Polyor SAS Research

AI-powered R&D for sustainable agriculture & soil conservation

Table of contents

EXECUTIVE SUMMARY

The growing interest in precision agriculture, artificial intelligence, carbon-farming, nutrient management, so-called regenerative agriculture as a means to *carbon dioxide removal* (CDR) through carbon sequestration masks some basic, and a priori inescapable limitations and conceptual flaws.

Regardless, the underlying goal remains making routine agricultural consultancy more sustainable, this even though at farm & plot-level very few precise agro-pedoclimatic data are routinely available & easily uploaded, i.e. RDN N-grain yields per hectare, their corresponding TUN N-fertilizer application rates, along with the centermost GPS coordinates of the plot. More recently, in-season microclimatic data and remotely sensed vegetation indices such NDVI are readily available via real-time sensors. The rest of the data collection is a bit of a crop shoot given the intrinsic heterogeneity of soil.

Still. Current DSS (decision support systems) were mostly developed as on-farm experiments by extrapolation & expansion of complex, process-based soil & crop models a priori ill-suited for such routine agricultural consultancy. Baseline sustainable benchmarks are also lacking, most sustainability assessments being made using composite indices more in line with subjective multi-criteria decision analyses rather than truly objective yield, application rate, and SOC thresholds. This lack of precise & accurate yield and N-fertilization recommendations has nurtured very chaotic, byzantine debates as to how to achieve sustainable agriculture and carbon-neutral cropping practices, let alone monetize CDRs through so-called carbon-offsets & credits.

AgroNum™ as an AI-based alternative to current nutrient management planning (NMP) circumvents most of these limitations. Using recognized boosting, non-algebraic core algorithms, and a vast array of open-sourced, low resolution agro-pedoclimatic data, very precise sustainable RDN N-grain-yields and their corresponding TUN N-fertilizer application rates are routinely predicted at the field-plot level across Europe. This is done using N-fertilizer response curves generically applicable to all non-*Fabaceae* grain bearing field-crops. This makes this DSS perfectly interoperable with all currently available in-season & in-field precision agriculture and nutrient management technologies.

AgroNum™ resolves the carbon-farming conundrum using an innovative concept; *refundable nitrogen credits* (RNCs). As an alternative to current soil-derived carbon-credits CDRs, RNCs are a direct measure of the amount of *supplemental* nitrogen remaining in the crop residues returned to the soil. This additional nitrogen guarantees the humification of these residues into stable SOM. This N is deemed refundable because it could have been otherwise harvested for profit as grain protein via RDN N-grain yields beyond the sustainable target RDN yields set by AgroNum™ response-curves. Not harvested for profit, this supplement N can be refunded as a service to the environment, such as SOC conservation for instance. These nitrogen credits attributable to sustainable modifications of current cropping practices were validated using a widely recognized and relatively easily implementable process-based model of SOC turnover, Roth-C.

Polyor SAS will now need to confront institutional barriers & gatekeepers, as well as scientific paradigms a priori hostile to such disruptions. Time will tell.

ABSTRACT

Complex, process-based models are abundant but often poorly adapted for use as decision support systems (DSS) in sustainable agriculture and soil conservation. AI applications such as AgroNum™ could also be more appropriate for carbon-farming and integrated fertilizer management. As most AI applications, this DSS is a sort of black box, albeit a very precise one. As a simple I/O system, AgroNum™ is *closed* – little or no supplemental nitrogen being leaked to the environment. This closure is effective given AgroNum™ calibration datasets excluding RUN N-fertilizer use efficiencies either too high or too low conducive to *soil organic carbon* (SOC) degradation & non-point source pollution.

Implemented as plot-specific N-fertilizer response curves, AgroNum™ provides both sustainable RDN N-grain target yields and their corresponding TUN N-fertilizer application rates. This approach to fertilizer management is very ergonomic for the user since only a minimal dataset is uploaded, and interoperable with all precision agriculture & in-season weather monitoring technologies.

Scientifically, AgroNum™ is based on the widely recognized *bimodality* of SOC dynamics with respect to RUN N-fertilizer use efficiency (NfUE). To render this bimodality operational, a series of *rational adjustments* (page xx) are proposed. The resulting plot specific sustainable yield references, rRSQ_run, can then be predicted using AgroNum™'s core AI boosting algorithm, and compared to observed RSQ_run to determine the sustainability of the cropping practice.

Of the approximately 33 000 cropping practices screened across Europe, 10% or so were deemed sustainable as understood and retained as the training dataset. In the process, *N-fertilizer response curves* (Figure 3) are generated at the plot level using a novel concept, i.e. the N-fertilizer requirement of the cropping practice per se – a_AgroNum ($a_{AgroNum}$).

Most importantly, and given the said closure characteristic of AgroNum™, i.e. N-losses to the environment given moderately high RUN N-fertilizer use efficiencies, *refundable nitrogen credits* (RNCs) are attributed to treatments modifying current (control) cropping practices. The calculations for obtaining these RNC estimates are described in the annex. This agro-environmental accounting resolves a series of problems currently plaguing carbon-farming.

The validation of AgroNum™ is argued – numerically & agronomically, as well as economically given the said refundable nitrogen credits. Validation is done with respect to habitual local or regional environmental means across Europe. Modified cropping practices using progressive treatments were also assayed as to their sustainability as understood in comparison to SOC turnover as modelled over 21 years starting 2 000 at numerous sites across Europe using an R® language implementation of the recognized Roth-C® model.

AgroNum™ can thus be seen as a precise, ergonomic, impartial, and cost-effective alternative to existing carbon & nitrogen budgeting schemes, most of which are far too complex, expensive & imprecise to be expansively adopted by farmers across Europe and worldwide.

INTRODUCTION

A slew of dynamic, process-based models has been developed. These complex amas of differential equations are quasi-inapplicable in routine agricultural consultancy given the number of variables & parameters involved that need to be precisely estimated over time & space.

This said, most decision support systems (DSS) for nutrient management planning seem to have been developed denying the fact that at the field & plot level there are very few precise and/or easily obtainable agronomic data, grain yield and its nitrogen & moisture contents, along with the nitrogen fertilizer application rates. All the other inputs and parameters fed to existing dynamic models are based on either error prone soil sampling and/or crude estimates.

More so, the expansion of process-based models at the plot & field level does not simply equate to on-farm experimentation (OFE). Also, sustainable agriculture requires baselines & benchmarks. These are not easily created using the said process-based models. Finally, indicators, often used in multi-criteria decision analysis (MCDA) are for their part ideologically loaded, too qualitative and often as data intensive as process-based models to be used for routine fertilizer recommendations.

So-called artificial intelligence algorithms can fulfill this data precision requirement by catering to low resolution, pixilated, georeferenced open-source agro-pedoclimatic data. AI-like random forest and boosting algorithms can transform such preexisting databases into ergonomic AI-based decision support systems for use in agricultural consultancy and nutrient management planning.

Carbon-farming and soil derived carbon-credits are also debatable. The existing knowledge base probably does not justify this focusing first and foremost on SOC sequestration (Moinet et al. 2023, Poulton et al. 2017). Some question whether SOC sequestration really matters for climate change (Minasny et al. 2023), or again the feasibility of carbon-farming given that soil organic matter contains N as well as C and it is unclear where this nitrogen will come from (Van Groenigen et al. 2017). Differences in nutrient stoichiometry imply that there are significant nutrient – nitrogen in particular, costs in sequestering carbon in soil organic matter. Richardson et al. 2014 argue that these nutrients should be accounted for in carbon trading schemes. Despite this, carbon-farming & SOC sequestration are getting a lot of traction as *the* main CDR mechanism in agriculture.

AgroNum™ is thus a critique, a response and an alternative to current N-fertilizer recommendations schemes using conventional balance & budgeting approaches, as well as a more robust and precise alternative current mrv & carbon-farming protocols. AgroNum™ monitors *refundable nitrogen credits* (RNCs) paid to the farmer, and this, without any soil sampling, IoT, data uploads, or burdensome and at times expensive carbon & nitrogen budgeting schemes currently proposed by carbon-farming & integrated fertilizer management advocates.

This draft working paper is an overview of the scientific basis & general features of this novel approach to nutrient management planning conducive to sustainable agriculture & SOC conservation.

1. About Polyor SAS

Polyor SAS Research (www.polyor.eu) is a small French privately owned R&D and IP holding company dedicated to sustainable agriculture & soil conservation. Polyor banks on a vast array of geo-referenced soil & climate data fed to various core AI algorithms.The resulting N-fertilizer response curves, nutrient management plans (NMPs) & soil-carbon accountability are then made interoperable with current precision agriculture. **Senus** Ltd (www.senus.com), a global leader in environmental technology, in partnership with Polyor SAS has recently announced the launch of its AI-powered NMP technologies across Europe.

Pierre-Philippe Claude – Polyor's ceo has developed & patented sustainable nutrient management planning technologies. Since 2008, Pierre-Philippe CLAUDE, Ph.D., agrologist, has developed a simple and ergonomic approach to sustainable agriculture & fertilizer management. He initially developed azotobacterial fertilization (AZB™). More recently, a digital approach using artificial intelligence (AI) - AgroNum™ - has been the primary goal of Polyor SAS's R&D effort. An exhaustive georeferenced database and an industrial property (IP) portfolio incarnate this innovative approach to sustainable agriculture and nutrient management. Polyor has since perfected the R&D & industrial property (IP) applicable to sustainable agriculture, integrated fertilizer management & on-farm experimentation of innovations such as azotobacterial fertilization (AZB™). An innovative and simple to use method - AgroNum™ - for evaluating the sustainability of cropping practices and calculating fertilizer recommendations has since been developed. Breaking with usual approaches to fertilizer management & precision agriculture, Polyor SAS Research emphasizes the ergonomics & ease of use decision support systems for sustainable agriculture & soil conservation.

- Polyor SAS - 5 Allée du Lys Rouge, 54000 Nancy, France
- www.polyor.fr / www.polyor.eu / polyor@polyor.fr
- +33- 06 74 57 70 90 - Pierre-Philippe CLAUDE, pdg

2. Research & development (R&D)

Polyor SAS's three R&D priorities ; (1) plot-specific N-response curves, (2) P, K & H nutrient management plans, and (3) refundable nitrogen credits (RNC) applicable to carbon farming.

Plot-specific N-response curves : Plot-specific N-fertilizer response curves generate fertilizer recommendations conducive to soil organic matter conservation. This involves curating the database by removing excessively high/low N-fertilizer use efficiencies (NfUE) known to deplete soil carbon.

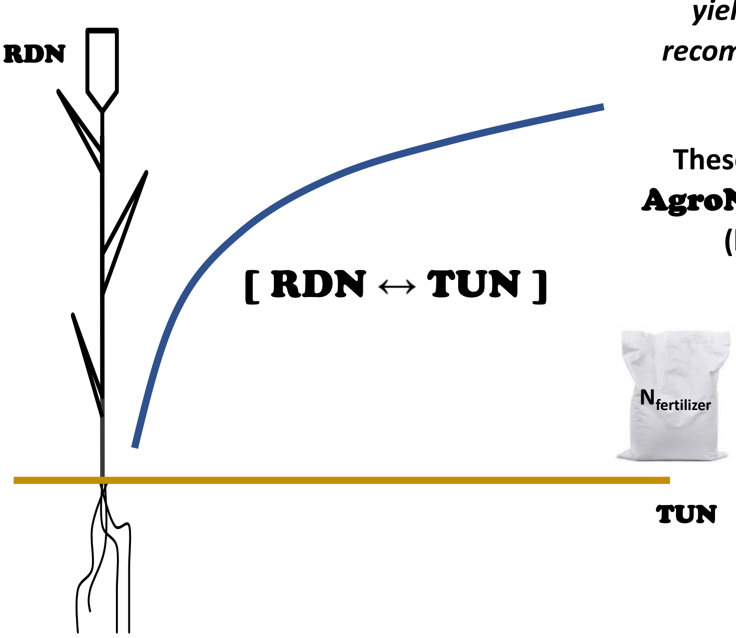
AgroNum™ uses generic, plot-specific, nitrogen response curves applicable to *all* grain bearing non-Fabaceae field-crops across Europe. Implemented as plot-specific N-fertilizer response curves, AgroNum™ thus provides both sustainable RDN N-grain target yields and their corresponding TUN N-fertilizer application rates. This approach to fertilizer management is very ergonomic for the user since only a minimal dataset is uploaded, and interoperable with all precision agriculture & in-season weather monitoring technologies.

