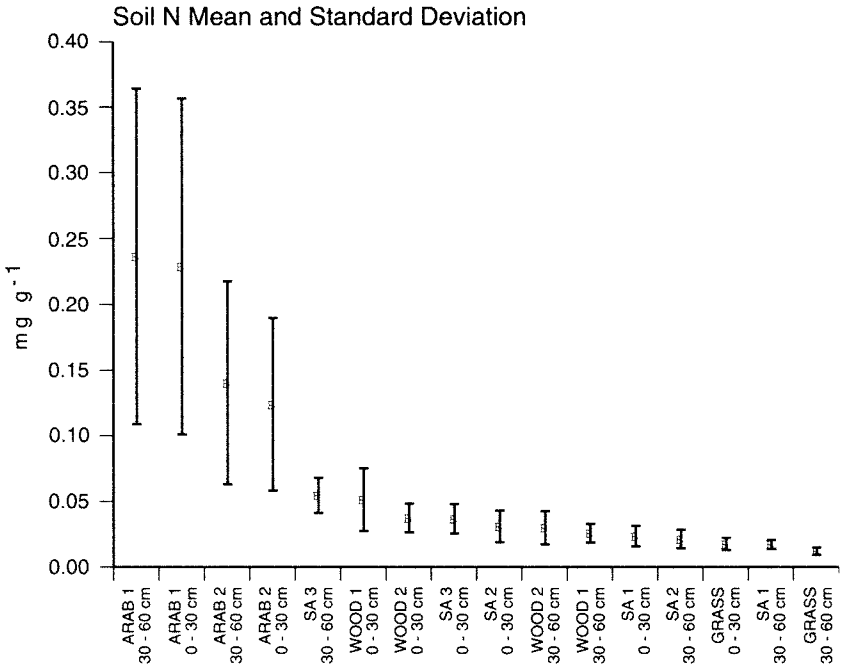

FIG.3.
Soil NO_3-N, mg g^{-1}, mean and + and–1 standard deviation from the mean shown

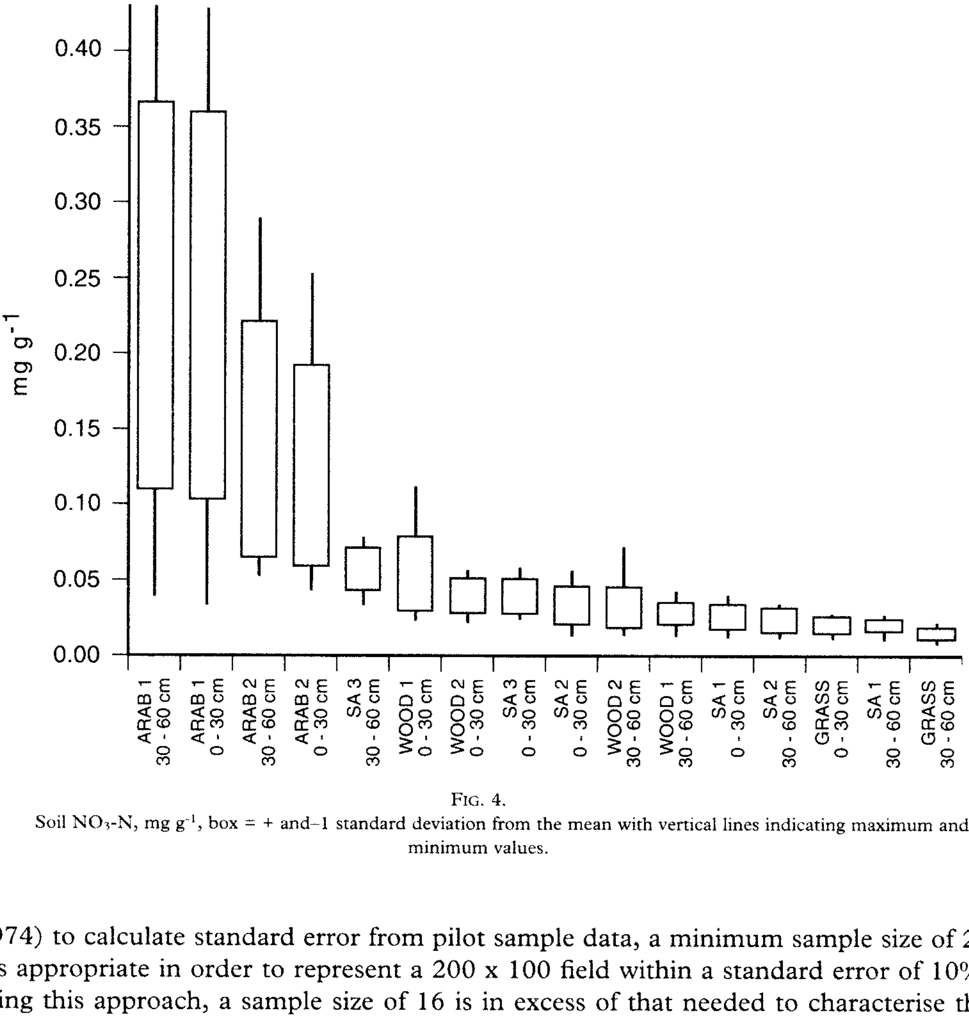

FIG. 4.
Soil NO_3-N, mg g^{-1}, box = + and–1 standard deviation from the mean with vertical lines indicating maximum and minimum values.

