Nutri2Cycle

Transition towards a more carbon and nutrient efficient agriculture in Europe

Circular economy and fertilisation: recovery of livestock effluents on agro-forestry plots.

Presentation of the demonstration carried out with the EARL Manicot (Charente-Maritime) for the Nutri2Cycle project.

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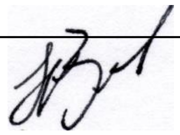

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1 INTRODUCTION

In France, the tradition of agronomic recycling of organic effluents includes the recovery of NPK fertilising elements in the fertilisation balance at farm level, or even at plot level. However, their use represents only a fraction of crop nutrition.
With the growing trend towards recycling organic waste collection and carbon storage to limit climate change, policy measures in France regarding the return of organic matter to the soil need to be strengthened: in 2018, the French government proposed to make the agricultural sector a driver of the circular economy by recovering all bio-waste by returning it to the soil (MTES, 2018).
At the same time, a new European regulation on fertilising materials (EU regulation 2019/1009 of 05/06/2019) puts the emphasis on the substitution of fertilising materials derived from industrial synthesis or extraction for reasons of economic independence, also invoking the principles of the circular economy.

With this replacement in mind, the focus has been on the farm's agro-residues, the recycling of which within the farm perfectly illustrates the definition of the circular economy. Livestock effluents are good examples of bio-sourced materials known as substitutes for synthetic fertilisers (MAROIS, 2019). Although the agronomic recycling of livestock manure was the subject of major development work in France between 1993 and 2006 (IDELE, 2008), the current challenge is to reposition organic inputs as significant components of fertilisation.

The emergence of the new European regulation has been accompanied by a number of European research and development projects looking at the use of fertilising materials derived from recycling.
This is the case of the Nutri2Cycle project (Horizon 2020 programme - project no. 773682), which is looking at the cycling of NP fertilising elements and carbon between agricultural and agro-processing centres.
As part of this project, the Chamber of Agriculture was asked to demonstrate the situation and possible changes in cycling on a farm combining livestock, crops and agroforestry.

Our demonstration had two aims:
1 - Highlighting and understanding the fertilising effect of effluents, in particular the nitrogen effect, on an agroforestry plot;
2 - Assess the effect of agroforestry establishment on carbon storage.

To do this, we monitored an agroforestry plot on a farm with a livestock and crop production unit at Saint Martial sur Né, in the Charente-Maritime département (17), for four years, from 2019 to 2022, using a monitoring protocol based on different zones established according to effluent spreading and the agroforestry situation.

This protocol combines :
a - an initial and final soil analysis, with mineralisation kinetics and organic matter fractionation;
b - Analytical characterisation of effluents ;
c - monitoring crop development using remote sensing.

The results obtained during the demonstration will be discussed with farmers to determine which elements of their fertilisation system need to be changed to move from recycling organic matter to optimum fertilisation management.

2 STUDY SETTING: EARL MANICOT (SAINT MARTIAL SUR NE).

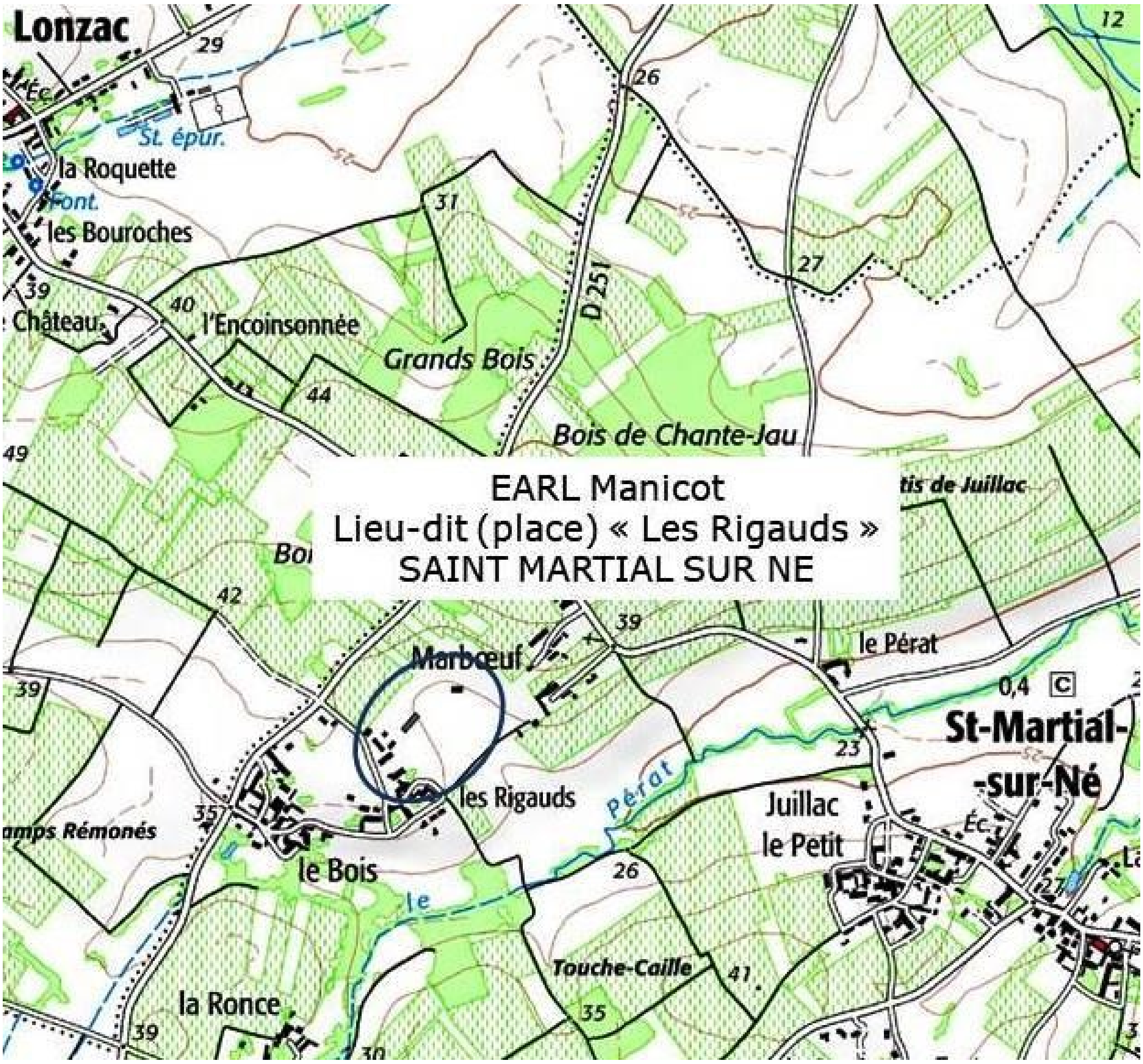


Figure 1: Geographical location of the farm

(Source: IGN, SCAN 25® - Charente-Maritime Chamber of Agriculture, 2019)

The Manicot family farm is mainly devoted to fattened goose rearing, with their processing into food and ready meals and direct sales.

Élevage d'oies
Foie gras
MANICOT

http://www.manicot.fr

With a UAA of 93 ha, this farm includes the following workshops:

Figure 2: Workshops on the Manicot farm

The farm has a UAA of 93 ha, with a 7 ha exercise area for the geese, planted with Dactyl and Fescue, and a crop production area of 86 ha used to feed the geese and for sale.

2.1 The agroforestry system.

Since 2002, EARL Manicot has been committed to improving the autonomy of its farms. and the transformation towards a more circular economy:

- Abandonment of winegrowing and development of cereal and protein crops for self-sufficiency in livestock feed;
- Wastewater treatment using reed beds;
- Wooden buildings ;
- Use of residual biomass for heating (wood and goose fat);
- Thermal and photovoltaic solar panels...

In 2010, EARL Manicot launched its agroforestry programme with

1. 5 ha of exercise area planted with traditional agroforestry to increase comfort animals (shading) and facilitate grassland production;
2. 8 ha of arable crops planted as linear coppice in strips 6 m wide and 36 m apart, for the production of biomass energy;
3. 380 linear metres of agroforestry on a drainage ditch at the outlet of the water treatment basin;
4. 570 linear metres of pollarded agroforestry to improve the landscape.

Hardy species include Hornbeam, Oak, Cherry, Dogwood, Maple, Ash, Hazel, Walnut, Pear, Apple, Blackthorn, Elm, Privet and Walnut.

Given the farm's interest in energy self-sufficiency, it is highly likely that, in the medium term, coppicing hedgerows within parcels will become a farm workshop in its own right.

From 2019 to 2022, in consultation with the farmers, we have set up a monitoring system for fertilisation programmes incorporating livestock effluent on the 8-hectare plot known as "La terrière-Champ", which is planted with linear coppice and cultivated with arable crops.

2.2 Production of livestock effluent.

The annual flock of 4,500 geese generates manure and slurry.

Normally, effluent is recycled on the farm, which is the case for most mixed farming and livestock systems: it is spread on plots far enough away from the town for reasons of neighbourliness, mainly on triticale.

Figure 3: Location of agroforestry zones
(Source: Chamber of Agriculture 17, 2019)

Figure 4: Rhizophyte pond, rangeland and agroforestry plantation in 2015.
(Source: EARL Manicot, 2015)

Figure 5: Intra-parcel linear coppicing in 2018
(Source: EARL Manicot, 2018)

Figure 6: Intra-parcel linear coppicing in 2019
(Source: Chamber of Agriculture 17, 2019)

In terms of equipment, the farm has its own slurry tanker and uses the manure spreader provided by its CUMA. Spreading manure therefore requires a little more organisation beforehand.

However, the two types o f effluent - slurry and manure - do not have the same properties fertilisers.

The demonstration operation undertaken with the farm should provide a better understanding of the effectiveness of the two types of effluent in improving their use as fertiliser.

3 MATERIALS AND METHOD: DEMONSTRATION DEVICE

3.1 Study area: the "La Terrière-Champ" plot

This parcel of more than 8 ha contains an area with hedges - West and South - and an open field area - East and North.

Figure 7: The "La Terrière-Champ" plot in March 2019.
(Source: Chamber of Agriculture 17, 2019)

It should be noted that the open field area to the north includes a site planted with vines.
until 2017.

The demonstration system divides the plot into four zones - from south-west to north-east :

1. An agroforestry strip A (0.956 ha), which will be sprayed twice in 2019 and 2021;
2. An agroforestry strip B (0.971 ha) which will be spread twice in 2020 and 2021;
3. An agroforestry zone C (1,665 ha) with conventional fertilisation using synthetic or extracted fertilisers ;
4. An open field zone D (4,744 ha) with conventional fertilisation.

Figure 8: Demonstration system on the "La Terrière-Champ" plot
(Source: Chamber of Agriculture 17, 2019)

It should be noted that the area under agroforestry influence - which represents 3.6 ha - contains 6 hedgerow lines for a total of 975 linear metres (110 to 220 m segments).

Figure 9: Intra-parcel hedgerow lines at "La Terrière-Champ" (in m).
(Source: Chamber of Agriculture 17, 2019)

For the sake of consistency, we will keep this configuration for the period 2019 - 2012.
2021.
It should be noted, however, that the agroforestry situation changed over the monitoring period:

- Establishment of new hedge segments in 2020 ;

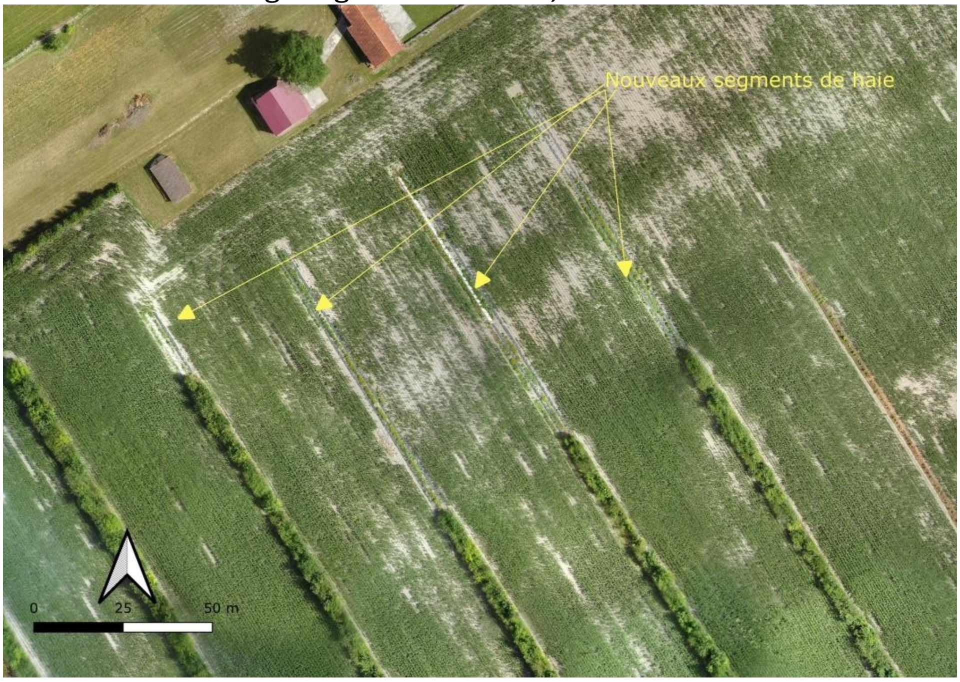


Figure 10: Hedge planting on the "Terrière-Champ" plot on 29/06/2020.
(Source: Chamber of Agriculture 17)

- Cutting of an initial section for wood-energy harvesting 2021 ;

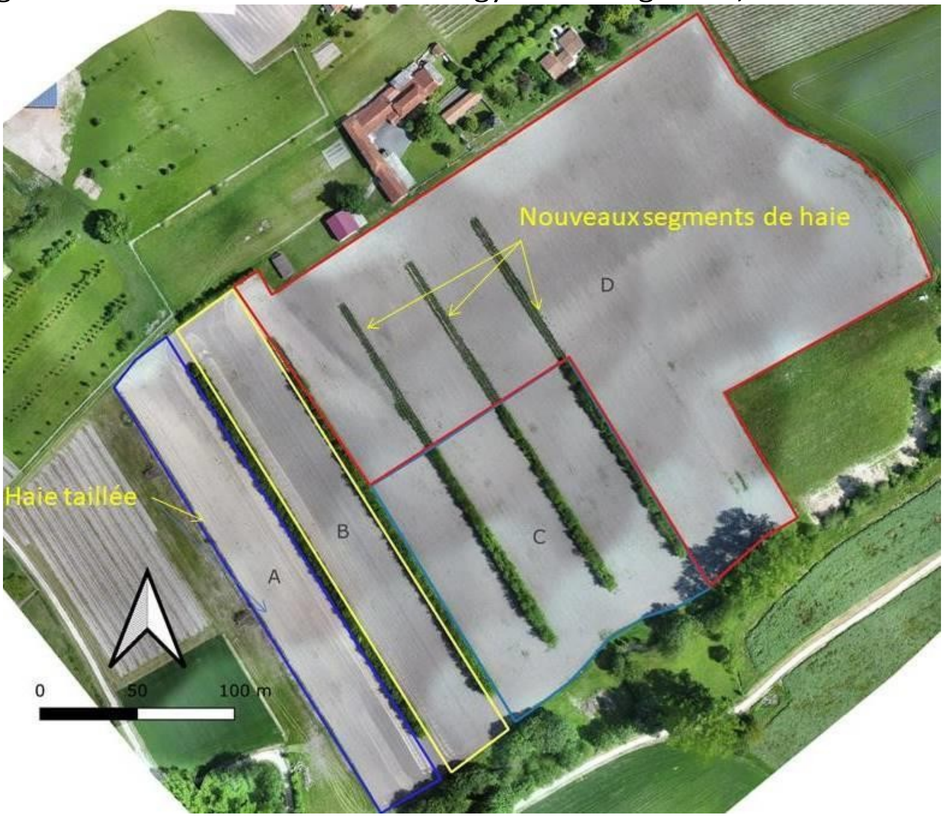


Figure 11: The "Terrière-Champ" plot on 27/05/2021.
(Source: Chamber of Agriculture 17)

- Cutting of a second segment in 2022 ;

Figure 12: The "Terrière-Champ" plot on 07/06/2022.
(Source: Chamber of Agriculture 17)

1er segment coupé en 2021 en cours de repousse
2ème segment coupé en 2022

Figure 13: Location of hedge segment cuttings in May 2022.
(Source: Agrobjectif and Chambre d'agriculture 17)

3.2 Itineraries of fertilization and protocols of monitoring protocols for the 2019 - 2022 campaigns.

Fertilization itineraries by zone were applied by the farmers for the different zones:

Bands/ Zones	Surface (ha)	2019	2020	2021	2022
A	0.956	Slurry + fertilisation mineral	Mineral fertilisation	Slurry + fertilisation mineral	Slurry + fertilisation mineral
B	0.971	Mineral fertilisation	Manure + fertilisation mineral	Slurry + fertilisation mineral	Mineral fertilisation
C	1.665	Fertilisation mineral	Fertilisation mineral	Fertilisation mineral	Fertilisation mineral
D	4.744	Fertilisation mineral	Fertilisation mineral	Fertilisation mineral	Fertilisation mineral

The simplified technical itineraries for the 2019 soft winter wheat (var. Izalco), 2020 maize (var. Vestas), 2021 maize (var. RGT XXACT) and 2022 soft winter wheat (var. IZALCO) campaigns on the "La Terrière-Champ" plot are presented on the following pages, along with the associated monitoring protocols.

These protocols include:

- effluent sampling for agronomic analysis;
- soil samples for agronomic and biological analysis;
- remote sensing images taken by drone to monitor vegetation, combined or not with ground measurements of the nitrogen situation using manual sensors.

For the first monitoring campaign - 2019 - we have gathered information on effluents and soils to establish a baseline situation, and we have tested monitoring using remote sensing and a hand-held sensor.
We also carried out observations and plant sampling before harvesting.

Monitoring of the 2020 campaign was less extensive, mainly because of reduced communication with farmers.

- ✓ We took soil samples in December 2019 to carry out mineralisation kinetics for the two strips under organic fertilisation A and B -.
  measurement of an after-effect of slurry on A and an effect for the 2021 campaign for B. But a menu error at the laboratory deprived us of the results.

- ✓ We repeated the soil sampling with manure application in September 2020 to assess nitrogen mineralisation a posteriori on B.

For the 2021 season - the second maize season - we have carried out more intensive monitoring work, in particular with more remote sensing measurements and ground sensors.
In addition, better communication with the farmers has enabled us to carry out plant sampling work for a more detailed assessment of the results of the fertilisation programme.

The fourth monitoring campaign, in 2022, was not included in the initial programme. However, we carried out two drone surveys for remote sensing, followed by soil sampling in the summer of 2022.

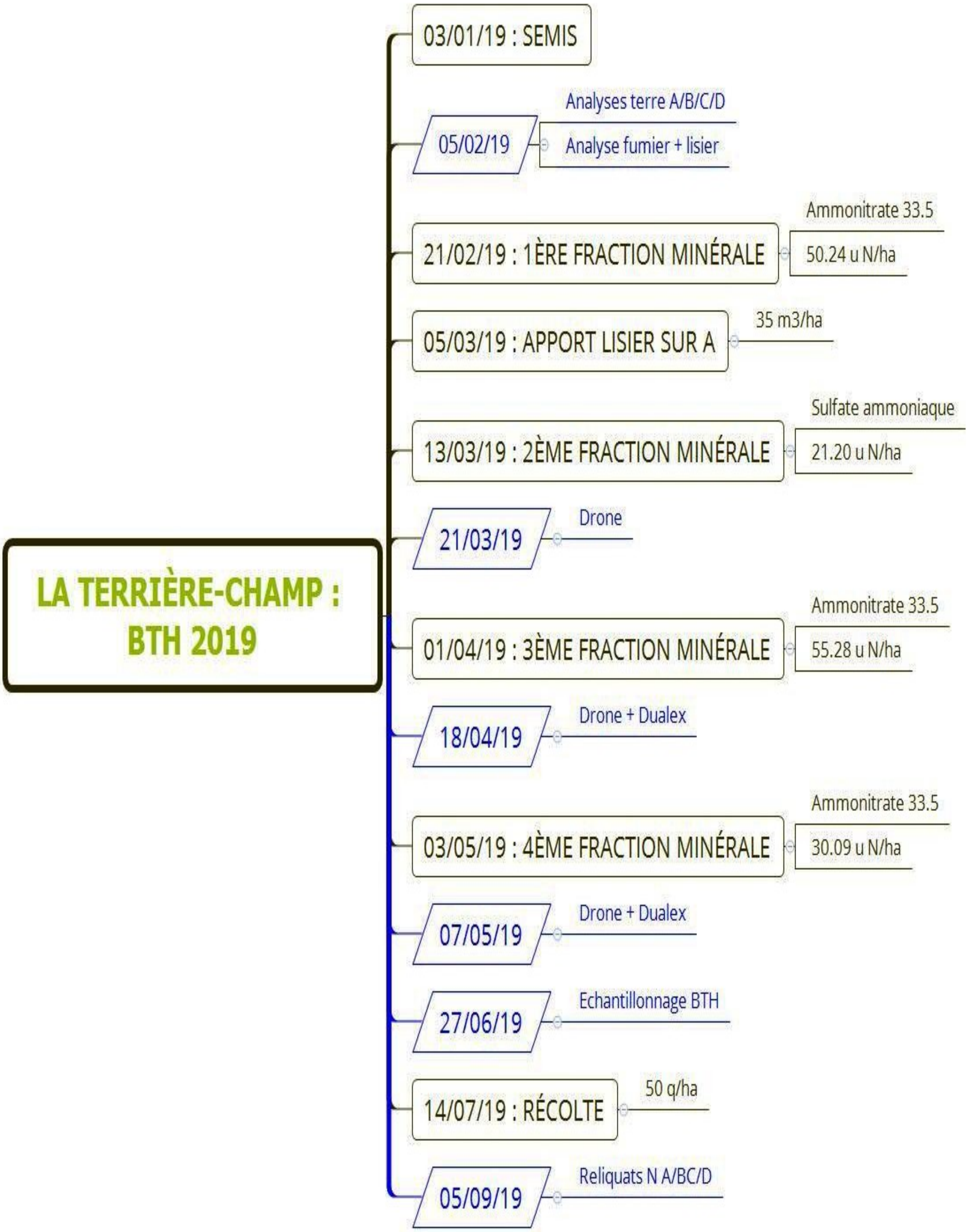


Figure 14: Technical itinerary (simplified) and monitoring protocol for the wheat crop 2019 winter tenders on the "La Terrière-Champ" plot

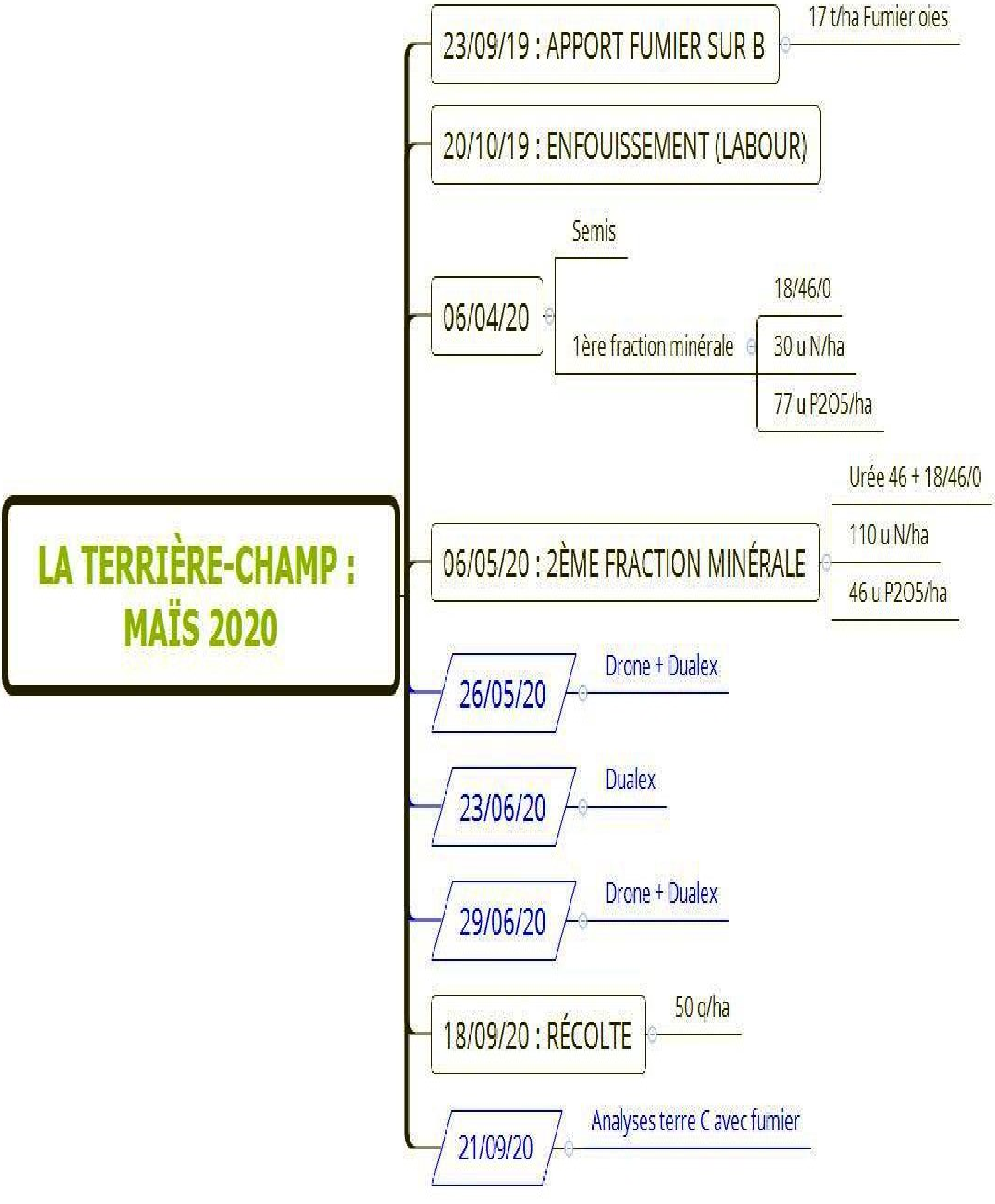


Figure 15: Technical itinerary (simplified) and monitoring protocol for the 2020 maize crop on the "La Terrière-Champ" plot.

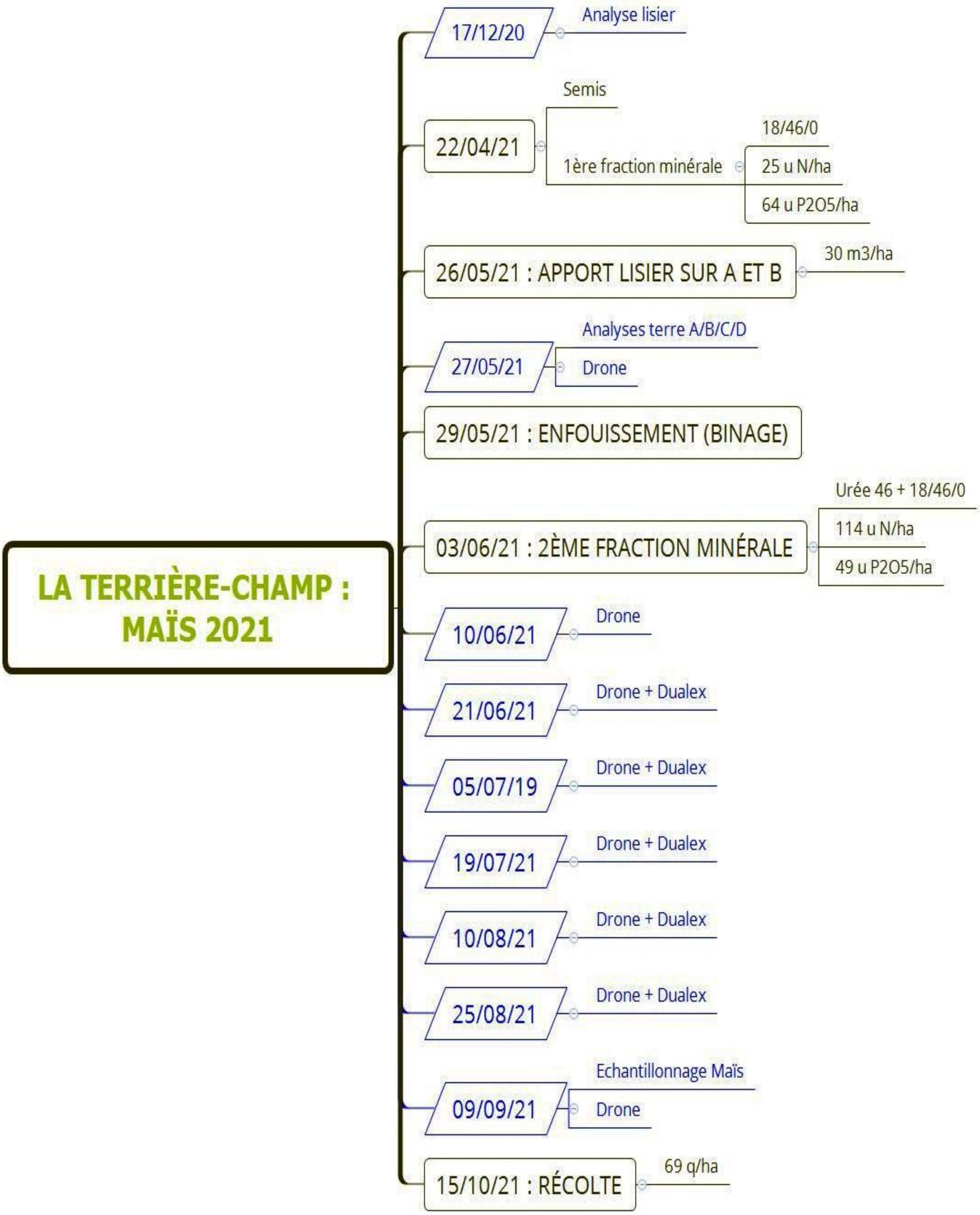


Figure 16: Technical itinerary (simplified) and monitoring protocol for growing Maize 2021 on the "La Terrière-Champ" plot.

