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Switzerland's EJP SOIL Stocktake

Tasks 2.1, 2.2 and 2.3

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Table of Contents

Summary

This report aims at transparently showing Switzerland's Stocktake contribution to EJP SOIL Tasks 2.1, 2.2 and 2.3, and is mainly addressed to the contributing Swiss stakeholders and National Hub members. For the Swiss contribution to EJP SOILs research roadmap we conducted three main activities. First, a stakeholder survey with 32 stakeholders representing different parts of the Swiss agricultural knowledge system. Second, a series of state of knowledge reports. Third, an analysis of current and planned agricultural, environmental and spatial planning policies and their targets and ambitions related to sustainable agricultural soil management.

The stakeholders largely agreed that the main challenges to sustainable agricultural soil management and connected research needs in Switzerland are soil compaction, soil erosion, soil organic carbon (SOC) loss and peat degradation, soil biodiversity loss and soil contamination. Soil sealing was considered an important soil challenge but fewer knowledge gaps related with it were identified.

A wide range of approaches and measures to improve the production, dissemination and application of knowledge on sustainable soil management (SSM) practices have been voiced by stakeholders. Based on the reviewed scientific literature, we concluded that for sealing, erosion, compaction, contamination and nutrient use efficiency the knowledge base is most advanced. However, scientific experts formulated research needs for all soil challenges.

In Switzerland's agricultural, environmental and spatial planning policies the maintenance of the functionality of soils and enabling its sustainable management have high priority. However, many policy targets are qualitative in nature and their current status remains unclear.

Our findings, as summarized in Table I, suggest that there is wide consensus among the views of stakeholders, researchers and policy makers on the most important soil challenges in Switzerland (i.e. soil compaction, soil sealing, soil erosion, SOC loss, soil biodiversity loss and soil contamination). These soil challenges are addressed by active or planned policies and are subject to past or ongoing research activities. For other, supposedly less urgent, soil challenges either the state of knowledge, the integration into policies or both are less advanced.

In regard to future research, we conclude (i) that additional methods to monitor and evaluate soil quality, soil functions and ecosystem services provided by soils need to be established, and (ii) the application of participatory multi-stakeholder approaches for the valuation of different soil functions, as well for the future direction of soil science research in general need to be more commonly utilized.

Table I EN: Summary of soil challenge importance, knowledge base and policy integration

Soil Challenge	Importance according to survey	Quality of knowledge base	Taken into account by policy
Soil Compaction	++	+	(+)
Soil Sealing	++	++	(+)
Soil Erosion	++	+	+
SOC loss	++	-	(+)
Soil Biodiversity loss	++	-	(+)
Soil Contamination	++	+	+
Peat degradation	+	-	
Low H_2O retention	+		
N_2O & CH_4 emissions	+	-	
Low nutrient use efficiency	+/-	+	(+)
Soil Acidification	+/-		
Soil Salinization	-		
Poor condition of the drainage systems	+	-	Not considered in the policy analysis
Qualitatively insufficient soil improvements	+		
Qualitatively insufficient soil recultivations	+		
Irrigation of unsuitable land	+/-		

Survey: ++: considered (rather) important by a majority of stakeholders
+: considered (rather) important by many stakeholder
+/-: consideration contradictory by stakeholder
-: considered (rather) unimportant by a majority of stakeholders

Knowledge: ++: good knowledge base
+: advanced knowledge base
-: non-advanced knowledge base
empty: Not considered in the State of Knowledge Report

Policy: +: addressed by active policies
(+):addressed by future policy ambitions
leer: no measures were found in the policy analysis

Zusammenfassung

Der vorliegende Bericht zielt darauf ab, den Beitrag der Schweiz zur EJP SOIL Bestandsaufnahme (Tasks 2.1, 2.2 und 2.3) transparent darzustellen, und richtet sich hauptsächlich an die beitragenden Schweizer Stakeholder und die Mitglieder des Schweizer 'National Hub'. Für den Schweizer Beitrag zur EJP SOIL 'research roadmap' führten wir drei Hauptaktivitäten durch. Erstens eine Stakeholder-Umfrage mit 32 Stakeholdern, die verschiedene Teile des landwirtschaftlichen Wissenssystems der Schweiz repräsentieren. Zweitens eine Reihe von drei Berichten zum aktuellen Wissensstand. Drittens eine Analyse der aktuellen und geplanten Landwirtschafts-, Umwelt- und Raumplanungspolitik sowie deren Ziele und Ambitionen in Bezug auf eine nachhaltige landwirtschaftliche Bodenbewirtschaftung.

Die Stakeholder waren sich weitgehend einig, dass die Hauptherausforderungen für eine nachhaltige landwirtschaftliche Bodenbewirtschaftung in der Schweiz Bodenverdichtung, Bodenerosion, Humusverlust (im Ackerbaugebiet) und Torfschwund, Verlust von Bodenbiodiversität und Bodenkontamination sind. Ebenfalls wurde der zugehörige Forschungsbedarf als relativ hoch eingeschätzt. Die Bodenversiegelung wurde als eine wichtige Herausforderung für die quantitative Bodenschutzpolitik betrachtet, aber es wurden wenige Wissenslücken in diesem Zusammenhang festgestellt.

Die Stakeholderbefragung ermöglichte die Zusammenstellung einer breite Palette von Ansätzen und Massnahmen zur Verbesserung der Erarbeitung, Verbreitung und Anwendung von Wissen über nachhaltige Bodenbewirtschaftung. Auf der Grundlage der gesichteten Literatur kamen wir zum Schluss, dass die Wissensbasis in Bezug auf Versiegelung, Erosion, Verdichtung, Kontamination und Nährstoff-Nutzungseffizienz am weitesten fortgeschritten ist. Wissenschaftliche Experten formulierten jedoch Forschungsbedarf für alle 'Soil Challenges'.

In der Landwirtschafts-, Umwelt- und Raumplanungspolitik der Schweiz haben die Erhaltung der Funktionsfähigkeit der Böden und die Ermöglichung ihrer nachhaltigen Bewirtschaftung hohe Priorität. Viele politische Ziele sind jedoch qualitativer Natur, und ihr aktueller Status bleibt unklar.

Unsere Ergebnisse, die in der untenstehenden Tabelle I zusammengefasst sind, deuten darauf hin, dass es einen breiten Konsens zwischen den Ansichten von Stakeholdern, Forschern und politischen Entscheidungsträgern zu den wichtigsten Herausforderungen für die Sicherung der Qualität und Quantität landwirtschaftlich genutzter Böden in der Schweiz gibt (d.h. Bodenverdichtung, Bodenversiegelung, Bodenerosion, Humusverlust, Verlust von Bodenbiodiversität). Diese 'Soil Challenges' werden durch aktive oder geplante politische Massnahmen angegangen und sind Gegenstand vergangener oder laufender Forschungsaktivitäten. In Bezug auf andere, vermeintlich weniger relevante 'Soil Challenges'[1] sind entweder der Wissensstand, die Integration in politische Massnahmen oder beides weniger weit fortgeschritten.

Im Hinblick auf die künftige Forschung kommen wir zu den Schlüssen, dass (i) zusätzliche Methoden zur Überwachung und Bewertung der Bodenqualität, der Bodenfunktionen und der von den Böden erbrachten Ökosystemleistungen bereitgestellt werden müssen und (ii) die Anwendung partizipativer Multi-Stakeholder-Ansätze für die Bewertung verschiedener Bodenfunktionen sowie für die künftige Ausrichtung der Bodenforschung im Allgemeinen stärker genutzt werden sollte.

[1] Der Sammelbegriff 'Soil Challenge' wird im Rahmen des EJP SOIL verwendet und fasst die verschiedenen Herausforderungen für die Erhaltung und Förderung der Bodenfunktionen und der von Böden erbrachten Ökosystemdienstleistungen zusammen. Der Begriff umfasst mitunter die im Deutschen verwendeten Sammelbegriffe der 'Bodenbedrohungen'. Eine mögliche Liste der 'Soil Challenges' kann der Tabelle I entnommen werden.

Tabelle I DE: Zusammenfassung der Relevanz der 'Soil Challenges', der zugehörigen Wissensbasis und deren Berücksichtigung in politischen Massnahmen.

Soil Challenge	Bedeutung gemäss Umfrage	Qualität der Wissensbasis	Berücksichtigung in Politik
Verdichtung	++	+	(+)
Versiegelung	++	++	(+)
Erosion	++	+	+
Humusverlust	++	-	(+)
Verlust von Bodenbiodiversität	++	-	(+)
Kontaminationen	++	+	+
Torfschwund	+	-	
Geringe Wasserhaltefähigkeit	+		
Lachgas- und Methanemissionen	+	-	
Geringe Nährstoff-Nutzungseffizienz	+/-	+	(+)
Versauerung	+/-		
Versalzung	-		
Schlechter Zustand der Drainagen	+	-	Nicht berücksichtigt in Recherche
Qualitativ ungenügende Bodenverbesserungen	+		
Qualitativ ungenügende Rekultivierungen	+		
Bewässerung von ungeeigneten Flächen	+/-		

Umfrage: ++: von der Mehrheit der Befragten als wichtig oder eher wichtig beurteilt
+: von vielen Befragten als wichtig oder eher wichtig beurteilt
+/-: Von den Befragten sehr unterschiedlich beurteilt
-: von der Mehrheit der Befragten als unwichtig oder eher unwichtig beurteilt

Wissensbasis: ++: weit fortgeschrittene Wissensbasis
+: fortgeschrittene Wissensbasis
-: geringe Wissensbasis
leer: wurde in der Literatur-Recherchen zum aktuellen Wissensstand nicht berücksichtigt

Politik: +: Von aktuellen Massnahmen berücksichtigt
(+): Von geplanten Massnahmen berücksichtigt
leer: Es wurden im Rahmen der Recherche keine Massnahmen gefunden

Résumé

Ce rapport vise à montrer de manière transparente le bilan de la contribution de la Suisse aux tâches 2.1, 2.2 et 2.3 de l'EJP SOIL et s'adresse principalement aux stakeholders suisses et aux membres du National Hub. Pour la contribution suisse de la feuille de route de recherche EJP SOIL, nous avons mené trois activités principales. Premièrement, une enquête auprès de 32 stakeholders représentant différentes parties du système suisse des connaissances agricoles. Deuxièmement, une série de rapports sur l'état des connaissances. Troisièmement, une analyse des politiques agricoles, environnementales et d'aménagement du territoire actuelles et prévues, ainsi que leurs objectifs et ambitions liés à la gestion durable des sols agricoles.

Les stakeholders ont largement convenu que les principaux défis de la gestion durable des sols agricoles ('soil challenges'[2]) et des besoins de recherche connexes en Suisse sont la compaction des sols, l'érosion des sols, la perte de carbone organique et la dégradation des tourbes, la perte de biodiversité des sols et la pollution des sols. L'imperméabilisation des sols est également considérée comme un défi majeur pour les sols, mais cette thématique souffre moins de lacunes dans les connaissances.

Un large éventail d'approches et de mesures visant à améliorer la production, la diffusion et l'application des connaissances sur les pratiques de gestion durable des sols (SSM) a été exprimé par les stakeholders. Sur la base de la littérature scientifique examinée, nous avons conclu que les connaissances sont les plus avancées pour l'imperméabilisation, l'érosion, la compaction, la pollution et l'efficacité de l'utilisation des éléments nutritifs. Cependant, les experts scientifiques ont formulé des besoins de recherche pour tous les défis du sol.

Dans les politiques d'agriculture, d'environnement et d'aménagement du territoire de la Suisse, le maintien des fonctions du sol et leur gestion durable sont une priorité absolue. Cependant, de nombreux objectifs politiques sont de nature qualitative et leur statut actuel reste incertain.

Nos résultats, tels que résumés dans le tableau ci-dessous, suggèrent qu'il existe un large consensus parmi les points de vue des stakeholders, des chercheurs et des décideurs politiques sur les principaux défis pour les sols en Suisse (à savoir la compaction des sols, l'imperméabilisation des sols, l'érosion des sols, la perte de carbone organique, la biodiversité des sols, perte et pollution du sol). Ces défis du sol sont abordés par des politiques actives ou planifiées et font l'objet d'activités de recherche passées ou en cours. Pour d'autres défis du sol, supposément moins urgents, soit l'état des connaissances, soit l'intégration dans les politiques ou les deux sont moins avancés.

En ce qui concerne les recherches futures, nous concluons (i) que des méthodes supplémentaires pour surveiller et évaluer la qualité des sols, les fonctions des sols et les services écosystémiques fournis par les sols doivent être établies, et (ii) l'application d'approches participatives multi-acteurs pour l'évaluation des différentes fonctions du sol, ainsi que pour l'orientation future de la recherche en sciences du sol en général, doivent être utilisées plus couramment.

[2] Le terme collectif 'soil challenge' est utilisé dans le contexte du programme EJP SOIL et résume les différents défis pour la conservation et la promotion des fonctions des sols et des services écosystémiques fournis par les sols. Ce terme englobe parfois les termes collectifs de "menaces pour les sols". Une liste possible de "défis pour les sols" figure dans le tableau I.

Table I FR: Résumé de l'importance du soil challenge importance, de la base de connaissances et de l'intégration dans les politiques

<table>
<tr><th>Soil Challenge</th><th>Importance selon l'enquête</th><th>Qualité de l'état des connaissances</th><th>Prise en compte dans les politiques</th></tr>
<tr><td>Compaction du sol</td><td>++</td><td>+</td><td>(+)</td></tr>
<tr><td>Imperméabilisation du sol</td><td>++</td><td>++</td><td>(+)</td></tr>
<tr><td>Erosion du sol</td><td>++</td><td>+</td><td>+</td></tr>
<tr><td>Perte de carbone organique</td><td>++</td><td>-</td><td>(+)</td></tr>
<tr><td>Perte de biodiversité</td><td>++</td><td>-</td><td>(+)</td></tr>
<tr><td>Pollution des sols</td><td>++</td><td>+</td><td>+</td></tr>
<tr><td>Dégradation des tourbes</td><td>+</td><td>-</td><td></td></tr>
<tr><td>Faible rétention d'eau</td><td>+</td><td></td><td></td></tr>
<tr><td>Emissions N_2O & CH_4</td><td>+</td><td>-</td><td></td></tr>
<tr><td>Faible efficacité des éléments nutritifs</td><td>+/-</td><td>+</td><td>(+)</td></tr>
<tr><td>Acidification du sol</td><td>+/-</td><td></td><td></td></tr>
<tr><td>Salinisation du sol</td><td>-</td><td></td><td></td></tr>
<tr><td>Drainage sub-optimal</td><td>+</td><td>-</td><td rowspan="4">Pas pris en compte dans l'analyse</td></tr>
<tr><td>Amélioration des sols sub-optimale</td><td>+</td><td></td></tr>
<tr><td>Remédiation/remise en culture sub-optimale</td><td>+</td><td></td></tr>
<tr><td>Irrigation adéquate sub-optimale</td><td>+/-</td><td></td></tr>
</table>

Enquête:	++: considéré (plutôt) important par une majorité de stakeholders
	+: considéré (plutôt) important par beaucoup de stakeholders
	+/-: considération contradictoire par les stakeholders
	-: considéré (plutôt) pas important par une majorité de stakeholders
Connaissances:	++: bon état des connaissances
	+: état des connaissances avancé
	-: état des connaissances peu avancés
	vide: pas pris en compte dans le rapport sur l'état des connaissances
Politiques:	+: pris en compte par des politiques actives
	(+): prise en considération par des ambitions de politiques futures
	leer: aucune mesure n'a été trouvée dans le cadre de la recherche

1 Introduction

EJP SOIL is a European Joint Programme Cofund on Agricultural Soil Management contributing to key societal challenges including climate change and future food supply. The objectives of EJP SOIL are to develop knowledge, tools and an integrated research community to foster climate-smart sustainable agricultural soil management that allows sustainable food production, supports soil biodiversity and sustains soil functions that preserves ecosystem services.