Again, farmers need only indicate the plot's centermost GPS coordinates, along with their target RDN nitrogen yield, or "offtake" ; the corresponding sustainable TUN N-fertilizer application rate will be recommended. And vice versa, a desired RDN N-fertilization rate triggers the corresponding sustainable TUN nitrogen-yield recommendation ;

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

AgroNum response curves adjust targeted **RDN** ***N-grain yields*** **(kg-N_{grain}/ha) to targeted TUN *N-fertilizer recommendations* (kg-$N_{fertilizer}$/ha), and vice ↔ versa.**

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



This baseline AgroNum N-fertilizer response curve is deemed sustainable because it was generated by an AI algorithm calibrated against a database from which cropping schedules with nitrogen fertilizer use efficiencies either too low or too high were removed. This culling is universally recognized as conducive to SOM conservation, or even build-up on carbon-depleted soils.

Again, AgroNum™ is based on the widely recognized *bimodality* of SOC dynamics with respect to RUN N-fertilizer use efficiency (NfUE). To render this bimodality operational, a series of *rational adjustments* are proposed. These plot specific sustainable yield *references*, rRSQ_RUN, can then be predicted using AgroNum™'s core AI boosting algorithm, and compared to observed RSQ_run to determine the sustainability of the cropping practice. Of the approximately 33 000 cropping practices screened across Europe, 10% or so were deemed sustainable as understood and retained as the training dataset. In the process, such *N-fertilizer response curves* are generated at the plot level using a novel concept - the N-fertilizer requirement of the cropping practice per se – a_AgroNum ($a_{AgroNum}$).

<u>P, K & H nutrient management</u> : Coupled plot-specific N-fertilizer response curves, P, K & attainable soil pH recommendations are generated. Such nutrient management plans (NMP) also include soil P & K critical thresholds for the fine-tuning of such sustainable fertilizer recommendations. 44 000 such AgroNum™ NMPs (nutrient management plans) have been generated across Europe. Rather than soil tests, the AgroNum reference soil P_Olsen, K_exchangeable, & pH_water&$CaCl_2$ values are indicated. If soil tests are available, these will appear and can be compared to these reference values. GPS coordinates are approximately at the center of the farm or field so that AgroNum™ N-fertilizer responses are usually applicable to the whole farm.

In-field & in-season precision agriculture modulations of this NMP can then be done by the farmer/consultant. AgroNum is interoperable with PA technologies. More so, NMPs can be made more *tenable*, by making sure that P&K use efficiencies, resulting soil pH and soil P&K critical thresholds are *commensurate* with regulatory norms across Europe. This *tenablility* (sic) should make these disruptive, but sustainable, NMPs more acceptable to both farmers and legislators.

An example – one of 22 000, of AgroNum™ NMP in France NUTS2 FRK2 after finetuning to make it more tenable to farmer, consultant & regulator. Notice that little or no bold red values appear as a result. Yellow highlighted items can be modified in the course of this finetuning. Brunish P & K recommendations are imperative since available soil P is below AgroNum™ generated thresholds, most of which are commensurate with existing European norms as estimated by Recena et al. 2022 and/or the Comifer. Given that for this site, environmental means as estimated by AgroNum™ AI algorithm are close to AgroNum™ sustainable means, pTEC is invoked sparingly as a means.

- **Δ target RDN_Na1** : adjust target RDN to render eventual soil pH tenable with current soil tests and/or observations
- **Δ NfUE_pTEC** : if NfUE seems un-economical/agronomical, sustainability can be intensified in lieu of pTEC & N-credits
- **Δ grain NPK_DM** : apply actual grain N, P, K and dry matter as obtained from non-*Fabaceae* grain harvest

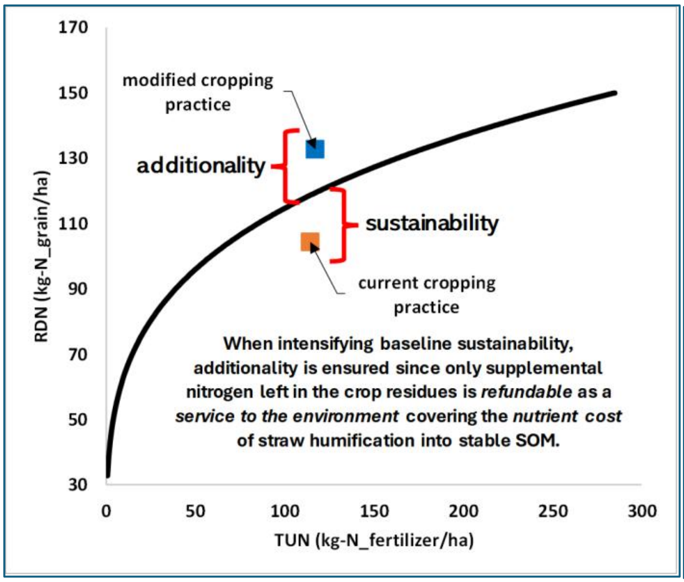
Variable	Units	BTH	ORH	*SCL*	CER	CLZ	ZEA	*TSL*	CLT
		non-Fabaceae field-crop							
n x Na1 → TUN	NA	**1.4**	**1.2**	**0.8**	**1.25**	**2**	**2**	**0.25**	1.27
TUN → target RDN	kg_Ng/ha	**121**	**116**	**104**	**117**	**132**	**132**	**77**	114
N	kg_Nf/ha	155	132	88	138	221	221	28	140
P	kg_P2O5/ha	31	28	15	27	40	49	15	29
K	kg_K2O/ha	27	27	12	28	48	54	12	30
NfUE	kg_Ng/kg_Nf	0.78	0.87	1.18	0.85	0.60	0.60	2.78	1.09
pH_h2o :: TUN	NA	6.37	6.97	6.34	6.37	6.51	6.72	6.68	6.57
pH_kcl :: TUN	NA	5.94	6.71	5.91	5.95	6.13	6.40	6.36	6.20
PfUE	kg_P₂O₅_grain/fert.	1.14	1.34	1.28	1.38	1.18	0.95	1.15	1.21
P_available/critical	NA	**1.12**	**1.00**	**0.98**	**1.12**	**1.09**	**1.04**	**1.04**	1.06
cTEP_polyor/europe	NA	1.22	1.37	1.39	1.22	1.26	1.31	1.31	1.30
KfUE	kg_K₂O_grain/fert.	1.03	1.16	1.33	0.92	0.66	0.79	1.41	1.04
Kavailable/Kcritical	NA	**0.94**	**0.94**	**0.94**	**0.94**	**0.94**	**0.94**	**0.94**	0.94
cTEK_polyor/europe	NA	0.81	0.80	0.80	0.81	0.81	0.80	0.81	0.81
pTEC	% + AgroNum	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	0%
carnac	kg_N/ha (€ ···)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
run_TRT	kg_Ngrain/Nfert	0.78	0.87	1.18	0.85	0.60	0.60	2.78	1.09
%N		**2.20**	**2.00**	**2.50**	**2.02**	**3.53**	**1.70**	**4.00**	2.56
%P2O5		**0.65**	**0.65**	**0.45**	**0.65**	**1.25**	**0.60**	**0.90**	0.74
%K2O		**0.50**	**0.55**	**0.40**	**0.45**	**0.85**	**0.55**	**0.88**	0.60
%DM		**100**	**100**	**100**	**100**	**100**	**100**	**100**	100

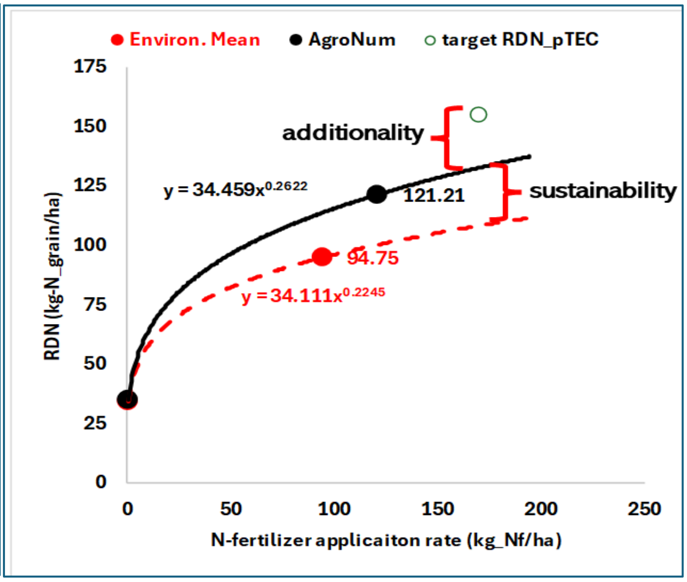
Farmers can interactively adjust RDN protein yield targets for the various non-*Fabaceae* grain bearing field crops (CLT) such as winter wheat (BTH), winter barley (ORH), rye (SCL), small grain cereals (CER), winter rapeseed (CLZ), grain corn (ZEA) or again sunflower (TSL). pTEC yield enhancing technologies can also be accounted for ; these can at times generate refundable N-credits in lieu of conventional soil-derived carbon credits. At harvest, grain N, P & K levels can be assessed to, either ascertain the degree of sustainability of the current cropping schedules, or again reset target grain NPK levels.

<u>Refundable nitrogen credits (RNC)</u> : As an ergonomic alternative to current carbon-farming & soil-derived carbon-credits, this simple soil-*samplingless* (sic) protocol ensures that crop residues contain sufficient nitrogen to be properly humified as soil organic matter. RNCs also get around issues of additivity, leakage, permanence, etc.

Nitrogen-fertilizer response curves can be used to evaluate, *precisely*, so-called *refundable nitrogen credits* (RNC). These N-credits are meant as a convenient and valuable alternative to current carbon-farming derived carbon-credits. RNCs are input oriented and reward at no cost to the user existing soil conservation efforts by inferring the amount of *supplemental nitrogen* left to the crop residues at harvest, nitrogen that could have otherwise been harvested *for profit* in the grain. This residue-nitrogen is a *valuable* service to the environment and thus deemed … *refundable*, at par with the real-time market price of nitrate ammonium, for instance. This said, such refundable nitrogen-credits will be *small* as compared to publicized carbon-farming derived carbon-credits, but again at little or no additional cost to the farmer.

RNC generation also ensures additionality of soil derived carbon dioxide removal certificats. Farmers *are refunded* only that amount of nitrogen left in the crop residues and effectively returned to the soil. Farmers and thus not being paid to attain sustainability per se as a baseline but rather for intensifying sustainability to avoid leakage as a result of decreased yields.





AgroNum refundable N-credits thus ensure *additionality* since only residue nitrogen *beyond* baseline sustainability are valued. More so, this crediting scheme is perennial, thus circumventing the usual *permeance* issue. *Leakage* is no longer an issue since RNCs imply yield increases. Finally, there is no risk of *mitigation deterrence*, since RNCs reenforce existing behavior rather than speculate on SOC stocks & accrual rates.

AgroNum thus facilitates baselining but also does away with the need for on-farm experimentation and the setting up of control plots. This said, current cropping practice or « control » can be arbitrary & difficult to identify. It is often simpler & fair to use AI-derived plot specific « environmental means » instead. Polyor has also developed an AI algorithm to estimate such precise plot specific environmental means to be advantageously used as controls. For instance, here is an example of a plot in Poland ;

Again, supplemental nitrogen returned to the soil by the crop residues will lead to SOC conservation or build-up. This supplemental N in response to cropping practice modification is precisely estimated by Polyor SAS's AgroNum AI & dbase with respect to local or regional environmental means across Europe. A tentative validation was attempled by pitting AgroNum RNC against estimated increases in soil organic nitrogen modelled over 21 years starting 2000 at numerous sites across Europe using an R-language implementation of the Roth-C model.

