Optimisation of nutrient budget in agriculture

D1.1 Mitigation Measures Catalogue (first draft version)

Funded by the European Union

Cover Delivery Report

Project Information	
Acronym	NutriBudget
Title	Optimisation of nutrient budget in agriculture
Project no.	101060455
Type of Action	RIA
Website	https://www.nutribudget.eu
Deliverable Information	
Title	Mitigation Measures Catalogue (first draft version)
WP number and title	WP1 – Design Opportunity Map for Effective Measures
Lead Beneficiary	UGent
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Reviewers	WU, WR, UVIC-UCC
Description	An overview of relevant agronomic measures contributing to agricultural sustainability [first draft version M9], based on pre-defined mitigation measures in WP4 and KPIs received from WP3.
Type	R – Document, report
Dissemination Level	PU - Public
Status	First draft
Submission due date	31st of May 2023
History of Changes	
Version 0.1	Draft created by UGent (02.06.2023) and revised by WP2-3-4 leaders
Version 1.0	Final version created by UGent (28.06.2023) and submitted
Version 1.1	The following changes were made upon the request of PO and reviewers: (i) Summary section turned into Executive Summary; (ii) In section 2.1 it is clarified that selection of 22 pre-identified measures took place during the proposal development stage; (iii) Minor revision was done on the numbers in Figure 3 (page 24) to remain consistent with the conclusions of measure selection in D4.1 and the experimental plan in D4.2; (iv) Technology readiness level (TRL) of each measure is listed in Table 3 (page 16-22) and summarized at Section 3.1 (page 24) to specify the implementation status of the pre-identified measures.
Version 2.0	Final version created by UGent (21.06.2024) and submitted

Preface

This study was carried out and published as a part of the European NutriBudget project funded by Horizon Europe programme (project number 101060455). The NutriBudget project aims to develop the prototype of a first-of-its-kind integrated nutrient management platform, called “NutriPlatform”, in various regions across Europe. The NutriPlatform will operate as a decision-support tool for farmers, advisors and regional authorities. Before the end of the project, the “NutriPlatform” (as a stand-alone or integrated in the existing European Commission promoted Farm Sustainability Tool (FaST) for nutrient management) will be tested and used by at least 40.000 farmers across Europe.

To achieve the above mentioned aim, one of the tasks within the NutriBudget project is to collect at least 50 of the best region-specific agronomic practices to optimise nutrient cycling and flows across different farming systems in the form of the Mitigation Measures Catalogue (MMC). The current document is the first version of the MMC that contains the results of a data collection focused mainly on i) the 22 pre-identified mitigation measures in the five NutriBudget pilot regions and ii) the identification of relevant indicators (NutriKPIs) to assess the performance of the pre-identified measures.

We would like to acknowledge the researchers and staff of Ghent University (Belgium), Wageningen University (the Netherlands), Stichting Wageningen Research (the Netherlands), Luonnovarakeskus - LUKE (Finland), BETA - University of Vic (Spain), University of Milano (Italy) and Research Institute for Organic Agriculture – FIBL (Switzerland), for their work and contribution.

The authors

Executive Summary

Deliverable (D) 1.1 *"Mitigation Measures Catalogue (first draft version)"* is part of NutriBudget work package (WP) 1. The WP1 *"Design Opportunity Map for Effective Measures"* aims to develop a Mitigation Measures Catalogue (MMC) by identifying relevant agronomic mitigation measures across the European Union (EU) that can contribute to agricultural sustainability across different agricultural systems (conventional, organic and agro-ecological), regions and countries. The MMC (D1.1) specifically aims to: i) identify at least 50 agronomic mitigation measures that contribute to nutrient budget optimisation in animal production, plant production and agro-processing agro-pillars, and (ii) provide impact-specific information to further assess the performance of the said measures.

NutriBudget consortium already pre-identified 21 (later split in 22) mitigation measures in the project preparation stage (which are considered as a part of the at least 50 measures) whose performance (for 19 out of 22; see D4.1) will be experimentally assessed in five NutriBudget pilot regions covering four distinct climate zones in Europe: Atlantic, Boreal, Continental, and Mediterranean. Among these pilot regions, four are characterised by a nutrient surplus (Atlantic, Boreal, Continental + nutrient surplus and Mediterranean), while one region experiences a nutrient deficit (Continental + nutrient deficit). Before the start of the experimental work in WP4, the state-of-the-art on agri-environmental impact of these 21 (later split in 22) pre-identified mitigation measures was evaluated in WP1 using data collected from literature, available "best practices databases" and long-term field experiments based on the soil fertility indicators, nutrient budgets and related environmental indicators identified in WP3. Therefore, this report is a first draft of the MMC (D1.1), until month (M) 9, reporting on the results of the data collection for the pre-identified mitigation measures (WP4).

The D1.1 (first draft version) is divided in four Chapters. **Chapter 1** presents an introduction to the current nutrient issues in European agricultural systems, followed by the solutions proposed in NutriBudget project and the main objectives of this deliverable. **Chapter 2** describes the methodology for the co-creation of the MMC, separating it in two stages: i) data collection during the first 9 months of the project implementation with a focus on the 22 pre-identified mitigation measures in WP4, and ii) the continuous update (M9 – M42) that concerns updates on the 19 mitigation measures (from the experimental work of WP4) and data collection for additional measures from other sources (e.g. EU FP7/H2020/LIFE CORDIS database, local national projects, operational groups, Nutri-actor network (WP6), etc). The results of the current data collection on the pre-identified mitigation measures are presented and discussed in **Chapter 3**. Until M9, a total of 107 references were collected and relevant data extracted and added to the MMC, which will serve as a valuable input for measure-impact assessments in WP1, modelling work in WP2 and WP3, and experimental work in WP4.Furthermore, Chapter 3 also provides an overview of the environmental indicators identified in WP3 according to which the impact-specific information for the measures was collected. Finally, **Chapter 4** provides a summary of the current conclusions and future perspective for the development of the MMC.

When classifying the 22 measures according to the type of the agricultural system, all 22 measures are suitable for conventional and agro-ecological system, and 6 of them for organic agricultural system. Sixteen measures from 22 can fit in Crop production agro-pillar, 9 in Animal husbandry agro-pillar and 5 in Agro-processing agro-pillar. This means that one measure can cover more than just one agro-pillar. Finally, 3 of the 22 measures have been fully implemented (TRL8-9), 12 measures have been validated or demonstrated in a relevant environment (TRL 5-7), 7 measures have been developed in the laboratory (TRL<5) and require scale-up validation and demonstration.

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List of Abbreviations

DoA	Description of the Action
DPSIR	Driver-Pressure-State-Impact-Response
EU	European Union
GA	Grant Agreement
KPI	Key Performance Indicators
M	Month since the project kick-off
MMC	Mitigation Measures Catalogue
MS	Milestone
SOC	Soil Organic Carbon
WP	Work package

1. Introduction

Agriculture is undergoing intensification to meet the demands of a growing population. This intensification has led to an increase in machinery and fertiliser use, causing a 68% increase in food production in Europe since the 1960s (Pretty, 2008). However, the increased application of nitrogen (N) and phosphorus (P) fertilisers has resulted in detrimental effects, showing negative impact on biodiversity, climate change, drinking and surface water quality, air quality, and human health (Amery & Schoumans, 2014; Cordell et al., 2009; European Commission, 2013; Kros et al., 2015; Tonitto et al., 2006; Velthof et al., 2014). The release of excessive N from agricultural fields into the environment can lead to increased emissions of nitrous oxide (N_2O) that contributes to global warming, and formation of particulate matter and ground-level ozone that affect human health (Butterbach-Bahl et al., 2013; Galloway et al., 2008). High levels of nutrient leaching or runoff can promote eutrophication of water bodies, causing excessive algal growth or formation of harmful algal blooms, leading to reduced oxygen levels and a decline in the aquatic biodiversity (Howarth et al., 2002; Schindler, 2006). Elevated nitrate levels in groundwater also pose a risk of nitrate contamination in drinking water, which is particularly concerning for vulnerable populations, such as infants, as it can lead to methemoglobinemia, also known as "blue baby syndrome" (Deutsch et al., 2012; Van Grinsven et al., 2016). Biodiversity loss is another critical consequence of nutrient pollution, as high nutrient levels can promote shifts in communities' structure, driven by changes in species composition and reducing overall biodiversity. This alteration in ecosystem structure can disrupt ecological processes and functions diminishing the stability and resilience of ecosystems (Bobbink et al., 2010; Diaz & Cabido, 2001). Furthermore, the impacts of intensive agriculture extend to the decline in soil organic carbon (SOC) content, which is exacerbated by climate change (Wiesmeier et al., 2016). This decline in SOC is of great concern for European soils due to its crucial role in ecosystem functioning (Haddaway et al., 2014; Panagos et al., 2013; Stolte et al., 2016). These issues highlight the urgent need for a transition towards more sustainable agricultural practices that aim to minimize nutrient losses, enhance soil health, and overall reduce the environmental impacts of agriculture. Implementing agronomic mitigation measures such as precision nutrient management, regenerative agriculture, and improved nutrient use efficiency can contribute to mitigate these challenges and promote a more sustainable and resilient agricultural system.

In line with the Zero Pollution action plan and the Farm to Fork Strategy, the Horizon Europe NutriBudget project aims to help agriculture to intensify sustainably in order to meet the demands of optimising yields without compromising environmental integrity or public health. NutriBudget will fill knowledge gaps and take significant steps forward beyond the state of the art in the following specific areas:

(I) Evaluating existing and novel mitigation measures to reduce emissions and increase nutrient use efficiency,

(II) Co-creating novel assessment tools for nutrient flows and performance monitoring (NutriKPIs) to closely follow the roadmaps to the desired status with balanced agronomic and environmental targets,

(III) Developing first-of-its-kind integrated NutriModels that holistically look at C and different nutrients (N, P, K, S, Mg, Ca, Zn, Cu) across different scales (at farm scale to regional and European scale), based on existing and new datasets and linking these to the NutriKPIs and mitigation measures, and

(IV) Implementing the NutriPlatform prototype as a new decision support tool (DST) for farmers and regional authorities to help achieve productive and sustainable agriculture goals in face of a growing world population.

