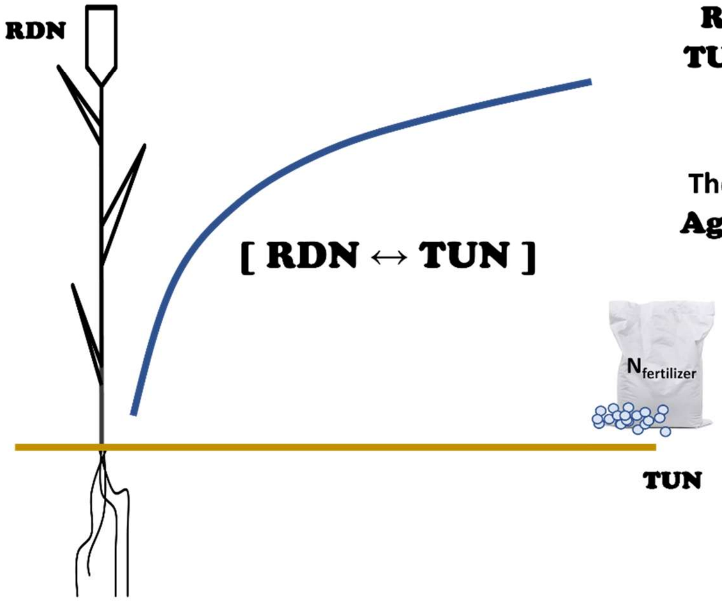
AgroNum™'s Rationale & Positioning

AgroNum™ : one field-plot → one $N_{fertilizer}$ response-curve

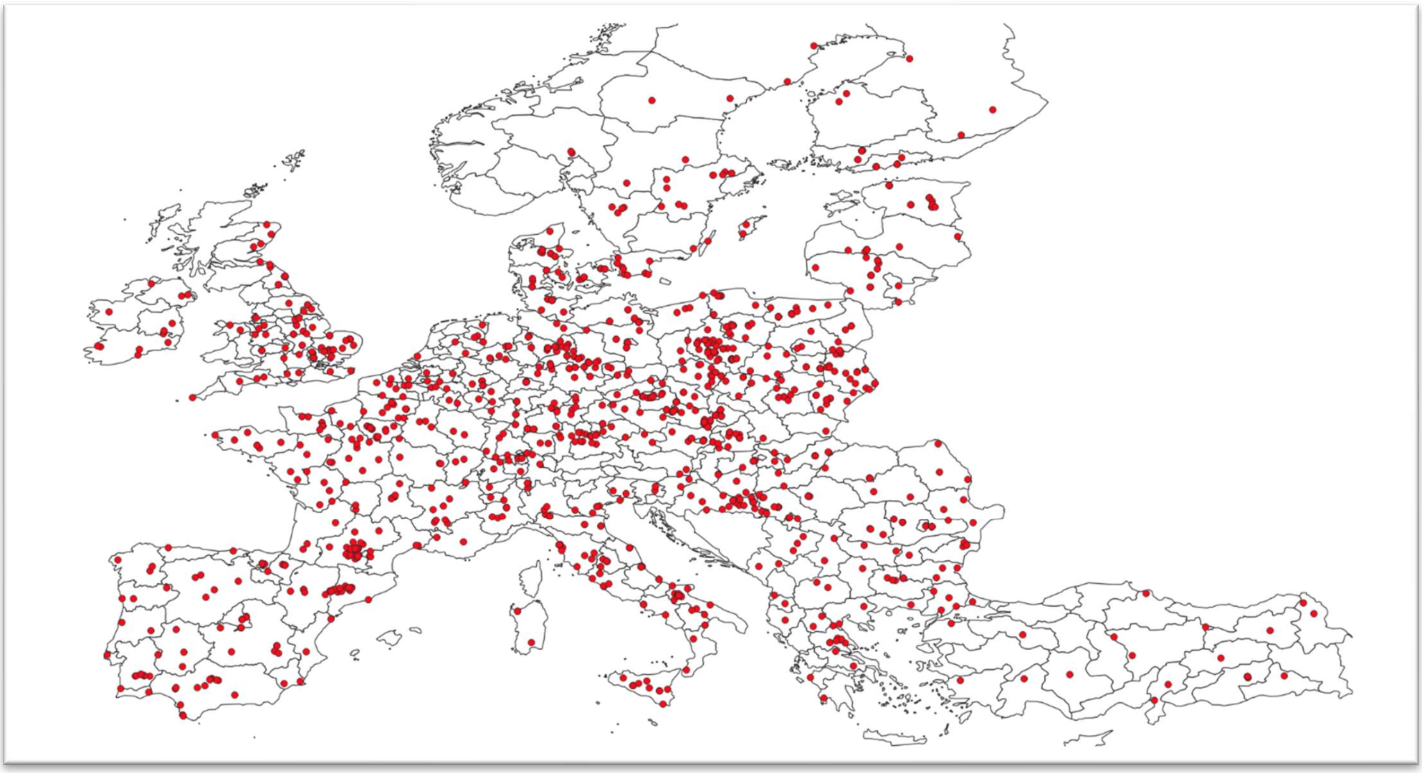


The **AgroNum** response curve adjusts targeted **RDN** *N-grain yields* (kg-N_{grain}/ha) to the targeted **TUN** *N-fertilizer recommendations* (kg-$N_{fertilizer}$/ha),

and vice ↔ versa.

These **RDN** ↔ **TUN** pairs are sustainable because **AgroNum** selects **RUN** *N-fertilizer use efficiencies* (kg-N_{grain}/kg-$N_{fertilisant}$) neither too high/low.

… and this, across Europe ;



AgroNum™’s Rationale & Positioning

As an integrated fertilizer management alternative for calculating N-fertilizer recommendations, **TUN (kg-N_fert/ha)** - AgroNum™ has the advantage of being precise, impartial, dynamic, easy to use and, most importantly, sustainable.

The accuracy of AgroNum™ is ensured by "*gradient boosting*" algorithms that are much more predictive than the usual algebraic s methods (e.g. linear regressions, analyses of variances, etc.). In addition, AgroNum is impartial because it is not necessary to describe in detail the cultivation practices since only the **nitrogen-yields, RDN (kg-N_grain/ha)** dictates the level of sustainability of the technical route.

AgroNum™ also enables the dynamic in-season adjustment according to weather and plot heterogeneity of these sustainable target nitrogen-yields, RDN. AgroNum™ is also (very) easy to use, the farmer having only to enter via www.polyor.fr the plot’s centermost GPS latitude & longitude, or again if desired the initial targeted level of nitrogen fertilization he/she wishes to apply.

The sustainable targeted nitrogen-yield, RDN, recommended by AgroNum™ are sustainable because they ensure not only the reduction of post-harvest residual nitrogen, but also the progressive nitrogen enrichment of crop residues as a function of TUN & RDN, thus ensuring their humification into stable organic matter. To do this, AgroNum™ identifies for each plot the RDN values with **N-use efficiencies, RUN (**kg-N$_{grain}$**/kg-N**$_{fertilizer}$**)** neither too low, nor too high.

This document describes AgroNum's™ rationale and positioning an integrated fertilizer management tool for sustainable agriculture. It will be more about soil conservation than carbon storage, alias carbon farming & sequestration, capture, etc. AgroNum™ also seeks to ensure sustainability in a more conventional way by integrating both socio-economic aspects such as *yield gaps,* and environmental aspects of sustainable development.

As a result, several observations, sometimes disruptive, will be made, namely;

- **Sustainable nitrogen-grain yields, RDN, response to N-fertilizers are more of a power function than quadratic or linear;**
- **It is non-symbiotic nitrogen-fixation, azb, which, at low nitrogen fertilization rates, TUN, dictates the sustainability of yields;**
- **At higher nitrogen fertilization rates, it is the progressive nitrogen enrichment of crop residues that ensures their humification;**
- **Not knowing precisely the soil carbon stocks, sustainable agriculture most ensure first and foremost the conservation of soil organic matter;**
- **It is therefore necessary to ensure that the RDN is constantly proportional to the input of nitrogen to the soil from soil-borne crop residues;**
- **To do this, the cropping schedules must de facto exclude nitrogen-use efficiencies, RUN, too low and too high;**
- **An algorithm designed for this purpose - AgroNum™, calculates for each plot the nitrogen requirement - a_AgroNum, of the most sustainable cropping schedules;**
- **The a_AgroNum concepts makes it possible to retro-calculate as a function of TUN sustainable RDN targets summarized as plot-specific nitrogen response curves, CRP_N.**

These AgroNum ™ response curves are applicable to all non-Fabaceae field crops including winter and spring cereals, rapeseed, maize and sunflower. The approach is validated by meta-analyses of the above findings on the basis of our current knowledge s in agronomy, for example that post-harvest nitrogen residue is mainly due to too low N-use efficiencies, that these will enrich the soil solution with nitrogen and promote the microbial attack of the carbon fraction of organic matter, or that crop residues are enriched in N according to the rate of nitrogen fertilization, etc. etc.

