1st report on NBS cases' implementation and transdisciplinary evaluation in Hungary/ Denmark/ Netherlands/ UK

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1. Introduction

The objective of the trans4num project is to develop and test innovative NBS (Nature-based Solutions) practices and pathways that contribute to a socio-ecological transformation of existing intensive agriculture systems towards increasingly sustainable nutrient management. As part of this, NBS innovations are implanted in four sites (Denmark, Hungary, the Netherlands and the UK). All insights from the NBS sites' activities will be documented in yearly reports. This report is the first yearly report in the form of D2.2.

1.1 Objectives

The main objective of D2.2 in the country reports on the first year's NBS is about experimental exploration, collected from each of the partners, including site-specific descriptions of the implementation and evaluation of the selected NBS, making use of approaches and protocols agreed upon in the tasks 1.2 and 1.4.

1.2 Rationale

To achieve these objectives, promising NBS potentials were selected for field implementation and testing in four study sites of the trans4num project, with active participation from farmers. In Denmark, the trans4num project selected two NBS for implementation: firstly, adjusting crop rotations to include more biomass and perennial crops, such as grass and grass-clover mixtures, for biorefinery purposes. This approach aims to produce protein for monogastric animals and fibre for ruminants while improving nutrient balances, local climate outcomes, and environmental benefits. Secondly, the use of bio-based fertilisers from organic waste streams, such as manure, aims to enhance nutrient circularity and reduce nitrogen loss. In Hungary, field experiments compare NBS with conventional intensive farming systems on 20 hectares, focusing on a three-year rotation of durum wheat, sorghum, and soya. The trials will evaluate soil quality and yield using sensor-based technology, to develop a monitoring and decision support system for farmers. In the Netherlands, research will explore the benefits of cover crops in rotation with seed potatoes and grass-clover mixtures with organic winter wheat, investigating optimal nutrient management practices. Additionally, the use of Lucerne (Alfalfa) and grass-clover pellets as biofertilizers will be tested as an alternative to conventional mineral fertilizers. In the UK, the focus is on diversifying arable rotations and utilizing bio-based fertilizers, including cover crops, green manure, and farmyard manure applications. Experiments will also test a mobile app for calculating nutrient content in manure and investigate recycled fertilizers from abattoir by-products as a phosphorus source.

In addition, the trans4num-CN (China) team conducted extensive research across the North China Plain, Southwest China, and Northeast China, focusing on key agricultural challenges by studying the effects of straw return, leguminous crop introduction, and optimized organic-inorganic fertilizer combinations on crop yield, nitrogen uptake, photosynthetic traits, root structure, and soil properties.

2. Report on NBS cases

2.1 Report on the NBS sites in Denmark

The Danish NBS site is progressing as planned. The site employs an inter- and transdisciplinary approach, fostering dialogue and involving all stakeholders in the co-creation of the targeted transformation. Danish partners utilize a blend of social and natural science methods. Stakeholder engagement activities and interviews have commenced, with a major stakeholder workshop/meeting scheduled for October 2024. The next step is to identify 2-5 ambassador farmers to serve as key informants. Interviews have been conducted with biogas facilities, biorefineries, farmers, and regulators in the area, with findings to be reported in 2025. For the quantitative assessment, the model is set up, and the next steps involve calculating/modelling biomass availability and nitrogen resources within a substance-flow modelling framework.

In terms of updates, we are now planning to assess stakeholder responses to regulation and adapted regulation governing the NBS. Our stakeholder group has expanded to include additional downstream value creation stakeholders and national public servants/regulators. We also aim to incorporate more economic cost and revenue data at the farm and crop levels in our assessments and modelling.

The Danish team focuses on implementing and testing NBS at the Denmark site by incorporating more grassland into crop rotations to reduce nutrient losses and enhance nutrient use efficiency. This initiative, led by AU in collaboration with local stakeholders and farmers, involves the use of a dynamic economic and environmental impact model developed by CFS (Klimafonden Skive). This model (Figure 1), which includes a simple representation of a green biorefinery, allows for flexible adjustments based on local data, helping farmers understand the implications of adopting NBS with grass/clover/alfalfa cultivation for protein extraction. Preliminary results, discussed with influential farmers, suggest that adopting these practices could yield favourable economic outcomes and significantly reduce nutrient leaching, particularly on vulnerable soils.

