Mineralisation of organic nitrogen

Effects of soil temperature and moisture content

The rate of nitrogen mineralisation in the soil increases with the temperature. But it is now possible to go further than this basic statement and forecast precisely the correlation with temperatures ranging between 0 and 35°C. In addition, the mineralisation process is faster on a moist soil. But what happens with a dry soil? Data on this subject is becoming more precise.

Even with a dry soil, nitrogen mineralisation can be significant. The study presented here actually demonstrates that in dry soil, mineralisation amounts to over 50% of the maximum nitrogen mineralisation potential.

The calculation of the daily mineralisation of nitrogen in the soil involves two stages:

- First of all, the potential mineralisation rate at the site must be known. It is linked to determined criteria, specific to the soil (clay and organic matter content)
- Secondly, climatic factors (soil temperature and moisture content) must be taken into consideration. This is possible through the concept of normalized time, which involves functions describing the effect of temperature and moisture on mineralisation.

Parameters have been established for those functions, concentrating on conditions in the northern half of France.
We have therefore tried to answer two questions with lab and field trials *(insert 1):*

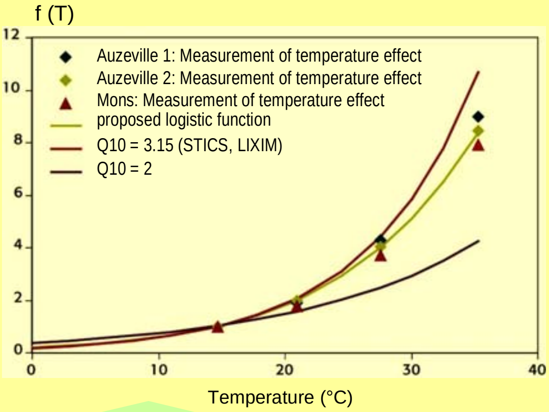
- Have the temperature and moisture content effects been properly described for a wide range of conditions?
- Can the mineralisation forecasting model be wrong in more variable situations, especially for moisture content, like in the case of irrigated crops?

Improvements in forecasting nitrogen mineralisation mainly apply to regions with hot weather conditions.

Reliable forecasting up to 35°C

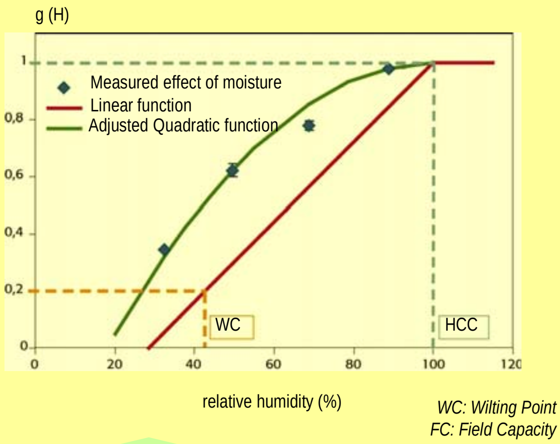
Nitrogen mineralisation increases exponentially as the temperature rises, or at least within a certain range of temperatures. This effect can be modelled using the “Q10” law. Q10 represents the multiplication factor of the mineralisation rate when the temperature rises by 10°C. It varies between 1.5 and over 3 in the international literature. 3.15 is currently being used in the French models to simulate the mineralisation of humified organic matter. In other words, mineralisation rate is more than three times greater when the temperature rises by 10°C.

Impact of temperature on the relative rate of nitrogen mineralisation: measures taken from the three soils being studied (two in the South - Toulouse – and one in the North - Mons -) *(fig. 1)*



When the temperature increases by 10°C, nitrogen mineralisation is multiplied by a factor of 3.15 for temperatures below 25°C. Between 25 and 35°C, mineralisation increases more slowly.
At temperatures above 25°C, the value currently used by French models (Q10 = 3.15) therefore overestimates the effect of temperature on mineralisation. As for models using a Q10 of 2, they are not suited to French conditions.
A new mathematical formula (logistic function) is more appropriate since it helps to forecast mineralisation up to 35°C (the curve fits with the points measured in the lab).

Impact of moisture on nitrogen mineralisation: measures taken from a soil in the South of France (Toulouse) *(fig. 2)*



A quadratic function helps to reproduce the measured effect of moisture content more precisely than a linear function: nitrogen mineralisation is still quite significant on dry soil, at 53% of its potential (observed when the soil is at field capacity), whereas, current reference data indicates that it only reaches 20%. The effect of moisture content on nitrogen mineralisation therefore looks as if it could be much lower than expected. Those results are to be confirmed.

From the lab to the field ➊

Our study was carried out in two stages:

- A lab experiment studied the effects of temperature and moisture content for a wide range of conditions.
- Those conditions were then used to simulate the dynamics of nitrogen mineralisation in the field for various sites, two of which will be used as examples in this paper.
  Three soils were incubated in the lab: two from the INRA Auzeville site (South West) and one from the INRA Mons site (North).
- Four temperatures were tested for each soil: 14, 21, 28 and 35°C.
- Four water content levels were tested for the Auzeville soil: 30, 50, 70 and 90% of FC (field capacity). The other two soils were incubated at 90% of FC in order to study the effect of temperature and reduce the risk of anoxia (absence of oxygen due to soil saturation) and therefore of denitrification (gaseous loss of nitrogen).