The EJP SOIL consortium consists of 26 partner institutions form 24 countries across Europe (Figure 1). EJP SOIL runs from 2020 to 2025 and has a total budget of approximately 80 Mio. €, with roughly half of this contributed by the participating institutions. Agroscope is representing Switzerland within the EJP SOIL consortium. Further information can be found on the EJP SOIL Website

Figure 1: European countries represented in EJP SOIL

1.1 Aim of this Report

This report summarizes Switzerland's national stocktake contribution to EJP SOIL Tasks 2.1, 2.2 and 2.3. The stocktake activities provide the basis for the development of EJP SOILs research roadmap. The roadmap will outline key research and capacity building priorities, support soil data harmonisation, policy-making and knowledge implementation.

This report is mainly addressed to the Swiss stakeholder and National Hub members that contributed to the different parts of this report. Furthermore, the report aims to inform an interested audience about the findings of the Swiss Stocktake and transparently show Switzerland's contribution to EJP SOIL Tasks 2.1 through 2.3.

1.2 Contribution to EJP SOIL WP 2

All parts of this report, except for the overall summary and conclusions, have fed into different tasks and deliverables within the EJP SOIL work package 2. Table 1 summarizes the correspondence of EJP SOIL tasks and sections of this report.

Table 1: Correspondence between report sections and EJP SOIL WP2 tasks

Report Section	Heading	Main author(s)	EJP SOIL WP2
2.2.1	Soil Challenge identification and research needs	O. Heller, N. Peter	Tasks 2.2.2 and 2.3
2.2.2	Knowledge System and Coordination	O. Heller	Tasks 2.2.2
2.2.3	Improving Knowledge Production, Dissemination and Use	O. Heller, N. Peter	Task 2.2.2 and 2.3
3	State of Knowledge Reports	O. Heller	Task 2.2.1
4	Policy Analysis	N. Peter	Task 2.1

2 Stakeholder Surveys

2.1 Approach

2.1.1 Stakeholder Identification and Selection

32 stakeholders have been recruited from the Swiss Agricultural Knowledge System[3].They represent all relevant levels of government (i.e. federal and cantonal) and organizations known for promoting the application of SSM (e.g. Swiss No-Till association). The stakeholders have manifold perspectives on soil management: farming operations, agricultural policy enforcement, education, soil protection, and site improvement (e.g. drainage). The selection of persons was based on their documented interest in SSM related topics (professional interest, participation in SSM related training, etc.) and the network of the involved research group (soil quality and soil use). A list of the involved stakeholders can be found in Annex I.

2.1.2 Questionnaires

Based on the EJP SOIL guidelines for WP2 [4,5] three questionnaires were designed. The topics of the questionnaires were:

1) Knowledge System
2) Research Needs
3) Challenges and Opportunities.

The questions and the framing of the questions were largely determined by the EJP SOIL guidelines and modified to suite the Swiss context.

The interviews were conducted using an online survey tool. Stakeholders received one or two of three different questionnaires, depending on their role in the knowledge system. 17 stakeholder received survey 1, 13 survey 2 and 16 survey 3. The allocation of stakeholders to surveys can be found in Annex I.

A total of 16 multiple choice and 21 open text questions were asked to the stakeholders. The complete list of questions in German can be found in Annex II. Questionnaires 1 and 2 were translated into French.

2.2 Results

On average, stakeholders spent 27 (±10) minutes to answer questionnaire 1, 37 (±28) minutes to answer questionnaire 2 and 57 (±33) minutes to answer questionnaire 3.

In this section, the questions and stakeholder answers were translated into English. Stakeholder answers were synthesised for enhanced readability.

All statements in this section (2.2 Results) reflect the views of stakeholders and not necessarily the views of the authors, Agroscope or EJP SOIL.

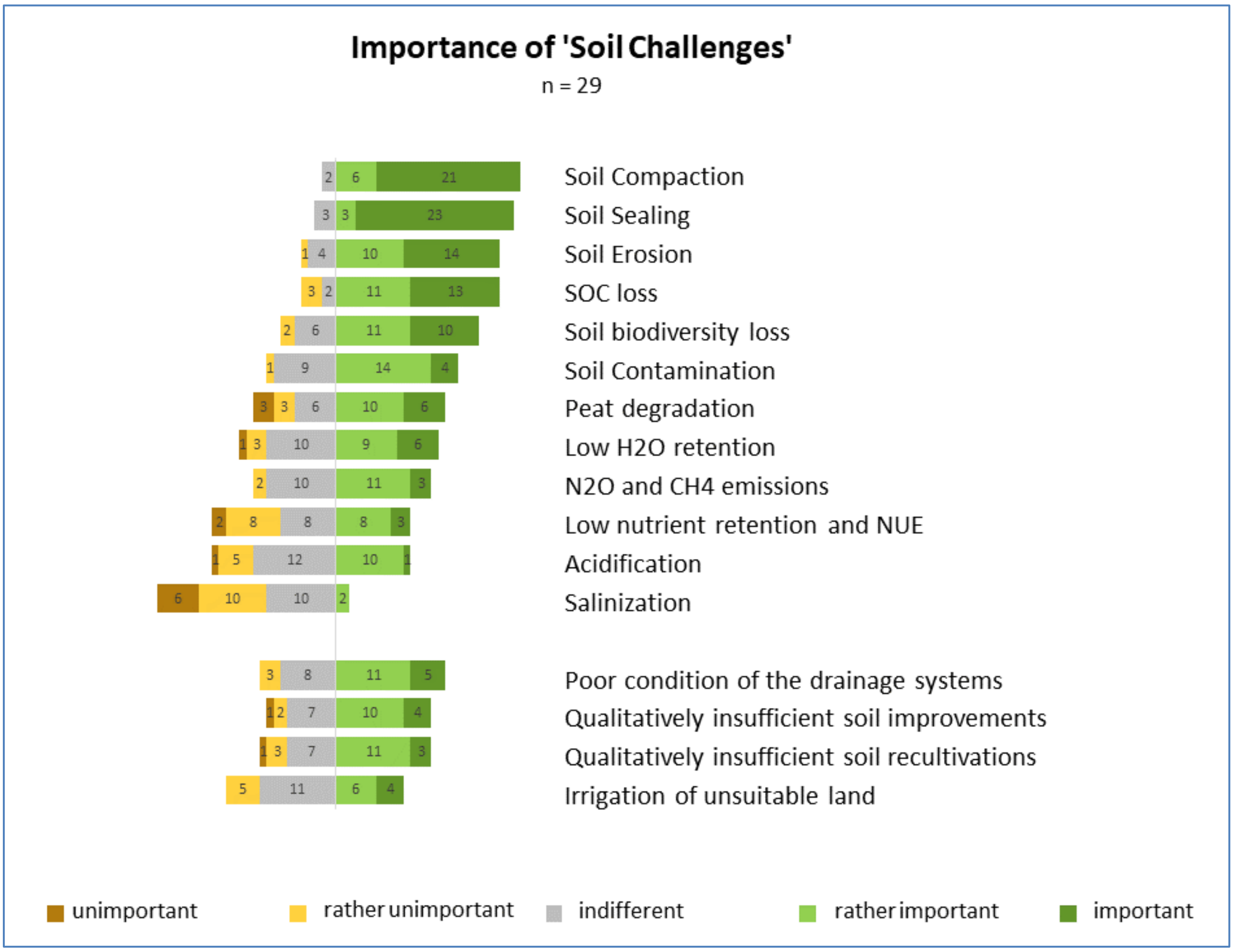
[3] Buess A. et al., 2011. Das Landwirtschaftliche Wissensystem der Schweiz. Agrarforschung Schweiz 2 (11-12), 484 – 489.
[4] Mulkholm L. J. & Thorsøe M. H., 2020. EJP SOIL Task 2.2: Knowledge availability and use – Guidelines for national analysis.
[5] Farina R., Di Bene C., Piccini C. & Vanino S., 2020. EJP SOIL Task 2.3: Identification of barriers and opportunities by scenario development.

2.2.1 Soil Challenge Identification and Research Needs

Importance of 'Soil Challenge'

In Figure 2, stakeholder opinions on the importance of 'Soil challenges' in Switzerland are displayed. In regards to 'SOC loss' we need to mention that two stakeholders stated to have answered this question with a focus on permanent grasslands.

Figure 2: Importance of 'Soil Challenges' as indicated by stakeholder

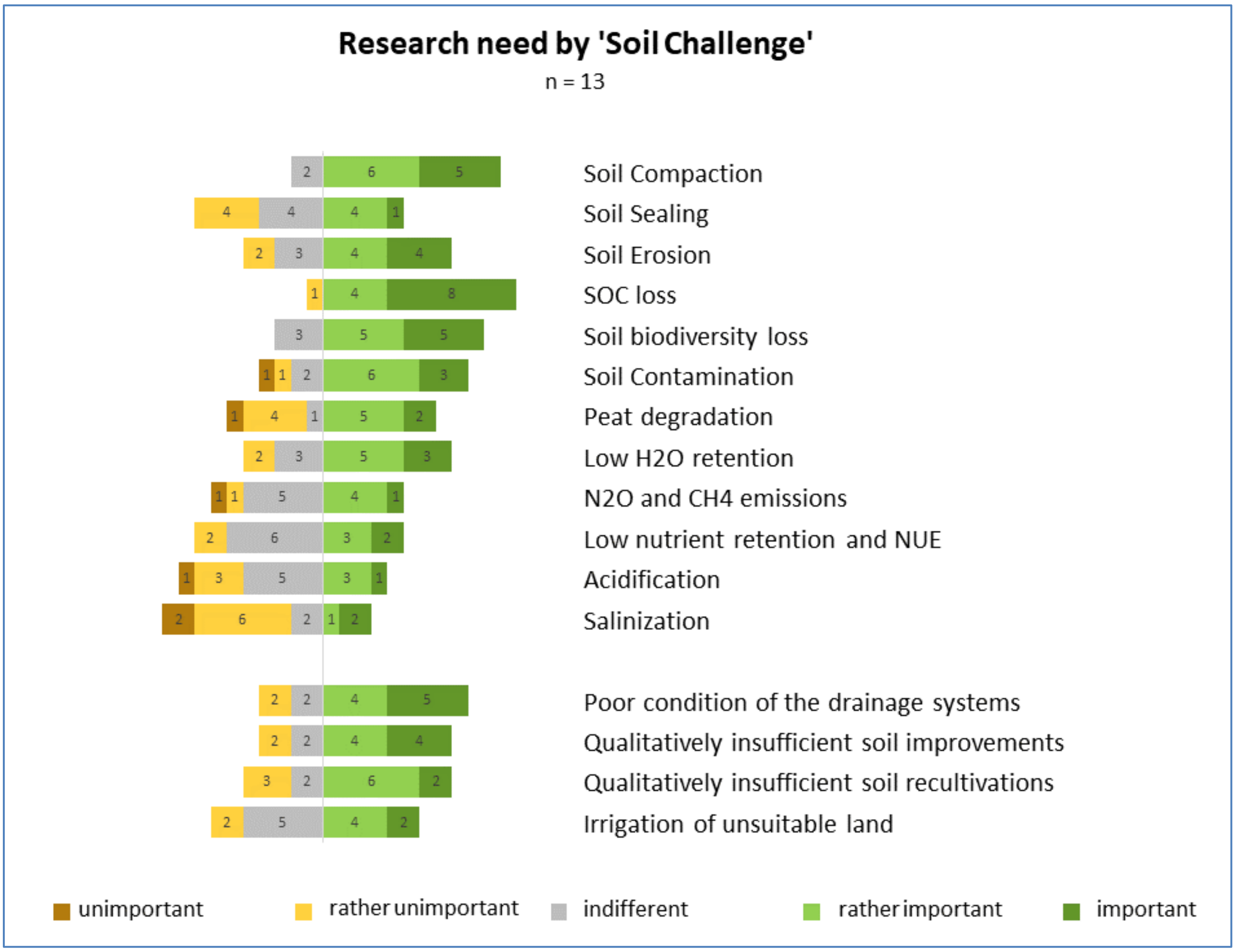


Research need by soil challenge

The stated research need by soil challenge (Figure 3) largely coincided with the stated importance of the soil challenges (Figure 2). An important exception was 'soil sealing', for which to stakeholders, research on this topic seems less important than for other soil challenges.

According to the majority of Swiss stakeholders, besides the 'official EJP SOIL Challenges' there are additional soil challenges that are important and need further research. These soil challenges are the optimization of soil water balances by improved drainage techniques, the technical reinstatement of soils (recultivation) and technical soil improvements (e.g. with off-site organic soil material). Only a few stakeholders considered the irrigation of unsuitable sites to be an additional soil challenge.

Figure 3: Importance of research needs per 'Soil Challenges' as indicated by stakeholder



Most important research needs

The most important, non-challenge-specific research gaps mentioned by stakeholders were:

- **Effective** approaches and methods for **dissemination of SSM knowledge** and practices need to be developed and established.
- A main open research question seems to be: "What are **site-adapted SSM practices** at a specific location or region?" Site characteristics are diverse (e.g. organic and mineral soils), thus their sustainable management is diverse too and needs to account for the interaction of multiple soil challenges.
- Efficient, holistic and **easy-to-apply soil quality indicators** need establishment to assess the suitability of SSM practices and systems.
- According to stakeholders concerned with drainage systems, there are many open questions regarding **efficient and effective drainage**. How to sustain, reinstate and improve drainage systems? Can drainage systems be optimized to minimize environmental impacts, for example by dynamic regulation of the ground water level? What are the overall effects of drainage systems on production, soils and environment?

Many stakeholders were concerned with knowledge gaps linked to specific soil challenges. Some of the knowledge gaps are listed below. Furthermore, stakeholder views on how to address the soil challenges of compaction, erosion, sealing, SOC loss and qualitatively insufficient recultivations are summarised in Annex **III**.