Bedrifter summeret

Areal, ha
900

Sædskifte	Afgrøde-fordeling %	Hektar med afgrøde	Udbytte/ ha (ton TS)	Udbytte (ton TS)	Udvaskning (Kg N)
Græs med kløver/lucerne under 50 pct. bælgpl. (omdr	10,0	90	11	900	945
Kløvergræs fabrik	16,7	150	11	1635	1818
Græs, slæt før vårsået afgrøde	0,0	22,5	11	70	0
Græs, udlæg/efterslæt efter korn	0,0	52,5	11	84	0
Silomajs	4,2	37,5	11	480	1181
Silomajs efter kløvergræs	2,5	22,5	11	288	1519
Vinterraps	9,8	87,75	3,3	290	1580
Vinterhvede	19,5	175,5	6,4	1123	2106
Vårkorn e. græs/kløvergræs m. Udlæg, N forfrugt høj	0,0	0	5,0	0	0
Vårkorn e. græs/kløvergræs m. Udlæg, N forfrugt lav	5,8	52,5	5,0	221	551
Vårkorn m. Efterafgrøde (modenhed)	21,0	189	5,0	945	2778
Vårkorn m. Udlæg (grønkorn)	5,8	52,5	10,9	341	551
Frøgræs	4,8			56	680
Sum	100			6432	13709
Sum foderafgrøder, svin				2578	
Sum foderafgrøder, kvæg				3348	
Nettoeksport fra bedrifter ekskl. Græsfrø				213	
Ændring i kvælstofudvaskning i forhold til nu-situation					-15362

	Antal dyr	Husdyr-gødning (Ton TS)	Ton FE (TS)	Foder-balance (Ton TS)
Årssøer	450	125	798	0
Smågrise	15300	10	783	0
Slagtesvin	3500	125	913	-1600
Malkekøer (stor race)	400	1057	3392	
Kvier	105	83	220	
Småkalve	110	31	58	
Slagtekalve	0		0	
Sum foderbehov og gødning, svin		260	2494	
Sum foderbehov og gødning, kvæg		1171	3669	
Samlet foderbehov			6163	

Figure 1: Example of farm input into the model developed by CFS

CFS and AU have also conducted interviews with key stakeholders in the NBS value chain (Figures 2 and 3), using an interview guide from WP1 (i.e., D1.2). These interviews, conducted in months 15-17, are informing the creation of information materials and an upcoming stakeholder workshop in autumn 2024. The workshop, organized with Skive Municipality, GreenLab Skive, and AU's Engineering and Agro departments, will explore collaboration opportunities, potential obstacles, and the need for further research to enhance the NBS value chain.

