Cover crops - Effects of the mineral nitrogen content of the soil

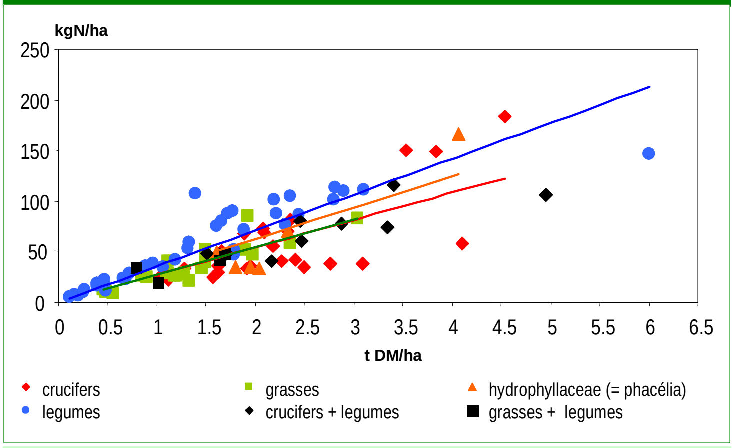
Capacity of cover crops to trap nitrate and to contribute to the nitrogen nutrition of the following crop

The decision to grow a cover crop has two objectives: to limit nitrate nitrogen leaching in the period between crops and to reduce, if possible, the nitrogen fertilisation of the following crop. How do various cover crops compare as nitrate traps? How do they affect the nitrogen fertilisation of the following crop?

Sole or in mixture, legumes are the best for using as nitrogen green manures.

The environmental function of a nitrate trapping cover crop (NTCC) is to absorb as much soil mineral nitrogen as possible before the onset of the drainage period. In fact, during this period (mainly autumn and winter in France), mineral nitrogen can be leached beyond the rooting range of the following crop, and eventually into the hydrographic network. The quantity of nitrogen absorbed by the cover crop is a function of the biomass produced and of the availability of nitrogen in the soil. As shown in *figure 1*, cover crops other than legumes (crucifers, grasses, phacelia) contain more or less the same amounts of nitrogen absorbed into the aerial parts, in spite of quite marked differences in the speed of, and potential for absorption *(tableau 1)*. Due to their capacity to absorb nitrogen from the soil and to fix it from the air, allowing them to continue to satisfy their nitrogen requirements when there is not enough in the soil; legumes have higher nitrogen contents for a given amount of biomass. Crucifer-legume and grass-legume mixtures therefore have intermediate concentrations between those of the species concerned.

Relation between biomass production of the cover crop (t DM/ha) and nitrogen accumulation in the aerial part *(fig. 1)*



For the same levels of biomass, the legumes concentrate more nitrogen in their aerial parts than the non-legumes.

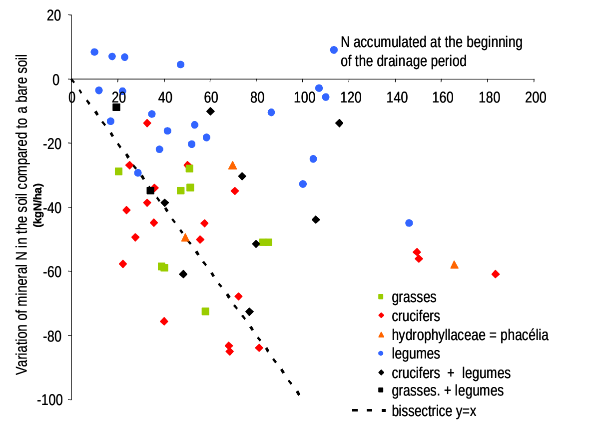
The capacity to « trap » nitrate in the soil

The performance of a cover crop as regards trapping nitrate is calculated when it is destroyed by calculating the reduction in the stock of mineral nitrogen in the soil at the start of the drainage period by difference from a control plot maintained with bare soil. *Figure 2* represents this effect as a function of the nitrogen accumulated in the aerial parts of the cover crop at the time of its destruction. In spite of some scatter of the results around the regression line, we see, for non-leguminous species, a relationship between the two variables. In certain cases, the reduction of the stock of soil mineral nitrogen is significantly greater than the amount of nitrogen absorbed by the aerial plants of the canopy. This can be explained largely by the quantity of nitrogen absorbed by the roots or by immobilisation induced by the presence of the vegetation. Opposite cases can be explained by different phenomena (beginning of drainage before the date of destruction, different mineralisation rates in bare soil and NTCC etc.). Among the non-legumes, the results do not show any big differences between species.

The « nitrate trapping » effect of non-leguminous species is highest.