(1974) to calculate standard error from pilot sample data, a minimum sample size of 20 was appropriate in order to represent a 200 x 100 field within a standard error of 10%. Using this approach, a sample size of 16 is in excess of that needed to characterise the two 20 x 20m sample plots used in this study at the 10% level.

Replicates of Land Use Sites.

Before proceeding to test the differences between land uses, there are two further considerations. One involves the evaluation of any differences between replicates of land use types and the other involves any differences between the two soil sampling depths.

The only thing in common between the three set-aside sites is that they have been set-aside. They all have different histories of land use before set-aside and thus there is no *prima facie* case why they should either exhibit the same characteristics and be treated as samples from the same population. Therefore, before comparison with the arable, woodland and grassland sites, a test should be performed to assess whether the set-aside sites in different fields were significantly different from each other (i.e. whether the 3 set-aside sites were (a) significantly different from each other and therefore should be compared with other land uses separately and in turn or (b) whether they were not and thus can be regarded as being from the same population and compared with other land uses as an amalgamated set of all set-aside data).

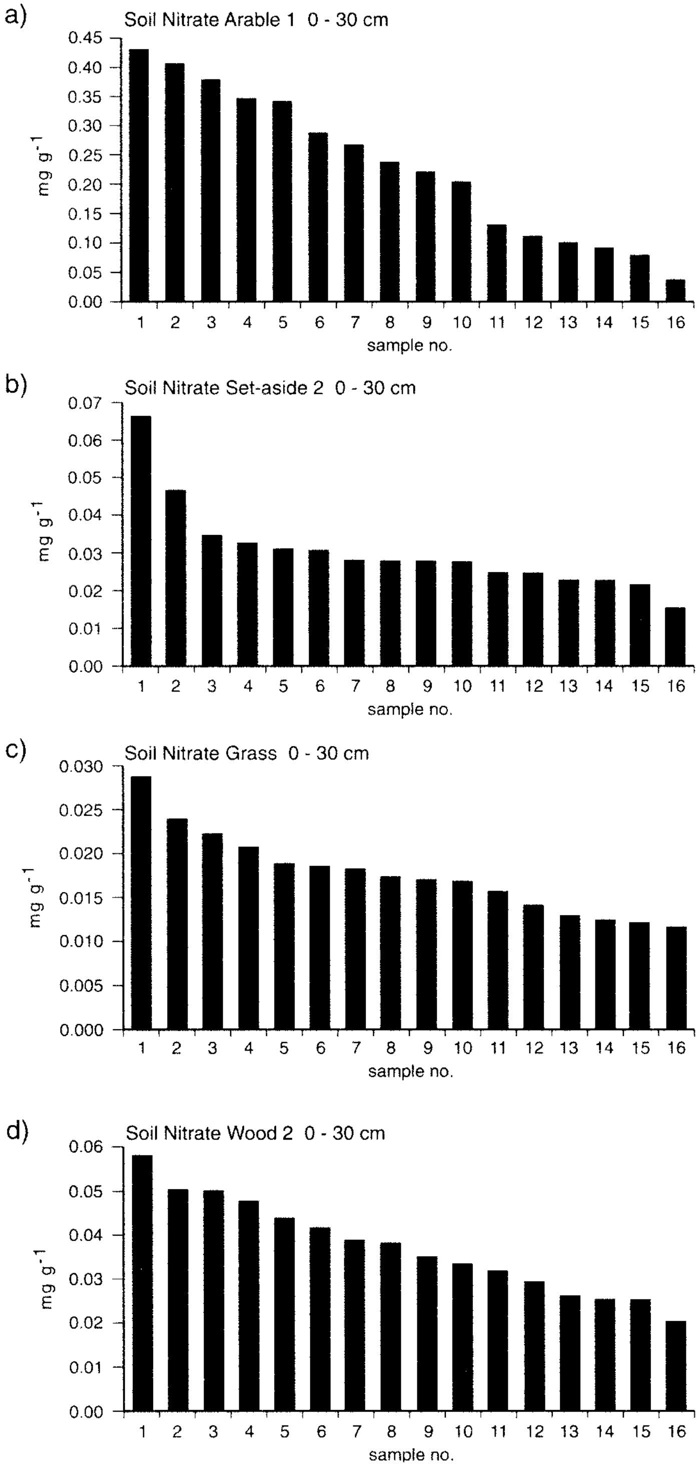

FIG 5a–d.