Polyor SAS has recently developed an artificial intelligence decision support system that sets sustainable targets for field-crop yields & their corresponding nitrogen fertilization rates. Agro-pedoclimatic data was fed to a core boosting algorithm. The resulting meta-model – AgroNum™, is easily implemented using only GPS coordinates ; no soil sampling, sensors, IoTs, drones, high resolution remote sensing, or even shapefiles are required. A dematerialized, prototypic MRV scheme, in sort.

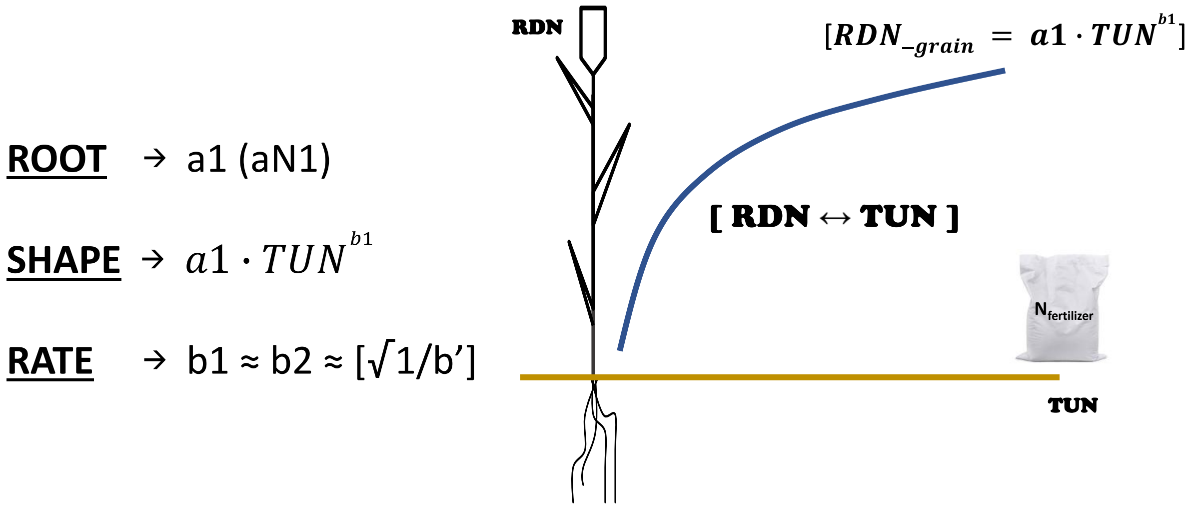
That said, AgroNum™ is first and foremost an ergonomic alternative – or rather a complement, to existing integrated fertilizer management schemes, and nutrient management plans. AgroNum™ uses plot-specific, N-response curves applicable to all non-Fabaceae field-crops across Europe. Farmers need only indicate the plot's GPS coordinates, and target nitrogen yield; the corresponding sustainable N-fertilizer application rate will be recommended. And vice versa, a desired N-fertilization rate triggers the corresponding sustainable nitrogen-yield recommendation. By sustainable is meant nitrogen target yields and/or fertilizer application rates that lead to intermediate nitrogen fertilizer use efficiencies (NfUE), neither too low, nor too high, conducive to SOM conservation, or build-up on carbon-depleted soils.

More recently, nitrogen-fertilizer response curves have been used to calculate refundable nitrogen credits (RNCs). These N-credits are meant as a convenient & valuable alternative to carbon-farming derived C-credits. These N-credits reward - at no additional cost, soil conservation efforts by inferring the amount of supplemental nitrogen left to the crop residues at harvest, nitrogen that could have otherwise been harvested for profit in the grain.

This nitrogen is a valuable service to the environment, and thus deemed refundable, at par with the real-time market price of nitrate ammonium, for instance. This said, refundable nitrogen-credits will be small as compared to publicized carbon-farming derived C-credits, but again at little or no additional cost to the farmer.

AgroNum refundable N-credits ensure additionality since only residue nitrogen beyond baseline sustainability are valued. More so, this crediting scheme is perennial, circumventing the permeance issue. Leakage is no longer an issue since RNCs imply yield increases. Finally, there is no mitigation deterrence, since RNCs re-enforce existing behavior rather than speculate on SOC stocks & accrual rates.

The operational validation of based on a series of meta-analyses. In a nutshell, we found that the "root, shape & rate" of AgroNum™ N-fertilizer response curves are legitimate. The implementation of AgroNum™ NPKH nutrient management plans are also inline with the current "plan, check, adjust & review" agricultural consultancy paradigm ;



eg. Nutri-Check_eu / https://platform.nutri-checknet.eu/about

3. Intellectual property

Polyor's IP portfolio (Polyor SAS Intellectual Property) as an asset. EPO links to patentable AI-powered innovations. Recall that Polyor SAS Research is first and foremost an intellectual property holding company dedicated to R&D for sustainable agriculture, soil conservation and nutrient management planning. This R&D efforts dates back to 2007. As of early 2025, Polyor has been granted over 30 european patents stemming from its own R&D on fertilizer management & azotobacterial fertilization (AZB™). More importantly, Polyor's IP strategy has recently shifted towards artificial intelligence (AI) powered nutrient management plans (NMP) dedicated to sustainable agriculture and soil conservation (AgroNum™). As an intellectual property holding company Polyor SAS's turnover and profits come from royalties paid by industrial licencees. This cash flow is systematically reinvested in Polyor's continuing R&D effort.

Some of the most recent Polyor patents pertaining to AgroNum™ are ;

- AZB_EP3335536: Indicators of soil quality and sustainability are not sufficiently quantifiable or precise. In addition, current N-fertilizer recommendations (Nf) recommendations according the so-called balance method does disregards soil free-living diazotrophs. By aggregating indicators of soil microbial & azotobacterial activity we can calculate Nf without having to grossly estimate early spring potential soil organic nitrogen mineralization (Mh) and thus circumvent the said balance equation.
- SQT_EP3821688: Agricultural consultancy cannot accurately assess *in situ cropping schedules*. SQT will detect at the plot level treatment effect as it affects N-fertilizer recommendations. This involves replacing the treatment & control strip-plots with plot-specific pedoclimatic references (rRSQ) obtained through predictive AI applied to existing agro-pedoclimatic data. Users need only supply the centroid latitude & longitude coordinates of the plot.
- BMK_EP4101280 : Currently, routine sustainability assessment at plot level is either too costly, qualitative or subjective. Using AI & a simple binary heuristic, the BMK solution ensures that the adjusted N-fertilizer use efficiency at a given yield intensity is neither too high or low and thus conducive to soil organic matter conservation. This involves the determination using a calibrated AI predictive algorithm of a reference rRSQ value.
- CRP_EP4252516: Sustainable nutrient management plans must take into account the aforesaid rRSQ as a function or target RDN nitrogen yields. CRP is an integrated fertilizer management method involving plot-specific N-fertilizer response curves. These indicate all possible sustainable TUN $N_{fertilizer}$ rates and their corresponding RDN N_{grain} target yields of non-*Fabaceae* field crops.
- AZG_EP4491001: Technical progress pTec can raise the CRP nitrogen response curve. To ensure that this yield intensification is sustainable as understood (EP4101280) they must not occur at the expense crop residue nitrogen involved in their proper humification into stable SOM. This nitrogen is thus a tradeable service to the environment. Yield intensification is thus constrained in such a way that N-fertilizer use efficiencies increases are greater RDN increases.
- PKH_EP25206011.6 (filed 0/10/2025): Recommended rates of P&K dPK fertilizer and critical P&K cPK soil thresholds are currently calculated using obsolete Mitscherlich response curves. cPK thresholds should instead be proportional to NPK fertilizer rates. cPK. Idem for soil pH as a function of TUN N-fertilization. PKH is thus interoperable with existing precision agriculture technologies dedicated to soil conservation and sustainable agriculture of non-*Fabaceae* field crops.
- TLS_FR2504187 (preliminary application): AgroNum can be more autonomous. This will involve using time series analyses and Pij transition probabilities. This will lessen the need for the continual updating of AgroNum's expansive agro-pedoclimatic dbases or hunting around for annualized multi-year local or regional averages. Standard R package such as *markovchain* and *markovchainFit* will be used to *discretize* these timeseries into categorical factors.

4. Context & challenges

Polyor's approach to sustainable agriculture and soil conservation is often at odds with carbon farming, regenerative agriculture & nutrient management planning dogma.

AgroNum™ resolves and/or circumvents most of the current issues plaguing this sector. In a sense, carbon farming and nutrient management planning through soil sampling are ill-fated. Soils across agricultural field plots are inherently heterogeneous and estimating soil carbon accumulation & accrual rates as required by carbon-farming would require in the whereabouts of 200 to 500 hundred "samples" per hectare.

Effectively, annual soil carbon accrual rates are most often of one to a few hundred kgs of carbon/ha/year, that is much less than 1% of the original SOC stocks that we wish to build-up. The error associated with existing SOC estimates through soil sampling are often one to two orders of magnitude larger than these accrual rates. The same can be said of soil N, P, K and pH.

Put simply, precise estimates of SOC accrual rates and NPK status requires not soil-sampling but soil-mapping. Given the hundreds of samples required for soil-mapping it is difficult to see how this cost could be offset by carbon credits or improved nutrient use efficiency. It seems as though the current carbon farming and nutrient management planning are based on the erroneous assumption that agricultural fields are homogeneous sampling units, large micro-plots in a sense.

This conceptual flaw leads to unresolvable problems such as non-additivity of carbon-credits given the lack of baselines, leakage and permanence issues, lack of precision, poor economics & ergonomics, etc. Though these issues have been heroically dealt with to some extent, it is still unclear how this could satisfy the regulatory and financial institutions involved in brokering such carbon credits, even given massive improvements in nutrient use efficiencies.

Polyor SAS's (www.polyor.fr) approach to SOC conservation does away with soil-sampling by proposing plot-specific N-fertilizer response curves are generated using proprietary AI algorithms & databases. These response curves are calibrated to exclude N-fertilizer use efficiencies either excessively high or low known to deplete SOC.

For given target grain yields nitrogen, phosphorus & potassium fertilizer recommendations are thus conducive to SOC conservation by preventing *both* soil mining at excessively high N-fertilizer use efficiencies *and* excessive residual soil mineral nitrogen levels at excessively low N-fertilizer use efficiencies.

Refundable N-credits are also calculated if & when technical innovations increase yields beyond the sustainable N-fertilizer response curves. These credits are incurred if & only if increases in N-fertilizer use efficiencies attributable to such innovations are superior to N-grain yield increases. This caveat ensures that sufficient supplemental nitrogen remains in the crop residues for their proper humification into stable soil organic matter."

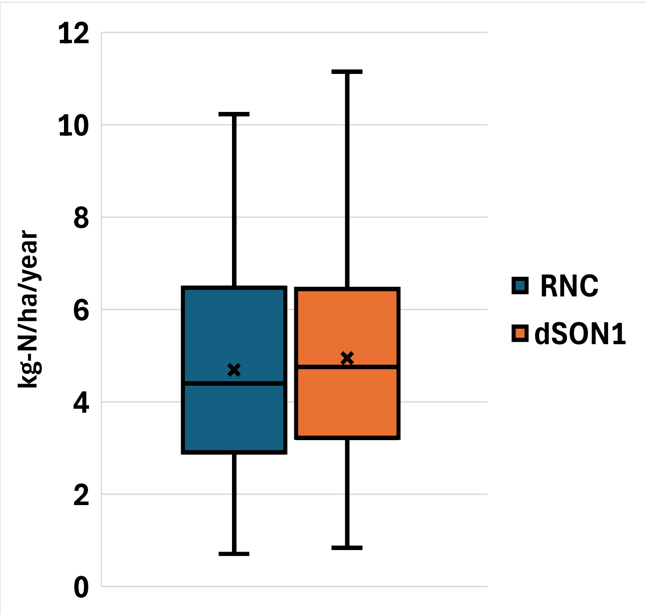
The following pages will put AgroNum™ into context. This will reveal how it can overcome, circumvent and/or resolve these lingering issues o f fairness, additivity, accountability, leakage due to yield gaps, precision, accuracy, ergonomics, interoperability, legality, (im)partiality, permanence and baselining (benchmarking).

