Environment

Nitrogen loss through leaching

Cover crops: immediate and sustainable benefits

What effect do cover crops, soil cultivation and straw management seem to have on nitrogen loss through leaching? Here is the answer yielded by the results of a long-term trial carried out over twelve years on the Boigneville site, near Paris.

Porous cups are laid out to collect the soil solution.

How relatively effective are various cropping techniques in limiting long-term nitrogen loss through leaching? The Boigneville "Environnement" trial was launched in 1992 to find an answer to this question. This long-term experiment is part of a series of trials initiated by ARVALIS-Institut du végétal at the beginning of the 1990s: Thibie in the Marne, northeastern France, (in collaboration with AREP) and Kerlavic in the Finistère, Brittany, (in collaboration with the chambres d'agriculture of Brittany). It was absolutely essential to quantify, over a long period of time, the impact of techniques which had been shown (ITCF, 1995) to be effective in the short-term in reducing nitrogen leaching. On that subject, the idea of "time bomb" prevailed, linked to the accumulation of nitrogen in the form of organic matter in the soil. Some people predicted an "explosive" remineralization, cancelling out any short-term benefits. We will see that this is absolutely not the case and that this fear was unfounded.
Three action levers were tested in this experiment (table 1):

• Crop residue management. Fifteen years ago, it was suggested that the absence of soil cultivation after harvest, and leaving the straw on the soil surface could help limit gross mineralization of nitrogen during the intercropping season. This method was therefore introduced (treatment 2) to be compared with the control practice which involved the early incorporation of residue through stubble cultivation (treatment 1).

Description of the eight experimental treatments (tab.1)

Treatment N° (1).	Soil cultivation	Crop residue	Cover crop
1	ploughing	stubble cultivation	-
2	ploughing	mulch (2)	-
5	ploughing	stubble cultivation	mustard (mechanically destroyed)
6	ploughing	stubble cultivation	mustard (chemically destroyed)
7	direct drilling	mulch	-
8	direct drilling	mulch	mustard
9	direct drilling	mulch	Cocksfoot (until 1994), followed by mustard in the intercropping season between peas and wheat, and rye in the intercropping seasons between wheat and barley and barley and peas
10	direct drilling	mulch	rye

(1) treatments 3 and 4 were abondoned – (2) straw left on the soil surface until ploughing time

Eight experimental treatments combining soil cultivation, straw management and cover crop were tested over a period of 12 years

Acknowledgement

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• **Soil cultivation regime: ploughing and direct drilling are compared.** The latter is used to establish main crops (peas, wheat, spring barley) and nitrate trapping cover crops (mustard, rye).
• **Nitrate trapping cover crops:** when included in a treatment, those crops were established systematically every year.

The combination of the different methods used with those three techniques (stubble cultivation / mulch, ploughing / direct drilling, presence / absence of nitrate trapping cover crops) define eight experimental treatments applied consistently between 1992 and 2004 (tab. 1). The nitrogen fertilisation of wheat and spring barley was adjusted annually for each treatment, depending on the mineral nitrogen residues measured at the end of winter, and on the quantity of mineralized nitrogen from the nitrate trapping cover crop, if present. All the other elements of the provisional balance method are assumed to be the same (expected yield, humus mineralization, impact of preceding crop residue).

Experimental site

The trial started in 1991. It was organised around a spring pea – wheat – spring barley rotation. All crop residues were put back into the soil. The following three techniques were used, combined with various practices, in order to assess their effectiveness in limiting nitrogen loss through leaching (table 1):

• Soil cultivation: main and cover crops were established either after ploughing (treatment 1 to 6), or by direct drilling (treatments 7 to 10)
• Crop residue management: no stubble cultivation until the following sowing, in order to make straw mulch (treatment 2)
• Systematic establishment of cover crops was tested for each soil cultivation regime. Sowing took place at the beginning of September and the crop was destroyed at the end of September (to sow wheat), or mid-November (before spring crops), allowing time for winter ploughing if it was part of the treatment in question.

Overview of the whole experiment

Various combinations of different practices resulted in eight experimental treatments (with three replicates). Each experimental field measured 9 m x 48 m and was equipped with a system capable of measuring nitrate concentrations in the soil solution at a depth of 90 cm. Linked to two lysimeters situated outside the trial fields, porous cups helped calculate the quantity of nitrogen leached below the level used by the roots (see insert 2).

The trial followed this protocol from harvest 1992 to harvest 2004, therefore including twelve measuring campaigns.