Plots of individual sample NO_3-N, mg g^{-1} data; concordance of bar graph heights indicates the low variability of the data.

TABLE 2. *The effect of slope position on soil nitrate*

Mean values of soil nitrate in mg g^{-1}
=: no significant difference at the 1% level (calculated value of $F < F_{crit}$)
\> or <: significantly different at the 1% level (calculated value of $F > F_{crit}$);
$F_{crit} = 8.861$ (1%); 4.600 (5%)

TOPSOIL = 0-30 cm, SUBSOIL = 30–60 cm
UPPER and LOWER refer to slope position

Land Use	Topsoil			Subsoil		
	Upslope		Down Slope	Upslope		Down Slope
Set-aside 1	0.022	=	0.025	0.017	=	0.018
	F_{calc} 0.344			F_{calc} 0.488		
Set-aside 2	0.033	=	0.028	0.018	=	0.024
	F_{calc} 0.493			F_{calc} 3.585		
Set-aside 3	0.032	=	0.041	0.047	<	0.062
	F_{calc} 2.562			F_{calc} 7.456		
Arable 1	0.213	=	0.244	0.211	=	0.262
	F_{calc} 0.224			F_{calc} 0.610		
Arable 2	0.118	=	0.130	0.130	=	0.150
	F_{calc} 0.122			F_{calc} 0.247		
Grass	0.018	=	0.017	0.011	=	0.013
	F_{calc} 0.005			F_{calc} 1.517		
Wood 1	0.040	=	0.062	0.023	=	0.028
	F_{calc} 4.486			F_{calc} 1.827		
Wood 2	0.036	=	0.038	0.027	=	0.033
	F_{calc} 0.081			F_{calc} 0.081		

The same principle applies to the other replicate sites but, for these, the differences are already evident enough to make it unnecessary to perform initial tests for differences between replicate land use sites. The two arable fields had contrasting crops, one with potatoes and one with spring barley, and this in itself indicates that each should be compared with other land use types separately and in turn. Similarly, while the two woodland plots do not have different land uses or land use histories, they are in different places in the woodland and thus they should also be treated separately.

For the three set-aside fields, amalgamating the data for the two up and down slope positions, as explained above (but keeping topsoil and subsoil samples separate), showed that they could not necessarily be regarded as the same (Table 3).

The tests showed significant differences between:

(1) topsoil 3 > topsoil 1,
(2) subsoil 3> subsoil1 and
(3) subsoil 3 > subsoil 2.

Not significantly different were:

(4) topsoil 2 = topsoil 3,
(5) topsoil 1 = topsoil 2 and
(6) subsoil 1 = subsoil 2.

TABLE 3. *Analysis of variance of data from the three set-aside plots.*

F_{crit} at the 1% significance level = **8.861** and 4.600 at the 5% level. Using the more rigorous approach of adopting the 1% level, for all the tests and F_{calc} from the tests has to be less than 8.861 for the set-aside sites to be regarded as comparable.

For the topsoils:

Set-aside fields 1 and 3 **were** significantly different
F_{calc} = **14.915**; mean field 1: 0.0235 < mean field 3: 0.0366.

Fields 3 and 2 **were not** significantly different
F_{calc} = **2.004**, means 0.0366 = 0.0308

Fields 2 and 1 **were not** significantly different
F_{calc} = **4.190**, means 0.0308 = 0.0235.

For the subsoils,

Fields 1 and 3 **were** highly significantly different
F_{calc} = **117.513**, means 0.0171 < 0.0544.

Fields 3 and 2 **were** significantly different
F_{calc} = **77.573**, means 0.0544 > 0.0213.

Fields 1 and 2 **were not** significantly different at the 1% level but were marginally so at the 5% level
F_{calc} = **4.606**, means 0.0171 = 0.0213.

Despite (4) to (6), the differences (1)–(3) indicate that the set-aside fields cannot be treated as one homogeneous population and should not be used as an amalgamated data set for comparison with other land uses.

Additionally, it has already been noted (Table 1) that field 3 had an extensive cover of nitrogen-fixing clover and the following sequence extracted from Table 3 supports the inference that clover would appear to be contributing to a high soil nitrate level in field 3:

- topsoil: field 3 (mean 0.0366) = field 2 (mean 0.0308) > field 1 (mean 0.0235) and
- subsoil: field 3 (mean 0.0544) > field 2 (mean 0.0213) > field 1 (mean 0.0171).

Soil depth

Soil nitrate profiles commonly show variation with depth, especially in cases where fertiliser has been recently applied. After application, nitrate levels are higher in the topsoil than the subsoil but subsequently the nitrate becomes distributed more evenly throughout the profile and, with leaching, may even show a higher level at depth than at the surface.

