Environment

Direct drilling and cover crops

How do they affect nitrogen mineralisation?

What long-term impact does a reduction in soil cultivation and the establishment of cover crops have on nitrogen mineralisation and the nitrogen fertilisation of crops? Here is a detailed answer, based on a 12 years trial carried out at the Boigneville Research Station.

In some cases, the nitrate trapping cover crop helps to absorb some mineral nitrogen from the soil, which otherwise would have leached out, and to subsequently release the mineralised part.

In order to assess the level of organic nitrogen mineralisation in the soil, measurements started in 1991, as part of the Boigneville "environment" trial *(insert 1)*. Five experimental systems, combining different soil cultivation techniques, straw management and the establishment or not cover crops, were used to measure, at regular intervals, the mineral nitrogen content of the soil, the amount of nitrogen absorbed by the primary crops (spring pea - wheat - spring barley) as well as by the cover crops, and the amount of nitrogen that leached out. The mineral nitrogen balance of the soil calculated between each measurement date helped to analyse the effect of cropping techniques on the soil nitrogen supply.

Soil cultivation does not affect mineralisation

The effect of soil cultivation (and straw management) on soil nitrogen mineralisation was studied, comparing systems T1, T2 and T7 (ploughing without cover crops, straw mulched between harvest and winter ploughing, direct drilling without cover crops, respectively).

Between December 1991 and September 2004, cumulative mineralisation was very similar for all three systems *(figure 1)*. The speed of apparent nitrogen mineralisation was 0.42, 0.45 and 0.42 kg N/ha/standard day (sD) [(1)] for the three systems respectively. Direct drilling therefore did not modify the average speed of nitrogen mineralisation compared with its speed in fields continuously ploughed for 12 years.

(1): Day with standard temperature (15°C) and moisture conditions (Field moisture capacity)

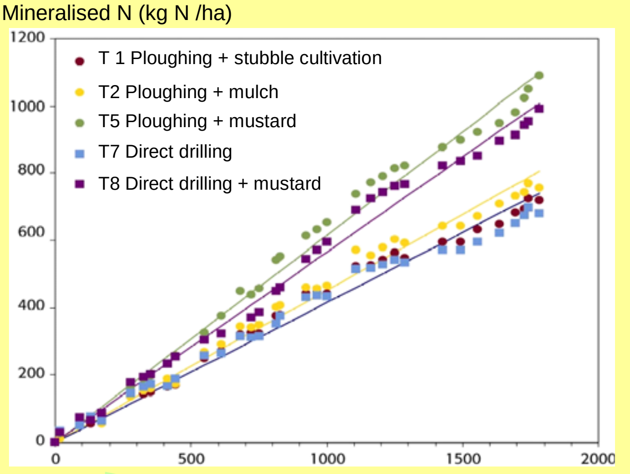
The five experimental systems *(tab. 1)*

System	Soil cultivation	Crop residue	Nitrate trapping cover crops
T1	Ploughing	Stubble cultivation	
T2	Ploughing	Mulch (1)	
T5	Ploughing	Stubble cultivation	Mustard
T7	Direct drilling	Mulch (continuously)	
T8	Direct drilling	Mulch (continuously)	Mustard

(1) Straw left on the ground until ploughing takes place

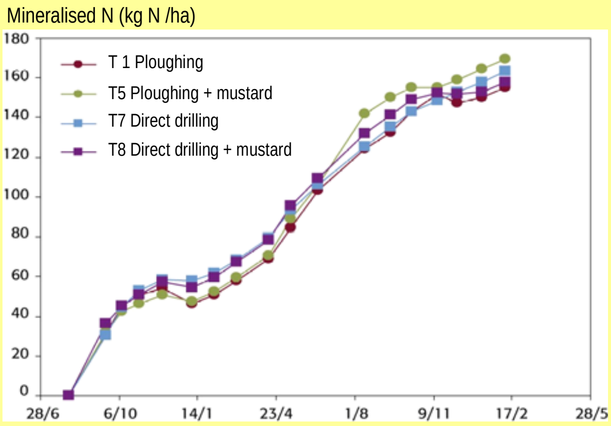
The cumulative effects of those five systems help to assess the impact of straw mulching (T2 – T1), direct drilling (T7 –T1), and nitrate trapping cover crops (T5 – T1 or T8 – T7) on nitrogen mineralization flux

Cumulative mineralisation of nitrogen in the soil from 1992 to 2004 (without taking account of pea crops) calculated using the nitrogen balance method *(fig. 1)*



Calculations show that with direct drilling, the speed of mineralisation (slope of straight lines fitted to measurements) is equal to (T7) or 8% slower than (T8) the speed of the control systems involving ploughing (T1 and T5 respectively). At the other end of the spectrum, the speed of mineralisation in the "straw mulch" system (T2) is 9% faster than the mineralisation speed recorded on ploughed land.