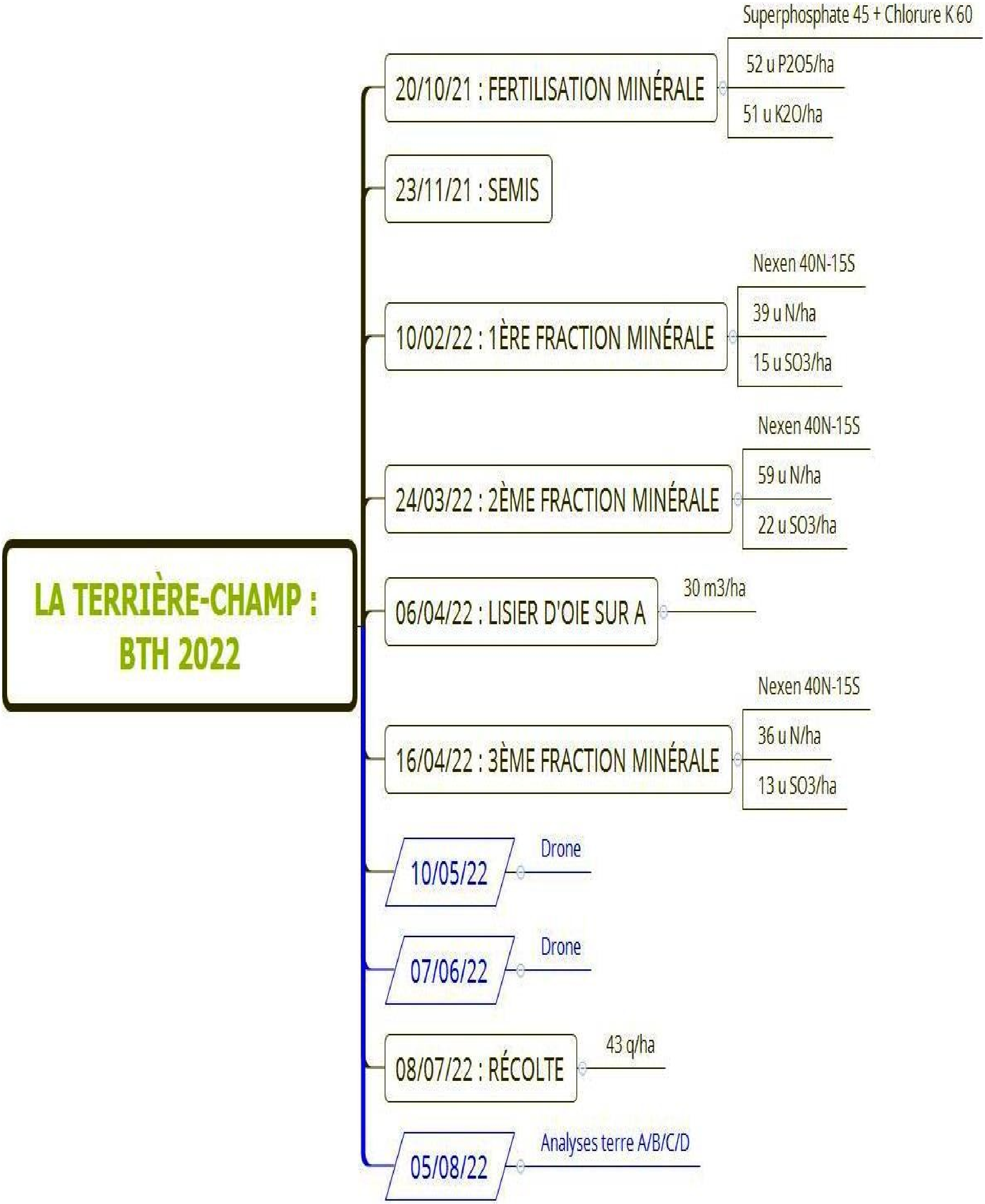


Figure 17: Technical itinerary (simplified) and monitoring protocol for the wheat crop winter tender 2022 on the "La Terrière-Champ" plot

The effluent and soil analyses were carried out by the AUREA Agro-sciences laboratory and the Celesta laboratory.

3.3 Innovative agronomic monitoring

3.3.1 Assessment of soil nitrogen fertility using mineralisation kinetics.

The mineralisation kinetics protocol is a simplified version of the French standard FD U44-163 designed in 2008 by the LCA laboratory - currently the AUREA Agro-sciences laboratory (BERNARD and GUILLOTIN, 2013). It is used to measure the proportions of soil organic nitrogen that are mineralised over a certain number of days of incubation: it is an assessment of the potential quantity of nitrogen supplied by the soil.
A modification was made in 2014 (BERNARD and GUILLOTIN, 2015): the measurement dates were repositioned on the basis of equivalences between crop cycles and incubation days for three significant crop cases in the Charente-Maritime department. Depending on climatic conditions, a cycle corresponds to 10 days (climatic situation unfavourable to mineralisation) to 30 days (very favourable conditions) with a median value of 20 days of incubation.
Under certain assumptions (depth, bulk density) concerning the horizon of mineralisation, we can evaluate the soil nitrogen input in kg N/ha.
We have already tested this method in agronomic monitoring in 2018 (BERNARD AND LOMBARD, 2019).

3.3.2 Soil carbon status and level of biological activity

We chose to assess the carbon situation in the soil using the organic matter fractionation protocol proposed by INRAe (underwater sieving method). The granulometric fractionation of organic matter makes it possible to isolate the humified part of the organic matter (fine fraction < 50 micrometres) from the labile part (coarse fraction > 50 micrometres). The humified fraction of organic matter corresponds to the "inert" and stabilised part, making up the "stable humus" fraction of the clay-humus complex. It evolves very slowly. The labile fraction of organic matter corresponds to the pool of organic matter undergoing transformation. Its carbon will evolve through mineralisation in the form of CO_2 and its nitrogen in the form of mineral nitrogen.
We consider that carbon storage in the soil can be assessed on the basis of the fraction of carbon in the soil.
humified organic matter.

We chose to measure microbial biomass (fumigation/extraction method derived from standard NF ISO 142 40-2) to assess soil biological activity.
Soil organic matter is made up of carbon, some of which is in microbial form: microbial biomass (MB). Measuring BM provides an indication of the size of the soil's microbial compartment. This living fraction of soil organic matter represents the quantity of
The "living carbon" contained in soil microbes, mainly bacteria and fungi, reacts quickly to changes in cultivation practices (ploughing, organic inputs, residue restitution, etc.). It is both a transforming compartment (soil mineralisation potential) and a compartment (storage) capable of trapping elements such as nitrogen.

3.3.3 Monitoring crop development using remote sensing.

The Charente-Maritime Chamber of Agriculture has previously carried out methodological development work (DE PIERREPONT and BERNARD, 2016) and application work (BERNARD and LOMBARD, 2019) for the use of remote sensing images in agronomic monitoring.

Figure 18: Soil profile and soil sample on the "La Terrière-Champ" plot, 2019
(Source: Chamber of Agriculture 17)

Figure 19: Drone and multispectral camera
(Source: Chamber of Agriculture 17)

The raw images were taken with a multispectral camera model multiSPEC 4C (version MSP11) from Airinov, carried by an eBee drone from SenseFly.
This camera records the reflectance of four wavelengths: 550 nm (green), 660 nm (red), 735 nm (red "limit") and 790 nm (near infrared). The images are processed with Pix4Dmapper pro © software to obtain the four initial reflectance maps, in the form of georeferenced images.

The basic images are interpreted as vegetation indices, algebraic combinations of reflectance values, which provide useful information about the vegetation (SRINIVAS et al, 2004 and CHEREL, 2010 cited by De Pierrepont and Bernard, 2016).

In particular, we will be using :

- Estimation of plant biomass on the ground using the NDVI index (ROUSE et al, 1972 cited by DE PIERREPONT and BERNARD, 2016);
- Assessment of the crop's level of nitrogen nutrition, modelled using the MTCI, MNLI, MSAVI2 or WDRVI indices (BERNARD and LOMBARD, 2019).

The NDVI is in the range [-1; 1]. Plant biomass on the ground is reported from value 0.2 and its density is positively correlated with the NDVI index over the interval [0.2 ; 1].
However, the index saturates at high biomass values.

3.3.4 Monitoring crop nitrogen nutrition using manual sensors.

Analysis of remote sensing images can be supplemented by ground-based measurements of plant nitrogen content, using the Dualex Scientific hand-held sensor (Force A company). The device measures chlorophyll and polyphenol levels in leaves.
For each measurement, the sensor displays the levels of chlorophyll and flavanols measured by fluorescence and calculates a nitrogen status index called NBI defined by the ratio of chlorophyll to flavanols.

Based on internal work, we use the following measurement scale:

1. NBI < 20 ⇒ crop needs nitrogen input;
2. 20 ≤ NBI < 30 ⇒ the crop's N level is balanced ;
3. NBI ≥ 30 ⇒ "Luxury" nitrogen consumption.

This device has a GPS receiver for locating measurements with a GIS tool.

Figure 20: Dualex sensor.
(Source: Chamber of Agriculture 17)

4 RESULTS: MONITORING THE RECYCLING OF ORGANIC EFFLUENTS IN AN AGROFORESTRY SITUATION FROM 2019 TO 2021.

4.1 Characterisation and quantification of effluents.

4.1.1 Agronomic value of effluent.

Table 1: Agronomic characterisation of livestock effluent from EARL Manicot.

Effluents	Slurry			Manure	Units
	05/02/2019	**17/12/2020**	***Average***	**05/02/2019**	
MS	3.5	2.2	*2.85*	19.1	% MB
MO	2.18	1.78	*1.98*	11.02	% MB
	62.55	79.56	*71.055*	57.71	% DM
N total	0.18	0.13	*0.155*	0.45	% MB
	5.2	5.9	*5.537*	2.36	% DM
Mineral N	0.04	0.06	*0.05*	0.05	% MB
	1.18	2.72	*1.95*	0.24	% DM
Organic N	0.14	0.07	*0.105*	0.4	% MB
	4.03	3.04	*3.535*	2.11	% DM
P2O5	0.11	0.1	*0.105*	0.24	% MB
	3.07	4.66	*3.865*	12.58	% DM
K2O	0.1	0.1	*0.1*	0.46	% MB
	2.93	4.62	*3.775*	24	% DM

DM: dry matter, in % gross matter - OM: organic matter.

NPK content on the crude is fairly low: less than 0.5% per element.
In its current state, this effluent does not qualify as a commercial fertiliser. But if they are

recycled on the farm, they do have a fertilising value.

4.1.2 Quantifying effluent production

The assessment of effluent stocks by cross-referencing the estimate made by the *Clé de sol* fertilisation software, the time taken by the animals to move around and the farmers' estimates produced a result of :

145 m3 of slurry and 25 tonnes of manure per year.

If we consider the estimated quantities and the results of the analyses, the effluent deposit represents a theoretical fertilising potential of :

N	P2O5	K2O
338 kg	**212 kg**	**260 kg**

4.1.3 Trace element content of effluent

Table 2: Trace element content of livestock effluent from EARL Manicot.

ETM (mg/kg MS)	**Slurry**		**Manure 2019**	***Reference thresholds*** *Order of 01/04/20 (LEGIFRANCE 2020)*
	2019	**2020**		
Cd	0.12	0.333	0.288	*1*
Cr	2.92	1.93	3.64	*120*
Cu	76.4	36.2	29.8	*300*
Hg	0	0	0.011	*1*
Ni	4.32	5.88	2.44	*50*
Pb	2.18	1.46	2.27	*120*
Zn	547	394	150.4	*800*

Compared to the proposed reference thresholds, the levels are quite low - less than 33% - apart from zinc - less than 68% - and no overruns.

A)

B)

Figure 21: Study areas A and B after manure application, on 27/05/21.
(Source: Chamber of Agriculture 17, 2021)

4.2 Condition and functioning of the soil on the "La Terrière-Champ" plot.

Three samples of soil were taken from the four study areas (A, B, C, D) for analysis on 05/02/19 (initial situation), 27/05/21 and 05/08/22 after the 2022 growing season.

4.2.1 Textural situation and physico-chemical characterisation: proposal for a soil profile

Table 3: Textural and physico-chemical characterisation of the "La Terrière- Champ" plot.

Zone		A%	L%	S%	Texture type[1]	pH	Total limestone (%)	CEC (meq/100g)
A	**2019**	40.9	42.8	16.3	AL	8.2	29.1	32
	2021	37.4	43.6	19		8.3	31.5	29
	2022	-	-	-	-	8.2	48.0	21.6
B	**2019**	42	38.3	19.7	AL	8.1	35.9	29.6
	2021	53.8	36	10.2	ALO	8.3	11.8	36.9
	2022	-	-	-	-	8.2	7.1	36.8
C	**2019**	51.1	35.2	13.7	ALO	8.1	16.3	34.9
	2021	53.3	35.4	11.3		8.3	14	33
	2022	-	-	-	-	8.2	25.8	28.3
D	**2019**	46.8	41.4	11.8	ALO	8.2	16.1	32
	2021	51.5	33.6	14.8		8.5	19.6	34.2
	2022	-	-	-	-	8.2	22.2	32.5
Parcel		***48***	***38***	***14***	***ALO***	***8.3***	***21.0***	***32.3***

1 according to JAMAGNE, 1967 quoted by BONNEAU and SOUCHIER, 1979.

The texture has a high proportion of clay and is classed as heavy clay. These soils have a high water retention capacity, and are very plastic and sticky when wet - they are known locally as "*amorous*" soils.
These soils tend to be basic - the pH is very even - with a significant presence of limestone - more than 15% of total limestone - which places the plot in the carbonate soil family.
This soil has a high chemical fertility potential - high CEC value.

Field investigations, with auger boring, supplementing analytical data indicate a soil profile of clayey redoxic Calcosol type (BERNARD, 2014). It is referred to as "Champagne" in vernacular terminology.

This is a soil with two pedological horizons:

1. The upper horizon, the main site of biological activity, with an average thickness of 20 cm and around 10% coarse elements;
2. The intermediate horizon, 30 to 40 cm thick, on which 50 to 70% of the soil depends. water capacity.

This is an interesting type of soil from the point of view of chemical fertility, but it is difficult to work in wet conditions and is less accessible than other types of soil.

It should be noted that the slope of the plot limits the potential for waterlogging or hydromorphy, with soil water circulating slowly across the land from north to south.

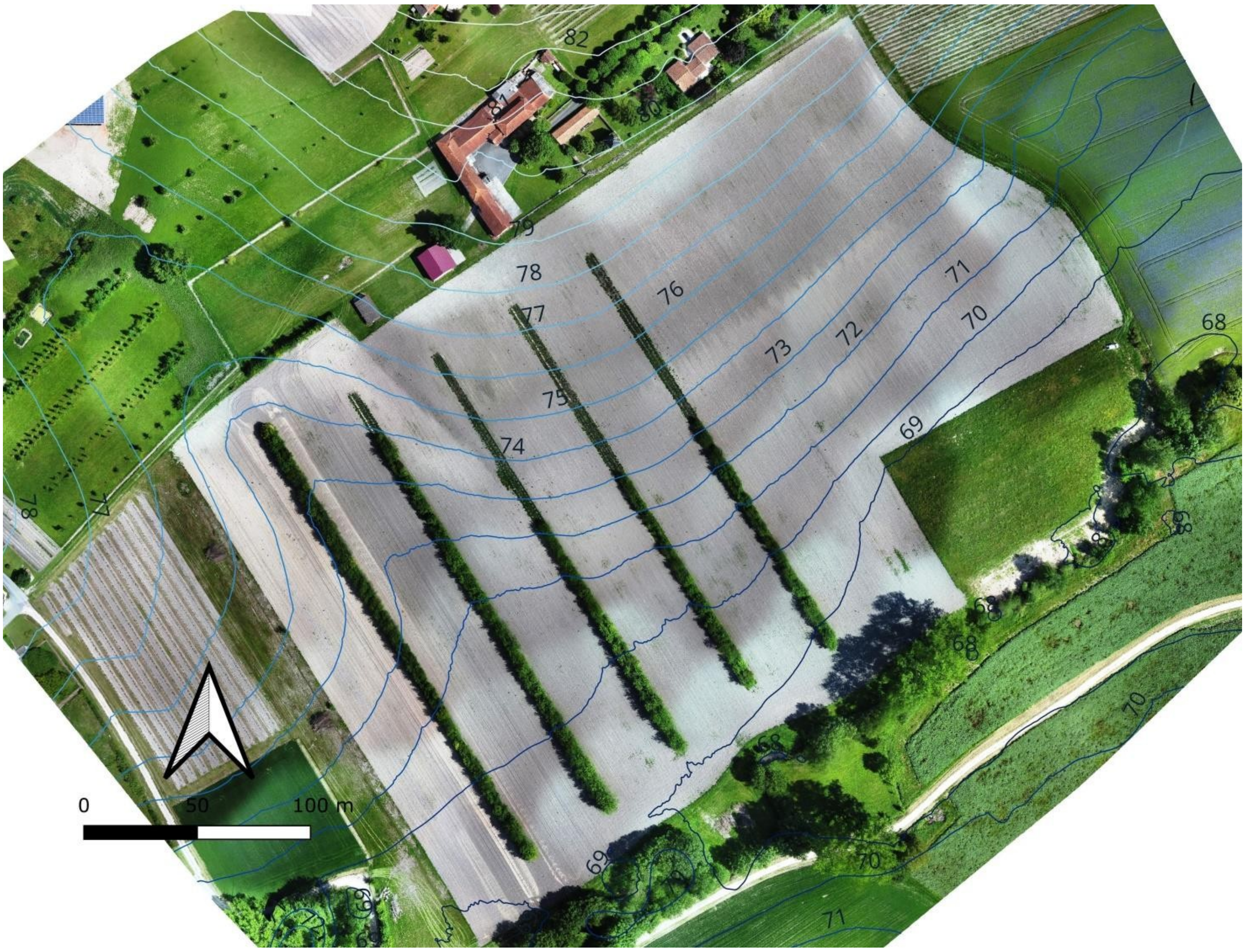


Figure 22: Slope of the "La Terrière-Champ" plot
(Source: Chamber of Agriculture 17, 2021)

N.B.
For calculating estimates of elementary soil stocks, in particular carbon (C) and nitrogen (N), we will use the following assumptions concerning the study areas and their floors :

Zones	A	B	C	D
Surface area (ha)	0.956	0.971	2.13	4.256
Plough horizon thickness (cm)	20	20	20	20
Mass per unit area (t/ha)	2700	2800	2600	2600
Coarse matter content EG (%)	10	10	10	10

These values were defined on the basis of our field investigations and were consolidated with modelling results from t h e INRAe STICS © tool.

4.2.2 Agronomic situation of the soil.

Table 4: Agronomic characteristics of the "La Terrière-Champ" plot

	A			B			References for calcosol redox clay[1]
	2019	**2021**	**2022**	**2019**	**2021**	**2022**	
OM (%)	2.6	2.9	2.3	3.2	3.4	3.1	6
Total N (%)	0.169	0.215	0.138	0.178	0.231	0.183	0.3
C/N	9.1	7.8	9.6	10.5	8.5	9.8	10.5
CaO (g/kg)	16.49	17.39	16.35	16.08	18.78	18.63	-
P2O5 JH (g/kg)	0.315	0.318	0.236	0.277	0.476	0.641	0.187
K2O (g/kg)	0.572	0.51	0.451	0.524	0.584	0.637	0.502
MgO (g/kg)	0.249	0.263	0.205	0.245	0.331	0.348	0.264
Na2O (g/kg)	0.035	0.056	0.04	0.031	0.062	0.054	0.052
	C			D			References for calcosol redox clay[1]
	2019	**2021**	**2022**	**2019**	**2021**	**2022**	
OM (%)	2.8	3.1	2.7	4	2.9	2.8	6
Total N (%)	0.171	0.184	0.159	0.202	0.175	0.178	0.3
C/N	9.3	9.8	10.0	11.4	9.7	9.2	10.5
CaO (g/kg)	18.56	18.77	17.37	16.91	18.18	17.88	-
P2O5 JH (g/kg)	0.507	0.438	0.298	1.482	0.596	1.064	0.187
K2O (g/kg)	0.679	0.542	0.693	1.447	0.808	1.188	0.502
MgO (g/kg)	0.333	0.315	0.270	0.443	0.354	0.409	0.264
Na2O (g/kg)	0.034	0.049	0.032	0.038	0.045	0.036	0.052

Colour interpretation: Low level - Desirable level - High level (depending on the laboratory).
[1] according to BERNARD, 2014.

The level of phospho-potassium stocks is quite high, higher than the average level observed in Champagne soils - particularly for phosphorus.
The Mg and Na elements are at a sufficient level, closer to the average.

The level of organic indicators is lower than in the case of the standard profile.
shows that the soil is quite active from a biological point of view.

We can propose an assessment of soil nitrogen fertility based on mineralisation kinetics data established for each study area.
The measurements are expressed as a percentage of mineralisation of the soil's initial nitrogen content. We also propose calculating the equivalent in kg of mineralised nitrogen/ha, under the assumptions concerning the surface mass of the upper horizon and the coarse element content.

Table 5: Soil nitrogen mineralisation kinetics for the "La Terrière- Champ" plot

Zone	Period	% of nitrogen mineralised after incubation			
		7 days	17 days	27 days	37 days
A	2019	0.3	0.7	1.4	1.3
	2021	0.52	1.36	2.05	2.64
	2022	0.1	0.6	0.8	1
B	2019	0.2	0.5	1.2	1.5
	2021	0.06	0.26	0.57	0.74
	2022	0.1	0.2	0.2	0.3
C	2019	0.4	0.9	1.7	2.3
	2021	0.49	0.94	1.2	1.35
	2022	0.2	0.3	0.4	0.4
D	2019	0.5	0.9	1.3	1.9
	2021	0.25	0.68	0.92	1.15
	2022	0.2	0.4	0.5	0.7
Zone	Period	**Nitrogen equivalent released after incubation (kg/ha)**			
		7 days	17 days	27 days	37 days
A	2019	12.8	29.9	59.9	55.6
	2021	27.8	72.7	109.6	141.1
	2022	3.4	20.1	26.8	33.5
B	2019	11.7	29.4	70.5	88.1
	2021	3.5	15.1	33.0	42.9
	2022	4.6	9.2	9.2	13.8
C	2019	18.2	40.9	77.2	104.4
	2021	20.6	39.6	50.5	56.9
	2022	7.4	11.2	14.9	14.9
D	2019	23.0	41.5	59.9	87.6
	2021	10.5	28.6	38.8	48.4
	2022	8.3	16.7	20.8	29.2
		7 days	14 days	21 days	28 days
Soil + manure 2020[1]	% N mineralised	0.3	0.4	0.5	0.5
	Equivalent kg/ha	23.4	31.2	39.1	39.1

[1] The protocol used by the laboratory is a variant with an overall incubation time of 28 days. and measurement dates different from those of the main protocol.

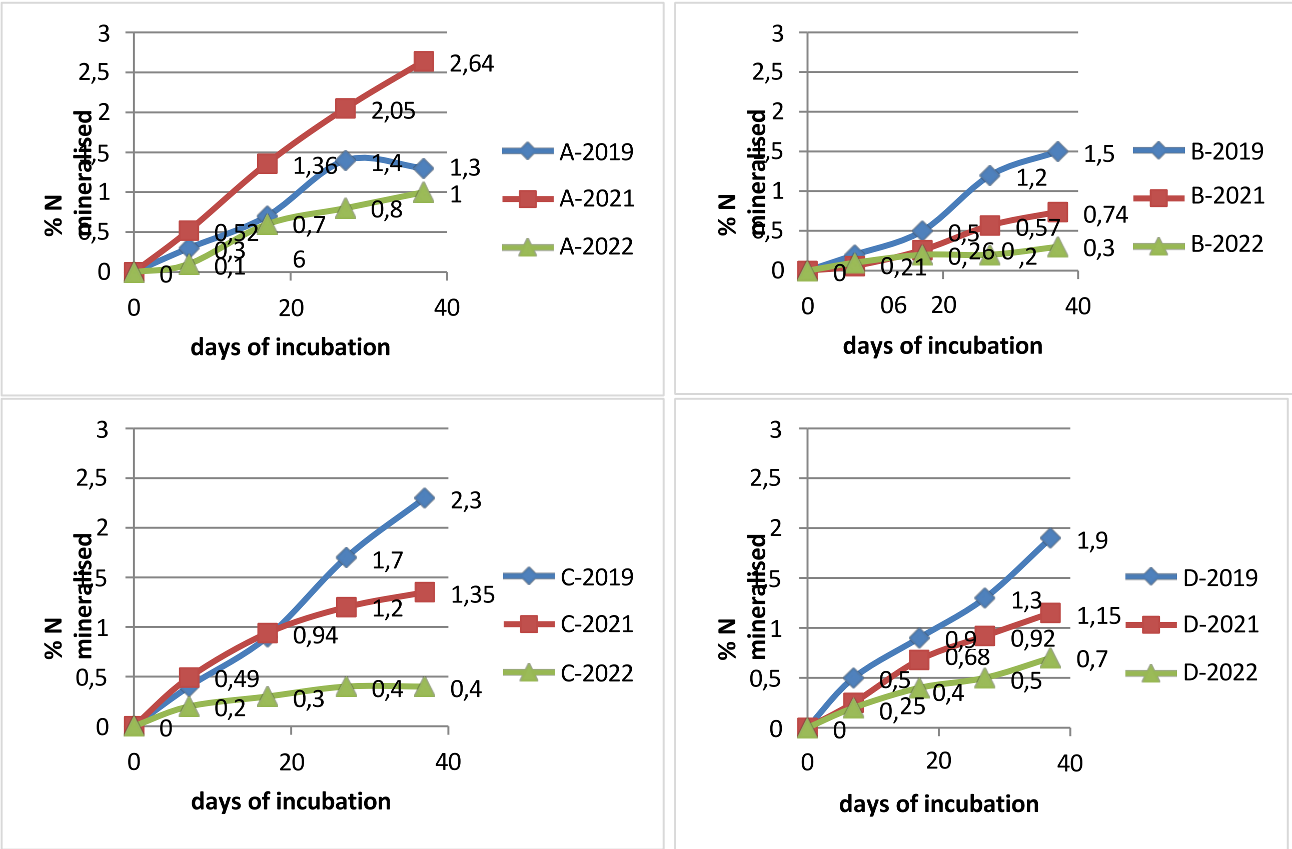


Figure 23: Soil nitrogen mineralisation kinetics for the "Terrière-Champ" plot study zones.

Measurements taken on 05/02/19 show the initial nitrogen fertility of the soil before the demonstration was set up.

Measurements taken on the soil of the plot mixed with manure for an input equivalent to 17 t/ha, in September 2020, reproduce the behaviour of the soil in zone B after input of manure for the 2020 crop.

Measurements taken on 27/05/21 and 05/08/22 show the level of nitrogen fertility in the soil of the four sites.

study areas based on effluent distribution :

	A	B	C	D
05/03/19	Slurry	No contribution organic	No contribution organic	No contribution organic
23/09/19	No contribution organic	Manure	No contribution organic	No contribution organic
26/05/21	Slurry	Slurry	No contribution organic	No contribution organic
06/04/22	Slurry	No contribution organic	No contribution organic	No contribution organic

The potential nitrogen available for the plot at the start of the demonstration averaged 67 kg/ha after 27 days of incubation and 84 kg/ha after 37 days of incubation.