Fairness, additivity & carbon accountability

Polyor SAS's AgroNum approach to sustainable agriculture & soil conservation distinguishes cropping-practice modifications simply "catching-up" by attaining sustainable RDN nitrogen-yields (kg-N_grain/ha) recommended by AgroNum™'s N-fertilizer response curves, from CP modifications that allow for sustainable technical progress beyond these curves. Refundable N-credits can then be emitted solely based on this additional N-yield increase "adding-up" to a more intensive form of sustainable agriculture, while ensuring additionality.

Participating farmers will eventually receive negotiable credit(s) for thus intensifying their sustainable cropping practices at no extra cost. These refundable N-credits (RNC) will eventually be paid to the farmer. This, without any of the soil sampling, IoT, data uploads, or burdensome – and expensive, carbon budgeting schemes usually proposed by advocates. Polyor SAS is presently working at standardizing & certifying AgroNum™ as a means of carbon-offset verification in lieu of existing MRV protocols.

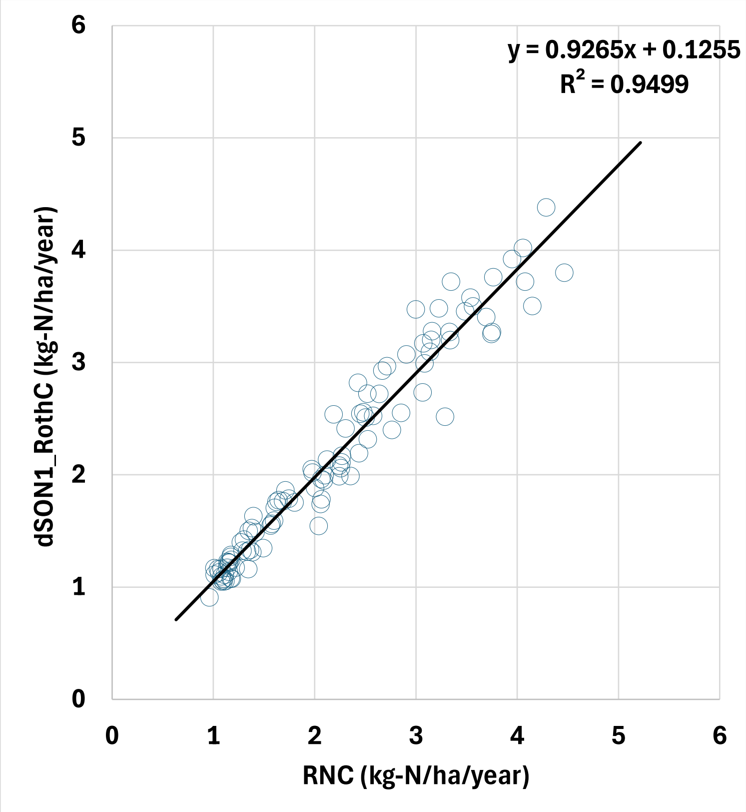
The pTEC concept as a means to RNCs is – to some, less intuitive and harder to grasp. Nevertheless, along with the AgroNum™ sustainable N-response curves per se, it will prove to be the most interesting feature of these next generation NMPs. The idea is to be fair, precise, cheap, avoid double-counting and leakage (e.g. lowering yields and increasing them unsustainably elsewhere) and ensure some form of permanence. This fairness relies on the ASQ environmental-mean ↔ RSQ sustainable-yields dichotomy.

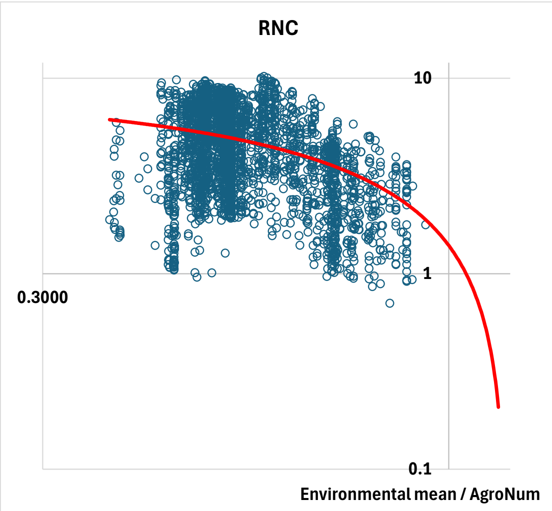


If/when environmental-mean yields are below the AgroNum sustainable-yields, farmers yielding beyond environmental means are exceptional and moving towards sustainability. If they were from that point on to go beyond the sustainable AgroNum curve, they could get RNCs if and only if the treatment effect in terms of nitrogen use efficiency is greater that the relative yield increase beyond the sustainable response curves This ensures that increased N-uptake will cover both grain and crop residue nitrogen requirements. If not, RDN grain-protein yield increases would deplete crop residue nitrogen and hinder the humification of these residues into stable SOM.

RothC® (RothC®) was used to validate the RNC concept. The model works best in the NW region of Europe, i.e. UK & Ireland for which and where it was designed and parameterized, and in Lower Saxony (DE) given the pedo-transfer functions of Weihermüller et al. 2013 (Weihermüller et al. 2013). For these field plots (n = 2827), the average 4.69 RNC are very comparable to the 4.95 dSON1 values derived from these modified RothC® runs.This involved modifying k.DPM, k.HUM & D-to-R ratio RothC® parameters as a function of pTEC thus taking into account the increased yields and C-inputs from crop residues. These functions derived from meta-analyses and will be shared & published if need be.

RNC and corresponding RothC® dSON1 values for 102 field plots across the UKC2 NUTS2 mapping unit (n = 102). Note that AgroNum™ functions best withing given mapping units, such as NUTS2 for instance. Also, RothC® as modified herein is not a pan-europeann alternative to AgroNum's RNC concept since RothC® as modified to generate dSON1 ≈ RNC is only applicable in the UK, IE & Lower Saxony (DE), whereas RNC can be conveniently calculated for any field plot, in any NUTS mapping unit across Europe. RothC® is only being used here as an experimental procedure for the validation of AgroNum™ as a effective tool for nutrient management planning and the quantification of SOL conservation and build-up. Note that the RNC concept has been patented by Polyor SAS and that this patent has since been granted by the EPO (EP4491001).

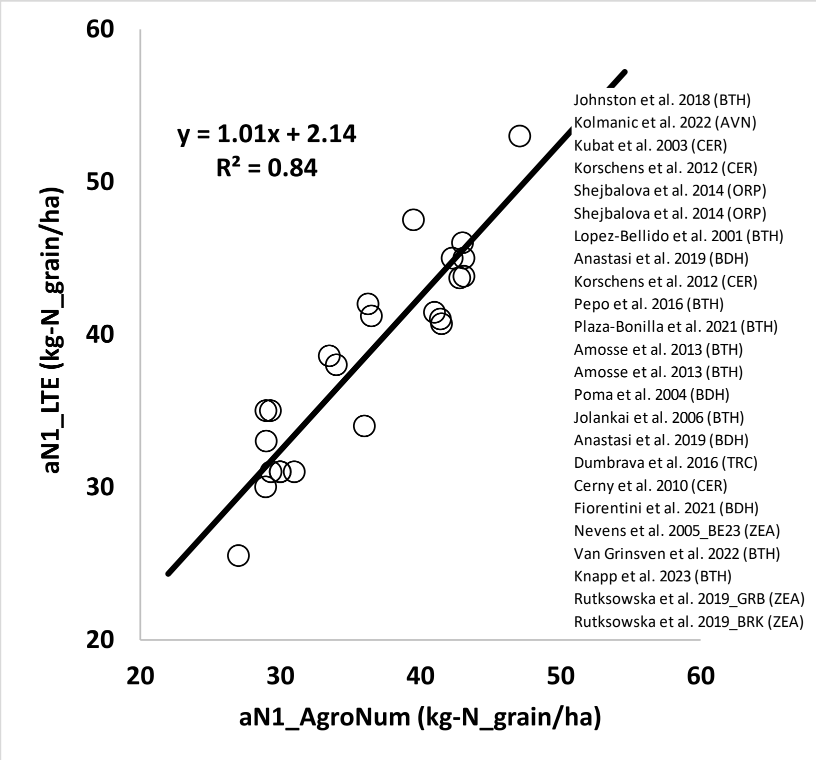




AgroNum™ refundable N-credits (RNC, alias carnac – *crédits azote remoboursables*, fr.) as a function of the ratio between environmental means RDN and the corresponding AgroNum RDN target at a for a particular TUN N-fertilization. For site with high environmental RDN means close to or above sustainable AgroNum™ targets, the number of eligible RNCs will dwindle - or even become negative if the environmental RDN mean is beyond sustainability. This is not an mathematical artefact but an illustration of how high yielding farmers in areas where the environmental means a too far behind sustainable AgroNum™ targets will be recognized as forerunners.

This is fair since farmers having already moved towards sustainability by increasing RDN will get the same credit as those who haven't even though they have less yield increases to muster since they've already covered some of the distance towards sustainability. RNCs would be calculated using environmental means as an unsustainable references applicable to all farmers. The higher performing farmers would just have to work less to get the same number of RNC. This way we don't run the risk of rewarding laggers or penalizing exceptional farmers.

Note that at TUN = 1, RDN ≡ aN1 on the aforesaid N-fertilizer response curve. These aN1 values are well correlated to the RDN grain-nitrogen yields at 0 N-fertilizer from long-term experiments (LTE) across Europe. AgroNum™ N-response curves indicate the sustainable target RDN at 1 kg-N_fertilizer/ha, i.e. aN1. In lieu of validation, there is seemingly a good correlation between aN1 values obtained from long-term experiments (LTE) across Europe. The values of aN1 dependent on the native azotobacterial activity of the soil, azb, is therefore predicted quite well.

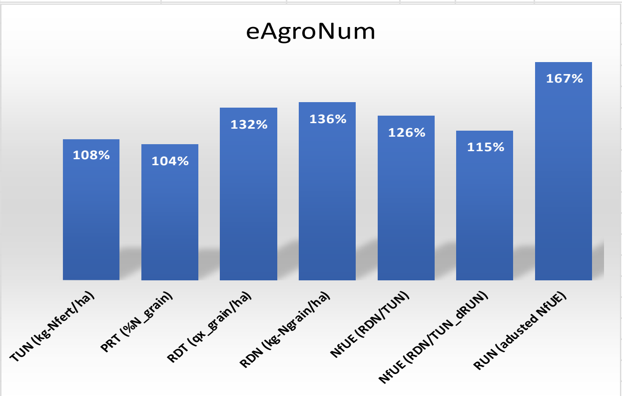


This value of aN1 is characteristic of the location of the agricultural plot and well correlated with the intrinsic productivity of the soil, iSQ (Toth et al. 2013). AgroNum™ N-response curves indicate the sustainable target RDN at 1 kg-N_fertilizer/ha, i.e. aN1. In lieu of validation, there is seemingly a good correlation between aN1 values obtained from long-term experiments (LTE) across Europe. The values of aN1 dependent on 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 well correlated with the intrinsic productivity of the soil, iSQ (Toth et al. 2013).

Leakage & yield gaps

Sustainable agriculture through carbon-farming & sequestration often advocates grain yield reductions to lower N-fertilization rates supposedly responsible for GHG emissions. This extensification can lead to "leakage" in that these missing yields will have to be produced elsewhere, often on more marginal land susceptible to soil degradation. This is especially disheartening given that yield gaps across Europe indicate that overall yields should increase, not decrease, in response to European & worldwide food security imperatives.

variable	rASQ env. means	rRSQ AgroNum	tTest		eAgroNum
TUN (kg-Nfert/ha)	128	139	0.00%		108%
PRT (%N_grain)	2.12	2.20	0.00%		104%
RDT (qx_grain/ha)	49.77	65.72	0.00%		132%
RDN (kg-Ngrain/ha)	99	135	0.00%		136%
NfUE (RDN/TUN)	0.77	0.97	0.00%		126%
NfUE (RDN/TUN_dRUN)	0.80	0.92	0.00%		115%
RUN (adusted NfUE)	0.70	1.17	0.00%		167%



For instance, Schils et al. 2018 (Schils et al. 2018) ; [in Europe /…/ the combined mean annual [grain] yield gap of wheat, barley, maize was 239 Mt, or 42% of the yield potential". More so, "[This] requires a substantial increase of the crop N-uptake of 4.8 Mt. Across Europe, the average N-uptake gaps, to achieve 80% of the yield potential, were 87, 77 and 43 kg N ha−1 for wheat, barley and maize, respectively." And in closing, "Emphasis on increasing the N use efficiency is necessary to minimize the need for additional N inputs."