- Knowledge on **avoiding soil compaction and the restoration of compacted soils** is said to be missing. The effect and impact of heavy machines and subsoil compaction on soil fertility and yields, strategies to avoid subsoil compaction in grasslands and strategies to reverse soil compaction were asked for.

- **Management factors of SOC dynamics** are not documented well enough. Advise on how to effectively and efficiently increase and maintain SOC stocks is needed.

- The **function, impact and state of soil biology** seems understudied. Methods to easily assess soil biological status and management strategies to improve soil biology are lacking. Furthermore, one stakeholder mentioned that the effect of microbial amendments (e.g. compost-teas) are understudied.

- The processes, activities and timescales for the **restoration of degraded soils** (e.g. compacted, contaminated or low SOC soils) are unknown according to stakeholders.

- Some stakeholders were asking for deeper understanding on the **long-term effects of chemical and mechanical crop protection** strategies on soil quality.

Most important gaps in current soil monitoring

Gaps in the current soil monitoring were mentioned by a few stakeholders and are summarised below. For further considerations, the statements mentioned below could be cross-referenced with a recent NABO foresight study[6].

- Some stakeholders said that the **existing monitoring networks** should **coordinate** more effectively and that outputs could be more targeted towards farmers and other stakeholders. Furthermore, the number of sites should be increased to represent the diversity of soils and soil management practices found in Switzerland. For example, the number of sites on organic soils ought to be increased and the site selection should allow the comparison of drained and undrained sites.

- The survey participants named **many additional aspects that could be monitored** in the future. The management (incl. drainage) of the monitoring sites should be described and assessed to evaluate management effects. Further, all sites should be evaluated with an integrated soil quality index, instead of just single parameters. The list of mentioned soil properties that could be examined is relatively long. Besides subsoil properties in general, it includes physical soil parameters, soil compaction, soil biology, SOC stock changes in the whole profile, peat degradation status, contamination by micro plastics and other 'toxic' compounds.

- A national **inventory** of the quantity and quality of the prime cropland with **'FFF'**-quality is a requested feature of a future soil monitoring system.

- Furthermore, the stakeholders asked how the findings of the monitoring networks can be used to draw **conclusions for the state of all soils**.

[6] Gubler A., Meuli R. G. & Keller A., 2020. Bedürfnisse der Kantone und des Bundes rund um ein Monitoring der Ressource Boden: Erfassung und Beurteilung von Risiko, Zustand und zeitlicher Entwicklung durch flächenhafte Erhebungen (Kartierung) und langfristige Beobachtung. Agroscope, NABO, Im Auftrag des Bundesamtes für Umwelt (BAFU), Zürich-Reckenholz.

2.2.2 Knowledge System and Coordination

State of the agricultural knowledge system

Stakeholders were asked for their opinion on eight statements about the state of the Swiss agricultural knowledge system and its capability to provide knowledge on SSM to farmers (Figure 4). There is considerable variation among the answers. In general, stakeholders involved in farmer education and advisory services were more likely to agree with the statements, whereas researchers and farmers representatives tended to disagree.

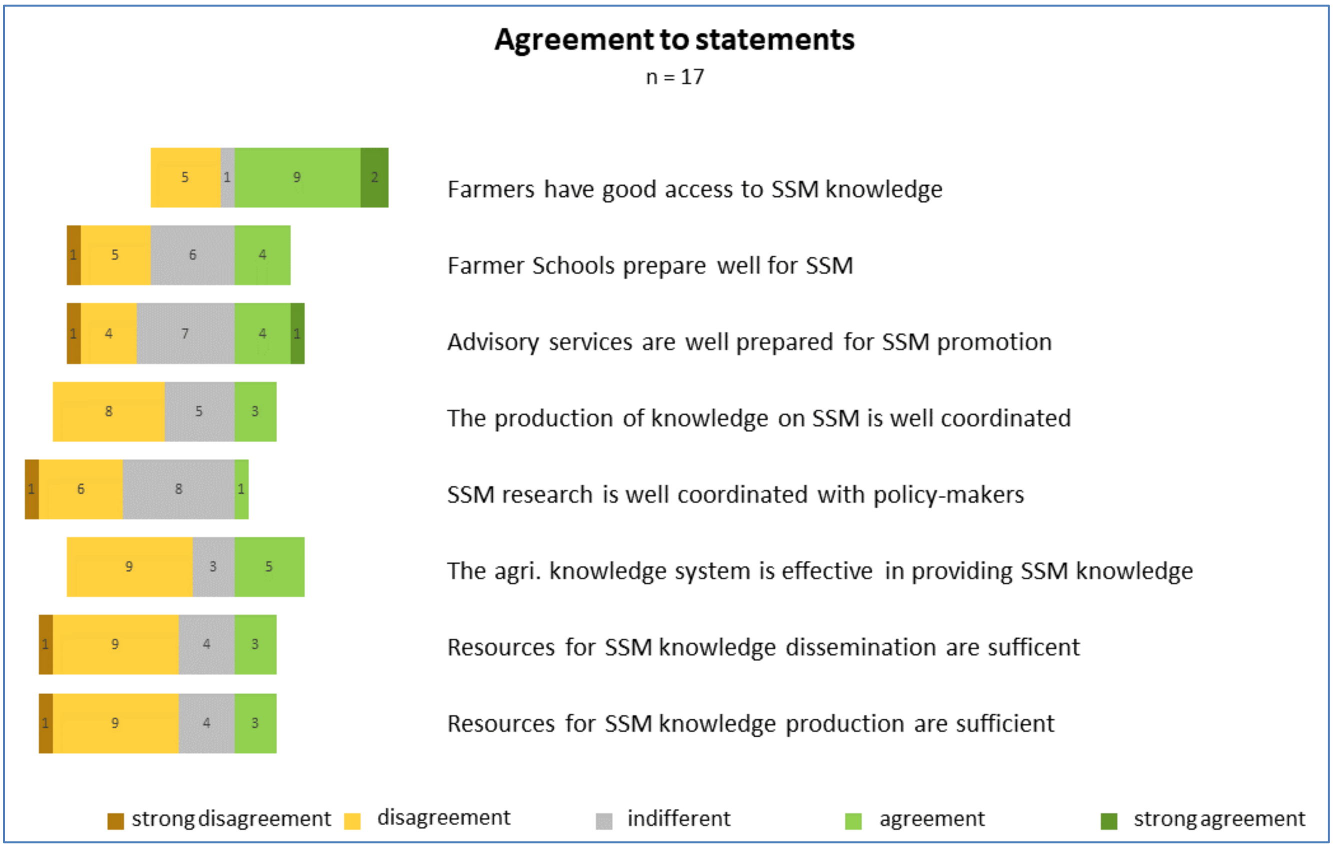


Figure 4: Stakeholders opinion on statements about the state of the Swiss agricultural knowledge system

Use of different platforms for SSM knowledge dissemination

Stakeholders were asked about the use of different platforms for SSM knowledge dissemination. Besides the platforms reported in Figure 5, other platforms were mentioned, including digital platforms (i.e. social media such as YouTube and messenger groups), the Swiss soil science society, and mandatory advisory services, e.g. as a part of voluntary direct payment programs, such as a 'Ressourcenprojekt'.

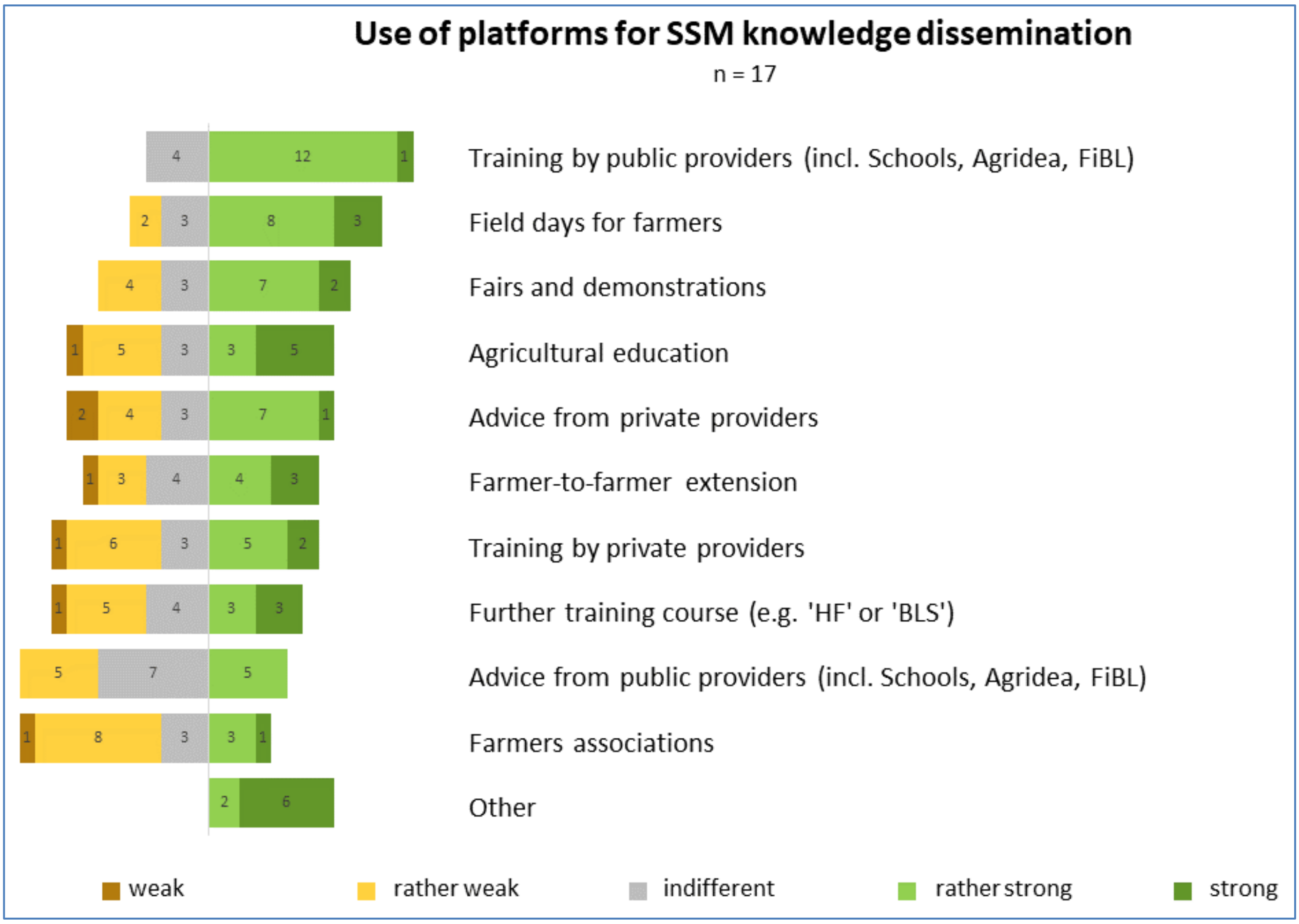


Figure 5: Use of different platforms for the dissemination of knowledge on sustainable soil management

How to improve coordination?

Stakeholders were asked how to coordination within the Swiss agricultural knowledge system could be improved:

- A **national strategy to SSM dissemination and advisory** could be developed. SSM communication and outreach could be harmonized.
- A national or regional **SSM network** could be established. The network should involve all relevant stakeholders, such as farmer groups and organizations (e.g. Swiss No-Till and the regenerative farming movement), advisors, researchers, existing networks (e.g. Forum Ackerbau), contracting companies and agricultural cooperatives. Furthermore, the network should be easily accessible.
  The network should provide the opportunity to exchange knowledge and experience on SSM. This network could host web-based platforms, apps and events. Shared content should involve information for farmers, advisors as well as authorities (e.g. Ressourcenprojekte). The coordination of this network should be adequately and permanently hosted and funded (e.g. Agridea).
  This proposed network could help to increase cooperation between producers (e.g. between potato, vegetable and sugar beet producers), increase cooperation and exchange between research and practitioners, and insure better linkage between research and policy makers and authorities.
  By the increased exchange, soil research shall be more strongly aligned with the needs of farmers and policy makers. Therefore, such research can provide effective support to advisors and farmers. Within the network it could also be decided what approaches, techniques and machines are to be assessed and later on promoted. The network could also facilitate common use of resources and competences among research activities.

- On the governmental level, **soil protection agencies** could be more **involved in** the **agricultural policy** framework and its enforcement.
- A **common terminology on SSM** needs establishment to attain a fruitful coordination of stakeholders. Some stakeholders use different terms and concepts when they talk about SSM related topics. Furthermore, this common terminology needs to be adapted to three languages (French, German, and Italian).

2.2.3 Improving Knowledge Production, Dissemination and Use

Approaches to improve the 'soil knowledge' base

Stakeholders found that there are multiple approaches to improve the 'soil knowledge' base in Switzerland (Figure 6). Besides the approaches suggested by EJP SOIL, participative development of research and policy as well as the support of digital learning were considered important.

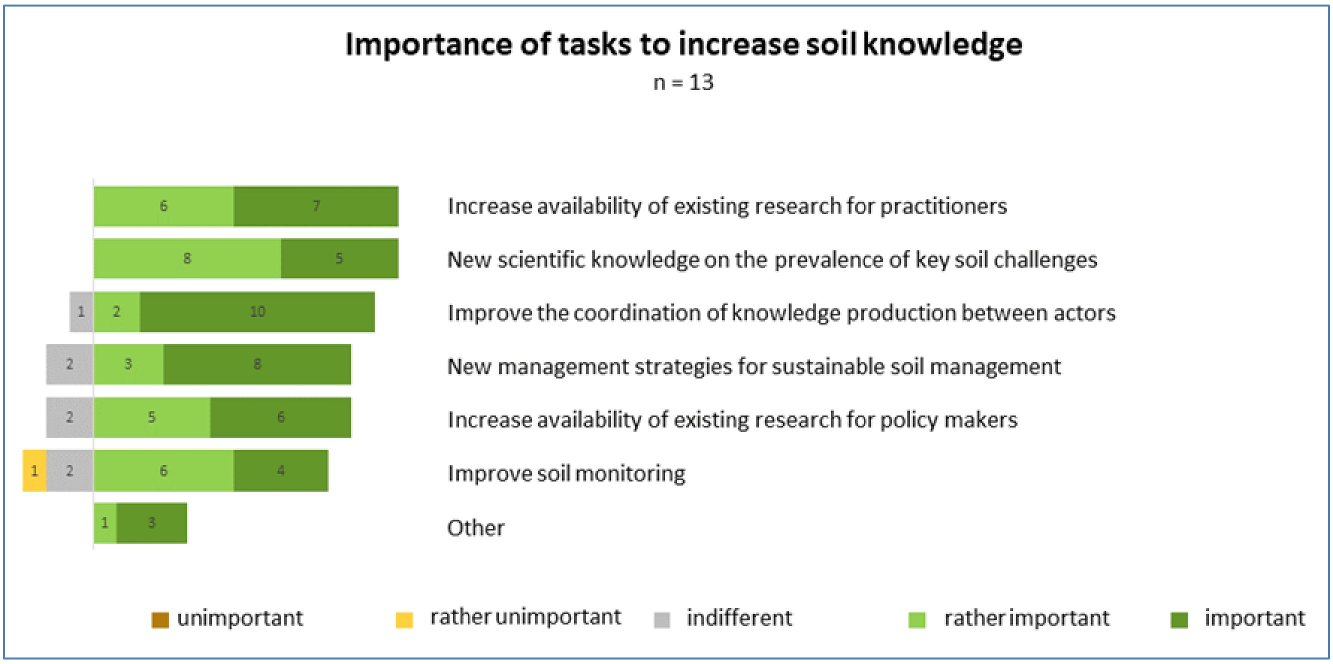


Figure 6: Stakeholders opinions on the importance of task to increase soil knowledge

How to improve knowledge production?