AgroNum™ has been tested virtually in Europe by building a database containing **20764 georeferenced cropping schedules**. AgroNum™ target yields are approximately 40% higher, in line with the yield gaps reported by Schils et al. 2018 in European cereal production. (→ www.polyor.fr / Validation / Grain & nitrogen yield gap reduction)

Field-crop yields similar to AgroNum™ recommendations are associated with pedoclimatic variables indicative of soil organic matter conservation. This meta-analysis, although statistically weak, nevertheless supports AgroNum's™ claims regarding the beneficial effect of avoiding cropping schedules with RUN N-fertilizer use efficiencies either too low or too high. (→ www.polyor.fr / Validation / Soil organic matter & carbon conservation)

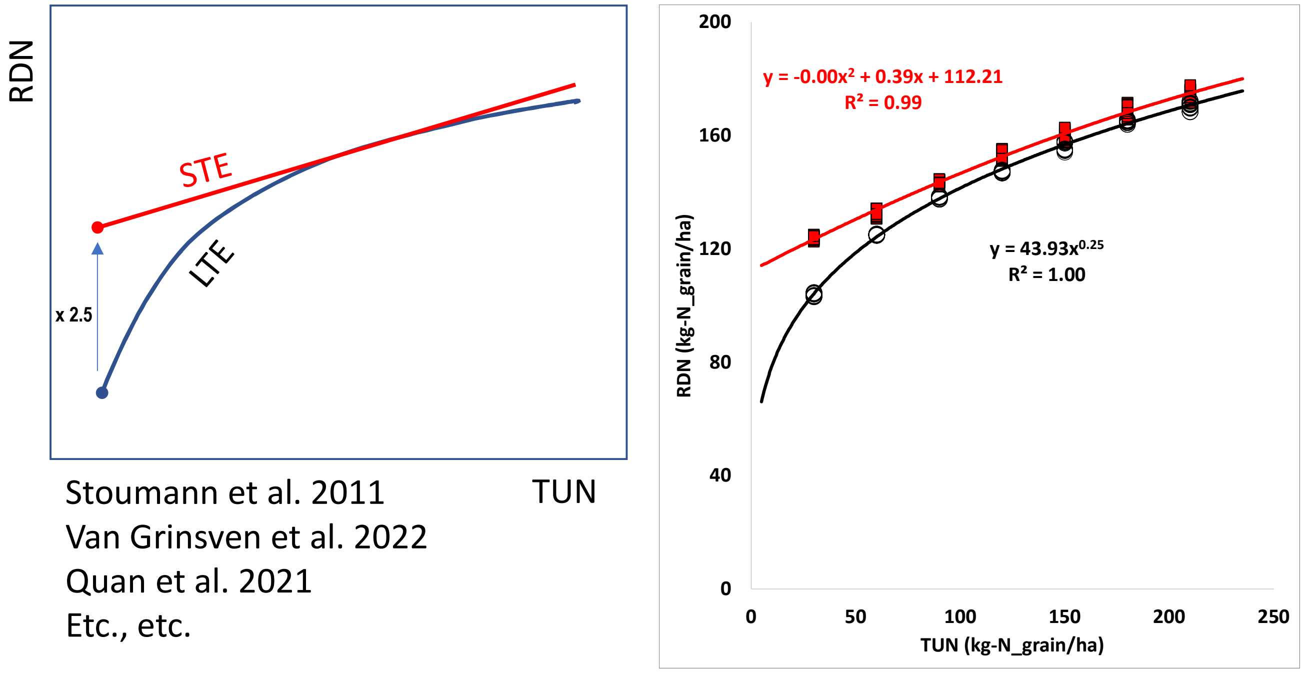
The precision & accuracy of the AgroNum™ algorithm was validated using a subset of 15% of the plots included in the dataset comprising only the most sustainable cropping schedules as understood herein (Figure 10). This stochastic approach, sometimes called "Monte Carlo", clearly demonstrates the power of this form of "artificial intelligence" applied to sustainable agriculture. (→ www.polyor.fr / Validation / Precise & accurate recommendations)

Finally, Polyor SAS's AgroNum™ concept is new and disrupts the state of the art in precision agriculture and integrated fertilizer management. It is therefore appropriate for Polyor SAS to develop a comprehensive intellectual property strategy via the French Inpi and the EPO (www.polyor.fr). These new patents will now complement Polyor's existing IP portfolio, in the past mainly dedicated to *azotobacterial fertilization*, AZB™

- **Sustainable nitrogen-grain yields, RDN, response to N-fertilizers are more of a power function than quadratic or linear;**

In the long term, i.e. sustainably, the nitrogen-yield, RDN, response to N-fertilizer, TUN, curves, are more of a power function than quadratic or linear (Figure 1). This is due to the depletion of residual nitrogen otherwise available in the short term. These nitrogen remnants need not be in integrated fertilizer management and therefore should not be considered when establishing sustainable target yields & fertilizer recommendations.

Figure 1: Sustainability is achieved over the long term. Long-term experiments (LTE) show that RDN nitrogen-yields without nitrogen fertilization, aN1, are significantly lower (low curve) on such LTE than on tests with more recent *short-term experiments* (STE).). The AgroNum™ nitrogen response curves (figure on the right) illustrate this phenomenon perfectly, for example one of the 1,300 plots tested (50.47300 N 3.20890 E).



Stoumann et al. 2011
Van Grinsven et al. 2022
Quan et al. 2021
Etc., etc.

The **STE**/**LTE** of published aN1 values is generally about 2.50, i.e. almost exactly the same as the ratios observed between aN1 values derived directly from RDN (top **red** curve, **Figure 1**) and those retro-calculated from the aforesaid median RUNs (bottom **black** curve) as selected by the AgroNum™. For instance, note here for this particular example that aN1/**aN1** = **112.21**/**43.93** = 2.55.

Table 1: Grain nitrogen-yields, RDN (kg-N_grain/ha), without nitrogen fertilizers (aN1) from bona fide long-term experiments (LTE) compared to the aN1 estimated by AgroNum™ at these same locations (latitude, longitude). The correspondence (Figure 2) is not perfect given that LTE rotations are not always without some sort of nitrogen inputs, residual and/or remanent nitrogen from legumes and various rotations being difficult to rule out. Oh well.

aN1_AgroNum	aN1_LTE	LTE Reference	latitude	longitude
43.11	45.00	Johnston et al. 2018	51.81056	-0.36927
28.95	30.00	Kolmanic et al. 2022	46.50303	15.63330
41.42	41.00	Kubat et al. 2003	50.08882	14.29138
36.26	42.00	Korschens et al. 2012	46.74180	17.23990
43.00	46.00	Shejbalova et al. 2014	49.55442	15.35057
42.80	43.70	Shejbalova et al. 2014	50.07404	14.17245
28.97	35.00	Lopez-Bellido et al. 2001	37.75978	-4.52902
29.33	31.00	Anastasi et al. 2019	37.38228	15.02198
42.27	45.00	Korschens et al. 2012	50.80129	10.22457
36.50	41.20	Pepo et al. 2016	47.55693	21.44690
29.00	33.00	Plaza-Bonilla et al. 2021	41.81180	1.16597
30.00	31.00	Amosse et al. 2013	44.61535	5.43880
30.00	31.00	Amosse et al. 2013	44.64879	4.88194
27.00	25.00	Poma et al. 2004	37.63686	13.76517
36.00	34.00	Jolankai et al. 2006	46.73393	17.23108
29.30	35.00	Anastasi et al. 2019	37.38226	15.02198
34.00	38.00	Dumbrava et al. 2016	44.50001	26.25716
41.50	40.70	Cerny_et_al._2010	49.55635	14.97752
31.00	31.00	Fiorentini et al. 2021	43.54308	13.36529
47.10	52.00	Nevens et al. 2018 (BE23)	50.98512	3.81723
43.11	43.80	Van Grinsven et al. 2022	51.81056	-0.36927