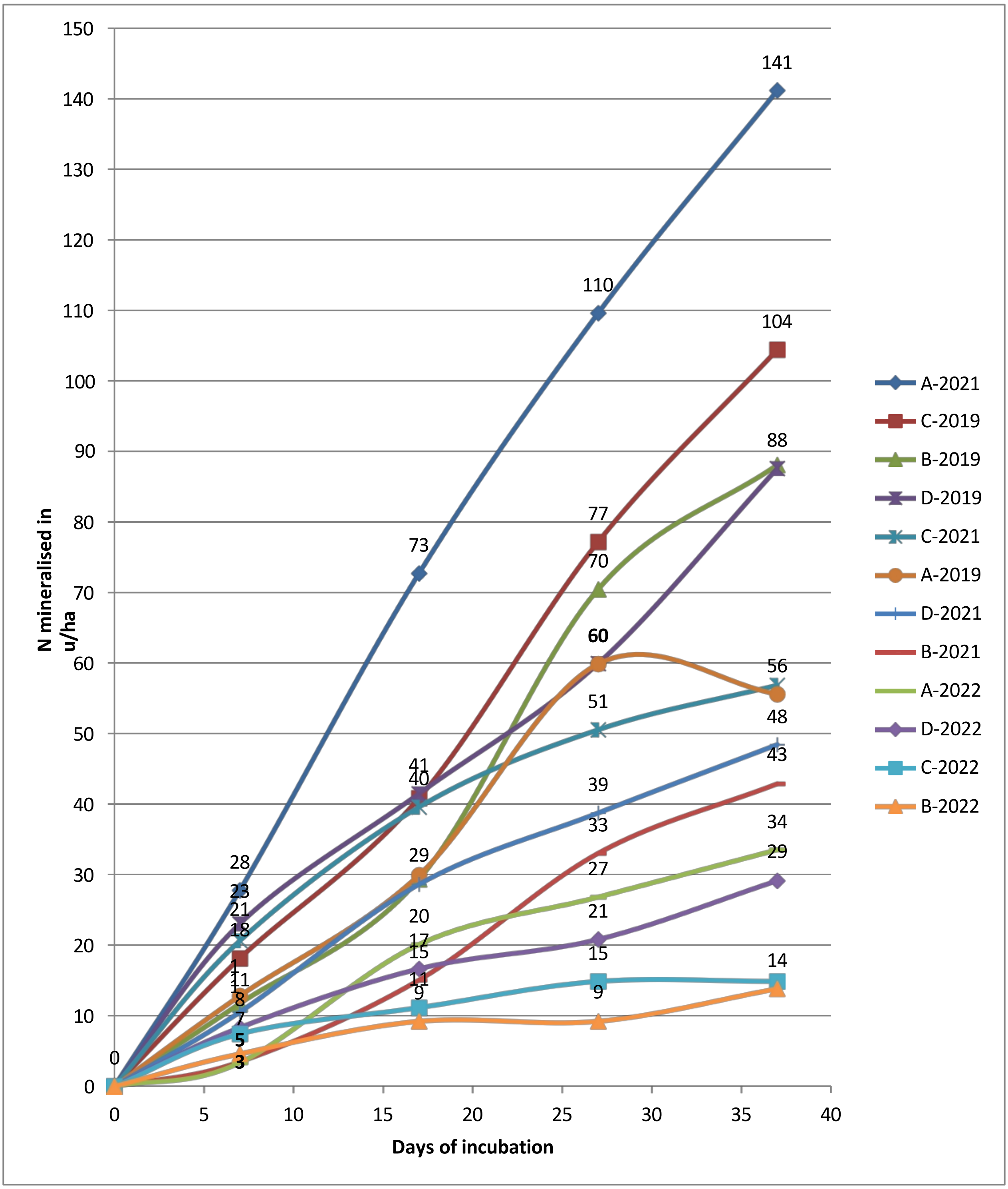


Figure 24: Potentially mineralisable nitrogen in soils in the study areas of the Terrière-Champ" plot, depending on the crop year.

On 27/05/21, the effect of organic inputs on mineralisation potential could be measured:

- For zone A, *the two manure inputs appear to have increased the mineralisation potential*, with a higher coefficient and a doubling of the available nitrogen potential;

- For Zone B,
    - The mineralisation kinetics of the mixture (soil + manure) show a plateau form that peaks at 0.5%, i.e. a potential available nitrogen of 39 kg/ha, which shows a short-term release of nitrogen;
    - However, the combination of manure and slurry inputs ***did not increase the potential for nitrogen mineralisation***, since the coefficient at 37 days of incubation fell sharply (by more than 50%).

- For zones C and D, the coefficients decreased. For these two zones, which serve as a control in relation to organic fertilisation, there was a drop of the same order of magnitude in the mineralisation coefficient at 37 days of incubation (around 40%) and a drop in available nitrogen potential from 96 kg/ha to 53 kg/ha.

In 2021, only nitrogen fertility in zone A seems to increase significantly, after two applications of liquid manure.

On 05/08/22, the mineralisation kinetics for all the areas studied showed a reduction in nitrogen fertility, with much lower mineralisation coefficients and available nitrogen potentials - particularly at 37 days.

- ✓ Zone A still has the highest value of available nitrogen potential: over 30 u N/ha at 37 days incubation,
- ✓ Less than 30 u N/ha for D,
- ✓ Less than 15 u N/ha for B and C.

It is likely that the behaviour of the soil samples taken in August expressed

- the impact of a fairly severe 2022 cropping season in terms of drought on the soil biocenosis.
- As well as the residual effect of crop residues.

Examination of the assessments o f potentially mineralisable nitrogen shows a strong heterogeneity according to zone and crop year.
It seems that climatic impacts and crop residue management have an influence on kinetic results and interfere with the interpretation of effluent inputs.

4.2.3 Carbon stock and biological state of the soil

Estimating the carbon content of the plot combines several indicators, including the distribution rates of bound and labile fractions of organic matter.
See table "Fractionation of organic matter and microbial biomass in the soil of the "La Terrière-Champ" plot".

- ✓ All four study areas have a high proportion of the fraction bound, so stable organic matter, *which s u g g e s t s a carbon stock that is more likely to be stable. sustainable*.

- ✓ Bound organic matter levels tend to be
  - fairly stable for zones B and C
  - more heterogeneous for zones A (effect of the 2021 cut?) and D

  These results raise the question of the 'mineralising' effect of slurry inputs.

- ✓ Zone D in the open field is distinguished by a rate of organic matter that decreases from 2019 to 2022, with the biggest increase in the rate of organic matter linked to: to In contrast to the agroforestry zones, the open field zone seems to be the site of a more pronounced maturation of its organic matter, which may be explained by lower inputs of plant residues than in the agroforestry zones.

We can propose an estimate of short- and medium-term stable carbon stocks for each zone and for the plot as a whole, based on rates of bound organic matter - which corresponds to stable carbon - the carbon rate and assumptions about soil density.
See table "Evaluation of the stable carbon stock of the "La Terrière-Champ" plot based on organic matter fractions".

- ✓ The stable carbon stock at the plot level is of the same order of magnitude in 2019 and 2021, but appears to be lower in 2022 (a climatic impact?).

- ✓ The stock of stable C remains relatively stable in the agroforestry zones. It seems to be decreasing in the open field zone.

Soil samples taken on 27/05/21 also provided us with the results of carbon mineralisation kinetics.

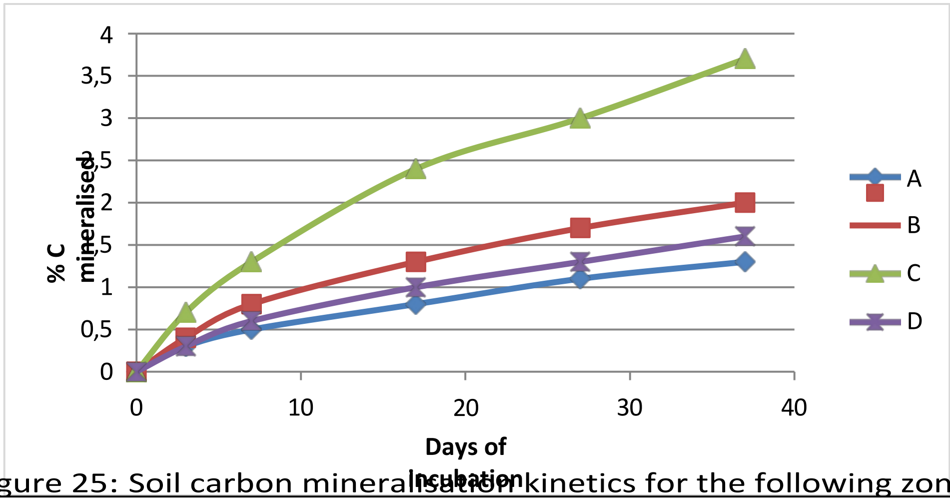


Figure 25: Soil carbon mineralisation kinetics for the following zones study of the "Terrière-Champ" plot

Table 6: Fractionation of organic matter and microbial biomass in the soil of the "La Terrière-Champ" plot

		A			B			C			D		
		2019	2021	2022	2019	2021	2022	2019	2021	2022	2019	2021	2022
MO	Total (%)	2.6	2.9	2.3	3.2	3.4	3.1	2.8	2.8	2.7	4	2.9	2.8
	Bound (% OM)	85.9	86	84.3	87.3	88.6	82.1	85.6	89.9	83.4	82.6	91	81.1
Laboratory advice		*High level of bound OM (>80%)*											
N	Total (%)	0.17	0.21	0.14	0.18	0.23	0.18	0.17	0.18	0.16	0.2	0.17	0.18
	Labile (% N)	10.9	7.5	13.6	10.1	8.7	11.7	10.5	9	12.3	15.7	8.2	14.5
Laboratory advice		*Low level of labile N (<15%)*									*medium*	*low*	
C/N	Total MO	9.1	7.8	9.7	10.5	8.5	9.8	9.3	9.8	10	11.4	9.7	9.2
	Linked MO	8.7	7.2	9.4	10.2	8.2	9.1	8.9	9.7	9.5	11.2	9.6	8.7
	Labile MO	11.3	14.4	11.9	13	11	15.2	13.3	11.1	14	12.5	10.9	12.1
Microbial biomass (% C)		5.07	1.5	-	3.58	4.64	-	4.52	4.1		3.52	3.52	-
Laboratory advice		*High*	*Low*	-	*Medium*	*High*	**-**	*High*		-	*Medium*		-

Table 7: Assessment of the stable carbon stock in the "La Terrière-Champ" plot based on organic matter fractions.

Period	**2019**				**2021**				**2022**			
Zones	A	B	C	D	A	B	C	D	A	B	C	D
Mass per unit area (t/ha)	2700	2800	2600	2600	2700	2800	2600	2600	2700	2800	2600	2600
EG rate (%)	10	10	10	10	10	10	10	10	10	10	10	10
C (%)	1.5	1.9	1.6	2.3	1.7	2.0	1.8	1.7	1.4	1.8	1.6	1.6
Bound OM (% OM)	85.9	87.3	85.6	82.6	86	88.6	89.9	91	84.3	82.1	83.4	81.1
Unit stock C (t/ha)	37	47	38	54	41	50	42	40	33	44	37	39
C stable(t/ha)	**32**	**41**	**33**	**45**	**36**	**45**	**38**	**36**	**28**	**36**	**31**	**31**
Surface area (ha)	0.956	0.971	2.13	4.256	0.956	0.971	2.13	4.256	0.956	0.971	2.13	4.256
Stock of stable C per zone(t)	30	40	69	191	34	43	81	154	26	35	67	133
Stable plot C stock (t)	331				312				261			

Zone C mineralises the highest proportion of carbon after 37 days incubation period, and zone A the least important.

4.2.4 Fractionation of organic matter versus mineralisation kinetics.

A comparison of labile nitrogen or carbon levels and mineralised nitrogen or carbon levels on the 37th day of incubation does not show a directly proportional relationship between the two types of indicator:

Period	Zone	Labile N rate (% total N)	*Mineralized N[1] (% total N)*	Labile C rate (% total C)	*Mineralized C (% total C)*
2019	A	10.9	*1.3*	-	-
	B	10.1	*1.5*		
	C	10.5	*2.3*		
	D	15.7	*1.9*		
2021	A	7.5	*2.64*	14	*1.3*
	B	8.7	*0.74*	11.4	*2*
	C	9	*1.35*	10.1	*3.7*
	D	8.2	*1.15*	9	*1.6*
2022	A	13.6	*1*	-	-
	B	11.7	*0.3*		
	C	12.3	*0.4*		
	D	14.5	*0.7*		

Maximum values highlighted in blue, minimum values highlighted in orange.

It is therefore not possible to make a direct estimate of soil nitrogen fertility or the intensity of overall biological activity using organic matter fractionation indicators alone.

However, it might be useful to verify the existence of a relationship between mineralised element rates, labile or bound element fractions and C/N ratios. Such a relationship would make it possible to predict the release of nitrogen or carbon on the basis of rapid analytical determination.

4.2.5 Microbial biomass indices

The values for measuring microbial biomass are quite variable from one area to another and from one period to another. It is difficult to draw any particular conclusion, other than that the overall level for the plot is slightly above average.

It would appear, however, that the higher microbial biomass measurements are associated with agroforestry zones.

4.2.6 Environmental situation of the soil.

Table 8: Trace element content of the soil in the "La Terrière-Champ" plot

ETM (mg/kg MS)		Cd	Cr	Cu	Hg	Ni	Pb	Zn
A	2019	0.75	41.5	12.5	0.021	13.2	16.0	49.2
	2020	0.81	50.0	11.5	0.027	18.1	16.5	48.8
	2022	0.59	33.7	8.9	0.013	11.6	11.2	37.4
B	2019	0.64	34.3	9.7	0.019	11.9	14.8	43.8
	2020	1.02	50.3	14.7	0.028	18.7	22.1	63.0
	2022	1.14	63.6	9.7	0.021	19.5	22.1	67.8
C	2019	0.84	48.8	13.3	0.022	15.6	18.6	61.9
	2020	0.89	47.8	12.6	0.022	15.6	20.2	62.1
	2022	0.85	45.9	16.1	0.016	14.2	17.7	52.5
D	2019	1.15	60.1	217	0.023	13.7	23.6	108.9
	2020	0.95	53.4	47.3	0.017	15.2	21.1	76.9
	2022	0.76	44.1	115.4	0.026	12.14	17.3	67
Investigation threshold (35 < Clay (%)< 50 - BAIZE, 1997)[1]		-	95	30	-	65	55	150
Investigation thresholds (BAIZE, 2000)[1]		0.7	100	35	-	70	60	150
Limits decree 08/01/1998 (Légifrance, 1998)		2	150	100	1	50	100	300

([1] Quoted by BERNARD, 2000)

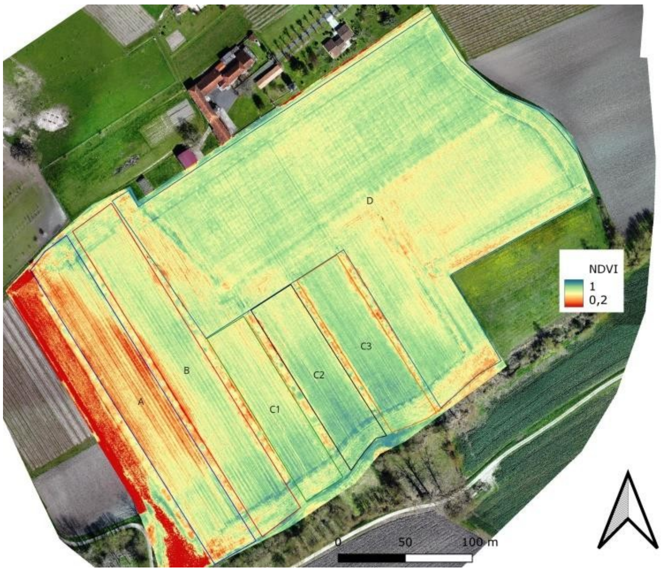
The presence of trace elements in the soil of the "La Terrière-Champ" plot is not significant that

- cadmium: although still below the official contamination threshold, almost all levels are above the investigation threshold proposed by BAIZE, 2000 and would encourage verification of the natural presence of cadmium in this type of soil;
- for copper in zone D: this is clearly due to the former presence of vines and the impact of copper antifungal treatments.

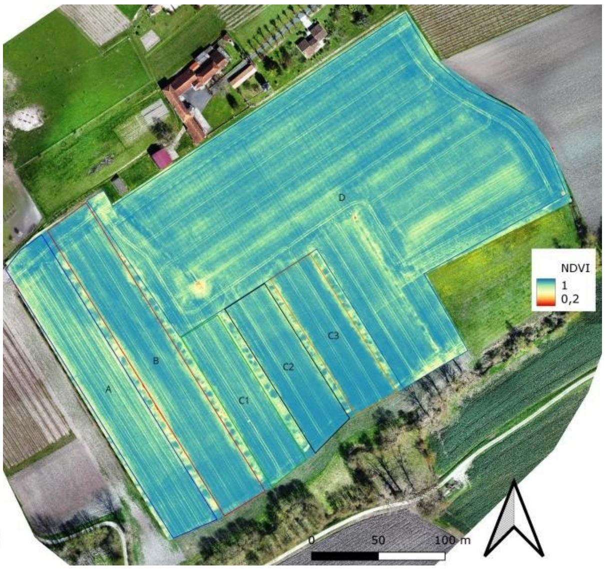
4.3 Cultural monitoring 2019

For a more accurate interpretation of the information provided by remote sensing on crop development, we divided study area C into three smaller zones to avoid the effect of hedgerow segments.

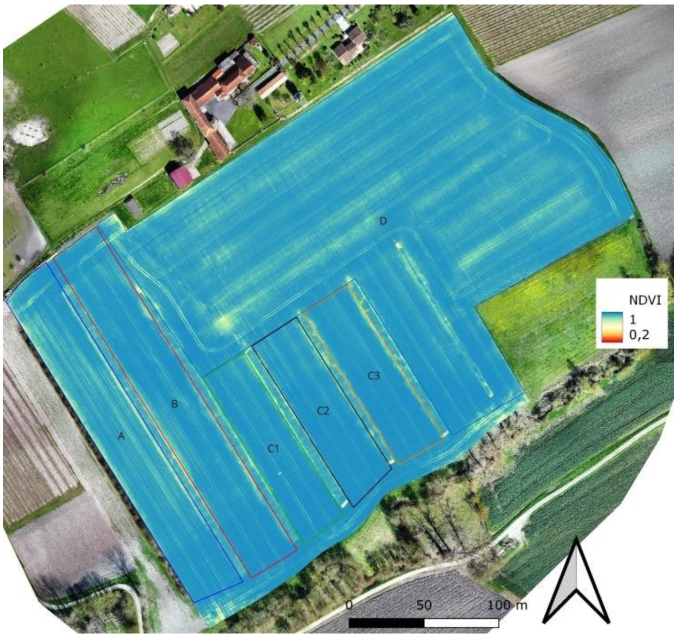
4.3.1 NDVI images 2019



21/03/19



18/04/19



07/05/19

Figure 26: NDVI images of the 2019 soft winter wheat crop

(Source: Chamber of Agriculture 17, 2019)

Using GIS (QGIS software) to analyse the images, we determined the following NDVI statistics by zone :

	21/03/2019			18/04/2019			07/05/2019		
	Avg[1]	AND[2]	CV[3]	Avg	AND	CV	Avg	AND	CV
A	0.5407	0.1269	23 %	0.8612	0.0688	8 %	0.9282	0.0423	5 %
B	0.6680	0.0959	14 %	0.8891	0.0515	6 %	0.9457	0.0252	3 %
C	0.7244	0.0894	12 %	0.9001	0.0453	5 %	0.9508	0.0236	2 %
D	0.6764	0.0791	12 %	0.8792	0.0498	6 %	0.9347	0.0268	3 %

[1] Averages. The value for C was calculated as a weighted average of the values for C1, C2 and C3. 2Standard deviations: same for C as above. [3] Coefficient of variation: SD/Avg

An examination of the index statistics and images shows that :

- On 21/3/19, after application of liquid manure to A and two mineral fractions to the whole farm
  of the system, plant biomass density is lower on strip A and higher on strip B.
  in zone C. There isn't really any additional effect from the manure. There is a
  a degree of heterogeneity within zones (coefficients of variation > 10%);
- On 18/4/19, after application of the third mineral fraction, and on 07/05/19, after application of the fourth, biomass densities maintained the same order of magnitude.
  classification C > B > D > A

4.3.2 NBI measures 2019

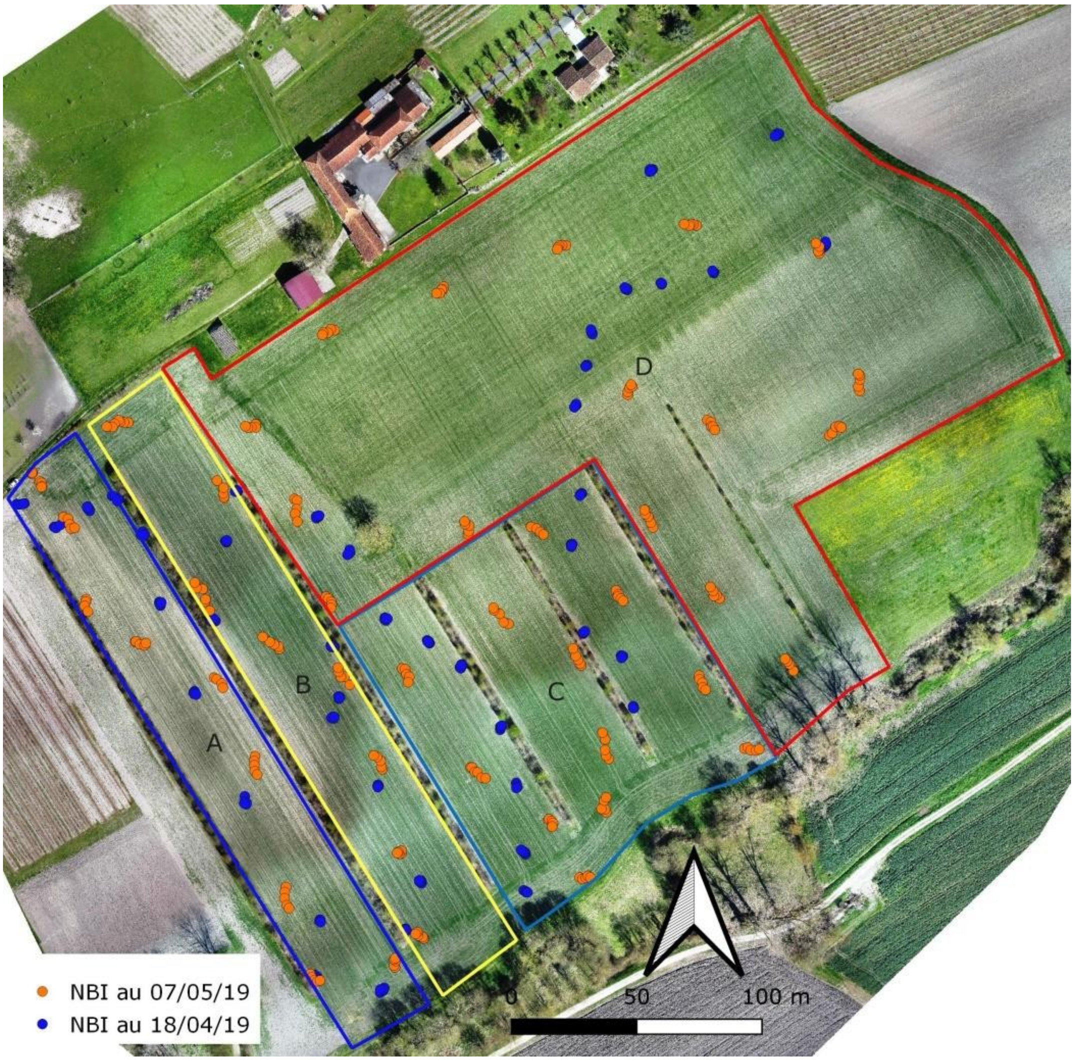


Figure 27: NBI measurements by ground sensor in 2019

(Source: Chamber of Agriculture 17, 2019)

Statistics on NBI index measurements on the ground :

	18/04/19			07/05/19		
	Avg[1]	AND[2]	CV[3]	Avg	AND	CV
A	31.4	8.31	26 %	23.7	5.59	24 %
B	30.0	5.09	17 %	24.6	8.06	33 %
C	30.9	6.39	21 %	25.9	6.74	26 %
D	29.2	8.06	28 %	22.6	4.62	20 %

[1] Averages. 2 Standard deviations. [3] Coefficient of variation: SD/Avg.

On 18/04 and 07/05, the level of nitrogen nutrition of the crop in each zone appeared to be as follows
sufficient (NBI > 20). However, there is heterogeneity within each zone (CV > 15%).

It should be noted that the values are lower in May than in April, even though a fourth nitrogen application was made: there is therefore another limiting factor in the nitrogen supply to the crop, at plot level.

Examination of images of the NBI index modelled from ground measurements and the indices of confirm the statistical trends of the measurements. They highlight :

- There is a clear disparity between zones;
- A lower level of nitrogen in zone D.

4.3.3 Plant sampling and 2019 harvest estimates.

We took plant samples for assessment on 27/06/19, prior to harvesting by the farmers on 14/07/19. We carried out three sampling replicates, i.e. three samples in each of the following three areas:

- Strip A = manure application and mineral fertilisation in agroforestry ;
- Strip B + zone C = mineral fertilisation in agroforestry ;
- Zone D = mineral fertilisation in open fields.

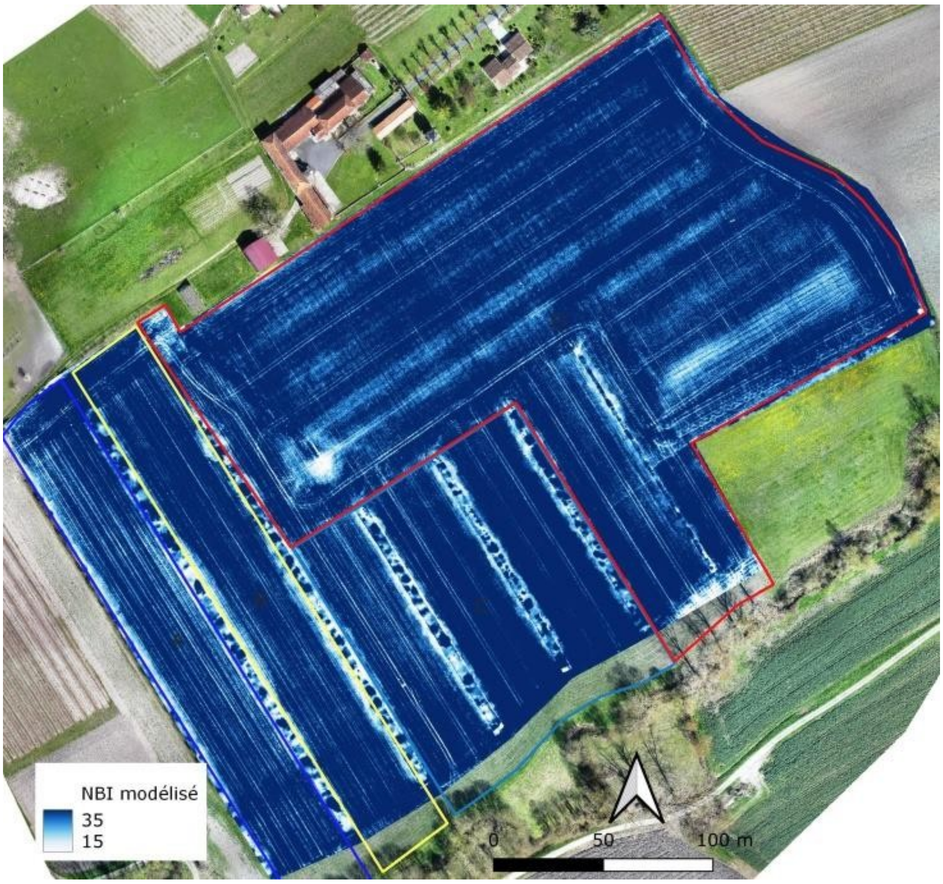
Table 9: Yield estimates for the three sample zones - 2019 soft winter wheat crop.

Zone	Sample	Yields	
		q (DM)/ha	q (14% hum)/ha
A	1	40	47
A	2	36	42
A	3	42	48
BC	1	41	48
BC	2	42	49
BC	3	48	56
D	1	58	67
D	2	55	64
D	3	53	62

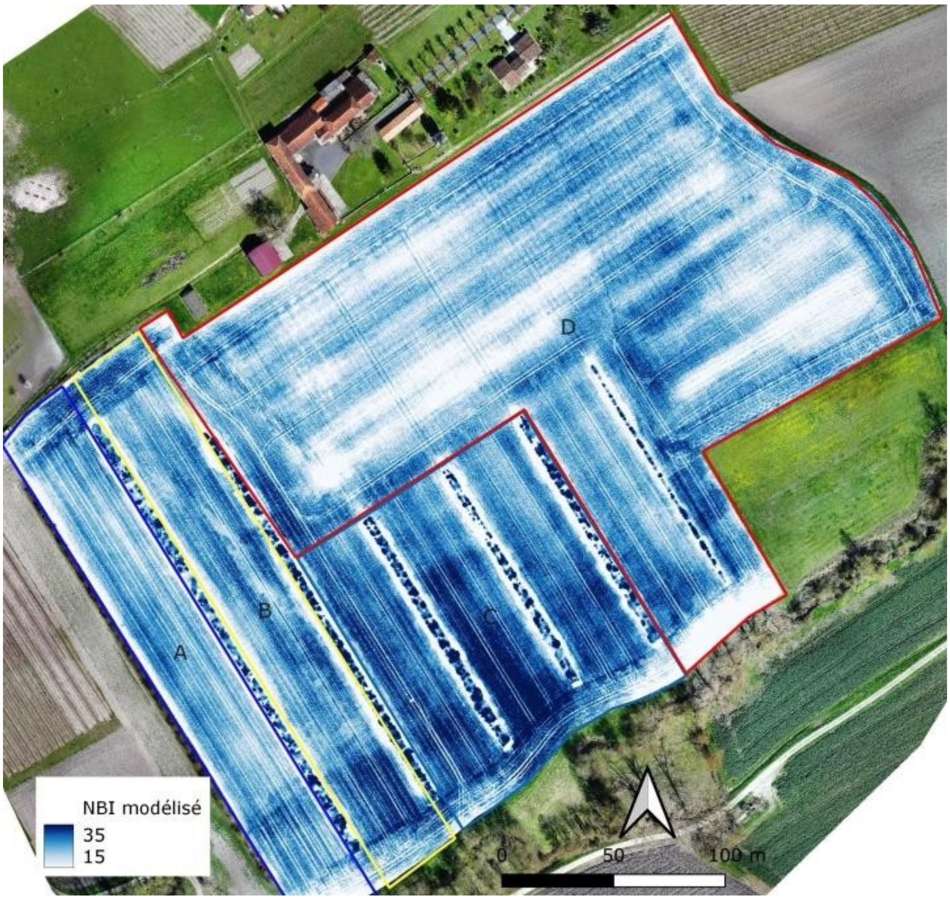
Average yields - calculated at 14% moisture content - for A, B/C and D are 45.5, 51 and 64 q/ha respectively.
The yield declared by the farmer for the whole of the "La Terrière-Champ" plot is 50 q (14%) /ha.