In addition, where there is a high organic content in the soil, as with woodland and grassland soils, it is common to find the highest amounts of organic matter near the surface following leaf litter deposition. Here an organic source of mineralisable nitrogen is to be found, yielding higher concentrations of nitrate at the surface.

For the soil samples at two depths (0–30 and 30–60 cm), the differences in soil nitrate between set-aside topsoil and subsoil were all significantly different for all sites (Table 4). The data show higher means in the topsoils in fields 1 and 2, as might be expected from the establishment of a surface cover of vegetation, but a higher subsoil level in field 3, again, by inference, relating to the presence of nitrogen-fixing root nodules on clover.

The arable topsoils and subsoils were not significantly different despite the surface application of fertiliser, the inference being that the fertiliser has become evenly distributed within the soil profile in the 5 months time period since application.

The data for grassland were significantly different (topsoil > subsoil). This is to be expected in grassland, with nitrate derived from organic nitrogen in a high organic matter content surface layer derived from leaf litter and near-surface roots as much as from inorganic fertiliser.

In a woodland, it is to be expected that the surface would be more nitrate rich, as for grassland, but site 1 differed from site 2 in that only site 1 displayed the expected pattern. The differences are unexplained but confirm that the woodland sites should be treated separately in the overall analyses.

Overall analysis of differences between land uses

It follows from the above consideration of replicates of land uses and depths that it will be necessary to compare each set-aside field (a) separately with each other land use site in turn and (b) each of these combinations separately for topsoil and subsoil.

AOV was then performed for all pairs of such data, using significant differences at the 1% level (shown in bold in Table 5). Where no significant differences existed between site pairs, the individual site data were amalgamated into groups of site data and re-tested against the next group of non-significantly different data till only the significantly different groups remained (the large number of results of the tests for all the pairings and groupings are not given in detail but see Table 5 for examples including topsoil and subsoil land use pairings and COMBINED GROUPS for a stage in the process which shows which groups should remain separate in bold and those which can be amalgamated not in bold). As a simple illustration: arable 1 topsoil and arable 1 subsoil were not significantly different nor were arable 2 topsoil and subsoil. Amalgamating the topsoil and subsoil and treating them as samples from the same population showed that arable 1 (top + sub) and 2 (top + sub) were significantly different.

As a result of this succession of tests Fig. 2 was re-drawn (Fig. 6) in order to show the significant differences that remained between groups.

TABLE 4. *Comparison of topsoil and subsoil nitrate means (mg g^{-1}) for the three set-aside fields.*

$F_{calc} > F_{crit}$ = significantly different at the 1% level, **F_{crit} = 7.562**. (5% = 4.17)

Field	Topsoil		Subsoil	F_{calc}
Sat-Aside 1	**0.0235**	**>**	**0.017**	**8.93**
Set-Aside 2	**0.031**	**>**	**0.021**	**7.46***
Set-Aside 3	**0.037**	**<**	**0.054**	**16.96**
Arable 1	0.229	=	0.236	0.03
Arable 2	0.124	=	0.140	0.42
Grassland	**0.017**	**>**	**0.012**	**16.97**
Woodland 1	**0.051**	**>**	**0.026**	**16.78**
Woodland 2	0.037	=	0.030	3.11

* marginal at 1%, s.d. at 5%.

Other groups which were internally not significantly different were:

1. set-aside 3 subsoil + wood 1 topsoil,
2. wood 2 top + subsoil + set-aside 3 topsoil + set-aside 2 subsoil,
3. wood 2 subsoil + wood 1 subsoil + set-aside 1 topsoil + set-aside 2 subsoil,
4. grassland topsoil + set-aside 1 subsoil.

Of the original 16 groups (8 land use sites x 2 depths), only 7 remained as significantly different, plotted on Fig. 7. This plot amalgamates disparate land-uses and so Fig. 8 is a plot in which the land-uses and top and subsoils are separated. The overall picture is presented more visually as Fig. 9, which shows the seven significantly different groups:

1. arable (potatoes) topsoil = subsoil, mean, 0.233 >
2. arable (spring barley) topsoil = subsoil, mean, 0.132 >
3. wood 1 topsoil = set-aside 3 subsoil, mean, 0.053 >
4. wood 2 topsoil = set-aside 2 topsoil = set-aside 3 topsoil, mean, 0.035 >
5. set-aside 1 topsoil = wood 1 subsoil = wood 2 subsoil = set-aside 2 subsoil, mean, 0.025>
6. set-aside 1 subsoil = grassland topsoil, mean, 0.017>
7. grassland 7 subsoil, mean, 0.012.

In this sequence, > shows that the differences between the data sets are significantly different at the 1% level.