To achieve the above-mentioned objectives, WP1 of the NutriBudget project aims to collect at least 50 of the best region-specific agronomic practices to optimise nutrient cycling and flows across different farming systems in the form of the Mitigation Measures Catalogue (MMC). By identifying relevant agronomic mitigation measures across the European Union (EU) (from existing literature and (ongoing) EU or national projects) the NutriBudget project aims to bridge the gap between actual and desired nutrient status (to be modelled in WP2) by addressing the impact of the mitigation measures across agricultural systems (conventional, organic and agro-ecological), regions and countries. In addition, WP1 aims to estimate the impact of said selected measures on defined monitoring indicators (determined in WP3) given local conditions of farms/fields (using meta-analytical approaches).

The first draft of the MMC (D1.1) focuses on the 22 pre-identified mitigation measures out of which only 19 measures will be experimentally assessed (WP4, selection process explained in D4.1) in 5 NutriBudget pilot regions (Atlantic, Boreal, Continental + nutrient surplus, Continental + nutrient deficit, and Mediterranean region), and provides impact-specific information for the further assessment of their performance in WP2, 3 and 4. In the upcoming period the MMC will be further updated with additional mitigation measures (on top of the 22 pre-identified) and their respective impact-specific information, to eventually reach at least 50 of the best region-specific agronomic practices for farmers and regional authorities that can help in achieving productive and sustainable agriculture goals in face of a growing world population.

2. Methodology

The co-creation of the MMC (D1.1) in Task 1.1 is divided into two stages: i) the first stage data collection from M1 to M9, and ii) continuous update until M42, following the methodology approach presented in Figure 1. Each of these data collection stages are explained in detail in the sections below.

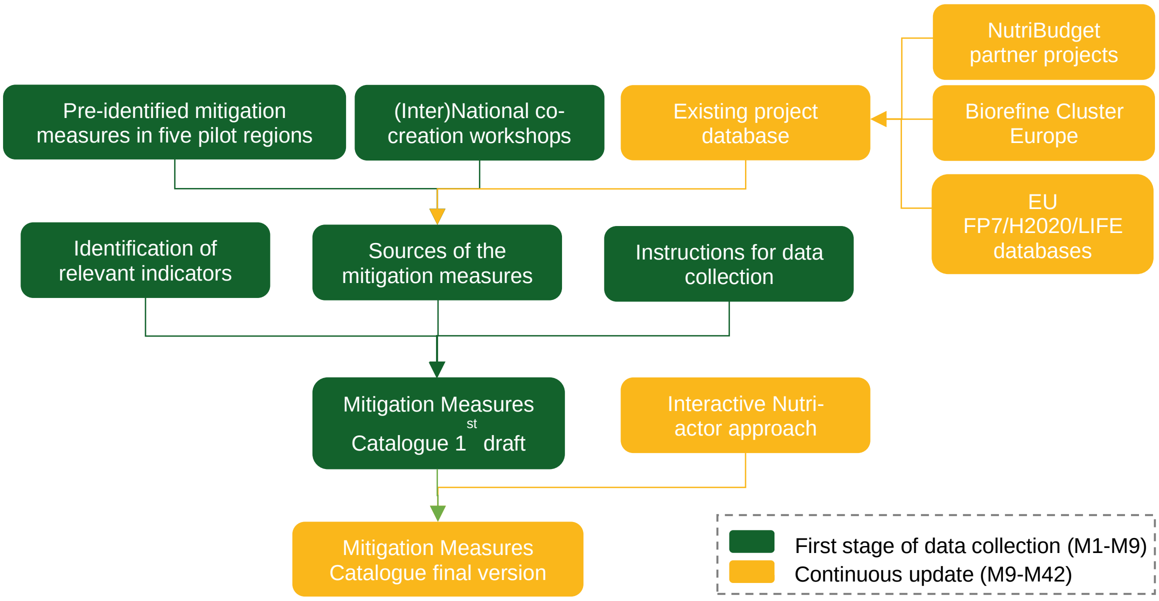


Figure 1 Methodology for the co-creation of Mitigation Measures Catalogue.

2.1. Stage 1: Pre-identified mitigation measures (M1 – M9)

As indicated in Description of the Action (DoA – part B, Table I), initially 21 (later split in 22) innovative agronomic mitigation measures were pre-identified (during the project development stage) in five pilot regions (Atlantic, Boreal, Continental + nutrient surplus, Continental + nutrient deficit, and Mediterranean region), based on the most relevant environmental problems (nutrient losses to water, nutrient imbalances, ammonia emissions, nutrient use efficiency, air quality, and soil contamination and compaction) in the respective region, previous work done in this research field and expertise of the NutriBudget consortium. Since identification of these measures happened during the proposal development stage, methodology presented in this deliverable did not include identification or selection process of these pre-identified measures. It is foreseen to experimentally assess 19 out of 22 measures in WP4 (final selection reported in D4.1) and also screen all 22 measures for their state-of-the-art (D1.1) as a part of the at least 50 measures that will be available in the final version of the MMC.

Due to a tight timeline for the design of the experimental work for these pre-identified measures in WP4 (*D4.2 Description of experimental set-up and methods used in each pilot due in M16*), the first stage of data collection for the MMC started with a literature review on the state-of-the-art of the pre-identified mitigation measures. Desk research on the existing results (published papers, reports or database, etc.) was conducted to collect the impact-specific information (environmental performance related use efficiency, nutrient losses, etc.), providing insights on current state-of-knowledge for each of the pre-identified mitigation measures. This information will allow WP1 to produce *D1.6 'Data /measurement matrix'* that indicates which analytical measurements still need to be performed in WP4 for certain measure, and as such will be implemented in the experimental plan (D4.2) of the five pilot regions.

The impact-specific information, so-called key performance indicators (KPIs), is identified by WP3 through the Driver-Pressure-State-Impact-Response (DPSIR) approach on the models involved in the NutriBudget project. A list of the relevant indicators (Section 3.2) was generated together with a detailed instruction to guide the data collection, including a brief description of the indicators, the associated measurements, and data units as well as the priority for WPs 1-2-3-4.

Combining the pre-identified mitigation measures and the relevant indicators, the MMC was drafted in excel format (Annex 1), serving as a working document for both the first stage data collection and continuing update stages. The MMC is shared among the project consortium through Microsoft SharePoint project drive.

Meanwhile, co-creation workshops with concerned stakeholders (i.e. farmers, farm advisers, policy makers, public administrator, researcher, etc.) at national level (Section 3.3) were organized in the period April – May 2023, with the aim to collect opinions on and experience with the pre-identified mitigation measures and the proposed NutriKPIs. The participants were also encouraged to propose additional mitigation measures that could be added for co-creation of the MMC which could perhaps also be considered for experimental work in WP4. Results from the co-creation workshops will serve for further improvements of the MMC display and also as another source for additional mitigation measures (on top of the 21 pre-identified).

2.2. Stage 2: Continuous update (M9 – M42)

Beyond the pre-identified mitigation measures, the final MMC version will contain over 50 mitigation measures that will be sourced through continuous investigation on, and update from the existing project database, including those projects in which NutriBudget partners are directly involved, the Biorefine Cluster Europe (www.biorefine.eu) platform as well as available EU FP7/H2020/LIFE databases. More specifically:

- **NutriBudget partner projects –** NutriBudget partners have been actively coordinating or involved in several National, EU and European Regional Development Fund (ERDF) - Interreg funding projects concerning agro-environmental issues (Table 1).
- **Biorefine Cluster Europe** (coordinated by UGent) - an open-access, free-of-charge collaborative platform between 85 EU projects (38 running and 47 finished) dealing with biobased circular economy and many with a dedicated focus for nutrient recycling.
- **Interconnect with locally developed and organized information** as being organized via EIP-AGRI OGs or other regional programs.
- Insights on current state-of-knowledge and proposed suitable measures (including their background, rationale,…) will also be gathered through the interactive **Nutri-Actor approach** (WP6) by making use of a combination of webinars, workshops (Section 3.3) and bilateral engagements, in which the existing extensive network of the NutriBudget consortium will engage farmers, agricultural, agro-industrial and scientific experts that take part in project activities of (related and relevant) research projects that NutriBudget will interact with.

Table 1 Relevant projects linking to NutriBudget project.

Project	Links to mitigation measures catalogue	Involved NutriBudget partners
Fertimanure	Promote innovative nutrient management technologies and strategies	UVIC-UCC (coordinator), UGent, UNIMI
NUTRI-KNOW	Improve nutrient management practices in agriculture by gathering and sharing knowledge for the benefit of both farmers and the environment.	UVIC-UCC (coordinator), UGent
DeliSoil	Apply circular bioeconomy methods to the food industry value chain with the aim to improve the use of residue streams and regional production of soil improvers	UVIC-UCC
Lex4Bio	Evaluate fertilizing potential of different types of bio-based fertilizers (BBFs) including the impact on fertilizing efficiency, human health, food and feed safety and environmental protection	LUKE (coordinator), Proman, UGent
Rustica	Demonstrate circular BBFs derived from side streams from the fruit and vegetable sector and implement optimized fertiliser strategies and value chains in rural communities	UGent
Nutri2Cycle	Identify the most efficient and effective mitigation measures to close agricultural nutrient loops according to a holistic triangle approach that covers animal and crop production via agro-processing industries	UGent (coordinator), WU, WR, UNIMI
Systemic	Advanced nutrient recovery and recycling via processing technologies, such as anaerobic digestion	WR (coordinator), UGent, UNIMI
Nutriman	Nitrogen and Phosphorus Thematic network on agro-technology and products related to nutrient recycling	UGent
Phos4You	Exploit the recovery potential of phosphorus from municipal sewage water as valuable fertilizers	UGent
Renu2Farm	Investigate the current situation on nutrients and technologies in the field of nutrient recovery in North-West Europe (NWE)	UGent, Arvalis
Nitroman	Recover mineral nutrients from surplus manure in the Flemish-Dutch border region	UGent
ALG-AD	Recover nutrients from anaerobic digestion of food and farm waste to cultivate algal biomass for animal feed and other products of value	UGent
Sea2Land	Produce advanced biobased fertilisers from fisheries wastes.	UGent, UVic-UCC, UNIMI & FiBL

3. Results and Discussion

3.1. Pre-identified mitigation measures in five pilot regions

With the aim of addressing the regional nutrient issues and reducing the most relevant environmental impact, initially 21 mitigation measures (DoA – part B, Table I) were pre-identified covering five NutriBudget pilot regions and **six categories of agricultural management** (Table 3). These six categories are designed on the agronomic relevance as well as their impact on the environment (Table 2).