In terms of measurement quality :

- The yield measurements we have obtained for zone D overestimate the overall performance of the zone. Three samples are therefore insufficient, as given the surface area and heterogeneity of this zone.
- The yield measurements for A and BC are more consistent with the yield value of the farmers and remote sensing observations.



To 18/04/19



To 07/05/19

Figure 28: Images of the modelled NBI index - Common winter wheat 2019

(Source: Chamber of Agriculture 17, 2019)

4.3.4 Post-harvest nitrogen measurements 2019

We took soil samples on 05/09/19 to measure soil nitrogen residues in a post-harvest situation. We worked on the three harvest sampling zones A, B/C and D

The residue values measured by the laboratory over two or three horizons, depending on the soil profile, are :

- 28 kg N/ha for A
- More than 50 kg N/ha for B/C and D

These values suggest that there was a greater stock of mineral nitrogen in zones B, C and D than in zone A at the start of the cropping season, which could explain the delay in A as seen by remote sensing.

4.3.5 Results for 2019

In 2019, we did not observe any additional fertilising effect linked to the application of liquid manure on
zone A, nor by remote sensing monitoring, nor by harvesting results.

Modelling of nitrogen supply by the soil before slurry spreading using kinetic results and taking into account local climatological data (Cognac station) gives values of

- 32 kg/ha for zone A,
- 42 kg/ha for zone B,
- 50 kg/ha for zone C,
- 42 kg/ha for zone D.

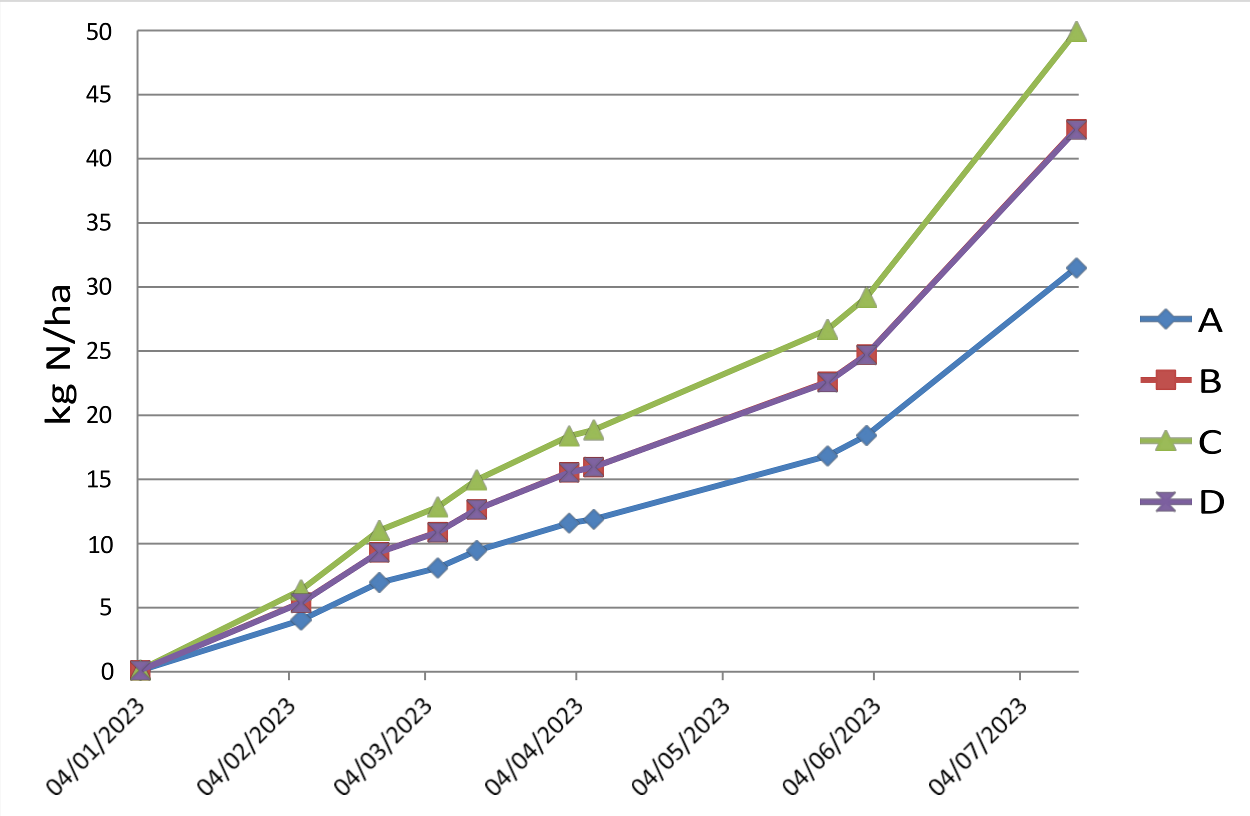


Figure 29: Soil nitrogen supply curves - 2019 growing season, plot "Terrière-Champ

Zone A has lower initial fertility, which has not been compensated for by the addition of liquid manure.

The 2019 growing season showed that :

- **Agroforestry planting has no negative impact on crop development, with zones B and C at average yield levels;**
- **A limiting factor prevented manure from being applied on 05/03/2019 in zone A.**

At this stage of the review we can consider the following limiting factors:

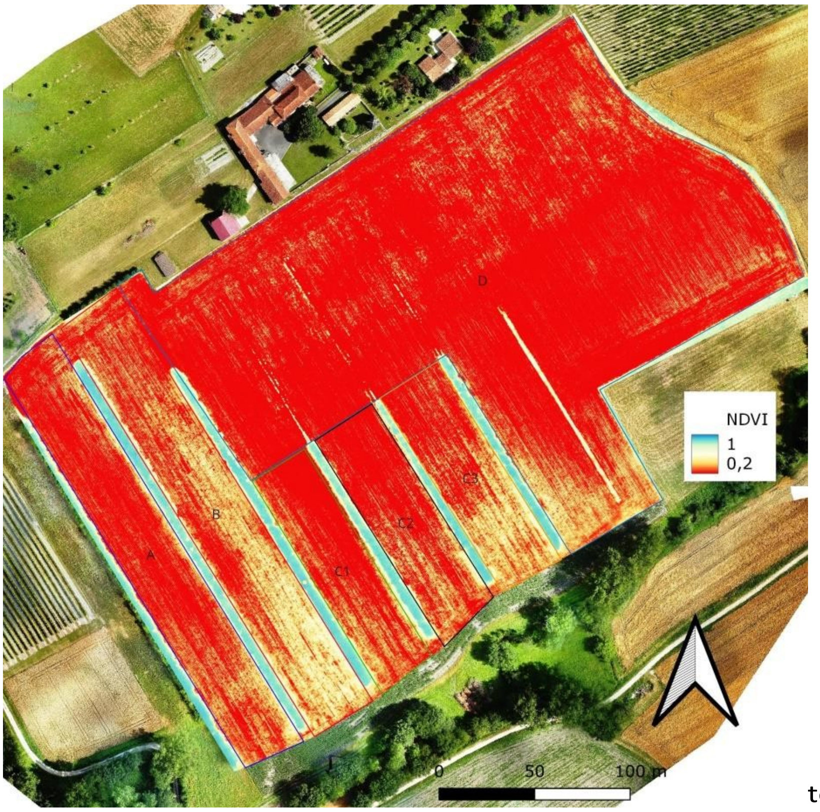
- limiting water conditions ;
- slurry applied too late;

The mineralisation capacity of the soil as such is not a limiting factor in terms of mineralisation results from the other zones.

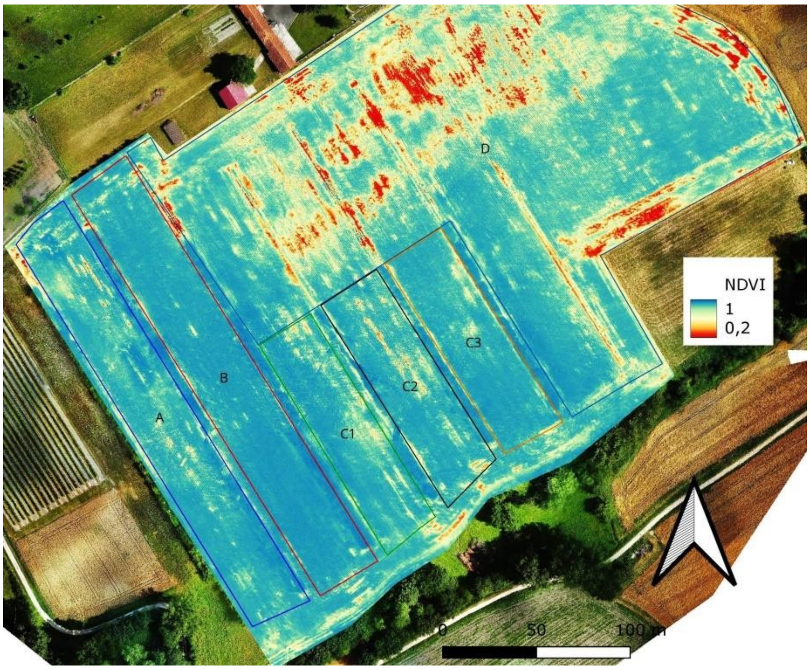
4.4 2020 crop monitoring

The international COVID 19 crisis disrupted the start of the monitoring of the 2020 maize crop on the "Terrière-Champ" plot and limited the number of field investigations.

4.4.1 NDVI 2020 images



to 26/05/20



to 29/06/20

Figure 30: NDVI images of the 2020 maize crop

(Source: Chamber of Agriculture 17, 2020)

NDVI statistics by zone in 2020 :

	26/05/20			29/06/20		
	Avg[1]	AND[2]	CV[3]	Avg	AND	CV
A	0.2689	0.1070	40 %	0.8897	0.0634	7 %
B	0.3696	0.1372	37 %	0.9160	0.0434	5 %
C	0.2717	0.1322	49 %	0.8842	0.0728	8 %
D	0.2030	0.1053	52 %	0.7654	0.1706	22 %

[1] Averages. The value for C was calculated as a weighted average of the values for C1, C2 and C3. 2Standard deviations: same for C as above. [3] Coefficient of variation: SD/Average

It can be seen from both the visual examination of the index maps and the statistical indicators that strip B, which received a goose manure application in September 2019, showed greater biomass development at the end of May and end of June 2020, all the fertiliser applications having been made by 06/05/20.

Examination of the index statistics and images shows that biomass densities follow the ranking order B > A/C > D

4.4.2 NBI 2020 measures

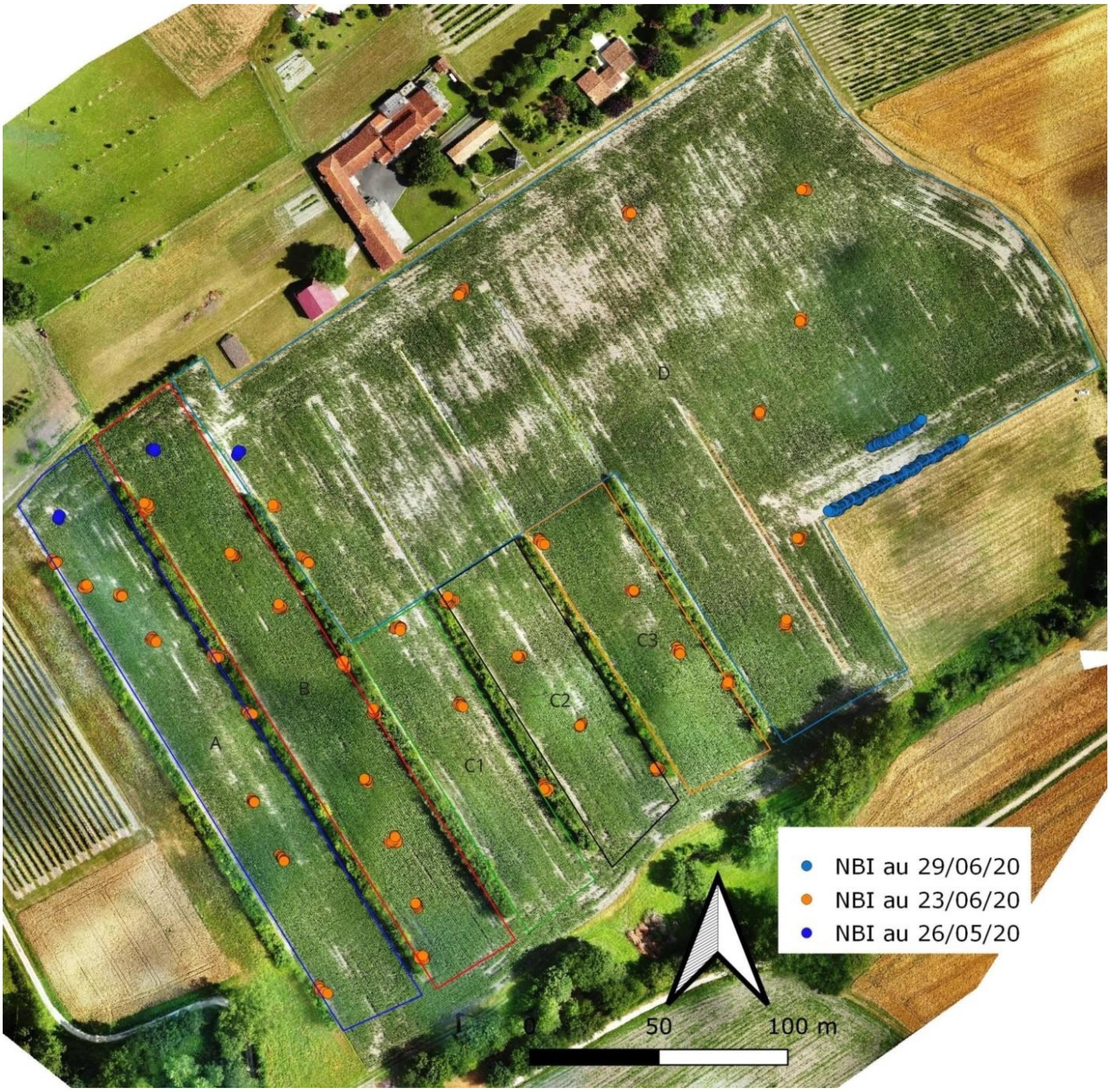


Figure 31: NBI index measurements by ground sensor in 2020

(Source: Chamber of Agriculture 17, 2020)

The measurements taken on 26/05/20 and 29/06/20 were only used to model the NBI index with the remote sensing indices.

Only the measurements taken on 23/06/20 have any direct statistical value:

	23/06/20		
	Avg[1]	AND[2]	CV[3]
A	23.8	4.71	20 %
B	31.4	8.91	28 %
C	24.4	6.60	27 %
D	25.1	5.84	23 %

[1] Averages. 2 Standard deviations. [3] Coefficient of variation: SD/Avg.

The level of nitrogen nutrition appears to be correct in all areas. However, the coefficients of variation - ≥ 20% - indicate heterogeneity within zones.

We find a higher level of nitrogen nutrition on band B.

4.4.3 Edge effect of linear coppice within plots

The ground measurement protocol applied on 23/06/20 enabled us to verify any border effect created by the presence of coppiced hedges:

Zones	Situation	Avg	AND	CV
A	Edge of hedge	21.6	4.42440916	20 %
	Centre zone	25.5	4.24397868	17 %
B	Edge of hedge	29.8	9.75112751	33 %
	Centre zone	32.7	7.99398224	24 %
C	Edge of hedge	23.3	7.58472501	32 %
	Centre zone	25.5	5.23529521	20 %

Although the averages are not really statistically distinct, we can see that :

- ✓ There was no significant depressive effect of the presence of the hedge on the nearby crop, since all the averages were above 20.
- ✓ However, the average index value for hedgerow-edge plants is slightly higher than the average index value for other plants.
  lower than in the centre of the zone.

The modelled NBI maps, in particular the one for 29/06/20, show the heterogeneity of the levels of nitrogen nutrition within the different zones.
Although the absolute values are not sufficiently accurate, because the modelling calculations have a "smoothing by construction" effect, we have used area statistics - the same principles as for the NDVI indices - to examine the differential values:

	26/05/20			29/06/20		
	Avg[1]	AND[2]	CV[3]	Avg	AND	CV
A	13.8	6.45	47 %	25.4	26.15	103 %
B	16.3	6.86	42 %	37.8	22.06	58 %
C	10.1	6.23	62 %	33.7	20.18	60 %
D	8.3	5.57	67 %	33.0	15.60	47 %

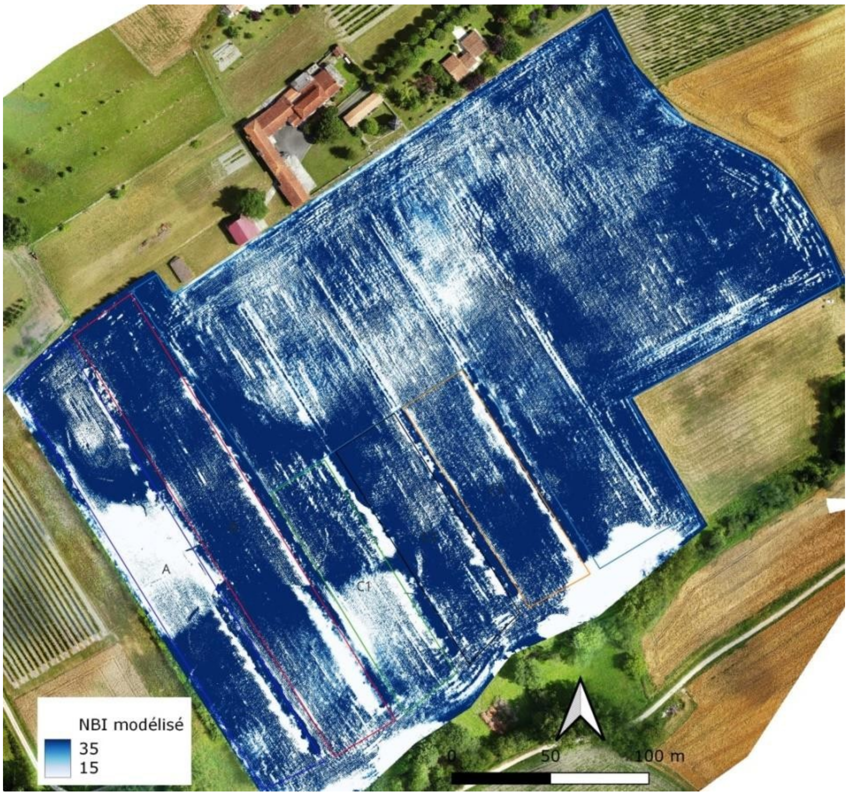
[1] Averages. The value for C was calculated as a weighted average of the values for C1, C2 and C3. 2Standard deviations: same for C as above. [3] Coefficient of variation: SD/Avg

On 26/05/20 and 29/06/20, the situation described on 23/06/20 was repeated, i.e. a higher level of nitrogen nutrition for band B.

It also appears that the situation in zone D improved from May to June. However, given the wide dispersion of values - CV > 40% - this trend should be treated with caution.

Note the significant heterogeneity that appears within the zones on the map of 29/06/20.

To 26/05/20



To 29/06/20

Figure 32: Images of the modelled NBI index - Maize 2020

(Source: Chamber of Agriculture 17, 2020)

4.4.4 2020 review

Due to a lack of organisation with the farmers, we were unable to take plant samples. We only have information on the yield obtained by the farmer at harvest: 50 q/ha on 18/09/20.

We will confine ourselves to what we have observed: a higher and more homogeneous level of development and nutrition in Zone B.

We propose *a posteriori* modelling of soil nitrogen supply after manure spreading in real conditions, based on kinetic results and local climatological data:

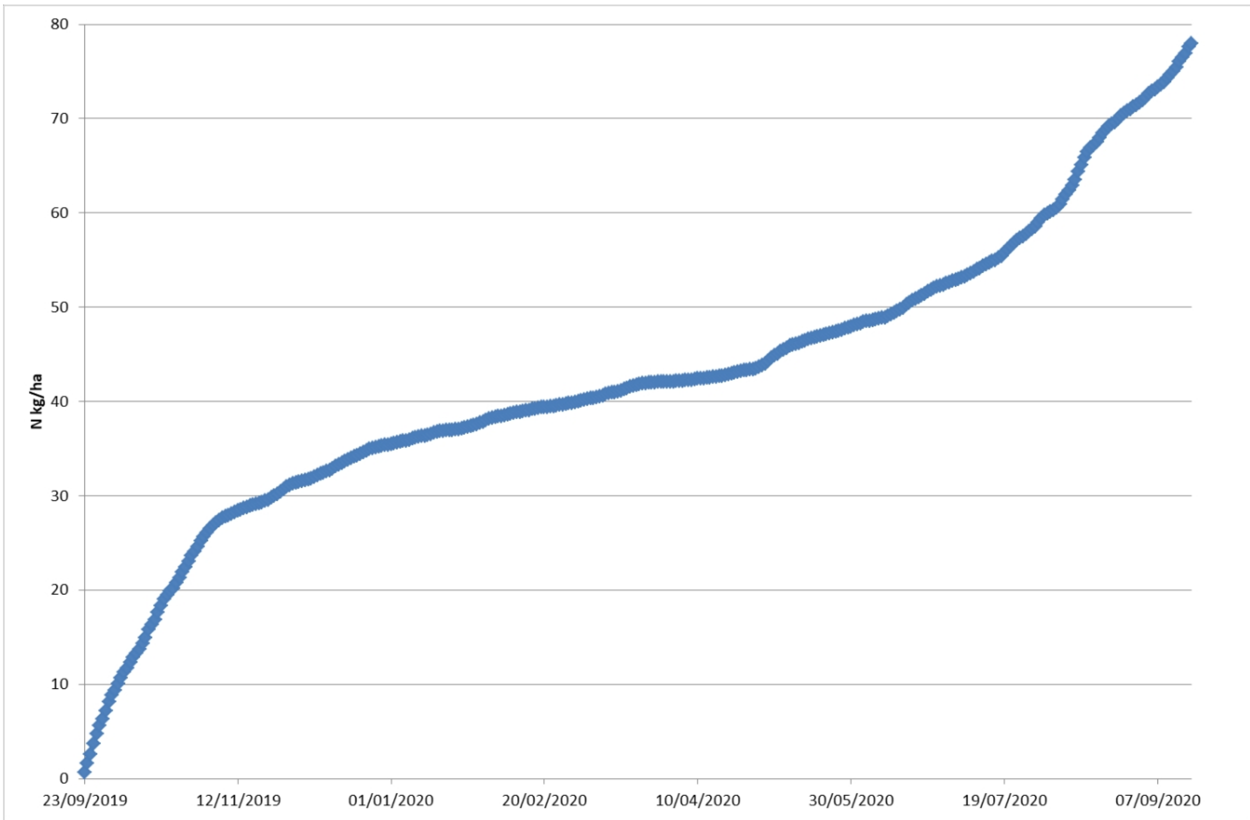


Figure 33: Soil nitrogen supply curve after manure application - 2020 cropping season, "Terrière-Champ" plot

F r o m spreading (23/09/20) to sowing (06/04/20), the soil in strip B, enriched by the manure releases around 40 kg of nitrogen/ha.
N.B.: this estimate is slightly overestimated because burial, which facilitates mineralisation, does not take place until 20/10, i.e. one month after manure application. The mineralization measurement protocol applies to a mixture of soil and manure.

From sowing to harvest (18/09/20), around 35 kg of nitrogen/ha is theoretically released.
through the floor.
So after spreading and during the maize's development cycle, around 75 kg of nitrogen/ha was released by the soil, which represents 50 to 79% more than the supplies provided by the control soils (zones C and D) in 2019.

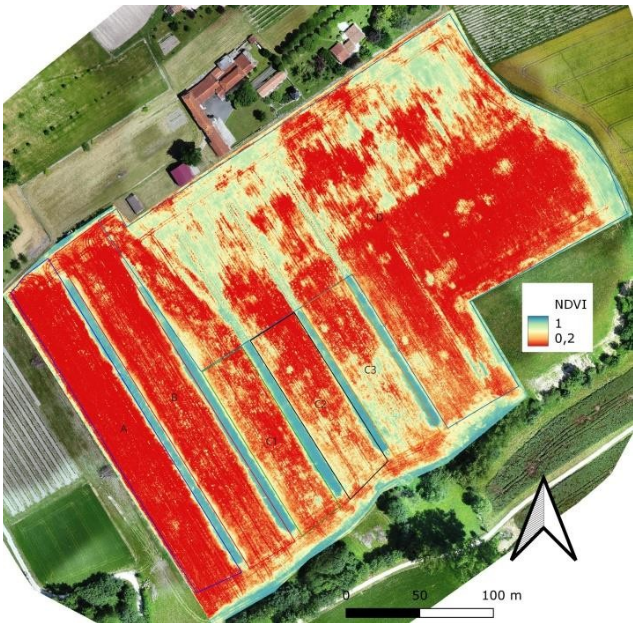
Band B benefited from the application of manure, the fertilising effect o f which resulted in biomass development and a higher level of nitrogen nutrition than in the other zones.

4.5 Crop monitoring 2021

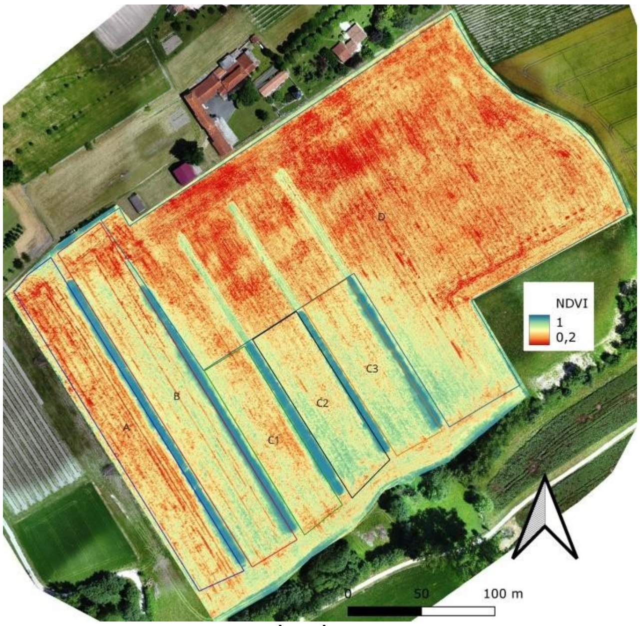
To monitor the 2021 maize crop, based on the experience of the 2020 campaign, we have organised more intensive monitoring with eight days of remote sensing photography and pre-harvest crop sampling.