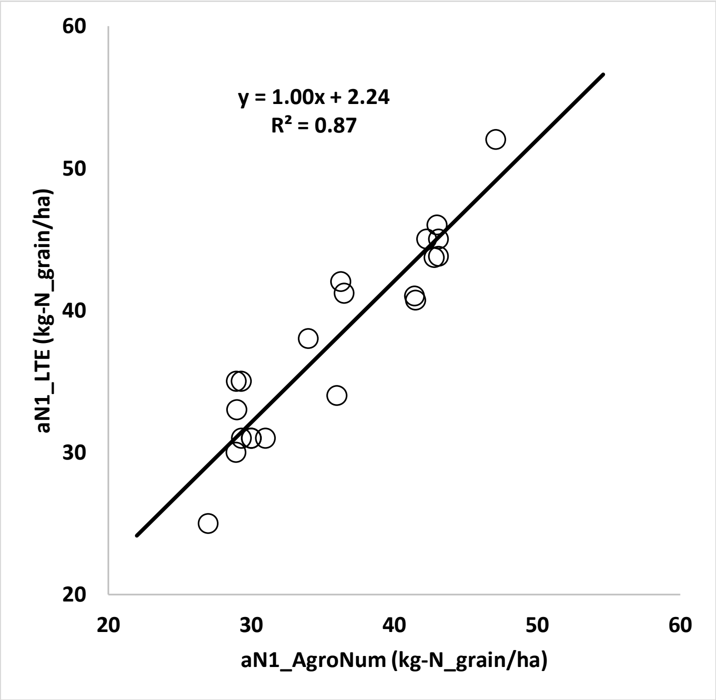


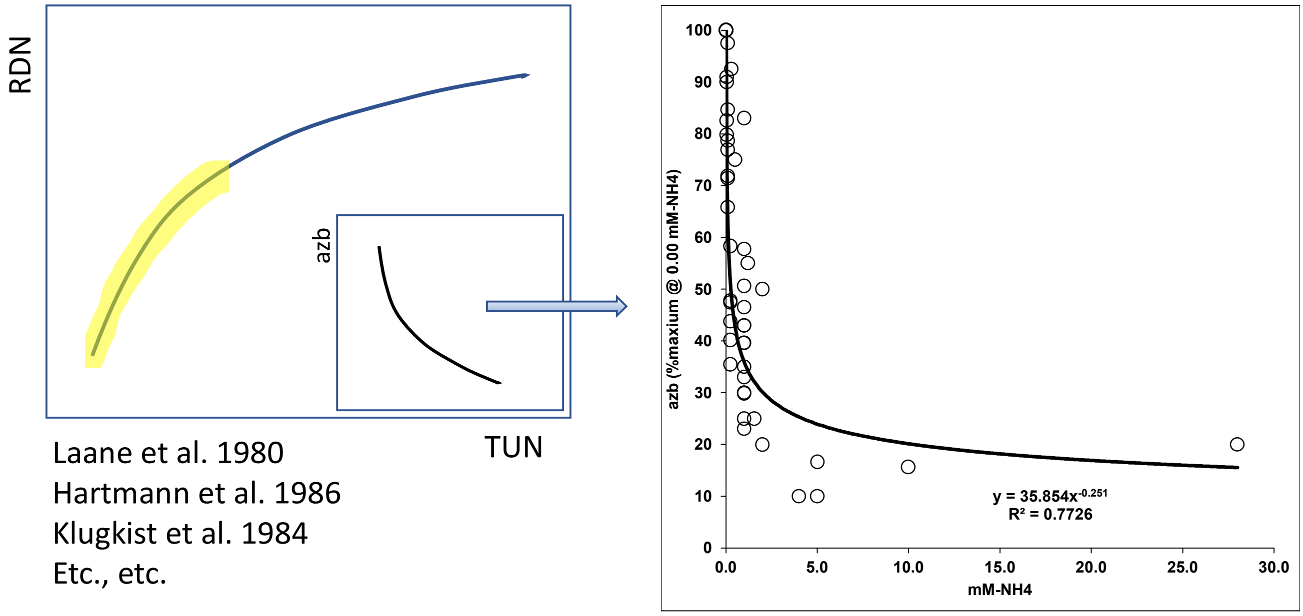
Figure 2: Graphical representation of the data in Table 1 of the aN1 RDN (without nitrogen fertilizer) from the series of long-term experiments (LTE) compared to the aN1 values generated by the AgroNum™ algorithm. According to Polyor SAS (www.polyor.fr), aN1 is mainly dependent on the non-symbiotic diazotrophic activity of the soil, known as *azotobacterial* (azb), especially in the presence of mulching crop residues left on the ground and buried in the topsoil.

It is thus possible to reproduce this correlation aN1_LTE :: aN1_AgroNum. The values of aN1 dependenton the native azotobacterial activity of the soil, azb, is therefore predicted quite well by AgroNum. This value of aN1 is characteristic of the location of the agricultural plot and fairly well correlated with the intrinsic productivity of the soil, iSQ (infra, Toth et al. 2013).

- **It is non-symbiotic nitrogen-fixation, azb, which, at low nitrogen fertilization rates, TUN, dictates the sustainability of yields;**

At low N-fertilization rates, this nitrogen response is steep and mirrors the rapid degradation of indigenous non-symbiotic N-fixation in soils, azb. This degradation of azb is also in power function of TUN (Figure 3), not so much because of residual of N-mineral, but rather because of the mineralization of nitrogen from crop residues. At approximately 1 mM N-NH_4 mineralized in the *residusphere*, azb atrophy (shut-off) is almost complete.

Figure 3: The atrophy the soil's basal non-symbiotic azotobacterial (azb) activity of the soil as a function of accumulated reactive ammoniacal nitrogen (millimolar, mM) in the *residusphere* and/or soil solution is essentially the inverse of the AgroNum™ target RDN nitrogen response curve (Figures 1 & 11). This so called *shut-off* of azb's nitrogenase is well known (Laane et al. 1980, Hartmann et al. 1986, Klugkist et al. 1984, etc.). Nb. 1 mM N-NH 4 → ≈ 14 kg N-NH_4/ha.

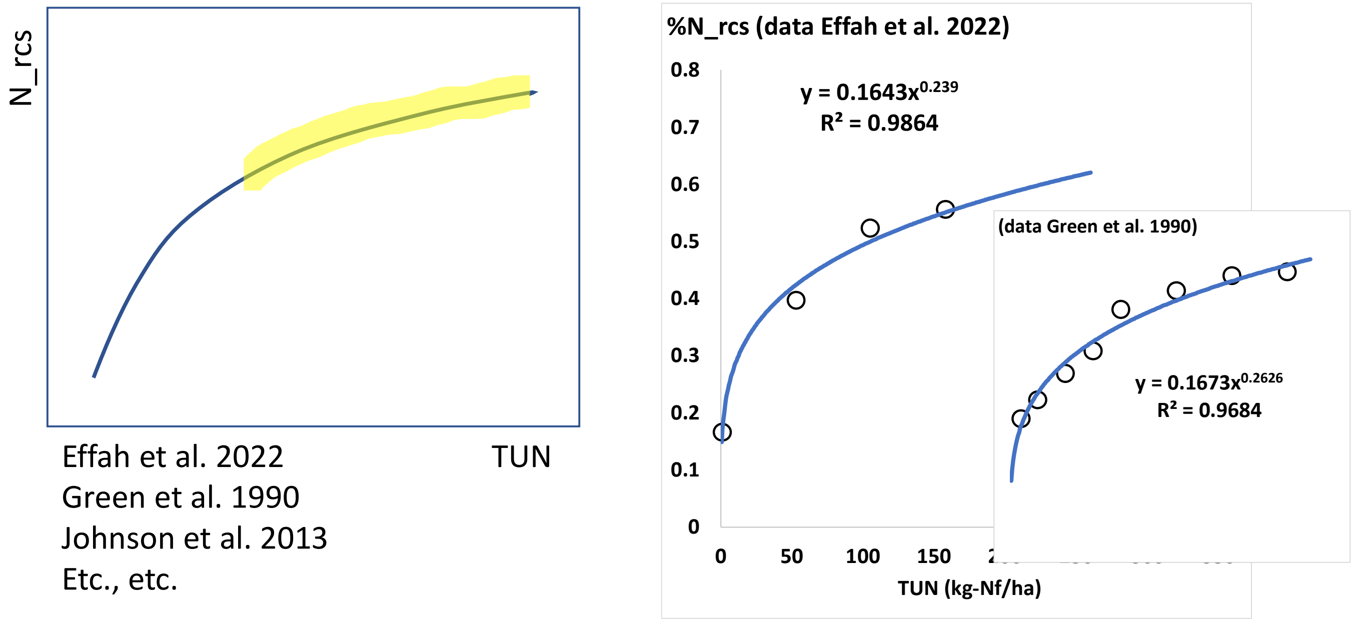


This non-symbiotic nitrogen fixation has long been underestimated in favor of an alleged deposition of nitrogen reduced directly from the atmosphere by precipitation. However, Polyor SAS maintains that azb is present at low TUN fertilization rates but decreases rapidly as a result of crop residues nitrogen mineralization (Figure 3).

