



HuMUS

Healthy Municipal Soils

Overview of best practices
in sustainable soil manage-
ment and soil health promo-
tion

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Executive Summary

Soil health depends on soil management. This deliverable provides an overview of stakeholder perspectives on soil management practices, including their current and possible acceptance and estimated potential. A dynamic questionnaire on perspectives of several stakeholder groups (farmers and foresters, agricultural and forestal advisors, researchers, policymakers, non-governmental organisations) on soil health and associated soil management practices was distributed in 10 countries, receiving 154 answers. The most-mentioned challenges for maintaining soil health were **(1) Improve soil structure, (2) Maintain/increase Soil Organic Carbon, (3) Enhance nutrient use efficiency, (4) Enhance water storage capacity, (5) Enhance soil biodiversity, and (6) Avoid soil erosion**. Deviating perspectives between stakeholders could be explained by their different focus (e.g., practical, societal). The challenge of soil contamination was perceived as less important in northern countries than it was in southern and eastern countries.

In a second step, a set of soil management practices (SMPs) was evaluated for their effectiveness in addressing certain soil challenges and for their general feasibility. The SMPs with the highest multifunctionality (effectiveness against several important soil challenges) were **(1) Permanent soil cover, (2) Cover/catch crops, (3) Use of organic fertilisers, (4) Diversifying crop rotations, and (5) Including leguminous pastures in crop rotations**. The perspective on their feasibility was positive: While two of these SMPs (2, 3) were assessed as easily feasible by more than half of the participants (also amongst farmers), all others (1, 4, 5) were perceived as at least moderately feasible by 80 % of respondents.

When asked for their needs to implement further SMPs on their farm or in their region, farmers most often mentioned missing knowledge, while non-farmers demanded providence of machinery. Regarding municipal support, both groups preferred the provision of infrastructure (cooperatives, processing units, service providers, etc.) over regional governance actions (e.g., regional/municipal management agreements). Regarding policy measures, subsidies stay the most valued option.

Amongst the most important soil challenges, production-oriented and society-oriented ones could be found. As the challenges were strongly interrelated and often concerned similar functions of the soil, soil management practices can address both production- and society-related challenges. This is of importance when communicating soil health challenges and respective management strategies, as it is likely to increase acceptance among stakeholders: Productivity-oriented soil improvements may also impact societal functions, and vice versa.

The study linked perspectives on a wide range of soil health challenges with partly un-specific groups of soil management practices, thus, results should be handled with care. However, most of the drawn links between soil challenges and associated SMPs are supported by literature. Cover/catch cropping and the use of organic fertilisers were perceived as very effective and easily feasible and should be central when developing strategies for improving soil health—these two practices are already strongly recommended by EU and national legislation. Organic farming relies on three of the five most multifunctional SMPs (3, 4, 5); its implementation can therefore be seen as a contribution to soil

health overall (even though not all aspects are positive for all soil challenges). These practices are, however, not limited to organic farming, and their implementation in conventional farming should as well be further supported.

Other categories, such as maintaining a permanent soil cover, are relevant to a wide set of farm operations and are more a vision than a realistic management practice, indicated by a comparably low feasibility.

Apart from increasing nutrient efficiency (EU nitrate directive) and avoiding soil erosion (CAP conditionality), the other main soil challenges have by now not been addressed by the EU (although all of them are mentioned in the Soil Monitoring Directive under progress). However, most of the SMPs suitable to react on those challenges are addressed by the CAP. Future legislative approaches addressing soil health should therefore try to strengthen and disseminate existing and easily applicable practices, also by including knowledge transfer.

List of abbreviations

EU	European Union
GMO	Genetically modified organisms
NGO(s)	Non-Governmental Organisation(s)
SOC	Soil Organic Carbon
SMP	Soil Management Practice

1 Introduction

1.1 Soil health in current European policy¹

Soil health has been recognised as the fundament of the transition towards a sustainable and resilient agricultural production system. Beyond agricultural productivity, soil health embraces the integrity of soil ecosystem services (Lehmann et al., 2020). However, a growing body of recent literature highlights that soils are—at a global scale—experiencing soil degradation (Montgomery, 2023). The resulting decline in soil health has far-reaching consequences for the environment and human well-being.

The primary drivers behind the deterioration of soil health can be attributed predominantly to human activities, particularly related to urbanisation, land-use changes, and agricultural practices (Montgomery, 2023). Právělie (2021) found the main degradation pathways to be aridity, land erosion by water, salinization, soil organic carbon (SOC) loss, and vegetation degradation—most of them of anthropogenic origin.

Decades of unsustainable land management have led to the current situation that the majority of European soils are in an unhealthy state (European Commission. Directorate General for Research and Innovation., 2020). Although various policies regulate aspects of soil health directly and indirectly, a comprehensive legal instrument for soil protection is still missing in the European Union (EU) (Buratti-Donham et al., 2024, Heuser, 2022). Recently, efforts have been made to strengthen soil health policy at the European level by introducing the EU Soil Strategy and related legal changes (e.g., the Soil Monitoring Directive) (European Commission, 2021, 2023).

1.2 Soil health and soil management practices

Soil health is critically influenced by soil management; approaches for sustainable soil management are therefore at the core of the Common Agricultural Policy and of current EU strategies (EU Science Hub, 2023). However, maintaining soil health is not limited to these agricultural or forestal approaches, as it must also rely on governmental and policy action, e.g., regarding pollution, nutrient cycling, or soil sealing. These policy aspects are addressed in the HuMUS project in deliverable D1.4 (“Compendium of soil health policies in selected partner countries”).

As agricultural and forest soils cover the greatest area of the European Union and can be addressed most directly via the Common Agricultural Policy, the focus of this deliverable lies on these soils. Management practices, involved stakeholders, and legislation would have been fundamentally different for other soil types.

Agricultural and forest soil management practices are very diverse: they address mechanical work (e.g., machine weights and traffic, tillage), cropping (e.g., selection and diversity of species on the field and over time, soil cover), fertilisation and irrigation practices, amongst others. The sustainability of a combination of these management practice dimensions cannot be evaluated generally but must be suitable for the site- and farm-specific requirements. Single management practices can be grouped (e.g., conservation tillage, containing all practices that do not use ploughing but still practice tillage), and there have been various studies evaluating their effect on single soil health parameters.

1.3 Soil management practices and social sciences

For reaching the EU's goal of strengthening the transition towards healthy soils (Directorate-General for Agriculture and Rural Development [DG AGRI], 2023), approaches are needed not only from the life sciences—raising people's awareness for soil health issues is crucial for long-term embedding in society and policy. The European Commission has recognised this by focusing the research and innovation programme within the Soil Mission (which also funded the HuMUS project) on social sciences. Current efforts on soil health policies are valuable and should lead to a profound and effective integration of soil protection into European legislation. To enhance the efficiency of their implementation, it is important how different groups of stakeholders look at soil health, its related needs, and solutions. Differing assessments of the importance of a soil threat or of the effectiveness of a management method necessitates exchange between stakeholder groups, and stakeholders sharing some priorities could join forces. This deliverable does not add to the diversity of sustainability evaluations of different soil management practices, rather, it focuses on the perspective of the affected stakeholder groups.

Therefore, the core of this deliverable is the data from a questionnaire where different types of stakeholders were asked for their opinion on the most important soil challenges in their region and related soil management practices to address these challenges. These perspectives could be helpful to get a more differentiated, stakeholder-specific view on management practices, including their current and possible acceptance and estimated potential. **This study should therefore not be interpreted as an expert review on the mentioned topics but as a contribution for estimating the acceptance and integration of measures strengthening specific soil management practices.**

2 Methodology of the questionnaire

2.1 Structure and content

The Chamber of Agriculture North-Rhine Westphalia (LWK NRW) and the University of Gastronomic Sciences, Pollenzo (UNISG) developed a combined online questionnaire for deliverables D1.4 and D1.5 on soil health policies and management practices, respectively, to avoid stakeholder fatigue of the various experts to be contacted during the project. Soil challenges and soil management practices (SMPs) had already been addressed in a survey conducted within the project “EJP Soil”. Whereas this former survey focused on the perspective of researchers (Paz et al., 2023), the herein presented questionnaire was targeting a broader group of stakeholders (farmers and foresters, agricultural and forestal advisors, policymakers, researchers, NGOs). However, the overall study design of Paz et al. (2023) was considered suitable and adopted accordingly. Corresponding questions were adapted to a more diverse group of stakeholders. Furthermore, additional questions focusing on farmers and a part on related policies were added. For forest soils, the discussed SMPs differed from those for agricultural soils; they were sourced from United States Department of Agriculture (2021) and supplemented with additional practices. The structure and all contents of the questionnaire that will be outlined shortly in this section can be found in Annex A.

The first part of the survey contained personal and demographic information about the participants, such as education, stakeholder group, working country, and work experience. Stakeholders identified as farmers and foresters or agricultural and forestal advisors were asked for more specific information about farm specialisation and size of their own or their clients' farms.

The opening question of the following section (Q11) dealt with the main three soil challenges of stakeholders' regions that could be selected from a list of eleven. The identified main soil challenges were central for the later, personalised questions. For farmers, foresters, and advisors, the following block of questions (Q12-Q19) first asked for existing, then for further possible soil health management practices on farm. For both groups, questions then enquired about already existing or additionally required support on several levels.

A list of soil management practices (adopted from Paz et al., 2023, as described above) was provided, and their effectiveness against each of three previously identified, regionally most important soil challenges was assessed in a three-step categorical manner: not effective, moderately effective, very effective. All soil management practices that were assessed as at least moderately effective in handling a soil challenge were transferred to the subsequent question, asking for an estimation of its feasibility (not feasible, moderately feasible, easily feasible). The selection of soil management practices to be assessed was different for stakeholders associated with either agricultural or forest soils.

The concluding part of the questionnaire asked for further implications on policy improvements, the use of participatory processes in soil health management, and further known actors in the field of soil health (network-building, distribution of the questionnaire).

2.2 Implementation and dissemination

The questionnaire was built with the online tool Qualtrics™ XM (Qualtrics, Provo, USA). It was designed in a branch structure, so depending on the stakeholder group, specific questions were excluded. This structure is also depicted in Annex A. All questions were

translated to the languages of the project partners (Albanian, Bulgarian, German, French, Italian, Macedonian, Dutch, Serbian, Slovenian, and Spanish) by auto-translate and a subsequent correction in a collaborative process with the respective partner organisations.

The questionnaire was open between 7 July 2023 and 19 September 2023. The HuMUS project partners were asked to disseminate the questionnaire amongst their regional stakeholders, aiming at 5 participants per group (farmer and forester, agricultural or /for-estal advisor, policymaker, researcher, NGO) and region. As dissemination was delayed in some countries due to the summer break, the planned answering time of two months was exceeded slightly.

Project partners were asked to select the contacted stakeholders based on the following criteria (Table 1):

Table 1: Criteria for selecting participants for the online questionnaire.

Stakeholders	Description
Farmers	<ul style="list-style-type: none"> • at least 5 years of experience in organic and/or biodynamic agriculture and/or agroecological practices, or: • at least 5 years of experience in conventional farming practicing regenerative agriculture
Foresters	<ul style="list-style-type: none"> • manager of public forest, • or of a farm's forest area used for wood production
Advisors	<ul style="list-style-type: none"> • at least 3 years of experience/information support related to soil health, organic agriculture, agroecological transition, or related topics
Policymakers	<ul style="list-style-type: none"> • at least 3 years of experience related to soil health at the regional level, organic agriculture, agroecological transition, or related topics
Researchers	<ul style="list-style-type: none"> • at least 3 years of experience in research related to natural science
NGOs	<ul style="list-style-type: none"> • at least 3 years of experience in work with stakeholders that use organic agriculture or conventional farmers with practices of regenerative agriculture

2.3 Data management and evaluation

Data management was prepared online using the built-in Qualtrics tool, and data was cleaned using Microsoft Excel 2016 (Microsoft Corporation, 2016). The clean evaluation sheet was imported into R (RStudio Team, 2022), where all subsequent graphical evaluations were processed.

As there were very few answers from foresters, not all questions could be evaluated, especially questions 22 and 23 (see Chapter 8.1) were not valid for evaluation. North Macedonia partners received many answers, including some from neighbouring Balkan countries. As those were too few to evaluate them by country, they are grouped as "North Macedonia & other Balkan countries".

3 Results

3.1 Characterisation of participants

We received 154 complete answers from ten countries and 430 total answer attempts. While the number of participants was quite equal between farmers/foresters, advisors, policymakers and researchers (30-40 each), only ten NGOs had answered the questionnaire. No region was able to fulfil a complete set of participants (five in each of the five stakeholder groups), but every region had several groups with at least five participants. Table 2 shows the distribution of participants.