For knowledge production, a lack collaboration and exchange, especially between research and farmers, seems to be a major issue (Figure 7 and Section 2.2.2). Furthermore, other approaches to improve the production of knowledge on SSM were mentioned by stakeholders:

- Many stakeholders voiced that soil research must be **more oriented toward the needs of the practice**. For example, farmers and advisors need a catalogue with specific practices or systems and not generalities or principles on soil management.
- The **complexity of SSM** practices and systems **needs to be addressed**. If the application of SSM knowledge is difficult to manage from an organizational point of view, the implementation will remain limited. Therefore, the participatory development of new solutions and decision support tools is important.

- **Research needs to be more system oriented**. It needs to go beyond single factor assessment (e.g. erosion, SOC). For example, soil challenges need to be assessed and addressed on the catchment-scale and with a value chain perspective. Aspects of the system orientation are for example: What are the effects of SSM practices and systems on productivity, yields and profits? What are the long-term effects of SSM practices and systems on soil quality? Are today's SSM practices future and climate proof? Are the new techniques applicable and feasible on the farm level?

- A **transdisciplinary approach** to identify and address possible conflicts of goals and trade-offs related to SSM (environmental, economic, social, traditional, etc.) needs to be considered. This approach should be able to account for farm level constraints to SSM adaptation, such as affordability, available labour, timing and prioritization.

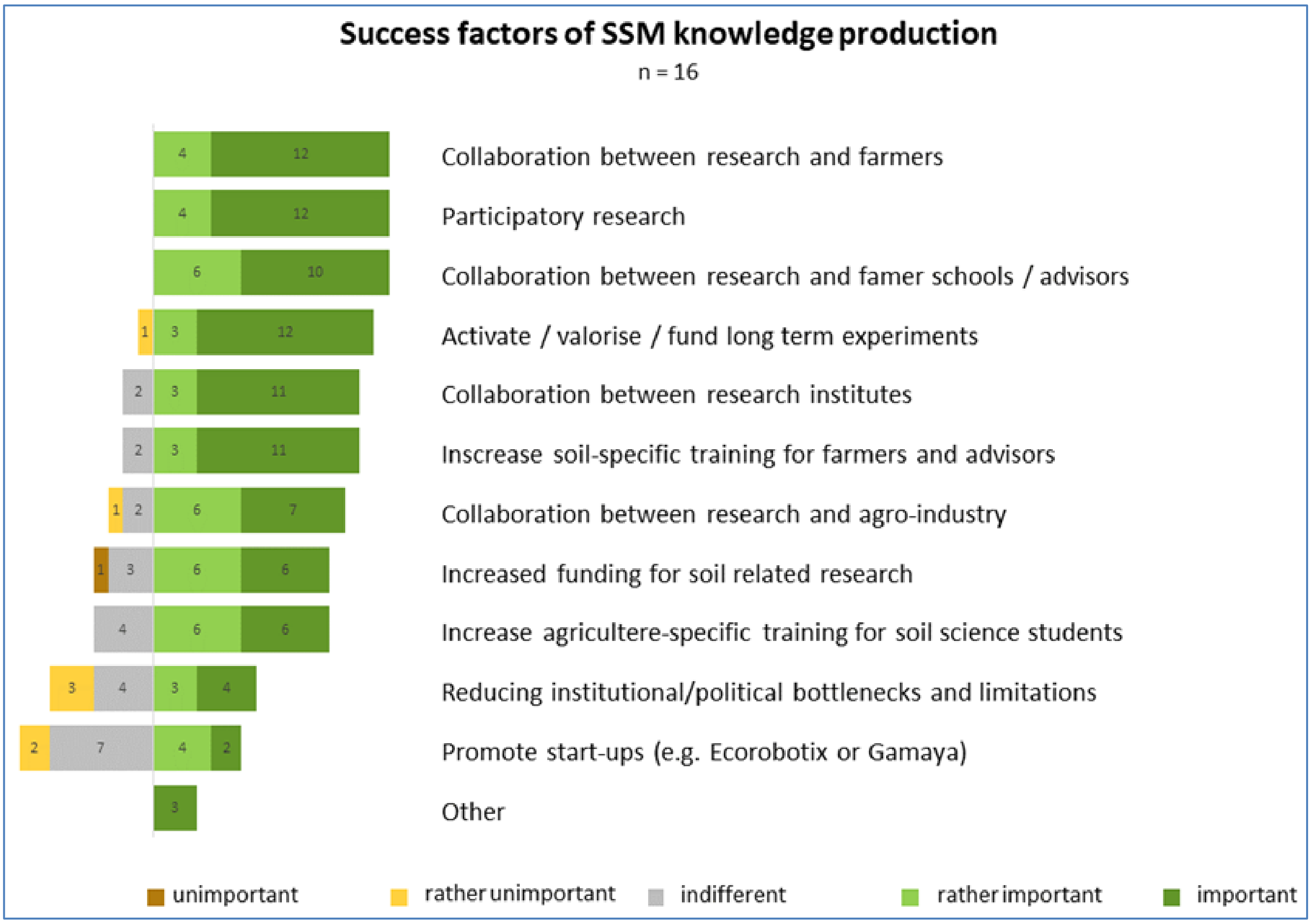


Figure 7: Stakeholders views on "how to improve the production of knowledge on sustainable soil management?"

How to improve knowledge availability and dissemination?

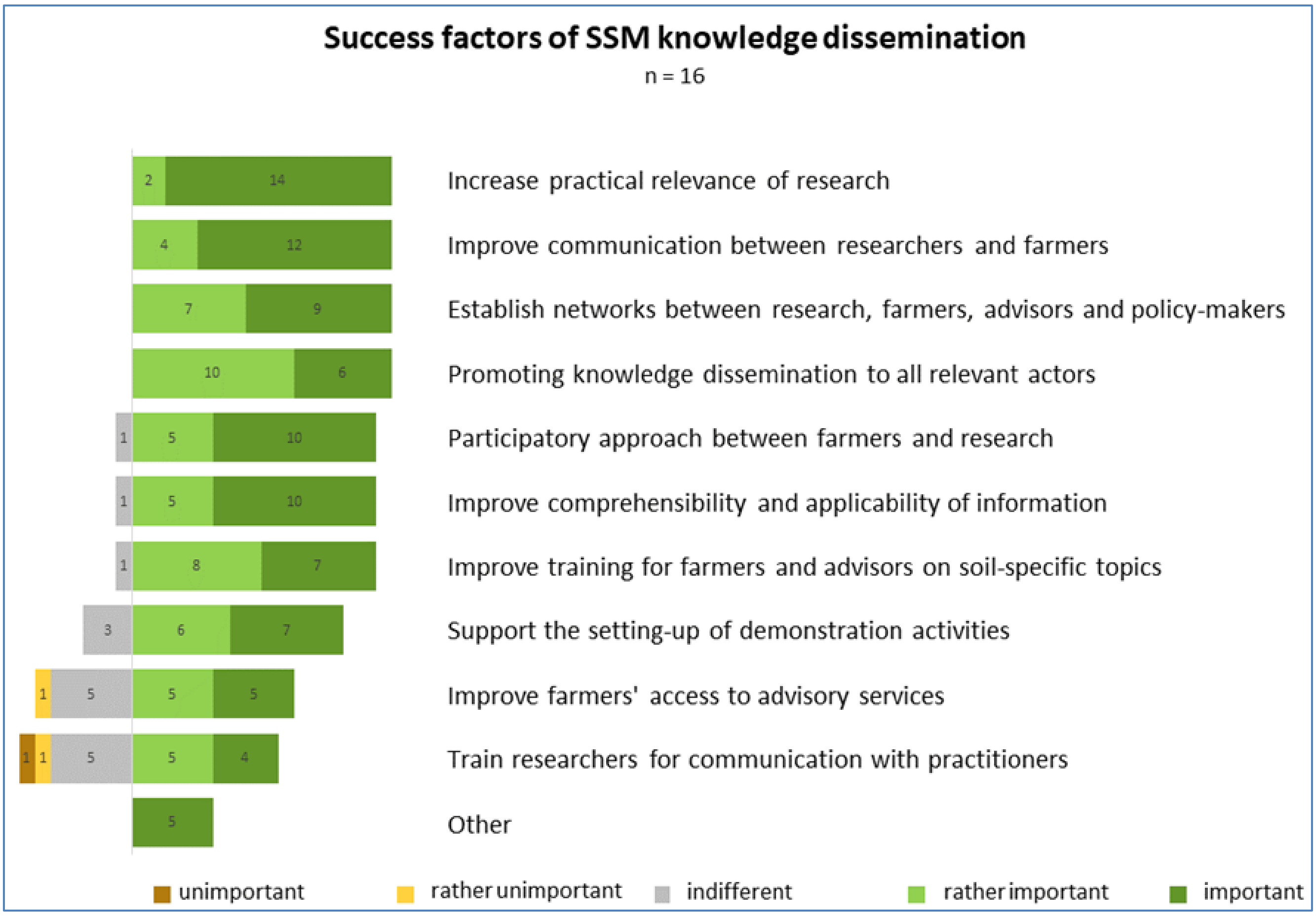


Figure 8: Stakeholders views on "how to improve the dissemination of knowledge on sustainable soil management?"

The stakeholders were asked to evaluate different approaches to improve the dissemination of SSM knowledge in Switzerland (Figure 8). The following approaches were voiced when stakeholders were asked for ways to increase the knowledge availability and dissemination for stakeholders and farmers.

- An accessible and easy to understand **web based platform for SSM knowledge** dissemination should be established to allow digital learning. Such a platform could include social media integration to facilitate digital networking. Multimedia products could be disseminated on this web-based platform.
- The development and maintenance of **integrated digital Tools** (i.e. Apps) could improve knowledge availability and use. A tool in which farmers can autonomously analyse the properties of their fields was said to be crucial for site-adapted soil management.
- Soil and SSM should become an **attractive cornerstone of agricultural education**. Education on soil should be strengthened at all levels; this includes an efficient exchange with professional colleagues, consultants and researchers, and systematic learning from professional colleagues. Teachers and consultants (but also application-oriented researchers) must also be able to deepen their knowledge of the subject and continue to train. For advisors, agricultural soil science related training could be organized, for example by Agridea. Furthermore, SSM should be specifically addressed in farmers' continued education.
- **Practical education and demonstrations**, such as field days, inspections of strip treatments and machine demonstrations need strengthening. They should be held on a regional basis to be accessible to farmers.

These educations and events could be guided but also accessible autonomously (e.g. by panels or QR codes).

- Operational groups to use **Farmer-to-Farmer dissemination** of SSM knowledge should be promoted to increase their reach. Operational groups are said to be successful due to the social learning processes, the collective encouragement as well as the common achievement of objectives. Such operational groups could use organizational, methodological and informational support by a secretariat and experts. Such a scheme would need adequate and stable funding.

- Knowledge on SSM could be made more easily available **to decision-makers by targeted educational courses** (e.g. by agricultural or university educational institutions or Agridea). Furthermore, relevant scientific output should include **brief policy summaries** of findings written specifically for politicians (not just scientific abstracts).

How to improve the use of knowledge?

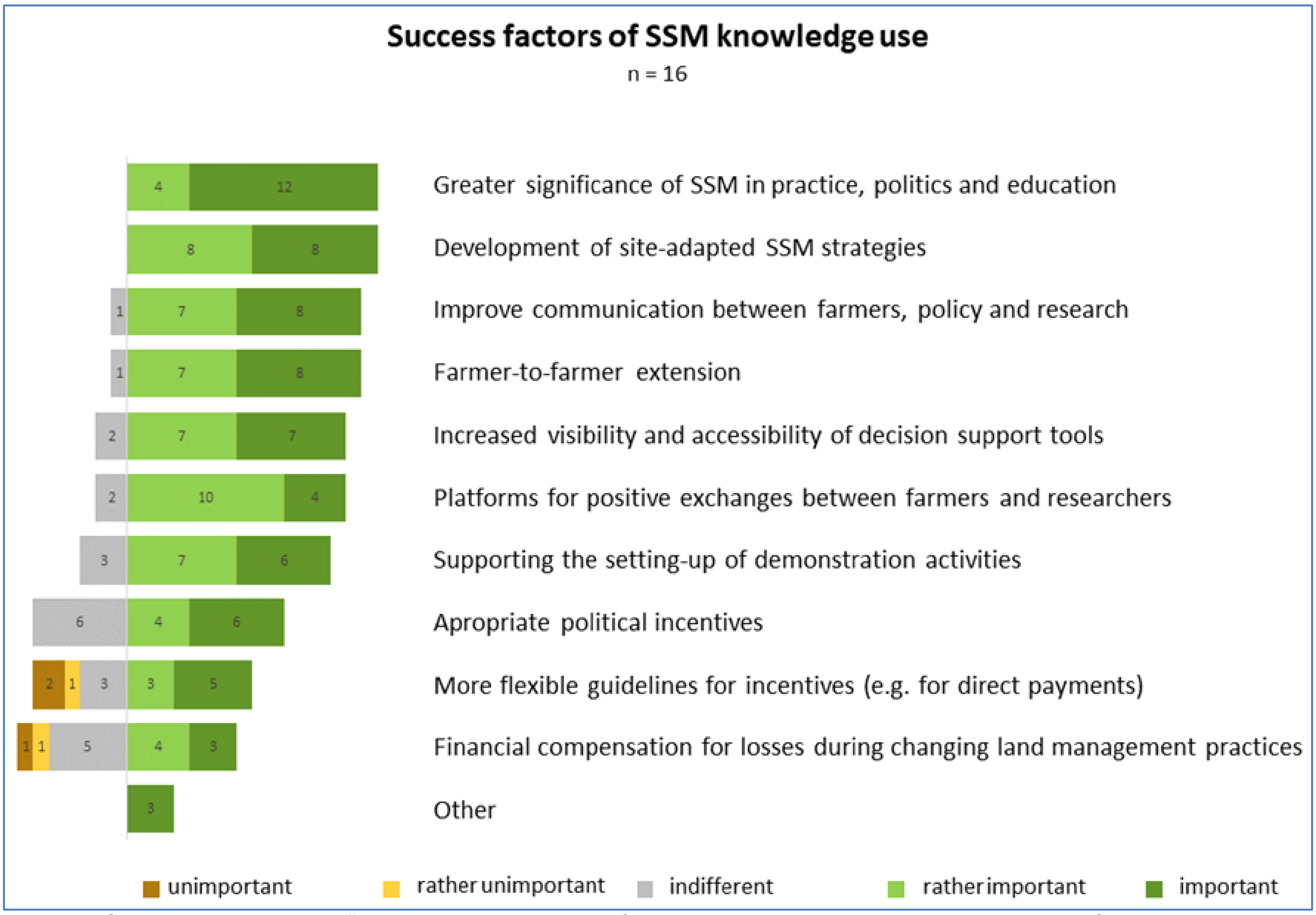


Figure 9: Stakeholders views on "how to improve the use of knowledge on sustainable soil management?"