- **At higher nitrogen fertilization rates, it is the progressive nitrogen enrichment of crop residues that ensures their humification;**

At higher and more conventional TUN nitrogen fertilization rates, the more abundant crop residues are gradually enriched in N. The current state of the art are reveals that such N-enrichment of crop residues is best described using a simple power function at the rate of b ≈ 0.2500 (Figure 4), almost identical and a continuation of that for the aforesaid azb atrophy as a function of TUN fertilization rate (Figure 3).

Figure 4: Although poorly documented in comparison to nitrogen offtake by grains, a meta-analysis of about twenty published articles (Effah et al. 2022, Green et al. 1990, etc. etc.) reveals that for non-*Fabaceae* field crops, the power function's rate of increase in crop residue N-contents (Figure 5), N_rcs, is in the whereabouts of ≈ 0.2500, i.e. perfectly comparable the AgroNum™ RDN target yields as a function of TUN fertilization-N rates (kg-$N_{fert.}$/ha ; Figures 1 & 11).



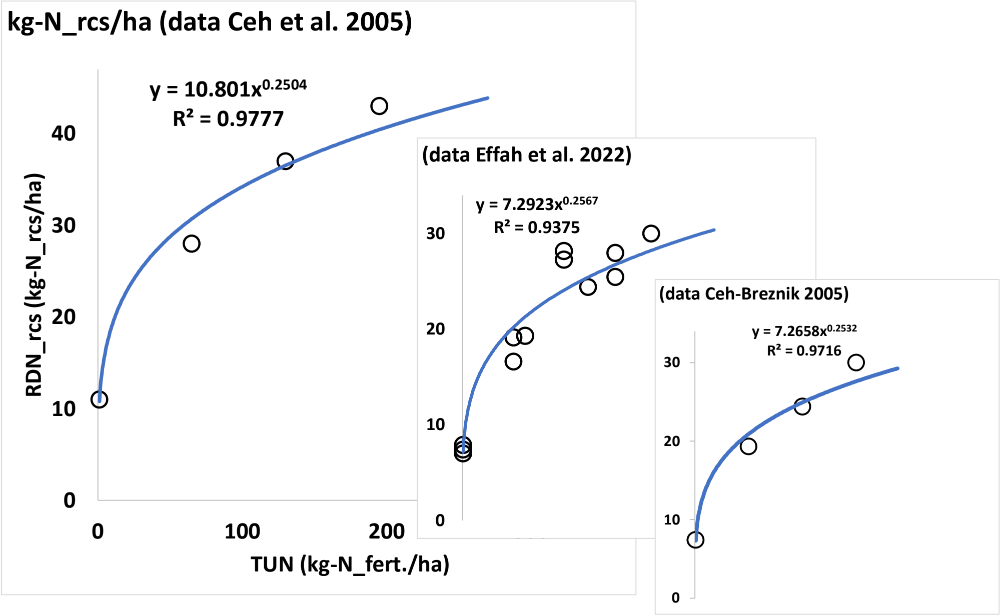


Figure 5: The power function's rate of increase of nitrogen input to soil from soil borne crop residues (kg-N_rcs/ha) is also approx. b ≈ 0.2500. Once again, this rate of increase coincides with that of the sustainable target RDN as proposed by AgroNum™ RDNs (Figures 1 &11) This synchrony insures crop residue humification supplied with sufficient N contributing to soil organic matter formation & conservation.

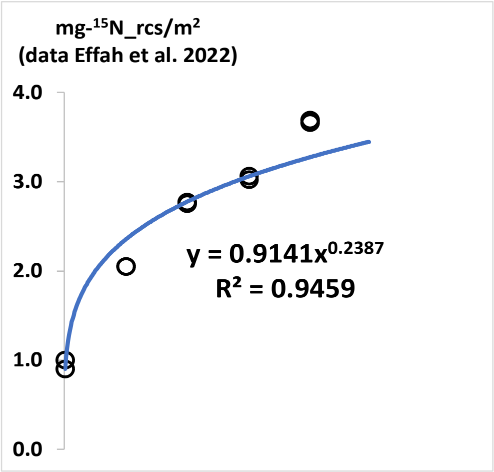


Figure 6: The progressive N-enrichment of crop residues is mainly due to a lowering of the rate of translocation of the nitrogen in above-ground biomass during grain filling. This nitrogen therefore remains in the soil borne crop residues. This accumulation of foliar nitrogen that is not (re)mobilized post-anthesis towards the grains is detectable using ^{15}N applied to the foliage and later found in crop residues; eg data from Effah et al. 2022.

- **Not knowing precisely the soil carbon stocks, sustainable agriculture most ensure first and foremost the conservation of soil organic matter;**

Interestingly, these b ≈ 0.2500 rates of increase for *both* RDN_grain & RDN_rcs are constant, set in sort, regardless of the type of non-*Fabaceae* field crop, cereals, maize, rapeseed & sunflower. Polyor SAS maintains that this synchronous rate of crop residue nitrogen accumulation dictates the level of sustainable nitrogen-yield.

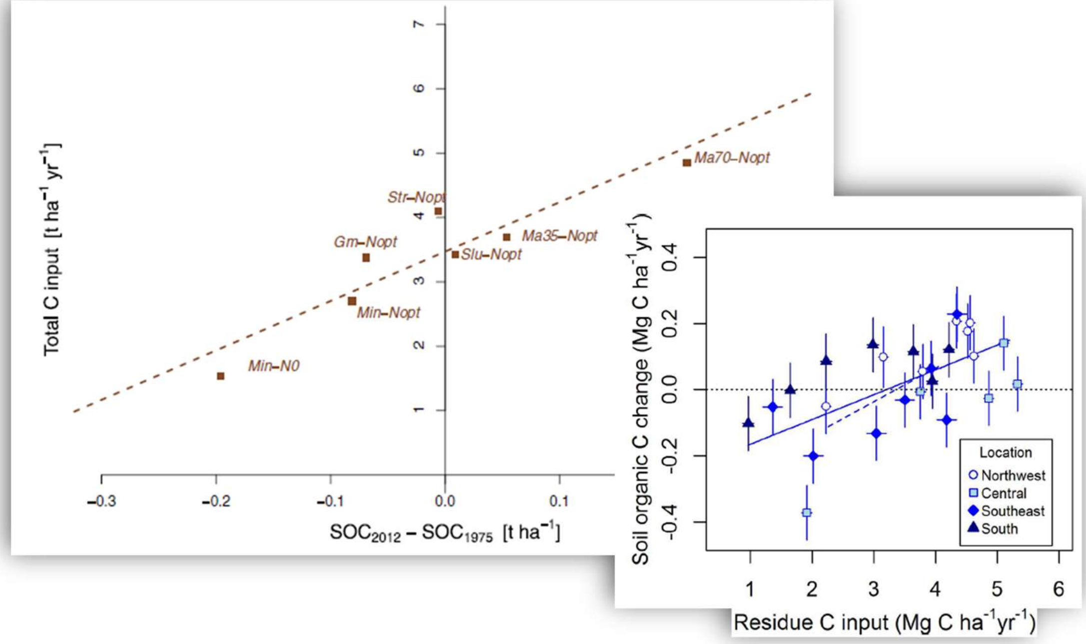
Indeed, with increasing TUN N-fertilization rates, more and more soil borne crop residues, RCS, increasingly N-rich are produced as power function of approximately b ≈ 0.2500 (Figures 4 & 5). Given that, in agricultural soils, these crop residues and soil organic matter have necessarily co-evolved, it is reasonable to believe that the atrophy of azb as of ≈ 1 mM N-NH4 is compensated by the N-enrichment of crop residues at such a rate. It can easily be demonstrated that amounts of crop residues at such %N_rcs increasing as a power function of TUN will humify constantly and thus conserve soil organic carbon, SOC, stocks over time, i.e. ;

$$b_{N\_rcs} \approx 0.2500 \xrightarrow[rCN_{som} \approx 8 - 10]{MRT \equiv 1/k \approx 75 \text{ annum}} \boxed{SOC_{20cm}} \Rightarrow [dSOC/dt] \approx 0$$

Given this b ≈ 0.2500 power function coefficient which dictates the increase in the contents & input of nitrogen from soi borne crop residues, it is easily demonstrable that the organic carbon content of the 20 cm of topsoil will be stable over time if the *mean residence time* (MRT) of this carbon once buried & humified is ≈ 75 years (Bolinder et al. 2020, Rabbi et al. 2013, Zhang et al. 2015, Anton et al. 2022, etc.), and the C/N ratio of the resulting organic matter about 8 to 10.