4.5.1 NDVI 2021 images

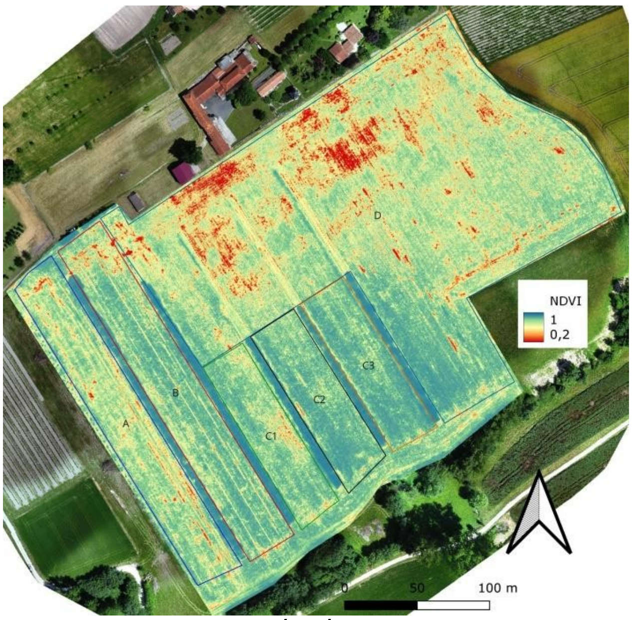
To 27/05/21



To 10/06/10



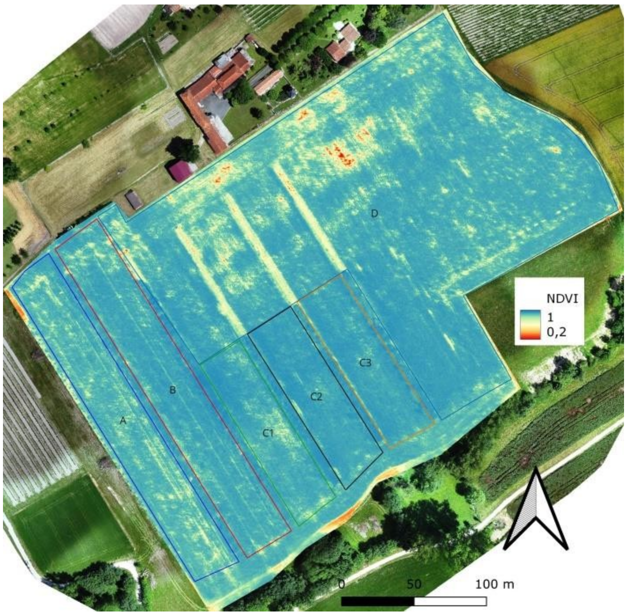
To 21/06/21



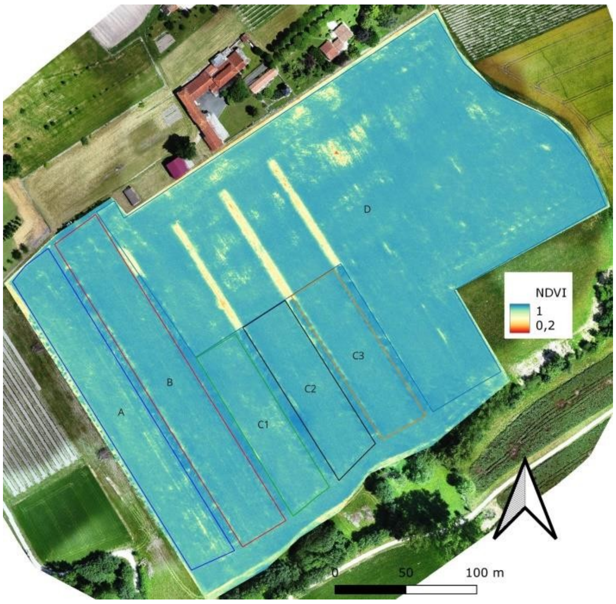
To 05/07/21

Figure 34: NDVI images of the maize crop 2021 - from 27/05 to 05/07 2021

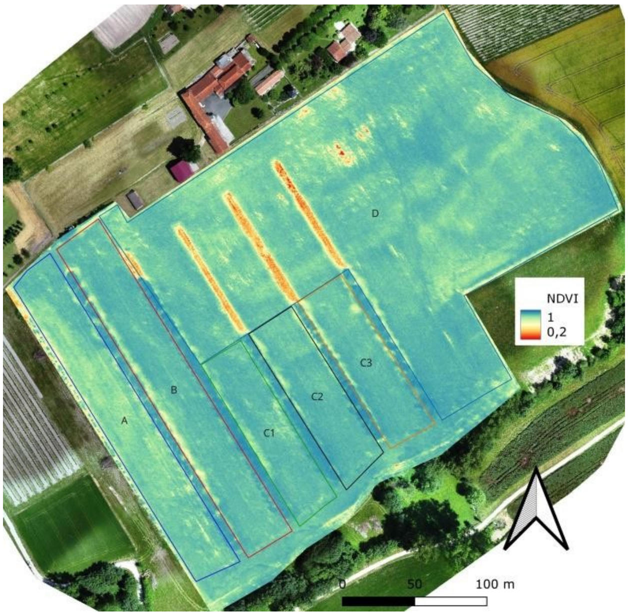
(Source: Chamber of Agriculture 17, 2021)



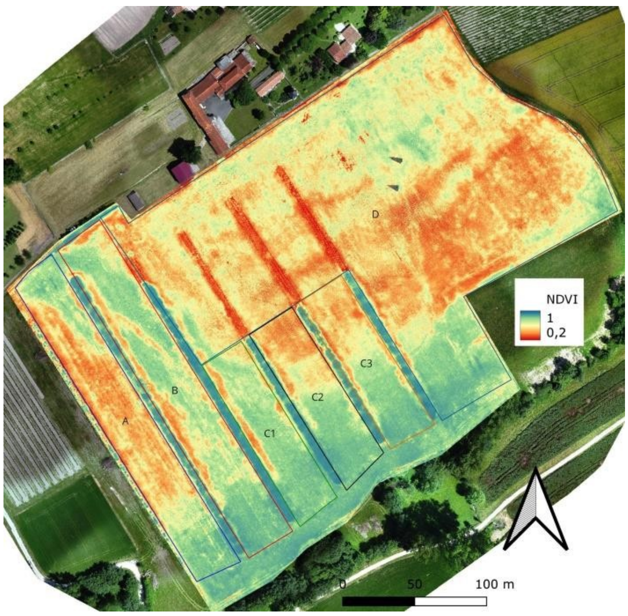
To 19/07/21



To 10/08/21



To 25/08/21



To 09/09/21

Figure 35: NDVI images of the maize crop 2021 - from 19/07 to 09/09 2021

(Source: Chamber of Agriculture 17, 2021)

NDVI statistics by zone in 2021 :

	NDVI[1]				CV[2]			
	A	B	C	D	A	B	C	D
27/05/2021	0.1471	0.1957	0.1981	0.1126	99 %	92 %	74 %	115 %
10/06/2021	0.2139	0.2987	0.4083	0.3954	68 %	57 %	40 %	52 %
21/06/2021	0.5067	0.6068	0.6259	0.4525	30 %	24 %	20 %	31 %
05/07/2021	0.7254	0.7851	0.8145	0.6809	17 %	14 %	10 %	23 %
19/07/2021	0.8843	0.9115	0.9194	0.8797	5 %	4 %	3 %	9 %
10/08/2021	0.8958	0.9119	0.9134	0.8969	3 %	2 %	2 %	7 %
25/08/2021	0.8435	0.8716	0.8763	0.8426	5 %	5 %	6 %	5 %
09/09/2021	0.5807	0.7016	0.6835	0.5501	27 %	19 %	22 %	25 %

[1] Average value. The value for C was calculated as a weighted average of the values for C1, C2 and C3. [2] Coefficient of variation: SD/Avg.

NDVI statistics provide a fairly detailed chronology of crop development:

- ✓ On 27/05, after the slurry and the first mineral fraction had been added, there was still a great deal of slurry in the soil.
  low plant biomass density (NDVI < 0.2), which is mainly in Band B and Zone C.

- ✓ On 10/06, after burial of the slurry and the second and final mineral application, the biomass densities are clearly shown in order of importance next : C > D > B > A.
  It will be noted that the cultural development is more marked on the site of the old vineyard.

- ✓ From 21/06, crop development continued until 25/08 in the following order of importance: C > B > A > D

- ✓ By 09/09, the dehiscence phase had begun and NDVI levels were decreasing The order of biomass densities is: B > C > A > D

4.5.2 NBI measures 2021

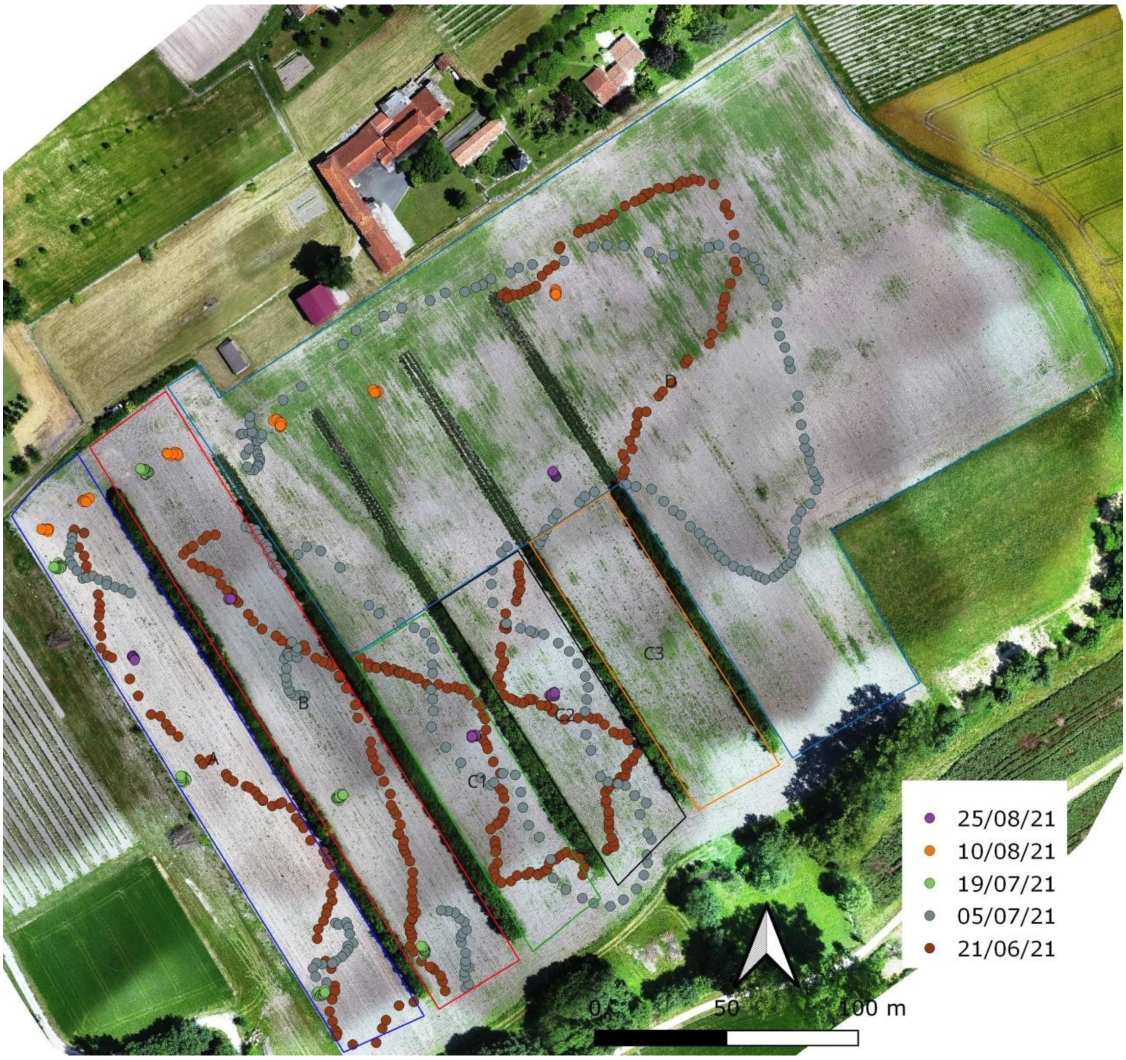


Figure 36: NBI index measurements by ground sensor in 2021
(Source: Chamber of Agriculture 17, 2021)

Only the ground measurements taken on 21/06/21 and 05/07/21 are complete for all of the zones and can be processed directly in statistics:

	21/06/2021			05/07/2021		
	Avg[1]	AND[2]	CV[3]	Avg	AND	CV
A	25.5	4.05	16 %	36.9	8.74	24 %
B	29.3	5.88	20 %	40.8	18.49	45 %
C	28.2	6.80	24 %	32.9	7.81	24 %
D	19.6	3.38	17 %	31.2	6.87	22 %

1Averages. [2]Standard deviations. [3] Coefficient of variation: SD/Avg.

Nutrition levels were sufficient and higher on all three measurement dates.

The order of nutrition levels is B > A/C > D.

We have also compiled area statistics from the modelling maps of the NBI index.
As in the previous chapter, we will remain cautious about absolute values and proceed by examining the differences:

		A	B	C	D
21/06/2021	Avg[1]	24.2	28.6	28.6	22.9
	CV[2]	23 %	20 %	17 %	19 %
05/07/2021	Avg	36.6	36.9	39.0	32.5
	CV	20 %	23 %	24 %	19 %
19/07/2021	Avg	60.0	64.1	68.2	57.3
	CV	19 %	24 %	25 %	27 %
10/08/2021	Avg	37.0	40.1	38.5	40.0
	CV	21 %	23 %	23 %	26 %
25/08/2021	Avg	30.0	36.5	32.2	32.1
	CV	19 %	29 %	23 %	503 %

[1] Average value. The value for C was calculated as a weighted average of the values for C1, C2 and C3. [2] Coefficient of variation: SD/Avg.

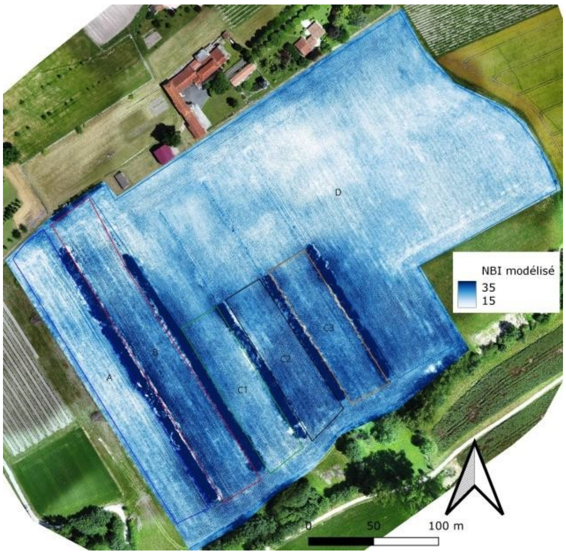
The results for the zone statistics are fairly comparable:

- Average NBI values that represent sufficient nutrition;
- A hierarchy of levels, with B or C ahead of A and D.

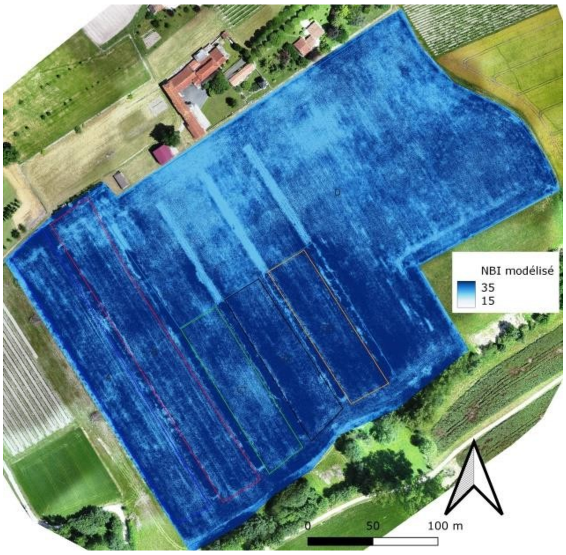
4.5.3 Influence of intra-parcel linear coppicing on nitrogen uptake

We were interested in a possible nitrogen recovery effect of intra-parcel coppicing.
On 10/06/21, we set up a basic system to try and demonstrate this effect: four strips in the plot, oriented perpendicular to the coppice, were given extra nitrogen.

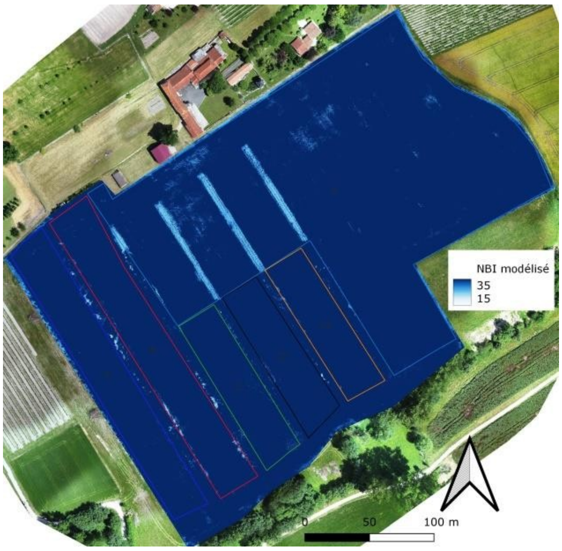
On the assumption that the principle of the NBI index was applicable to tree species in coppices, we took measurements on 25/08/21 with the hand-held sensor on the maize crop within the strips and on the adjacent trees, as well as on an area of coppice and an area of maize without any additional nitrogen input, which served as controls.



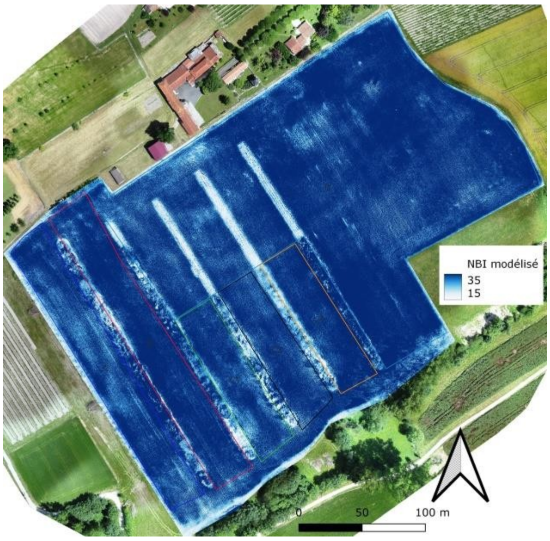
To 21/06/21



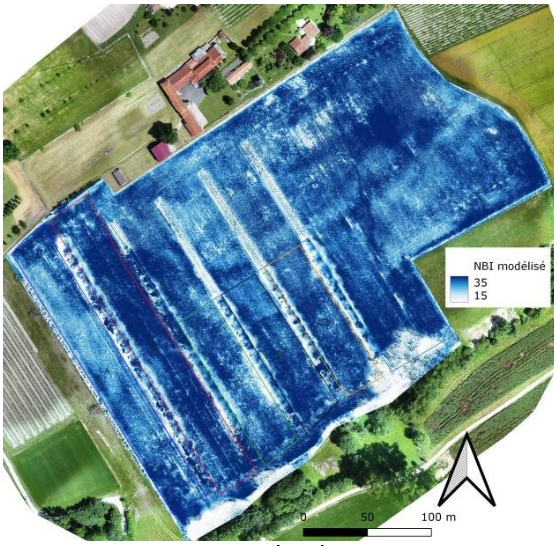
To 05/07/21



To 19/07/21



To 10/08/21



To 25/08/21

Figure 37: Images of the modelled NBI index - Maize 2021

(Source: Chamber of Agriculture 17, 2021)

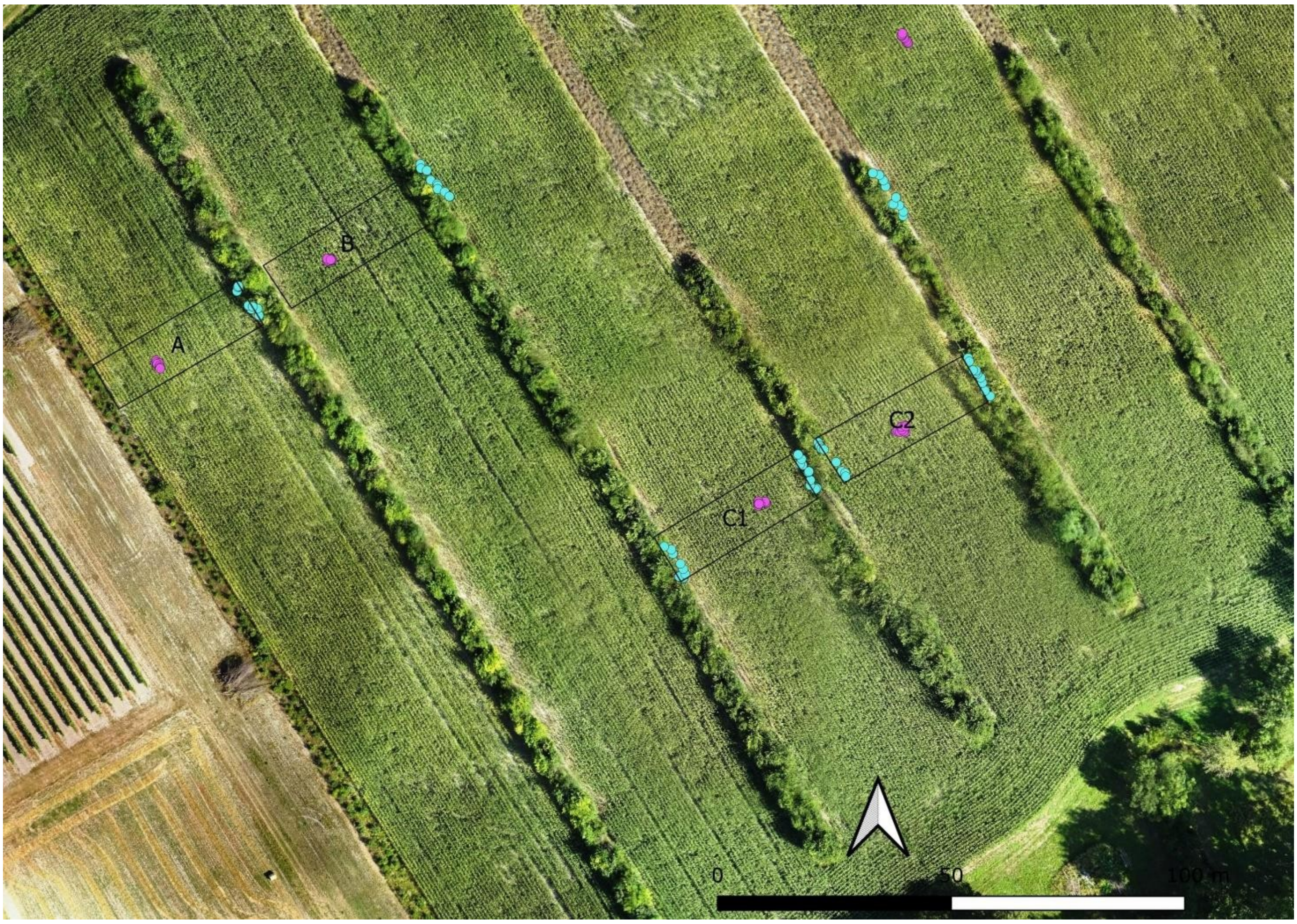


Figure 38: Device for testing the effect of coppice nitrogen recovery intraparcel - Maize 2021

(Source: Chamber of Agriculture 17, 2021)

Ground measurements on maize crops are shown in dark and those on coppice in light.

Protocol for additional nitrogen :

Bands	Surface area (m²)	Urea 46 applied (kg N/ha)
a	394	46.7
b	391	47.0
c1	381	48.3
c2	403	91.4

Breakdown of measures :

	Situation	Number
On coppice	ab: coppice segment surrounded by a and b	10
	b: segment on the edge of b	10
	c1: segment on the edge of c1	10
	c1c2: segment enclosed by c1 and c2	20
	c2: segment on the edge of c2	10
	Control: out-of-band segment with N	10
Grain maize	a	10
	b	10
	c1	10
	c2	10
	witness	9

Results obtained :

	Situation	Average NBI
On coppice	ab: coppice segment surrounded by a and b	24.1
	b: segment on the edge of b	28.1
	c1: segment on the edge of c1	30.6
	c1c2: segment enclosed by c1 and c2	31.9
	c2: segment on the edge of c2	25.8
	Control: out-of-band segment with N	25.3
Grain maize	a	27.3
	b	37.0
	c1	33.7
	c2	33.4
	witness	25.5

Analysis of variance and comparison of means tests showed no difference between the control and the other modalities, either for the coppice segments or for the maize.

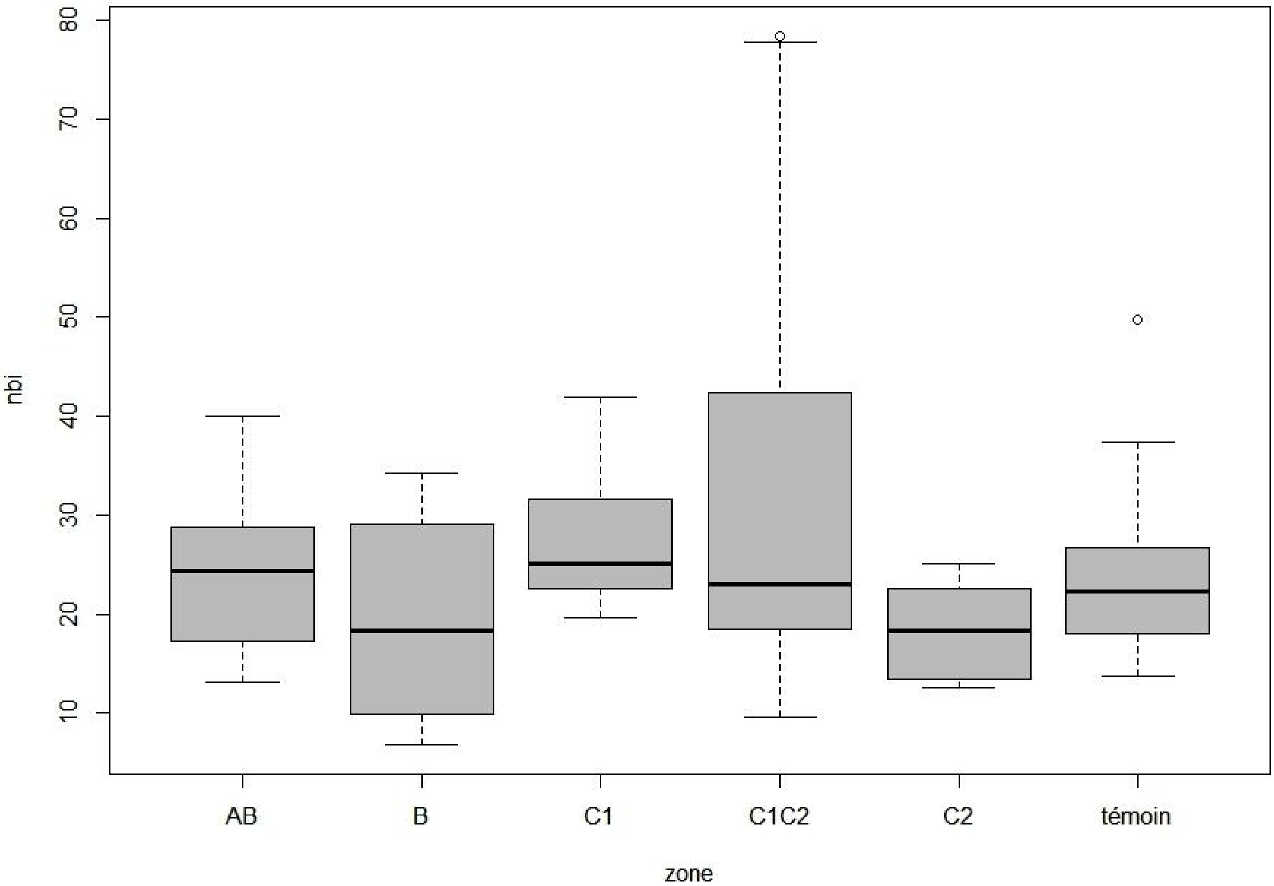


Figure 39: Boxplot of NBI measurements on coppice segments at 25/08/21

The boxplot representation visually confirms these results for the coppice segment measurements: there is no significant difference between the segments bordering the strips with additional nitrogen and the control segment.

In terms of maize cultivation within the strips, there was slightly more difference between the control with no additional nitrogen input and strips B, C1 and C2 with input but not with A.