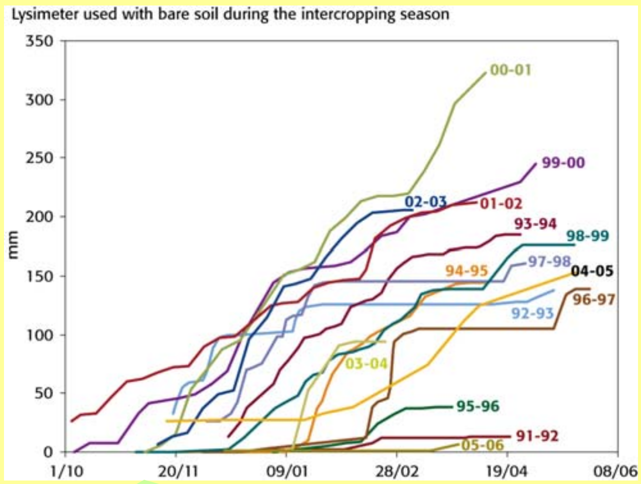
Very slight drainage water flow, extremely variable from one year to the next and hardly affected by cover crops

The climate south of Paris resulted on the whole in low volumes of drainage water (an average of 170 mm/year for the period studied), and extremely variable from one year to the next: between 40 and 320 mm/year (figure 1).

The establishment of mustard hardly reduced the volume of drainage water: 7 mm/year, i.e. 3% on average for the twelve years studied. This corroborates Alexandre's findings (2004), which show, through simulation with the STICS model (INRA), that the average volume of drainage water is only reduced by 8% over 30 years. Plant transpiration would be partly offset by a reduction in soil evaporation due to the presence of a cover crop. Over the past fifteen years, drainage water flow rarely started before the end of November and 80% of total drainage flow occurred before the end of February. Techniques designed to prevent nitrogen loss through leaching must therefore be able to manage this risk mainly during the winter period.

At Boigneville (south Parisian basin), the very small amount of drainage water requires very delicate management of nitrogen flows in order to control the quality of the leaching water

Variation in volumes of drainage water from year on theBoigneville site, (South parisian basin) *(fig.1)*



The amount of drainage water varies greatly from year : from 40to 320 mm/year

Leaching measurement

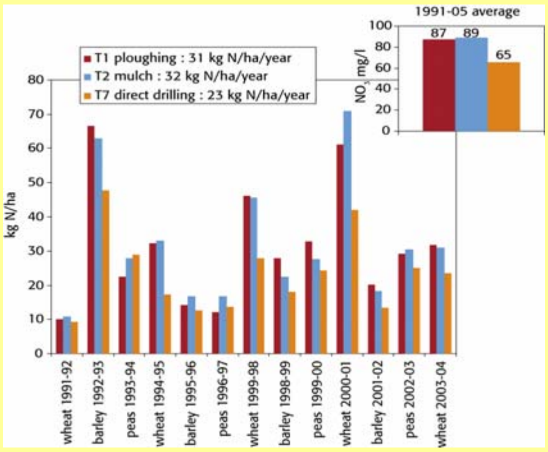
The nitrate concentration in the soil solution was measured under each experimental field through a series of seven porous cups laid out sub-horizontally at a depth of 90 cm, which helped collect water during the drainage season (samples taken at 3 to 5 different dates, depending on the year). The quantity of leached nitrogen in each field is calculated by multiplying the average nitrate concentration by the quantity of drainage water. The water drainage was measured in two lysimeters located outside the trial, but receiving the same crop succession (with or without cover crop), and calculated according to the trapezoidal calculation method (Lord and Sheperd, 1993).

Profile of soil used for the trial

Impact of straw management and of soil cultivation regime

The impact of eliminating early stubble cultivation after harvest (mulch technique) has been analysed by comparing treatments 1 and 2. This elimination did not help to change the mineral nitrogen profile at the beginning of the drainage period (rainy season). This is consistent with knowledge previously acquired: not to incorporate straw means doing without this early source of mineral nitrogen available on the surface. Conversely, direct drilling affects the mineral nitrogen profile, including deep in the soil, with a reduced risk of nitrogen transfer through leaching. This is specifically due to soil cultivation since this technique also involves straw mulching on the surface, which, as we have just seen, does not reduce leaching when combined with ploughing.

Average quantity of nitric drained, and its concentration in drainage water for the three treatments without any cover crops *(fig. 2)*



Straw mulch does not help reduce leaching. Stopping ploughing in favour of direct drilling reduces the nitrate concentration average by a very significant 25%

Figure 2 compares the annual leaching figure for each of those two treatments ("ploughing + mulch" and "direct drilling"), our "control" being represented by treatment 1. The "mulch" technique proved unable to reduce winter nitrogen leaching, whereas eliminating ploughing obtained better results: 24 kg N.ha^{-1}.year^{-1} with direct drilling, compared with 32 with ploughing. However the level of concentration found in drainage water under root level remained high, in spite of the rigorous management of nitrogen fertilisation in cereal crops: between 68 and 95 mg NO3.l^{-1} depending on the treatment. Those results are consistent with those obtained in other similar experiments, like the Thibie experiment for instance (average concentration of 111 mg NO3.l^{-1} for the "bare soil in winter" treatment between 1992 and 2003).