Again, this stable SOC dynamic is easily demonstrated using dynamic models (Century, EPIC, etc.), some of which are quite simple (ROTH-C, Wallach et al. 2021, etc.), or even by meta-analyses (Makowski et al. 2018) of published data such as those in Figure 7. At the risk of overstating, this illustration & demonstration effort is currently underway at Polyor SAS. **At this stage, let us simply say that agronomic consultancy as understood by Polyor SAS must first and foremost set sustainable target grain-N yields (RDN; kg-N$_{grain}$/ha) as a power function of TUN (kg-N$_{fert}$/ha) at a rate of increase b ≈ 0.2500 equal to that of the nitrogen returned to soils by soil borne crop residues. In sustainable agriculture, doing so will ensure that soil borne crop residues will always contain sufficient nitrogen to be properly humified into stable organic matter at a C/N ratio ≈ 8 to 10 (Van Groenigen et al. 2018, etc.).**

Figure 7: Examples of published data (Maltas et al. 2018, Poffenbarter et al. 2017, etc., etc.) used for the meta-analysis. For instance, 3 to 4 tons/ha/hear of carbon input from crop residues corresponding to a TUN N-fertilization rate ≈ 150 kg-N./ha characteristic of intensive maize or wheat crops are sufficient here to maintain ('0.0') – i.e. conserve, soil carbon stocks as in sustainable agriculture by means of soil organic matter conservation as advocated by AgroNum™.



For instance, in these two particular cases, 3-4 tons of C/hy/year from crop residues are in fact characteristic of somewhat intensive field crops. We could also portray lower carbon inputs and resulting soil carbon levels just as sustainable. Once again, AgroNum™ advocates the conservation, rather than the build-up, of soil organic matter by ensuring a proportionality RDN$_{grain}$/RDN$_{rcs}$ more synonymous with conservation than sequestration of organic carbon in the soil, regardless of the level of field crop yield or TUN N-fertilization rate.

- **It is therefore necessary to ensure that RDN_grain is constantly proportional to the input of nitrogen to the soil from soil-borne crop residues, RDN_rcs;**

In the long term, sustainable RDN_grain target yields are therefore proportional to the nitrogen "yields", or rather returns, of soil-borne crop residues, RDN_rcs.

- Mathematically, this is equivalent to stating $[\boldsymbol{RDN\_grain = a1 \cdot TUN^{b1}}]$ ≡ $[\boldsymbol{RDN\_rcs = a2 \cdot TUN^{b2}}]$. Note that the proportion **RDN$_{rcs}$/RDN$_{grain}$** is a constant equal to **a2/a1** *if and only if* **b1 = b2**, namely if and when **[a2·TUN b2/a1·TUN b1] = [a2/a1 · TUN($^{b2 - b1)}$]** = $\boldsymbol{a2/a1 \cdot 1}$
- Graphically (Figure 8), plotting a2/a1 reveals that when **b2 = b1**, the input & N content of soil-borne crop residues, RDN_rcs, is proportional to that of grain nitrogen-yields, RDN_grain. This proportionality is here synonymous with sustainability.
- Agronomically, the challenge is therefore to **establish precisely for each agricultural plots a RDN_grain response curve as a power function of TUN, so that b1 is equal or close to 0.2500** knowing that $[\boldsymbol{RDN\_grain = a1 \cdot TUN^{b1}}]$.

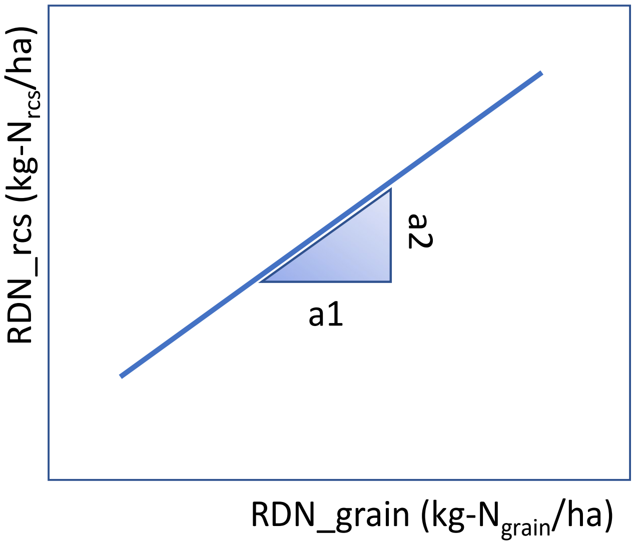


Figure 8: Graphical representation of the correspondence between grain nitrogen-yields, RDN_grain (kg-N_grain/ha) and nitrogen crop-residues input - RDN_rcs (kg-N_rcs/ha) as advocated by AgroNum™ specifying sustainable target nitrogen-yields, RDN_grain, with median N-fertilizer use efficiencies, RUN (kg-N_grain/kg-N_fertilisant) neither too high nor too low. The ratio a2/a1 is specific to each plot.

Most often, a1 ≈ 33 and a2 ≈ 10 kg-N/hectare, or again ≈ 0.20%N_rcs in terms of N content rather that yield. This ratio a2/a1 is constant and specific to the plot and considering that for the moment only a1 is known. Regardless, plot-specific a2 values will be further obtained over time from farm and survey data.

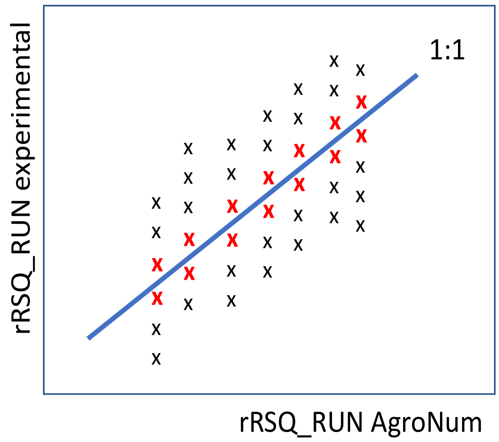
- **To do this, the cropping schedules must de facto exclude nitrogen-use efficiencies, RUN, either too low or too high;**

To achieve this constant balance between RDN_grain and RDN_rcs, cropping schedules with nitrogen N-use efficiencies, RUN, either too high or too low must be identified and excluded from the dataset. This said;

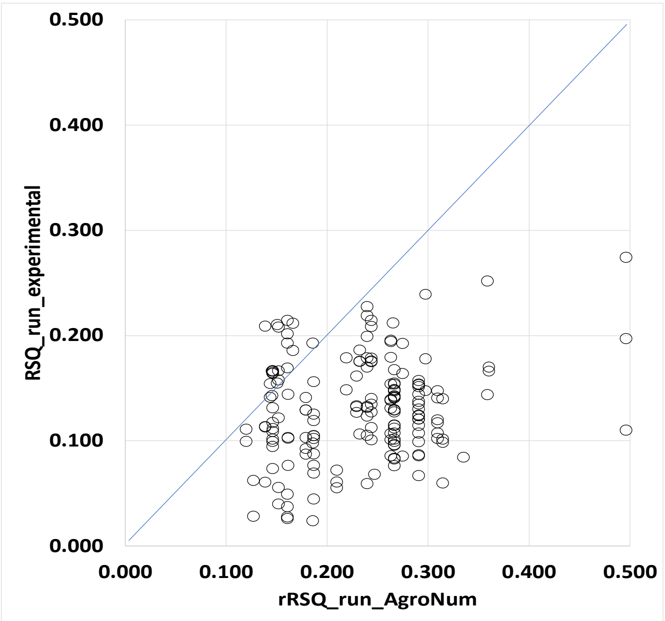
- It is recognized that *low* RUNs promote not only the accumulation of post-harvest residual mineral nitrogen source of pollution, but also the attack of carbonaceous organic matter by soil microorganisms with low C/N ratios and fond of mineral nitrogen.
- It is also well known that *high* RUNs (alias, nitrogen-fertilizer use efficiencies) will necessarily deplete soil borne crop residues of their nitrogen and thus hinder their humifications into stable organic matter which also has low C/N ratios of around 8 to 10.

A georeferenced & pan-European database containing thousands of such median RUNs was therefore used to parameterize an artificial intelligence algorithm, AgroNum™, capable of ***accurately retro-calculate*** sustainable target RDN_grain as a function of TUN N-fertilizer rates and such median RUNs.

Figure 9 : Reiterative selection of (16220!) experimental cropping schedules deemed sustainable by excluding nitrogen fertilizer use efficiencies, RUN, too low & too high as compared to AgroNum's rRSQ recommendations. The selected cropping schedules (red "X"s) are retained in the database, and the AgroNum™ model reparameterized before being reapplied to still more experimental RUN data from other locations. And so on, repeatedly until high predictive precision is achieved (Figure 10).