Table 2: Participants of the soil health questionnaire, characterized by stakeholder and county.

	France	North Macedonia & other Balkan countries	Italy	Germany	The Netherlands	Slovenia	Bulgaria	Spain	Total (per stakeholder)
farmer/forester	4	4	9	9	2	5	4	1	38
agricultural/forestal advisor	12	13	3	7	1	1	2	2	41
policy making/ administration	3	7	4	3	4	2	5	2	30
researcher	1	10	6	6	4	2	2	4	35
NGO	0	2	1	2	1	0	4	0	10
Total (per country)	20	36	23	27	12	10	17	9	154

Most of the participating farmers were experienced; 47 % had more than 30 years of working experience, while no participating farmer had worked less than 5 years. Similarly, a significant proportion of researchers (40 %) had more than 30 years of work experience, while only 6 % had less than 5. In the case of advisors and policymakers, most had 10-30 years of working experience.

A quarter of the farmers were either arable farmers or fruit growers, followed by horticulture and dairy farming. Most of the fruit growers were located in South Tyrol (Italy). Farm size varied from less than one hectare to 260 hectares, when including foresters up to 10,000 hectares. About half of the farms were under organic management. Due to the diversity of agricultural production, no apparent relationship was detected between the type of production, farm management (organic or conventional), and farm size.

Most of the advisors were not especially focused on organic farms; production focus of their clients was arable farming (57 %), followed by dairy farming, horticulture, and fruit growing.

3.2 Perspectives on soil challenges

Out of a set of 11, each participant was asked to select the three most important challenges for improving soil health in their region (see Table 3). These challenges were adopted from Paz et al. (2023), being aware of the fact that they were partly overlapping and interconnected in their effects. For further evaluation, the selection of three challenges was not treated as a ranking but as an equivalent selection of 3 out of 11. As challenges and associated soil management practices for forest soils fundamentally differ from those for agricultural soils, they were evaluated separately (see chapter 3.8).

Table 3: List of soil challenges for improving soil health. Each participant was asked to select the three most important ones for their region.

Code	Soil Challenge
1	Maintain/increase Soil Organic Carbon (SOC)
2	Avoid N₂O and CH₄ emissions from soils
3	Avoid peat degradation
4	Avoid soil erosion
5	Avoid salinisation and alkalinisation
6	Avoid acidification
7	Avoid contamination
8	Improve soil structure
9	Enhance soil biodiversity
10	Enhance soil nutrient use efficiency
11	Enhance water storage capacity

Across all regions and stakeholders, six challenges were the most mentioned:

- (1) **Improve soil structure**
- (2) **Maintain/increase Soil Organic Carbon**
- (3) **Enhance nutrient use efficiency**
- (4) **Enhance water storage capacity**
- (5) **Enhance soil biodiversity**
- (6) **Avoid soil erosion.**

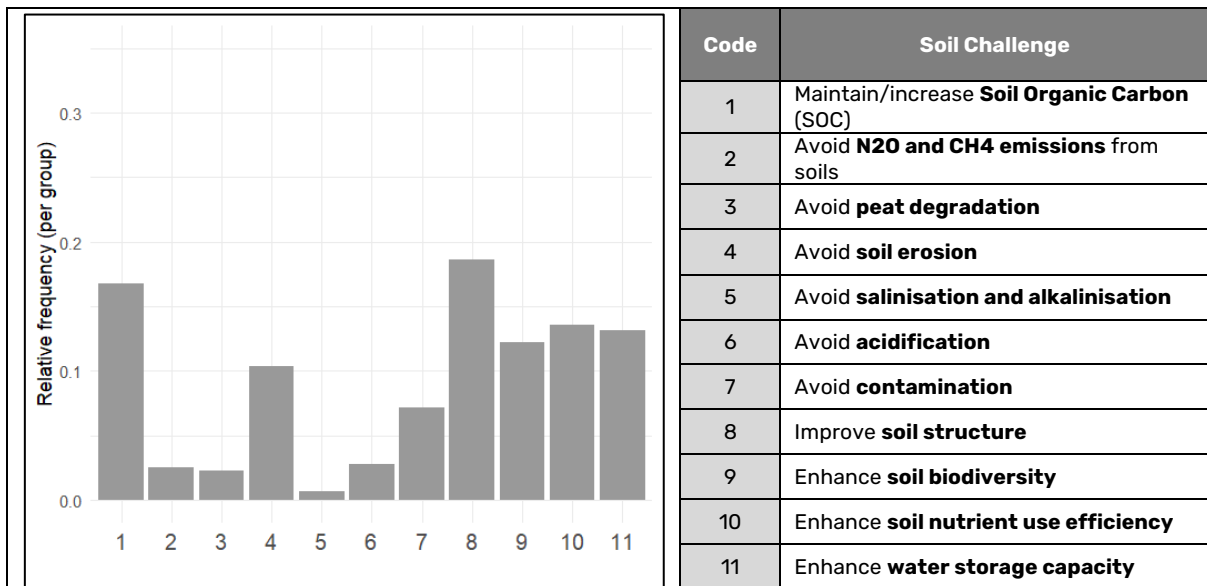


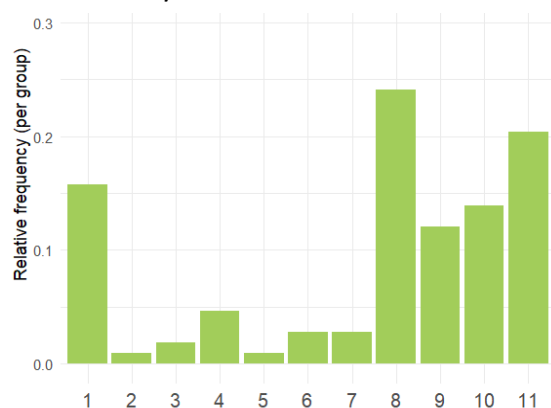
Figure 1: Relative frequency of votes per soil challenge (1-11) as an overview across all countries and stakeholders (except foresters) (n = 147)

When comparing different stakeholder groups, differences between more practical (farmers, agricultural advisors) and more abstractly thinking stakeholders (policymakers, researchers and NGOs) arise. **Soil contamination** especially is rated higher in the latter group. Moreover, policymakers and NGOs voted more often for challenges with societal impact, such as **erosion, peat degradation**, and less often for productivity-associated challenges such as soil structure, nutrient use efficiency, or water storage capacity. For an exemplary comparison of the two stakeholder groups, see Figure 2; a complete overview on the challenge mentions by stakeholder and/or country can be found in Annex B.

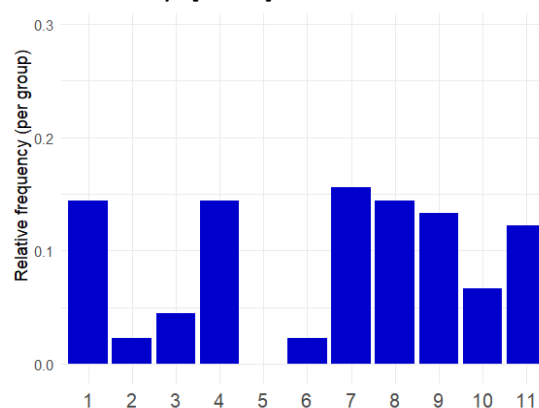
Between countries, systematic differences are visible: While participants from northern countries (Germany, The Netherlands, France) rarely mentioned **soil contamination**, in Italy and Spain it was more frequently selected, and in Slovenia, Bulgaria, and North Macedonia it was one of the most mentioned challenges. Most of the mentions of peat degradation came from the Netherlands.

There are differences in the weighing amongst the identified six most important soil challenges across all countries, however, their selection holds true for all countries when ignoring the country-specific importance of soil contamination. In Italy and Bulgaria, **soil biology** was one of the highest-rated challenges, while it was one of the least in Germany. **Maintaining/increasing SOC** was assessed most important in Germany, Italy, and Spain. In France, **enhancing water use efficiency** received most votes, while **avoiding erosion** did so in Bulgaria. In all other countries, improving **soil structure** was mentioned most often. (See Annex B)

Main activity: **farmer or forester**



Main activity: **policy maker**



Code	Soil Challenge
1	Maintain/increase Soil Organic Carbon (SOC)
2	Avoid N2O and CH4 emissions from soils
3	Avoid peat degradation
4	Avoid soil erosion
5	Avoid salinisation and alkalinisation
6	Avoid acidification

Code	Soil Challenge
7	Avoid contamination
8	Improve soil structure
9	Enhance soil biodiversity
10	Enhance soil nutrient use efficiency
11	Enhance water storage capacity

Figure 2: Relative frequency of mentions per soil challenge (1-11, see Table 3 for a legend), as selected by farmers (left, n = 36) and policymakers (right, n = 30)

3.3 Best associated soil management practices (SMPs)

In a second step, participants were asked to evaluate the effectiveness of a predefined set of soil management practices (SMPs) (for a complete list see Table A 4 in Annex D) in addressing the previously selected 3 most relevant soil challenges in their respective regions. Participants could assign the categories “Not effective” (0), “Moderately effective” (1), and “Very effective” (2) for each combination of SMP and soil challenge. The data was evaluated to build a set of SMPs being most effective for a selected challenge. For the six most important soil challenges (see chapter 3.2), these sets are displayed in Figure 3. As our aim was to identify versatile SMPs, we only included SMPs that were ranked at least twice amongst the ten most effective practices (identified for each soil challenge).

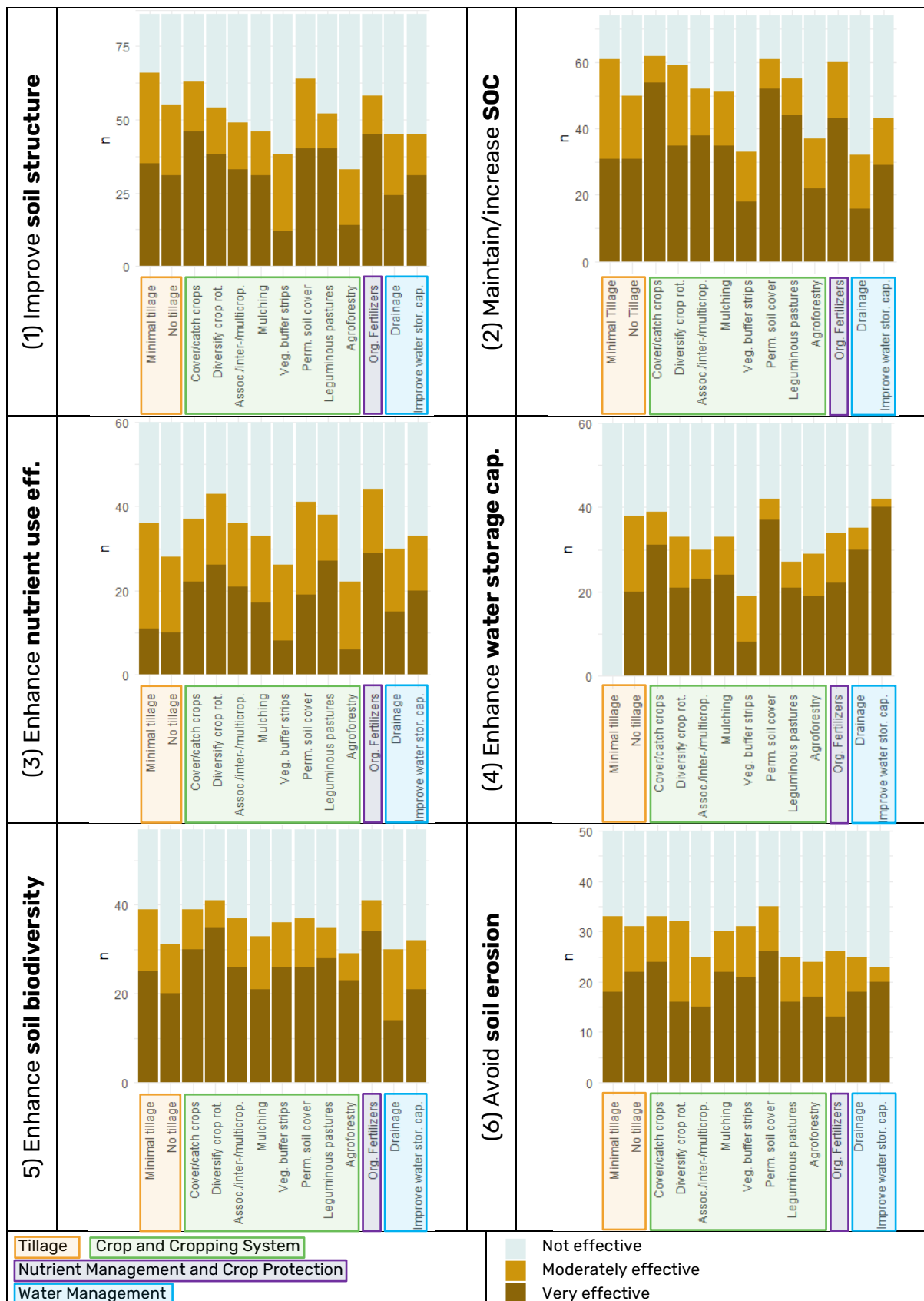


Figure 3: Selection of soil management practices (SMPs) assessed effective in addressing a specific soil challenge. Only soil management practices that were mentioned at least twice amongst the top ten of these six most important challenges were included in these graphs. SMPs were grouped and colour coded. The sample size (n) varies because every participant only evaluated the chosen three most important challenges. A table with rank sums can be found in Annex D.