Overall, AgroNum target grain yields [RDT] for 11 non-Fabaceae grain bearing field crops (mostly cereals, but also rapeseed, sunflower & maize) are substantially higher than conventional environmental means. Even more so in terms of grain-nitrogen yield [RDN, alias N-uptake]. This, at essentially the same overall N-fertilizer application rates [TUN], increases N-fertilizer use efficiency [NfUE]. Single handedly, AgroNum™ target yields close most the cereal yield gaps across Europe.

Sustainable agriculture & soil conservation in field-crop production is also all about reducing yield gaps. Schils et al. 2018 (Schils et al. 2018) were quite explicite in that respect. At the risk of self-promotion, Polyor SAS's AgroNum approach to setting sustainable cereal target yields & N-fertilizer recommendations seems to be a means to that end. As compared to conventional regional (local) yield-averages often used as proxies for target-yields, AgroNum sustainable target grain & nitrogen yields are on average & 70% of the time higher.

Alas, Don et al. 2023 (Don et al. 2023) and De Rosa et al. 2023 (De Rosa et al. 2023) when introducing notions such as accrual, negative emissions, etc., infer leakage since the “accrual” (sic) of SOC stocks in European croplands are said to come from their conversion to … grasslands.

Precision & accuracy

Recall that agricultural consultancy relies on very few routine precise measurements; the center-most GPS coordinates of the plot, dry grain nitrogen yield & N-fertilization, along with some local meteorological data. Estimating the rest of the of the field-plot’s pedoclimatic data is a crap shoot. Measuring soil SOC and/or NPK stocks and fluxes through sampling is inescapably imprecise.

Soil conservation through "carbon farming" may need to be revisited if sampling & monitoring costs are too steep. Bettigole et al. 2023 (Bettigole et al. 2023) is a bit of an eye-opener. Simpler - for the user anyway, AI-based methods of ensuring soil organic matter conservation in intensive field-crop production may be warranted.

This is true for nutrient management planning in general. For instance, Schut et al. 2025 (Schut et al. 2020) is particularly critical of fertilizer recommendations. They evaluated the influence of errors introduced due to soil sampling and chemical analyses within and among laboratories. Fertilizer recommendations ranged from 86 to 186, 0–58 and 38–114 kg N, P and K ha-1 respectively. Laboratory services and digital applications providing field-specific recommendations promise more accuracy than soil sampling & analysis can deliver ; field-specific fertilizer recommendations based on a single composite soil sample is indeed a “pipe-dream” (sic).

Despite its focus on CDR (carbon dioxide removals) in Californian forests, Joseph Wilson’s 2024 article (Wilson et al. 2024) is nevertheless relevant to the carbon-farming conundrum. Wilson evokes baseline projections, carbon-sequestration, degrees of uncertainty, measurement processes & their costs, subjectivity, alternative approaches;

- “Projections about the uncertain future are not necessary for generating a measurement model for financial awards.”
- “Many financial aspects remain to be determined, like the credit value to be ascribed to a unit of carbon and the temporal structure of the award.”
- “There are also a number of costs for the absolute approach that come along with a more focused attempt to link sequestered carbon to credits.”
- “The absolute approach is likely to be less attractive to investors, making it a less marketable approach.”, etc., etc.

This type of “philosophical” critique of CDR carbon-farming projects would be well appreciated. For instance, SOC baselines & projections are still being debated while SOC credits are already being emitted and brokered. Idem for the market value & cost of soil derived CDRs. Despite this, alternative approaches could be less attractive to investors for lack of “over-crediting”.

Complex, process-based models of soil & plant CNPS processes have been proposed as a means to greater precision and accuracy. But How accurate are process-based dynamic field-crop models? *On average*, pretty good ; eg. Wallach et al. 2018 (Wallach et al. 2018). AgroNum has more of an AI bent to it probably more ergonomic & precise when it comes to agricultural consultancy.

Costs & Economics

"Carbon credits' greatest problems have been their inability to live up to the ***offset*** claims made on the back of them. Even if some of the ***credits*** were creating an ***impact***, it is very hard to prove that a ton was truly avoided or removed thanks to the purchase of a credit. /.../ Instead, companies should use credits to claim they ***contribute*** to climate action (Robert Höglund's report from COP28 (Hoglund_2025)). The same can be said of soil-derived carbon-offsets & credits as proposed by carbon farming advocates. Paraphrasing, [offset → credits → impact → contribution]. An alternative would be [contribution → (offset) → credits → impact]. This is not just a play on words, but rather realistic appraisal of current mrv schemes dedicated to carbon-farming. Measuring offsets in terms of carbon sequestration at the field & farm level is inherently imprecise, burdensome & costly.

Even more to the point, Berta & Roux 2024 (Berta & Roux 2024) are critical of the economics of carbon-farming as currently advocated ; cf. "The endless expansion of carbon offsetting: sequestration by agricultural soils in historical perspective" / Cambridge Journal of Economics 2024. Despite this, carbon-farming as a means of SOC build-up & sequestration are getting a lot airtime. This said, the jury seems to be still out, not having reached any consensus. For instance ;

- " ... the existing knowledge base does not justify the current trend to set global agendas focusing first and foremost on SOC sequestration." Moinet et al. 2023 (Moinet et al. 2023)
- " ... This raises the question of whether SOC sequestration matters for climate change." Minasny et al. 2023 (Minasny et al. 2023)
- " ... We question the feasibility of the 4p1000 goal, using basic stoichiometric arguments. Soil organic matter (SOM) contains nitrogen as well as C and it is unclear what will be the origin of this N." Van Groenigen et al. 2017 (Van Groinigen et al. 2017)
- " ... We conclude that there are severe limiations to achieving the "4 per 1000" goal in practical agriculture over large areas." Poulton et al. 2017 (Poulton et al. 2017)
- " ... based on differences in nutrient stoichiometry, we highlight the significant 'hidden nutrient cost' /../ in sequestering of carbon in SOM. The 'cost' of these nutrients should be considered /.../ and accounted for in carbon-trading schemes" Richardson et al. 2014 (Richarson et al. 2014)
- etc., etc., etc.

Despite this persistent hum, carbon-farming & SOC sequestration are still getting a lot of traction as THE main CDR mechanism in agriculture. Is this excitement really justified at this stage?
Are **mrv** technologies keeping up? Will the bubble burst? It would be interesting to look into the socio-economics of all this; Barbato et al. 2023 (Barbato et al. 2023) have already done so, to some extent. Polyor SAS's AgroNum approach to sustainable agriculture & soil conservation (https://www.linkedin.com/company/polyor-sas/about/?viewAsMember=true) is thus poised as an alternative to the current carbon-farming/sequestration paradigm. Time will tell.

A more cost-effective approach would be to measure inputs to soil organic matter conservation as a contribution to sustainable agriculture, and then ascribed credits to these inputs based on their costs. For instance, maintaining or accumulating 100 kg of soil organic carbon implies increasing soil organic nitrogen by 10 kg. Ensuring that this nitrogen requirement of soil organic carbon build-up is met by inputting these additional 10 kg of nitrogen is a creditable contribution to sustainable agriculture. For instance, Polyor SAS's AgroNum™ approach to sustainable agriculture & soil organic matter conservation can assess such contribution to climate action. Sustainable grain-nitrogen yields and their corresponding N-fertilizer recommendations easily identified using plot-specific nitrogen response curves. More so, increasing yields beyond these AgroNum™ response curves will in certain circumstances generate refundable nitrogen credits, or RNCs, paid to the farmer in lieu of carbon-farming derived carbon-credits.

Legal framework

The Günther et al. 2024 article (Günther et al. 2024) regarding the European Commission's carbon removal certification framework (CRCF) merits a readthrough. Quite (too!?) critical of current carbon-farming, let me quote a few snippets ;

- "the CRCF does not provide any further details on baseline determination"
- "certain emissions and removals by sinks are more difficult to identify and monitor /…/ leading to accounting inaccuracies /…/."
- "the use of carbon farming /…/ cannot even be considered "permanent carbon storage."
- "temporary carbon storage credits is also a questionable approach, as these credits have largely failed as a carbon crediting instrument due to the risk of reversal of carbon pools."
- "carbon removal units as offsets is particularly worrying given that the current proposal allows for the certification of temporary removal methods, such as carbon farming"
- "possibility of double claiming of emissions."
- "ambiguities when it comes to permanent and temporary carbon storage."
- "likely cause shifting effects when relevant actors shift their use of resources to countries/regions with less stringent environmental rules."
- "the CRCF merely requires that carbon removal activities have a neutral impact on or generate co-benefits /…/ only a voluntary requirement."

In short, Günther et al. 2024 conclude that the current CRCF;

- ✓ does not sufficiently take into account the normative hierarchy between different mitigation measures mandated by EU and international law.
- ✓ allows for temporary carbon approaches, such as carbon farming, without providing a clear floor for short-term storage limits.
- ✓ doesn't set any limits on the use of carbon credits thus allowing temporary removals to offset fossil fuel emissions and double claiming.
- ✓ allows for non-legislative acts for aspects of carbon removal certification that are questionable due to the lack of clear definitions regarding permanent and long-term carbon storage. [via carbon farming]
- ✓ inadequately addresses shifting effects that may inadvertently lead to increased GHG emissions and biodiversity degradation in other regions due to land-use change.
- ✓ is not aligned with CAP since carbon farming practices may be eligible for certification while simultaneously qualifying as mandatory requirements for CAP support /…/ doubling funding

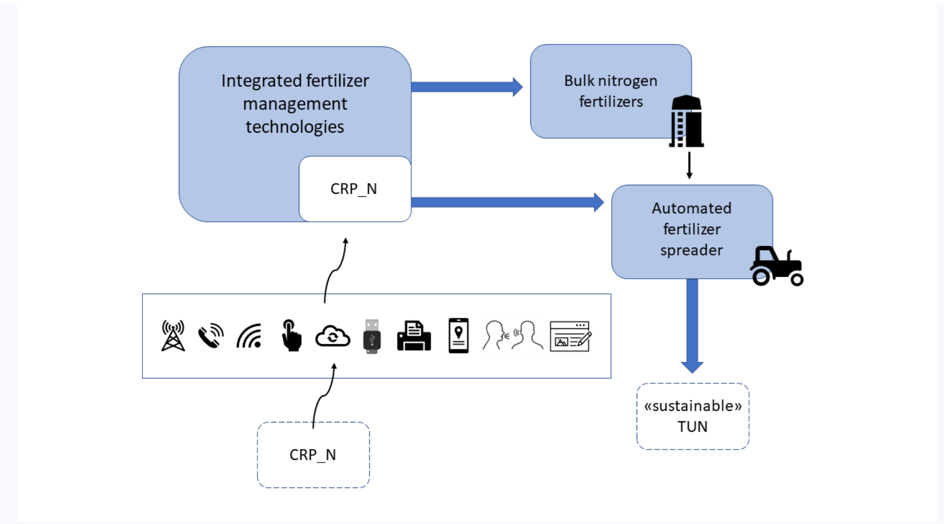
Gûnther et al. 2024 further concluded that " … to prevent further delays in achieving effective climate action, it is crucial to deviate from the current path of carbon farming activities being incentivized by voluntary carbon credits."