The field experiment includes two fields with soil kept bare, the previous crop residue having been removed from the fields:

- Auzeville (INRA Toulouse experimental site). This soil was studied during the incubation process and monitored between July and September 2003;
- Warmeriville (North East) monitored between August 1998 and June 1999.

Regular soil samples (weekly or monthly depending on the site) helped to determine the progressive changes in the soil water and mineral nitrogen profiles on four basic layers, and from that, to deduce, thanks to the LIXIM programme, the net nitrogen mineralisation under field conditions.

However, our study has shown that above 25°C, this 3.15 figure overestimates the effect of temperature on mineralisation *(figure 1)*. A new formula (logistic function) is proving more appropriate for temperatures up to 35°C, without modifying results for the 0-25°C range.
Improvements in forecasting nitrogen mineralisation are therefore expected mainly for regions with hot weather conditions.

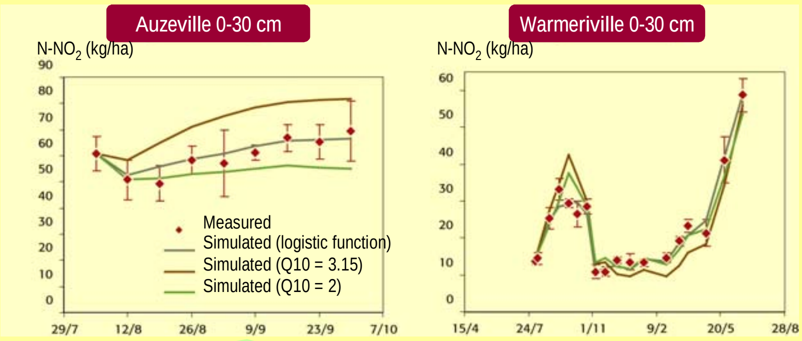
How does soil moisture affect mineralisation?

Having reviewed published data, we consider that the correlation between soil moisture content and speed of nitrogen mineralisation is linear:

- Its maximum value is 1 (maximum mineralisation potential) when moisture content is equal to or above field capacity (FC). In other words, when the soil water retention capacity has been reached or exceeded, the soil mineralises nitrogen within the potential determined by the temperature.
- Its minimum value has been set at 0.2 for a level of moisture content equal to or below the wilting point (WP). When the soil is dry and no longer allows plant growth, mineralisation is equal to or below 20% of its potential.

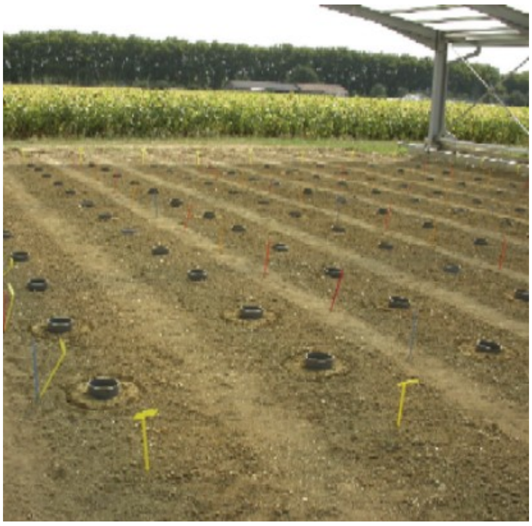
Between those two moisture content levels, the mineralisation rate increases linearly.

Progression of nitrate stocks at the Auzeville and Warmeriville sites, measured and simulated using the LIXIM programme, for different temperature functions: new function proposed by our study (logistical), Q10 = 3.15 function (currently used) and Q10 = 2 function *(fig. 3).*



The measurements made in the field confirm that the temperature and moisture content effects are being properly taken account of in forecasting the progression of nitrate stocks in the soil at both sites. The pertinence of the law of action of temperature rule on mineralisation was verified in the field. Those graphs show that the new forecast is more reliable in the South, where temperatures are higher.

The first phase of the research focused on the measurements made during the incubation process.



Experiment to measure gaseous nitrogen loss (denitrification).

On dry soil

Finally, this study showed that the effect of soil moisture content on nitrogen mineralisation is more limited than expected *(figure 2).* On dry soil (moisture content level corresponding to the wilting point), the level of mineralisation is equal to 53% of the potential observed at field capacity (which is 100%), whereas the initial model gave a value of 20%.

For the soil of the Auzeville (South West) site, this result is however consistent with a recent bibliographical review which shows that the effect of moisture content on mineralisation is subject to tremendous variations according to pedoclimatic conditions. This might indicate that the moisture content function is not universal. Should the lower sensitivity of the Auzeville soil mineralisation to moisture content variations be interpreted as a sign that the microflora is adapting to more frequent stressful conditions in this southern French climate? The question remains unanswered and requires further study and results in order to understand this phenomenon.