3.4 Impact and multifunctionality of selected soil management practices

All soil management practices were ranked according to an impact index calculated according to the formula depicted in Figure 4. In brief, each vote assessing an SMP as “moderately effective” was counted once, whereas each vote assessing an SMP as “very effective” was counted twice. For the overall impact index of a certain SMP, the votes over all challenges were summarized.

$$Impact_{agroforestry} = \sum_{i=Challenge\ 1}^{Challenge\ 11} (n\ (not\ effective)_{agroforestry \cap i} \times 0 + n\ (moderately\ effective)_{agroforestry \cap i} \times 1 + n\ (very\ effective)_{agroforestry \cap i} \times 2)$$

Figure 4: Calculation of the impact index per soil management practice. The votes were included irrespective of which challenge they referred to.

Based on this artificial index incorporating importance (number of votes) and effectiveness of a SMP against all soil challenges, we selected five SMPs to describe more thoroughly in fact sheets (see Annex E): **(1) Permanent soil cover, (2) Cover/catch crops, (3) Use of organic fertilisers, (4) Diversifying crop rotations, and (5) Including leguminous pastures in crop rotations.** This selection would have been the same when only concentrating on the six selected challenge of highest overall importance. A detailed ranking of all SMPs can be found in Table A 1 of Annex C. For the six most important soil challenges, a challenge-wise effectiveness ranking is displayed in Table A 3 of Annex D.

3.5 Perspectives on feasibility of SMPs

Subsequently, for each practice that was assessed effective by the participant, its feasibility was enquired on a three-step scale (not feasible, moderately feasible, easily feasible). A complete overview on feasibility rating across all stakeholders is provided in Figure 5. Apart from terrace farming, which requires fundamental changes in land cultivation and landscape design, many SMPs were assessed as at least moderately feasible by more than 80% of participants. Among the five most effective and multifunctional ones (highlighted, see chapter 3.4), two were assessed as easily feasible by more than half of the participants (**Cover/catch crops, Use of organic fertilisers**).

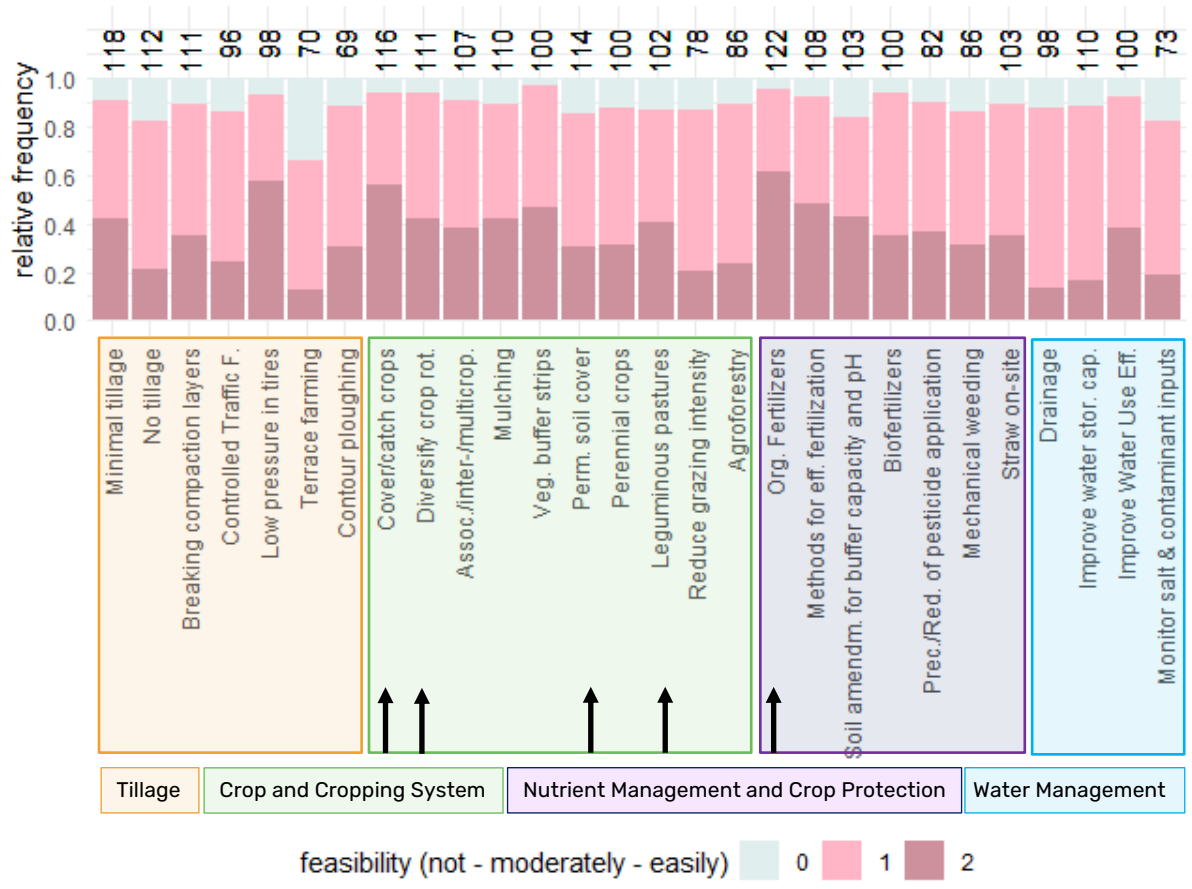


Figure 5: General perspective of all stakeholders on the feasibility of the chosen effective soil management practices. The SMPs were categorised (colours); the top five practices from chapter 3.4 are highlighted with arrows. Because not all methods were assessed as effective beforehand, the number of assessments (above the bars) varies.

Does this assessment hold true for all stakeholder groups? Figure 6 shows the perspective of the different stakeholder groups on the 13 most effective SMPs presented in Chapter 3.3. The views on at least moderate feasibility stayed similar, with agricultural advisors and NGOs being most pessimistic regarding feasibility. Ratings for easily feasible were most similar for farmers and researchers, with both having a higher proportion of easily feasible in their ratings compared to other stakeholders. Farmers attributed a high feasibility especially to organic fertilisation and cover/catch cropping.



Figure 6: Stakeholder-specific assessment of feasibility of the 13 soil management practices (SMPs) considered most effective. The SMPs are in alphabetical order. Numbers above the bars indicate the number of assessments (n).

3.6 Established soil management practices on farm/in the region

We asked farmers about management practices related to soil health that are already established on their farm. This question was included in the questionnaire before asking to assess the SMPs as described in chapters 3.3 to 3.5 to avoid suggestive bias. If possible, the resulting free-text answers were assigned to the SMPs presented in chapter 3.4. In case the answers would not fit any of the pre-defined SMPs, they were introduced as new management practice.

In parallel, we asked all non-farmer stakeholders for management practices related to soil health they consider already established in their specific region. As results were similar amongst advisors, policymakers, and researchers, and NGO responses were too few for a separate evaluation, we decided to evaluate them as a group of “non-farmers” for this question.

Farmers were answering this question extensively; we received about 3 answers per participant, while for non-farmers the average was 2 answers per participant.

The farmers’ individual answers were attributed to the SMP categories described in chapter 3.3, new SMP categories were set up where necessary. The most-mentioned categories attributed to management practices that farmers already apply are displayed in Table 4. The mentions per SMP were quite low because of the diversity of answers—farmers mentioned 34 SMPs established on their farms, non-farmers 41 SMPs established in their region.

Table 4: Selection of the 10 most-mentioned categories of established SMPs on farm (farmers) and in the region (non-farmers), respectively. SMPs appearing in both selections are coloured. The number of mentions is displayed in brackets. As multiple SMPs would have entered the last place on the non-farmers’ list, they were excluded.

Farmers— established SMPs on-farm (n)	Non-farmers— established SMPs in the region (n)
Use of organic fertilisers (10)	Use of organic fertilisers (31)
Precision/reduction of pesticide application (9)	Non-inversion/Reduced tillage (25)
Cover/catch crops (8)	Cover/catch crops (24)
Non-inversion/Reduced tillage (7)	Permanent soil cover (20)
Associations/intercropping/multicropping (7)	Diversifying crop rotations (18)
Hedges/ agroforestry (6)	Methods for efficient fertilisation (12)
Diversifying crop rotations (5)	No till/Direct seeding (10)
Self-composting, vermiculture (5)	Soil analyses (7)
Extensification measures (5)	Leave straw on-site (6)
Organic farming (4)	

3.7 Further possible soil management practices on farm or in the region

After asking for already established soil management practices, stakeholders were asked for further possible management practices on their farm (farmers) or in their region (non-farmers).

Table 5 describes the farmers' view on potentially feasible SMPs and the needs for implementation. The practice of increasing importance of farm animals was mainly articulated by a group of organic Tirolese fruit growers and should not be generalised.

Table 5: Most mentioned SMP categories of farmers' answers regarding potentially feasible SMPs on their farms, supplemented with needs for implementation. If less than five participants and half of the answers per category mentioned the need, it was excluded. All numbers indicate the total number of farmers' mentions (n).

SMP	Mentions (n)	Needs		
		... on farm (n)	... in municipality/region (n)	... regarding policy instruments (n)
Use of biofertilisers	5	Knowledge (3)	-	Subsidies (3)
Self-composting, vermiculture	4	Knowledge (3)	Infrastructure (3)	Subsidies (3)
Increase importance of farm animals	4	Personnel (4)	Governance (2)	Subsidies (3)
Precision/reduction of pesticide application	3	Machinery (2)	-	Legislative changes (2)
Mulching	3	Machinery (2)	-	Subsidies (2)
Lighter machines	3	Machinery, Knowledge (3)	Governance, Infrastructure (3)	Subsidies (3)

Similarly, Table 6 shows the responses of non-farmers regarding potentially feasible SMPs to improve soil health in their region. On-farm needs are mentioned most often, possibly because they are the most apparent.

Table 6: Most mentioned SMP categories of non-farmers' answers regarding potentially feasible SMPs in their regions, supplemented with the needs for implementation. If less than five participants and half of the answers per category mentioned the need, it was excluded. All numbers indicate the total number of farmers' mentions (n).

SMP	Mentions (n)	Needs		
		...on-farm (n)	... in municipality/region (n)	... regarding policy instruments (n)
Use of organic fertilisers	16	Machinery (9)	Governance (6)	Legislative changes (8)
Diversifying crop rotations	13	Knowledge (10)	Market access (6)	Subsidies (7)
Associations/ intercropping/ mul-ticropping	12	Knowledge, Machinery (9)	Infrastructure (7)	Subsidies (6)
Methods for efficient fertilisation	11	Machinery (10)	Infrastructure (6)	Subsidies (6)
Non-inversion/Reduced tillage	9	Knowledge, Machinery (8)	Infrastructure (3)	Subsidies (4)
Soil analyses	9	Machinery (7)	Infrastructure (4)	Subsidies (6)

As depicted in Table 7, the **need for knowledge** was rated higher amongst farmers as it was amongst non-farmers. Furthermore, the need for knowledge was rated higher than the need for machinery.

The most important need at the regional and municipal level is the **provision of infrastructure** (cooperatives, processing units, service providers...). **Subsidies** were the most important policy instrument for both groups. **Tax exemptions** were mentioned amongst non-farmers as a possible instrument, while they stayed nearly unmentioned by farmers. These numbers of mentions, however, should be interpreted with care: the related practices in both groups are different, as shown before (Table 5, Table 6).