Table 2 Six categories of agricultural management and their impact on the environment.

Six categories of agricultural management	Uptake	Soil Status	Leaching	CO_2	CH_4	N_2O	NH_3
Tools, techniques, and systems for higher-precision fertilisation	x	x	x			x	X
Innovative management systems, tools and practices for optimised nutrient and GHG management in animal husbandry				x	x		x
Novel feeds produced from agro-residues			x	x	x		x
Innovative soil, fertilisation and crop management systems and practices for enhanced N, P, efficiency and increased OC content	x	x	x	x	x		
Substituting primary nutrient resources by biobased products in practice		x	x			x	x
Nature-based solutions			x	x	x	x	

Furthermore, as stated in HORIZON-CL6-2021-ZEROPOLLUTION-01 call, the results of NutriBudget project are expected to improve nutrient budget and flows by identification of optimal combinations of nutrients in different **agricultural systems (conventional, agro-ecological and organic)** following, when possible, a holistic approach of the plant and animal productions system. As the definitions of the mentioned agricultural systems are not always straightforward in the literature or in a public eye, they were discussed among the WP leaders and pilot leader regions on how to differentiate between the agricultural systems in line with NutriBudget aims. As Nutribudget focuses on optimisation of nutrients, the mentioned systems can be differentiated by the type of an input origin (synthetic mineral source, bio-based source and/or factory farming origin). More precisely, the three types of the agricultural system are described as:

- **Conventional agriculture** manages resource inputs (relies mostly on synthetic chemical based pesticides and mineral fertilisers) uniformly, ignoring the naturally inherent spatial heterogeneity of soil and crop conditions between and within fields (Corwin and Scudiero, 2019).
- **Agro-ecological agriculture** (also known as regenerative agriculture) is a holistic approach that relies on and maximises the use of ecological processes (for example use of precision fertilisation and use of bio-based fertilisers) to support agricultural production. By working more with nature and ecosystem services, agro-ecology aims to: strive for more soil health through good management of the organic matter content and by stimulating soil life, closing nutrient cycle, more biodiversity, reduction of external inputs, including pesticides, fertiliser, and fossil

fuels; increased use of local resources, etc. Organic farming can be seen as one of several agroecological approaches, which further include agroforestry and permaculture among others (EU, 2021; ILVO, n.d., GIZ, 2020).

- **Organic agriculture** is characterised by the prohibition of synthetic chemical fertilisers and pesticides. The overall principles which support organic farming are the use of natural resources by managing biological processes of ecological systems, and limited use of non-renewable resources and off-farm inputs (EC, 2007). Organic farming follows practices designed to minimise the human impact on the environment, while ensuring the agricultural system operates as naturally as possible; such practices may include wide crop rotation, very strict limits on chemical synthetic pesticide and synthetic fertiliser use, a prohibition of the use of genetically modified organisms, choosing plant and animal species that are resistant to disease and adapted to local conditions, and raising livestock in free-range, open-air systems (i.e. no factory farming) and providing them with organic feed (EC, 2007; EC/CEU, 2020; Pepin et al., 2021).

Finally to follow the holistic approach of the plant and animal production systems, the NutriBudget mitigation measures also cover the following three **agro-pillars: crop production, animal husbandry and agro-processing**. This approach has been adapted from the Nutri2Cycle H2020 project and the basic understanding is to re-connect the intensified crop production and animal husbandry agro-pillars via optimised management and technologies that result from agro-processing pillar (Figure 2).

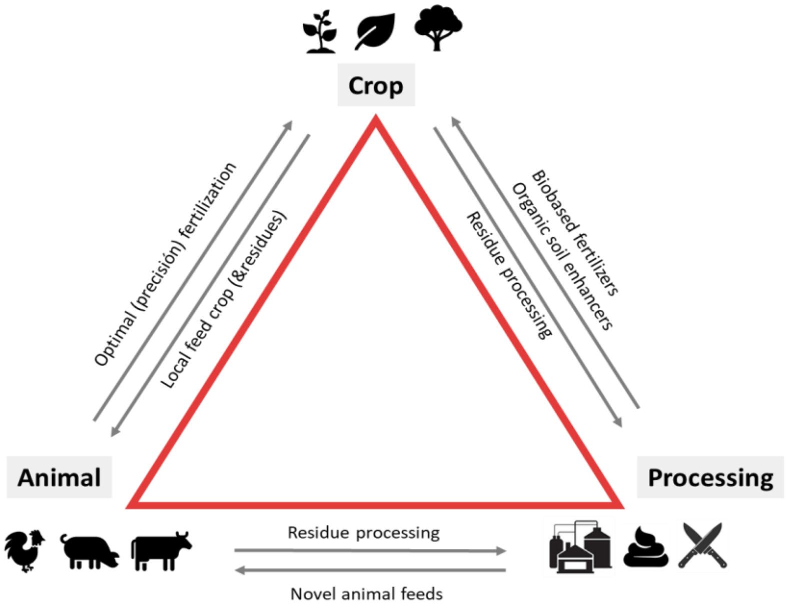


Figure 2 Triangle model for reconnecting nutrient and carbon flows between conventional agro-pillars, adapted from Nutri2Cycle H2020 project.

In order to classify the 21 pre-identified measures according to the category of agricultural management, type of agricultural system and type of agro-pillars, first the initial titles of the specific innovative mitigation measures (compared to the original version in DoA, part B, Table I) were revised to provide more precise information about the focus of the mitigation measures (Table 3).

Table 3 Overview of pre-identified mitigation measures with original (DOA, part B, Table I) and new proposed titles, and their classification according to the category of agricultural management, type of agricultural system and type of agro-pillar.

Category of agricultural management	Shortlist title	Specific innovative measures requiring more research (as written in the DoA part B, Table I)	No. of pre-identified measure	New proposed title for the 'Specific innovative measures requiring more research'	Proposed pilot region (country)	Agricultural system	Agro-pillar	TRL (Technology readiness level)
Tools, techniques, and systems for higher-precision fertilisation	Precision farming - optical sensing technologies	Advanced sensor technologies for seeding, fertilising, biocide application	1	Advanced sensor technologies for application of liquid biobased fertilisers (i.e. pig urine, ammonium sulphate, liquid fraction of digestate, mineral concentrate) to tackle nutrient variability of field and products	Atlantic (BE)	Conventional and Agro-ecological	Crop production	TRL7. The concept and methodology of this measure have been tested and demonstrated in several field trials (practical environment) in Germany and Belgium, with results of crop and soil nutrient flows available in the MMC.
	Integration of satellite technology	Management zones with satellite and harvester data	2	Precision Fertilization of bio-based fertilisers and/or mineral fertiliser through Multilevel Data Integration	Mediterranean (ES)	Conventional and Agro-ecological	Crop production	TRL6. The technology has been implemented and tested in Germany and Belgium. This measure will be tested in field trials in Catalonia, Spain.
	Precision fertilisation techniques	Precision injection of nutrient-rich organic wastes	3	Updating precision injection system to reduce NH_3 emission by using biobased fertilisers (digestate from organic agro-food waste and sludge)	Continental + nutrient surplus (IT)	Conventional and Agro-ecological	Crop production	TRL7. The technology has been demonstrated on an precision injection device developed by the company and used in field trials (not yet commercial) and results have been published. In NutriBudget project, the technology will be tested on a new device designed to enhance the efficiency and environmental sustainability of BBF use.
	Precision fertilisation techniques	Fertiliser placement practices	4	Fertiliser placement practices of mineral and/or organic fertilisers (with focus on Mg and S)	Continental + nutrient deficit (CH)	Conventional, agro-ecological and organic	Crop production	TRL 5-6. Technology has been tested in the field experiments in Switzerland, further demonstration is planned to address the imbalanced nutrient status concerning

Category of agricultural management	Shortlist title	Specific innovative measures requiring more research (as written in the DoA part B, Table I)	No. of pre-identified measure	New proposed title for the 'Specific innovative measures requiring more research'	Proposed pilot region (country)	Agricultural system	Agro-pillar	TRL (Technology readiness level)
								deficiencies of Zn, S and N and uncertain Mg supply in the existing fields in the pilot region.
			5	Sensor technologies for correcting potential nitrogen deficiency for achieving optimal yields with synthetic nitrogen fertilisers	Boreal (FI)	Conventional and Agro-ecological	Crop production	TRL6. Sensor technologies for correcting N deficiency have been demonstrated at a field scale with cereals. In NutriBudget this technology will be demonstrated with grass.
Innovative management systems, tools and practices for optimised nutrient and GHG management in animal husbandry	Anaerobic digestion strategies for optimised nutrient and energy recovery from manure	Pocket digestion	6	Pocket (on-farm) digestion of animal manure to mitigate the greenhouse gas emissions	Atlantic (BE)	Conventional and Agro-ecological	Agro-processing and Animal husbandry	TRL8. The concept and methodology of pocket digestion have been demonstrated and validated at the farm-scale (pocket) in the frame of several projects such as PocketPower and Nutri2Cycle, resulting in a wealth of available data suitable for NutriBudget evaluation (WP1) and modelling (WP2, WP3) work. This technology has been implemented to treat livestock manure and generate biogas as a green energy source for commercial purpose.
	~~Anaerobic digestion strategies for optimised nutrient and energy recovery from manure~~	~~Anaerobic digestion of animal slurry and byproducts~~		~~Mineral fertilizer replacement potential of liquid fraction of digested pig slurry with high N/P ratio (FI)~~	~~IT, FI~~	*Incorporated into two mitigation measures below: (i) Mineral fertiliser replacement using digestate and derived products (ammonium sulphate)(No.18); (ii) Mineral fertiliser replacement potential of digested pig*		

Category of agricultural management	Shortlist title	Specific innovative measures requiring more research (as written in the DoA part B, Table I)	No. of pre-identified measure	New proposed title for the 'Specific innovative measures requiring more research'	Proposed pilot region (country)	Agricultural system	Agro-pillar	TRL (Technology readiness level)
						slurry with high N/P ratio and Yara fertiliser (low P) (No.20)		
	Use of additives in manure management	Use of zeolites and high-adsorbance clays to reduce NH3 volatilisation and improve separation efficiencies	7	Advanced NH_3 emissions mitigation using Zeolites and High-Absorbance Clays	Mediterranean (ES)	Conventional and Agro-ecological	Animal husbandry	TRL4-5. Tests are being conducted under controlled conditions in the laboratory for NH_3 emissions, and pot trial in greenhouse at Beta facilities
	Nutrient mass analysis to better map and understand NCP flows at farm level	Improved planning of C and nutrient flows	8	Improved balancing of C and nutrients at farm and field level	Continental + nutrient deficit (CH)	Conventional, agro-ecological and organic	Animal husbandry and Crop production	TRL2. A wealth of available data can be extracted from the past research on 15 fields and 10 farms in Switzerland. This measure focus on a theoretical approach to investigate the impacts of field-level measures on farm-level operations and their effects on various nutrients budget.
Novel feeds produced from agro-residues	Floating plants grown on liquid agro-residues as a new source of proteins	Cultivation of Lemna (sp.) in liquid wastes	9	Dual-Purpose Lemna Cultivation: Alternative Protein and Green Manure Production	Mediterranean (ES)	Conventional and Agro-ecological	Agro-processing, Animal husbandry and Crop Production	TRL3-4 for pot-test to evaluate duckweed biomass as fertiliser, tests were carried out at laboratory level and then pot trials will be performed under controlled conditions in the greenhouse; TRL6-7 for Lemna bioreactor - Duckweed cultivation on effluent of nitrification and denitrification: the pilot plant for growing Lemna using liquid fraction of slurry treated with a nitrification-denitrification wastewater treatment system is in operation.