EP22152629.6
EP20194102.8
EP22210746.8
Etc., etc.



As an example (Figure 9) taken from EP22152629.6, the reference AgroNum ("rRSQ_run", on the x-axes) indicates that only certain experimental cropping schedules with RSQ_run (RUN) close to the [1:1] line will be putatively retained as sustainable in anticipation of an nth reiterative reparameterization of the algorithm. Nota that these for the most part, these experimental values RSQ_run are here are mostly *below* the divider (see below).

[Recall re. RSQ. The evaluation of the sustainability of cropping schedules involves a *triple adjustment*, according to iSQ, d_{RUN}, & rRSQ (EP22152629.6; figure 3) to express RDN and RUN *rationally* without risk of numerical drift. The simple N-use efficiencies, run, are first standardized using a value, d_{RUN}, as an inverse power function of N-fertilization rate to compare cropping schedules at different TUN. This first ratio is then re-adjusted according to any index of the inherent productivity of the plot, iSQ, in ordre to compare plots of different sites and agro-pedoclimates. Finally, these readjusted N-use efficiencies are compared to the sustainable AgroNum™ reference, rRSQ, specific to the plot in this location. See EP22152629.6 (figure 3), or contact Polyor SAS.]

- **An algorithm designed for this purpose - AgroNum™, calculates for each plot the nitrogen requirement - a_AgroNum, of the most sustainable cropping schedules**;

This retro-calculation is carried out as follows;

$$RDN = TUN/a\_AgroNum$$

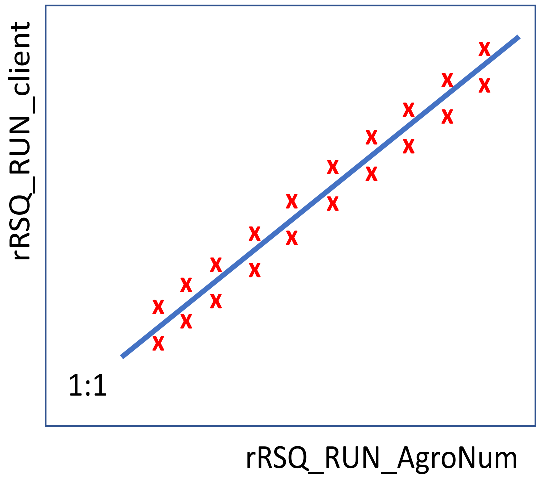
knowing that, $$a_{AgroNum} = \frac{1}{\sqrt{RUN\ x\ d_{RUN}}} ,$$

and $$RUN = rRSQ_{RUN} x\ iSQ$$

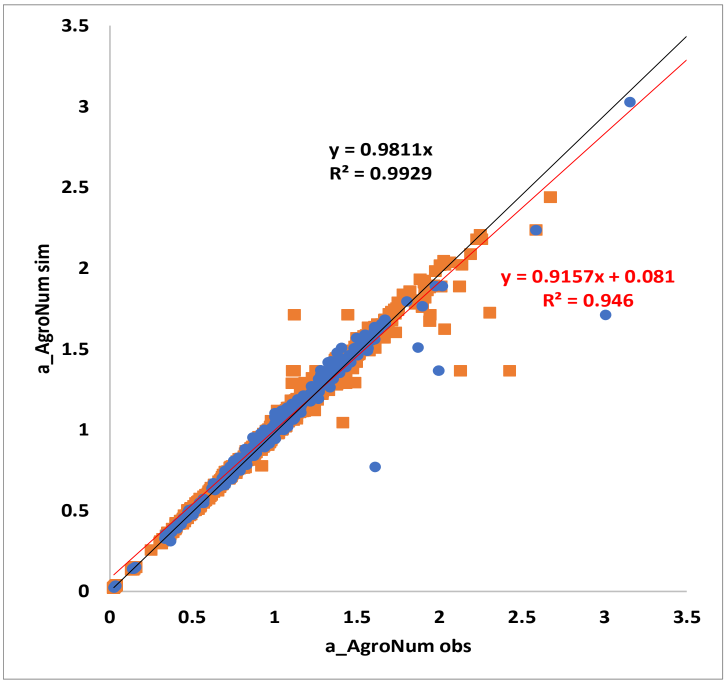
Here, a_AgroNum is the N-fertilizer requirement of the sustainable cropping schedule or cropping practice, a new concept in integrated fertilizer management, and d_{RUN} an adjustment factor for RUN as a function of TUN so as to allow the comparison of RUNs at different TUNs. Empirically & putatively, $d_{RUN} = 1400\ x\ TUN^{-1.5}$

An example (Figure 10) taken from EP22210746_8. The relationship of a_AgroNum (kg-N_fertilizer/kg-N_grain) values previously known (observed) and predicted (simulated) using the AgroNum™ algorithm. To carry out this validation, 15% of the sustainable cropping schedules dataset is retained for stochastic analysis.

Figure 10: Application of the AgroNum™ algorithm parameterized using N-use efficiencies, RUN, sustainable cropping schedules as understood. Each plot is thus fitted with sustainable RUNs retro-calculated at various TUN nitrogen fertilization rates. Using a_AgroNum, an AgroNum™ RDN_grain::TUN AgroNum™ response curve can then be created for each of the client plots (Figure 11). Most importantly, the algorithmic prediction (simulation) of a_Agronom is very precise at around 95%.



EP22152629.6
EP20194102.8
EP22210746.8
Etc., etc.



- **The a_AgroNum concepts makes it possible to retro-calculate as a function of TUN sustainable RDN targets summarized as plot-specific nitrogen response curves, CRP_N.**

The AgroNum™ algorithm will therefore generate for each site where an agricultural plot is located a series of sustainable target RDN_grain at various TUN nitrogen fertilization rates. These RDN :: TUN pairs are advantageously portrayed as **CRP_N response curves** (Figure 11), i.e. power functions $\boldsymbol{RDN\_grain = a1 \cdot TUN^{b1}}$ | **b1 ≈ 0.2500**. These response curves are then used for dynamic intra-annual adjustments according to the weather, or intra-plot by modulation according to the heterogeneity of the soil, of N-fertilizer recommendations. This is all about integrated fertilizer management, N-fertilizer recommendations & sustainable agriculture.

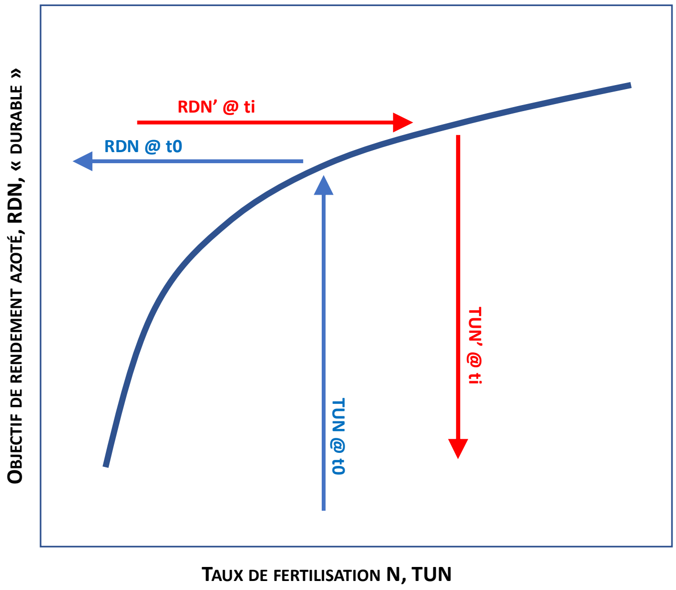


Figure 11: Schematized CRP_N nitrogen-fertilizer response curve applicable to all non-*Fabaceae* field crops, such as winter & spring cereals, rapeseed, maize and sunflower. This AgroNum™ CRP approach to integrated fertilizer management is dynamic because the initial yield targets and recommendations at time t_0 can subsequently be adjusted and modulated at time t_i in response to the changing weather conditions and/or the heterogeneity of the plot (cf. EP22210746.8).

For example, in Table 2, a field-plot whose centermost GPS coordinates are [48.06772 / N 01.50613], the AgroNum™ recommendations would be as follows. Note the values of aN1, Na1, and more practically and usual TUN and RDN at 125% of Na1.

Table 2: Example of an AgroNum™ analysis proposed to a hypothetical customer ("9999").