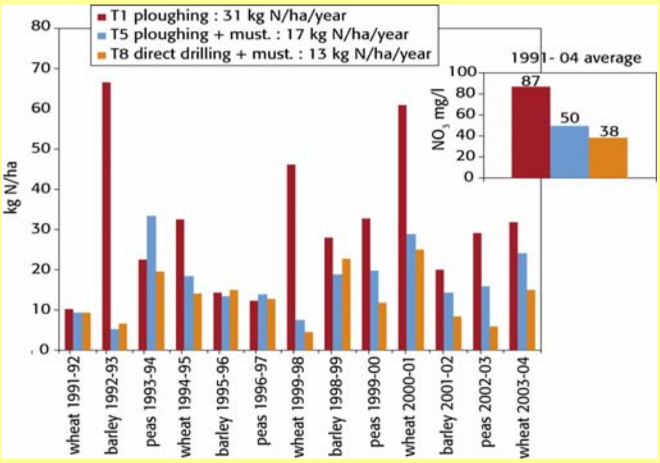
Cover crops: undoubtedly effective

The biomass produced by cover crops varied from year to year (table 2), or was even non-existent in one case in four. On the whole, those failures were due to emergence problems (drought) or to phytoxicity of dm.ha^{-1} for mustard and 0.8 t dm.ha^{-1} for rye, corresponding respectively to 41 and 22 kg N.ha^{-1} of nitrogen absorbed by the aerial parts of the plants.

In spite of their limited development, the cover crops still helped reduce nitrogen leaching (figure 3). The amount of nitrogen leached with treatments 5 and 8 (whose all intercropping periods were sowed with cover crops) was much lower than for the "control treatment", treatment 1.

Quantity of water drained average nitrogen concentration in drainage water of each of the two treatments including cover crop *(fig. 3)*

T5 : ploughing + mustard and T8 : direct drilling + mustard, between 1991 and 1995. The control treatment, T1, with ploughing and bare soil, is the same as treatment used for figure 2



Leaching varied more from year to year than because of the techniques used and being tested. Cover crops show how effective they are by reducing the average nitrate concentration of leaching water by more than half

Therefore, the average nitrate concentration found in the drainage water over the whole duration of the trial was reduced by 43% with the "ploughing + mustard" system and by 54% with the "direct drilling + mustard" system, compared with treatment 1: the average concentration calculated over the 13 drainage seasons for each of those two treatments was equal to or below the 50 mg NO3.l-1 threshold agreed for a whole catchment area. However, two important points should be highlighted here:

• The type of year played a much more significant role (factor of 7 between the extremes) in the average annual nitrate content of drainage water than the parameters of a specific experimental treatment (factor 2). Therefore, the efficacy of the measures designed to preserve water quality can only be assessed in the long-term.

• It is possible to reach a concentration of 50 mg NO3.l-1 in drainage water without having to consider changing cropping systems, provided cover crops are introduced. It is indeed the only lever which proved effective enough. In addition, all the experiments of this type, as well as recent simulation work carried out by INRA (Lacroix et al., 2005), show that it is a fallacy to hope that current arable systems will result in average nitrate concentrations in drainage water much below this threshold. As an example, the establishment of a cover crop at every intercropping season within a sugar beet – peas – wheat rotation over the twelve years of the Thibie trial resulted in an average concentration of 52 mg NO3.l-1 in the drainage water.

Table 3 shows that all the experimental treatments including a cover crop led to much lower average nitrate levels in drainage water than treatments with bare soil during the intercropping season. The impact of cover crops on the average nitrate content of drainage water is less significant for treatments 9 and 10, which saw the lowest growth and lowest quantities of nitrogen taken up by rye-based cover crops (table 2). However, the average concentrations calculated for each of those two treatments are already easily compatible with the water quality preservation objectives.

Main crop yields

When the soil was ploughed regularly, crop yields were not significantly altered by the introduction of cover crops: + 2% for the whole trial duration (figure 4). Stopping ploughing in favour of direct drilling (T7) resulted in some significant yield drops, including for spring peas, due to problems in controlling emergence.