DISCUSSION

Fig. 9 suggests that topsoils are generally higher in nitrate than subsoils in the woodland, set-aside and grassland with the exception of set-aside 3 where nitrogen fixing clover is present.

It can be concluded that set-aside is generally lower than arable land, similar to, or slightly lower than woodland and also higher than or similar to grassland.

The interpretations of these differences are liable to be speculative but could include a low level of inherited organic matter (and thus low levels of mineralisable nitrogen) in the arable fields converted to set-aside and a high degree of leaching in well-drained soils, giving such a rapid reversion, and especially leading to the low levels in the fertilised but sandier-textured grassland plots.

Other data sets are available which may assist with the interpretations above. There are nitrate data for 1983 and 1984 published by Trudgill *et al.*, (1991) and data from a field class held at Easter 1992. Comparisons with the 1983/4 data, however, would be unsound as it is clear that nitrate levels not only vary with season but also from year to year: data can only be compared for different fields at the same time and thus the only sound comparison which can be made is that between the high September 1992 arable levels and the low September 1992 set-aside levels rather than 1992 set-aside with 1983/4 arable.

It is useful, however, to cite the set-aside and arable values both taken at Easter (at the end of March) in 1992. These are shown in Fig. 10 with an order of Arable > (recently fertilised) Grassland > Set-aside > Woodland at that time of year. This helps to confirm the already low levels of nitrate relative to arable earlier in the same year and the rapidity of the reversion.

TABLE 5. *Analysis of variance results for land uses.*

F_{crit} = 7.562

F_{calc} values given in table

$F_{calc} > F_{crit}$ = significantly different at the 1% level

TOPSOIL

	SA 1	SA 2	SA 3	A 1	A 2	G	W 1	W 2
SA 1		4.19	**14.91**	**41.13**	**36.63**	6.81	**19.4**	**16.95**
SA 2			2.00	**38.01**	**27.72**	**16.89**	**9.29**	2.52
SA 3				**35.9**	**27.30**	**39.7**	4.90	0.03
A 1					**8.54**	**43.64**	**29.87**	**35.70**
A 2						**41.43**	**17.22**	**26.95**
G							**30.49**	**44.3**
W 1								4.59

SUBSOIL

	SA 1	SA 2	SA 3	A 1	A 2	G	W 1	W 2
SA 1		4.61	**117.5**	**47.18**	**40.40**	**21.44**	**18.54**	**15.17**
SA 2			**77.57**	**45.29**	**37.47**	**24.55**	3.02	5.63
SA 3				**32.17**	**19.10**	**155.5**	**61.61**	**28.74**
A 1					6.63	**49.42**	**43.49**	**41.49**
A 2						**43.87**	**34.78**	**31.71**
G							**51.03**	**30.64**
W 1								1.36

COMBINED GROUPS

$F_{calc} > F_{crit}$ = significantly different at the 1% level

F_{crit} at 1% = 7.562 except * = 7.062, $ = 7.22

F_{crit} at 5% = 4.17 except * = 4.00, $ = 4.05

	A2 Topsoil + A2 Subsoil	SA3 Subsoil + W1 Topsoil	SA2 Topsoil +SA2 Subsoil	W1 Subsoil + W2 Subsoil	SA1 Topsoil	G Topsoil	G Subsoil
A1 Topsoil + A1 Subsoil	**15.5***						
A2 Topsoil + A2 Subsoil		**36.99***					
W2 Topsoil + Subsoil		**9.14$**	1.01$				
SA1 Topsoil				2.14$			
SA2 Subsoil					0.69	3.17	
SA1 Subsoil						0.09	**21.44**