Category of agricultural management	Shortlist title	Specific innovative measures requiring more research (as written in the DoA part B, Table I)	No. of pre-identified measure	New proposed title for the 'Specific innovative measures requiring more research'	Proposed pilot region (country)	Agricultural system	Agro-pillar	TRL (Technology readiness level)
	Floating plants grown on liquid agro-residues as a new source of proteins	Floating wetland plants or algae	10	Duckweed cultivation on agricultural wastewater (pig manure and aquaculture) as alternative protein source for animal feed	Atlantic (BE)	Conventional and Agro-ecological	Agro-processing and Animal husbandry	TRL5-6. The concept and methodology of duckweed cultivation in agricultural waste streams have been tested at lab-scale and demonstrated at pilot scale in Belgium, the potential of the resulted biomass as animal feeds has been validated using both theoretical approach and animal experiments. Further validation at pilot scale over a whole growing season is planned in WP4 of NutriBudget project.
			11	Microalgae cultivation on digestate as alternative protein source for animal feed	Atlantic (BE)	Conventional and Agro-ecological	Agro-processing and Animal husbandry	TRL5-6. The concept and methodology of microalgae cultivation in agricultural waste streams have been tested at lab-scale and demonstrated at pilot scale in Belgium as well as other European countries, the potential of the resulted biomass as animal feeds has been assessed via theoretical approach. Further validation at pilot scale is planned in WP4 of NutriBudget project.
	Utilization of crop residues in animal feed	Pytoextraction for recovery and remediation of microelements	12	Phytoextraction of Cu and Zn from metal-contaminated soil for animal feed	Atlantic (BE)	Conventional and Agro-ecological	Crop production and Animal husbandry	TRL4. The concept and methodology of phytoextraction of Cu and Zn from metal-contaminated soil have been tested at lab-scale, and the potential of the resulted biomass as animal feeds has been validated using both theoretical and

Category of agricultural management	Shortlist title	Specific innovative measures requiring more research (as written in the DoA part B, Table I)	No. of pre-identified measure	New proposed title for the 'Specific innovative measures requiring more research'	Proposed pilot region (country)	Agricultural system	Agro-pillar	TRL (Technology readiness level)
								animal experiments. The scale-up demonstration and validation is challenging because the existence of soils only contaminated with Cu and/or Zn is scarce.
	Utilization of crop residues in animal feed	Utilization of grass and faba bean as a protein sources for pig and poultry	13	Grass and faba bean as novel protein sources for pig and poultry - focus on protein extraction and quality	Boreal (FI)	Conventional and Agro-ecological	Animal husbandry	TRL5. Both grass juice and faba bean have been tested as a protein source for pig and poultry.
Innovative soil, fertilisation, and crop management systems and practices for enhanced N, P, efficiency and increased soil OC	Deep rooted crops to reduce nutrient losses and fertiliser use	Cultivation of improved Faba bean varieties in no-till system	14	Reduction of nutrient losses with deep rooted crops (faba bean) in a no-till system	Boreal (FI)	Conventional, Agro-ecological and Organic	Crop production	TRL2. As a deep rooted crop, faba bean has a potential to improve soil structure and improving water penetrating into soil and thus reducing both surface flow of water and erosion, the main route for P losses to surface waters.
	Carbon sequestration	Effect of soil properties on mineralization of organic matter	15	Effect of soil properties on mineralisation of organic matter	Boreal (FI)	Conventional, Agro-ecological and Organic	Crop production	TRL 3. The concept of adjusting N fertilization rates according to soil clay/organic C ratio has been experimentally tested and shown promising. The methods of analysis are well established and generally available from soil testing laboratories. The technique still lacks validation and guidance values.
	~~Catch crops to reduce N losses in soil and increase biogas production~~	~~Novel perennial cereal varieties~~		~~Kernza Perennial Cereal Cultivation for enhanced nutrient retention and mitigation of N leaching to groundwaters~~	~~ES~~	*Incorporated with another mitigation measure below titled: Deep-Rooted Nutrient Cycling with Kernza Perennial Cereal to mitigate*		

Category of agricultural management	Shortlist title	Specific innovative measures requiring more research (as written in the DoA part B, Table I)	No. of pre-identified measure	New proposed title for the 'Specific innovative measures requiring more research'	Proposed pilot region (country)	Agricultural system	Agro-pillar	TRL (Technology readiness level)
						nutrient losses to soils and groundwaters (No.22)		
	Practices for increasing soil organic matter content	Nor or minimum tillage, digestate having high biological stability	16	The effect of biological stability degree on carbon and nitrogen	Continental + nutrient surplus (IT)	Conventional and Agro-ecological	Crop production	TRL 8-9. This measure has been tested and demonstrated in both lab and field conditions in continental region, data is available in MMC for a state-of-the-art investigation and previous research published by the UNIMI research group. In this project, the focus is on assessing the fate of C and N in the soil originating from materials with different degrees of biological stability in various incubation trials (TRL 4).
Substituting primary nutrient resources by biobased products in practice	Substituting external mineral input from synthetic fertilisers by recycled organic based fertilisers in arable farming	Zeroing use of mineral fertilisers, use of recycled sources, and adapted/reduced fertiliser inputs	17	Adapted and balanced fertiliser inputs based on diagnosis by a combination of farmgate balances, soil and plant analysis	Continental + nutrient deficit (CH)	Conventional, Agro-ecological and Organic	Crop production	TRL 5-6. Technology has been tested in the field experiments in CH. with strip experiments to test recycled nutrient sources that could help to balance inputs of N, P and K together with those of S, Mg and/or Zn.
			18	Mineral fertiliser replacement using digestate and derived products (ammonium sulphate)	Continental + nutrient surplus (IT)	Conventional and Agro-ecological	Crop production	TRL9. This measure has been tested in several field trials in Italy and Belgium. Experiment in this project focus on further assessment of the agronomic and environmental impact of digestate and derived products at field scale application, providing extra data for the nutrient flow within the system

Category of agricultural management	Shortlist title	Specific innovative measures requiring more research (as written in the DoA part B, Table I)	No. of pre-identified measure	New proposed title for the 'Specific innovative measures requiring more research'	Proposed pilot region (country)	Agricultural system	Agro-pillar	TRL (Technology readiness level)
								and support the implementation of this type of BBF under the new EU regulation 2019/19.
	Pig manure processing and replacing mineral fertilisers	Pig manure upgrading	19	Enhanced and Optimised Fertilisation with Upgraded Pig Manure Products to avoid nutrient excess in soils	Mediterranean (ES)	Conventional and Agro-ecological	Crop production	TRL5-6 The methodology of this measure has been tested in field trials
	Pig manure processing and replacing mineral fertilisers	Fertilising efficiency of liquid fraction of pig slurry with high N/P-ratio	20	Mineral fertiliser replacement potential of digested pig slurry with high N/P ratio and Yara fertiliser (low P)	Boreal (FI)	Conventional and Agro-ecological	Crop production	TRL7. Mineral replacement potential of recycled fertilisers (e.g. digested pig slurry) has been demonstrated earlier at a field scale. In this project the focus is on demonstrating the potential of these fertilisers for grass when broadcasted at a field level.
Nature-based solutions	Systems which limit nutrient dispersal	Constructed wetlands	21	Constructed wetlands: tertiary treatment of pig manure towards discharge water	Atlantic (BE)	Conventional and Agro-ecological	Agro-processing and Animal husbandry	TRL6-7 The concept and methodology of using constructed wetland for wastewater treatment have been tested and demonstrated at different scales of the already existing constructed wetlands in Belgium and beyond.
	Systems which limit nutrient dispersal	Subsoil nutrient extraction with new genetic resources	22	Deep-Rooted Nutrient Cycling with Kernza Perennial Cereal to mitigate nutrient losses to soils and groundwaters	Mediterranean (ES)	Conventional, Agro-ecological and Organic	Crop production	TRL4-5. The use of Kernza perennial cereal was tested at laboratory level and currently we are conducting field trials.

During the revision of the pre-identified mitigation measures by pilot region leaders, not only revised titles were proposed, but also the following changes were made in the list and hence in the MMC (Table 2):

- Initially *'Tools, techniques, and systems for higher- precision fertilisation'* category counted 4 mitigation measures. Since the aim is to have precision fertilisation as a common mitigation measure across the five NutriBudget pilot regions in WP4, additional measure *('Sensor technologies for correcting potential nitrogen deficiency for achieving optimal yields with synthetic nitrogen fertilisers'* – No.5) was added by the Borel pilot.