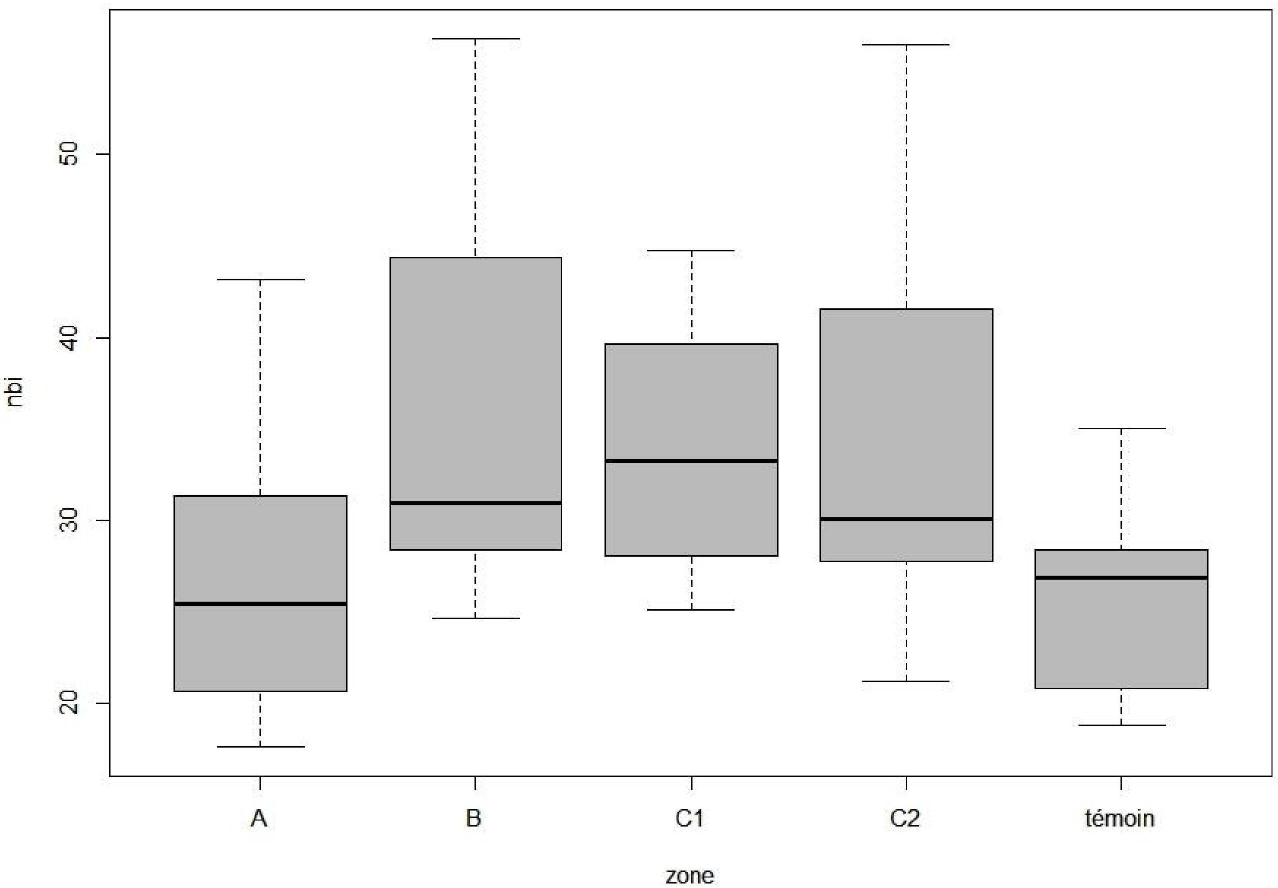


Figure 40: Boxplot of NBI measurements on maize grain strips with additional nitrogen applied on 25/08/21

4.5.4 Plant samples and harvest estimates for 2021.

We sampled maize cobs for yield measurements on 09/09/21, prior to harvest by the farmers on 15/10/21.

We took four samples for each of the study zones in our system:

- Band A = two manure applications in 2019 and 2021 and mineral fertilisation with agroforestry planting ;
- Band B = one manure application in 2020 and one liquid manure application in 2021 + mineral fertilisation for agroforestry planting
- zone C = mineral fertilisation in agroforestry plantations ;
- Zone D = mineral fertilisation in open fields.

Average yields - calculated at 25% moisture content - are :

- ✓ **78.2 q/ha for A ;**
- ✓ **74.1 q/ha for B ;**
- ✓ **74.6 q/ha for C ;**
- ✓ **63.7 q/ha for D ;**

giving an estimate of **69.3 q/ha for the plot as a whole**.

The ***yield declared*** by the farmer for the whole of the "La Terrière-Champ" plot is ***69 q (25%) /ha***.

Table 10: Assessment of yields for the four sample zones - grain maize 2021.

Zone	Sample	Yields	
		q (DM)/ha	q (25% hum)/ha
A	1	*52.6*	70.1
A	2	*59.9*	79.9
A	3	*49.6*	66.2
A	4	*72.5*	96.7
B	1	*61.3*	81.7
B	2	*71.3*	95.1
B	3	*24.1*	32.1
B	4	*65.5*	87.3
C	1	*62.6*	83.5
C	2	*52.0*	69.3
C	3	*68.1*	90.8
C	4	*41.0*	54.7
D	1	*44.1*	58.7
D	2	*55.2*	73.5
D	3	*43.2*	57.5
D	4	*48.6*	64.8

We can see that the difference between the agroforestry zones and the control zone in the open field is in line with the results given by the crop development images.

4.5.5 Review 2021.

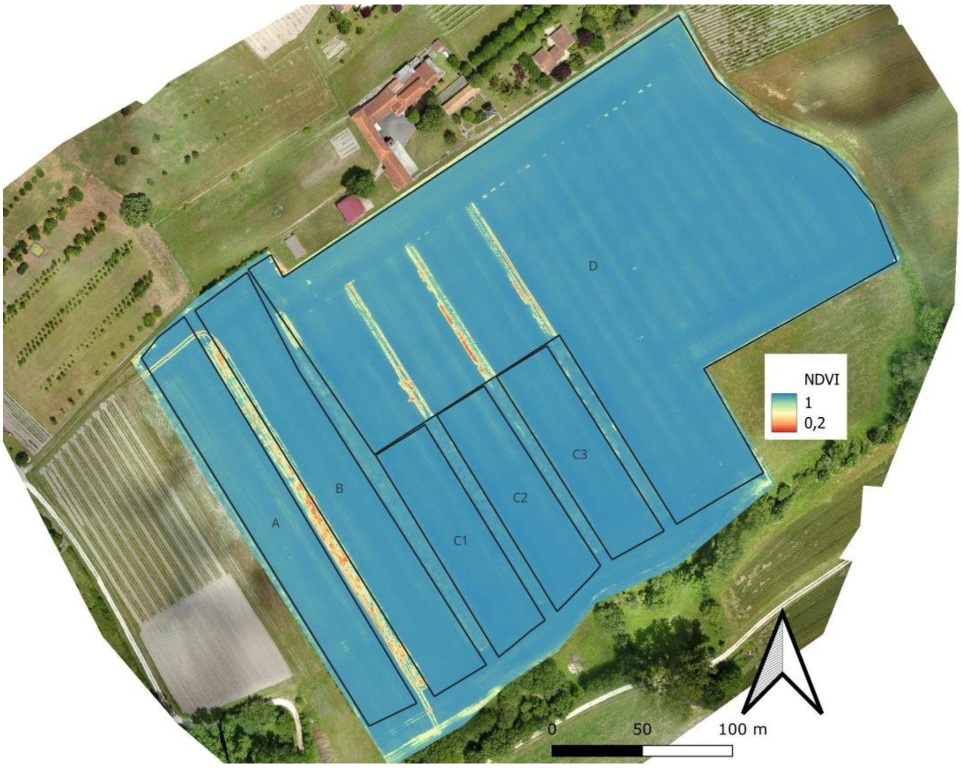
The results for the 2021 season confirm what was observed in 2019 and 2020:

- ✓ **No depressive effect but rather a positive one from the presence of linear coppices on crop development ;**
- ✓ **Little obvious effect of organic inputs in addition to fertilisation mineral.**

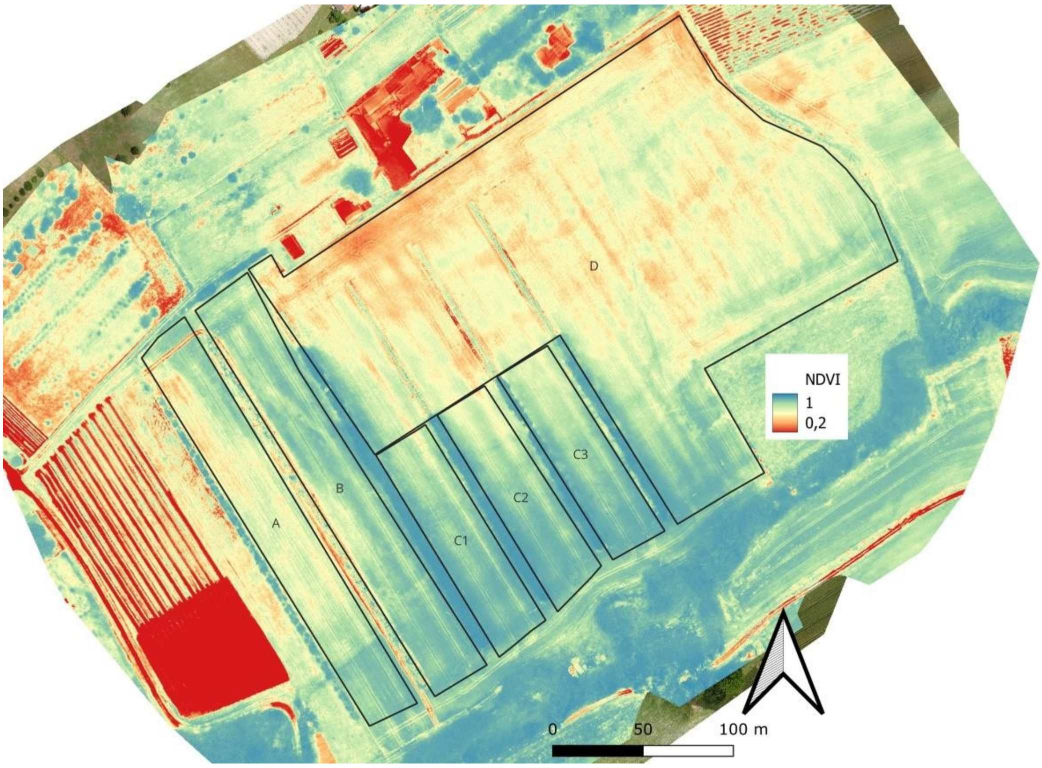
4.6 Cultural monitoring 2022

The 2022 crop monitoring was very brief, with two drone flights in May and June.

4.6.1 NDVI 2022 images



At 10/05/2022



At 07/06/2022

Figure 41: NDVI images of the 2022 soft winter wheat crop

(Source: Chamber of Agriculture 17, 2022)

NDVI statistics by zone in 2022 :

	NDVI1				CV2			
	A	B	C	D	A	B	C	D
10/05/2022	0.9377	0.9521	0.9613	0.9496	3.6 %	2.3 %	0.9 %	2.3 %
07/06/2022	0.7075	0.8060	0.8241	0.6299	15.2 %	8.9 %	7.6 %	10.5 %

[1] Average value. The value for C was calculated as a weighted average of the values for C1, C2 and C3. [2] Coefficient of variation: SD/Avg.

NDVI maps and statistics show the state of crop development:

- ✓ On 10/05, with all the mineral inputs and manure added, there was a very high density of plant biomass (NDVI > 0.9), with the following density rankings average biomass C>B>A>D.

- ✓ By 07/06, probably as a result of the climatic impact, the index values had fallen and were more varied. But the ranking of biomass densities remained the same: C > B > A > D.

On both monitoring dates, vegetative development was more marked in the three agroforestry zones.

4.6.2 Review 2022.

The ***yield declared*** by the farmer for the whole of the "La Terrière-Champ" parcel was **43 qx/ha** on 8 July 2022.

The yield value is entirely consistent with the NDVI levels observed in June 2022.

In 2022, there will be a positive effect on the development of agroforestry areas, but no significant effect on the area concerned from the addition of livestock effluent, which will probably come too late.

5 THE FERTILISING EFFECT OF RECYCLING ORGANIC EFFLUENT: FOUR YEARS OF MONITORING.

5.1 Method: fertilisation balance and crop modelling

A comparison of the various fertiliser inputs made to the plot over the 4 years of monitoring was carried out using the fertilisation balances proposed by the Clé de Sol ® fertilisation reasoning tool from the company I-cone (Isagri).

Yield results for each study area and for each year of monitoring were simulated using INRAe's STICS crop modelling tool (version 1.5.1) to help understand the nitrogen behaviour of effluent or mineral fertiliser inputs.
The parameters of STICS were based on the measurements presented above, while retaining overall consistency with my observations each year.
Without going into all the details of these settings and their construction, let's just mention a few important choices.

5.1.1 Choice of soil type.

the comparative analysis of different simulation scenarios showed that it was preferable to retain only one soil type for the four study areas, in order to achieve greater consistency between the observations obtained by remote sensing and the simulation results.
Furthermore, despite the division of the parcel space into distinct zones, the remote sensing maps show heterogeneity within each zone, which can be partly interpreted by variations in soil characteristics. The use of four distinct profiles does not improve the consistency or accuracy of the simulations.
We must also take into account the topographical gradient according to the north-south orientation of the plot - see chapter 4.2 - which is another major cause of heterogeneity.

The profile chosen is that of a calcareous clay-loam soil with two horizons of 20 and 35 cm, i.e. a total depth of 55 cm, as presented in chapter 4.2.

The characteristics required for the simulation were assessed on the basis of measurements taken in 2019, 2021 and 2022, particularly those in zone A.

This soil profile contains between 90 and 100 mm of useful reserve.

The simulations for each zone were sequenced so that the water, carbon and nitrogen balances were carried over from one cropping season to the next.

For the Soil Key parameterisation, we have identified four different types based on physico-chemical analyses, for a precise assessment of soil PK fertility.

5.1.2 Climatological situation

Climatological data is from the Météo-France station in Cognac (16).

These values are fairly representative in terms of temperature and overall radiation, but may differ from the farm's situation in terms of rainfall and evapotranspiration data.

5.1.3 Varietal matches

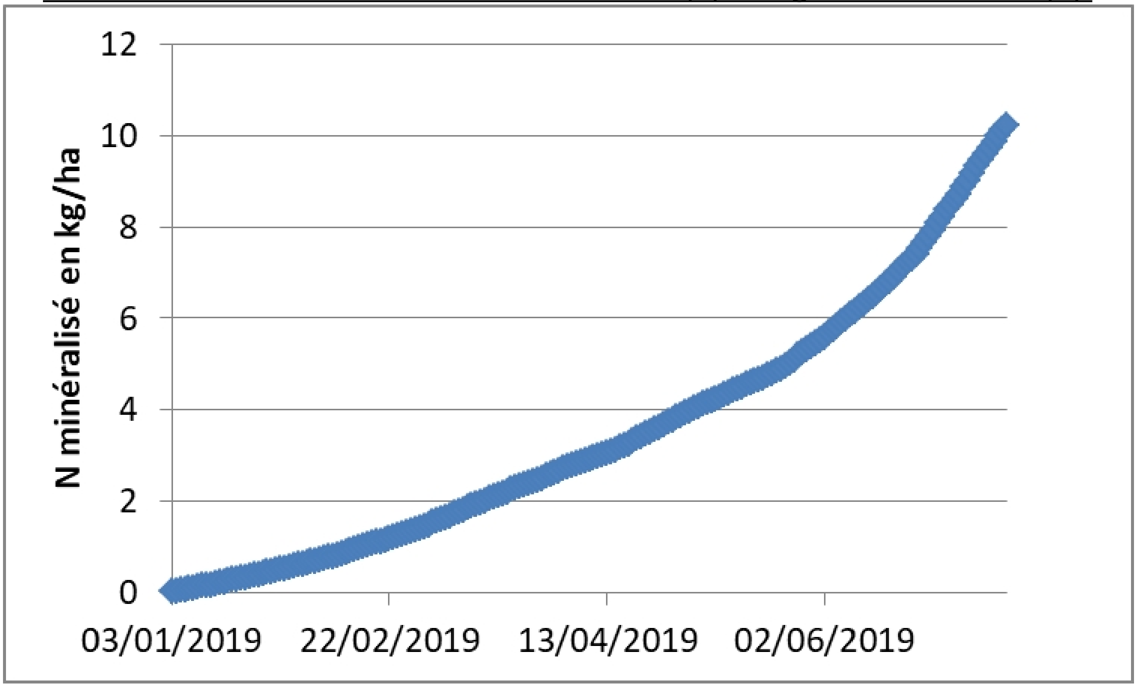
Soft Winter Wheat and Grain Maize varieties sown in the 2019 to 2010 growing seasons are as follows 2022 do not exist in the original STICS variety database.
They have either been reconstituted or replaced by an older variety with fairly similar properties.
This is a possible cause of distortion between simulations and field observations.

5.2 This is shown by the simulations of the soil/crop system on the 'Terrière-Champ' plot.

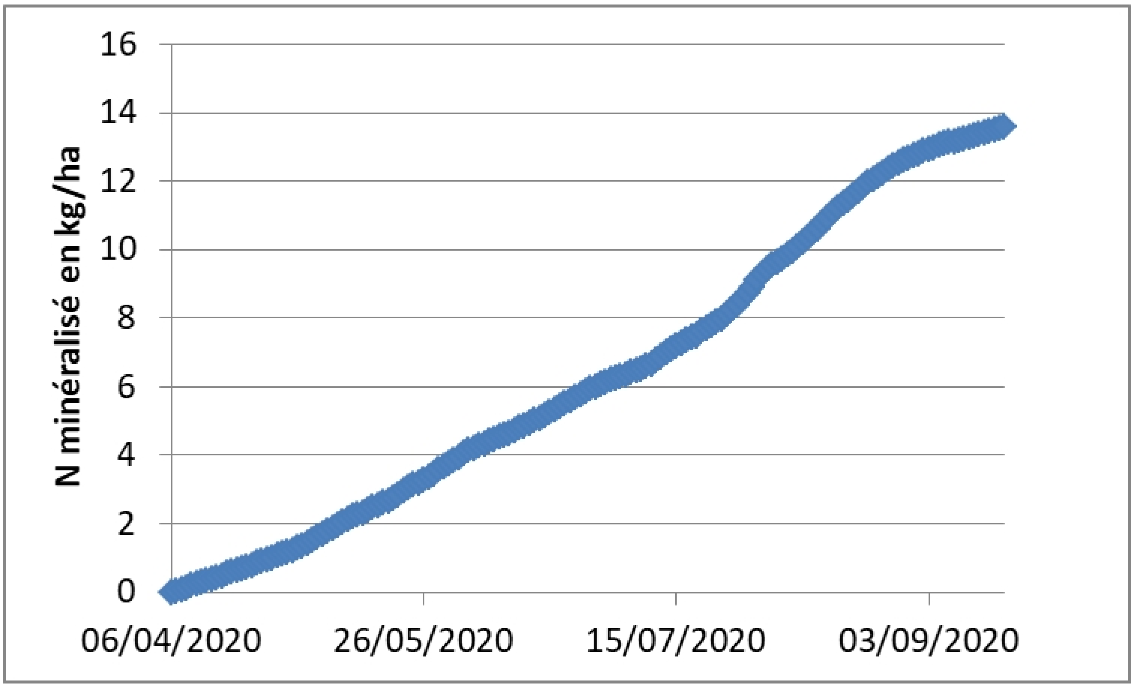
5.2.1 Mineralisation of nitrogen from soil organic matter

If we consider the amount of nitrogen mineralised from soil organic matter between sowing and harvesting dates as that available to the crop, the mineralisation curves obtained by simulation for each of the cropping seasons show that **the supply of nitrogen from the soil is around 15 kg N/ha**.

Figure 42: Nitrogen mineralisation curves for soil organic matter between sowing and harvest imulated for soft winter wheat 2019 (a) and grain maize 2020 (b).



a)



b)

This is the value used to calculate fertilisation balances.

Compared with the values in Figure 24, this is a low value among those that have been calculated from kinetic measurements.
It is possible to explain this difference by an increase in the effect of the mineralization kinetics protocol, which describes more favourable mineralization conditions than those corresponding to the "Terrière - Champ" plot, in a dry clay context.

5.2.2 Situation of the soil mineral nitrogen stock at the start of the balance sheet.

The soil mineral nitrogen stock values required for the fertilisation balance were established at :

1. **45 kg N/ha for the 2019 soft winter wheat crop** - *the "pea" precedent and measurements taken at the end of 2019 have been taken into account in calculating this value;*
2. **25 kg N/ha for the 2020 grain maize crop** - *simulation values and measurements taken at the end of 2019 were used to calculate this value;*
3. **10 kg N/ha for grain maize 2021** - *based on the values of the chained simulations ;*
4. **21 kg N/ha for the 2022 soft winter wheat crop** - *based on the values of the chained simulations ;*

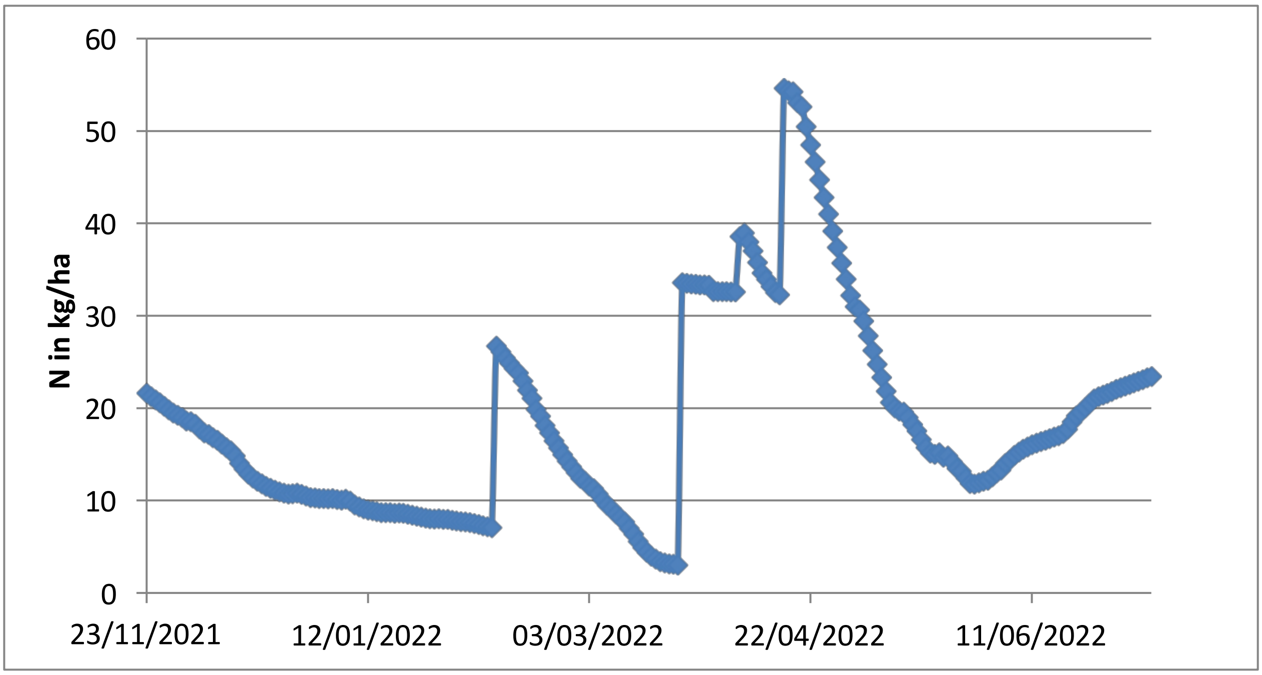


Figure 43: Example of a simulation of the soil mineral nitrogen stock between the opening and closing of the balance sheet for soft winter wheat production in 2022.

5.3 Study of fertilisation balances

5.3.1 Soft winter wheat 2019

See figure 44.

The simulated yields obtained by modelling - *see illustration 44* - are as follows
the following order of parcels: C>B>D>A.
These results are consistent with observations made by remote sensing - see chapter 4.3.1 - and to a lesser extent with yield measurements - see chapter 4.3.2.

The elementary balance table shows that

- The N balance is slightly positive for study zone A - which received manure for the 2019 crop - and slightly negative for the other zones.
- The P balance tends to be in deficit - for zones A, B and C - or in balance - for zone D.
- The K balance is slightly positive for Zone A and balanced for the other zones.

Calculating the balances using the "Soil key" tool shows that zone A, which received the manure, would have benefited from an additional input of

- 24 kg N/ha
- 17 kg P2O5/ha
- 20 kg K2O/ha

The lower yields in this zone compared to the other zones explain the higher costs.
balance sheet in N and K profit.

Two other scenarios were simulated for zone A with STICS in order to assess the effectiveness of the nitrogen fertilisation itinerary:

- a scenario with an earlier application date of 5 February to test the effect of an earlier application date.
  more advanced mineralisation ;
- a scenario with 40 mm of irrigation on 15 May 2019 to improve plant nutrition.

The results obtained :

Scenario	**A initial with slurry input to 5 March**	**A with earlier contribution to 5 February**	**A with contribution on 5 March and 40 mm irrigation**
Simulated yield in q/ha	50.4	49.7	65.2
Addition of nitrogen contained under mineral form in slurry in kg/ha	14	14	14
Nitrogen from nitrogen mineralisation of slurry in kg/ha	33	33	33
Simulated cumulative leaching in kg N/ha	7	7	7

The best yield simulation is obtained significantly by introducing water by irrigation.

There has been no change in the assessment of additional nitrogen in both
other scenarios, nor of the assessment of the value of leaching.

Examination of the simulation curves for nitrogen uptake by the crop according to the three scenarios - *Figure* 45 - shows **two periods of higher uptake for the scenario with irrigation**, which explains the higher yield.

CLÉ de SOL

Exploitation : EARL MANICOT
Campagne : 18/19

Réalisé - Balance de fertilisation

Libellé	SAU	Parcellaire Analyse - Date	Culture	Rdt	Éléments fertilisants	Besoins kg/ha	Fournitures kg/ha	Apports Org. kg/ha	Apports Min. kg/ha	Total Apports kg/ha	Solde kg/ha
A	0,96	05/02/19	Blé amélio d'hiver 3,	50,0	N	210	65	24	157	181	36
Ilot , parcelle			grain + paille		P2O5	60	12	17	0	17	-31
			Dérobée :		K2O	90	90	20	0	20	20
					CaO	1 355	500	20	0	20	-835
					MgO	26	0	6	0	6	-20
B	0,97	01/02/19	Blé amélio d'hiver 3,	55,0	N	230	65	0	157	157	-8
Ilot , parcelle			grain + paille		P2O5	66	0	0	0	0	-66
			Dérobée :		K2O	99	99	0	0	0	0
					CaO	1 323	500	0	0	0	-823
					MgO	27	0	0	0	0	-27
C	1,67	01/02/19	Blé amélio d'hiver 3,	56,0	N	233	65	0	157	157	-12
Ilot , parcelle			grain + paille		P2O5	67	13	0	0	0	-54
			Dérobée :		K2O	101	101	0	0	0	0
					CaO	1 525	500	0	0	0	-1 025
					MgO	32	32	0	0	0	0
D	4,74	01/02/19	Blé amélio d'hiver 3,	54,0	N	226	65	0	157	157	-4
Ilot , parcelle			grain + paille		P2O5	65	65	0	0	0	0
			Dérobée :		K2O	97	97	0	0	0	0
					CaO	1 390	500	0	0	0	-890
					MgO	37	37	0	0	0	0

* compte tenu de l'application du CAU

Figure 44: Fertilisation balance for the four study zones for the "La Terrière-Champ" soft wheat plot Winter 2019.

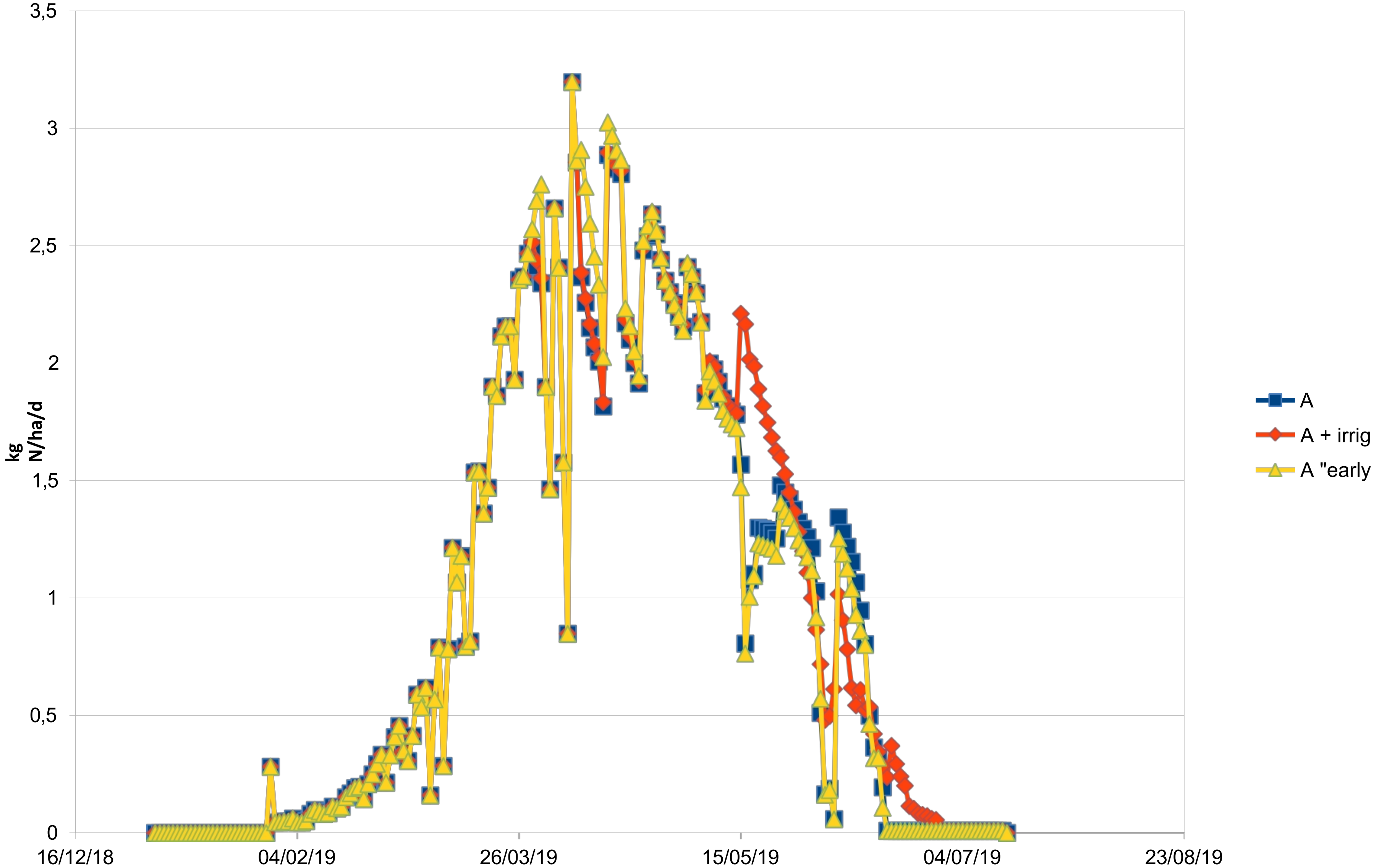


Figure 45: STICS evaluation of the nitrogen absorbed by the 2019 wheat crop in the three scenarios "A initial", "A with irrigation" and "A with earlier manure application".