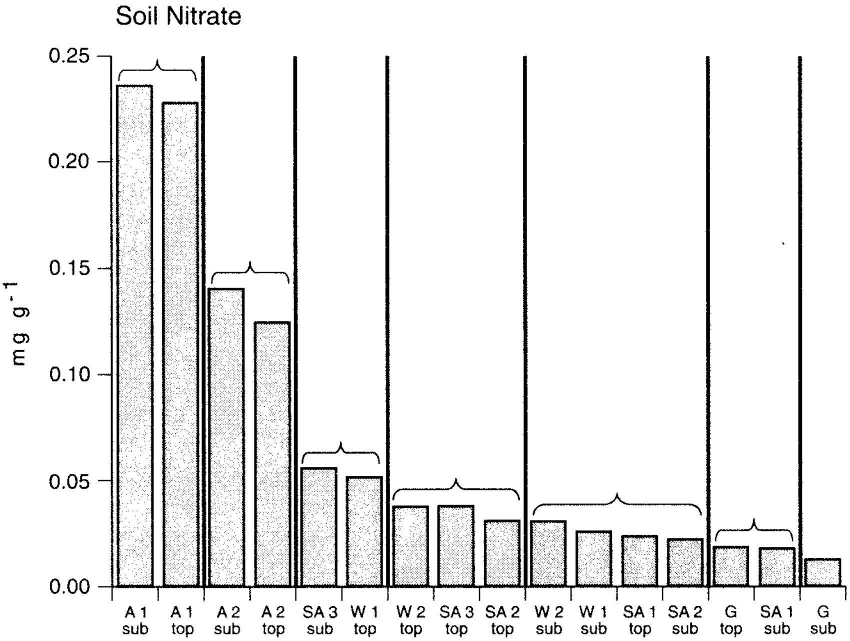

FIG. 6.
Soil NO$_3$-N, mg g^{-1} data from each site showing significantly different groups (1% level) separated by vertical lines and non-significantly different groups bracketed.

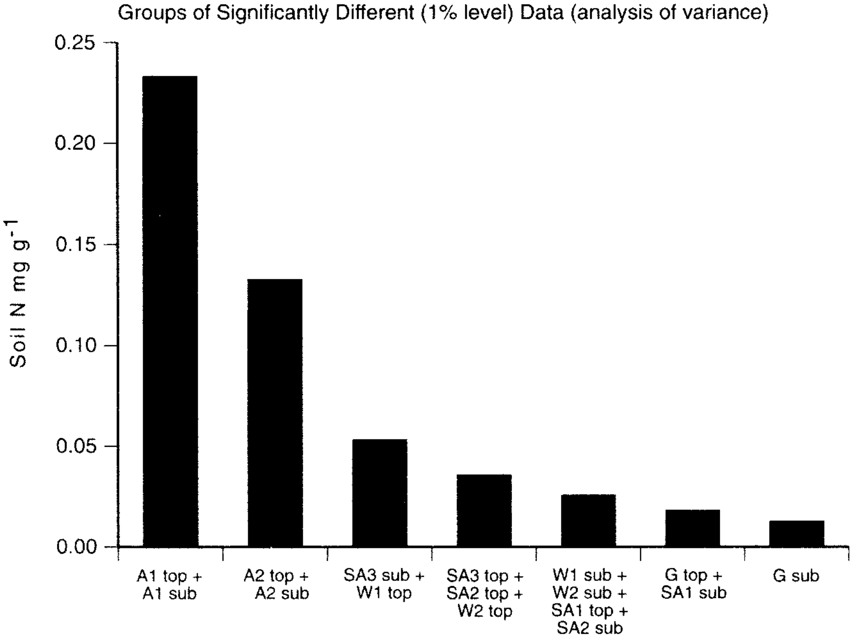

FIG. 7.
Soil NO$_3$-N, mg g^{-1} data showing significantly different groups (1% level) as amalgamated bars.

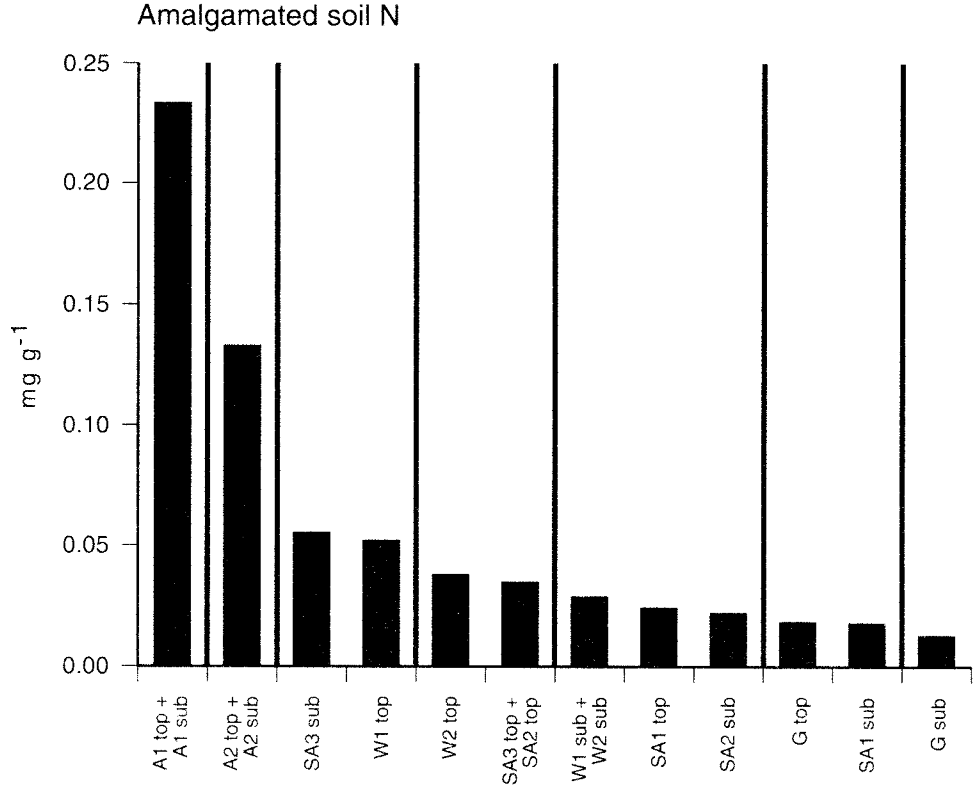

FIG.8.
As for Fig. 7, but differentiated by land use.