Besides assessing different factors and approaches to foster the use of knowledge (Figure 9), the stakeholders voiced many ideas on how the use of knowledge on SSM and the application of SSM practices could be promoted.

- **Transparent information** on SSM practices needs to be accessible and **useful to farmers**. This information should show benefits but also costs and disadvantages. Furthermore, it should increase the visibility of best practice examples.

- An **integrated, site-adapted perspective on SSM** that accounts for complexity and trade-offs needs to be developed. Such a perspective needs to include site characteristics, plant protection, nutrient management, soil biodiversity, soil biological activity, soil health, nutrient and water retention, etc.

- A major barrier to SSM application was mentioned: “If the application of SSM knowledge on the farms is not **economically viable**, this knowledge is not implemented and effective, therefore: economic incentives are important and organizationally clever options for action are helpful.” Multiple ideas to increase the economic incentives for SSM were mentioned by stakeholders:
  - SSM should be addressed more strongly in **agricultural policy** and its instruments. For example, SSM and soil quality maintenance could be included in the ‘Ökologischer Leitsungsnachweis’ or targeted direct payments (e.g. ‘Ressourceneffizienzbeiträge’, ‘Ressoucenprojekte’) could be further improved to facilitate SSM dissemination. Furthermore, direct payments could be linked to continued SSM training.
  - Many ideas about **site-adapted or more flexible direct payments** were voiced. Direct payments could be linked to soil and site properties (site-adapted management). More flexible contribution systems, without overly specific requirements, were said to enable the farmers to make better use of their knowledge and expertise. Furthermore, not specific practices should receive subsidies, but the long-term achievement of soil quality objectives should be rewarded. Stakeholders also mentioned that such soil quality objectives need to be realistic, i.e. site-adapted.
  - Existing or new **labels** could put more emphasis on SSM and thus create economic incentives for farmers to adopt SSM practices.
  - However, a stakeholder concerned with agricultural policy execution advised that (new) **regulations must be efficient and effective to enforce and control**. Another stakeholder added that control-based systems tend to become too complex to handle.

- Concluding the survey, a stakeholder mentioned that current efforts need to be continued, as “constant dripping wears away the stone”.

2.3 Summary and Discussion

Overall, the stakeholders voiced that the sustainable management of Swiss soils face manifold challenges. The challenges in decreasing order of mentioning are: compaction, sealing, erosion, SOC loss, soil biodiversity loss, contamination, peat degradation, sub-optimal drainage, low water retention capacity, nitrous oxide and methane emissions, qualitatively insufficient technical soil improvements and recultivations, low nutrient use efficiency. On the other hand, soil acidification, salinization as well as the irrigation of unsuitable sites were considered minor challenges to sustainable soil use in Switzerland.

The importance of research needs largely coincided with the perceived importance of the soil challenges. An important exception was ‘soil sealing’, for which research seems less important than for other soil challenges. This may be caused by the fact that soil sealing is addressed by spatial planning, thus the limitation of soil sealing is mostly hindered by political will and not by knowledge gaps. Furthermore, our selected stakeholder were mostly focused on agricultural soil use. This may have led to a lower relevance-score for soil sealing.s

Multiple stakeholders mentioned specific research needs to address single or multiple soil challenges. Others mentioned rather general research needs, e.g. ‘how to disseminate SSM knowledge efficiently?’; site-adapted SSM practices; easy-to-apply soil quality indicators. Some stakeholders suggested to improve soil monitoring, e.g. by increased coordination between existing monitoring systems (i.e. NABO and KABOs) or additional survey parameters. Furthermore, stakeholders involved in agricultural structural improvement voiced the need for more efficient and effective drainage systems.

When asked about state of the Swiss agricultural knowledge system many stakeholders agreed that farmers have good access to SSM knowledge, e.g. by specific trainings and field days. On the other hand, some stakeholders said that the current knowledge system was not sufficiently effective in providing SSM knowledge. This indicates that there are other sources of knowledge accessible to farmers outside the ‘traditional’ knowledge system. However, there was considerable disagreement on the state of the knowledge system. As a general trend, advisors and teachers evaluated the knowledge system more positively than the researchers and farmers representatives did.

Many stakeholders voiced that coordination within the knowledge system could be improved by a variety of measures. Such measures include a national strategy for SSM dissemination and advisory services as well as a national or regional SSM network that involves interested farmers, researchers, teachers, advisors and policy makers. In general, the knowledge base could be improved by increased availability of existing research to farmers and policy makers as well as new scientific knowledge on the prevalence of key soil challenges, such as compaction or SOC loss.

Knowledge production could be improved by increased collaboration within the agricultural knowledge system, including for example participatory research approaches. More collaboration could lead to higher system orientation of research questions and thus to higher relevance and applicability of the produced knowledge for farmers and policy makers alike. Additionally, long term experiments could generate new knowledge on the long term effects of SSM practices. This proposed research activities may need increased funding.

Knowledge dissemination could benefit from improved communication and networks among farmers, researchers, advisors and policy makers. Furthermore, demonstration activities and farmer-to-farmer extension (e.g. operational groups) were said to increase the dissemination of SSM practices. Besides, soil and SSM should become more relevant in farmers and advisors education and training. All these approaches could be supported by digital knowledge platforms and decision support tools that foster autonomous learning and digital networking.

Knowledge use and application of SSM practices could be improved by site-specific information on appropriate SSM practices. This information should transparently show costs and benefits of specific SSM practices as well as include successful organizational options. Furthermore, the incentives for farmers to apply SSM practices should be increased, e.g. by agricultural policies or market driven instruments such as labels.

Overall, stakeholders have shown a large consensus on the predominant soil challenges and approaches on how to address the soil challenges. Many stakeholders voiced that the different actors within the knowledge system should cooperate more intensively to increase the relevance of SSM related research to practitioners as well as to increase the dissemination and application of knowledge of SSM practices. The consensus among the stakeholders was less pronounced in their opinions on the state of the agricultural knowledge system and specific approaches to foster the production, dissemination and application of SSM knowledge. The different views are most likely linked to the differing role within the knowledge system and the differing professional focus that the stakeholders have.

3 State of Knowledge Reports

3.1 Approach

We produced three 'State of Knowledge Reports' according to the EJP SOIL guidelines for T2.2.1[7]. The reports are between 1 and 2 pages long. The topics of the reports were:

- Report 1: State of Knowledge on Soil Carbon Stocks (Annex IV)
- Report 2: State of Knowledge on 10 major Soil Challenges (Annex V)
- Report 3: Management Strategies to address 9 major Soil Challenges (Annex VI)

The reports were based on a review of the recent literature and input from 9 scientific experts. The literature was identified with the support of the scientific experts (Table 2). We reviewed 17, 91, and 72 sources for Reports 1, 2, and 3, respectively.

Table 2: Scientific experts consulted for State of knowledge Reports

Topic	Expert
Soil organic carbon	Jens Leifeld (Agroscope), Peter Weisskopf (Agroscope)
Peat degradation	Jens Leifeld (Agroscope)
Soil contamination	Reto Meuli (Agroscope)
Soil erosion	Volker Prasuhn (Agroscope)
Optimal soil structure	Peter Weisskopf (Agroscope)
Soil Sealing	Silvia Tobias (WSL)
Nutrient retention and use efficiency	Frank Liebisch (Agroscope), Ernst Spiess (Agroscope)
N2O and CH4 emissions	Daniel Bretscher (Agroscope)
Soil biodiversity	Franz Bender (Agroscope)

3.2 Summary and Discussion

According to Report 1 (Annex VI), knowledge on SOC stock dynamics in Switzerland originates largely from long term field experiments across the country. National estimates on SOC stocks and their changes were most recently estimated for the period 1990 to 2018. The SOC storage potentials for a wide range of measures has already been estimated. However, further research is needed to increase the accuracy of the SOC related estimations and to assess additional measures.

Based on the literature, the following 10 soil challenges were considered most relevant in Report 2 (Annex V): sealing, erosion, compaction, SOC loss, peat degradation, soil biodiversity loss, contamination, low nutrient use efficiency, N_2O and CH_4 emissions and sub-optimal water balance. For 9 of 10 challenges, strategies, approaches or even concrete measures were identified in Report 3 (Annex VI).

From our reports we can conclude that for sealing, erosion, compaction, contamination and nutrient use efficiency the knowledge base seems most advanced. For SOC loss, peat degradation, soil biodiversity loss, N_2O and CH_4 emissions as well as sub-optimal water balance it seems less advanced. However, scientific experts formulated research needs for all soil challenges.

[7] Mulkholm L. J. & Thorsøe M. H., 2020. EJP SOIL Task 2.2: Knowledge availability and use – Guidelines for national analysis.

4 Policy Analysis

4.1 Approach

The policy analysis was carried out according to the EJP SOIL guidelines[8] and consisted of two phases. The first phase was a desk study in which policy documents were analysed to detect current policy ambitions. In the second phase, key stakeholders were asked to complement the analysis with the current status of policy realisations.

Phase 1: Desk study on current policy ambitions

Phase 1 consisted of three steps: (i) identification of relevant policy documents; (ii) analysis of the policy documents; (iii) validation by key persons.

In step i, a list of policy documents was compiled that formulate targets for agricultural soils or mention management practices that impact agricultural soils.

In step ii, the listed documents were analysed to extract the following information:

- Policy targets
- Indicators used to monitor the targets
- Current status of the indicators
- Tools or methods used for monitoring
- Farm management practices that are mentioned in the documents
- Other policy instruments mentioned in the documents used or to be developed

In step iii, we asked key persons to complement and validate the analysis of the policy document with their knowledge and experience.

Phase 2: Stakeholders views on current policy realisations and future aspirational goals

Where available, recent reports were considered to evaluate the current policy realisations. For the policies and targets where no reports were available, the involved key persons provided their input and opinion.

Table 3: Overview of tables and annexes related to the policy analysis

Table / Annex	Content
Table 4	List of policy documents
Table 5	List of key persons
Annex VII	Descriptions of policies, instruments, indicators and monitoring tools
Annex VIII	List of policy targets
Annex IX	Overview of management practices mentioned by policy documents
Annex X	Policy targets by soil challenge and current realisations
Annex XI	List of other instruments to achieve aspirational goals

4.2 Results and Discussion

4.2.1 Policy Inventory and Key Persons

An overview of 33 policies that impact agricultural soils and soil management is provided Table 4. Input from key persons was used to differentiate between ‘priority 1’ and ‘priority 2’ documents. Overall, 12 policies were considered ‘priority 1’. In Annex VII, brief descriptions of policy packages as well as related instruments, indicators and monitoring tools of ‘priority 1’ documents are provided.

[8] Ruysschaert G. & Jacob M., 2020. EJP SOIL Task 2.1: Identifying current policy ambitions and future soil aspirational goals - Guidelines for analysis at the member state level.

Policies that directly influence soils and soil management were often found in federal ordinances, which specify the general targets of federal acts. These federal regulations apply to all of Switzerland. The enforcement of these federal ordinances, however, is often delegated to the cantons.

Table 4: List of policy documents of importance for agricultural soils in alphabetical order

Abbreviation	Policy Name[a]	Responsible	Priority
ADWO	Ordinance on the Avoidance and the Disposal of Waste (A1/1/2016) - Verordnung über die Vermeidung und die Entsorgung von Abfällen (VVEA)	FOEN	2
AP-22+	Agricultural Policy 22+ (D12/2/2020) - Agrarpolitik 22+	FOAG	1
AP-GE	Action plan Green Economy (A8/3/2013) - Aktionsplan Grüne Wirtschaft	DETEC	2
AP-PPP	Action Plan Plant Protection Products (A6/9/2017) - Aktionsplan zur Risikoreduktion und nachhaltigen Anwendung von Pflanzenschutzmitteln (AP PSM)	FOAG	1
ChemRRO	Ordinance on the Reduction of Risks relating to the Use of Certain Particularly Dangerous Substances, Preparations and Articles (A1/8/2005) - Verordnung zur Reduktion von Risiken beim Umgang mit bestimmten besonders gefährlichen Stoffen, Zubereitungen und Gegenständen	FOAG; FOEN	2
CSA	Climate Strategy for Agriculture (A31/5/2011) - Klimastrategie Landwirtschaft	FOAG	1
CSO	Contaminated Sites Ordinance (A1/10/1998) - Altlastenverordnung (AltlV)	FOEN	2
DPO	Direct Payments Ordinance (A1/1/2014) - Direktzahlungsverordnung (DZV)	FOAG	1
EGA	Environmental Goals Agriculture (A2008) - Umweltziele Landwirtschaft	FOEN; FOAG	1
EPA	Federal Act on the Protection of the Environment (A1/1/1985) - Bundesgesetz über den Umweltschutz	FOEN	2
FAA	Federal Act on Agriculture (A1/1/1999) - Landwirtschaftsgesetz (LWG)	FOAG	1
G-NFA	Implementation guidelines on nutrients and use of fertilizers in agriculture (A2012) - Vollzugshilfe Nährstoffe und Verwendung von Düngern in der Landwirtschaft	FOEN; FOAG	2
G-PPPA	Plant Protection Products in Agriculture (A2013) - Pflanzenschutzmittel in der Landwirtschaft	FOEN	2
G-SPA	Guidelines for soil protection in agriculture (A2013) - Vollzugshilfe Bodenschutz in der Landwirtschaft	FOEN; FOAG	2
NCHA	Federal Act on the Protection of Nature and Cultural Heritage (A1/1/1967) - Bundesgesetz über den Natur- und Heimatschutz (NHG)	FOEN	2
NRP68	National Research Programme NRP 68 'Overall Synthesis' (05/2018) - Nationales Forschungsprogramm NFP 68 'Gesamtsynthese'	NRP 68	1
OFLN	Ordinance on the Federal Inventory of Landscapes and Natural Monuments (A29/3/2017) - Verordnung über das Bundesinventar der Landschaften und Naturdenkmäler (VBLN)	FOEN; FOC; FEDRO	2
OFO	Organic Farming Ordinance (A1/1/1998) - Bioverordnung	FOAG	1
OISA	Ordinance on information systems in the field of agriculture (A1/1/2014) - Verordnung über Informationssysteme im Bereich der Landwirtschaft (ISLV)	FOAG	2
OPMF	Ordinance on the Placing on the Market of Fertilisers (A1/3/2001) - Verordnung über das Inverkehrbringen von Düngern (DüV)	FOAG	2
OSIA	Ordinance on Structural Improvements in Agriculture (A1/1/1999) - Verordnung über die Strukturverbesserungen in der Landwirtschaft (SVV)	FOAG	2
OSME	Ordinance on maximum stocks in meat and egg production (A1/1/2014) - Verordnung über Höchstbestände in der Fleisch- und Eierproduktion (HBV)	FOAG	2
PAL	Protection of arable land (A2012) - Schutz des Kulturlandes	FOAG	2
SBS	Swiss Biodiversity Strategy (A6/9/2017) - Strategie der Biodiversität Schweiz	FOEN	1
SCCS	Strategy for Adaptation to Climate Change in Switzerland (A2/3/2012) - Strategie zur Anpassung an den Klimawandel in der CH 2014-2019	FOEN	2
SCP	Switzerland's climate policy (A2018) - Klimapolitik der Schweiz	FOEN	2
SoilPO	Soil Pollution Ordinance (A1/10/1998) - Verordnung über Belastung des Bodens (VBBo)	FOEN	1