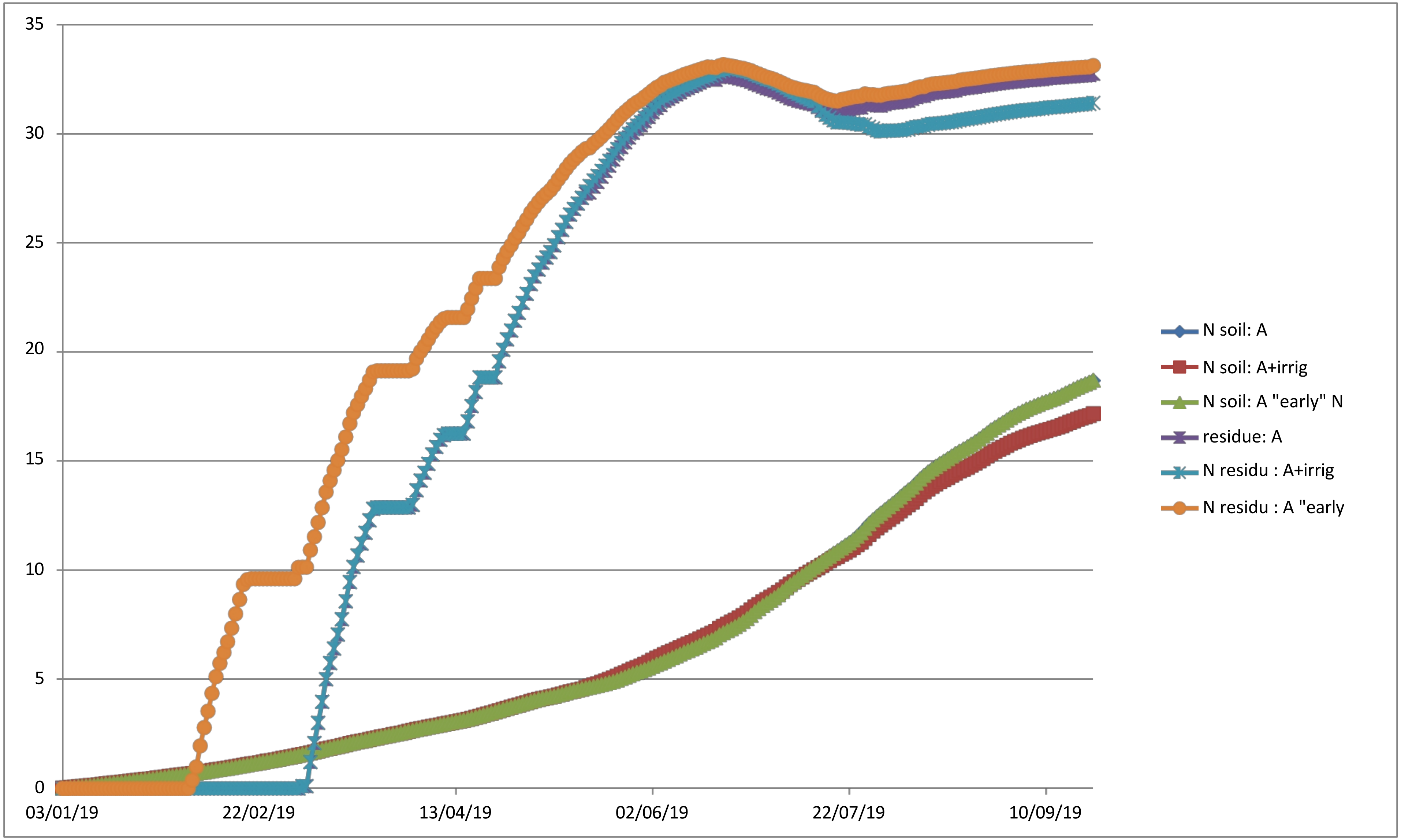


Figure 46: STICS evaluation of nitrogen mineralisation from soil organic matter (soil N) and the organic fraction of liquid manure (residual N) for the 2019 wheat crop in the three "A initial", "A with irrigation" and "A with earlier liquid manure" scenarios.

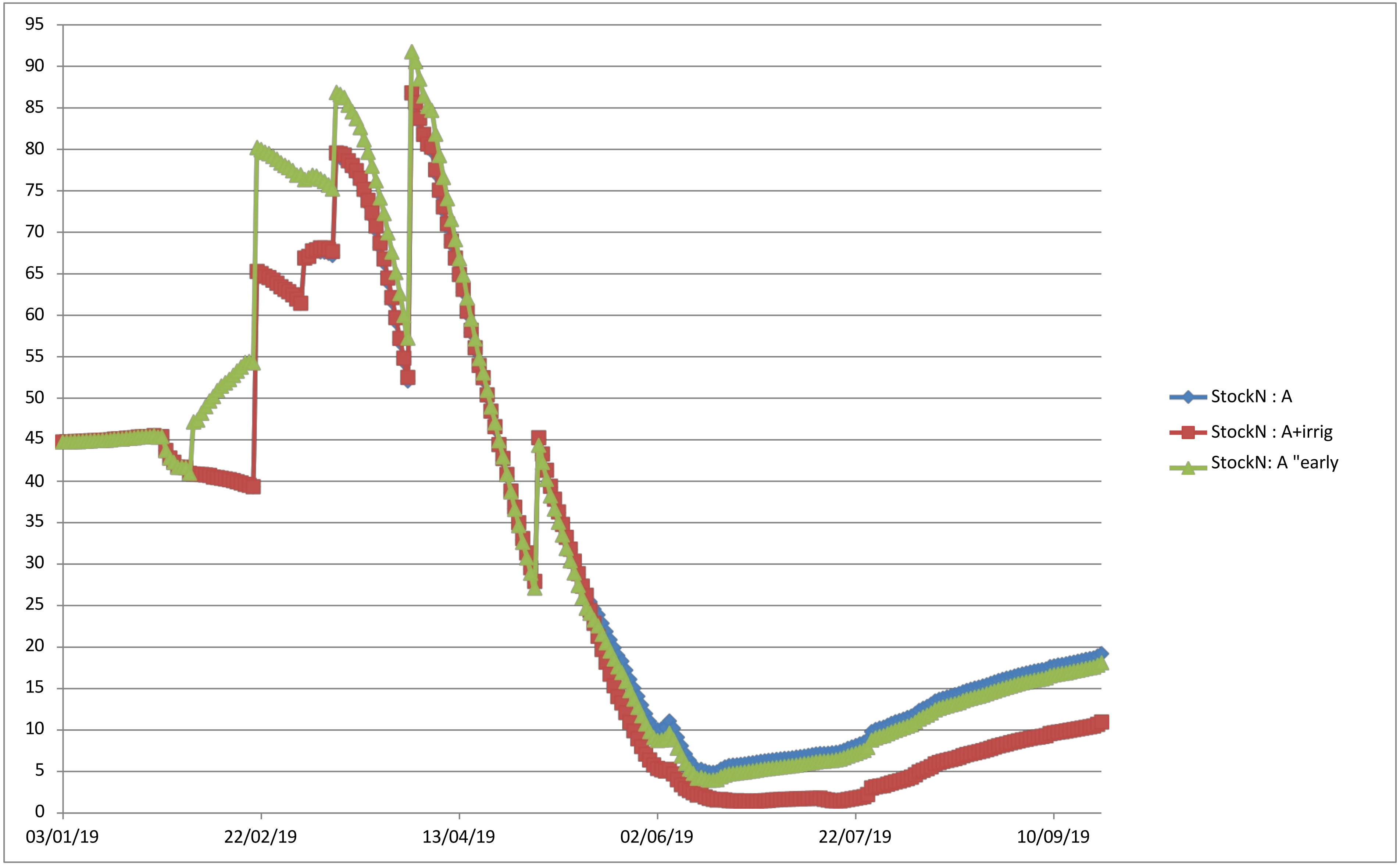


Figure 47: STICS evaluation of the soil mineral nitrogen stock (StockN) for the 2019 wheat crop in the three scenarios "A initial", "A with irrigation" and "A with earlier manure application".

Examination of the simulation curves for the mineralisation of organic nitrogen in soil or slurry as a function of the three scenarios - *Figure 46* - shows that the mineralisation results are virtually identical in all three scenarios.

Examination of the soil mineral nitrogen stock simulation curves according to the three scenarios - *Figure 47* - shows the best use of the stock for the scenario with irrigation.

The simulation results show that it is the water conditions in the soil that influence the effectiveness of additional nitrogen.

It should also be noted that the higher simulated yield values in zones B, C and D - to match remote sensing observations - were obtained with a corrective water input corresponding to

- ✓ ***or to a more favourable distribution of moisture in the soil as a result of the topography ;***
- ✓ ***or the protective effect of coppice strips in zones B and C.***

The total nitrogen input from the slurry is **63 kg N/ha** . On the basis of the simulations, and taking into account the evaluation of 8 kg/ha from the manure lost through volatilisation, 14 + 33 - 8 = **39 kg/ha are available for the crop** during development, i.e. almost **62% of the** total input.

However, the limiting water conditions meant that not all the nitrogen could be used.

5.3.2 Grain maize 2020

See figure 48.

The simulated yields obtained by modelling follow the following plot order: B>A>C>D.
These results are consistent with observations made by remote sensing - see section 4.4.1.

The elementary balance table shows that

- The N balance is positive for all the study areas, in particular for the two mineral fertilisation-only zones, C and D.
- The P balance sheet is largely positive for all zones.
- The K balance is slightly positive for zones A and B, negative for C and positive for D.

Calculating the balances using the "Soil key" tool shows that zone B, which received the input of manure, would have benefited from an additional contribution of

- 12 kg N/ha
- 16 kg P2O5/ha
- 47 kg K2O/ha

The STICS simulations carried out for the four zones A, B, C and D show that

- The additional nitrogen input in zone B from manure is estimated at 8 kg/ha in immediate mineral form plus 5 kg/ha from mineralisation of manure (with residues), i.e. 13 kg N/ha - *see figure 50* - which is consistent with the "soil key" balance;
- The soil supply simulated by STICS is estimated at 23 kg N/ha ;
- Simulations of nitrogen uptake in each zone - *Figure 49* - show a slightly higher uptake in zone B in the second half of crop development, which is confirmed by soil nitrogen stock assessments - *Figure 51* - which fall more sharply in zone B from mid-July.

CLÉ de SOL

Exploitation : EARL MANICOT
Campagne : 19/20

Réalisé - Balance de fertilisation

Parcellaire Libellé	SAU	Analyse - Date	Culture	Rdt	Éléments fertilisants	Besoins kg/ha	Fournitures kg/ha	Apports Org. kg/ha	Apports Min. kg/ha	Total Apports kg/ha	Solde kg/ha
A	0,96	05/02/19	Maïs	60,0	N	153	25	0	141	141	13
Ilot , parcelle			grains <100 q/ha		P2O5	42	54	0	124	124	136
			Dérobée :		K2O	30	43	0	0	0	13
					CaO	1 302	513	0	0	0	-789
					MgO	25	4	0	0	0	-21
B	0,97	01/02/19	Maïs	64,0	N	162	25	12	141	153	16
Ilot , parcelle			grains <100 q/ha		P2O5	45	0	16	124	140	95
			Dérobée :		K2O	32	0	47	0	47	15
					CaO	1 269	500	62	0	62	-707
					MgO	26	0	14	0	14	-11
C	1,67	01/02/19	Maïs	55,0	N	142	25	0	140	140	24
Ilot , parcelle			grains <100 q/ha		P2O5	39	8	0	123	123	93
			Dérobée :		K2O	28	5	0	0	0	-23
					CaO	1 463	500	0	0	0	-963
					MgO	28	28	0	0	0	0
D	4,74	01/02/19	Maïs	50,0	N	130	25	0	140	140	35
Ilot , parcelle			grains <100 q/ha		P2O5	35	35	0	123	123	123
			Dérobée :		K2O	25	25	0	0	0	0
					CaO	1 333	500	0	0	0	-833
					MgO	33	33	0	0	0	0

* compte tenu de l'application du CAU

Figure 48: Fertilisation balance for the four study zones on the "La Terrière-Champ" plot for the 2020 grain maize crop.

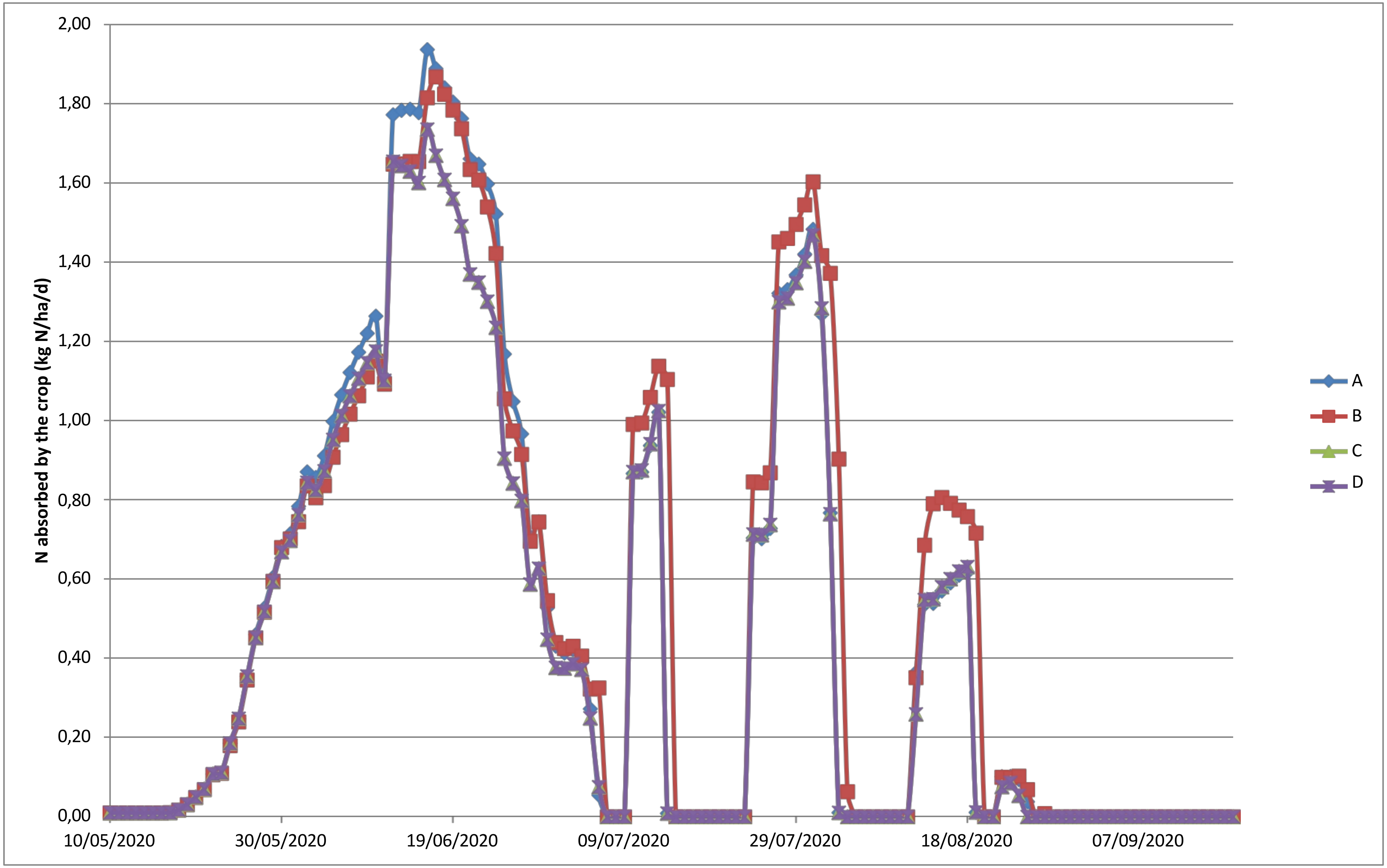


Figure 49: STICS evaluation of nitrogen absorbed by the 2020 grain maize crop for zones A, B, C and D.

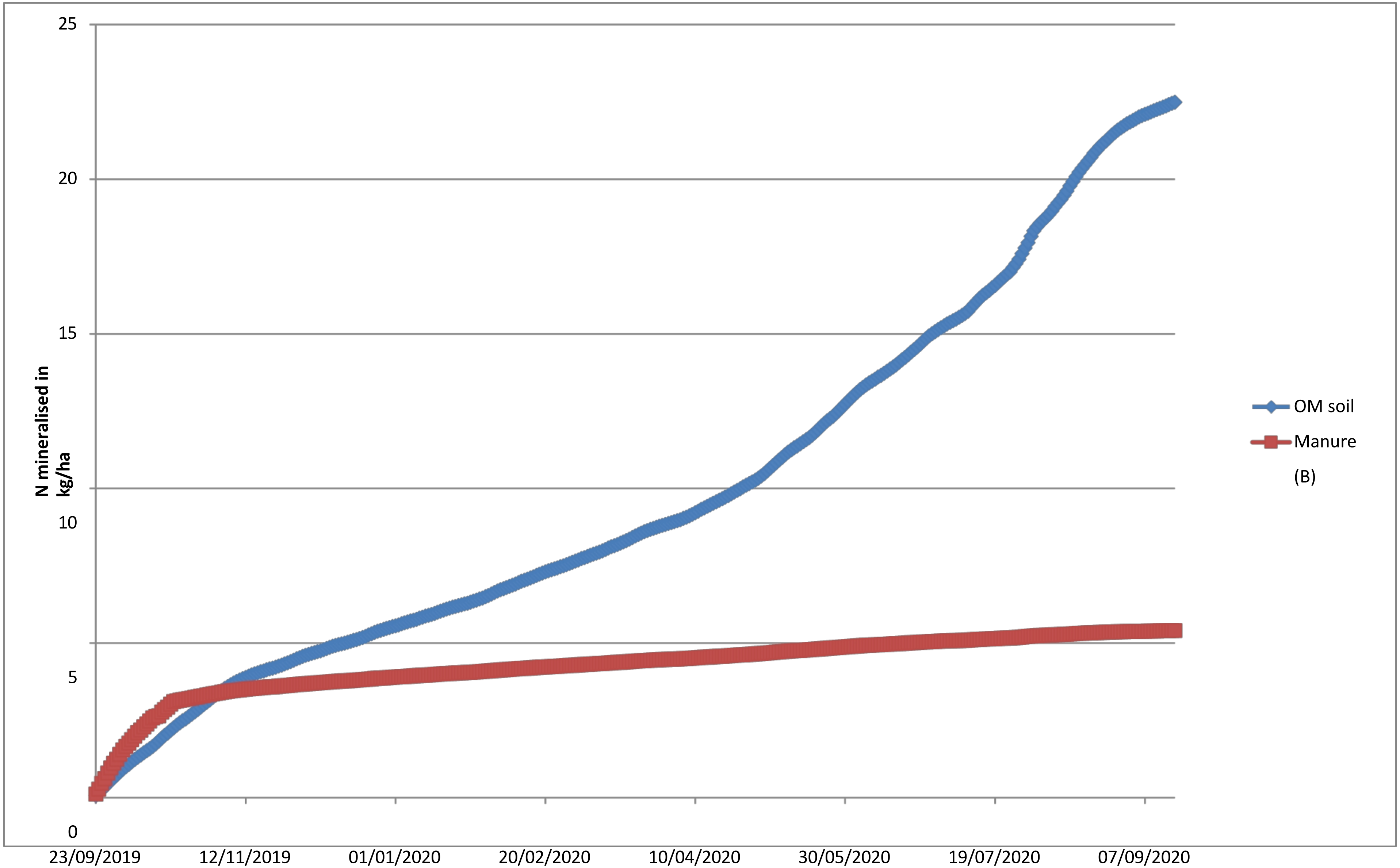


Figure 50: STICS evaluation of nitrogen mineralisation from soil organic matter (SOM) and manure (B) for the 2020 grain maize crop.

Figure 51: STICS evaluation of soil mineral nitrogen stock under 2020 grain maize for the four zones A, B, C and D.

In 2020, the addition of manure had no real effect on nitrogen fertilisation, compared with the soil supply or the rest of the fertilisation programme. The most significant contribution is that of potassium.

The total nitrogen input from manure is **77 kg N/ha**. On the basis of simulations, **13 kg/ha of manure are supplied to the crop**, but 8 kg/ha are lost to volatilisation, leaving only **5 kg/ha for crop development**, i.e. around **6%** of the total input.

It is also likely that the manure had an amending effect, improving the condition of the soil in zone B, which could explain the homogeneity of plant development measured by remote sensing.

Note that the simulated yield values for the four zones A, B, C and D were obtained with the same corrective water input, which probably corresponds to local rainfall events not taken into account by the reference weather station.

5.3.3 Grain maize 2021

See figure 52.

The simulated yields obtained by modelling follow the following plot order: B>A>C/D.
These results are fairly consistent with the observations made by remote sensing - see chapter. 4.5.2. - and with the 2021 harvest estimate - see section 4.5.4.

The elementary balance table shows that

- The N balance is positive for all the study areas.
- The P balance sheet is largely positive for all zones.
- The K balance is slightly positive for zones A and B thanks to the manure input, while it is negative for zone C and balanced for zone D.

Calculating the balances using the "soil key" tool shows that zones A and B, which received manure, would have benefited from an additional input of

- 20 kg N/ha
- 14 kg P2O5/ha
- 18 kg K2O/ha

The STICS simulations carried out for the four zones A, B, C and D show that

- The additional nitrogen input in zones A and B from liquid manure is estimated at 18 kg/ha in immediate mineral form plus 18 kg/ha from the mineralisation of manure and residues, i.e. 36 kg N/ha - *see figure 54* - which is greater than that proposed in the "Clé de sol" balance sheet;
- The soil supply simulated by STICS is estimated at 12 kg N/ha ;
- Simulations of nitrogen uptake in each zone - *Figure 53* - show slightly higher uptake.
    - for Zone B over the July period,
    - for Zone A at the beginning of August
- Soil nitrogen stock assessments - *Figure 55* - show that manure application to A and B leads to an increase in soil nitrogen stock that is 10 units higher than that of C and D. This difference is maintained until the end of the cycle. The relative increase in nitrogen stock as a result of the 2021 crop is of the order of 20 kg/ha.

The total nitrogen input from slurry is **38 kg N/ha**. Based on the simulations, **36 kg/ha are available for the crop** as it develops. **Volatilisation of** nitrogen from slurry was estimated at **10 kg/ha** in the simulations. **The amount of nitrogen supplied by liquid manure that is actually useful is 26 kg/ha**, i.e. around **68% of the total supply**.

CLÉ de SOL

Exploitation : EARL MANICOT
Campagne : 20/21

Réalisé - Balance de fertilisation

Libellé	SAU	Analyse - Date	Culture	Rdt	Éléments fertilisants	Besoins kg/ha	Fournitures kg/ha	Apports Org. kg/ha	Apports Min. kg/ha	Total Apports kg/ha	Solde kg/ha
A	0,96	05/02/19	Maïs	55,0	N	136	15	20	139	158	37
Ilot , parcelle			grains 100-120 q/ha		P2O5	39	39	14	113	127	128
			Dérobée :		K2O	28	28	18	0	18	19
					CaO	1 263	500	13	0	13	-750
					MgO	24	0	7	0	7	-16
B	0,97	01/02/19	Maïs	56,5	N	139	15	20	138	158	34
Ilot , parcelle			grains 100-120 q/ha		P2O5	40	40	14	111	126	126
			Dérobée :		K2O	28	28	18	0	18	18
					CaO	1 232	500	13	0	13	-720
					MgO	24	0	7	0	7	-17
C	1,67	01/02/19	Maïs	51,0	N	132	15	0	138	138	21
Ilot , parcelle			grains <100 q/ha		P2O5	36	36	0	111	111	112
			Dérobée :		K2O	26	5	0	0	0	-21
					CaO	1 419	500	0	0	0	-919
					MgO	27	21	0	0	0	-6
D	4,74	01/02/19	Maïs	51,0	N	132	15	0	138	138	21
Ilot , parcelle			grains <100 q/ha		P2O5	36	36	0	111	111	112
			Dérobée :		K2O	26	26	0	0	0	1
					CaO	1 293	500	0	0	0	-793
					MgO	33	33	0	0	0	0

* compte tenu de l'application du CAU

Figure 52: Fertilisation balance for the four study zones on the "La Terrière-Champ" plot for the 2021 grain maize crop.

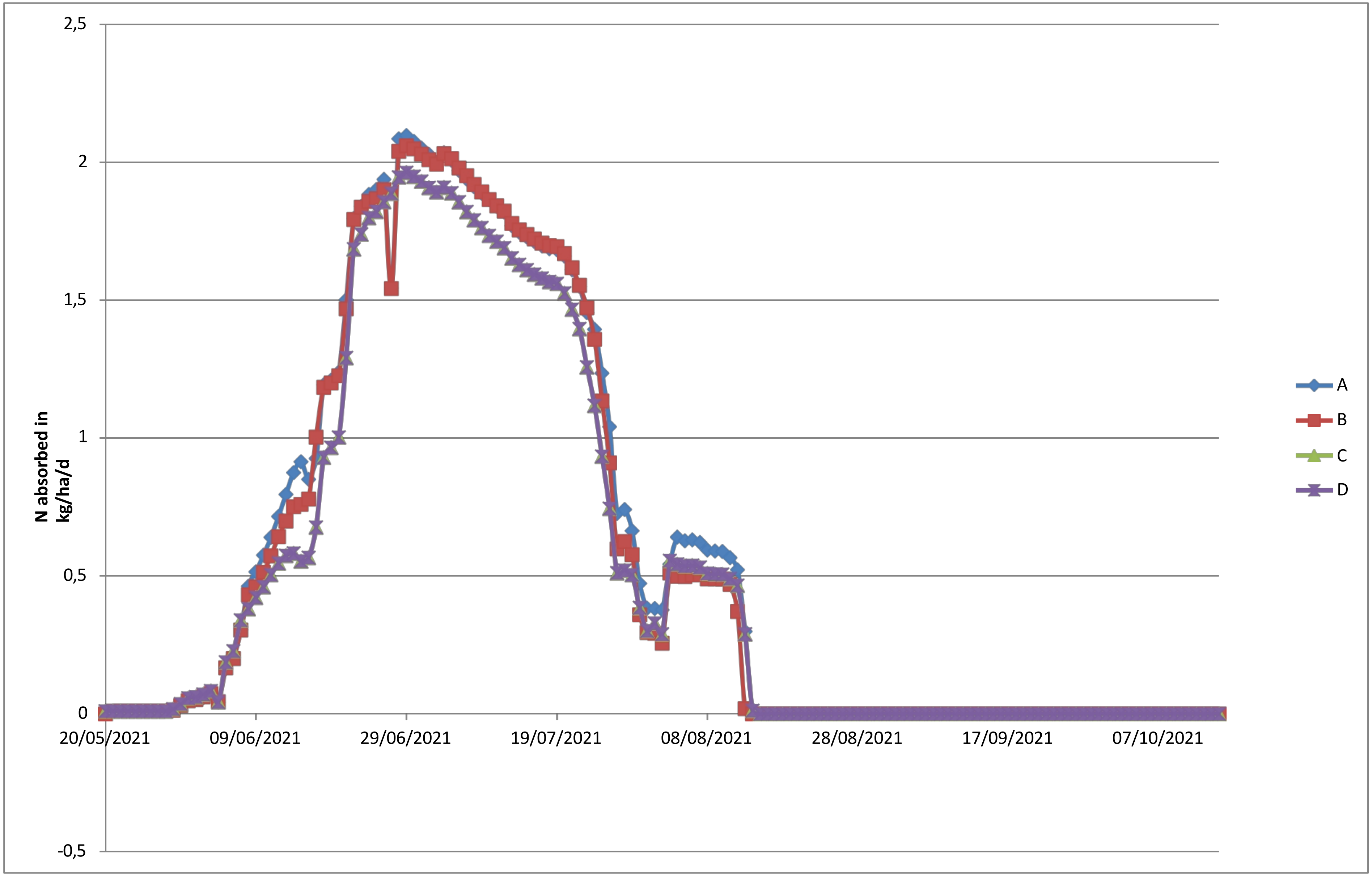


Figure 53: STICS evaluation of nitrogen absorbed by the 2021 grain maize crop for zones A, B, C and D.