Next step: real field conditions

The mineral nitrogen profiles simulated using the LIXIM programme, confirm that using the logistic function for temperature produces a better match with the figures observed *(figure 3 and table 1)*. The more tenuous differences observed at Warmeriville are explained by a much lower average temperature on this site. Therefore, the advantages of the new temperature function are more easily verified in the conditions observed in the South of France (high temperatures) and in summer for all other areas. In addition, this function has the benefit of remaining valid for colder conditions (northern France) and in winter, which makes it more sound. This work also shows that summer mineralisation can remain high, even with a relatively dry soil, because high temperatures compensate for the impact of ground dryness. The same can be said of winter mineralisation, low temperatures being partially compensated for by optimum soil moisture content.

Impact of the choice of temperature function on the quantity of nitrogen mineralised in field conditions simulated with the LIXIM programme, for the two experimental sites studied (Auzeville and Warmeriville) *(tab. 1)*

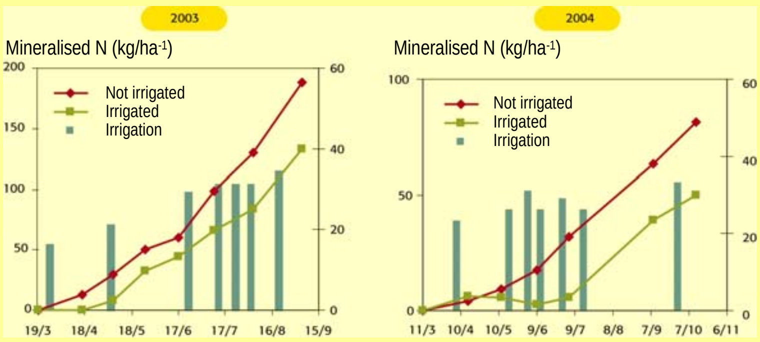
	Average soil temperature (°C)	Average soil moisture content (% dry soil)	Mineralised N (kg / ha)		
			Logistic function	Q10 = 3.15 function	Q10 = 2 function
Auzeville (56 days)	27.9	9.8	45	61	34
Warmeriville (324 days)	10.2	20.3	114	119	122

Care should be taken when soils are saturated. Beyond field capacity, the net nitrogen mineralisation forecast can be inaccurate. Denitrification (gaseous loss of nitrates) can be triggered off when the soil approaches saturation point (winter period or irrigation in summer). This phenomenon, caused by a lack of air circulating in the soil, can lead to significant nitrogen losses, which must be taken into consideration.

Trials led by ARVALIS Institut du végétal in the Drôme region (South East) in 2003 and 2004, highlighted the fact that apparent mineralisation is lower in irrigated fields than in non irrigated fields (figure 4). This could be due to the denitrification process.

This hypothesis was reinforced by an experiment carried out at Auzeville (170 mm of irrigation water), where denitrification was estimated using the balance method with radiolabelled nitrogen (^{15}N) and represented on average 30 kg N/ha over a two month period. In that study, a temporary case of saturation, lasting only a few hours, was enough to cause a loss of several kilogrammes of NO_3 / ha in summer. Over-intensive irrigation is therefore not advisable in summer after the application of mineral fertiliser: irrigation levels should not exceed the seepage capacity of the soil, in order to avoid saturating it, even temporarily. But we also know that in order to reduce the risk of volatilisation, irrigation can help to ensure that the mineral nitrogen contained in fertiliser is well distributed throughout the first centimetres of top soil after spreading on dry soil. Those results reinforce the need for well thought out irrigation management, applying the required water quantity at an appropriate flow.

Impact of irrigation on nitrogen mineralisation, calculated in the field using the LIXIM programme, on the Etoile site (South East) *(fig. 4)*



Apparent mineralisation (calculated supposing that there is no denitrification) is lower in irrigated fields than in non irrigated fields. In reality, irrigation encourages both mineralisation and even more so denitrification, which transforms nitric nitrogen into nitrogen gas (N2O and N2). This phenomenon is triggered when the soil moisture content approaches saturation.

Mathieu VALÉ (INRA)
François LAURENT
f.laurent@arvalisinstitutduvegetal.fr
Bruno MARY, Éric JUSTES (INRA)
Michel MANGIN
m.mangin@arvalisinstitutduvegetal.fr

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Conclusions and prospects

This study has helped to refine the laws of action of temperature and moisture content on the mineralisation of organic nitrogen in the soil and to extend and apply them to a wide range of conditions. A complementary study including varied types of soils (different textures, pH, organic matter content) could help to define more precisely the impact of moisture content for a wider range of environmental conditions.

However, the results obtained from this study show that it is possible to take into account the pedoclimatic conditions in order to forecast the nitrogen mineralisation rate. At the same time, ARVALIS' work also focused on improving forecasting of the potential mineralisation rate, based on the physical, biological and cultural characteristics of the soil. This will be developed in an additional article.

This work must be considered further from a climate change perspective. For example, a 2°C rise in average soil temperature, with the soil moisture regime remaining the same, should result in a rise of 25% in the level of mineralisation.

Regular soil samples were carried out in order to monitor the dynamics of mineral nitrogen on bare soil.