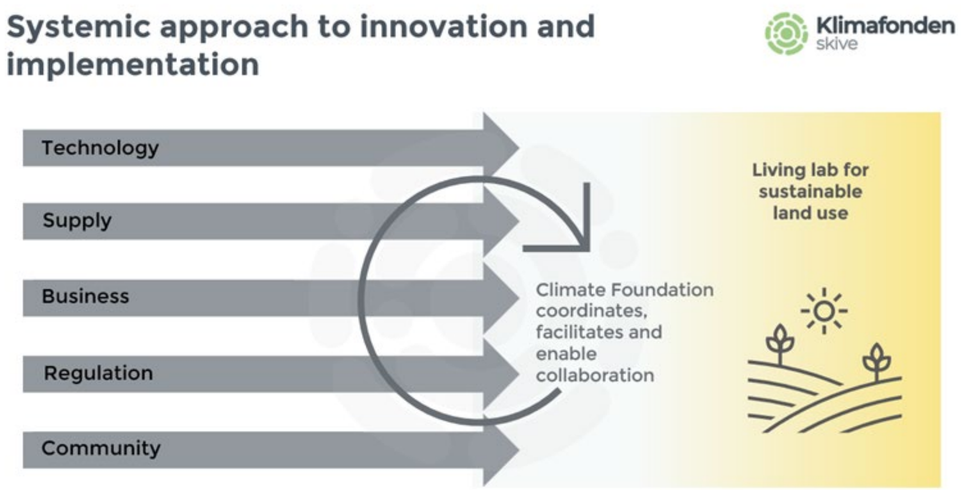

Figure 2: Stakeholder landscape for the NBS interviews in Denmark

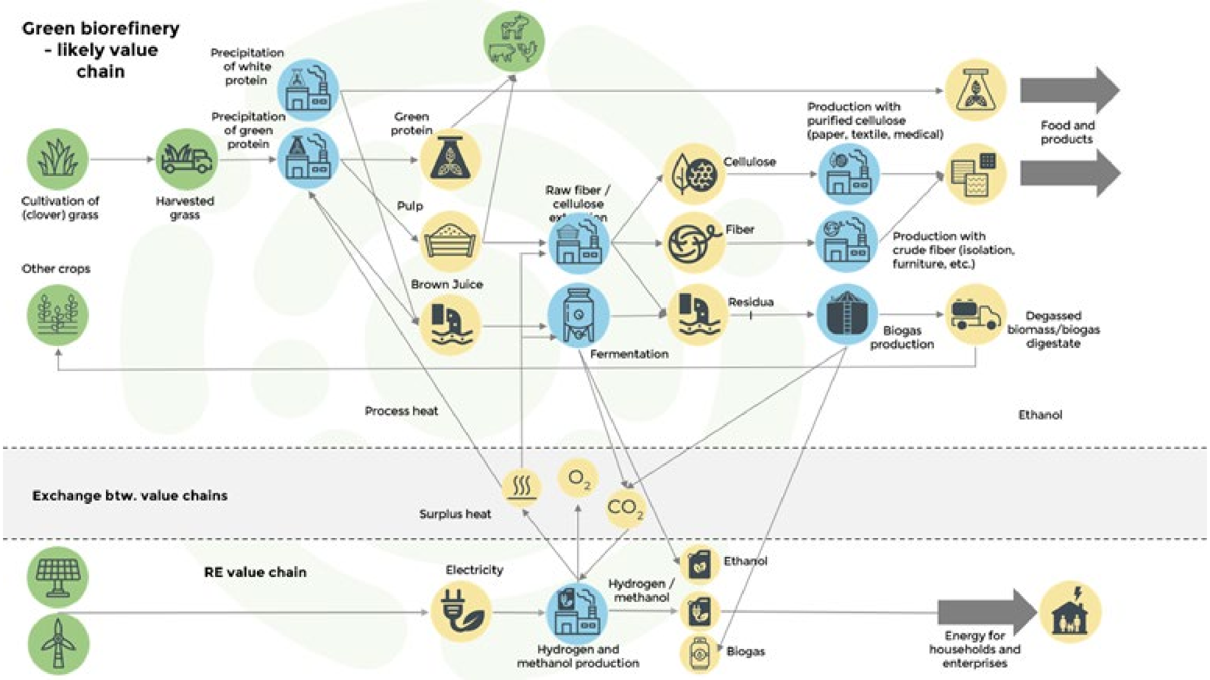

Figure 3: Representations of the NBS value chain in Denmark

Additionally, CFS has identified potential businesses, individuals, and institutions that could participate in the NBS value chain, using desk research and direct dialogues (Figure 3). This work supports the planning of the autumn 2024 workshop and contributes to understanding the broader stakeholder landscape. CFS has also engaged with four ministries to establish a regulatory sandbox, facilitating swift regulatory adjustments needed for large-scale NBS demonstrations. Overall, these efforts have provided a comprehensive overview of the NBS value chain, including connections to green energy sectors like ethanol/e-methanol and biogas. Information gathered throughout the project is being used to develop accessible materials for stakeholders and policymakers, ensuring broad awareness and support for the NBS initiatives.

2.2 Report on the NBS sites in the Netherlands

The Dutch NBS sites are progressing as planned. At the Ebelsheerd location, the winter wheat test fields are nearly harvested, allowing for yield figures and crop observations to be processed. Construction is scheduled for the 2025-2026 growing season. During the past growing season, several groups of interested parties, primarily growers, visited the test fields. The processed results will be presented in a lecture next winter.

The potato trial at the Kollumerwaard location is in full swing, with several observations still to be made during the growing season. Due to the busy schedules of the potato growers, a video has been recorded at the test field explaining the results so far. This video is shared via the email newsletter and on social media. The full results will also be shared through a webinar during the upcoming winter seasons. Soil and leaf sampling are proceeding according to plan and is still ongoing.

To implement and test NBS innovations at the North Holland sites, the project team at Wageningen University (WU) conducted extensive fieldwork at the SPNA **Planty Organic fields (POF)**, encompassing various crop rotations and fertilization strategies. Soil and crop samples were collected at different intervals, prepared in WU laboratories, and sent to other labs for further analysis. The research focused on assessing the long-term effects of 'cut-and-carry' fertilization—a practice initiated in 2012 and continued with consistent crop rotation and fertilization schemes since 2015. In this method, a leguminous crop mixture is harvested multiple times per season, stored, and applied as a natural fertilizer in the subsequent season based on nitrogen content analysis using the NDICEA online tool.

To enhance soil fertility, compost was added to specific plots starting in 2021, and its effects on soil composition, yield, and crop quality were monitored. Soil samples were collected twice annually, covering different depths and using varied methodologies due to budgetary constraints. Analyses included soil physical properties, chemical properties, and microbial community assessments. The data revealed distinct differences in nutrient content, soil structure, and microbial diversity across the fields, with notable variations between conventional and organic management practices.

SPNA facilitated multiple meetings with farmers, positioning them as crucial stakeholders and end-users of NBS. These gatherings included presentations of trial field results and discussions on practical applications of the research. Notably, on December 13, 2023, a meeting was held at the Ebelsheerd site to discuss winter wheat trials, attracting around 50 attendees. Another meeting on February 20, 2024, focused on potato trial fields at Kollumerwaard, also drawing significant interest.