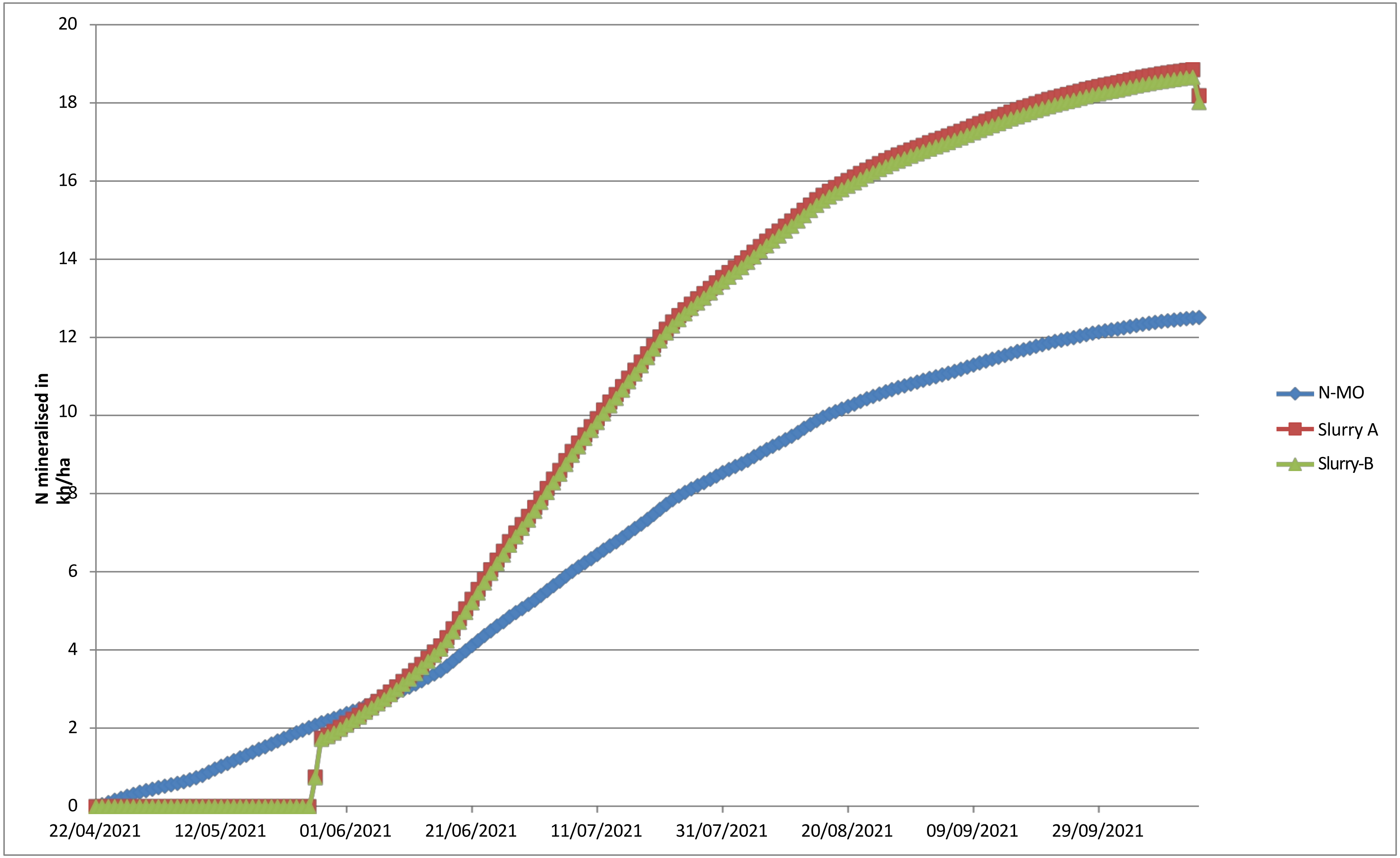


Figure 54: STICS evaluation of nitrogen mineralisation from soil organic matter (N-MO) and manure (zones A and B) for the 2021 grain maize crop.

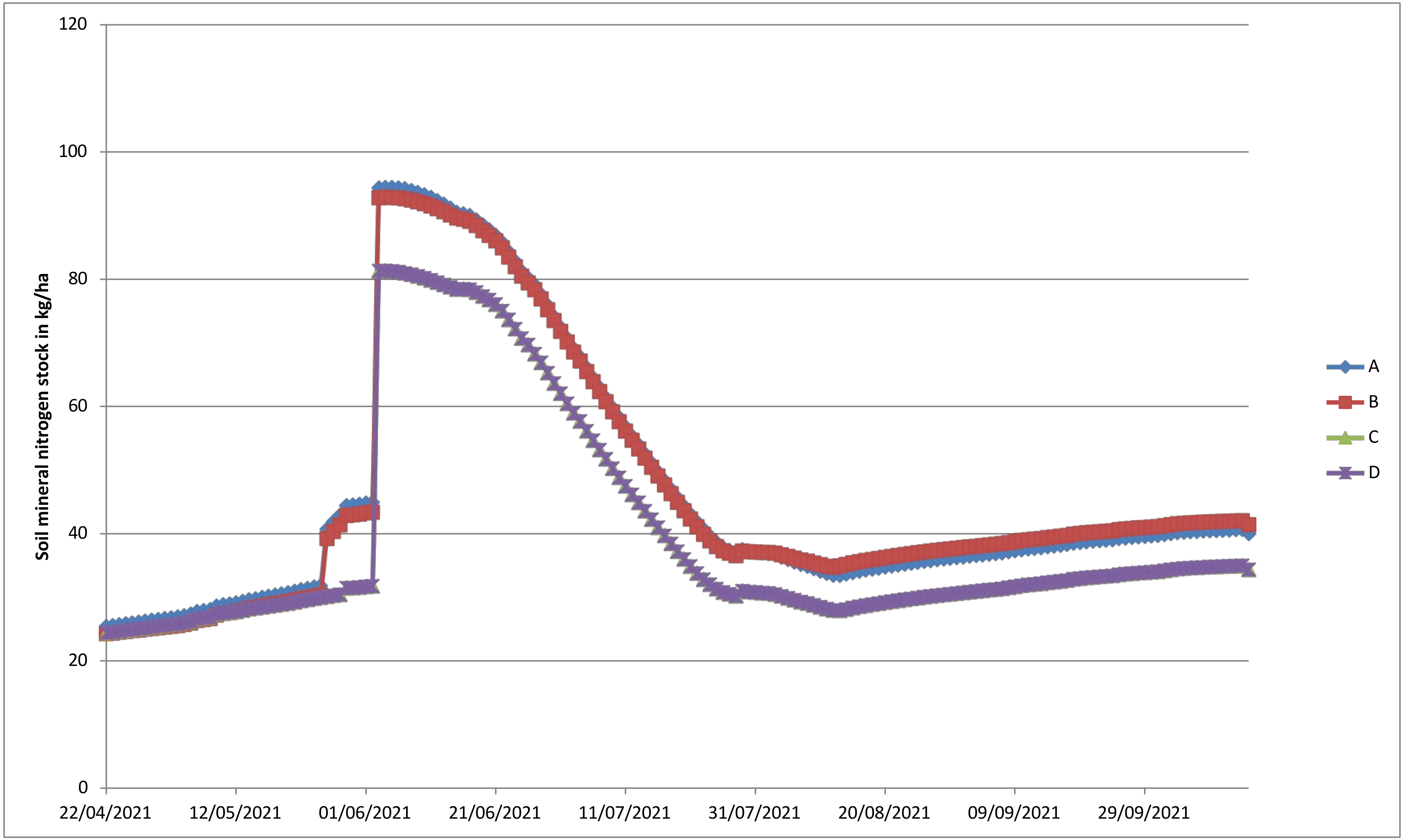


Figure 55: STICS evaluation of soil mineral nitrogen stock under the 2021 grain maize crop for the four zones A, B, C and D.

As in the previous growing season, the simulated yield values for the four crops were as follows zones A, B, C and D were obtained with the same amount of corrective water.

5.3.4 Soft winter wheat 2022

See figure 56.

The simulated yields obtained by modelling follow the following plot order: C>B>A>D.
These results are consistent with observations made by remote sensing - see section 4.6.1.

The elementary balance table shows that

- The N balance is slightly positive for zone A and negative for the other zones. study.
- The P and K balances are largely positive for all zones.

Calculation of the balances using the "Soil key" tool shows that zone A, with a manure application, would have benefited from an additional application of

- 17 kg N/ha
- 16 kg P2O5/ha
- 20 kg K2O/ha

The STICS simulations carried out for the four zones A, B, C and D show that

- The additional nitrogen input in zone A from liquid manure is estimated at 15 kg/ha in immediate mineral form plus 30 kg/ha from the mineralisation of manure and residues, i.e. 45 kg N/ha - *see figure 58* - which is greater than that proposed in the "Clé de sol" balance sheet;
- The soil supply simulated by STICS is estimated at 13 kg N/ha ;
- Simulations of nitrogen uptake in each zone - *Figure 57* - show higher uptake in zone A for the period April to May.
- Soil nitrogen stock assessments - *Figure 59* - show that manure applied to A on 06/04/22 increased soil nitrogen stock by up to 12 units compared with B, C and D. Post-harvest, the difference was 7 kg/ha.

The total nitrogen input from slurry is **47 kg N/ha**. Based on the simulations, **45 kg/ha are available for the crop** as it develops. **Volatilisation of** nitrogen from slurry was estimated at **9 kg/ha** in the simulations. **The amount of nitrogen supplied by liquid manure that is actually useful is 36 kg/ha**, i.e. around **76% of the total supply**.

As for the 2019 soft winter wheat crop, the simulated yield values have been adjusted on the basis of remote sensing observations using corrective water inputs to reflect the heterogeneity of water behaviour within the plot.
As in 2019, soil water conditions will influence the effectiveness of the additional nitrogen application.
As in 2019, **areas planted with agroforestry generally have a slightly higher yield estimate**.

CLÉ de SOL

Exploitation : EARL MANICO
Campagne : 21/2

Réalisé - Balance de fertilisation

Libellé	SAU	Analyse - Date	Culture	Rdt	Éléments fertilisants	Besoins kg/ha	Fournitures kg/ha	Apports Org. kg/ha	Apports Min. kg/ha	Total Apports kg/ha	Solde kg/ha
A	0,96	01/05/21	Blé amélio d'hiver 3,	44,0	N	169	26	17	133	150	7
Ilot , parcelle			grain + paille		P2O5	53	63	16	52	67	77
			Dérobée :		K2O	79	91	20	51	71	83
					CaO	1 425	508	14	0	14	-903
					MgO	25	5	8	0	8	-12
B	0,97	01/05/21	Blé amélio d'hiver 3,	44,5	N	171	26	0	133	133	-12
Ilot , parcelle			grain + paille		P2O5	53	63	0	52	52	61
			Dérobée :		K2O	80	92	0	51	51	63
					CaO	1 538	508	0	0	0	-1 030
					MgO	29	29	0	0	0	0
C	1,67	01/05/21	Blé amélio d'hiver 3,	45,5	N	174	26	0	133	133	-15
Ilot , parcelle			grain + paille		P2O5	55	55	0	52	52	52
			Dérobée :		K2O	82	82	0	51	51	51
					CaO	1 538	500	0	0	0	-1 038
					MgO	29	29	0	0	0	0
D	4,74	01/05/21	Blé amélio d'hiver 3,	42,0	N	162	26	0	133	133	-3
Ilot , parcelle			grain + paille		P2O5	50	50	0	52	52	51
			Dérobée :		K2O	76	76	0	51	51	51
					CaO	1 489	500	0	0	0	-989
					MgO	29	29	0	0	0	0

* compte tenu de l'application du CAU

Figure 56: Fertilisation balance for the four study zones for the "La Terrière-Champ" soft wheat plot Winter 2022.

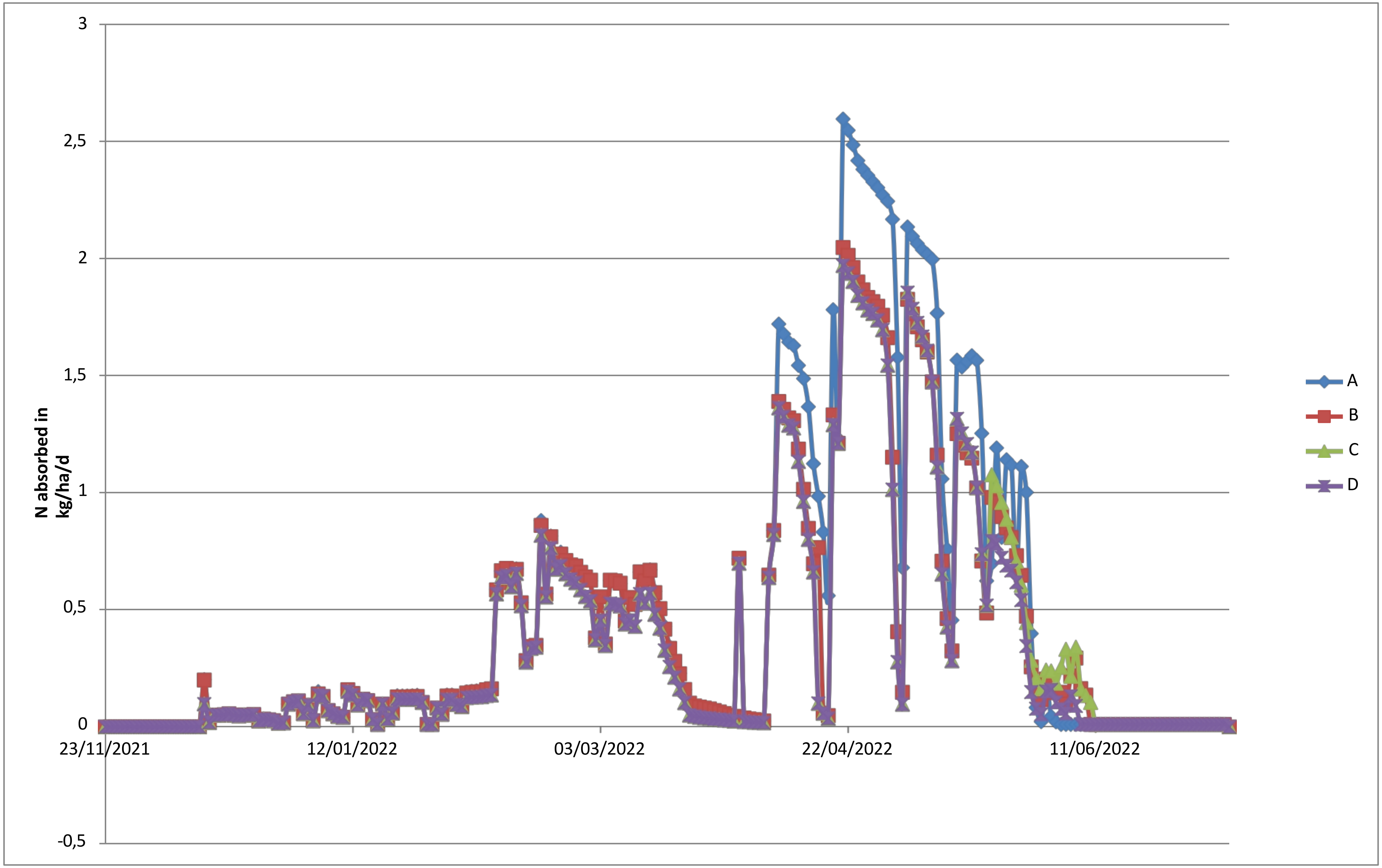


Figure 57: STICS evaluation of the nitrogen absorbed by the soft wheat crop in 2022 for zones A, B, C and D.

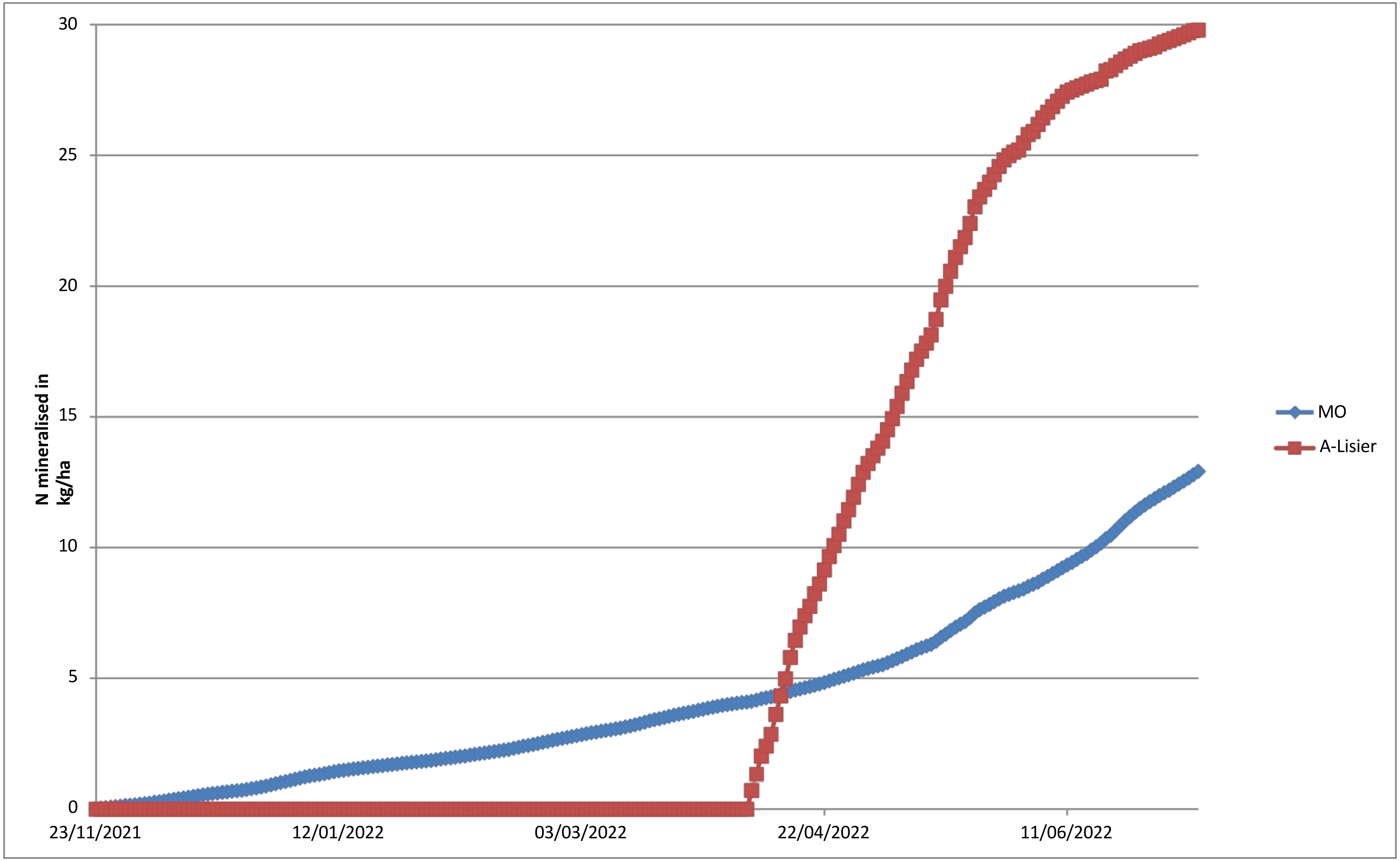


Figure 58: STICS evaluation of nitrogen mineralisation from soil organic matter (N-MO) and manure (zone A) for the 2022 soft wheat crop.

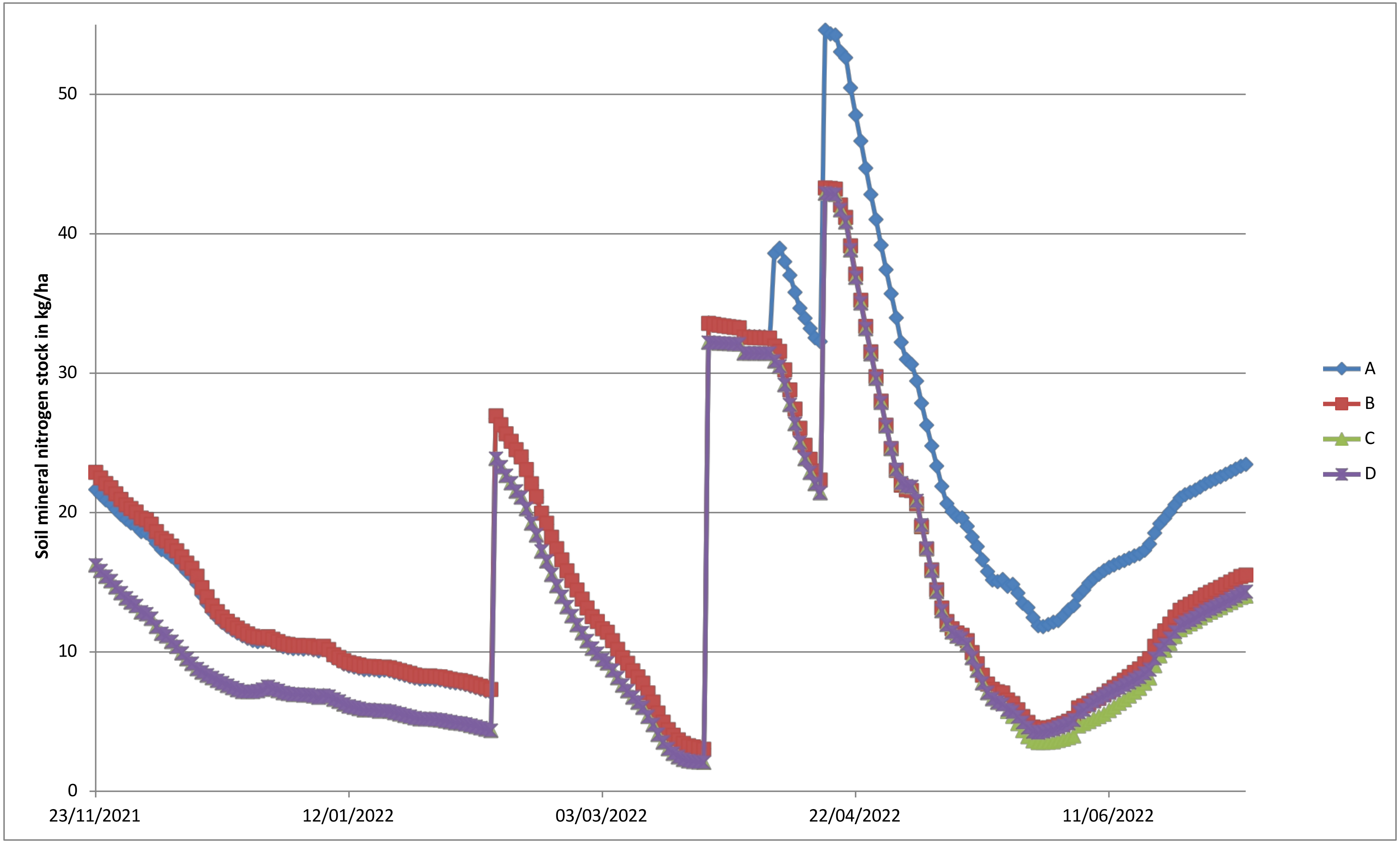


Figure 59: STICS evaluation of soil mineral nitrogen stock under the 2022 soft wheat crop for the four study zones A, B, C and D.

6 CONCLUSION: WHAT CAN BE DONE TO IMPROVE THE RECYCLING OF EFFLUENT ON AGROFORESTRY PLOTS?

After four growing seasons, with all the measurements and observations presented above, let's summarise the findings on effluent recycling routes and recommendations for agronomic recovery.

6.1 Agronomic interest of effluents

6.1.1 Recycling potential within the farm

Although the two cases of effluent do not contain any of the three major fertilisers at the same level as a commercial product - the NPK content is well below 2% of the gross mass - they do not contain any of the three major fertilisers at the same level as a commercial product.

-

For the four crop seasons monitored, the doses to be supplied, calculated on the basis of balance sheet items such as P and K requirements and requirements minus soil N inputs, are as follows

- 136 kg/ha for N,
- 50 kg/ha for P2O5,
- 60 kg/ha for K2O.

Given the amount of manure available - *assessed in chapter 4.1.* - **applying 6 t/ha of manure and 36 m3/ha of liquid manure to 4 ha of the plot** would **theoretically cover 100% of P and K requirements and 62% of N requirements**.

The farm's effluent contributes to the fertilisation of 4 ha out of 86 ha of UAA.
cultivated, i.e. 5%.

The farm therefore remains dependent on significant external supplies.

6.1.2 Expressing the nitrogen fertilising value of effluents

Monitoring of vegetative development and fertilisation balances over four growing seasons showed that the potential fertilising effect of organic effluent was often not very marked, due to its sensitivity to water conditions in this type of clay-limestone soil.

The amount of nitrogen potentially available from manure has been estimated, by cross-checking test results and simulations over one crop year, at **17% of the total input**, but losses through volatilisation, if burial is delayed too long, can halve this efficiency.

The potentially available nitrogen from slurry, estimated over three years of monitoring, is evaluated at **88% of the total input**. Losses through volatilisation can be as high as 19%.

6.1.3 Assessment of risks of nitrogen leaching in the practices of fertilisation.

The simulations carried out using STICS proposed an assessment of nitrogen losses by leaching (in kg/ha) for each growing season (in kg/ha) :

	Zone A	Zone B	Zone C	Zone D
2019	7	6	6	6
2020	6	4	3	3
2021	7	5	6	6
2022	2	2	1	1

These results reflect a fairly low risk of leaching in general, with no real impact.
the input of organic effluent.

The risks of loss through volatilisation are of the same level of intensity.

6.2 Management of the organic matter in the plot's soil.

During the four years of monitoring, we focused on the two competing effects of effluent management on soil organic matter: ***improving soil organic fertility*** and ***carbon sequestration.***

6.2.1 Soil organic fertility.

The state of the soil's organic fertility was assessed in particular by carrying out nitrogen mineralisation kinetics on soil samples from the different study areas of the plot - *see pages 29 to 31*.
We found that the results varied considerably depending on the fertilisation methods used and the cropping seasons: an analysis of variance cross-tabulated the "zone" and "season" effects.
"The 'year' indicator shows that there is more difference between years than between zones.

Depending on the technical itinerary and the climatic season, we observed for the
mineralization values ranging from 15 to over 100 kg N/ha.

Interpretation of the microbial biomass analyses did not provide any significant indication of changes in plot fertility, apart from the observation that biomass indices were generally higher in the agroforestry zones than in the open fields zone.

6.2.2 Carbon storage in soils

Analyses of the fractionation of soil organic matter confirmed the high proportion of stable carbon in the soil of the plot, whose clay-limestone nature is fairly favourable to a form of fossilisation of organic matter.

The carbon stock was estimated at an average of 300 t for the entire plot, giving a density of 36 t/ha.

6.3 The effect of agroforestry?

6.3.1 An agro-forestry effect?

The results of the monitoring over the four growing seasons, as well as the more specific examinations of the effects of the borders in 2020 and 2021 - *see chapters 4.4.3 and 4.5.3* - show ***that there is no negative agronomic effect from the intra-parcel coppice, but rather a positive effect*** - protective effect against excessive solar radiation, improved water circulation, etc. - on the neighbouring crops.

We need to be cautious about the importance given to this effect, as there may be confusion with other influencing factors, in particular the topographical factor, which is quite apparent on this plot.

However, if we compare the results obtained in agroforestry zones A and B, which extend over the entire topographical transect of the plot, with the results in agroforestry zone C and the results in open field zone D, which also extends over the entire topographical transect, the differences in plant biomass density and yield seem to be linked to the establishment of the hedges.

6.3.2 Extending the use of agro-forestry

Through various testimonials - INNOV'ACTION open days in 2019 and 2022, presentation video - the Manicot farm has expressed its satisfaction with the wood energy production results of the hedgerows installed on the "La Terrière-Champ" plot.

The farmers declared their intention to **continue their programme of planting hedges within parcels, up to a maximum of 40 ha** of their UAA, in order to achieve energy self-sufficiency in heating.

6.4 Recommendations for spreading on agroforestry plots.

The farm's effluents are usually used on plots of the UAA planted with Triticale.
Nevertheless, the four years of demonstration work on the Nutri2Cycle project have shown that the the effluent could be used on other crops grown on the farm.
Sunflowers and even oleic hemp could also be considered.

Based on the observations made during the four growing seasons covered by the project, we can make the following proposals for use on agroforestry plots.

1. The effluents can be used on the same plot at a **rate of 35 m3/ha of slurry and 6 tonnes/ha of manure**. It might be worth investigating the feasibility of **mixing the manure with the slurry** before applying it to the soil.

2. In the case of the plot monitored during the project, inputs could be **alternated every other year between the open fields zone and the agroforestry zone**, with the following benefits
    a. maintenance of phospho-potassium stocks ;
    b. improvement in soil structure, which is conditioned by the high content in clay.

3. Before spring crops, subject to accessibility of the most accessible plots clay, the effluent could be spread **before plant cover in autumn**.

4. **On clay soils**, **spreading** should be carried out fairly **early** - in compliance with the action programme for vulnerable areas - and with **rapid burial** by shallow tillage. On **loamier soils**, **spreading** should be carried out **later** - during the season of full vegetative development in March-April.

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