Biomass produced and nitrogen absorbed by cover crops by the time they were destroyed (part above soil surface) *(tab.2)*

Biomass (t DM/ha)													
treatment	1991	1992	1993	1994	1995	1996	1997	1998	1999		2001	2002	2003
5	0.80	1.36		1.19	1.36		1.60	1.14	1.31	2.46	0.57		1.41
6	0.78	1.47		1.12	1.37		1.29	1.12	1.52	2.16	0.59	1.08	1.36
8	0.77	1.37		0.90			0.84	0.97	1.38	1.44	0.48	0.74	1.49
9		0.30		1.19				0.39		1.16	0.30	0.91	1.14
10		0.96		1.27		1.02		0.62	1.04	0.96	0.58	0.95	1.01
Absorbed N (kg/ha)													
treatment	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
5	37	44		47	51		69	33	45	50	23	33	56
6	36	47		45	62		57	35	50	47	23	33	54
8	36	36		40			35	33	51	42	18	23	62
9		14		36				11		33	10	22	35
10		25		34		21		14	16	26	20	26	34

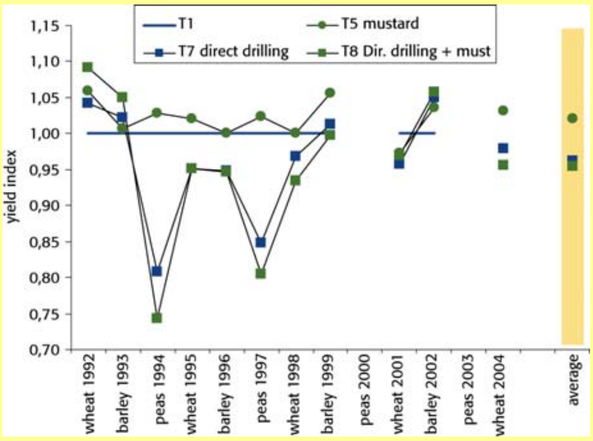
Green background = mustard, orange background = rye, blue background = cocksfoot (undersown with peas)
Where there is no figure entered, the cover crop did not grow. The years correspond to the date when cover crops were destroyed.

Average biomass production : 1.2 t DM/ha for mustard and 0.8 t DM/ha for rye

Soil type										
The trial is located on a plateau on the north-eastern boundary of the Beauce region (large arable production area south of Paris). The soil is made up of clayey loam, moderately deep, freely drained, and overlaying a calcareous substrate which appears at a depth of 60 to 100 cm										
Physical and chemical characteristics										
horizon	Clay (0-2µm) %	Fine silt (2-25µm) %	coarse silt (25-50µm) %	fine sand (50-200µm) %	coarse sand (200-2000µm) %	$CaCo_3$ %	Water pH	CEC cmol.kg[1]	O.M. %	C/N
0-25 cm	24.5	28.6	36.3	4.6	2.0	0.3	7.7	18	1.69	8.7
25-50 cm	30.5	27.8	35.0	3.6	1.5	0.6	7.8		0.96	7.6

Yield index of treatments T5, T7 and T8 compared with the control treatment T1 (fig.4)

T5 : ploughing + mustard and T8 : direct drilling + mustard, between 1991 and 1995. The control treatment, T1, with ploughing and bare soil, is the same as treatment used for figure 2



Direct drilling penalized pea yields in particular. Under a continuous ploughing regime, mustard did not affect crop yields

Wheat and spring barley nitrogen fertilisation calculated using the balance sheet method was not significantly modified by the introduction of nitrate trapping cover crops. This is due to the fact that those crops are in competition with the following ones for the mineral nitrogen contained in the soil. It is worth remembering that the establishment of nitrate trapping cover crops incurs an additional 18 €/ha when the soil is ploughed, and 44€/ha with direct drilling. Such a difference in costs is attributable to additional costs associated with labour and the slug control product used (Labreuche *et al*, 2006).

Important points to remember

The three action levers tested over 12 years in this trial help confirm that:

• Not incorporating straw soon after harvest (mulch technique) does not help limit nitrogen loss through leaching, when compared with the control treatment. In order to make the most of the nitrogen immobilisation potential of the residue, it should be incorporated into the soil as early as possible after harvest.

• Direct drilling helps to limit nitrogen transfer through leaching. However, the average nitrate concentration of drainage water remains high if no cover crops are established (nitrate trapping crops).

Average quantities of leached nitrogen and concentration in drainage water (1991 – 2004). *(tab. 3)*

treatment	1	2	5	6	7	8	9	10
leached N ($kg\ N.ha^{-1}.year^{-1}$)	31 a	32 a	17 bc	17 bc	23 b	13 c	17 bc	19 bc
concentration ($mg\ NO_3.l^{-1}$)	87 a	89 a	50 bc	49 bc	65 b	38 c	49 bc	55 bc

In green : treatments with cover crops.

Figures followed by the same letter a, b, or c are not significantly different with a confidence level of 5%.

The treatments which include cover crops resulted in much lower levels of nitrate in drainage water than treatments with bare soil during the intercropping season.

For more information

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• Sowing cover crops turned out to be a technique with immediate benefits, and those benefits also proved sustainable over the years of the trial (similar to the other ARVALIS-Institut du végétal's experiments of this type).

The bundle of seven porous cups laid out at the beginning of the trial (1991) and the networkof capillary tubes to collect the soil solution