Effect of soil cultivation regime and nitrate trapping cover crops on the mineralisation of nitrogen in the soil, as determined on bare soil between 3/08/03 and 8/02/05 *(fig. 2)*



(From Oorts et al., 2006). (Previous crop in 2003: peas, straw taken off field)

Twelve years of direct drilling and/or cover crops did not significantly modify the soil's ability to mineralise organic nitrogen: therefore, the techniques which were tested have no cumulative effect.

In order to characterise mineralisation more precisely, it was measured on bare ground from August 2003 to February 2005 (INRA Laon – Reims collaboration). The plots were divided into two, and half of the ground was kept bare of any vegetation for 18 months. Water and nitrogen content were measured for the three horizons in the soil every three weeks, in order to calculate net nitrogen mineralisation between each date, using the Lixim software. This showed that soil cultivation only has a very slight impact on the amount of nitrogen which is mineralised *(figure 2)*. Mineralisation speed ranged between 0.48 and 0.50 kg N/ha/standard day. Therefore, 12 years without any deep soil cultivation did not significantly modify the soil nitrogen mineralisation regime. This observation corroborates the findings of another long-term trial (32 years) also carried out at Boigneville.

Effect of cover crops on the supply of nitrogen from the soil

The total absence of any ploughing for 12 years, with direct drilling instead, did not bring any significant changes to the level of mineralisation of nitrogen in the soil. The trends observed do not conclude that nitrogen fertilisation of the crops should be modified.

The "environment" trial also helped to measure the effect of cover crops on the supply of nitrogen from the soil. Systems T5 (ploughing) and T8 (direct drilling) saw the systematic establishment of mustard during the intercropping season, but in some years (1993 and 1996) the cover crops did not grow. With the exception of those cases, the aerial part of the plants accumulated an average of 44 kg N/ha in ploughed fields and 37 kg N/ha with direct drilling *(table 2)*. This corresponds to the recycling of 489 and 374 kg N/ha respectively over the 12 years of the study.

The experiment (1991-2004) (insert 1)

Different combinations of three techniques were applied to a pea - wheat - spring barley rotation, in order to assess their effectiveness in limiting nitrogen leaching:

- soil cultivation: the primary crops and cover crops were established either on ploughed land (systems T1, T2 and T5), or by direct drilling (systems T7 and T8).
- crop residue management: no stubble cultivation in order to keep straw mulch until the following sowing (system T2).
- systematic establishment of cover crops (systems T5 and T8) was tested for each soil cultivation regime. The cover crop was sown at the beginning of September and destroyed at the end of September (for wheat to be sown) or mid-November (before spring crops), allowing the possibility for winter ploughing if the systems included it.

The soil of the trial fields is a clayey silt of average depth (25% clay and 1.7% OM at the surface), free drained and formed on a calcareous substrate appearing at a depth of 60 - 100 cm.

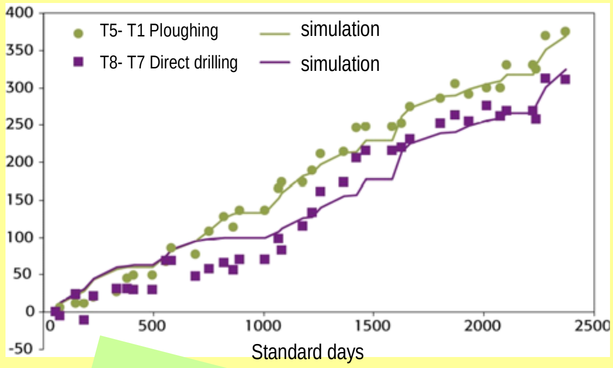
Nitrogen accumulated in the aerial part of mustard plants (kg N/ha) at the time of their destruction *(tab. 2)*													
System	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
T5 Ploughing	37	44	0	47	51	0	69	33	45	50	23	33	56
T8 Direct drilling	36	36	0	40	0	0	35	33	51	42	18	23	62

The figure 0 represents no cover crop growth. The years are those of the date of destruction of the nitrate trapping cover crops.

Measurement of organic nitrogen stocks at the end of the trial period (0-50 cm horizon, February 2005) (tab. 3)				
	Ploughed soil		Direct drilling	
	Bare soil (T1)	Mustard (T5)	Bare soil (T7)	Mustard (T8)
Kg N/ha	6931	7044	6968	7192

At the end of 13 years of trial, there is no significant difference in the total quantity of organic nitrogen in the soil (probability = 26%, standard error of measurements = 2%).