Detailed methodologies were developed for various trials, including:

- **Conventional Winter Wheat Trial:** Initiated with the variety Bennington, this trial involved different nitrogen application strategies, with careful monitoring of crop conditions and final yield assessments. The study aimed to optimize fertilization for improved crop performance, with statistical analysis conducted to validate findings.
- **Organic Winter Wheat Trial:** This trial featured the variety Calgary, with four different fertilization treatments, including the use of bio-fertilizers and organic amendments like pig slurry and grass-clover pellets. The trial was designed to compare the effects of organic inputs on crop health and yield, with data analyzed using Analysis of Variance (ANOVA).
- **Potato Trial Field:** This trial aimed to evaluate the efficacy of NBS in protecting seed potatoes from virus infections via aphid control. The trial, featuring the variety Fontane, included regular observations of crop conditions and a thorough post-harvest analysis of yield and quality.

The results from the 2023 sampling and trials were compiled and analyzed, showing promising outcomes in terms of yield, soil health, and microbial diversity. The findings were documented in scientific articles and reports, contributing valuable insights into sustainable agricultural practices. The project also initiated a new cycle of trials for 2023-2024, including continued research on winter wheat and seed potatoes, with adjusted methodologies based on previous findings. These efforts are expected to refine the understanding of NBS impacts and support the broader application of sustainable agriculture practices.

Overall, the work achieved significant progress in meeting the project's objectives, involving detailed scientific research, stakeholder engagement, and practical application trials. The outcomes advance the understanding of sustainable agricultural practices and foster collaboration with key stakeholders, laying the groundwork for further research and practical implementation.

2.3 Report on the NBS site in Hungary

The Hungarian NBS site is progressing as planned. In 2024, the crops were rotated, and durum wheat, soya, and sorghum were sown. Monitoring and measurements are ongoing this year as well. May and June have been extremely rainy, causing occasional delays in applications and sampling. Throughout the growing season, the trial is continuously monitored using soil and plant sampling, as well as remote sensing techniques. These methods not only check the trial but also assist in making nutrient application decisions based on the measured nutrient status of the soil and plants. Soil samples from both conventional and NBS sites are also being taken for carbon-emission analysis. A larger stakeholder meeting and demonstration is planned for September, featuring several field demonstrations such as soil profile descriptions and assessments of soil structure and vegetation on the trial field.

Building on the output from tasks 1.2 and 2.1 and using harmonised procedures (D1.4-D1.5), the hungarian team conducts a socio-economic and agronomic baseline assessment of the NBS site Szigetköz, Northwest Danubian Valley in Hungary, and describes important nutrient management related challenges on the site. On the experimental farm and beyond, the potential of selected NBS is explored through field trials, modelling approaches and invited expertise. The SZE carries out the design, scientific supervision and continuous monitoring of the field tests, while the PMA is responsible for the technical implementation of the tests.

Researchers from SZE, in collaboration with PMA staff, planned the design of the tests at the beginning of the project, and PMA carried out the soil preparation, planting, cultivation and harvesting on the NBS and non-NBS test areas (cf. Figure 4).

1. year		2. year		3. year	
NBS	CONVENTIONAL	NBS	CONVENTIONAL	NBS	CONVENTIONAL
Spring durum wheat	Spring durum wheat	Sorgum	Sorgum	Soya	Soya
Soya	Soya	Spring durum wheat	Spring durum wheat	Sorgum	Sorgum
Sorgum	Sorgum	Soya	Soya	Spring durum wheat	Spring durum wheat

Figure 4: Rotation scheme of durum wheat, sorghum and soya in Szigetköz, NW Danubian Valley, HU

The Hungarian NBS site is in Kimle in the Szigetköz. Experimentations of the NBS site are conducted in three replications comparing the NBS potentials with conventional intensive farming systems. The trial is conducted on a 20-ha land with a three-year rotation: durum wheat, sorghum and soya (Figure 4).

During the growing season in 2023, the trial was continuously monitored with soil, plant sampling and remote sensing techniques (Figure 5), helping to make the nutrient application decisions based on the measured nutrient status of the soil and plant. Soil samples from conventional and NBS sites were taken for carbon-emission analysis. After the harvest of the soya and sorghum, all the trial results were collected and the database was built for statistical analysis and evaluation, the results of the soil, plant samplings, drone monitoring, CO_2 measurements and yield results were evaluated. After the first year, we did not find significant differences between the conventional and NBS treatment results in the case of leaf, soil sampling and yield results. In the case of the evaluation of soybean pod size and number of beans, we found significant differences between the conventional and NBS treatments. The number and size of the pods were much better on the NBS site. The most significant differences between conventional and NBS treatments were in the case of CO_2 measurements. The CO_2 emission was higher on the conventional sites compared to the NBS sites. On the NBS site ploughing was skipped, so the soil was not disturbed, and its CO_2 emission was lower. In 2024 the crops were rotated. All the crops were sowed. Monitoring is continuing this year as well. This May and June are extremely rainy, so sometimes there were some delays in applications and in sampling.