SP-CP	Sectoral Plan for Prime Cropland Protection (A8/4/1992) - Sachplan Fruchtfolgeflächen (SP FFF)	ARE	1
SRS	Status Report on Soil in Switzerland (A30/11/2017) - Zustandsbericht Boden in der Schweiz	FOEN	1
SSD	Strategy for sustainable development 2016-1019 (A27/1/2016) - Strategie nachhaltige Entwicklung 2016-2019	ARE	2
SSfS	Spatial Strategy Switzerland (A2012) - Raumkonzept Schweiz	ARE	2
SSS	Soil Strategy Switzerland (A1/5/2020) - Bodenstrategie Schweiz	FOEN; FOAG; ARE	1
WPO	Water Protection Ordinance (A1/1/1999) - Gewässerschutzverordnung (GschV)	FOEN	2

[a]: A: date of approval; D: date of draft (in case documents are in final phase but not approved by the government yet)

The table lists the Swiss policies that relate to the management of agricultural soils. Ordinances are legislative decrees, which are subordinate to the Constitution and the federal acts. They implement the legal provisions as well as supplement and complete them. The federal agricultural policy, which is revised every four years, provides a framework enabling Swiss farmers to fulfil their responsibilities to society, as defined by the Federal Constitution in Art. 104.

Furthermore, below are a few points to consider regarding these policies:

The AP22+ is undergoing parliamentary consultation and is controversially discussed. A demand for a suspension of the work on the document is currently pending.

For the SSS, there is no action plan yet. An action plan will be developed in the next few years.

Revision of CSA is ongoing in the framework of a holistic 'Climate Strategy Switzerland' (according to Daniel Felder, FOAG, personal communication, 17.8.2020).

The development of a chemical soil atlas is ongoing, including an area-wide mapping of soil contamination. This mapping will serve as a base to develop guide values and an area-wide monitoring tool (according to Gudrun Schwilch, FOEN, personal communication, 21.8.2020).

For each policy document, a key person, mostly at federal offices, that was closely involved with the development of the policy or has good knowledge on its content and history was identified (Table 5).

For each policy document, a key person, mostly at federal offices, that was closely involved with the development of the policy or has good knowledge on its content and history was identified (Table 5).

Table 5: List of key persons for policy analysis

Person	Institution	Expertise / Input [a]
Daniel Bretschter	Agroscope	SRS
Daniel Felder	FOAG	CSA
Marcel van der Heijden	Agroscope	Soil biodiversity
Felix Herzog	Agroscope	SBS
Frank Liebisch	Agroscope	SRS, DPO
Jochen Mayer	Agroscope	OFO
Gudrun Schwilch	FOEN	National Hub, G-SPA, EGA, SRS
Ernst Spiess	Agroscope	SRS
Jan Wäspe	FOAG	AP-PPP
Peter Weisskopf	Agroscope	DPO, SP-CP, SoilPO
Michael Zimmermann	FOAG	National Hub, AP22+, SSS

[a:] Policy abbreviations according to Table 4

4.2.2 Policy Ambitions

Results

An overview of soil related targets of the policies, and the current status of the indicators used to monitor these targets can be found in Annex VIII. Annex VIII also lists current or future instruments to monitor or foster the targets.

In Annex IX, management practices that are mentioned in the policy documents for reaching soil related targets are indicated. Annex IX lists policies that address a specific soil or other environmental challenge by promoting specific management practices. All management practices mentioned in the policy documents are listed regardless of whether or not they are mandatory or will be encouraged on a voluntary basis with or without economic incentives.

Discussion

We found many policies which have a direct or indirect influence on soils and soil management. The most important policy instruments are the DPO and the well established direct payment system, which acts as an incentive programme. This direct payment system is considered a success, and will therefore be further developed and extended. In May 2020, the first 'Soil Strategy Switzerland' (SSS) was published, which summarizes the status of Swiss soils, and strengthens their sustainable use and protection. It was compiled as a joint action of the federal offices for agriculture (FOAG), for the environment (FOEN) and for spatial development (ARE).

In total, 178 targets and sub-targets were extracted from 33 policies. Of all the assessed targets, 64 targets were specific to soils, 45 targets were specific to agricultural soils, and 69 targets were not soil specific, but included regulations for soils as a part of the larger environmental context. Therefore, around 25% of extracted targets are specific for agricultural soils and its management.

For most of these policies, the main targets are related to the soil challenges of soil contamination, nutrient retention and efficiency, soil sealing, soil compaction, soil erosion, GHG emissions, maintenance of SOC and not further specified soil functions. There are regulations targeting soil contamination from fertilizer and plant protection products. In these national policies, soil biodiversity is indirectly included in the definition of 'biodiversity', but until now, measures are concentrated on soil surface biodiversity. Biodiversity for soils is discussed specifically in the relatively new SSS for the first time. No policies are currently addressing soil acidification and salinization. According to our stakeholder survey (Section 2), the latter two challenges are of little importance in Switzerland, which could explain the lack of such targets.

Specific management practices, like reduced tillage or reduced application of mineral fertilizer, are promoted through direct payments, but are not compulsory. Other management practices, like permanent soil cover, improvement of soil structure or site-adapted management practices are part of 'good soil management practices', which are compulsory to receive direct payments, but are mostly requested in a qualitative or semi-quantitative way.

In the past few years, there has been a stronger focus on the protection of soils, both qualitatively and quantitatively. For example, the SP-CP, which protects the highest quality cropland, ensures that a minimum area of the country's best cropland remains protected against soil sealing. Additionally, there is currently a strong push on smart crop rotation (i.e. aiming to target specific goals based on local environmental drivers) and site-adapted agriculture. Many development processes are already planned or ongoing (see Annex VIII for (I) and (P)), but there is still a strong need for research to develop accurate and applicable tools and indicators. Above all, the practical applicability of research results must be improved in order to achieve direct effects through transfer into practice.

4.2.3 Policy Realisation

Results

Annex X shows current realizations extracted from respective reports or provided by key persons.

Discussion

The stakeholder survey results show a large consensus on the most pressing soil challenges (Figure 2): compaction, sealing, erosion, loss of SOC and soil biodiversity and contamination. Active policies and strategies focus on contamination, erosion as well as GHG and ammonia emission. Compaction, loss of SOC, soil sealing and loss of soil biodiversity need more focus in the coming years.

Despite straightforward targets, the timeline for target achievement is not always explicit. Additionally, there are many qualitative targets, where it is difficult to evaluate the status of target achievement. Furthermore, many targets are not monitored and there are no indicators known or established yet. This issue is pointed out and addressed by the National Research Programme "Sustainable Use of Soil as a Resource" (NRP 68) as well as the SSS. The recently established KOBO (Swiss competence centre for soils) is dedicated to coordinating and harmonizing soil data, as well as supporting the development and establishment of methodologies and tools to monitor soil indicators. Therefore, the development of missing indicators and monitoring tools may be fostered in the future.

One important tool that has shown to be effective in the past is the agricultural direct payment system (DPO), a well established and continuously improved system. For example, the management practices promoted by the DPO have been scientifically proven to be beneficial on a larger scale. However, there has been criticism that there is little room for new technologies and practices that could be implemented or tested. Regional programmes, such as ‘Ressourcenprojekte’, can provide a framework to test new technologies or alternative measures, which could potentially be incorporated into the direct payment schemes in the future.

4.2.4 Other Approaches

Regarding the ‘other instruments’ listed in Annex XI, these were mainly market-driven suggestions, which aim to use economic incentives to drive adoption of SSM practices. Along these lines, it should be noted that in 2019, 15% (around 170,000 ha on 6814 farms) of all Swiss farms were managed organically (Federal Statistical Office, 2020). Around 20% (288,340 ha on 9103 farms) of all Swiss farms were managed according to IP-SUISSE guidelines (Niklaus Hofer, IP-Suisse, personal communication, 2.9.2020). Both labels promote SSM practices.

4.3 Summary and Discussion

The policies reviewed in this section concern a large set of environmental and agricultural measures which affect soil quality either directly or indirectly. In summary, we found that maintaining the functionality of soils and enabling its sustainable management have high priority in Switzerland. This is reflected by the large number of agricultural, environmental and spatial planning policies and ordinances in place at the national level. These aim to ensure the SSM, prevent harmful environmental impacts and preserve high quality croplands from sealing. In the past, the policies focus were mostly on avoiding contamination, erosion as well as GHG and ammonia emission. In the future, compaction, loss of SOC, soil sealing and loss of soil biodiversity ought to become more important.

Many of the reviewed policy targets are qualitative in nature. The qualitative nature hinders the determination of whether or not the intended targets are met. To some degree, this can be explained by the lack of easily accessible soil and soil management information, i.e. the lack of appropriate soil quality indicators, monitoring systems and harmonized databases.

5 Overall Summary and Conclusions

Stakeholder survey

The stakeholders largely agreed that the main challenges to sustainable agricultural soil management in Switzerland are soil compaction, soil erosion, SOC loss, soil biodiversity loss and soil contamination. For these qualitative soil challenges a relatively high relevance of research needs were voiced. The consensus among stakeholders on the importance of peat degradation, sub-optimal drainage, low water retention capacity, N_2O and CH_4 emissions, qualitatively insufficient technical soil improvements and recultivations as well as low nutrient use efficiency was less pronounced. Although soil sealing was considered an important qualitative soil challenge, only few knowledge gaps related with soil sealing were identified.

A wide range of approaches to improve the production, dissemination and application of knowledge on SSM practices have been voiced by stakeholders. The approaches include:

- Forge a national strategy for SSM dissemination and advisory services
- Increase communication, collaboration and networking within the agricultural knowledge system
- Foster participatory multi-stakeholder research approaches
- Increase the system orientation of research questions
- Increase the relevance and applicability of the produced knowledge for farmers and policy makers
- Increase the availability of existing knowledge to practitioners and policy makers
- Produce new scientific knowledge on the prevalence of key soil challenges
- Foster demonstration activities and farmer-to-farmer extension (e.g. operational groups)
- Foster soil and SSM in education and training
- Foster digital knowledge platforms and decision support tools
- Foster autonomous learning and digital networking
- Foster site-specific, applicable information on appropriate SSM practices
- Foster economic incentives for farmers to apply SSM practices

State of Knowledge

Based on the reviewed scientific literature, soil sealing, erosion, compaction, SOC loss, peat degradation, soil biodiversity loss, contamination, low nutrient use efficiency, N_2O and CH_4 emissions and sub-optimal water balance were considered most important. It was concluded that for sealing, erosion, compaction, contamination and nutrient use efficiency the knowledge base is most advanced. However, scientific experts formulated research needs for all soil challenges.

Policy Analysis

Within Switzerland’s environmental and agricultural policies, maintaining the functionality of soils and enabling its sustainable management are high priorities. However, many policy targets are qualitative in nature and their current status remains unknown. Although many regulations for soil protection and SSM are in place, coordinated efforts are needed to develop sustainable solutions to tackle specific soil challenges.

Conclusions

Our findings, as summarized in Table 6, suggest that there is a wide consensus within the views of stakeholders, researchers and policy makers on the most important soil challenges in Switzerland. These soil challenges are addressed by active or planned policies and are subject to past or ongoing research activities. For other, supposedly less urgent soil challenges, either the state of knowledge, the integration into policies or both are less advanced.

Table 6: Summary of soil challenge importance (Section 2), knowledge base (Section 3) and policy integration (Section 4)

Soil Challenge	Importance according to survey	Quality of knowledge base	Taken into account by policy
Soil Compaction	++	+	(+)
Soil Sealing	++	++	(+)
Soil Erosion	++	+	+
SOC loss	++	-	(+)
Soil Biodiversity loss	++	-	(+)
Soil Contamination	++	+	+
Peat degradation	+	-	
Low H_2O retention	+		
N_2O & CH_4 emissions	+	-	
Low nutrient use efficiency	+/-	+	(+)
Soil Acidification	+/-		
Soil Salinization	-		
Poor condition of the drainage systems	+	-	Not considered in the policy analysis
Qualitatively insufficient soil improvements	+		
Qualitatively insufficient soil recultivations	+		
Irrigation of unsuitable land	+/-		

Survey: ++: considered (rather) important by a majority of stakeholders
+: considered (rather) important by many stakeholder
+/-: consideration contradictory by stakeholder
-: considered (rather) unimportant by a majority of stakeholders

Knowledge: ++: good knowledge base
+: advanced knowledge base
-: non-advanced knowledge base
empty: Not considered in the State of Knowledge Report

Policy: +: addressed by active policies
(+):addressed by future policy ambitions
leer: no measures were found in the policy analysis

Based on our findings and the opinions voiced by stakeholders (Section 2) and key persons (Section 4), we conclude that further research and development is required to provide methods to monitor and evaluate soil quality, soil functions and ecosystem services provided by soils. However, in supplying functional soil information and soil management solutions, we suggest that a multidisciplinary approach be employed, both in the valuation of different soil functions, as well as in the future direction of soil science research in general. For example, stakeholders pointed out that there is a raising public and professional interest in alternative agricultural systems (e.g. regenerative agriculture, agroforestry, and permaculture), which could be addressed and answered by future research projects. We recommend to use a participatory multi-stakeholder approach for the development of such projects. This will allow the integration of knowledge from famers, advisors, researchers and policy makers. As a result, the applicability and effectiveness of practical solutions and the acceptance by the target groups (e.g. practitioners) could improve.