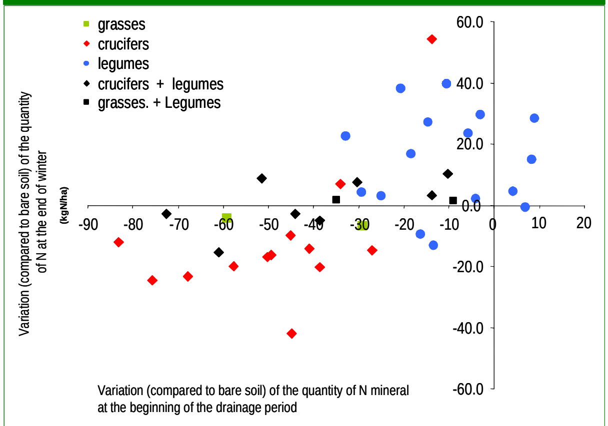
Non-leguminous cover crops have a proven environmental effect, but they do not offer real advantages for the nitrogen nutrition of the following crop.

Relation between the quantity of nitrogen accumulated in the aerial parts at the start of the drainage period and the variation, compared with bare soil, of the quantity of mineral N of the soil at the same time *(fig. 2)*



It is interesting that legumes are less efficient than crucifers or grasses in reducing the stock of mineral nitrogen in the soil before the start of the drainage period.

Relation between the variation (compared to bare soil) of the quantity of N mineral at the beginning of the drainage period, and the variation (compared to bare soil) of the quantity of N at the end of winter. *(Fig 3)*



Non-leguminous species reduce the quantity of mineral nitrogen in the soil at the start of the drainage period more than legumes. But after destruction, the latter return more nitrogen by mineralisation. The effect of the legumes on the end of winter residue is either neutral or positive. The non-leguminous species have either no effect or a negative one.

On the other hand, the behaviour of the legumes is unusual. Although having absorbed roughly similar quantities of nitrogen in their aerial parts, their capacity to reduce the mineral nitrogen stock of the soil is less than that of non-legumes. This is explained partly by the fact that the root system of legumes may be less efficient than that of a grass or a crucifer in absorbing soil mineral nitrogen. (Peas, for example, have shallower and sparser root systems). On the other hand, symbiotic nitrogen fixation takes over when the soil nitrogen is no longer sufficient to satisfy the needs of the plant, which is well before it has absorbed all the mineral nitrogen stock of the soil. Here also, crucifer-legume mixtures have efficiencies in between those of the species concerned.

Return of the trapped nitrogen to the following crop

The supply of soil nitrogen to the following crop is evaluated by measuring the stock of mineral nitrogen present in the soil at the start of the predictive balance (« end of winter residue ») and by estimating the quantities of nitrogen arising from the mineralisation of organic matter (including the residues of the cover crop) between the date of measuring the end of winter residue and the end of absorption by the crop.

In a low-leaching situation, non-leguminous species tend to reduce the end of winter residue, whereas legumes do the opposite.

The end of winter residue is made up of the stock of mineral nitrogen present at the start of the drainage period plus that arising from the mineralisation of organic matter, minus losses (mainly leaching, but also immobilisation, denitrification etc.) until the date of measuring the residue. Compared with a bare soil, a cover crop has a depressive effect on the initial stock of nitrogen and returns more or less nitrogen by mineralisation after destruction. Compared with a bare soil, non-leguminous cover crops either have no effect or else reduce the end of winter residue *(figure 3)*.

In fact they reduce the initial stock quite markedly whilst returning rather little of the nitrogen by mineralisation during the winter, which, if there is not much leaching, results in a fall in the end of winter residue. Conversely leguminous cover crops have a neutral or positive effect on the end of winter residue (figure 3), due to a lower efficiency in reducing the mineral nitrogen stock at the onset of drainage and by a greater mineralisation of the nitrogen originating from the residues after destruction. Crucifer-legumes and grass-legume mixtures have intermediate effects between those of the species concerned.

The quantities of mineral nitrogen absorbed by cover crops are proportional to the biomass produced.

Experiments studied

Numerous experiments have been carried out on catch crops over the last twenty years. The results used in this article come from 17 trials done in France from 1991 to 2008 by ARVALIS – Institut du végétal and by partners from the technical committee of FDGEDA Aube (whom we thank for their collaboration), in the following experimental conditions :

• sowing at the end of August / beginning of September,
• destruction at the end of November / beginning of December at the start of the drainage period,
• measurement of the end of winter residue from early February until mid-March,
• following crops : maize, spring barley, sugar beet,
• various soil types (silts, chalk, gravels).

Their main objective was to compare the capacity of different species to trap nitrate before the start of the drainage period and to return the nitrogen to the following crop. Cover crops of crucifers (mustard, radish, rape), grasses (Italian rye-grass, rye, oats), phacelia and legumes (clover, Fescue, peas, field beans, lentils) were studied. Some trials also included grass-legume or crucifer-legume mixtures.

The table at the end of the article provides information for a wider range of species than those studied in the trials.
Given that certain species have not yet received much study, their qualities may sometimes be deduced by analogy with related and better-known species.

All plant covers have a « nitrate trapping » effect. The most effective in this respect are the crucifers.

The longer the interval between the destruction of the cover crop and the planting of the following crop, the larger will be the contribution of mineral nitrogen from the cover crop residues to the end of winter residue.