Ergonomics & interoperability

Carbon-farming as agricultural consultancy must be ergonomic, easy to use. Reijneveld et al. 2023 (Reijneveld et al. 2023) describe Soil Carbon Check as a rapid tool for monitoring SOC sequestration in farmer fields and for guiding farmers to increase SOC [soil organic carbon] sequestration. This said, in the section "Implementation challenges" the authors 2023 nevertheless state that "There is still limited standardization of soil sampling and SOC analyses methods, for various reasons (history, capacity, cost and knowledge). Soil sampling strategies and depth are critical issues here. Are accredited soil sample collectors needed, or can famers take the soil samples? What is the sampling design, soil depth, the number of subsamples, maximum size of the field?" In a sense, and despite notable advance in analytical procedures, the problem remains whole since error prone soil sampling IS the major limitation to implementing carbon-farming via C-sequestration in soils.

Polyor SAS's AgroNum™ approach to SOC conservation is inherently ergonomic. Plot specific N-fertilizer response curves provide baseline sustainable grain-N target yields (RDN), along with their corresponding N-fertilizer application rates (TUN). Farmers need only provide the centermost latitude/longitude GPS coordinates of the field-plot, along with current target yields and N-fertilization rates. This provides the user with a disturbingly simple & ergonomic solution to SOC conservation & integrated fertilizer management that can be used in carbon-farming.

$$\boldsymbol{AgroNum}\begin{pmatrix} \boldsymbol{client}_{number} \\ \boldsymbol{RDN}_{target_{yield}} \\ \boldsymbol{TUN}_{N_{fertilizer}} \\ \boldsymbol{latitude}_{gps} \\ \boldsymbol{longitude}_{gps} \end{pmatrix}$$



Polyor's AgroNum (www.en.polyor.fr) integrated fertilizer management (ifm) solution could represent a major paradigm shift in sustainable agriculture.

On-farm experimentation is no answer. Sustainable agriculture involves the use of innovative inputs. How can these innovations be assayed on-farm? The usual answer is "on-farm experimentation", or OFE. Some recent reviews by Lacoste et al. 2022 (Lacoste et al. 2022) & Cho et al. 2021 (Cho et al. 2021) are quite enlightening. This said, all these OFEs involve some sort of control vs treated strip-plot comparison. How revolutionary is this mere transposition of conventional experimental protocols on-farm? A more radical and ergonomic approach would be to do away with cumbersome control & treated plots, and then infer treatment effect directly from the whole plot's harvested grain yield. Though counter intuitive for some, AgroNum™ N-fertilizer response curves enable this sort of user-friendly in situ experimentation without any form of design, controls, strip-plots or sub-sampling. This does away with sampling error given the inevitable heterogeneity of agricultural fields. By using such AgroNum™ N-response curves, inter-annual grain yield comparisons from different cropping schedules at different N-fertilization rates can be made. Production & experimentation, all in one.

(Im)partiality & prescriptive regenerative agriculture

Carbon-farming ... or soil (organic matter) conservation? Soinne et al. 2024 (Soinne et al. 2024) recent is a reminder that things might be simpler than they look. Though Sionne's article is nuanced, they nevertheless state that ; "Alongside the aim of increasing OC accrual in mineral agricultural soils, we should stress the importance of maintaining [conserving] the current OC stocks /…/".

I tend to agree. Sustainable agriculture is all about conserving soil organic matter. Soil-borne crop residues need to be sufficiently rich in nitrogen to be properly humified into stable SOM. Polyor SAS has been developing and simple algorithm - AgroNum - that ensures that cereal crop-residues across all of Europe contain sufficient nitrogen to that effect.

Current carbon-farming implies that we know, precisely, the stocks, accrual rates, pristine SOC levels, and critical SOC thresholds. This sounds very heroic. Why not focus on SOC conservation, … and let the soils decide for themselves. Poorer soils will accumulate SOC, richer soils maintain it. Either way, soil organic matter conservation provides a refundable service to the environment.

Permanence

The issue of permanence can plague carbon-farming & sequestration efforts. For instance, see Dynarski et al. 2020 (Dynarski et al. 2020) or again Paul et al. 2023 (Paul et al. 2023). Bluntly, Paul et al. 2023 state that; "While increasing SOC is a cornerstone for more sustainable cropping systems, private carbon certificates fall short of expectations for climate change mitigation as permanence of SOC sequestration cannot be guaranteed."

A solution to lack of permanent soil carbon sequestration as an outcome would be to guarantee dedicated nitrogen inputs as a means of SOC conservation, or even build-up in carbon-depleted soils. Polyor SAS's AgroNum™ approach to sustainable agriculture & soil conservation does just that. Modified cropping practice that generate sufficient supplementary nitrogen to increase yield without depleting cellulosic crop residue of the nitrogen needed for their humification into stable soil or matter ($C/N \approx 10$) will be allocated (refundable) nitrogen-credits.

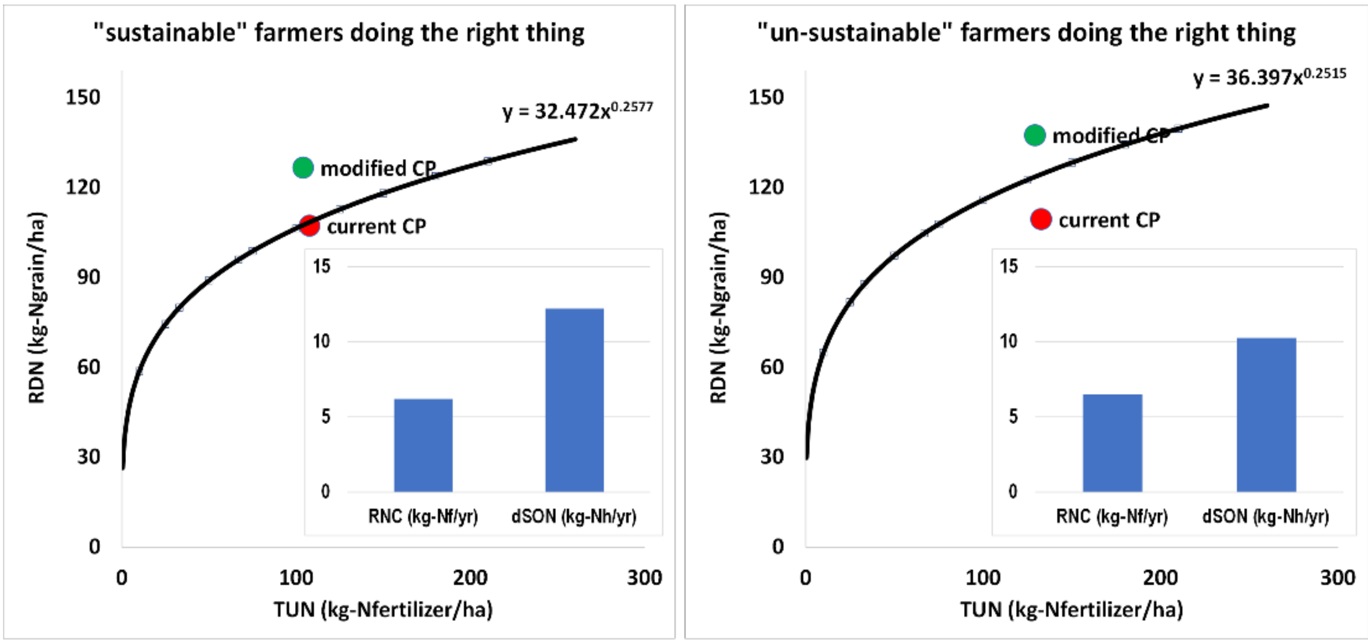
AgroNum is thus a precise & convenient alternative to conventional carbon-farming that must quantify, not only the amount of carbon sequestered, but also its permanence as a function of its often poorly estimated mean residence time. AgroNum's insistence on providing a means to, rather than a guarantee of, SOC conservation is in itself a paradigm shift worth considering.

Put simply, the said supplementary N-credits as a "means to" can be quantified & monitored much more precisely than SOC stocks as an "outcome of" carbon-farming. For lack of SOC permanence, AgroNum refundable N-credits are emitted annually and thus ensure a perennial input of nitrogen dedicated to the humification of crop residues into stable SOC.

Baselines & LTE

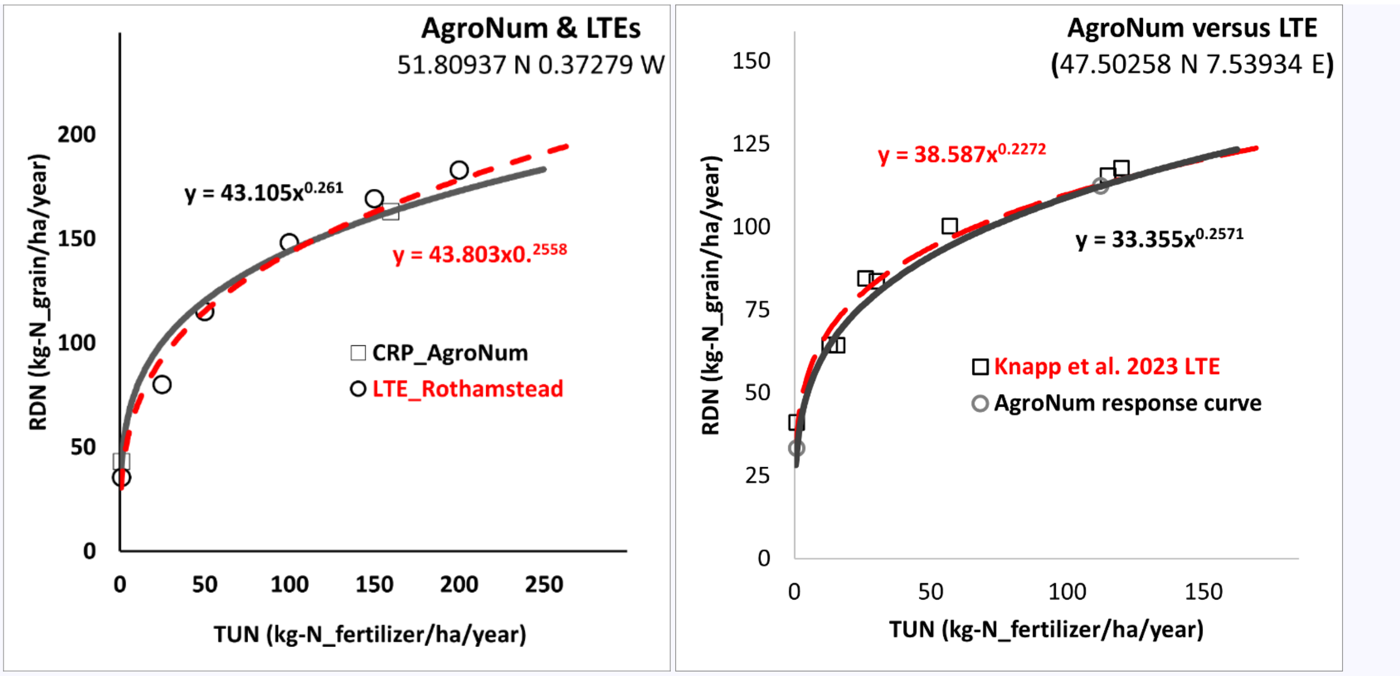
Carbon-farming derived carbon-credits imply baselines. This is a major limitation given that such baselines are very difficult, if not impossible to obtain (cf. Alexia Kelly's post). Needless to say, this critique also applies to conventional carbon-farming.

Polyor SAS has, in a sense, circumvented this conventional baseling problem by redefining soil organic matter (SOC) baselines in terms of nitrogen, and C-credits in terms of (refundable) nitrogen credits (RNC ; kg-N_fertilizer/year). The plot-specific N-fertilizer response curves generated using Polyor's AgroNum AI *are* the baselines against which current *cropping-practices* (CP) sustainability can be evaluated. Modifications to current CP that increased soil organic matter and nitrogen (dSON ; kg-N_humified/ha/year) will be fully creditable only if current CP are themselves sustainable, i.e. if current grain-N yields (RDN ; kg-N_grain/ha/year) sit on the said AgroNum N-fertilizer response curve. Modifications to un-sustainable current cropping practices with initially lower N-fertilizer use efficiencies will thus get less credit or, as is the case herein, need to be twice as effective to get the same number of N-credit.