6 Acknowledgments

The authors wold like to thank all involved stakeholders as well as all scientific and policy experts that contributed to the content of this report.

7 Annexes

Annex I: Stakeholder List

Annex II: Survey Questionnaires

Annex III: Stakeholder Perspective: How to address Soil Challenges?

Annex IV: Report 1: State of Knowledge on Soil Carbon Stocks

Annex V: Report 2: State of Knowledge on Soil Challenges

Annex VI: Report 3: Management Strategies to address Soil Challenges

Annex VII: Policy Descriptions

Annex VIII: Policy Analysis

Annex IX: Management Practices

Annex X: Policy Realisations

Annex XI: Other Instruments

Annex I: List of participants of the 'Stakeholder survey'

#	Surname	Name	Organization	Survey 1	Survey 2	Survey 3
1	Affolter	Gregor	BBZ Arenenberg	X		X
2	Bärtschi	Daniel	Agricultura Regeneratio	X	X	
3	Burgos	Stéphane	HAFL	X	X	
4	Charles	Raphaël	FiBL	X		X
5	Chervet	Andreas	Kanton Bern	X	X	
6	Ciocco	Franca	Plantahof	X		
7	Füllemann	François	Kanton Waadt		X	
8	Furrer	Tobias	INFORAMA	X		X
9	Günter	Markus	BABU GmbH			X
10	Guyer	Urs	Bio Suisse	X		X
11	Hellemann	Petra	BLW, Geosuisse		X	
12	Keller	Armin	KOBO			X
13	Krebs	Rolf	ZHAW			X
14	Lüscher	Andreas	Agroscope, AGFF		X	
15	Lüthi-Probst	Mirjam	IP Suisse	X		X
16	Meier	Toni	AgroCO2ncept	X		
17	Minder	Reto	Swiss No-Till	X	X	
18	Niggli	Jeremias	FiBL	X		X
19	Oberhänsli	Ivana	Kanton Zürich			X
20	Schaffner	Laurence	Mandaterre	X	X	
21	Schaub	Daniel	Kanton Aargau, Cercle Sol		X	
22	Schenk	Oskar	Lohnunternehmen Schweiz			X
23	Schwegler	Markus	Kleinbauernvereinigung			X
24	Schwilch Brünisholz	Gudrun	BAFU			X
25	Spuhler	Markus	Agridea	X		X
26	Stadelmann	Franz	Kanton Luzern		X	
27	Weisskopf	Peter	Agroscope	X	X	
28	Zihlmann	Urs	Agroscope	X		
29	Zürrer	Martin	myx GmbH			X
30						X
31				X	X	
32					X	
				17	13	16

Survey 1: Knowledge System
Survey 2: Research Needs
Survey 3: Challanges and Opportunities

Three Stakeholders did not explicitly consent to be named in this list.

Annex II: Questionnaires of the 'Stakeholder survey'

German Version – Deutsche Version

Questionnaire 1: Knowledge system - Wissenssystem

Frage	Antwort Typ
Frage / Aussage 1: "Für Bewirtschaftende ist die Zugänglichkeit von Wissen für die nachhaltige Bodenbewirtschaftung gut."	5-stufige Likert-Skala
Frage / Aussage 2: "Junge LandwirtInnen werden in der Ausbildung gut auf eine nachhaltige Bodenbewirtschaftung vorbereitet."	5-stufige Likert-Skala
Frage / Aussage 3: "Die landwirtschaftlichen Beratungsdienste sind gut auf die Vermittlung von Wissen über nachhaltige Bodenbewirtschaftung vorbereitet."	5-stufige Likert-Skala
Frage 4: Wie kann Ihrer Meinung nach die Zugänglichkeit von Wissen für die nachhaltige Bodenbewirtschaftung für verschiedene Akteure erhöht werden?	Offene Frage
Frage / Aussage 5: "Die Koordination zwischen den verschiedenen Akteuren zum Erarbeiten von Wissen für die nachhaltige Bodenbewirtschaftung ist gut."	5-stufige Likert-Skala
Frage / Aussage 6: "Die Koordination zwischen Forschung und Politik hinsichtlich Forschungsaktivitäten für die nachhaltige Bodenbewirtschaftung ist gut."	5-stufige Likert-Skala
Frage 7: Wie könnte Ihrer Meinung nach die Koordination zur Erarbeitung und Verbreitung von Wissen für die nachhaltige Bodenbewirtschaftung zwischen den beteiligten Akteuren verbessert werden?	Offene Frage
Frage / Aussage 8: "Insgesamt ist die Wirksamkeit des landwirtschaftlichen Wissenssystems zur Vermittlung von Anwendungswissen für die nachhaltige Bodenbewirtschaftung genügend."	5-stufige Likert-Skala
Frage / Aussage 9: "Die Ressourcen zur Verbreitung von Wissen für die nachhaltige Bodenbewirtschaftung sind ausreichend."	5-stufige Likert-Skala
Frage / Aussage 10: "Die Ressourcen zur Erarbeitung von Wissen für die nachhaltige Bodenbewirtschaftung sind ausreichend."	5-stufige Likert-Skala
Frage 11.1: Wie stark werden Ihrer Meinung nach die folgenden Plattformen zur Verbreitung von Wissen für die nachhaltige Bodenbewirtschaftung genutzt: Weiterbildung durch öffentliche Anbieter (inkl. LW-Schulen, Agridea, FiBL); Flurbegehungen; Messen + Vorführungen; Landw. Grundbildung; Beratung durch private Anbieter; Arbeitskreise; Weiterbildung durch private Anbieter; Weiterbildungslehrgang (z.B. HF, BLS); Beratung durch öffentliche Anbieter; Vereine und Verbände; Weitere	Je Option eine 5-stufige Likert-Skala
Frage 11.2: Falls oben die Option "Weitere" gewählt wurde: Welche weiteren Plattformen?	Offene Frage
Frage 12: Gibt es Ansätze, Methoden und Überlegungen zur Verbreitung von Wissen über nachhaltige Bodenbewirtschaftung, die aus Ihrer Sicht besonders vielversprechend sind?	Offene Frage
Frage 13: Gibt es Anmerkungen welche in den vorhergehenden Fragen keinen Platz hatten und für die genannten Themenbereiche relevant sind?	Offene Frage
Frage 14: Gibt es Anmerkungen grundsätzlicher Art die Sie uns mitteilen möchten?	Offene Frage
Frage 15: Wie viel Zeit haben Sie für die Beantwortung des Fragebogens aufgewendet?	Offene Frage

Questionnaire 2: Research needs - Forschungsbedarf

Frage	Antwort Typ
Frage 1: Die nachfolgenden Fragen werden für das folgende Anbaugebiet beantwortet:	Futterbaugebiet / Ackerbaugebiet / Beide
Frage 2: Wie relevant sind die folgenden Bodenbedrohungen Ihrer Einschätzung nach: Bodenverdichtung; Bodenversieglung; Bodenerosion; Humusverlust; Verlust der Bodenbiodiversität; Bodenkontamination; Torfschwund; Geringe Wasserspeicherkapazität des Bodens; Lachgas- & Methanemissionen; Zu geringe Nährstoffnutzungseffizienz; Bodenversaurung; Versalzung; Subobtimale Regulation des Bodenwasserhaushalt; Suboptimale Bodenaufwertungen; Suboptimale Bodenrekultivierungen; Subobptimale Bewässerungseignung	Je Option eine 5-stufige Likert-Skala
Frage 3: Wie gross ist Ihrer Einschätzung nach der Forschungsbedarf im Bezug auf die folgenden Bodenbedrohungen: Bodenverdichtung; Bodenversieglung; Bodenerosion; Humusverlust; Verlust der Bodenbiodiversität; Bodenkontamination; Torfschwund; Geringe Wasserspeicherkapazität des Bodens; Lachgas- & Methanemissionen; Zu geringe Nährstoffnutzungseffizienz; Bodenversaurung; Versalzung; Subobtimale Regulation des Bodenwasserhaushalt; Suboptimale Bodenaufwertungen; Suboptimale Bodenrekultivierungen; Subobptimale Bewässerungseignung	Je Option eine 5-stufige Likert-Skala
Frage 4.1: Wie relevant sind Ihrer Einschätzung nach die folgenden Ansätze zur Verbesserung der Wissensbasis: Bessere Verfügbarkeit von bestehendem Wissen für Bewirtschaftende; Mehr Wissen über die räumliche Verbreitung der Bodenbedrohungen; Bessere Koordination der verschieden Akteure für die Erarbeitung von Wissen; Neue Bewirtschaftungsstrategien für eine nachhaltige landwirtschaftliche Bodennutzung; Bessere Verfügbarkeit von bestehendem Wissen für politische Entscheidungsträger und Behörden; Mehr Wissen über die zeitliche Entwicklung der Bodenbedrohungen (Monitoring); Weitere	Je Option eine 5-stufige Likert-Skala
Frage 4.2: Falls oben die Option "Weitere Ansätze" gewählt wurde: Welche weiteren Ansätze wären sinnvoll oder wichtig?	Offene Frage
Frage 5: Welches sind Ihrer Meinung die wichtigsten Wissenslücken bezüglich den Bodenbedrohungen? (max. 3)	Offene Frage
Frage 6: Welches sind Ihrer Meinung nach die wichtigsten Lücken beim Bodenmonitoring?	Offene Frage
Frage 7: Welches sind Ihrer Meinung nach die wichtigsten Wissenslücken in Bezug auf nachhaltige Bodenbewirtschaftung?	Offene Frage
Frage 8: Wie könnte Ihrer Meinung nach die Anwendung von Wissen zu nachhaltiger Bodenbewirtschaftung von Bewirtschaftenden gestärkt werden?	Offene Frage
Frage 9: Wie könnte Ihrer Meinung nach die Anwendung von Wissen zu nachhaltige Bodenbewirtschaftung bei der Ausarbeitung von regulatorischen Massnahmen gestärkt werden?	Offene Frage
Frage 10: Gibt es Anmerkungen welche in den vorhergehenden Fragen keinen Platz hatten und für die genannten Themenbereiche relevant sind?	Offene Frage
Frage 11: Gibt es Anmerkungen grundsätzlicher Art die Sie uns mitteilen möchten?	Offene Frage
Frage 12: Wie viel Zeit haben Sie für die Beantwortung des Fragebogens aufgewendet?	Offene Frage

Questionnaire 3: Challenges and opportunities - Herausforderungen und Möglichkeiten

Frage	Antwort Typ
Frage 1.1: Wie wichtig sind folgende Faktoren zur Förderung der Wissensentwicklung für nachhaltige landwirtschaftliche Bodenbewirtschaftung? Zusammenarbeit zwischen Forschungsinstituten und landw. Praxis; Partizipative Forschung stärken (zwischen landw. Praxis und Forschung); Zusammenarbeit zwischen Forschungsinstituten und Bildungs-/Beratungsinstitutionen; Unterstützung von Langzeitversuchen; Zusammenarbeit zwischen den Forschungsinstituten; Boden-Themen in der landw. Ausbildung und in der Beratung stärken; Zusammenarbeit zwischen Forschungsinstituten und der Industrie (Lohnunternehmen, Maschinenhersteller, Betriebsmittelhersteller, ...); Generell mehr Ressourcen für die Bodenforschung bereitstellen; Landw. Boden-Themen in der universitäteren Ausbildung stärken; Vereinfachung von Regulation und Bürokratie; Unterstützung von Start-Ups (z.B. Ecorobotix oder Gamaya); Weitere	Je Option eine 5-stufige Likert-Skala
Frage 1.2: Falls oben die Option "Weitere" gewählt wurde: Welche weiteren Ansätze?	Offene Frage
Frage 2.1: Wie wichtig sind folgende Faktoren zur Förderung der Verbreitung von Wissen für die nachhaltige landwirtschaftliche Bodenbewirtschaftung? Praxisbezug der Forschung stärken; Austausch zwischen Forschenden und der landw. Praxis verbessern; Netzwerke zwischen Forschung und landw. Praxis, Beratung, Bevölkerung sowie Politik stärken; Verbreitung von Boden-Wissen fördern (in Bildung/Beratung, Gesellschaft, Politik, landw. Praxis); Partizipativer Vorgehensweise zwischen Forschung und landw. Praxis fördern; Verständlichkeit von vorhandenen Informationen verbessern; Ausbildung von LandwirtInnen und Beratungspersonen zu Boden-Themen verbessern; Demonstrationsaktivitäten (z.B. Anbauversuche, Flurbegehungen) fördern; Zugang der LandwirtInnen zur Beratung verbessern; Forschende in der Kommunikation mit LandwirtInnen weiterbilden; Weitere	Je Option eine 5-stufige Likert-Skala
Frage 2.2: Falls oben die Option "Weitere" gewählt wurde: Welche weiteren Ansätze?	Offene Frage
Frage 3.1: Wie wichtig sind folgende Faktoren zur Förderung der Anwendung bzw. der Umsetzung von Wissen für die nachhaltige landwirtschaftliche Bodenbewirtschaftung? Höherer Stellenwert des Themas 'nachhaltige Bodenbewirtschaftung' in landw. Praxis, Politik und Bildung; Entwicklung von standortangepassten Bodenbewirtschaftungsstrategien; Intensiverer Austausch zwischen landw. Praxis, Politik und Forschung; Austausch zwischen LandwirtInnen stärken (z.B. Arbeitskreise, Von Bauern für Bauern, ...); Verfügbarkeit und Sichtbarkeit von Entscheidungshilfen, digitalen Hilfsmitteln (z.B. Apps) oder anderen Technologien; Plattformen für Erfahrungsaustausch (Webseiten, Workshops, Magazine, Vereinigungen, Interessensgemeinschaften u.ä.)]; Demonstrationsaktivitäten (z.B. Anbauversuche, Flurbegehungen); Verbesserte agrarpolitische Anreize (z.B. Zahlungen für Zielerreichung statt Massnahmen); Felxiblere Richtlinien (z.B. für Direktzahlungen); Finanzielle Kompensation, falls während der Umsetzung Ertragseinbussen anfallen; Weitere	Je Option eine 5-stufige Likert-Skala
Frage 3.2: Falls oben die Option "Weitere" gewählt wurde: Welche weiteren Ansätze?	Offene Frage
Frage 4: Wie relevant sind die folgenden Bodenbedrohungen für die landwirtschaftlichen Böden in der Schweiz Ihrer Einschätzung nach: Bodenverdichtung; Bodenversieglung; Bodenerosion; Humusverlust; Verlust der Bodenbiodiversität; Bodenkontamination; Torfschwund; Geringe Wasserspeicherkapazität des Bodens; Lachgas- & Methanemissionen; Zu geringe Nährstoffnutzungseffizienz; Bodenversaurung; Versalzung; Subobtimale Regulation des Bodenwasserhaushalt; Suboptimale Bodenaufwertungen; Suboptimale Bodenrekultivierungen; Subobptimale Bewässerungseignung	Je Option eine 5-stufige Likert-Skala
Für welche Bodenbedrohung beantworten Sie die folgenden 4 Fragen?	Dropdown
Frage 5: Wie gross ist die Notwendigkeit von neuem Grundlagenwissen zu dieser Bodenbedrohung? Wo sind die grössten Probleme und Möglichkeiten bei der Erarbeitung von neuem Wissen zu der Bodenbedrohung?	Offene Frage
Frage 6: Welches sind die grössten Probleme und Möglichkeiten bei der Verbreitung von Wissen zu der Bodenbedrohung?	Offene Frage
Frage 7: Welches sind die grössten Probleme und Möglichkeiten bei der Umsetzung bzw. der Anwendung von Wissen zu der Bodenbedrohung?	Offene Frage
Frage 8: Ist das bestehenden Wissen bzw. die Information zu dieser Bodenbedrohung einfach zugänglich und anwendbar? Wie könnte die Zugänglichkeit und die Anwendbarkeit des bestehenden Wissens allenfalls erhöht werden?	Offene Frage
Für welche Bodenbedrohung beantworten Sie die folgenden 4 Fragen?	Dropdown
Frage 9: Wie gross ist die Notwendigkeit von neuem Grundlagenwissen zu dieser Bodenbedrohung? Wo sind die grössten Probleme und Möglichkeiten bei der Erarbeitung von neuem Wissen zu der Bodenbedrohung?	Offene Frage
Frage 10: Welches sind die grössten Probleme und Möglichkeiten bei der Verbreitung von Wissen zu der Bodenbedrohung?	Offene Frage
Frage 11: Welches sind die grössten Probleme und Möglichkeiten bei der Umsetzung bzw. der Anwendung von Wissen zu der Bodenbedrohung?	Offene Frage
Frage 12: Ist das bestehenden Wissen bzw. die Information zu dieser Bodenbedrohung einfach zugänglich und anwendbar? Wie könnte die Zugänglichkeit und die Anwendbarkeit des bestehenden Wissens allenfalls erhöht werden?	Offene Frage
Für welche Bodenbedrohung beantworten Sie die folgenden 4 Fragen?	Dropdown
Frage 13: Wie gross ist die Notwendigkeit von neuem Grundlagenwissen zu dieser Bodenbedrohung? Wo sind die grössten Probleme und Möglichkeiten bei der Erarbeitung von neuem Wissen zu der Bodenbedrohung?	Offene Frage
Frage 14: Welches sind die grössten Probleme und Möglichkeiten bei der Verbreitung von Wissen zu der Bodenbedrohung?	Offene Frage
Frage 15: Welches sind die grössten Probleme und Möglichkeiten bei der Umsetzung bzw. der Anwendung von Wissen zu der Bodenbedrohung?	Offene Frage
Frage 16: Ist das bestehenden Wissen bzw. die Information zu dieser Bodenbedrohung einfach zugänglich und anwendbar? Wie könnte die Zugänglichkeit und die Anwendbarkeit des bestehenden Wissens allenfalls erhöht werden?	Offene Frage
Frage 17: Gibt es Anmerkungen welche in den vorhergehenden Fragen keinen Platz hatten und für die genannten Themenbereiche relevant sind?	Offene Frage
Frage 18: Gibt es Anmerkungen grundsätzlicher Art die Sie uns mitteilen möchten?	Offene Frage
Frage 19: Wie viel Zeit haben Sie für die Beantwortung des Fragebogens aufgewendet?	Offene Frage