Table 7: Total mentions of needed resources, ignoring the related practice, for farmers and non-farmers. Counts (n) can be higher than the absolute number of participants, as the needs could be mentioned per practice.

Level	Farmers (n)	Non-farmers (n)
On-farm	Knowledge (25) Machinery (15) Personnel (13)	Machinery (132) Knowledge (92) Personnel (58)
Municipal/regional level	Infrastructure (17) Market access (10) Governance (8)	Infrastructure (79) Governance (67) Market access (30)
Policy instruments	Subsidies (23) Legislative changes (16) Tax exemptions (1)	Subsidies (102) Legislative changes (49) Tax exemptions (24)

3.8 Forest soils

Due to the low participation of foresters and forestal advisors, all stakeholders working with forest soils were evaluated jointly. Regarding the most important soil challenges for forest soils, **soil structure** was mentioned most often—comparable to agricultural soils. **Soil erosion** was mentioned just as often, followed by **soil biodiversity** (Figure 7).



Figure 7: Relative frequency of mentions per soil challenge (1-11), as selected by foresters and forestal advisors (n = 7).

Similarly to farmers and agricultural advisors, foresters and forestal advisors also assessed a list of SMPs for their effectiveness against the selected most important soil challenges (see Q22 in Annex A). Unfortunately, the responses from foresters and forestal advisors were too few to be evaluated for every challenge. Despite having received few responses, a cumulative effectiveness of the SMPs for forest soils, as described in

chapter 3.4, could be calculated. The most effective practices were (see Table A 2 in Annex C):

- (1) operating equipment on established roads and trails
- (2) operating equipment on woody debris
- (3) time forest stand improvement activities in ways that minimize soil and vegetation damage
- (4) establish ground cover on unused roads and landings
- (5) establish ground cover on disturbed areas
- (6) avoid disturbing forest litter and the soil surface.

4 Discussion

4.1 Limitations of the methodology

Due to the approach of integrating two tasks into one questionnaire and the depth of the questions, the online form became comparably long and complex. Although the branched structure reduced unnecessary questions, the questionnaire took about twenty minutes to complete. This explains the high number of answering attempts that were not completed. However, a certain number of incomplete answers is usual, e.g., due to test runs by the distributing members, or refreshing the page due to connection problems.

The branched structure helped to reduce the effort for each participant: Each participant was only asked to evaluate the effectiveness of certain soil management practices for the three challenges they had considered most important before. However, this also implied that for subsequent questions the number of respondents and thereby the certainty of achieved answers would vary. More precisely, in Figure 3 the number of responses (n) is different for every challenge (compare number of responses (n) on the y axis), just as in Figure 5 for every SMP.

We collected demographic data on the participants (education, profession, work experience, region and country, and for farmers and advisors also data on production system (conventional or organic), farm size, type of production). This opened up a huge variety of regionalised or stakeholder-specific possibilities of evaluation. In contrast to Paz et al. (2023) who categorised stakeholders by environmental zones according to Metzger et al. (2005), we used the factors stakeholder and country, as the most important indicators for political processes associated with these SMPs.

4.2 Perspectives on soil challenges

The six soil challenges mentioned as most important across all stakeholders and countries correlate strongly: increasing soil organic carbon improves soil structure and, thus, water storage capacity. At the same time, higher SOC influences soil erosion stability and nutrient leaching and could also improve soil biology. This game-changing potential of soil organic carbon is well-known, however, its complex interconnectedness with associated management practices makes drawing quick conclusions difficult.

Soil structure was mentioned most often across all stakeholders and regions, for agricultural soils as well as for forest soils. Soil structure was also recognised as a very important factor for soil health in the scientific community; it is important to maintain implicit as well as productivity properties of soils (Bussaard & van Faassen, 1994; Lehmann et al., 2020). Although this has been common sense for many years, the drivers of deterioration of soil structure (e.g., soil compaction by inappropriate passing or heavy machine loads) are hard to change, often due to conflicting economic or short-term objectives.

Nutrient use efficiency and **water storage capacity** were also amongst the most-mentioned soil challenges, being most relevant for farmers and agricultural advisors. In contrast, less productivity-oriented challenges such as soil biodiversity and soil erosion were mentioned more often by NGOs and policymakers. This shift was expectable; however, many at first glance production-oriented soil challenges are of high societal and/or environmental relevance. For instance, nutrient efficiency impacts nitrate leaching and eutrophication, and soil structure and water storage capacity affect erosivity and the water retention capacity of the landscape. Conversely, challenges like soil erosion and soil biodiversity seem to be less important to farmers and agricultural advisors. If these

challenges shall be addressed, their economic relevance for farming should be assessed and communicated. For instance, the annual loss of agricultural productivity in severely affected areas of Europe is estimated to be about 0.43 % (Panagos, Standardi et al., 2018). In contrast, direct economic implications of soil biodiversity loss are mostly unknown.

Some soil challenges were region-specific. Amongst the participating countries, the Netherlands have the highest share of peatland (Tanneberger et al., 2017). Consequently, the importance of **peat degradation** was ranked highest there. Within Europe, this challenge might also be of high relevance for Scandinavian and Baltic countries, Ireland, and Great Britain, exhibiting even higher peatland shares of their total area. For containing peat degradation of agricultural soils in the Netherlands, sustainable solutions for all affected stakeholders must include research of life scientists as well as of social scientists (Liu et al., 2023; Norris et al., 2021). **Soil contamination** was mentioned predominantly in participating countries from Eastern and Southern Europe. Contamination risks are often country-specific and may result from current or past fertiliser and pesticide legislation, mining and industrial activities (see Panagos, Ballabio et al. (2018) for an example of copper contamination), or waste treatment policies. Although some heavy metal contaminants (Cobalt, Copper, Manganese) appear more frequently in Southern and/or Eastern Europe, this challenge is more widespread than our results indicate: More than 28% of the total surface area of the EU exceed the thresholds for at least one heavy metal contaminant (with a majority of contaminations rather caused by natural backgrounds than by anthropogenic activities, however) (Tóth et al., 2016).

4.3 Perspectives on associated soil management practices

For the most important soil challenge “**improving soil structure**”, the most important SMPs were cover/catch cropping, permanent soil cover, use of organic fertiliser, and minimal/reduced tillage. From a scientific point of view, this selection holds true: Cover/catch cropping improves the stabilization of large soil aggregates (Qi et al., 2022), decreases penetration resistance (Abdollahi & Munkholm, 2014), and can alleviate subsoil compaction, especially in combination with reduced tillage (Martlew et al., 2023). Reduced tillage (and especially no tillage) can increase aggregate stability (Nunes et al., 2020). All mentioned practices can positively impact soil organic carbon contents of the topsoil (e.g., Crystal-Ornelas et al., 2021; McClelland et al., 2021). While cover/catch cropping and the use of organic fertilisers were also the SMPs considered most easily feasible, reduced tillage was on rank 7, and permanent soil cover on rank 20. Amongst farmers, feasibility of reduced tillage was lower than amongst other stakeholders. **This means that for the most important soil challenges across Europe, two of the most effective SMPs (cover/catch cropping and the use of organic fertilisers) are also easily feasible—these practices are or should be a baseline for improving soil structure.** Reduced tillage and permanent soil cover are also very effective but may be more difficult to apply for the majority of farmers. These practices are comparably knowledge-intensive and, especially in organic farming of vegetables and certain row crops, require specialised solutions and trade-offs (Zikeli & Gruber, 2017). At the same time, (elements of) reduced tillage were mentioned fourth most by farmers to be already established on their farms, and the use of organic fertilisers and cover crops was mentioned even more frequently. Based on these answers, the most promising SMPs for improving soil structure are well known, widely established and easily feasible. If soil structure remains an important issue, we need to consider whether other SMPs are more promising or if we should intensify efforts of increasing the use of these widespread practices even further, where possible.

Technical SMPs aiming specifically at the improvement of soil structure (low tyre pressure, Controlled Traffic Farming) were not amongst the 13 most versatile and effective SMPs, but also their effectiveness to improve soil structure was assessed comparably low (rank 13 and 8, respectively). A different but more holistic way to reduce soil compaction in agricultural soils is the reduction of axle loads, which is often demanded by soil scientists. In a HuMUS workshop in Germany, this approach was discussed with quadruple helix stakeholders. The participants identified the following main reasons for increasing axle loads and untimely passing in agriculture:

- The further spread of inter-farm labour means that the time windows for tilling and harvesting are becoming narrower, as they are based on the contractors' deadlines. At the same time, profitable economies of scale are achieved with large machines, especially in the area of contract labour. Thus, a reduction in production scale comes at the expense of (monetary) profitability.
- For certain crops (sugar beet, but also vegetable crops such as carrots or green peas), the time of harvest is largely determined by the customer and the capacity utilisation of the processing plant and inevitably leads to untimely use of heavy harvesting machinery. This conflict is difficult to resolve, as it would be unprofitable to maintain corresponding overcapacity in processing. The fresh vegetable sector depends on daily harvesting, which is also difficult to change.
- Large axle loads are supposedly compensated for by wider contact surfaces (wide tyres, tyre pressure control systems). Although this equation works for the topsoil area, it cannot counteract the compaction in the subsoil area caused by excessive axle loads. Subsoil compaction can be avoided primarily by reducing the absolute axle loads.

According to research, a regulatory limitation in this respect would be a simple and effective option. Efforts have already been made to establish corresponding regulations, including at the European level, but so far without success. The most promising approach would be to freeze the currently widespread axle loads while at the same time protecting existing machines. A limited axle load requires the adapted production of corresponding harvesting machinery—the smaller the regulated area, the less attractive the market for it. A corresponding regulation should therefore ideally be sought at EU level. A differentiated restriction on the use of harvesters with high axle loads, taking into account soil type and soil moisture, was generally considered too complex and uncontrollable.

The challenge “**maintaining/improving soil organic carbon contents**” calls for nearly the same selection of practices as the challenge “improving soil structure”, cover crops, permanent soil cover, and organic fertilisers being most mentioned. This is not surprising considering that the positive effects of these SMPs on soil structure can—not exclusively, but in part—be attributed to their positive effect on SOM contents (see Kay, 2018 for a detailed review). The next two SMPs in the cumulative effectiveness ranking are “including legume-based grassland/pastures in crop rotation” and “diversifying crop rotations”. These management-oriented practices are more difficult to implement but the former may be promising: first because the stability of certain soil organic carbon pools increases in non-disturbed soils (Denef et al., 2001; Vos et al., 2018; Wiesmeier et al., 2014), and second because lower carbon to nitrogen ratios in (certain) legume roots (Li et al., 2020) contribute to an increased carbon use efficiency of the soil microbiome and, consequently, increased humus reproduction (Friedel & Scheller, 2002; Ridgeway et al., 2022). Diversification of crop rotations, in contrast, remains an unspecific measure yet utile for farm resilience. Perennial fodder legumes were not mentioned amongst the ten most widely established SMPs. The needs for augmenting the use of fodder legumes were stated to be mostly on-farm (machinery, knowledge and personnel) while the needs for diversifying crop rotations were more diverse (regional support such as market access,

policy instruments such as subsidies). The use of fodder legumes and other pastures in the crop rotation may be promoted by improving knowledge on the management and associated benefits of fodder legume cropping, as it was executed in a participative process for grain legumes by Notz et al. (2023).

Enhancing nutrient use efficiency (NUE), the third-most important challenge, mentioned the use of organic fertiliser as most effective practice, interestingly followed by the diversification of the crop rotation, methods for efficient fertilisation, and the implementation of leguminous pastures. The use of organic fertilisers can improve the efficiency of (partially replaced) mineral fertiliser inputs and can increase yields by improving soil quality, as was found for rice production systems (Iqbal et al., 2019; Zhang et al., 2018). Similarly, cropping leguminous pastures can reduce mineral nitrogen inputs, associated gaseous losses, and leaching of nutrients (Lötjönen & Ollikainen, 2017). The optimisation of the crop rotation can reduce nitrate leaching (Eriksen et al., 2004), and so can other soil quality parameters such as SOC or bulk density (Karlen et al., 2006) and, thus, improve NUE. The only technical method in this selection was optimising fertilisation processes by better aligning spatial and temporal nutrient availability with crop demands. This SMP contains multiple tools, from improved timing of fertiliser application and precision farming techniques to nitrification inhibitors. Effectiveness and feasibility can therefore not be assessed generally. Apart from cropping leguminous pastures, all mentioned SMPs were amongst the 10 most easily feasible ones.