- It was observed that initially proposed measure *'Anaerobic digestion of animal slurry and by products' (FI, IT)* does not contribute to the *'Innovative management systems, tools and practices for optimised nutrient and GHG management in animal husbandry'* category as it does not focus on the anaerobic digestion technology and mitigation of GHG, but rather on the use of digestate derived fertilisers as replacement for synthetic mineral fertilisers. Therefore, the measure *'Anaerobic digestion of animal slurry and by products' (FI, IT)* was removed from the mentioned agricultural management category and added to the category *'Substituting primary nutrient resources by biobased products in practice'* in the form of (i) *Mineral fertiliser replacement using digestate and derived products (ammonium sulphate) (IT, No.18)*; (ii) *Mineral fertiliser replacement potential of digested pig slurry with high N/P ratio and Yara fertiliser (low P) (FI, No.20).*

- As the initially proposed measure *'Floating wetland plants or algae'* combines cultivation of duckweed and algae, and algae are not wetland plants and do not float, it was requested by UGent to make a split of the mentioned measure in the following two measures: (i) *Duckweed cultivation on agricultural wastewater (pig manure and aquaculture) as alternative protein source for animal feed* (No. 10) and (ii) *Microalgae cultivation on digestate as alternative protein source for animal feed* (No. 11).

- The initially proposed measure '*Zeroing use of mineral fertilisers, use of recycled sources, and adapted/reduced fertiliser inputs'* that was assigned to CH and IT was split in the following two measures as the pilots take a different approach in tackling the substitution of synthetic mineral fertilisers: (i) *Adapted and balanced fertiliser inputs based on diagnosis by a combination of farmgate balances, soil and plant analysis* (CH, No. 17) and (ii) *Mineral fertiliser replacement using digestate and derived products (ammonium sulphate)* (IT, No. 18).

- Finally, the initial measure *'Novel perennial cereal varieties*' was double counted, and therefore removed from the category *'Innovative soil, fertilisation, and crop management systems and practices for enhanced N, P, efficiency and increased soil OC'*, and will be assessed as a part of *'Nature-based solutions'* category (*Deep-Rooted Nutrient Cycling with Kernza Perennial Cereal to mitigate nutrient losses to soils and groundwaters*, No. 22).

With all the above stated changes, the final count of the mitigation measures in Table 3 is 22: amounting to 21 pre-identified (DOA, part B, Table I) and 1 additionally added measure by the Boreal pilot to reach the aim of having precision fertilisation as a common mitigation measure across the five pilot regions.

When classifying the measures from Table 3 according to the **six agricultural management categories**, it can be observed that some measures can fit into more than one category (Figure 3). For example:

- Measure No. 22 '*Deep-Rooted Nutrient Cycling with Kernza Perennial Cereal to mitigate nutrient losses to soils and groundwaters'* also fits *'Innovative soil, fertilisation, and crop* *management systems and practices for enhanced N, P, efficiency and increased soil OC'* category

- All five measures in the '*Tools, techniques, and systems for higher- precision fertilisation'* category also aim to substitute synthetic mineral fertilisers and hence could fit the category *'Substituting primary nutrient resources by biobased products in practice'*
- Measure *'Phytoextraction of Cu and Zn from metal-contaminated soil for animal feed*' (No. 12) and *'Reduction of nutrient losses with deep rooted crops (faba bean) in a no-till system'* (No. 14) could also be seen as *'Nature-based solutions'.*

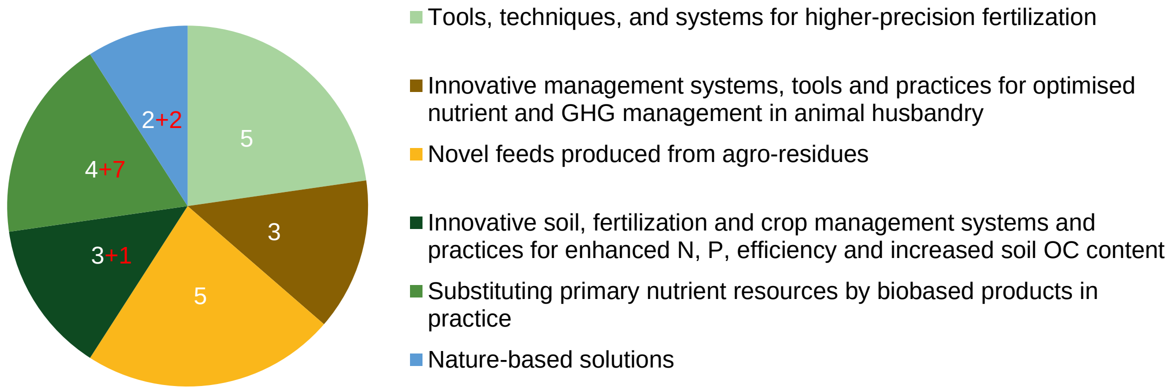


Figure 3 Number of pre-identified agronomic mitigation measures in each category. Some mitigation measures fit into more than one category, marked as "+ number" in the figure.

When it comes to the classification according to the **type of the agricultural system**, all measures are applicable to all three types as they aim to contribute to agricultural sustainability by optimising nutrient budgets. However, if we take into consideration the type of an input origin (synthetic mineral source, bio-based source and/or factory farming origin) that pilot regions will use in experimental work of WP4, we can classify all 22 measures in conventional and agro-ecological system, and 6 of measures in organic agricultural system.

Finally, 16 measures from 22 listed ones can fit in Crop production agro-pillar, 9 in Animal husbandry agro-pillar and 5 in Agro-processing agro-pillar. This means, as indicated in Table 3, that one measure can cover more than just one **agro-pillar**.

To specify the implementation status of the pre-identified measures across Europe, the technology readiness level (TRL) was introduced (Table 3) on the basis of the background data collected in the MMC. In summary, 3 of the 22 pre-listed measures have been fully implemented (TRL8-9), 12 measures have been validated or demonstrated in a relevant environment (TRL 5-7), 7 measures have been developed in the laboratory (TRL<5) and require scale-up validation and demonstration.

3.2. List of relevant indicators

In environmental system analysis, the Driver-Pressure-State-Impact-Response (DPSIR) approach is often used as a causal framework to describe interactions between society and environment. The approach distinguishes between drivers, pressures, state, impacts, and responses. This approach partly fits to the main topics of the NutriBudget project, especially regarding to pressure, state, and impact variables. Starting with the basic site properties of the mitigation measures, Sections 3.2.1 - 3.2.4 introduce the following four types of indicators: agro-ecological site properties (A), pressure indicators (D), effect indicators (E) and performance indicators (P). All these indicators were proposed by WP3 and listed in MMC in order to collect available information on the state-of-the-art of the mitigation measures.

3.2.1. Agro-ecological site properties

The agro-ecological site properties include all physical-chemical-biological properties of agro-ecosystems that affect the fate of nutrients in the whole farming system, and are presented in Table 4.

Table 4 Agro-ecological site properties to be selected for use in NutriBudget project, and its relevance* for four WPs.

Class	Indicator	Description	WP1	WP2	WP3	WP4
A1	Farm system	Agricultural category: conventional, agro-ecological, organic	+	++	+	++
A2	Basic Soil Properties	Basic soil properties such as texture, mineralogy (clay, sand, silt content), CEC, bulk density, rootability, groundwater depth, slope, Al and Fe oxides	+	++	+	D
A3	Optional Soil Properties	Optional soil properties affecting fate of nutrients: POM, DOM, LFOM, respiration, PMN, bacterial and fungal biomass, C and N in microbial biomass, biodiversity, infiltration capacity, pF curve (water holding capacity, wilting point, field capacity)	-	+	-	D
A4	Climatic conditions	Weather conditions controlling fate of nutrients: precipitation, potential evaporation, mean temperature, sunlight	+	++	+	++
A5	Climatic zone	Climatic region: Atlantic, Continental, Mediterranean, Boreal	+	++	+	+
A6	Land use	Agricultural pillar: crop, animal, bioprocessing	+	++	+	D
A7	Housing system	The type of stable / storage system (open or closed), etc	-	++	+	D

** relevance per indicator is abbreviated as high (++), medium (+), not relevant (-) or being dependent on the pilot (D).*

3.2.2. Pressure indicators

Pressure indicators are variables that alter the properties of the agro-ecosystem via changes in farm management (including nutrient inputs, mitigation strategies, maintenance, etc.), and are presented in Table 5.

Table 5 Pressure indicators to be selected for use in NutriBudget project, and its relevance* for four WPs.

Class	Indicator	Description	WP1	WP2	WP3	WP4
D1	Soil Nutrient** inputs	Total nutrient input via fertilizer or manure applied to the soil (kg / ha)	+	++	+	D
D2	Farm Nutrient inputs	Total carbon and nutrient inputs on the farm (kg / farm)	-	+	+	D
D3	Application placement	Application technique used to apply nutrients (placement of fertilizer/manure): broadcasted, injected, banded, satellite based, …	+	+	-	D

D4	Application Type	Fertilizer / manure category to be applied: inorganic, enhanced fertilizers, manure, compost, treated, etc.	+	++	-	D
D5	Application timing	Use of optimized fertilizer timing via either splitting of the doses or via weather dependent timing for highest NUE	+	++	-	D
D6	Farm area	The area for production of crop, animal or bioprocessing products. For Nature-Based Solutions, it refers to the proportional farm area that leading to non-productive (agronomic) land	+	+	+	D
D7	Manure or feedstock composition	The elemental composition of animal manure or manure products (focus on C, N, P and K) or feedstock	-	++	-	D
D8	Crop management	Crop management practices that improve the nutrient efficiency on field or farm level: Crop rotation, catch crops (yes/no), incorporation of straw (yes/no), strip cultivation (yes/no), integrated pest management (yes/no)	+	++	+	D
D9	Soil Management	Soil management practices that improve the nutrient efficiency on field or farm level: tillage depth, liming (yes/no), use of biostimulants (yes/no), …	+	++	+	D
D10	Animal and manure Management	Properties describing the animal system: number of animals, grazing period, animal category, animal density, manure acidification, manure treatment technology, …	+	++	-	D

** Relevance per indicator is abbreviated as being high (++), medium (+), not relevant (-) or being dependent on the pilot (D).*
*** Nutrient refers to the series N, P, K, Ca, Mg, Na, S, Cu and Zn, possibly Cd*

3.2.3. Effect indicators

Effect indicators refer to variables that change due to the impact of altering nutrient inputs/ and/or management strategies, such as nutrient uptake, surplus, losses and pools that can be measured or modelled. The list of effect indicators selected for the use in NutriBudget project is given in Table 6.