The speculation that arable fields have a relatively low level of organic matter can be supported by Easter 1992 data as shown in Fig. 11. The wheat and potato fields sampled showed levels of about half that of grass and wood land at 5–6% organic matter (by weight loss on ignition at 400°C) as compared to permanent pasture at 11% and woodland at 15%

Nitrate leaching is facilitated by the rapid movement of water through the soil but this is hindered in compacted soils where porosity decreases. Bulk density data for September 1992 (Fig. 12) show not only that the set-aside fields have a lower bulk density than the arable, presumably a 'recovery' effect but also, this supports the possibility that rapid flow could be occurring in set-aside areas. There are, however, no data on these fields prior to set-aside and thus it cannot be concluded that these did not already have a lower bulk density when they were under arable.

CONCLUSIONS

There were clear significant differences between some land uses and soil nitrate levels in September 1992. In particular, the set-aside fields were all significantly different from, and lower than, the arable fields. Knowing that these set-aside fields were fertilised at

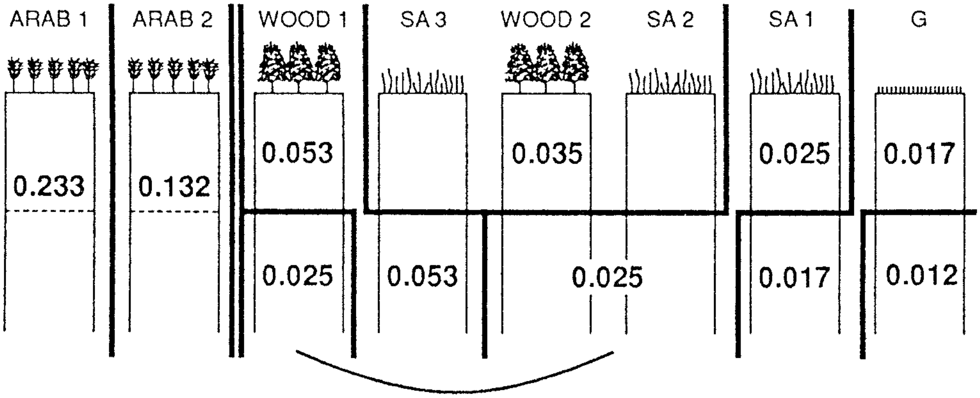

FIG.9.
A visual plot of the differences and similarities between the soil NO_3-N, mg g^{-1} data from each site. .

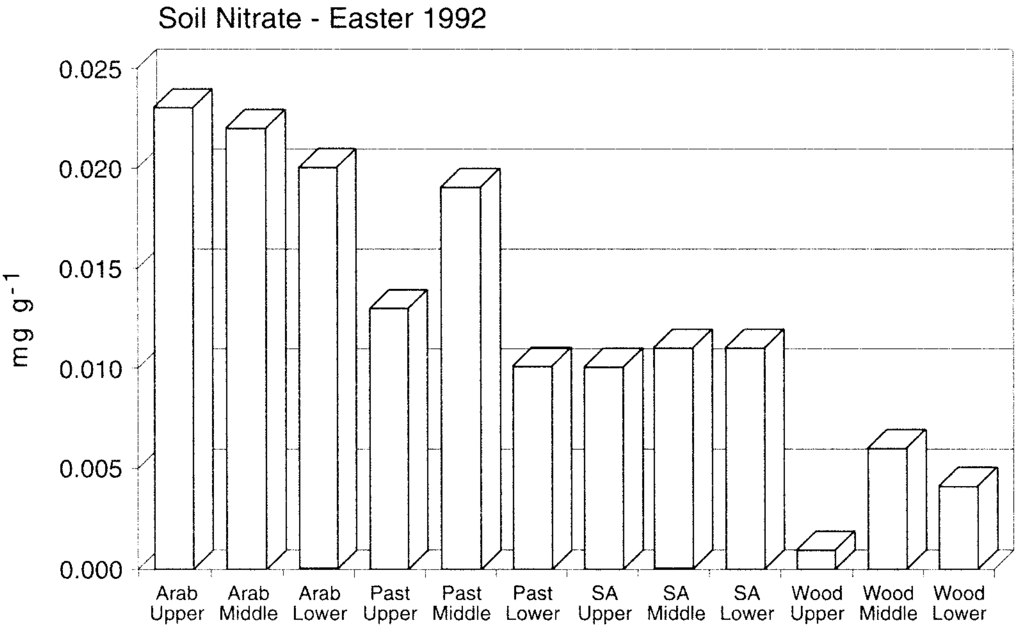

FIG.10.
Soil NO_3-N, mg g^{-1} and land use, Easter 1992.