While the three most effective SMPs to **enhance water storage capacity** (improve soil water storage capacity through SOC enhancement, establish permanent soil cover, and cover cropping) focus on the lack of water, the next practices (improve drainage systems, manage the water table and flooding) dealt with the excess of water. This points at the ambivalence of water storage in European contexts in times of climate change: while certain regions are in urgent need to save water, others might want to mitigate the risk of untimely rainfalls followed by water logging, limiting plant growth as well as soil trafficability. The consequences of climate change for water management (and other productivity factors) are significant but vary between regions, and European agricultural policies are required to allow flexible and region-specific solutions (Olesen & Bindi, 2002). Apart from cover cropping, a comparably low feasibility was assigned to all other effective SMPs for this challenge. This reflects the complexity of water storage capacity.

The fifth most important soil challenge “**enhance soil biodiversity**” was just as complex as the last-mentioned—but the most promising approaches to address it are well-known. Amongst the top five SMPs, three improve the temporal and spatial diversity in the crop rotation: diversifying main crops, establishing cover crops, and using associations, inter- or multi-cropping. Crop rotation can significantly impact soil biodiversity (Venter et al., 2016). Similar effects were found for cover cropping (Kim et al., 2020) and several multi-cropping approaches (Ehrmann & Ritz, 2014). Thus, participants’ approach to tackle endangered soil biodiversity with increased diversity of the cropping system seems valid. The two remaining of the top five associated SMPs are the use of organic fertiliser and reduced tillage, both stimulating microbial activity in the topsoil (Watts et al., 2010; Zuber & Villamil, 2016). The most prominent effect of reduced tillage on soil organisms is the increase in earthworm population (Briones & Schmidt, 2017). Of the five associated SMPs being assessed as most effective, all were amongst the eleven most easily feasible ones. Although each single SMP can be implemented in many different ways in practice, practices associated with this complex challenge are comparably simple.

For **soil erosion**, associated SMPs aimed mainly to provide soil cover permanently or in vulnerable times of the year (cover crops). While no-tillage systems maintain the soil structure and cover, mulching aims to provide soil cover after tillage by application of

textured materials like straw, grass, or crop residues. This system is especially useful for intensive crops such as vegetables, where no-till strategies are difficult to realise. The remaining SMP amongst the top 5 is “establishing vegetated buffer strips”, standing for an off-site approach preventing the expansion of smaller erosion events from vulnerable soils. In a recent publication, Boardman and Vandaele (2023) conclude that avoiding soil erosion should go beyond on-field measures: It is important “to ‘disconnect’ the agricultural landscape from rivers, built-up areas, and natural habitats” (Boardman & Vandaele, 2023). One solution to that could be buffer strips, the fourth most feasible practice in our survey; however, they are applied scarcely in practice. While mulching and cover cropping were assessed as easily feasible, no-till and other strategies for permanent soil cover were seen as difficult to realise (third last in the ranking). Generally, no-tillage systems mainly rely on the herbicide Glyphosate to control cover crops or weeds while maintaining an undisturbed soil cover for direct seeding and planting. As half of the participating farmers were organic where Glyphosate application is prohibited, their view on feasibility of no-till systems might have biased the results. In Europe, no-till systems are less established than in other regions (Beckie et al., 2020). This has several reasons, one being certainly the comparably high cropping intensity in Europe aiming at the maximization of yields rather than minimization of production costs (no-till approach). Secondly, the ban of genetically modified (GMO), Glyphosate-tolerant crop varieties may have as well contributed to reduced no-till adoption rates. The latter allow for easy no-till systems with trade-offs that have led to their prohibition (risks and low acceptance of GMOs, Glyphosate-resistant weeds, possible health and environmental risks of Glyphosate and potentially persistent Glyphosate metabolites, concentration of the seed market, etc.).

Interestingly, no-till systems are not only assessed as less feasible than reduced-tillage systems but also as less effective against four of the six major soil challenges (apart from soil erosion and water use efficiency). No-till systems can negatively affect soil structural properties (Ernst et al., 2020; Skaalsveen et al., 2019), and, consequently, reduce nutrient efficiency (Ernst et al., 2020). The assumed reduced positive effect on soil biodiversity or soil organic carbon cannot be strengthened by scientific evidence by now.

Amongst the five most effective and multifunctional SMPs, three represent basic principles of organic agriculture: **diversifying crop rotations, use of organic fertilisers, and including legume-based grassland/pastures in crop rotations**. Thus, by increasing the share of organic agriculture in the European Union following the objectives of the Farm to Fork Strategy (European Commission, Directorate-General for Health and Food Safety, 2020), key SMPs can become more widespread. For the two remaining top five SMPs (cover cropping and permanent soil cover), there is no obvious preference for a farming system: cover cropping is prescribed by fertilisation laws and the CAP and limited by soil type and the following crop. As organic farmers do not have herbicides as *ultima ratio*, they tend to have less **cover crops** and **permanent soil cover** than cutting-edge conventional farmers. However, this conclusion might not be true for the majority of conventional farmers. In summary, the significance of organic farming for application of SMPs is positive for several practices, while being indifferent for others.

4.4 Implications for forest soils

Due to the main working fields of the organisations distributing the questionnaire and due to the different working structure in forestry, the participation of foresters and forestal advisors was so low that a general evaluation, as executed for agricultural soils, was not possible.

The main soil challenges for forest soils were similar to the ones of agricultural soils: soil erosion, soil structure, soil biodiversity, and water storage capacity. Both systems have

gone through intensification processes and are increasingly affected by climate change-induced extreme weather events. However, associated practices are fundamentally different. The SMPs with high effectiveness to main forest soil challenges focus on organising and minimising traffic in sensitive areas and seasons, reducing impact of unavoidable machine traffic, and establishing ground cover by litter or vegetation.

5 Conclusion

We have lined out the perspectives of five different stakeholder groups on major challenges of soil health and on the management practices that they attributed as effective and feasible to face those challenges.

Although all soil challenges have already been addressed elsewhere, the importance of soil structure may be remarkable. However, all soil management practices related to soil structure are well-known and widely established; many of them are already part of national or EU legislation, or CAP/GAEC regulations. Thus, the main challenge is not the establishment of new methods or technical solutions but the further dissemination and distribution of already established methods and the increase of their effectiveness. One strategy for this has been outlined at the European level as lighthouses and living labs. We need to find out what prevents the adaptation of well-known SMPs in a certain region and by certain stakeholders and find specific solutions on site.

The collected data could not only have been evaluated by country or stakeholder but also by region, production, and other social factors that were included in the questionnaire. This would have exceeded the scope of this deliverable, but the authors are open to sharing the collected data for further evaluation.

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Annexes

Annex A: Questionnaire

In the following, the questions and process of the survey will be described. Additional information is provided in text boxes. Comments in green indicate information on the structure.

Preface

On-line questionnaire for collection best practices and best policies on soil health

This questionnaire will take no more than 20 minutes to complete. Its aim is to identify best management practices for soil health and best related policies. The stakeholders with a relation to the soil management—farmers and advisors, policymakers, representatives of NGO—are very welcome to participate. Your replies will remain anonymous and the data will feed into a larger research being done as part of the HuMUS project. We kindly ask you to complete the questionnaire once you start it, otherwise we can not use your answers.

The HuMUS project is part of the EU Mission 'A Soil Deal for Europe' (Soil Mission), which aims to lead the transition to healthy soils via sustainable soil management. The focus of HuMUS is to activate and engage municipalities and regions to play their role in the Soil Mission. In a first step, we want to create knowledge of the importance and value of soil health and its challenges and drivers across Europe. With your participation in this questionnaire, you help us to collect and assess practices to improve soil health in your region—together with answers of the other participants across Europe, we hope to create a profound basis for further work in the project.

As we are referring various times to the phrase of healthy soils, please find below our understanding of it:

The soil is a vital living system/ecosystem/organism and it is healthy when it permanently

- *provides food and biomass production, including in agriculture and forestry;*
- *absorbs, stores and filters water and transforms nutrients and substances, thus protecting groundwater bodies;*
- *provides the basis for life and biodiversity, including habitats, species and genes;*
- *acts as a carbon reservoir;*
- *provides a physical platform and cultural services for humans and their activities;*
- *acts as a source of raw materials;*
- *and constitutes an archive of geological, geomorphological and archaeological heritage.*

If you feel unsure about answering a question, please skip it.

Demographic information

Q1. Do you agree to take part in this survey? The data collected will be used in Hu-MUS research activities.

Yes No (If “No” was selected, participation was aborted)

Q2. You work in

[Single choice with 15 countries of the project members, including “other” (free text field)]

Q3. Could you specify your region?

[Single choice with NUTS-2 regions of the country selected before]

Q4. Your main activity is

- farmer/forester
- agricultural advisor/forestal advisor
- policy making/administration
- researcher
- NGO

Q5. Could you specify your education?

- secondary school
- agricultural/technical training (1–3 years)
- university (or similar)
- Other: _____

Q6. Your working experience is:

- less than 5 years
- 5–10 years
- 10–20 years
- 20–30 years
- More than 30 years

Q7. Most of your farmland is used for: (only for Q4–farmer/forester group)

- arable farming
- horticulture
- fruit growing
- fodder (for meat production)

- fodder (for dairy farming)
- fodder (for laying hens)
- forestry
- Other: _____

Q8. Most of your clients are using their farmland mainly for: (only for Q4—agricultural/forestal advisor group)

- arable farming
- horticulture
- fruit growing
- fodder (for meat production)
- fodder (for dairy farming)
- fodder (for laying hens)
- forestry
- Other: _____

Q9: You use the following type of farm management (only for Q4—farmer/forester group)

- Conventional
- Organic
- Other: _____

Q9: You use the following type of farm management (only for Q4—agricultural/forestal advisor group)

- Conventional
- Organic
- Other: _____

Q10: What is your farm size (cultivated farmland, approximately, in hectares)? (only for Q4—farmer/forester group)

[Numeric free text field]

Soil challenges

Q11: What are the main three soil challenges in your region? Please bring them to the top of the list by dragging and dropping. Only ranks 1–3 will be relevant.

- Maintain/increase Soil Organic Carbon
- Avoid N2O and CH4 emissions from soils
- Avoid peat degradation
- Avoid soil erosion
- Avoid salinisation and alkalinisation
- Avoid acidification
- Avoid contamination
- Improve soil structure
- Enhance soil biodiversity
- Enhance soil nutrient use efficiency
- Enhance water storage capacity

Questions only for farmers/foresters (see Q4)

	<p>Q12: Think of your farm/forest. What practices do you already implement that are especially related to soil health? (each time when “soil health” was mentioned, a definition was provided in a pop-up)</p>	<p>Q13: Do you receive some kind of institutional support for the practices you already apply? Please specify. Please make sure to tick either “no support” or a combination of the other options.</p>				
	<p>If you feel like some of these practices are uncommon, please help us understanding them by providing additional information, e.g. a link, a reference or a short description.</p>	No support	EU subsidies	National/ regional subsidies	Informational support (advice, training)	Other kind of support
1	(free text field)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
...						
5	(free text field)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Q14: Which further practices to improve soil health do you know (that might be viable for your farm in the future)?

(5 free text fields)

Q15 What are the needs for adopting the selected additional soil management practices to improve soil health...

	a) ... on your farm?				b) ...in your municipality/region?		c) ... regarding policy instruments?		
	knowledge	machinery	personnel	governance	infrastructure (cooperatives, processing units, service providers...)	market access	subsidies	tax exceptions	Legislative changes
1	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
...	(instead of 1–5, the answers given in Q14 were displayed)								
5	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Questions for non-farmers/-foresters (see Q4)

	Q16: What are the most common practices already implemented on the farms of your region that are especially related to soil health?	Q17: Is there some kind of institutional support available for these practices? Please specify. <i>Please make sure to tick either "no support" or a combination of the other options.</i>				
	If you feel like some of these practices are uncommon, please help us understanding them by providing additional information, e.g. a link, a reference or a short description.	No support	EU subsidies	National/ regional subsidies	Informational support (advice, training)	Other kind of support
1	(free text field)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
...						
5	(free text field)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Q18: Which further practices to improve soil health do you know (that might be viable for your region)?