Table 6 Effect indicators to be selected for use in NutriBudget project, and its relevance* for four WPs**.**

Class	Indicator	Description	WP1	WP2	WP3	WP4
E1	Crop yield	The dry matter crop yield production (kg / ha)	+	++	+	D
E2	Crop nutrient** uptake	The crop nutrient uptake (kg / ha)	+	+	+	D
E3	Nutrient surplus soil	The total nutrient surplus being the difference between inputs and crop uptake	+	++	+	D
E4	Nutrient surplus farm	The difference between farm nutrient inputs and outputs	+	+	+	D
E5	Soil C and nutrient contents/pools	The soil carbon and nutrient status in the topsoil (0-30 cm), being derived from soil extractions for a. Total carbon and nutrient pools in the soil b. Reactive nutrient pools c. Bioavailable in soil solution	+	++	+	D
E6	Soil acidity	The pH value of the topsoil	+	++	+	D
E7	N and P losses	Losses of nitrogen via volatilisation (NH_3), nitrous oxide (N_2O) or leaching (NO_3, PO_4) or runoff (N and P)	+	+	-	D

Class	Indicator	Description	WP1	WP2	WP3	WP4
E8	GHG emissions	Losses of CH4 or N2O at farm or field level	+	+	-	D
E9	Biodiversity index	An index reflecting the crop heterogeneity across the landscape promoting biodiversity	-	-	+	D
E10	Farm Energy balance	Total energy consumption / generation at farm level	-	-	-	D

** Relevance per indicator is abbreviated as being high (++), medium (+), not relevant (-) or being dependent on the pilot (D).*
*** Nutrient refers to the series N, P, K, Ca, Mg, Na, S, Cu and Zn, possibly Cd.*

3.2.4. Performance indicators

Performance indicators in NutriBudget context describe mainly gaps between a current and a targeted status with respect to e.g. nutrient inputs, surpluses, losses or contents/pools that cannot be measured but only calculated from effect indicators. The list of performance indicators selected for the use in NutriBudget project is given in Table 7.

Table 7 Performance indicators to be selected for use in NutriBudget project, and its relevance* for four WPs**.**

Class	Indicator	Description	WP1	WP2	WP3	WP4
P1	Soil carbon and nutrient** status Gap	Gap between current and target/critical nutrient* contents/pools (includes carbon)	+	++	+	-
P2	Losses Gap for C, N and P	Gap between current and target/critical C, N and P losses: NH_3, N_2O, NO_3, CO_2, CH_4, and P	-	+	+	-
P3	Nutrient Surplus Gap	Gap between current and target/critical nutrient surplus, derived as the soil C and nutrient status gap (indicator P1) divided by a target time plus unavoidable or critical losses.	-	+	+	-
P4	Nutrient Input Gap	Gap between current and target/critical nutrient inputs, derived from the critical / target nutrient surplus plus target crop uptake	-	+	+	-
P5	Nutrient Use Efficiency (NUE)	The ratio of nutrient uptake divided by the nutrient inputs	+	+	+	+
P6	NUE Gap	Gap between current and target nutrient use efficiency, depending on target crop yields	-	+	+	-
P7	Emission Fraction Gap	Gap between the current and target fraction of the applied N and P that is lost via volatilisation, leaching or runoff	+	+	+	+
P8	Farm-gate C, N and P Efficiency Gap	Gap between current and target farm gate balances for C, N and P.	-	+	+	D
P9	Soil Quality Index	An index reflecting the distance to target for optimum soil health given the OSI framework (or adapted version of it)	-	-	+	D

** Relevance per indicator is abbreviated as being high (++), medium (+), not relevant (-) or being dependent on the pilot (D).*
*** Nutrient refers to the series N, P, K, Ca, Mg, Na, S, Cu and Zn, possibly Cd*

3.3. Inputs provided in the Mitigation Measures Catalogue up to M9

Based on the identified indicators and their relevance for each WP (Table 4-7), a list of selected indicators was created to differentiate the minimum required datasets for each agricultural management category (marked as “x” in Table 8). The first stage of data collection resulted in 107 references (from published papers, reports, or databases, etc.) with 417 observations sets (i.e. each treatment represents one observation set). The resulted first version of MMC is available as a working document in the project MS SharePoint folder (see Annex 1 the screenshots of two mitigation measures as examples). The collected information will be further evaluated for use in other WPs based on the defined minimum datasets.

Table 8 Overview of the indicators* involved in each category of the agricultural management.

Indicators	Tools, techniques, and systems for higher-precision fertilisation	Innovative management systems, tools and practices for optimised nutrient and GHG management in animal husbandry	Novel feeds produced from agro-residues	Innovative soil, fertilization and crop management systems and practices for enhanced N, P, efficiency and increased soil OC content	Substituting preliminary nutrient resources by biobased products in practice	Nature-based solutions
Mitigation measure code	x	x	x	x	x	x
Publication_treatment code	x	x	x	x	x	x
Treatment details	x	x	x	x	x	x
Data entry	x	x	x	x	x	x
Reference	x	x	x	x	x	x
Category (A1)	x	x	x	x	x	x
Manure properties (A1)		x	x			
Basic soil properties (A2)	x		x	x	x	x
Optional Soil Properties (A3)	\		\	\	\	\
Climate conditions (A4)	x	x	x	x	x	x
Nutrient input to the system (D1, D2)	\	\	\	\	\	\
Crop management (D4, D5, D6, D8)	x		x	x	x	
Soil management (D1, D9)	x		x	x	x	
Bioprocessing system (A7)		x	x			x
Feedstock properties (D7)		x	x			x
Final product properties (D7)		x	x			x
Animal and manure management (D10)		x	x			
Crop/biomass yield (E1, E2)	x		x	x	x	\
Canopy status (E1, E2)	\					
Nutrient output from the system (E3, E4)	\	\	\	\	\	\
Soil nutrient status (E5)	x		x	x	x	
Soil acidity (E6)	x	\	\	x	x	
Emissions (E7, E8)	x	x	\	\	\	x

Indicators	Tools, techniques, and systems for higher-precision fertilisation	Innovative management systems, tools and practices for optimised nutrient and GHG management in animal husbandry	Novel feeds produced from agro-residues	Innovative soil, fertilization and crop management systems and practices for enhanced N, P, efficiency and increased soil OC content	Substituting preliminary nutrient resources by biobased products in practice	Nature-based solutions
Water quality (E8)		\	\	\	\	x
Biodiversity (E9)	x		\			x
Farm energy balance (E10)		x				x
Measured impact	x	x	x	x	x	x
Relevant remarks for the modellers	\	\	\	\	\	\

** Indicators marked with "x" are minimum dataset for mitigation measures in relevant category, while indicators marked with "\" are "good to have".*

3.4. Additional mitigation measures from co-creation workshops

The outcomes of the five national workshops (MS2) were discussed online with the NutriBudget consortium on 10th May 2023, which led to a list of additional mitigation measures proposed by national stakeholders during the national co-creation workshops (Table 9). These proposed measures will be further investigated and evaluated to decide if they can be included into continuous update of the MMC. The results of this work will be presented in the next version of D1.1 at M42.

Table 9 Additional mitigation measures of interest for regional nutrient issue. No new mitigation measures were proposed by stakeholders in Continental + nutrient surplus pilot region.

Pilot region	Organizer	Regional interest for additional mitigation measures
Atlantic	UGent (BE)	• Precision application of animal manure • Which crops to grow for nutrient and energy recovery in the 3 m buffer between waterways and fertilization zones
Continental + nutrient deficit	FiBL (CH)	• Kinsey/Albrecht fertilization planning • Usage of residues and non-marketable crops as nutrient input • Addition of ramial wood chips as soil improver/fertilizer
Boreal	LUKE (FI)	• Support for crop farmers to accept manure spreading on their fields • Support for cultivating winter crops for reducing erosion and better targeting of support for cover crops on regions with high risk for flooding • Increasing grass area • Separation of liquid and solid fraction of manure with gypsum
Mediterranean	UVIC-UCC (ES)	• Livestock systems incorporating multiple species • Producing animal feed from seaweed • Technological applications for precise administration of animal feed

4. Conclusions and Future perspective

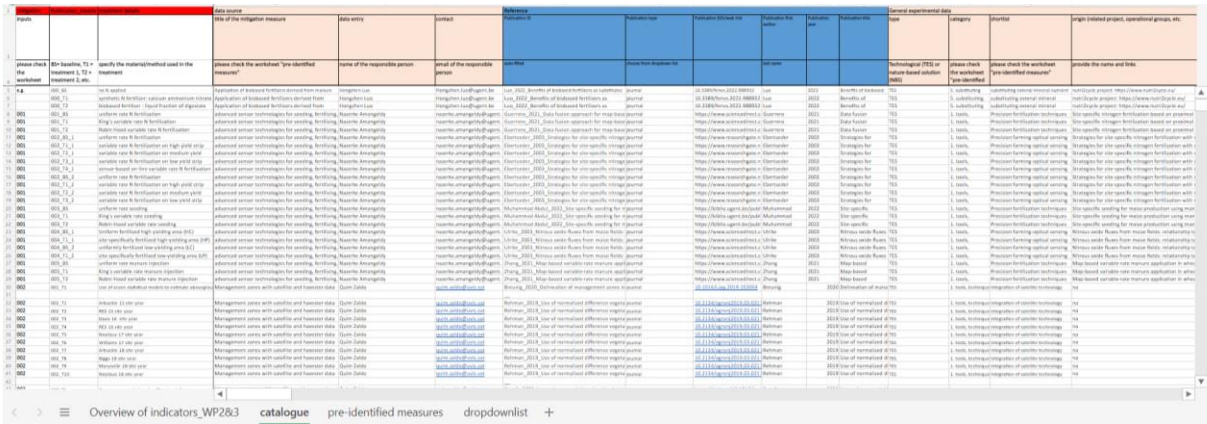
The first stage of data collection resulted in a first version of the Mitigation Measures Catalogue (D1.1) that consists of 22 pre-identified mitigation measures in five pilot regions. When classifying the 22 measures according to the type of the agricultural system, all 22 measures are suitable for conventional and agro-ecological system, and 6 of them for organic agricultural system. Sixteen measures from 22 can fit in Crop production agro-pillar, 9 in Animal husbandry agro-pillar and 5 in Agro-processing agro-pillar. This means that one measure can cover more than just one agro-pillar. Finally, 3 of the 22 measures have been fully implemented (TRL8-9), 12 measures have been validated or demonstrated in a relevant environment (TRL 5-7), 7 measures have been developed in the laboratory (TRL<5) and require scale-up validation and demonstration.