Additional mineralisation is attributable to the decomposition of mustard plants, with ploughing as well as direct drilling, between 1992 and 2004 *(fig. 3)*



By adjusting a simple cover crop mineralisation model, the curve representing the system involving ploughing (continuous green line) can be satisfactorily reproduced and serve as a basis to deduce the typical kinetics of basic mineralisation of mustard, as indicated in figure 4. Simulation of the system involving direct drilling is less successful.

The establishment of a mustard crop at each intercropping season of the pea - wheat - spring barley rotation increased the nitrogen supply from the soil. This increase is a short-term effect: after 13 successive establishments of cover crops, the organic nitrogen mineralisation and stocks in the soil are not affected by any cumulative effect.

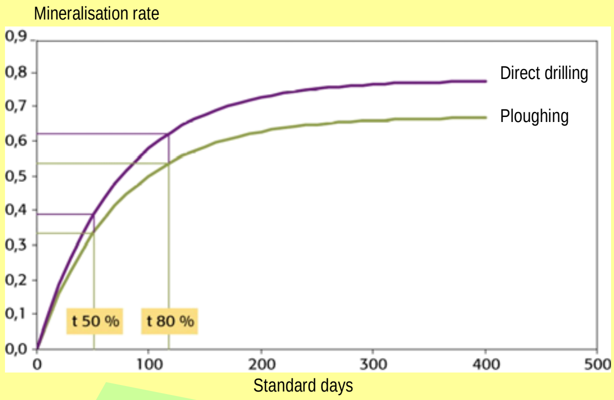
With cover crops, the amount of mineralised nitrogen was higher than without them *(figure 1)*. This additional mineralisation comes from the nitrogen contained in mustard plants (above ground and roots) at the time of their destruction. It was slightly lower with direct drilling than when the ground was ploughed *(figure 3)*, probably because of a lower rate of nitrogen recovery from the residue of catch crops *(table 2)*.
The kinetics of mineralisation of the nitrogen recycled by mustard plants, which represent the basic decomposition of the thirteen successive cover crops, help set an average function of mineralisation of the nitrogen contained in their aerial parts. *Figure 4* represents this basic typical kinetics.

Two important characteristics of mustard residue can then be identified:

- the proportion of nitrogen likely to be mineralised at the end of the decomposition process. The figures recorded as part of this study, ranging from 67 to 78%, are high compared with the 25 to 50% mentioned in other research. The fact that roots and fallen leaves are not taken into account only partly explains this difference. In fact, the only deduction we could make from our study was the annual mineralisation rate, based on long-term monitoring of the kinetics of the mineralisation attributable to mustard. Models that are more “mechanistic” would work better with this type of approach. However, cover crop residue seems to have reached the same stage of decomposition with both soil cultivation regimes (*figure 4* shows very similar kinetic “plateaux”), in spite of the fact that in T7 (direct drilling) the residue was not incorporated.
- the time required for half the potentially mineralisable nitrogen to be mineralised is 51 standard days (sD) for both T5 and T8.

Direct drilling, implemented continuously for 12 years, did not modify the average mineralisation speed of soil nitrogen.

Basic kinetics of mustard mineralisation, deduced from figure 3 (fig. 4)



In order to reproduce the kinetics of mineralisation shown in figure 3, we must assume that each mustard residue decomposes according to a typical pattern presenting two characteristics:

• the proportion of organic nitrogen from nitrate trapping cover crops mineralised at the end of the process (67% with ploughing and 78% with direct drilling) ;

• the time required for half of this nitrogen to decompose (indicated by t 50%): 51 standard days for both soil cultivation regimes. 80% decomposition is reached in 127 standard days, which is much shorter than a calendar year.

The higher level of mineralisation noted when cover crops were involved is due to the nitrogen contained in the last mustad crop before the cereal crop.

Figure 4 shows that 80% of the mineralisation process is completed in 117 sD, i.e. much shorter than a calendar year (around 180 sD at Boigneville). This result confirms the fact that the residue of young plants at the time of their destruction decomposes quickly and releases very little or no nitrogen after 12 months.

Therefore, the potentially faster mineralisation noted in *figure 1* for fields where mustard was used as a cover crop, is purely due to the short term mineralisation of their residue, indisputably confirming *figure 2*. Measurements having started more than 8 months after the last mustard was destroyed, most of the mineralisation of this last nitrate trapping cover crop was completed. Since there is no significant difference between the systems that included a mustard crop and those that did not, the 12 successive cover crops therefore had no cumulative effect on soil mineralisation.