(5 free text fields)

Q19 What are the needs for adopting the selected additional soil management practices to improve soil health...

	a) ... on-farm?			b) ...in your municipality/re-gion?			c) ... regarding policy instruments?		
	knowledge	machinery	personnel	governance	infrastructure (cooperatives, processing units, service providers...)	market access	subsidies	tax exceptions	Legislative changes
1	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
...	(instead of 1–5, the answers given in Q18 were displayed)								
5	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Questions for agricultural soils (for farmers/agricultural advisors: all answers apart from "forestry" in Q7 or Q8)

Q20 In the first question, you indicated that the main soil challenges in your region are:

(three most important question from Q11 listed here)

In your opinion, what are the most effective soil management practices to tackle these challenges in your region (regardless of feasibility)? (It was explained that leaving the box empty would mean "not effective to tackle this challenge", due to technical reasons)

	Dynamic entry: Most important challenge from Q11		Dynamic entry: 2 nd most important challenge from Q11		Dynamic entry: 3 rd most important challenge from Q11	
	Moderately effective	Very effective	Moderately effective	Very effective	Moderately effective	Very effective
Non-inversion/ Reduced tillage (Info) (additional information about the practice was provided in a pop-up window)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
... (all soil management practices mentioned in Table A 4 were listed in this manner)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Q21: Thank you for indicating moderately/very effective soil management practices to tackle the main soil challenges in your region. However, not all effective practices may be feasible* as well.

In your opinion, which of the selected practices are the most feasible* ones to tackle these soil challenges in your region?

* Feasibility in this context addresses e.g. costs, labour, knowledge, agronomic limitations, equipment/machines...

	Not feasible	Moderately feasible	Easily feasible
Non-inversion/ Reduced tillage (Info)*	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Here, only the soil management practices were displayed that had been selected moderately or very effective in Q20)			

Questions for forest soils (for foresters/forestal advisors: only answer "forestry" in Q7 or Q8)

Q22 In the first question, you indicated that the main soil challenges in your region are:

(three most important question from Q11 listed here)

In your opinion, what are the most effective soil management practices to tackle these challenges in your region (regardless of feasibility)? (It was explained that leaving the box empty would mean "not effective to tackle this challenge", due to technical reasons)

	Dynamic entry: Most important challenge from Q11		Dynamic entry: 2 nd most important challenge from Q11		Dynamic entry: 3 rd most important challenge from Q11	
	Moderately effective	Very effective	Moderately effective	Very effective	Moderately effective	Very effective
Operate equipment on established roads and trails and minimize travel into the general forest area	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

In the same manner, the following forest soil management practices were listed:

- Operate equipment on woody debris (slash) in areas with sensitive or wet soils
- Sequence forest management activities (back to front) to limit the number of equipment passes
- Use smaller and lighter equipment, track equipment, low pressure tires, and lighter loads. Where appropriate, use mules, draft horses or other animals for moving harvested trees
- Restore heavily compacted areas (e.g., by sub-soiling or other mechanical method)
- Time forest stand improvement activities in ways that avoid or minimize soil erosion, compaction, rutting, and damage to remaining vegetation, and that maintain hydrologic conditions
- Protect roads using water bars/rolling dips
- Establish ground cover on roads and landings that are not in use
- Establish ground cover on disturbed areas
- Avoid disturbing forest litter and the soil surface
- Retain downed tops and other unharvested materials for ground cover, nutrient recycling, and organic matter retention
- Add woody material to the soil by girdling or cutting non-merchantable trees or trees of undesired species
- Use extended rotations to keep carbon on the site for a longer period
- Use of organic fertilisers
- Use of soil amendments for buffer capacity and pH
- Other (free text fields)

Q23: Thank you for indicating moderately/very effective soil management practices to tackle the main soil challenges in your region. However, not all effective practices may be feasible* as well.

In your opinion, which of the selected practices are the most feasible* ones to tackle these soil challenges in your region?

** Feasibility in this context addresses e.g. costs, labour, knowledge, agronomic limitations, equipment/machines...*

	Not feasible	Moderately feasible	Easily feasible
Operate equipment on established roads... *	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Here, only the soil management practices were displayed that had been selected moderately or very effective in Q22)

Questions for all participants

Q24: Which improvements in regional policies should be made in order to support the adaption of these practices and to improve soil health in your region?

(5 free text fields. This question pointed to Q21 for farmers/agricultural advisors, to Q23 for foresters/forestal advisors, and to Q18 for all other stakeholders)

Q25: Do you know about any participatory process related to soil health improvement in your region?

For this survey, participation is to take part in decision making processes at different levels. It means that the stakeholders and/or the citizens take part in the final product of these processes. Only information and communication are not participation.

Yes

No

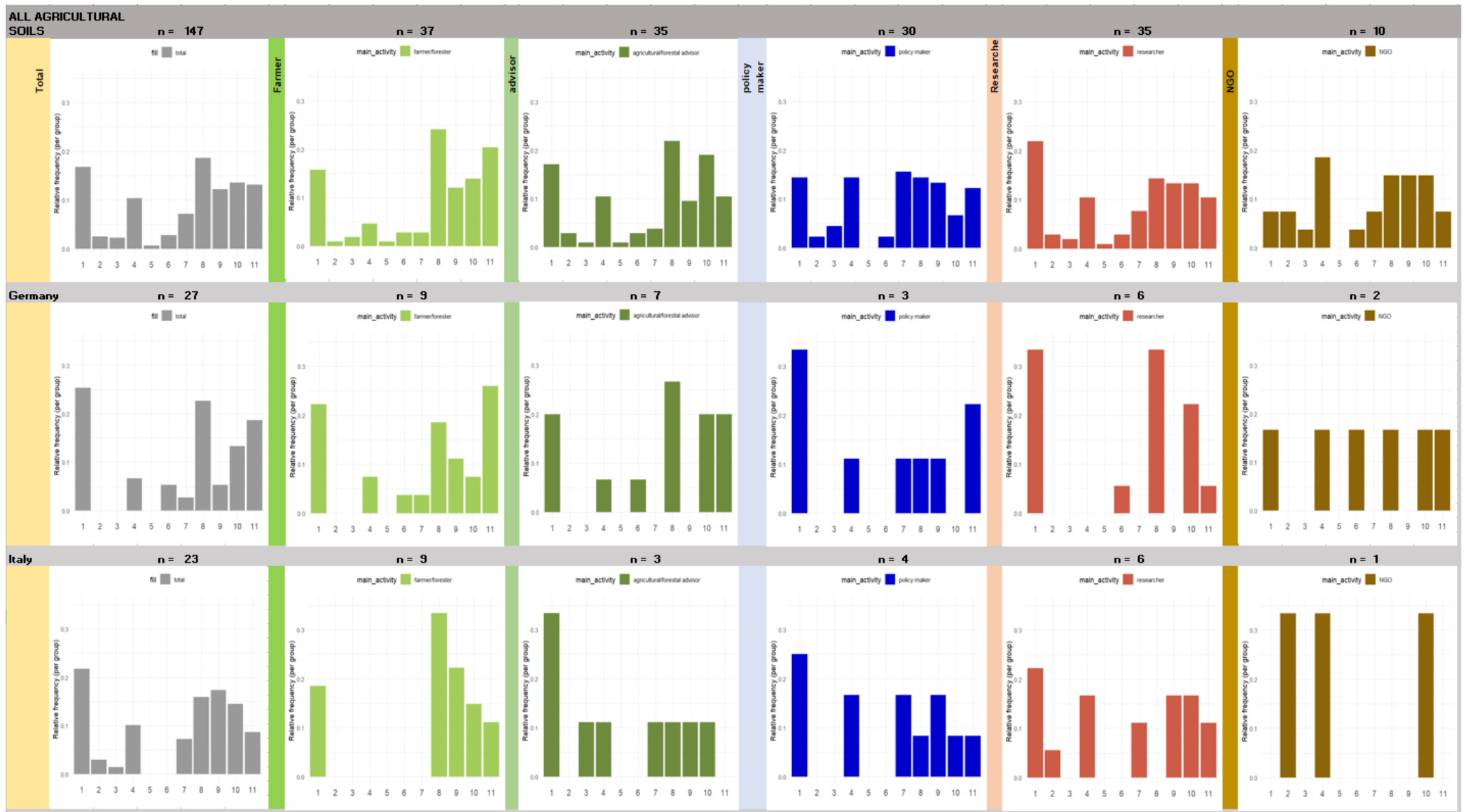
Q26 (when selected "Yes" in Q25): We are very interested in learning more about these participatory processes for improving soil health. We would be grateful if you could provide us with your contact details. This will enable us to contact you later in the project if we have any questions on this topic. (free text field)

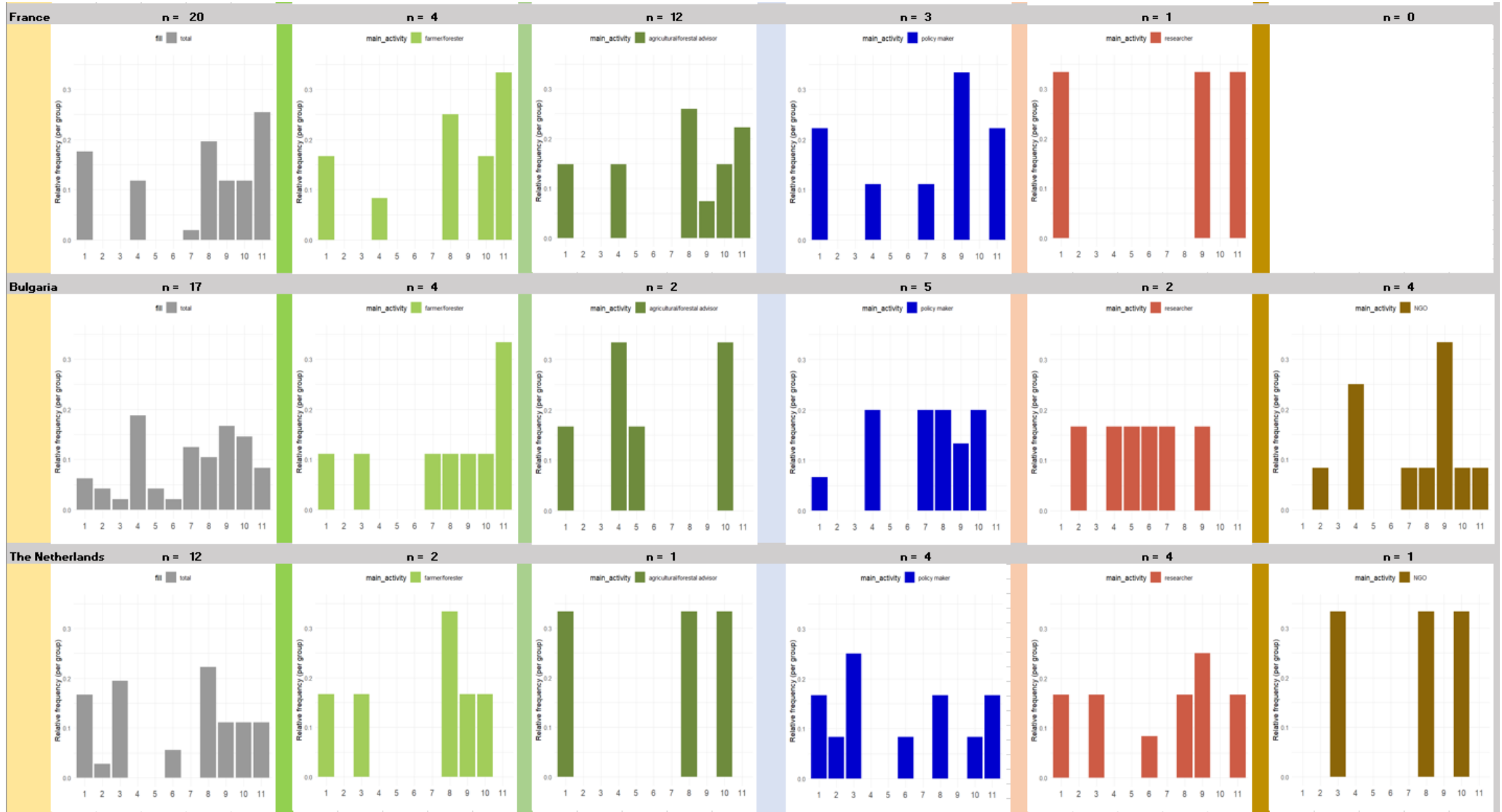
Q27: We would be glad if you could help us creating a strong and multidisciplinary network for soil health assessment and management.