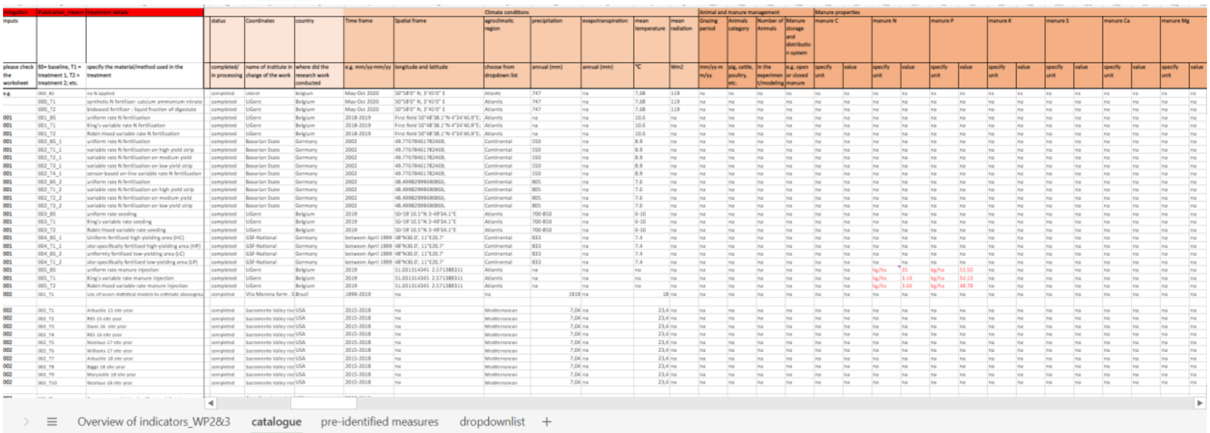
On top of these 22 measures, also 12 mitigation measures were proposed by regional stakeholders during the co-creation workshops. These 12 measures will be further evaluated for consideration as potentially new mitigation measures in the updated version of the MMC (at M42). As a starting point, background data from a total of 107 references (including published papers, reports, databases, etc.) were listed for the 22 pre-identified mitigation measures in the MMC, covering the identified indicators in WP3. This deliverable also serves as a strong supporting document for the evaluation and prioritisation of the pre-identified mitigation measures for further experimental work in WP4.

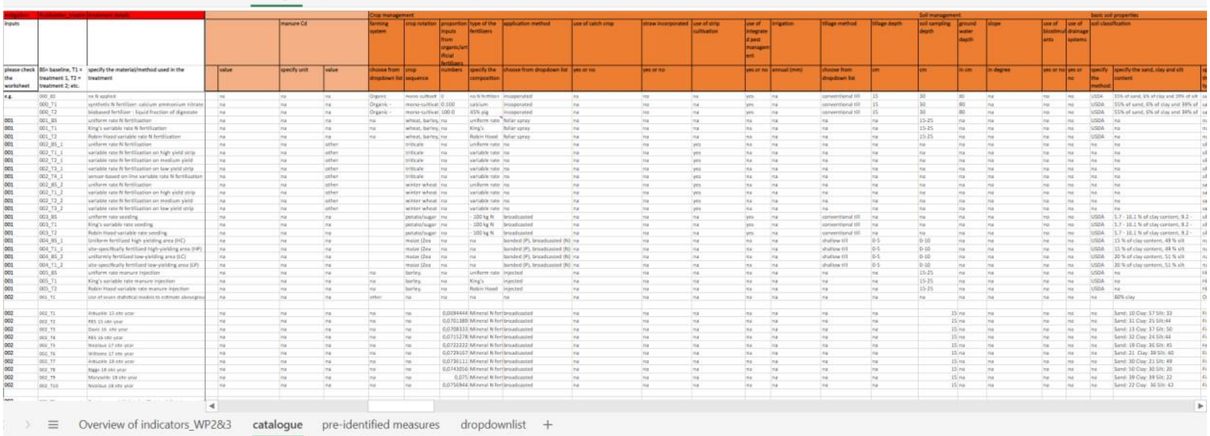
To ensure a good quality of the data presented in the MMC, a throughout quality control will be conducted, following criteria of data use in meta-analysis (T1.2) and modelling (WP2). Meanwhile, the MMC will be continuously updated with i) additional measures (including their background, rationale, data availability…) resulted from a broader scanning into relevant EU projects and databases; ii) opinions and suggestions collected through interactive Nutri-actor approach; and iii) new data from field experiments with innovative mitigation measures in five pilot regions (WP4).

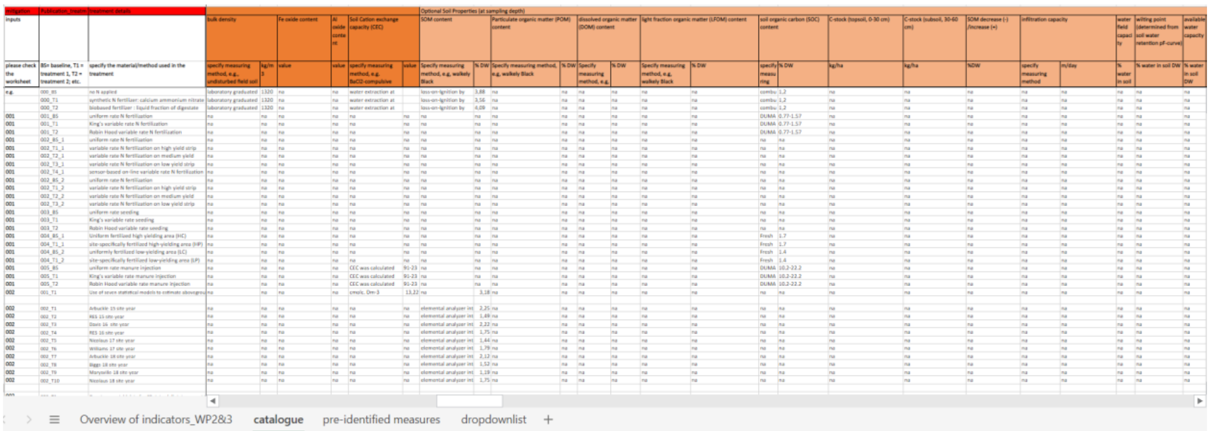
Annexes

Annex 1 Screenshot of the Mitigation Measure Catalogue as a working document in the project MS SharePoint folder.