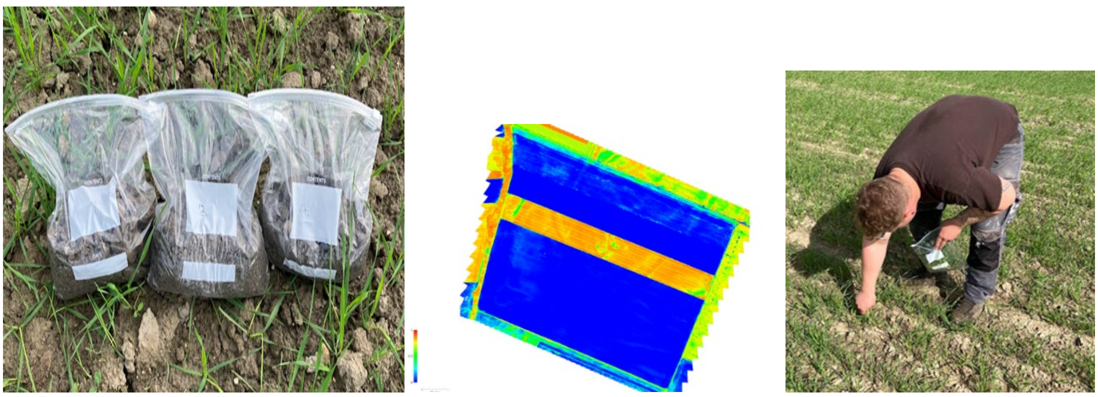

Figure 5: Soil sampling, remote sensing techniques, and plant sampling applied in Hungary

Furthermore, PKE has undertaken the task of monitoring biodiversity changes, with a particular focus on ornithological surveys in the Szigetköz region. Szigetköz (HUFH30004) is a Natura 2000 site of significant nature conservation importance, where the aim is to conduct bird observations as part of a baseline assessment and establish a methodical foundation for a monitoring system in selected areas. Following the initial baseline survey conducted in the first year, observations will continue for the next two years. Results of the first-year bird monitoring: in Szigetköz 206 bird species have been observed, representing 57% of the Hungarian avifauna. Among them, 166 species are protected, 19 are highly protected, and 21 species are not under any protection. 134 species are known to breed in the area. The avifauna of Szigetköz's forests shows similarities in species composition to those found in the mid-mountain forests; however, the population density is one and a half to two times higher. The coexistence of various habitat types allows the settlement of numerous rare and highly protected bird species (such as the black stork and white-tailed eagle). Among the riverine areas in Hungary, Szigetöz stands out with the highest number and diversity of bird species. During the 2023 survey in the Szigetköz sample area (located next to the trans4num experimental site), a total of 36 bird species were observed. Among these, 28 species were likely or breeding in the area, while the remaining species were occasional or regular foragers, but not nesting in the sample areas.

PKE is an environmental education organization with a field centre. It hosts a significant number of guests ranging from kindergarten to retirement age, but mainly school classes are visiting PKE. In this reporting period, PKE planned the inner and outdoor educational tools to present the trans4nums' NBS solutions and their necessity. More precisely, PKE designed 10 Mobil tools, named, ''NBS Help – Mobil Tools'', and presented their designs at the trans4num Online General Assembly on the 7th of March 2024. The construction of the tools is planned to be finalized in M23. PKE aims to use them in engagement events.

PKE has also organized two engagement events at the Szigetköz Experience Centre in Dunasziget, with 18 participants, including 10 farmers, on April 3, 2024, and 26 participants, including 14 farmers, on April 18, 2024. The events invited local farmers and expert scientists to participate in a program that included pre- and post-meeting data collection via questionnaires on attitudes towards NBS, a methodological primer on NBS, a brief project presentation, and an overview of the Kimle research area's durum wheat, sorghum, and soybean plots. The sessions featured discussions on sustainability, soil life, and farming methods integrated with NBS. The 26 participating farmers shared their practices and experiences with NBS, which were meticulously recorded for future work packages. The data and insights collected from the event minutes and questionnaires are currently being processed.

2.4 Report on the NBS sites in the United Kingdom

Field trials at the Rothamsted Research North Wyke site have faced challenges due to drought conditions following the sowing of spring wheat and oat plants in April 2023, and extreme over-winter rainfall after the sowing of winter wheat and oat plants in September 2023. While crop production for the spring crops was much lower than expected, a harvest was completed and processed. The winter crops largely failed due to field flooding during the winter of 2023-24, leading to the abandonment of those plots. New plots are planned for winter crops to be harvested in 2025 and 2026 at two new locations near the research site.

The Rothamsted Research Harpenden and Brooms Barns sites are running as planned, though they too have been affected by the very wet winter and spring of 2023-24. Late sowing of winter wheat to minimize Take-all and Blackgrass issues failed on the clay loam soil at Harpenden. Early October-sown winter wheat looks good, although disease control has been costly in damp spring conditions. Spring wheat, which replaced the late-sown winter wheat, struggled in the wet May weather. After six years of attempting late sowing of winter wheat, this technique will be discontinued due to the high risk of crop failure.