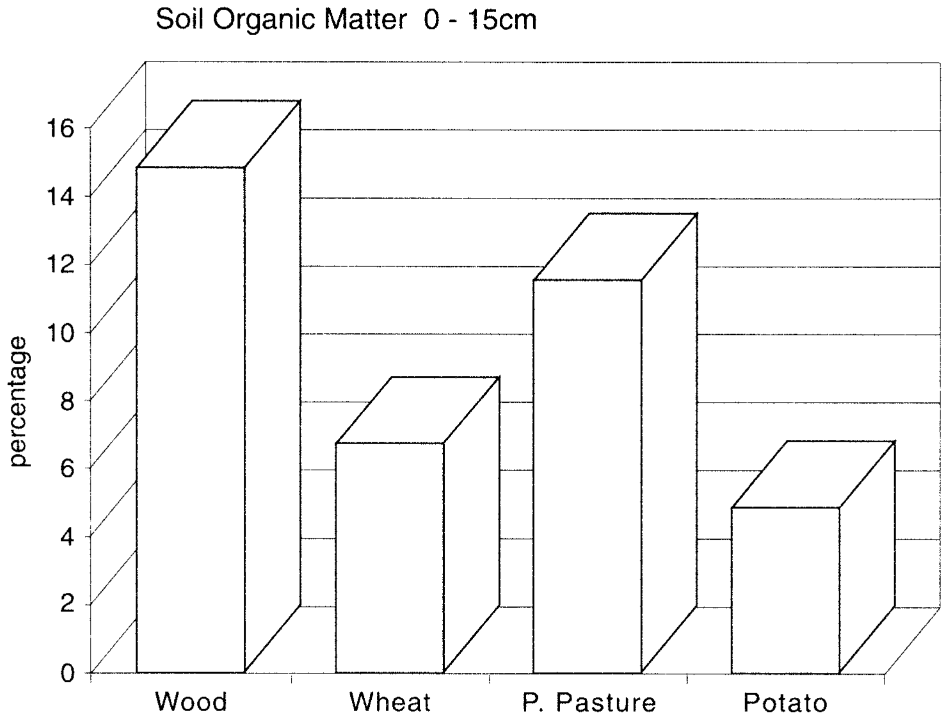

FIG. 11.
Soil organic matter % at 0–15cm depth and land use, Easter 1992

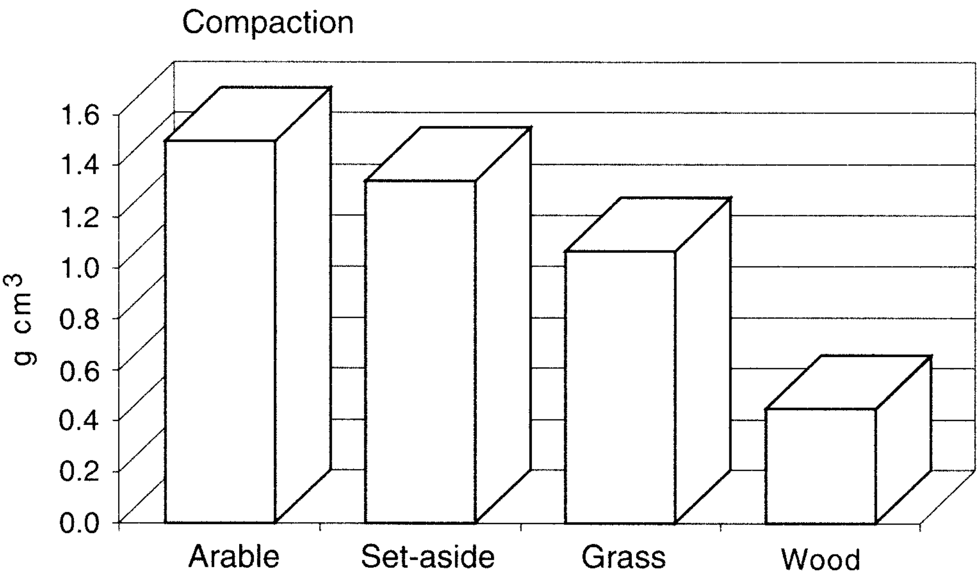

FIG. 12.
Soil compaction and land use, g cm^{-3}, September 1992.

the same level as those which were still under arable as little as 1 or 2 years ago appears to indicate a rapid rate of loss of soil nitrate. This would tend to suggest a rapid rate of nitrate loss in highly permeable, poorly retentive soils.

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