This use of AgroNum N-fertilizer response curves as baselines for the assessment of the truly sustainable of modifications to current cropping-practices is thus fair and impartial (see above). Farmers doing the "right thing" when increasing yields & N-fertilizer use efficiency will be fully credited for doing so only if current CP are sustainable. "Un-sustainable" farmers merely “catching-up” will get less refundable N-credits or need to work twice as hard to get the same number of N-credit.

AgroNum™ N-fertilizer response curves (CRP) sit well with those obtained from certain European long-term experiments (LTE). This specific LTE is situated at Rothamsted, Harpenden UK, and the data adapted from Van Grinsven et al. 2022 (Van Grinsven et al. 2022).



The RDN grain-nitrogen yield response to TUN N-fertilization on LTEs is analogous to AgroNum™ N-fertilizer response curves. Herein, data from Knapp et al. 2023 for winter-wheat over 30 site-years - Knapp et al. 2023 ; grain nitrogen contents are inferred from Hildermann et al. 2010 (Hildermann et al. 2010). Thus, across Europe, AgroNum™ N-fertilizer response curves tend to reflect sustainable LTE yield responses to N-fertilizer.

AgroNum™ validation as a means to soil organic carbon & nitrogen conservation. 200 field-plots whose cropping practices (CP) were modified to increase grain yields in accordance with Polyor SAS's AgroNum™ N-fertilizer response curves were modelled using an R version of the well-known soil organic carbon model, Roth-C.

Attaining AgroNum target grain yields through such CP modifications stabilizes total soil organic matter degradation over time. After 22 years as of 2000 this conserves an additional 3 tons (2790 kg) of soil organic carbon (SOC) at an average accrual rate of 125 kg-C/ha/year, or approximately 12 kg-N of soil organic nitrogen per year (dSON).

Using AgroNum™, it can be inferred that a portion of these 12 kg-N_SON is effectively crop residues nitrogen resulting from sustainable grain yield increases with respect to AgroNum™ N-fertilizer response curves. In sort, this is a form of sustainable intensification of field-crop production.

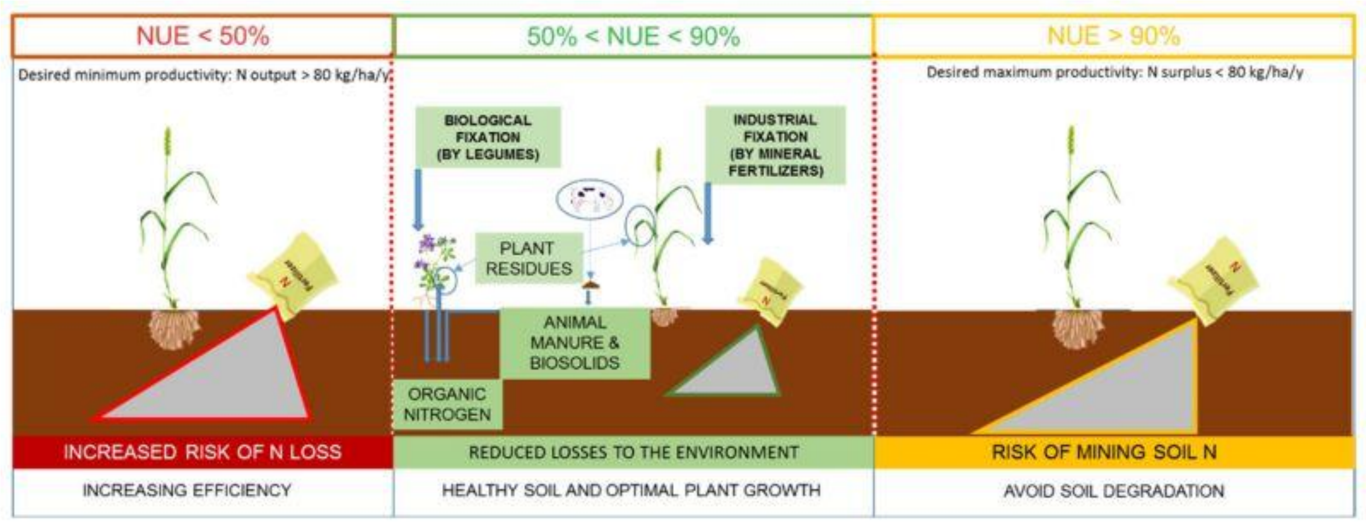
This supplemental soil organic nitrogen, dSON, accrued over time as grossly modelled using RothC is quite well correlated to AgroNum™ derived refundable nitrogen credits, or RNC, also expressed as kg-N_SON/ha/year. This said, AgroNum™ is easily implementable at the field-plot level. More so, the aforesaid dSON fraction commensurate with such refundable N-credits (RNC) is derived using AgroNum™, not RothC per se. Polyor SAS's AgroNum is thus THE convenient way of expressing not only SOC accumulation, but also and more importantly the corresponding sustainable target yields.

Sustainable N-fertilizer response curves for cereal & other non-*Fabaceae* field-crops are not quadratic but quasi power functions. This fact has been around for some time; Lassaletta et al. 2014 (Lassaletta et al. 2014), Bodirsky et al. 2014 (Bodirsky et al. 2014). This said, Polyor SAS's AgroNum N-fertilizer response curves go much further.

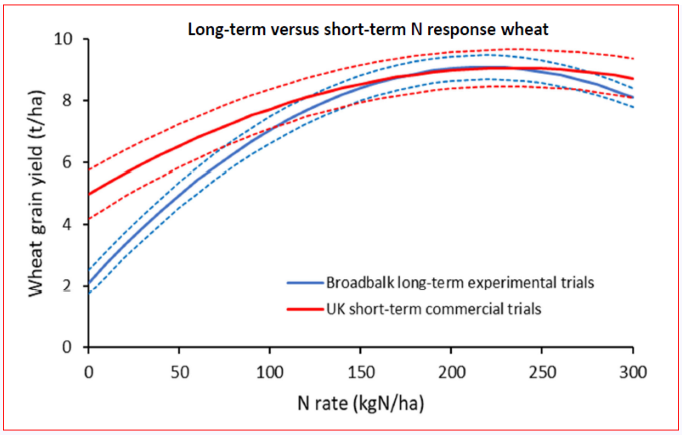
- First, they represent sustainable grain yields by excluding de facto N-fertilizer use efficiencies (NfUE) either too low or too high unconducive to soil organic matter conservation.
- Second, N-fertilizer response curves depicted by Lassaletta et al. 2014 & Bodirsky et al. 2014 give 0 yields at 0 N-fertilizer, which is strange since 0 N-fertilizer in temperate long-term experiments consistently yield around 25 to 35 kg-N/hectare offtake per year. This inherent low-level soil productivity is part of AgroNum N-fertilizer response curves.
- Third, and most importantly, AgroNum nitrogen response curves are plot-specific, and easily generated knowing only the plot's centermost GPS coordinates. This ergonomy represents a breakthrough in agricultural consultancy greatly facilitating sustainable agriculture & carbon-farming.

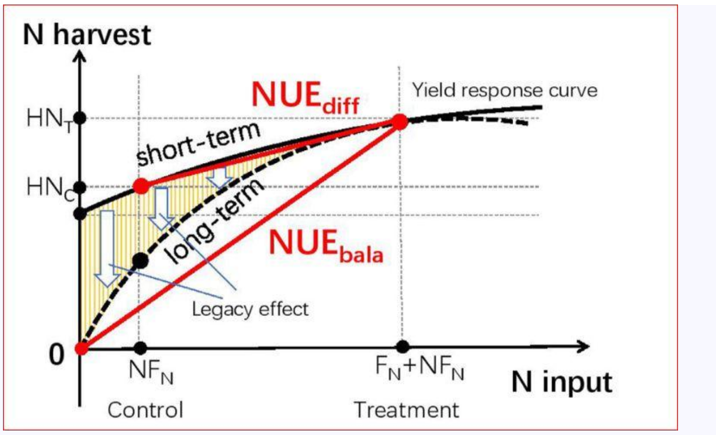
How can we benchmark sustainable cropping-practices? One way would be to eliminate the risk of residual post-harvent N-loss due to low N-fertilizer use efficiencies (NUE), AND the risk of "soil minining" due to excesively high NUEs than tend to deprive crop residues of N needed for their humification into stable soil organic-matter. For instance, herein (next page) figure 2 from Malinas et al. 2022 (Malinas et al. 2022) ;

This is precisely what accomplishes - routinely at the plot-level across Europe for any N-fertilization rate, Polyor SAS's AgroNum approach to integrated fertilizer management for sustainable agriculture.



These (below, left) long-term N-fertilizer response (blue) curves for wheat (Van_Grinsven et al. 2022 (Van Grinsven et al. 2022) are very similar to Polyor's AgroNum N-response curves ;





Sustainable-agriculture is long-term. Nitrogen-fertilizer response curves from long-term experiments (LTE) for cereal & other non-leguminous field-crops reflect this. For instance, above (right) a figure taken from Quan et al. 2021 (Quan et al. 2021) demonstrating that short-term experiments over-estimate the supply of soil-derived mineral-N to the crop. N-fertilizer recommendations based on such short-term responses cannot be sustainable … in the long-term. Unique & plot-specific, AgroNum Nf-response curves are in fact very similar in shape to those described by Quan et al. 2012 & other researchers. AgroNum is thus a convenient alternative to traditional - and not necessarily sustainable, balance-sheet approaches to integrated fertilizer management.

5. References & bibliography

Amossé et al. (2013). Relay intercropping of legume cover crops in organic winter wheat: Effects on performance and resource availability. *Field Crops Research*, *145*, 78–87. https://doi.org/10.1016/j.fcr.2013.02.010

Anastas et al. (2019). Performances of durum wheat varieties under conventional and no-chemical input management systems in a semiarid Mediterranean environment. *Agronomy*, *9*(12), 788. https://doi.org/10.3390/agronomy9120788

Barbato, C.T. and Strong, A.L. (2023) "Farmer perspectives on carbon markets incentivizing agricultural soil carbon sequestration," *npj Climate Action*, 2(1). Available at: https://doi.org/10.1038/s44168-023-00055-4.

Berta, N. and Roux, A. (2024) "The endless expansion of carbon offsetting: sequestration by agricultural soils in historical perspective," *Cambridge Journal of Economics*, 48(3), pp. 451–470. Available at: https://doi.org/10.1093/cje/beae008.

Bettigole, C. *et al.* (2023) “Optimizing Sampling Strategies for Near-Surface Soil Carbon Inventory: One Size Doesn’t Fit All,” *Soil Systems*, 7(1). Available at: https://doi.org/10.3390/soilsystems7010027.

Bodirsky, B.L. and Müller, C. (2014) “Robust relationship between yields and nitrogen inputs indicates three ways to reduce nitrogen pollution,” *Environmental Research Letters*. Institute of Physics Publishing. Available at: https://doi.org/10.1088/1748-9326/9/11/111005.

Cerny et al. (2010). Mineral and organic fertilization efficiency in long-term stationary experiments. *PLANT SOIL ENVIRON., 56, 2010 (1): 28–36*.

Cho, J.B. *et al.* (2021a) “Proposed method for statistical analysis of on-farm single strip treatment trials,” *Agronomy*, 11(10). Available at: https://doi.org/10.3390/agronomy11102042.

Cho, J.B. *et al.* (2021b) “Proposed method for statistical analysis of on-farm single strip treatment trials,” *Agronomy*, 11(10). Available at: https://doi.org/10.3390/agronomy11102042.

De Rosa, D. *et al.* (2024) “Soil organic carbon stocks in European croplands and grasslands: How much have we lost in the past decade?,” *Global Change Biology*, 30(1). Available at: https://doi.org/10.1111/gcb.16992.

Don, A. *et al.* (2024) “Carbon sequestration in soils and climate change mitigation—Definitions and pitfalls,” *Global Change Biology*. John Wiley and Sons Inc. Available at: https://doi.org/10.1111/gcb.16983.

Dumbravă et al. (2016). Grain Yield and Yield Components at Triticale under Different Technological Conditions. *Agriculture and Agricultural Science Procedia*, *10*, 94–103. https://doi.org/10.1016/j.aaspro.2016.09.023

Dynarski, K.A., Bossio, D.A. and Scow, K.M. (2020) “Dynamic Stability of Soil Carbon: Reassessing the ‘Permanence’ of Soil Carbon Sequestration,” *Frontiers in Environmental Science*. Frontiers Media S.A. Available at: https://doi.org/10.3389/fenvs.2020.514701.