On the sandy loam soil at Broom's Barn, the wheat crops fared better in the wet conditions. At both sites, the oilseed rape harvest is just days away, marking the beginning of the most intense period of work, which includes harvesting, compost applications, cover crop sowing, and finally cash crop sowing.

The theory of planned behaviour is being used for quantitative social science analysis. Qualitative analysis will be conducted using ethnographic methods and semi-structured interviews, along with workshop activities at stakeholder engagement events. The first event was held in May 2024, featuring a tour of the trial site in Harpenden and afternoon workshop activities. An online event is scheduled for November 2024, with three in-person events and one online event planned for 2025. These events will focus on themes such as soil carbon/soil health, pests, weeds and diseases, compost management, and cover crops. Semi-structured interviews and ethnographic observations with farmers at their farms began in July 2024.

Rothamsted Research implements and tests NBS innovations at main sites in Harpenden and North Wyke. RRes staff worked with the wider consortia on D2.1 – providing detail on the UK-based NBS sites. Considerable effort has gone towards establishing and maintaining these trials. This includes:

1) A replicated block fertilizer trial was set up at the Rothamsted Research North Wyke site in April 2023 consisting of three crops – spring wheat, spring oats and a grass & clover ley. The wheat and oat plots were fertilized in three applications with the same total amount of nitrogen, phosphorus, potassium and sulphur from three different types of material; standard industrial fertilizers, a mixture of farmyard manure and standard fertilizers, and a mixture of novel bio-based fertilizer (Thallo) made from agricultural by-products and standard fertilizers. The standard fertilizers applied were Nitram, triple superphosphate, muriate of potash and kieserite. Both wheat and oats were fertilized with a total of 80 kg P_2O_5/ha, 65 kg K_2O/ha, 25 kg SO_3/ha and 160 kg N/ha for the oats and 180 kg N/ha for the wheat. A nil addition control was also incorporated into the trial. Each crop and fertilizer type were replicated five times in plots measuring 5m x 2m. Plant biomass production was assessed in early September 2023 when the grain was mature. The grass and clover plots were not fertilized (as per standard practice) to allow the clover to establish. A prolonged dry period resulted in poor plant growth, with a subsequent influx of weed plant species. The plots were re-established in autumn 2023 but it is too soon for any conclusive results due to the unusual weather patterns in these years.

2) Between 01.12.2022 – 31-05.2024, RRes managed the UK-based LSRE, which is composed of four management factors—phased rotations, cultivation (conventional vs reduced tillage), nutrition (additional organic amendment vs standard mineral fertilization) and crop protection (conventional vs smart crop protection). Through precise farm management, these factors are combined in a balanced design resulting in 24 emergent cropping systems at each

site (Harpenden, Hertfordshire, UK and Brooms Barn, Suffolk, UK). We are observing interactions between management factors and the environment on crop yields. Of particular interest is the fate of organic sources of nitrogen (living and dead mulch) and the opportunities to reduce mineral fertilisers. This will be the focus of work over the next 6-12 months.

Initial results from the Large-Scale Rotation Experiment show there was a significant cropping system effect on the annual system calorific yield ($p<0.001$) (Figure 6). The amended and standard plots for a given rotation × cultivation × crop protection system were always found together suggesting this factor has yet to play a big role in differentiating system productivity. However, in only one case was the standard system (no organic amendment) more productive than the amended plot. There was an indication that reduced tillage and smart crop protection had a detrimental effect on productivity; the most productive systems of the 3- and 5-year rotations were all ploughed with conventional crop protection. The frequency of Oil Seed Rape crop failures was likely important in determining the ranking of systems; as Oil Seed Rape represents a higher proportion of total production in the 3-year system, any failures will have a disproportionate effect in those systems (the four least productive systems were all in the 3-year rotation).

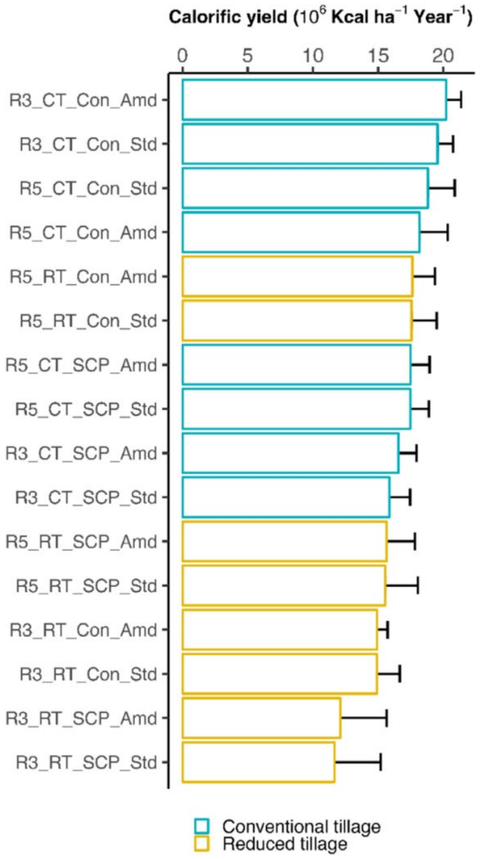

Figure 6: Calorific yield of different cropping systems. Data included were from the 3-year (R3) and 5-year (R5) rotations at both sites in 2020–2021.