Overview of indicators_WP2&3
catalogue
pre-identified measures
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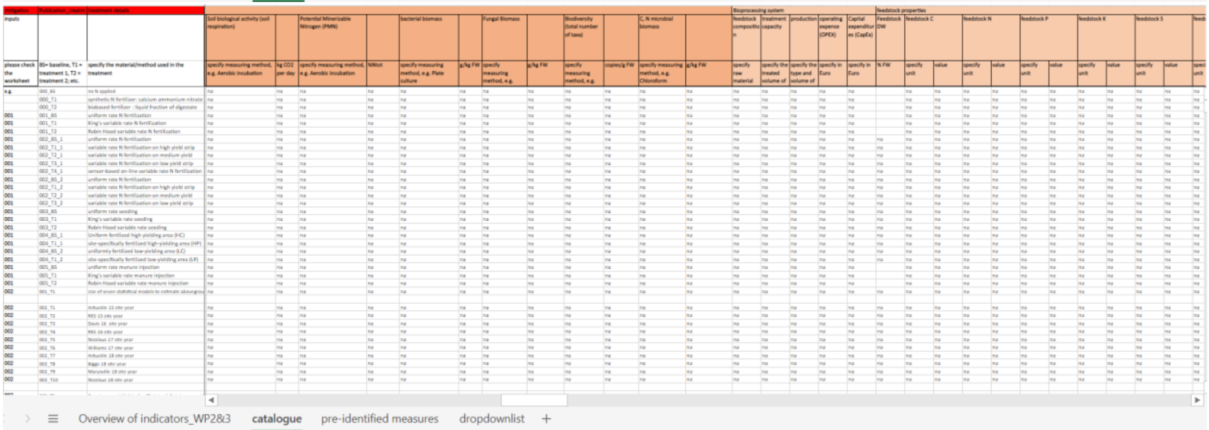
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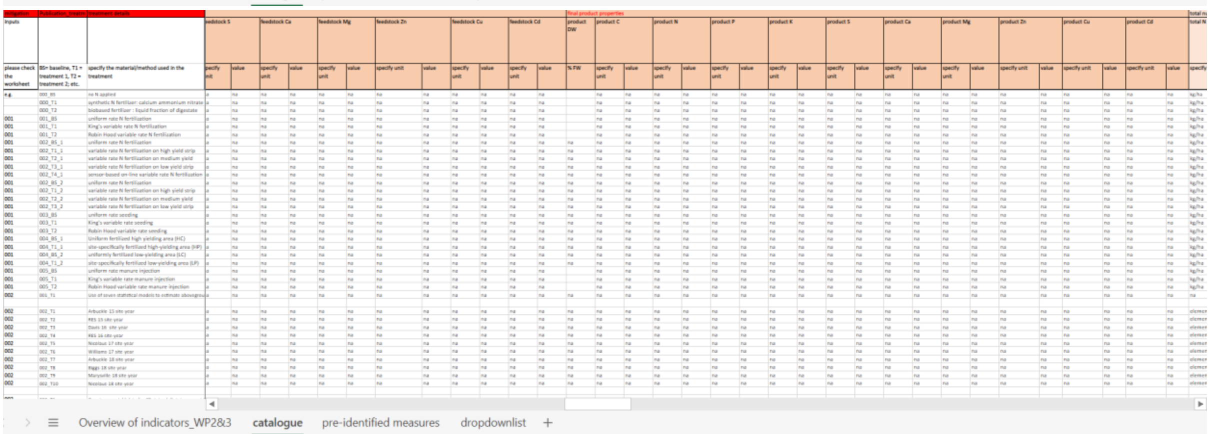
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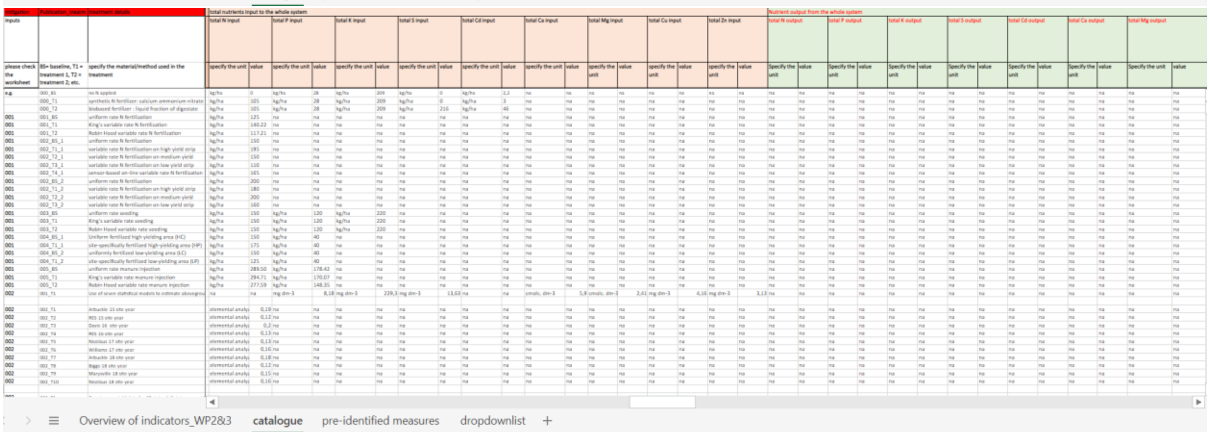
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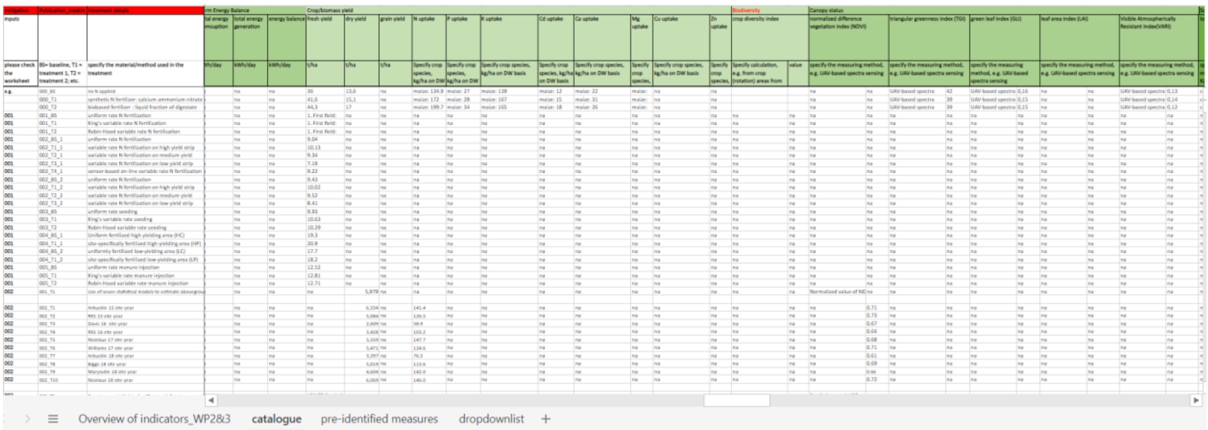
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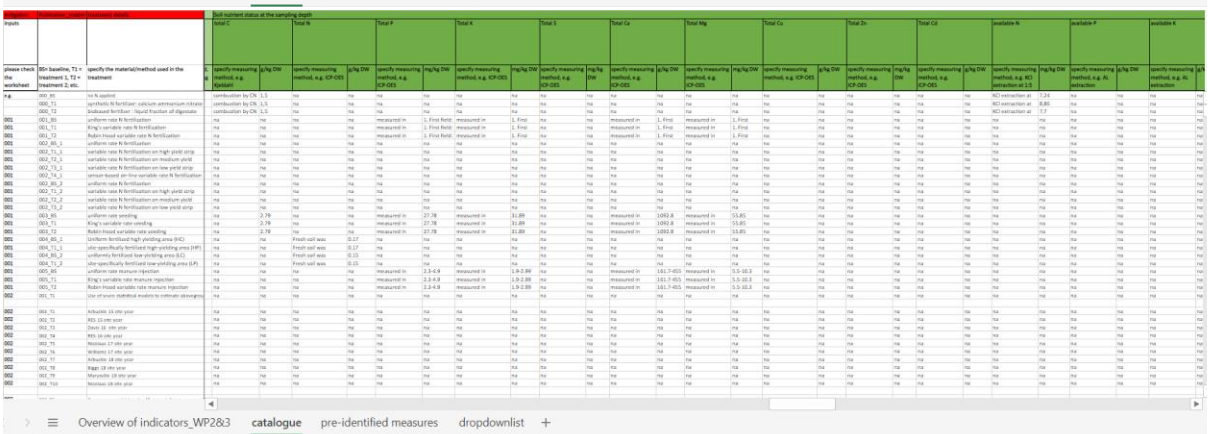
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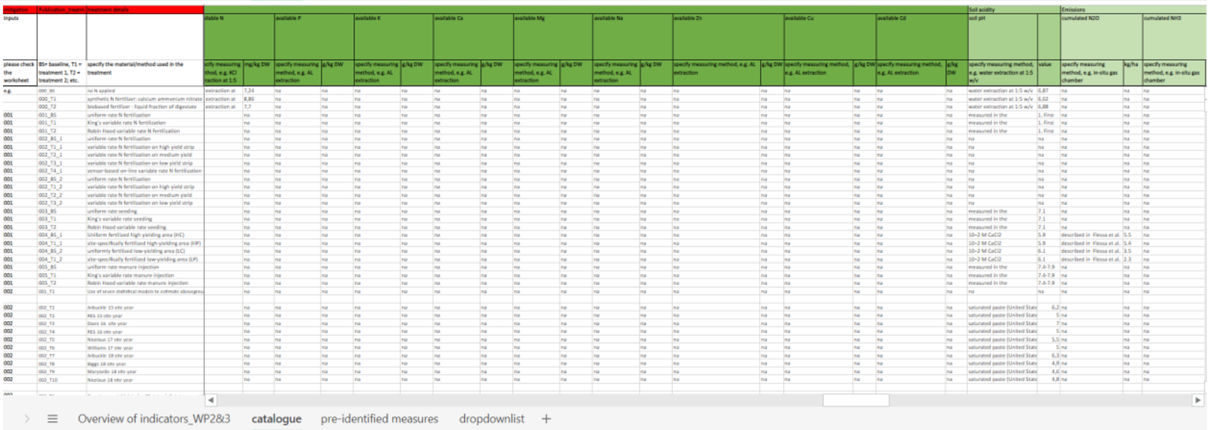
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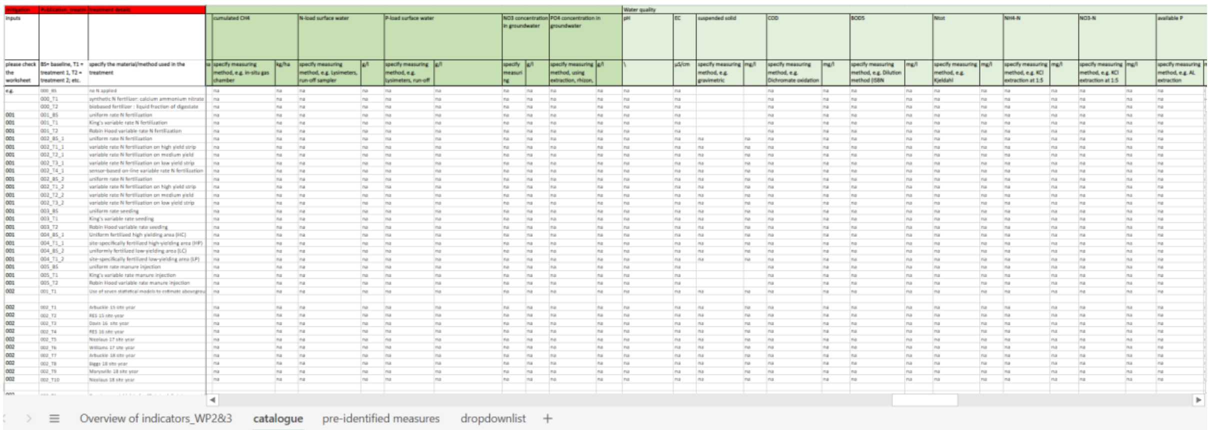
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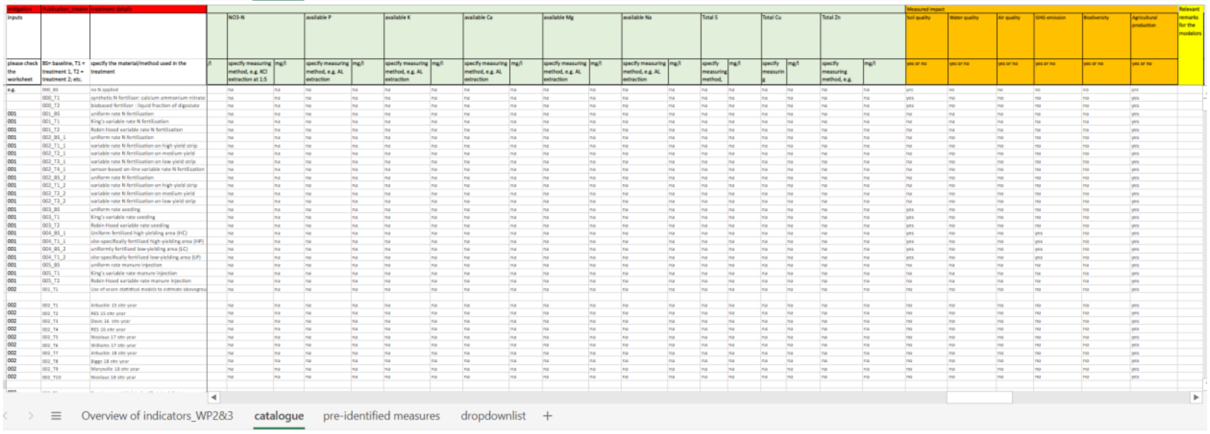
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Optimisation of nutrient budget in agriculture

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Funded by the European Union