Fiorentini et al. (2021). Remote and proximal sensing applications for durum wheat nutritional status detection in mediterranean area. *Agriculture (Switzerland)*, *11*(1), 1–18. https://doi.org/10.3390/agriculture11010039

Grzebisz, W. and Łukowiak, R. (2021) “Nitrogen gap amelioration is a core for sustainable intensification of agriculture—a concept,” *Agronomy*. MDPI AG. Available at: https://doi.org/10.3390/agronomy11030419.

Günther, P. *et al.* (2024) “Carbon farming, overestimated negative emissions and the limits to emissions trading in land-use governance: the EU carbon removal certification proposal,” *Environmental Sciences Europe*, 36(1). Available at: https://doi.org/10.1186/s12302-024-00892-y.

Hartemink, A.E. and Minasny, B. (no date) *Digital Soil Morphometrics*. Available at: http://www.springer.com/series/8746.

Hildermann, I. *et al.* (2010) “Nutrient use efficiency and arbuscular mycorrhizal root colonisation of winter wheat cultivars in different farming systems of the DOK long-term trial,” *Journal of the Science of Food and Agriculture*, 90(12), pp. 2027–2038. Available at: https://doi.org/10.1002/jsfa.4048.

Johnston, A. E., & Poulton, P. R. (2018). The importance of long-term experiments in agriculture: their management to ensure continued crop production and soil fertility; the Rothamsted experience. *European Journal of Soil Science*, *69*(1), 113–125. https://doi.org/10.1111/ejss.12521

Jolankai -Zoltan, P., & Kismanyoky, T.-T. (2006). EFFECT OF NITROGEN AND PESTICIDES ON THE YIELD AND PROTEIN CONTENT OF WINTER WHEAT. *Alps-Adria Scientific Workshop Opatija, Croatia*.

Knapp et al. (2023). Organic cropping systems maintain yields but have lower yield levels and yield stability than conventional systems – Results from the DOK trial in Switzerland. *Field Crops Research*, *302*. https://doi.org/10.1016/j.fcr.2023.109072

Knapp, S. *et al.* (2023) “Organic cropping systems maintain yields but have lower yield levels and yield stability than conventional systems – Results from the DOK trial in Switzerland,” *Field Crops Research*, 302. Available at: https://doi.org/10.1016/j.fcr.2023.109072.

Kolmanič et al. (2022). The Effect of Cultivation Practices on Agronomic Performance, Elemental Composition and Isotopic Signature of Spring Oat (Avena sativa L.). *Plants*, *11*(2). https://doi.org/10.3390/plants11020169

Körschens et al. (2013b). Effect of mineral and organic fertilization on crop yield, nitrogen uptake, carbon and nitrogen balances, as well as soil organic carbon content and dynamics: results from 20 European long-term field experiments of the twenty-first century. *Archives of Agronomy and Soil Science*, *59*(8), 1017–1040. https://doi.org/10.1080/03650340.2012.704548

Kubát, J., Klír, J., & Pova, D. (2003). The dry matter yields, nitrogen uptake, and the efficacy of nitrogen fertilisation in long-term field experiments in Prague. In *PLANT SOIL ENVIRON* (Vol. 49, Issue 8).

Lacoste, M. *et al.* (2022a) “On-Farm Experimentation to transform global agriculture,” *Nature Food*. Springer Nature, pp. 11–18. Available at: https://doi.org/10.1038/s43016-021-00424-4.

Lacoste, M. *et al.* (2022b) “On-Farm Experimentation to transform global agriculture,” *Nature Food*. Springer Nature, pp. 11–18. Available at: https://doi.org/10.1038/s43016-021-00424-4.

Lassaletta, L. *et al.* (2014) “50 year trends in nitrogen use efficiency of world cropping systems: The relationship between yield and nitrogen input to cropland,” *Environmental Research Letters*, 9(10). Available at: https://doi.org/10.1088/1748-9326/9/10/105011.

Lobell, D.B., Cassman, K.G. and Field, C.B. (2009) “Crop yield gaps: Their importance, magnitudes, and causes,” *Annual Review of Environment and Resources*, 34, pp. 179–204. Available at: https://doi.org/10.1146/annurev.environ.041008.093740.

Lopez-Bellido, R. J., & Lopez-Bellido, L. (2001). Effciency of nitrogen in wheat under Mediterranean conditions: effect of tillage, crop rotation and N fertilization. *Field Crops Research*, *71*, 31–46.

Mălinaş, A. *et al.* (2022a) “Current Status and Future Prospective for Nitrogen Use Efficiency in Wheat (Triticum aestivum L.),” *Plants*. MDPI. Available at: https://doi.org/10.3390/plants11020217.

Mălinaş, A. *et al.* (2022b) “Current Status and Future Prospective for Nitrogen Use Efficiency in Wheat (Triticum aestivum L.),” *Plants*. MDPI. Available at: https://doi.org/10.3390/plants11020217.

Minasny, B. *et al.* (2017) “Soil carbon 4 per mille,” *Geoderma*. Elsevier B.V., pp. 59–86. Available at: https://doi.org/10.1016/j.geoderma.2017.01.002.

Minasny, B. *et al.* (2023) “Soil Carbon Sequestration: Much More Than a Climate Solution,” *Environmental Science and Technology*. American Chemical Society, pp. 19094–19098. Available at: https://doi.org/10.1021/acs.est.3c07312.

Moinet, G.Y.K. *et al.* (2023) “Carbon for soils, not soils for carbon,” *Global Change Biology*, 29(9), pp. 2384–2398. Available at: https://doi.org/10.1111/gcb.16570.

Nevens, F., & Reheul, D. (2005). Agronomical and environmental evaluation of a long-term experiment with cattle slurry and supplemental inorganic N applications in silage maize. *European Journal of Agronomy*, *22*(3), 349–361. https://doi.org/10.1016/j.eja.2004.05.003

Paul, C. *et al.* (2023a) “Carbon farming: Are soil carbon certificates a suitable tool for climate change mitigation?,” *Journal of Environmental Management*, 330. Available at: https://doi.org/10.1016/j.jenvman.2022.117142.

Paul, C. *et al.* (2023b) “Carbon farming: Are soil carbon certificates a suitable tool for climate change mitigation?,” *Journal of Environmental Management*, 330. Available at: https://doi.org/10.1016/j.jenvman.2022.117142.

Pepó, P. (2016). Correlation between fertilization and baking quality of winter wheat cultivars. *Columella : Journal of Agricultural and Environmental Sciences*, *3*(2), 15–23. https://doi.org/10.18380/szie.colum.2016.3.2.15

Plaza-Bonilla et al. (2021a). Nitrogen fertilization strategies for improved Mediterranean rainfed wheat and barley performance and water and nitrogen use efficiency. *European Journal of Agronomy*, *124*. https://doi.org/10.1016/j.eja.2021.126238

Plaza-Bonilla et al. (2021b). Nitrogen fertilization strategies for improved Mediterranean rainfed wheat and barley performance and water and nitrogen use efficiency. *European Journal of Agronomy*, *124*. https://doi.org/10.1016/j.eja.2021.126238

Poma et al. (2004). Crop rotation, nitrogen fertilization and genotype effects on durum wheat productive characteristics. *Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 60*. http://om.ciheam.org/article.php?IDPDF=4600066

Poulton, P. *et al.* (2018) “Major limitations to achieving ‘4 per 1000’ increases in soil organic carbon stock in temperate regions: Evidence from long-term experiments at Rothamsted Research, United Kingdom,” *Global Change Biology*, 24(6), pp. 2563–2584. Available at: https://doi.org/10.1111/gcb.14066.

Poulton, P.R., Johnston, A.E. and White, R.P. (2013) “Plant-available soil phosphorus. Part I: The response of winter wheat and spring barley to Olsen P on a silty clay loam,” *Soil Use and Management*, 29(1), pp. 4–11. Available at: https://doi.org/10.1111/j.1475-2743.2012.00450.x.

Quan, Z. *et al.* (2021) “Different quantification approaches for nitrogen use efficiency lead to divergent estimates with varying advantages,” *Nature Food*, 2(4), pp. 241–245. Available at: https://doi.org/10.1038/s43016-021-00263-3.

Reijneveld, J.A. *et al.* (2023a) “SOIL CARBON CHECK: A TOOL FOR MONITORING AND GUIDING SOIL CARBON SEQUESTRATION IN FARMER FIELDS,” *Frontiers of Agricultural Science and Engineering*, 10(2), pp. 248–261. Available at: https://doi.org/10.15302/J-FASE-2023499.

Reijneveld, J.A. *et al.* (2023b) “SOIL CARBON CHECK: A TOOL FOR MONITORING AND GUIDING SOIL CARBON SEQUESTRATION IN FARMER FIELDS,” *Frontiers of Agricultural Science and Engineering*, 10(2), pp. 248–261. Available at: https://doi.org/10.15302/J-FASE-2023499.

Richardson, A.E. *et al.* (2014) “The inorganic nutrient cost of building soil carbon,” *Carbon Management*, 5(3), pp. 265–268. Available at: https://doi.org/10.1080/17583004.2014.923226.

Rutkowska, A. (2019a). Productivity, nitrogen use efficiency and water use efficiency of maize for grain in long term field experiments. *Polish Journal of Agronomy*, *37*, 11–15. https://doi.org/10.26114/pja.iung.384.2019.37.02

Rutkowska, A. (2019b). Productivity of winter oilseed rape depending on its nitrogen and water use efficiency. *Polish Journal of Agronomy*, *39*, 10–15. https://doi.org/10.26114/pja.iung.403.2019.39.02

Schils, R. *et al.* (2018) "Cereal yield gaps across Europe," *European Journal of Agronomy*, 101, pp. 109–120. Available at: https://doi.org/10.1016/j.eja.2018.09.003.

Schut, A.G.T. and Giller, K.E. (2020) "Soil-based, field-specific fertilizer recommendations are a pipe-dream," *Geoderma*, 380. Available at: https://doi.org/10.1016/j.geoderma.2020.114680.

Shejbalova et al. (2014). Nitrogen efficiency of spring barley in long-term experiment. *PLANT SOIL ENVIRON*, Vol. 60, 2014, No. 7: 291–296.

Soinne, H. *et al.* (2024) "High organic carbon content constricts the potential for stable organic carbon accrual in mineral agricultural soils in Finland," *Journal of Environmental Management*, 352. Available at: https://doi.org/10.1016/j.jenvman.2023.119945.

van Grinsven, H.J.M. *et al.* (2022) "Establishing long-term nitrogen response of global cereals to assess sustainable fertilizer rates," *Nature Food*, 3(2), pp. 122–132. Available at: https://doi.org/10.1038/s43016-021-00447-x.

van Groenigen, J.W. *et al.* (2017) "Sequestering Soil Organic Carbon: A Nitrogen Dilemma," *Environmental Science and Technology*. American Chemical Society, pp. 4738–4739. Available at: https://doi.org/10.1021/acs.est.7b01427.

Wallach, D. *et al.* (2018) "Multimodel ensembles improve predictions of crop–environment–management interactions," *Global Change Biology*, 24(11), pp. 5072–5083. Available at: https://doi.org/10.1111/gcb.14411.

Wallach, D. *et al.* (2021) "Multi-model evaluation of phenology prediction for wheat in Australia," *Agricultural and Forest Meteorology*, 298–299. Available at: https://doi.org/10.1016/j.agrformet.2020.108289.

Weihermüller, L. *et al.* (2013) "Simple pedotransfer functions to initialize reactive carbon pools of the RothC model," *European Journal of Soil Science*, 64(5), pp. 567–575. Available at: https://doi.org/10.1111/ejss.12036.

Wilson, J. (2023) "Modeling the measurement of carbon dioxide removal: perspectives from the philosophy of measurement," *Frontiers in Climate*, 5. Available at: https://doi.org/10.3389/fclim.2023.1283333.