CT conventional tillage, RT reduced tillage, Con conventional crop protection, SCP smart crop protection, Amd standard fertilization plus amendment with additional organic materials, Std standard fertilization.

RRes also piloted stakeholder engagement with 40 farmers during a 'Research Insight' day at the North Wyke trial site on June 14, 2023. This event included a presentation on the trans4num project by Dr Rob Dunn and a visit to the field site to discuss the NBS approach and treatments. Attendees included local farmers, NGO staff (e.g., Environment Agency), and agronomists (Table 1).

Table 1: A summary of the attendees of the stakeholder event on 14.06.2023

Stakeholder Type	Number	Specific Organisations
Advisor	5	Westcountry Rivers Trust, Farm Carbon Toolkit,
Farmer	28	
Commercial Director	1	Agriton
Agronomist	1	Mole Valley Farmers
Government Agency	1	Environment Agency
Farming Association	1	NFU
Grand Total	**37**	

From July 2023 to May 2024, RRes has been expanding on D1.2 in preparation for D1.4. They have initiated collaborative discussions across the consortium, including online workshops in September 2023, to develop a more specific manual applicable to each NBS site. Further engagement events included another ‘Research Insight’ day at North Wyke on January 18, 2024 (Table 2), focusing on effective language for stakeholder engagement, and a third event at Harpenden using the Large-Scale Rotation Experiment on May 24, 2024, involving 12 stakeholders like farm advisors, farmers, journalists and researchers. This latter event piloted activities designed for implementation at all NBS sites. Results from these activities are still pending.

Table 2: A summary of the attendees of the stakeholder event on 18.01.24

Stakeholder Type	Number	Specific Organisations
Farm Advisor	2	
Farmer	4	
Journalist	1	
Researcher	5	
Grand Total	**12**	

2.5 Report on the NBS sites in China

The trans4num-CN team carried out extensive research across the North China Plain, Southwest China, and Northeast China, targeting key agricultural challenges to meet project objectives. The experiments focused on studying the impact of straw return, the introduction of leguminous crops, and the optimal combination of organic and inorganic fertilizers on various factors, such as crop yield, nitrogen uptake, photosynthetic traits, root structure, and soil properties. The following section presents activities conducted at three Nature-Based Solutions (NBS) sites:

North China Plain:

The project aimed to tackle critical issues such as decreasing soil organic matter, deteriorating soil properties, and inefficient grain and soybean rotation practices. The focus was on developing a sustainable high-yield and high-efficiency grain and soybean production system. This involved analyzing mechanisms for efficient resource utilization and soil fertility enhancement. Key agronomic control techniques were identified to promote sustainable crop rotation, integrating biotechnology, light, and simplified farming management practices. The team developed and demonstrated 2-3 key technologies for improving grain and soybean rotation systems, along with a comprehensive regional integration technology system. These technologies were applied across 2,000 hectares, resulting in an average yield increase of 10% and a 10% reduction in fertilizer use.

A long-term field trial commenced in 2023 in Zhalantun City, Inner Mongolia Autonomous Region, comparing five farming methods: no tillage with rotation cropping, deep loosening biennially with rotation cropping, ploughing with rotation cropping, rotary tillage with rotation cropping, and rotary tillage with continuous cropping. Soybean yields under these treatments are projected to range from 3.1 to 3.6 t/ha. This comparison has led to the development and integration of simplified soybean production technologies tailored for Northeast China.

Southwest China:

In Chongqing City, a field experiment on 'Partial Organic Substitution for Chemical Fertilizer' was initiated (Figure 7).

Figure 7: Field experiment on 'Partial Organic Substitution for Chemical Fertilizer' in Southwest China

The region's purple soil, characterized by 88% sand, 5% silt, and 7% clay, supports a chili-cabbage rotation system. The experiment evaluated the effects of different treatments, including organic waste applications like biochar, chicken manure, kitchen waste, and straw, on soil aggregate stability and carbon dynamics.

Preliminary results from 2023 revealed that partial organic substitution (POS) improved aggregate organic carbon stability (AOCS), particularly with biochar, which significantly increased organic carbon content across soil aggregates. Biochar showed marked improvements in aggregate stability, soil organic carbon (SOC), and recalcitrant carbon content compared to straw, which had a lesser impact due to increased microbial respiration and carbon degradation. These findings underscore the potential of biochar to enhance AOCS under sustainable nutrient management practices.