Fields, some of which are carried directly from www.polyor.fr	*Units*	*Values*
Customer number assigned by Polvor SAS	NA	**9999**
Centermost GPS coordinate of the plot, longitude	WGS84	**01.50613**
Centermost GPS coordinate of the plot, latitude	WGS84	**48.06772**
Eurostats administrative unit, NUTS2	NA	**FRB0**
Productivity index (cf. Toth et al. 2013), iSQ	NA	**8.800**
Sustainable RDN without fertilization-N (azb), ***aN1***	kg-N grain/ha	**41.94**
Sustainable "pivot" RDN when RDN ≡ TUN, ***Na1***	Kg-N grain/ha	**147.53**
TUN initially targetted by the farmer	kg-N fert./ha	**100**
Proposed sustainable target RDN	kg-N fert./ha	**133.78**
RDN initially targetted by the farmer	kg-N grain/ha	**100**
Predicted corresponding sustainable TUN	kg-N fert./ha	**31.49**
Recommended TUN equivalent to 125% of Na1	kg-N fert./ha	**184.46**
Sustainable target RDN at this TUN = 125% of Na1	kg-N grain/ha	**156.10**
Standard N-fertilizer use efficieny for these TUN & RDN	kg-N grain/kg-N fert.	**0.846**

The AgroNum™ analysis/recommendation report in Table 2 is seemingly very simple. It only includes the few data already entered by the user via www.polyor.fr, namely the plot's centermost GPS latitude & longitude coordinates. The name of the Eurostat NUTS2 administrative unit, as well as one particular , the iSQ index (Toth et al. 2013) are also reported. Two key values, **aN1** & **Na1** conveniently indicate the sustainable productivity level for that particular plot, relatively high in this case given the relative high yields of the Parisian plain in France. If the user wishes to stipulate a particular target TUN (eg. 100), the corresponding sustainable RDN target is indicated (134). Conversely, an RDN target set at a rather low 100 by the farmer, will correspond to an even lower TUN of just 32 kg-N_fert./ha. This is why AgroNum™ de facto proposes a TUN equivalent to about 125% of the "pivot" RDN corresponding here to a sustainable target RDN of about 156 kg-N_grain/ha.Note that the standard N-fertilizer use efficiency, run (kg-N_grain/kg-N_fertilizer) is thus at about 85%, a N_fUE level often considered to be sustainable in itself.

This type of AgroNum™ recommendation has been carried out in more than 1300 locations across Europe; the plots in these locations are represented geographically in Figure 12. In addition, a *meta-model* was developed and implemented. This facilitates and enhances AgroNum's™ real-time interactivity.

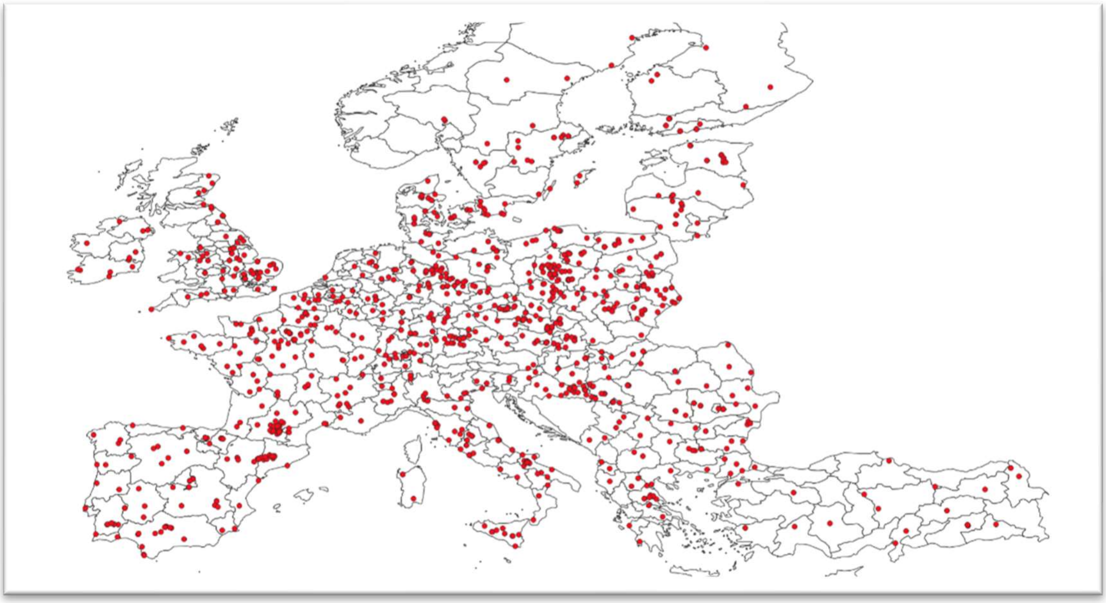


Figure 12: Geographical representation of 1392 sites across Europe with the agricultural plots used for the parameterization of the AgroNum™ meta-model. The map's background depicts an index of soil texture derived from ESDAC data. Each agricultural plot is necessarily fitted with an iSQ index of the inherent productivity of the soil.

For the time being, AgroNum is applicable in the Balkans but not Turkey due to the lack of proper soil and climate data. Moreover, the arable land of eastern Turkey is not really temperate. The application of AgroNum™ in Turkey will follow.

AgroNum™ is perfectly interoperable with precision agriculture technologies and predictive micro-climatology. The site and plot specific CRP_N nitrogen-fertilizer response curves summarize the different recommended nitrogen fertilization application rates. These TUNs can then be split-applied conventionally over the season considering the *azoto-nutritional* (NNI) status of the crop as it develops. It is sometimes advantageous, in the context of precision agriculture, to modulate in-season as a function of soil heterogeneity and/or plot-level *Baysian* weather forecasts. In all cases, there is interoperability between the CRP_N response curves and any of the aforementioned IOTs, cellular networks, wifi, memory cards, *clouds*, insertable USB keys, or by telephone, facsimile, or simple manual, voice or written activations.

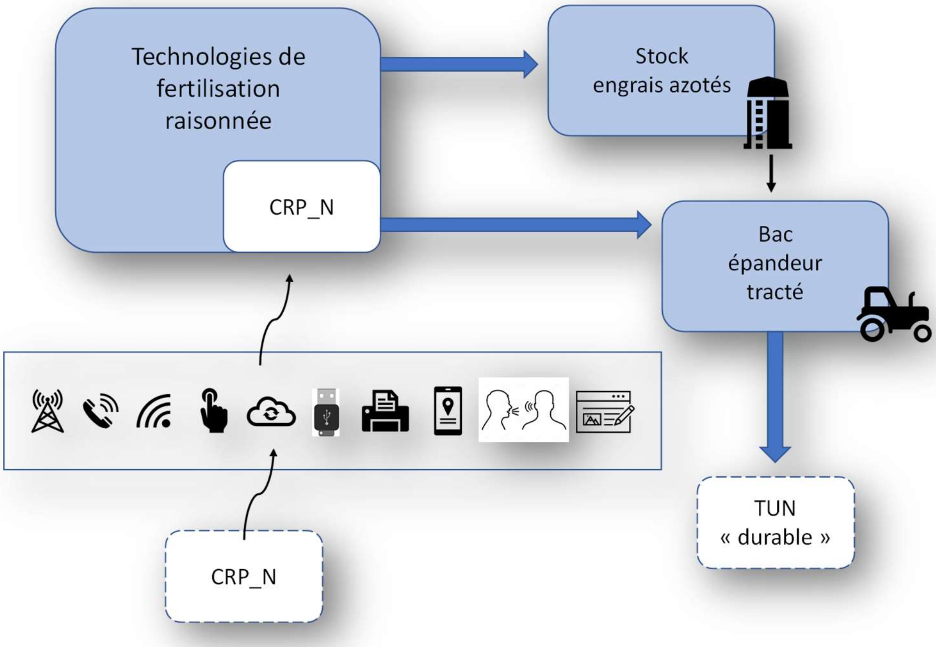


Figure 13: Schematic representation of AgroNum™ interoperability. This integrated fertilization management technology will necessarily affect the make-up, bulking and application of predicted nitrogen fertilizer recommendations, regardless of the interface between the algorithm and the field application apparatus or device. AgroNum™ is artificial intelligence applied to the development of sustainable agriculture.

Let's summarize. The very aspect of AgroNum's N-fertilizer response curves reflects the progressive increase in crop-residue N-content as a function N-fertilizer rates, TUN (kg-N_fertilizer/ha). This progressive N-enrichment of crop residues is recognized (eg. Effh et al. 2022) and ensures their humification into stable organic matter with little/no increase in residual nitrogen and/or nitrous oxide (N_2O) emissions.

AgroNum™ identifies sustainable cropping practices, regardless of the cropping schedules they involve, by recommending N-grain target yields, RDN, with N-fertilizer use efficiencies, RUN, neither too low nor too high. We thus rule out situations that are;

(i) either conducive to soil organic matter degradation and nitrate pollution of the vadose zone when RUN values are relatively low, or rather;

(ii) not conducive enough to the formation of soil organic matter from abundant soil-borne crop residues insufficiently rich in nitrogen when RUN values are relatively high.