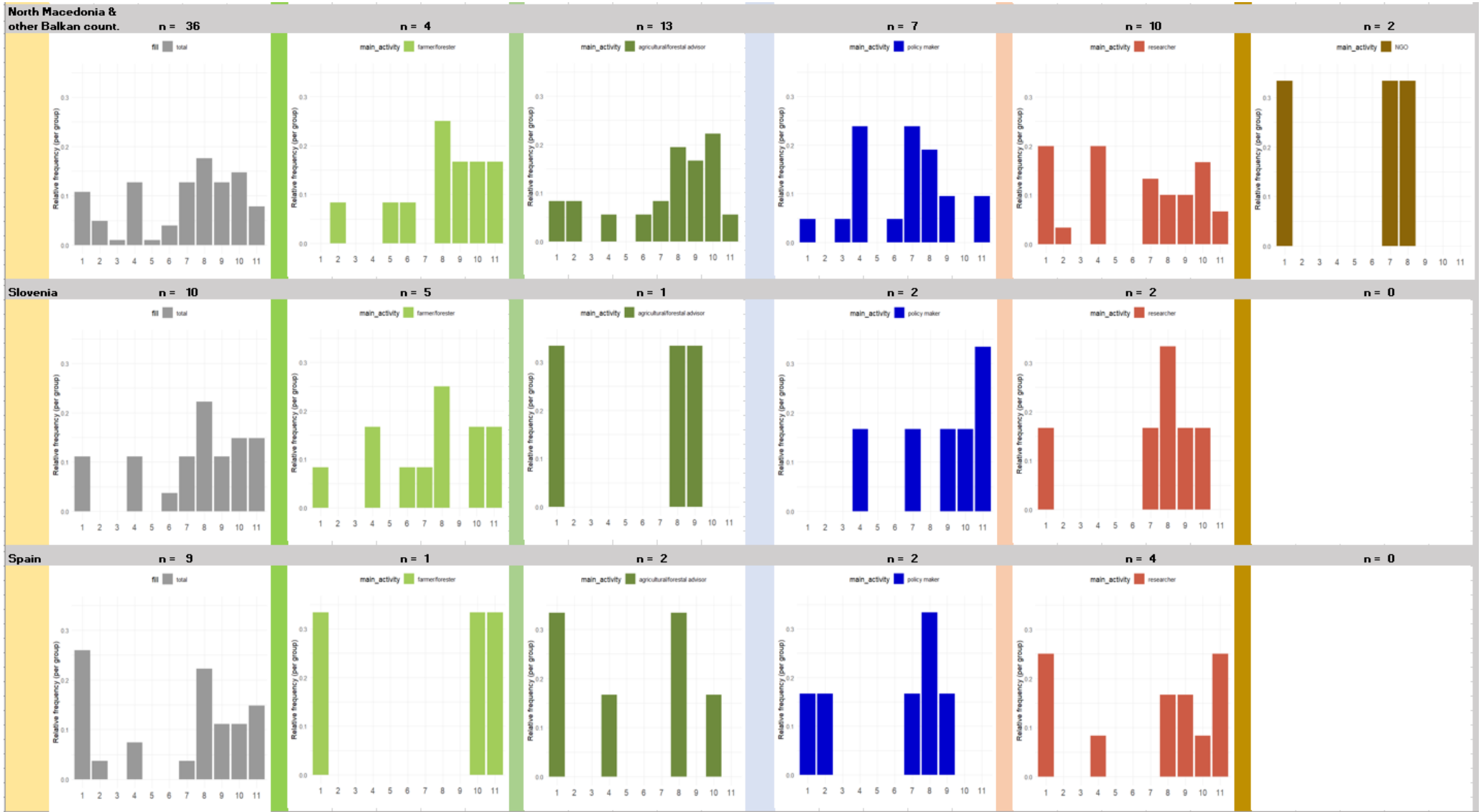
Which stakeholders/initiatives on soil health do you know in your region? Please also indicate contact information, if possible. (free text field)

Q28: Would you like to suggest us something more? (free text field)

Annex B: Soil challenge priorities by stakeholder and country





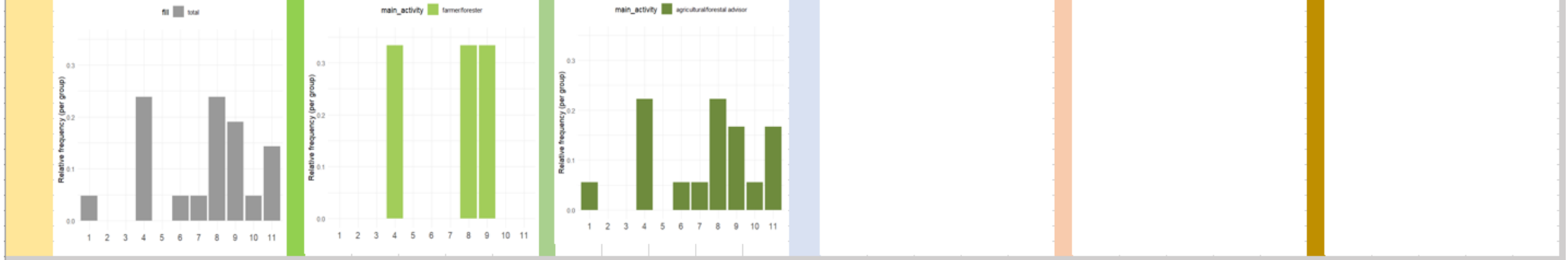


ALL FOREST SOILS

n = 7

n = 1

n = 6



Annex C: Indexing impact and multifunctionality of selected soil management practices

Table A 1: "Impact index" of each soil management practice, calculated from all assessments over all challenges. According to the procedure described in chapter 3.4, all SMPs were ranked after their effectiveness regarding all soil challenges.

Soil management practice	Impact
Permanent soil cover	528
Cover/catch crops	514
Use of organic fertilisers	493
Diversifying crop rotations	463
Include legume-based grassland/pastures in crop rotation	449
Improve soil water storage capacity	429
Associations/intercropping/multicropping	414
Mulching	412
Non-inversion/Reduced tillage	406
No till/Direct seeding	404
Leave straw on-site	378
Perennial crops	362
Drainage systems, manag. water table and flooding	358
Methods for efficient fertilisation	345
Increase water use efficiency	345
Use of biofertilisers	343
Use of soil amendments for buffer capacity and pH	340
Breaking compaction layers	337
Vegetated/grass buffer strips	304
Controlled Traffic Farming	304
Hedges/ agroforestry	299
Precision/reduction of pesticide application	290
Mechanical weeding	277
Low pressure in tires	269
Reduce grazing intensity	228
Contour ploughing	202
Terrace farming	197
Monitor salt & contaminant inputs	33

Table A 2: “Impact index” of each soil management practice, calculated from all assessments over all challenges. According to the procedure described in chapter 3.4, all SMPs were ranked after their effectiveness regarding all soil challenges. Due to few responses, the impact index was only calculated for the challenges “Avoid soil erosion”, “Improve soil structure”, and “Enhance soil biodiversity”, which were the most mentioned ones amongst foresters. More detailed descriptions on the SMPs can be found in Annex 8.1, Q22.

Soil management practice	Impact
Operate equipment on established roads and trails	5
Operate equipment on woody debris (slash)	5
Time forest stand improvement activities in ways that minimize soil and vegetation damage	5
Establish ground cover on unused roads and landings	5
Establish ground cover on disturbed areas	5
Avoid disturbing forest litter and the soil surface	5
Reduce soil compaction (smaller and lighter equipment, track equipment, low pressure tires, draft horses)	4
Protect roads	4
Retain downed tops for ground cover	4
Add woody residues to the soil	4
Use extended rotations to store carbon longer	4
Sequence forest management activities to limit the number of equipment passes	3
Restore heavily compacted areas	3
Use of organic fertilisers	0
Use of soil amendments for buffer capacity and pH	0

Annex D: Indexing impact of soil management practices challenge-wise

Table A 3: Selection of the 10 most effective soil management practices (SMPs) per challenge. Shown for the 6 challenges considered most important across all regions. The selection criteria was cumulative effectiveness, as calculated in Figure 4. A legend for the abbreviations of the SMPs is provided in Table A 4.

8—Improve soil structure		1—Maintain/ increase Soil Organic Carbon		10—Enhance soil nutrient use efficiency		11—Enhance water storage capacity		9—Enhance soil biodiversity		4—Avoid soil erosion	
SMP	Cum. Eff.	SMP	Cum. Eff.	SMP	Cum. Eff.	SMP	Cum. Eff.	SMP	Cum. Eff.	SMP	Cum. Eff.
cover_crop	109	cover_crop	116	org_fert	73	water_stor	82	div_cr	76	soil_cover	61
soil_cover	104	soil_cover	113	div_cr	69	soil_cover	79	org_fert	75	cover_crop	57
org_fert	103	org_fert	103	eff_fert	65	cover_crop	70	cover_crop	69	no_till	53
mini_till	101	leg_pasture	99	leg_pasture	65	drain	65	mini_till	64	buffer_str	52
div_cr	92	div_cr	94	soil_cover	60	wue	63	as_int_mult	63	mulch	52
leg_pasture	92	mini_till	92	cover_crop	59	no_till	58	leg_pasture	63	mini_till	51
no_till	86	as_int_mult	90	biofert	58	mulch	57	soil_cover	63	div_cr	48
comp_lay	85	straw_os	89	as_int_mult	57	org_fert	56	buffer_str	62	perennials	47
ctf	84	mulch	86	straw_os	54	div_cr	54	pest_app	59	drain	43
as_int_mult	82	no_till	81	soil amend	53	as_int_mult	53	eff_fert	56	water_stor	43

Table A 4: Glossary for abbreviations of soil management practices (SMPs).

Abbreviation	Soil management practice	Abbreviation	Soil management practice	Abbreviation	Soil management practice
agroforestry	Hedges/ agroforestry	eff_fert	Methods for efficient fertilisation	pest_app	Precision/reduction of pesticide application
as_int_mult	Associations/intercropping/ multicropping	graz_intensity	Reduce grazing intensity	salt_cont	Monitor salt & contaminant inputs
biofert	Use of biofertilisers	leg_pasture	Include legume-based grassland/pastures in crop rotation	soil amend	Use of soil amendments for buffer capacity and pH
buffer_str	Vegetated/grass buffer strips	low_pres	Low pressure in tires	soil_cover	Permanent soil cover
comp_lay	Breaking compaction layers	mech_weed	Mechanical weeding	straw_os	Leave straw on-site
cont_plough	Contour ploughing	mini_till	Non-inversion/Reduced tillage	terrace	Terrace farming, structural measures against erosion
cover_crop	Cover/catch crops	mulch	Mulching	water_stor	Improve soil water storage capacity
ctf	Controlled Traffic Farming	no_till	No till/Direct seeding	wue	Increase water use efficiency
div_cr	Diversifying crop rotations	org_fert	Use of organic fertilisers		
drain	Drainage systems, managing water table and flooding	perennials	Perennial crops		

Annex E: Fact Sheets on soil management practices (SMPs)

For a higher-quality version of the Fact Sheets, please consult the separate files attached.

Fact sheet on soil management practices

Permanent Soil Cover

Overview:

Striving for permanent soil cover can provide manifold benefits for soil health, soil biology and structure, and erosion control. Whereas a true permanent soil cover can only be provided by direct seeding methods or mulching, ways to maximise soil cover include cover cropping, minimizing soil disturbance, cultivating perennials, etc.

Potentials to tackle soil challenges

Strategies of maximising soil cover rely on reduced soil disturbance, which is positive for Soil Organic Carbon accumulation near the surface, stabilising soil aggregates, and extended plant covers. Their roots provide carbon (SOC levels) and build up soil structure (root growth, exudates). This effect and the direct physical barrier of the stand lowers erosivity. Moreover, improved soil structure increases infiltration and drainage and, hence, water storage capacity. A structured, healthy soil also provides good conditions for soil biology.

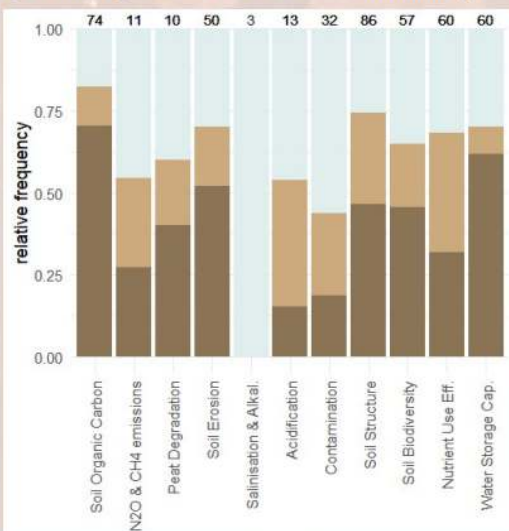


Fig. 1: Relative frequency of the effectivity assessments of permanent soil cover in coping with the different soil challenges: „Not effective“ (blue), „Moderately effective“ (light brown), „Very effective“ (dark brown). Numbers above the bars indicate the number of participants assessing the effectivity for every challenge.