Northeast China:

In response to the low utilization of straw resources and poor soil fertility in the Huang-Huai-Hai region, the team developed a straw-dominated crop-mushroom rotation system (Figure 8). This innovative approach led to substantial improvements in crop yields and soil health, with wheat yields increasing by 23.5%, soil organic matter by over 60%, and available nutrients by over 40%. The system also drastically reduced weed populations by over 90%, providing significant economic benefits of up to 18,000 Euros per hectare.

Figure 8: Straw-dominated crop-mushroom rotation system in Northeast China

The team also focused on optimizing mushroom cultivation and residue utilization technologies. By experimenting with different straw inputs and mushroom inoculation rates, the team identified an optimal setup of 9 tons of straw and 200 kg of inoculant per 667 m², which maximized yield and quality. To support this system, a specialized material-spreading machine was developed and deployed.

3. Summary- implications and outlook

The trans4num project aims to develop and test innovative NBS for sustainable nutrient management in agriculture across Denmark, Hungary, the Netherlands, and the UK. This first report (D2.2) focuses on the implementation and evaluation of NBS in these countries, detailing experimental approaches and stakeholder engagement.

Initial results show promising benefits, such as improved nutrient balances, reduced nitrogen loss, and enhanced soil health and that active participation from farmers and other stakeholders is crucial for the project's success, with ongoing workshops and interviews to gather insights and foster collaboration.

The implementation of NBS in the trans4num project has encountered several challenges and opportunities. First, the diversity of the four NBS sites and innovations in the trans4num project present both opportunities and challenges. Some of the implications and some strategies are:

1. **Tailored solutions**: Each site requires solutions tailored to its specific environmental, economic, and social conditions. This diversity can lead to a rich variety of successful practices that can be adapted to other regions.
2. **Knowledge sharing**: The diverse experiences and outcomes from different sites can provide valuable insights and lessons that can be shared across the project and beyond.
3. **Scalability**: Successful implementation in diverse settings can demonstrate the scalability and adaptability of NBS, encouraging broader adoption.

Overcoming challenges

1. **Customized approaches**:
    - Site-Specific research: Conduct thorough research to understand the unique conditions and needs of each site. This includes soil health, climate, local biodiversity, and socio-economic factors.
2. **Stakeholder engagement**:
    - **Local involvement**: Engage local stakeholders, including farmers, community members, and local authorities, in the planning and implementation process. Their local knowledge and buy-in are crucial for success.
    - **Capacity building**: Provide training and resources to stakeholders to build their capacity to implement and maintain NBS.
3. **Knowledge exchange**:
    - **Workshops and seminars**: Organize regular workshops/seminars to facilitate knowledge exchange between different sites. This can help share best practices and innovative solutions.
    - **Documentation and dissemination**: Document the processes, challenges, and successes at each site and disseminate this information through reports, publications, and online platforms.
4. **Policy support**:
    - **Advocacy**: Advocate for supportive policies and regulations that facilitate the implementation of NBS. This includes financial incentives, technical support, and regulatory frameworks that encourage sustainable practices.
    - **Collaboration with policymakers**: Work closely with policymakers to ensure that the lessons learned from the project are integrated into broader agricultural and environmental policies.

Other challenges relate to:

1. **Stakeholder engagement**: Ensuring active and continuous participation from farmers and other stakeholders can be difficult. Their involvement is crucial for the success of the project, but it requires significant effort to maintain their interest and cooperation.
2. **Economic viability**: While NBS can offer long-term economic benefits, the initial costs and changes in farming practices can be a barrier for some farmers. Convincing them to invest in these solutions requires demonstrating clear, short-term economic gains.
3. **Technical challenges**: Implementing NBS involves complex technical processes that need to be tailored to specific local conditions. This requires extensive research and adaptation, which can be time-consuming and resource-intensive.
4. **Policy and regulatory support**: The success of NBS also depends on supportive policies and regulations. Navigating the existing regulatory frameworks and advocating for necessary changes can be challenging.
5. **Monitoring and evaluation**: Continuous monitoring and evaluation are essential to assess the effectiveness of NBS. This requires robust data collection and analysis systems, which can be challenging to establish and maintain.

Despite these challenges, the project is making progress and showing promising results. By addressing these challenges through a combination of tailored approaches, stakeholder engagement, knowledge exchange, and policy support, the trans4num project can effectively leverage the diversity of its NBS sites to achieve sustainable and scalable outcomes.

The project highlights the potential of NBS to transform intensive agriculture into more sustainable practices, contributing to climate resilience and environmental protection.

Future research is related to continued monitoring and evaluation which are essential to refine NBS practices and ensure their scalability and effectiveness. Another essential element will be the engagement with policymakers while regulators are necessary to create supportive frameworks for large-scale implementation of NBS.

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