The build-up of soil organic matter is a function of grain yield and soil-borne crop residues (Omara et al. 2019/bis, Stella et al. 2019, Benjamin et al. 2016). That said, the nitrogen content of soil-borne crop residues increases with the nitrogen fertilization rate (eg. Effah et al. 2022, Rutkowska et al. 2016, etc.), even when and if gradually lowering RUN. This relative nitrogen enrichment of crop residues will increase their degree of humification, humification closely linked to the carbon/nitrogen/phosphorus stoichiometry of soil organic matter and crop residues (Kirkby et al. 2016/bis, Janssen et al. 1996, Nicolardot et al. 2001, Cotrufo et al. 2013, Richardson et al. 2014).

However, if these rates of increase, b, as function of TUN for RDN and N_rcs are comparable (≈ 0.24 ↔ 0.26), or better still identical, the amount of nitrogen returned to the soil by crop residues will therefore necessarily be proportional to the AgroNum™ sustainable target grain-nitrogen yield, RDN. Mathematically, if b1 ≈ b2 when RDN = a1·TUN b1 and N_rcs = $a2 \cdot TUN^{b2}$, the ratio a2/a1 is constant (Figure 8). This a2/a1 proportionality of N_rcs & RDN ensures the humification of crop residues, and therefore their possible sequestration, or storage, in soils as stable organic matter; see for example Van Groenigen et al. 2017.

It appears that these rates, or coefficients, of increase are essentially constant regardless of the plot, crop or cropping practice, at about 0.24 ↔ 0.26. Recall once again that it is this synchrony of AgroNum's RDN target grain nitrogen-yields and the N-content of soil-borne crop residues (%N_rcs) & yields (kg-N_rcs/ha ; below) that ensure the humification of this straw into stable organic matter. A meta-analysis of 20 or sol scientific articles revealed that these values are reproducible.

The a2/a1 ratio and the b2 ≈ b1 equality are in themselves a sort of validation of AgroNum™. For instance, (Figure 14) a yield target response curve, RDN, nitrogen fertilizer, TUN, AgroNum response curve (CRP_N) perfectly in agreement with that of a long-term experiment (LTE; Van Grinsven et al. 2022). The targeted AgroNum™ RDN increase at about the same rates as the nitrogen content of crop residues, %N_rcs, or of the remaining foliar ^{15}N in crop residues (eg., data from Effah et al. 2022);

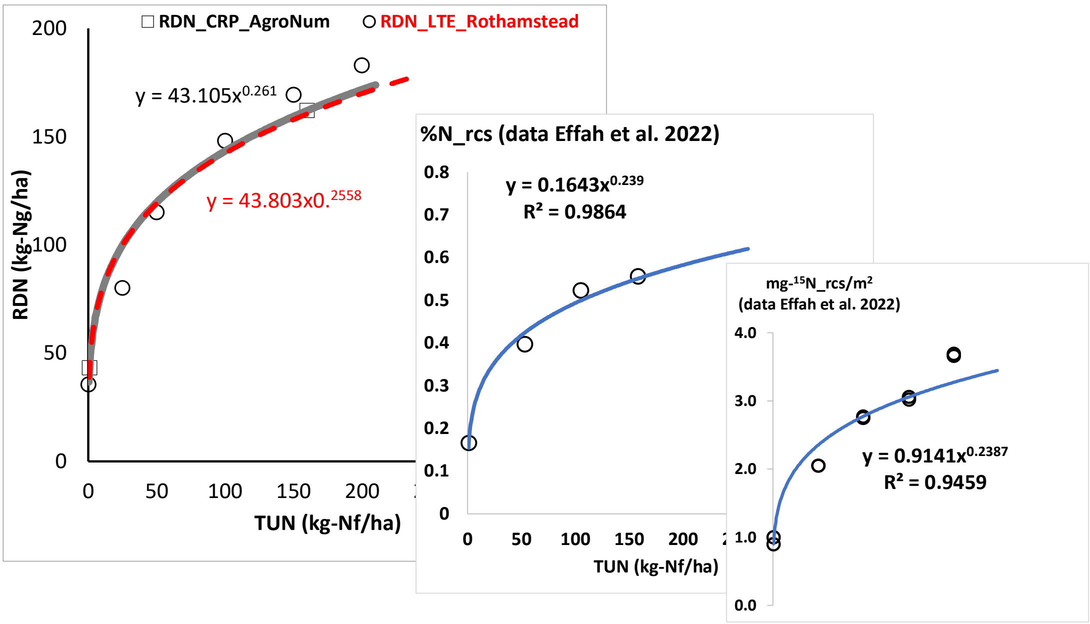
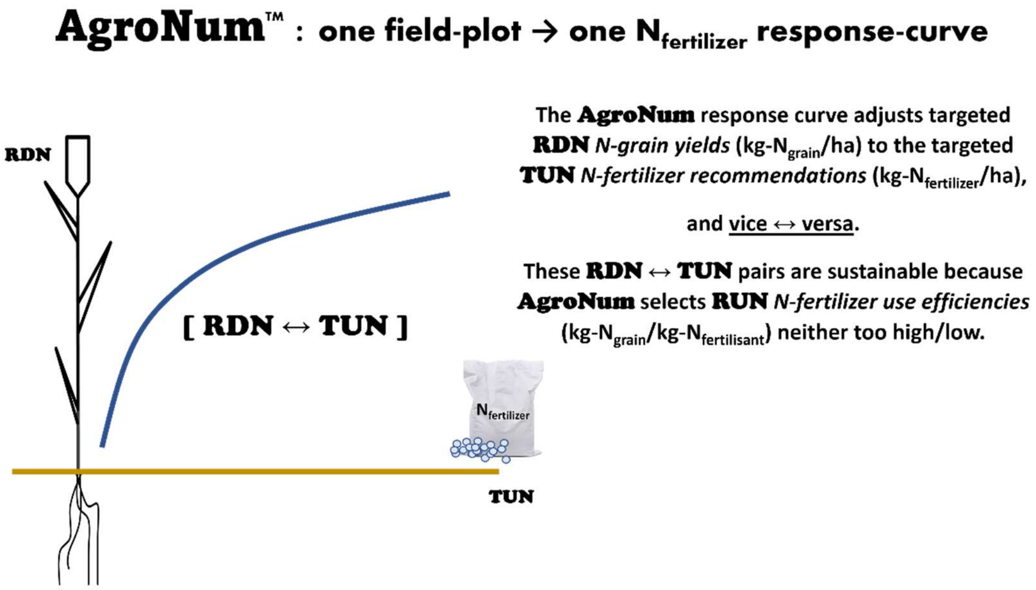


Figure 14: An nth validation of AgroNum™'s CRP_N nitrogen response curves when compared to an "LTE" curve (van Grinsven et al. 2022), Recall their synchrony with the progressive nitrogen enrichment of crop residues as a function of nitrogen-fertilization. Once again, it is this synchrony that ensures the supply of sufficient nitrogen to the soil necessary to humify crop residues into stable organic matter.

In sustainable agriculture, one will simultaneously seek to (i) increase N-fertilizer use efficiency, RUN, to minimize the microbial attack of SOM by soil microorganisms fond of residual mineral-N, and (ii) increase the N-content of crops residues, especially at high yields, to ensure their humification, even, if need be, at the risk of damping increases in RUN. It so happens that AgroNum™ (Figure 15; www.polyor.fr) achieves this delicate balance by screening for cropping schedules with RUNs that are either too low or too high (EP4101280). As a result, the AgroNum™ algorithm selects the most sustainable cropping practices & scheduels by matching target RDN & sustainable TUN



AgroNum™ : one field-plot → one $N_{fertilizer}$ response-curve

The **AgroNum** response curve adjusts targeted **RDN** *N-grain yields* (kg-N_{grain}/ha) to the targeted **TUN** *N-fertilizer recommendations* (kg-$N_{fertilizer}$/ha),

and vice ↔ versa.

These **RDN** ↔ **TUN** pairs are sustainable because **AgroNum** selects **RUN** *N-fertilizer use efficiencies* (kg-N_{grain}/kg-$N_{fertilisant}$) neither too high/low.

Figure 15: AgroNum's™ proposed commercial positioning. The farmer only has to fill in the centermost GPS coordinates latitudes & longitudes most in the center of the plot, or if he/she wishes to specify the desired yield objective or fertilization rate. De facto, Polyor SAS will transmit to the user a "pivot" RDN (Na1) when a_AgroNum = 1.00, i.e. RDN ≡ TUN, or again a sustainable target RDN for TUN when a_AgroNum = 125% of the Na1 pivot.

***

References (www.polyor.fr)