Direct seeding of soybean into living mulch (intercropped rye). © D. Gärtling

Perspectives on feasibility

Although half of farmers saw it highly feasible, other stakeholders were more pessimistic. Especially direct seeding or mulching approaches are difficult to establish in certain cropping systems (e.g., vegetables, organic farming).

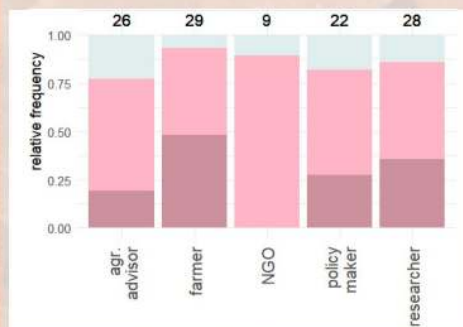


Fig. 2: Relative frequency of the feasibility assessments of permanent soil cover per stakeholder: „Not feasible“ (blue), „Moderately feasible“ (light red), „Easily feasible“ (dark red). Numbers above the bars indicate the number of stakeholders assessing the feasibility.

Although reaching permanent soil cover may be reserved to specialised cropping approaches, increasing the time when soil is covered benefits soil health.

Fact sheet on soil management methods

Cover/Catch Crops

Overview:

Cover crops, or catch crops, are non-commercial crops planted to improve soil quality between main crops. Both pure and mixed stands with or without legumes are common. Summer catch crops can be cultivated after cereals before seeding a winter crop. Winter catch crops usually cover the soil over winter, before tillage for a summer crop. They can also be combined with no-till systems.

Potentials to tackle soil challenges

Cover crops were assessed as very effective against all six major soil challenges (Fig. 1). They can improve carbon storage in the soil, prevent erosion in vulnerable times, and benefit soil biodiversity by providing soil cover throughout the year. Roots improve soil crumbling and can break compaction layers. Catch crops prevent nitrate from mineralisation and from leaching, and leguminous partners bind atmospheric nitrogen. Although cover crops are known to consume water, they were assessed as being overall beneficial for water storage capacity, e.g. by their effects on soil structure (increased infiltration).

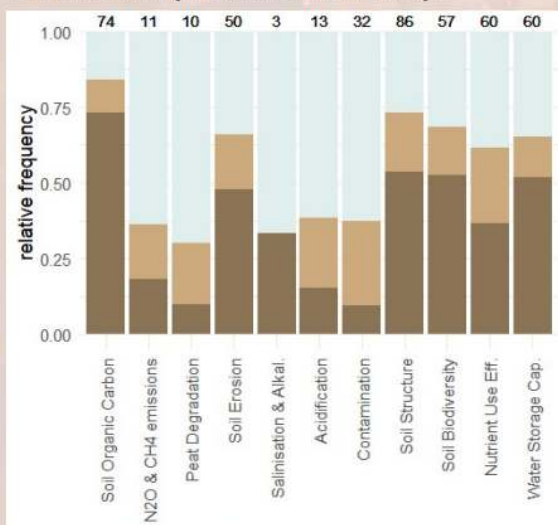


Fig. 1: Relative frequency of the effectivity assessments of cover/catch crops in coping with the different soil challenges: Not effective (blue), moderately (light brown), or very effective (dark brown). Numbers above the bars indicate the number of participants assessing the effectivity for every challenge.



© Pixabay/Ehrecke

Perspectives on feasibility

Nearly all stakeholders assessed feasibility as high or very high (Fig. 2). Consequently, they have been established widely in many regions.

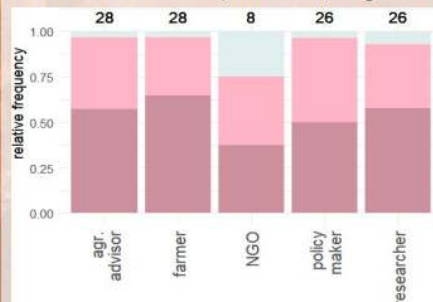


Fig. 2: Relative frequency of the feasibility assessments of cover/catch crops per stakeholder: „Not feasible“ (blue), „Moderately feasible“ (light red), „Easily feasible“ (dark red). Numbers above the bars indicate the number of stakeholders assessing the feasibility.

The inclusion of cover crops into crop rotations is simultaneously effective and feasible. It may not be appropriate in every case (e.g., late harvest, weather conditions for seeding) but should be part of any sustainable cropping system.

Fact sheet on soil management practices

Using Organic Fertilisers

Overview:

In a circular agriculture, deploying organic materials with the harvest requires the return of organic byproducts as a fertiliser. This can be sourced from livestock (e.g., manure, slurry), plant residues (e.g., composting, silage), industry (e.g., feather meal, potato protein), or even sewage treatment plants.

Potentials to tackle soil challenges

The return of organic materials to the field was estimated effective to increase Soil Organic Carbon stocks. First of all, organic inputs contribute directly to the labile (metabolizable) soil organic matter (SOM) pool. Furthermore, soil microorganisms feeding on this labile SOM pool contribute to the build up of stabilized SOM (i.e. mineral associated organic matter). Overall, soil biology is positively affected and produces compounds that increase soil stability and structure. As many organic fertilizers also contain considerable amounts of nutrients, the nutrient use efficiency not only of the crop but of the cropping system increases.



Perspectives on feasibility

Feasibility was estimated high amongst all stakeholders, especially from the perspective of farmers and researchers.

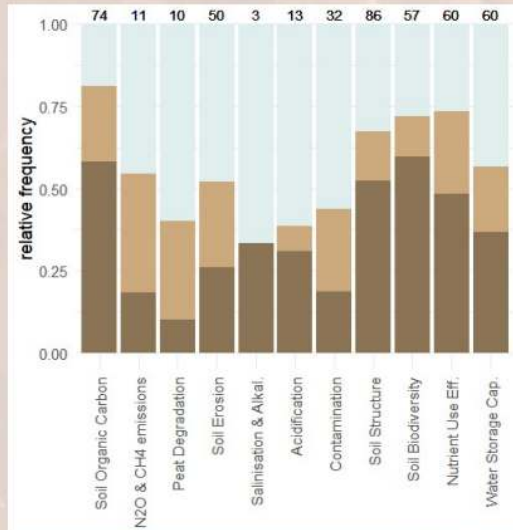


Fig. 1: Relative frequency of the effectivity assessments of using organic fertilizers in coping with the different soil challenges: Not (blue), moderately (light brown), and very effective (dark brown). Numbers above the bars indicate the number of participants assessing the effectivity for every challenge.

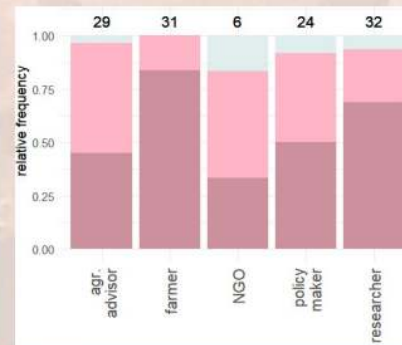


Fig. 2: Relative frequency of the feasibility assessments of using organic fertilisers per stakeholder: „Not feasible“ (blue), „Moderately feasible “ (light red), „Easily feasible“ (dark red). Numbers above the bars indicate the number of stakeholders assessing the feasibility.

Although cropping solely with organic fertilisers is difficult in certain crops (e.g., brassicaceae) and extensive or mountainous regions (challenges of availability, spreading), it should be promoted as a sustainable and valuable element of plant nutrition.

Fact sheet on soil management methods

Diversifying Crop Rotations

Overview:

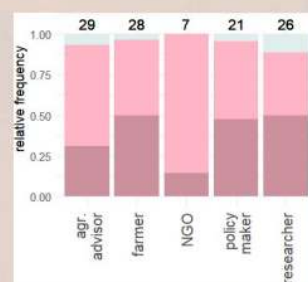
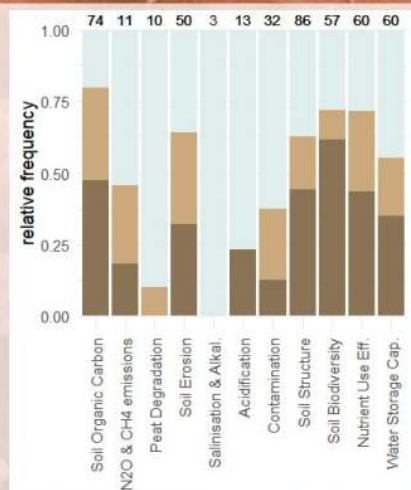
Although arable monocultures are becoming less prevalent in the EU, conventional crop rotations often contain not more than 3 crops. Diversifying crop rotations not only increases the economic stability of a farm but has several positive effects: Less dominance of problematic weeds, less plant diseases, and, when including legumes, additional fertilisation due to their atmospheric nitrogen fixation. This culminates in a reduction of inputs (pesticides, fertilisers). However, selling only a few main crops may be easier and in the short run more economical.



Potentials to tackle soil challenges

A diversified crop rotation was estimated to build up Soil Organic Carbon levels, e.g., by including fodder legumes. Their binding of atmospheric nitrogen may also increase nutrient use efficiency, and including clover or other perennial crops may positively affect soil structure. High crop diversity was also associated with high soil biodiversity.

Fig. 1: Relative frequency of the effectivity assessments of cover/catch crops in coping with the different soil challenges: „Not effective“ (blue), „Moderately effective“ (light brown), „Very effective“ (dark brown). Numbers above the bars indicate the number of participants assessing the effectivity for every challenge.



Perspectives on feasibility

Overall feasibility was high, however, a great share of participants estimated the practice as moderately feasible. Thus, changes are possible but require certain conditions (e.g., marketing of certain crops, machinery, knowledge).

Fig. 2: Relative frequency of the feasibility assessments of cover/catch crops per stakeholder: „Not feasible“ (blue), „Moderately feasible“ (light red), „Easily feasible“ (dark red). Numbers above the bars indicate the number of stakeholders assessing the feasibility.

Fact sheet on soil management practices

Include legume-based grassland/pastures in crop rotations

Overview:

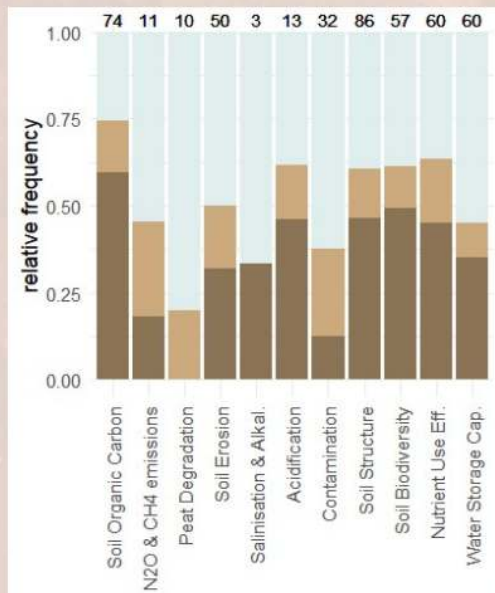
Amongst leguminous crops, fodder legumes such as clover or alfalfa bind the greatest amounts of atmospheric nitrogen. With increasing application of mineral fertilisers and more arable farms, their cultivation decreased. Cropping is similar to other pastures, but often without nitrogen fertilisation and grazing.

Potentials to tackle soil challenges

The effect of fodder legume cropping on Soil Organic Carbon stocks was estimated high—fixation provides additional nitrogen to the microorganisms. Plant residues, roots, and their exudates supplement carbon, and the stability of organic matter increases with non-disturbance of the soil. This rest and the densely rooted topsoil are also beneficial for soil structure and soil biodiversity. Reduced fertilizer amounts reduce acidification and increase nutrient use efficiency.



Clovergrass stand © KleeLuzPlus (S. Glowacki)



Perspectives on feasibility

More than half of farmers and researchers assessed the practice as easily feasible, with overall >80% estimating at least a moderate feasibility.

The benefit of fodder legumes on soil health is widely accepted. In organic agriculture, including leguminous pastures in the crop rotation is a standard procedure. Especially for farmers that have a use for the fodder themselves, this practice is of high interest (also in conventional farming).

Fig. 1: Relative frequency of the effectivity assessments of using organic fertilizers in coping with the different soil challenges: „Not effective“ (blue), „Moderately effective“ (light brown), „Very effective“ (dark brown). Numbers above the bars indicate the number of participants assessing the effectivity for every challenge.