The mineralisation of the nitrogen from the cover crop residues begins when they are destroyed. In the 6-9 months which follow, they represent at most 50% of the total nitrogen absorbed. The higher the nitrogen content of the cover crop and the quantity absorbed, the greater is the mineralisation. A fraction of this mineralised nitrogen is present in the measurement of the end of winter residue. The remaining fraction, returned during the phase of rapid absorption by the crop, has to be measured (the MrCI term of the predictive balance method). Table 1 shows the values of MrCI for different situations. The longer the period between the date of destruction of the cover crop and the date of measurement of the end of winter residue, the smaller is the fraction which remains to be mineralised (most of the supply being measured in the residue). This mineralisation contribution from the catch crop does not exceed 30 kg N/ha, this figure being for a pure legume cover crop.

Non-leguminous cover crops reduce quite markedly the stock of N in the soil in autumn, and in spring they return only part of the nitrogen absorbed.

Whether to use a cover crop as a « nitrogenous green manure »

Usually the reduction in the end of winter residue by non-leguminous cover crops is not entirely compensated by the extra mineralisation that they generate in the spring. Hence, planting this type of cover may have no effect on the nitrogen nutrition of the following crop. In some cases (for example low-leaching situations), it may result in the need for extra nitrogen fertiliser for the following crop. Only the use of pure legumes cover crops, or mixtures with other species, contributes positively to the nitrogen nutrition of the following crop, and so, in certain situations, may allow the nitrogen fertiliser dose to be reduced by comparison with a crop sequence without a catch crop.

What effect do cover crops have on PK nutrition ?

Apart from nitrogen, cover crops absorb other mineral elements, in particular phosphorus and potassium. The few experimental data presently available indicate absorptions in the order of 8 to 10 kg P_2O_5 and 30 to 35 kg K_2O per tonne of dry matter produced (crucifers/grasses/composites). After destruction, all the potassium is rapidly returned to the soil (in the same way as harvest residues). For phosphorus, part is rapidly returned (mineral phosphorus in the plant) and the rest is mineralised in variable quantities according to the C/P ratio of the cover crop. The P and K thus liberated compensate for the fall in availability of each in the soil caused by the uptake by the cover crop. They can even increase their bio-availability compared with bare soil by reason of their transfer from depth, where they are taken up in a relatively unavailable state, to the surface, where they are returned in an immediately available form. Given the quantities involved, this effect concerns mainly potassium. Of course it can only affect the crop yield in soils of low availability (exchangeable K_2O values below the so-called “critical” threshold of the crop considered).

Table 1 : Main characteristics of cover crops as regards limitation of nitrate leaching (the NTCC effect) and their contribution to the nitrogen nutrition of the following crop.								
				NTCC effect on the nitrogen fertilisation of the following crop				
					MrCI (kgN/ha) *(5)*			
					Starting date for the balance (RSH) (6)			
					February		April	
	Species	**Rate of absorption of soil mineral nitrogen** (1)	**Potential absorption of soil mineral nitrogen** (2)	**Growth rate of the cover crop** (4)	**November to december**	**January**	**November to december**	**January**
Crucifers	Forage radish	+ + +	+ + (+)	Low or medium	10	15	0	10
				High	15	20	5	15
	White mustard	+ + +	+ + (3)	Low or medium	10	15	0	10
				High	15	20	5	15
Grasses	Italian rye-grass	+ + (+)	+ + +	Low or medium	10	15	5	10
				High	15	20	10	15
	Rye	+ +	+ + +	Low or medium	0	5	0	5
				High	10	10	5	10
	Spring oats	+ +	+ +	Low or medium	0	5	0	5
				High	10	10	5	10
Hydrophyllaceae	Phacelia	+ + (+)	+ + +	Low or medium	0	5	0	5
				High	10	10	5	10
	Sunflower	+ +	+ +	Low or medium	0	5	0	5
				High	10	10	5	10
	Nyger	+ +	+ (+)	Low or medium	0	5	0	5
				High	10	10	5	10
Legumes	Common Fescue	+	+	Low or medium	25	30	20	25
				High	30	30	30	30
	Forage peas	+	+	Low or medium	25	30	20	25
				High	30	30	30	30
	Field beans	+	+	Low or medium	25	30	20	25
				High	30	30	30	30
		+ +	+ +	Low or medium	15	20	10	15
				High	20	20	20	20
		+ +	+ +	Low or medium	15	20	10	15
				High	20	20	20	20

+ = low to medium ; ++ = medium to high ; +++ = high to very high

(1) Capacity of the cover crop to absorb fairly rapidly the nitrogen in the soil in relation to the growth rate. (2) Maximum nitrogen absorption capacity in the soil (related to the maximum growth rate and the capacity to accumulate nitrogen beyond what is strictly necessary for maximum growth rate). (3) Limitation by early flowering (4) A high growth rate is characterised by a biomass of the aerial parts of more than about 3 t DM/ha. (5) MrCI = additional mineralisation due to catch crops (in addition to the measurement of end of winter residue). (6) EWR :End of Winter Residue. (7) Date of destruction of the cover crop.

For example, a radish crop of average development is destroyed in November before planting spring barley. In this case, the predictive balance of the barley will include a surplus supply of 10 kg N/ha due to the mineralisation of the cover crop residues (MrCI) after the date of measurement of the end of winter residue.

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