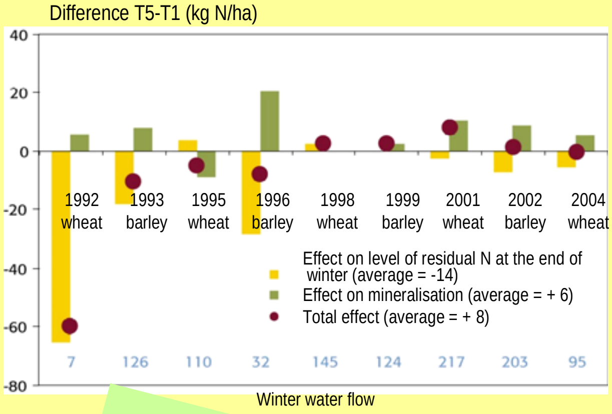
In addition, the fact that there is no significant difference in organic nitrogen stocks in the soil between the different systems at the end of the trial *(table 3)*, proves that the cumulative effect of cover crops is negligible in the medium-term (13 years).

What consequence does this have on nitrogen fertilisation?

In order to quantify the effects that the decomposition of cover crop residue has on nitrogen availability, three key agricultural periods were defined: presence of mustard (from its sowing to its destruction), beginning of residue mineralisation (from destruction to end of winter), mineralisation phase during period of heavy consumption by subsequent primary crop. They are called phases 1, 2 and 3 respectively. The difference in mineralisation between systems that included a mustard crop and those that did not, helps to determine the effects of the cover crop on the quantity of nitrogen available in the soil. Two thirds of the mineralisable nitrogen has been released before the end of winter (phase 2 corresponding to an average of + 16 kg N/ha). The low impact during the period of heavy demand by cereal crops (phase 3 + 6 kg N/ha) is explained by the rapid decomposition of barely developed mustard plants during the winter.

Besides this effect on spring mineralisation, the cover crop also modifies the level of residual mineral nitrogen at the end of winter, but to a variable extent depending on winter weather conditions. *Figure 5* indicates the annual figures representing both those effects, the sum of which helps to evaluate what this implies in terms of nitrogen fertilisation of crops. If winter rainfall is low and leads to less than 50 mm of water drainage through the soil (this was the case in 1991-92 for instance), the late mineralisation of mustard residue does not release enough nitrogen to compensate for the significant reduction in residual nitrogen at the end of winter (Re) due to the cover crop uptake. In this case, nitrogen fertilisation rate must be increased. Conversely, if winter rainfall is high, the nitrate trapping cover crop uses up some mineral nitrogen from the soil, stopping it from leaching out of the field, and later releases the mineralised part.

Effects of mustard on nitrogen availability for the following cereal crops *(fig. 5)*



The average increase in mineralisation in cereal crops which is attributable to the spring mineralisation of mustard plants (green histograms) is + 6 kg N/ha. In addition, the cover crop reduces residual N at the end of winter (Re) by an average of 14 kg N/ha (yellow histograms). The sum of both terms (brown circles), when it is positive, represents the potential saving in nitrogen fertiliser resulting from the mustard crop, compared to "bare ground".

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Thanks go to Pascal Thiébeau (INRA) for carrying out the calculations necessary for figure 2, and to Bernard Nicolardot (INRA) for allowing it to be published ahead of the article from which it was extracted.

In the Boigneville trial, the overall balance was neutral: average fertilisation over 12 years needed to be the same with a cover crop as with bare soil, in spite of cover crops halving leaching levels. These conclusions corroborate those drawn form another long-term trial carried out in Thibie, northeastern France. This competition for available nitrogen in the months that follow their destruction can be seen as a "paradoxical" effect of cover crops, which are primarily meant to limit nitrogen losses. It is likely to occur if:

- when the previous crop is being harvested, most of the mineral nitrogen contained in the soil is concentrated in the top layers of soil;
- the following crop is very deep-rooted;
- winter rainfall is low.

Therefore, with nitrate trapping crops, annual fertilisation may have to be adjusted, depending on winter weather conditions. Although the introduction of cover crops does not result in a significant reduction in medium-term nitrogen fertilisation, nitrogen recycling through a combination of reduced leaching and improved organisation should, logically, contribute to it in the long term (at least 20 years).

In this experiment, winter ground cover did not result in a reduction in average nitrogen fertilisation of wheat and spring barley.

Compared to a similar field with bare ground during the intercropping season, the presence of cover crop:
1- reduces the level of residual mineral nitrogen at the end of winter, especially if it was a dry winter,
2- increases nitrogen mineralisation during the period when crops consume large amounts of nitrogen.
The balance of both those effects can be variable. Their sum can be positive or negative, depending on the case (winter rainfall, soil type…). In the case of the Boigneville trial, the overall balance was neutral. Average nitrogen fertilisation could not be reduced in spite of cover crops helping to reduce leaching by half.