Avoid soil compaction
12 participants contributed to this open question section. Answers that appeared more than once are prioritized. Single answers were summarized.

How great is the need for new basic knowledge about this soil threat? What are the biggest problems and opportunities in the development of new knowledge about soil compaction?

1. Basic knowledge exists, transfer to practice is missing
2. Lack of comparability of different methods
3. Site specific knowledge is missing

What are the major barriers and opportunities in the dissemination of knowledge on soil compaction?

1. Lack of awareness of the problem
2. Promotion of knowledge of new technologies and the dangers of soil compaction in education
3. Promotion of visualization tools

Active dissemination measures were suggested to tackle the problem and to overcome the large distance between research and practice

What are the biggest barriers and opportunities in implementing or applying knowledge about soil compaction?

1. Conflict of objectives between economic incentives and soil protection
2. Lack of availability of light machinery
3. Lack of awareness of the problem, as degradation is slow and difficult to see
4. High dependence on and lack of flexibility of contractors

The trend towards heavier machinery, the time pressure from contractors and the economic incentives of higher yields often make farmers take decisions at the expense of soil protection. There is lack of incentives to make soil protection profitable. Also, there are not enough applicable decision support and visualization tools.

Is the existing knowledge or information on soil compaction easily accessible and applicable? How could the accessibility and applicability of existing knowledge be increased?

1. Economic aspects are often given higher priority than soil protection
2. Transfer of knowledge on new technologies to practice should be improved
3. There is a need for simpler and more comprehensible decision-making aids in agricultural practice

Generally, economic factors are more profitable than soil protection. Contractors and machinery manufacturers have to be involved in research, to change the current trends and shift towards light machinery and to more awareness for soil protection. Also, education still focuses on tillage. Soil protection and sustainable management are often just a side note.

Avoid soil erosion
6 participants contributed to this open question section. Answers that appeared more than once are prioritized. Single answers were summarized.

How great is the need for new basic knowledge about this soil threat? What are the biggest problems and opportunities in the development of new knowledge about 'soil erosion'?

1. Basic knowledge exists, transfer to practice is missing

If, then there is a lack of multidisciplinary research directions that also include social aspects. In addition, there is often a lack of understanding of the connection between problem and cause. The lack of a national overview makes it even more difficult.

What are the major barriers and opportunities in the dissemination of knowledge on 'soil erosion'?

1. Lack of problem awareness and interest among students and practitioners

Existing knowledge must be imparted more strongly in education in order to strengthen this awareness. There is a lot of experience on the subject, but there is a lack of systematic exchange and coordinated dissemination.

What are the biggest barriers and opportunities in implementing or applying knowledge about 'soil erosion'?

1. Lack of problem awareness
2. Conflict of objectives between plant protection and soil protection

Oversimplified, sustainable plant protection promotes promotes tillage to avoid use of plant protection products, soil protection promotes use of herbicides to avoid tillage. Compromise solutions are not yet known and there is hardly any information material available that discusses this conflict constructively. Here too, economic incentives predominate and soil protection is often neglected.

Is the existing knowledge or information on 'soil erosion' easily accessible and applicable? How could the accessibility and applicability of existing knowledge be increased?

1. Raising awareness for the problem
2. Improve applicability of factsheets
3. Harmonize recommendations of soil and plant protection
4. Improve availability of assessment of the current situation
5. Improve active and attractive dissemination

Various conflicting objectives make it difficult for farmers to make the 'good' decision. There is a lack of user-friendly fact sheets that provide support and draw attention to the consequences. Again, the lack of problem awareness is often mentioned. There is also a lack of an assessment of the current situation, on the basis of which decisions can be made. Also, improvement of existing information material, and (attr)active dissemination thereof was suggested as a solution.

Avoid soil sealing
6 participants contributed to this open question section. Answers that appeared more than once are prioritized. Single answers were summarized.

How great is the need for new basic knowledge about this soil threat? What are the biggest problems and opportunities in the development of new knowledge about 'soil sealing'?

1. Basic knowledge exists
2. There is a need for knowledge on soil functions

Currently, soil sealing is evaluated according to area only, neglecting the importance of soil functions

What are the major barriers and opportunities in the dissemination of knowledge on 'soil sealing'?

1. Improve awareness of the finality of soil loss through sealing
2. Raise awareness for the importance of soil functions, when talking about soil sealing

Improved dissemination might result in prioritization of scientific interests in political decisions and incentives, towards increased soil protection. Currently, soil protection is not profitable. The current increase in climate-related topics should be used to raise the awareness of the importance and potential of soils.

What are the biggest barriers and opportunities in implementing or applying knowledge about 'soil sealing'?

1. Lack of awareness of soil quality, when talking about soil sealing
2. Economical value of built-up areas is much higher than unbuilt land

The problem is multidisciplinary and the political process is difficult to coordinate. Financial incentives to promote soil protection are not enough. Economic interests and the construction sector are prioritized. Legal regulations are sometimes vague, sometimes too rigid to find a site specific solution.

Is the existing knowledge or information on 'soil sealing' easily accessible and applicable? How could the accessibility and applicability of existing knowledge be increased?

1. Knowledge is available but not accessible
2. Available knowledge is not considered as important

There is a lack of area-wide monitoring data (soil function maps) as a basis for spatial planning and to underline the urgency of the problem.

Avoid loss of soil organic matter (SOM)
7 participants contributed to this open question section. Answers that appeared more than once are prioritized. Single answers were summarized.

How great is the need for new basic knowledge about this soil threat? What are the biggest problems and opportunities in the development of new knowledge about 'loss of SOM'?

1. basic knowledge exists, transfer to practice is missing

There is a lack of applicable and accurate decision support tools. Trend analyses and site-specific solutions are missing

What are the major barriers and opportunities in the dissemination of knowledge on 'loss of SOM'?

1. Effects of measures are invisible in the short term and are therefore not considered effective
2. Topic not sufficiently represented in education
3. Lack of awareness of the problem

Large gap between research and agricultural practice hamper dissemination. Basic knowledge is often missing, e.g. there is a different understanding of 'humus' itself

What are the biggest barriers and opportunities in implementing or applying knowledge about 'loss of SOM'?

1. Conflict of objectives: economic pressure vs. sustainable soil management
2. Lack of awareness

Is the existing knowledge or information on 'loss of SOM' easily accessible and applicable? How could the accessibility and applicability of existing knowledge be increased?

1. Knowledge is available and accessible
2. Lack of awareness and incentives to use them

Improvement of active dissemination, participatory approaches and finding applicable solutions.

Avoid sub-optimal recultivations
4 participants contributed to this open question section. Answers that appeared more than once are prioritized. Single answers were summarized.

How great is the need for new basic knowledge about this soil threat? What are the biggest problems and opportunities in the development of new knowledge about 'sub-optimal recultivations'?

Basic knowledge exists. Well educated specialists are not enough. There is a lack of independent inspecting authorities. Often, there is no monitoring, which hinders improvement of basic knowledge.

What are the major barriers and opportunities in the dissemination of knowledge on 'sub-optimal recultivations'?

Factsheets and guidelines are not harmonized and not updated according to the state of research. Collaboration between authorities and farmers, affected by sub-optimal recultivations, could improve dissemination. Lack of inspection hinders exchange of experiences. Also, there is a lack of awareness for the problem.

What are the biggest barriers and opportunities in implementing or applying knowledge about 'sub-optimal recultivations'?

Lack of awareness for the problem, shortage of well educated specialists and lack of nationally uniform guidelines and guide values

Is the existing knowledge or information on 'sub-optimal recultivations' easily accessible and applicable? How could the accessibility and applicability of existing knowledge be increased?

Improving awareness for the problem, active dissemination through advisory services and managing authorities. Creation of a mediation platform could improve the situation, as well as nationally uniform guidelines and guide values.

Switzerland's State of Knowledge on Soil Carbon Stocks

Environnemental zones adressed: ALS, CON

Monitoring

Knowledge on soil organic carbon (SOC) stock dynamics in Switzerland originates largely from long-term field experiments (e.g. DOK [1], ZOFE [2], Tänikon [3], Frick [4], Oberacker [5] and Oensigen [6]). A review by Keel *et al.* [7] found that topsoils lost SOC at an average rate of 0.29 t C ha^{-1} yr^{-1}, even though many of the investigated treatments were expected to lead to SOC increases. The review found that SOC change rates were mainly driven by C inputs, soil cover and initial SOC stocks. The type of land use or soil tillage had no significant effect. The analysis suggests that current efforts to manage soils sustainably need to be intensified [8]. A cantonal monitoring study reported complementary findings. Over time, SOC levels in integrated production systems were decreasing where as in organically managed arable lands SOC levels were slightly increasing. However, the organically managed arable soils had lower overall SOC levels [9].

In contrast, the Swiss Soil monitoring Network (NABO) found that SOC remained stable for an ensemble of 30 arable sites, although increasing and decreasing trends were observed for individual sites. For some sites, changes in the agricultural management of cropland triggered substantial changes in SOC. Moreover, sites with a low ratio of SOC/clay (< 1/10) generally showed more positive trends than sites with higher ratios.

Modelling carbons stocks and carbon stock changes

For the Swiss climate reporting, SOC stocks and SOC stock changes in mineral and organic soils were estimated for the period 1990 to 2018 [10, chap. 6.5 & 6.6]. Mineral soil SOC stocks and their associated changes were calculated using the RothC model. The implementation and evaluation of the model is described in detail in Wüst-Galley *et al.* [11]. Organic soil SOC stocks for climate reporting were calculated based on the work of Leifeld *et al.* [12, 13]. The annual net carbon stock change in organic soils was estimated according to reassessed measurements across Europe including Switzerland [12-15].

For farmers, Agroscope has developed a decision support tool to assess SOC stock changes at the plot level based on input and SOC decomposition [www.humusbilanz.ch, 16].

SOC sequestration potential

The SOC storage potentials of a wide range of management strategies have been assessed.

The theoretical SOC sequestration potential of full no-till adaptation was estimated to be 0.35 Mt CO_2 yr^{-1}. The full conversion of all cropland to grassland and the restoration of all cultivated peatlands were estimated to sequester 1.1 Mt CO_2 yr^{-1}. However, the realization of the theoretical sequestration potential would drastically alter Switzerland's agricultural structure. Further, the authors concluded that due to the country's already high proportion of grassland as well as integrated and organic cropping, the sequestration potential in Switzerland's arable land is small compared to other countries [12].

A recent study estimated the mean technical SOC sequestration potential of improved agricultural management practices (0.9 Mt CO_2 yr^{-1}), deep ploughing (0.8 Mt CO_2 yr^{-1}) and biochar application (2.2 Mt CO_2 yr^{-1}) [17].

An ongoing study by Leifeld, Keel and Wüst-Galley is further assessing the SOC sequestration potential of biochar, cover crops and agroforestry at the Swiss national level.

Information and knowledge gaps

According to J. Leifeld, the lack of available soil information at sufficient spatial and temporal resolution are the main limitations to soil related modeling and estimations. Especially information on land-use, clay content, subsoil skeleton content, subsoil carbon stocks and the hydrological state of soils are often unavailable.

Subsoil organic carbon dynamics, historical and recent above- and belowground carbon inputs [18], and the impact of the hydrological status of the soil on SOC dynamics were identified as the main knowledge gaps.

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Switzerland's State of Knowledge on 10 major Soil Challenges

Environmental zones addressed: ALS, CON

This report addresses the Swiss state of knowledge and knowledge gaps on the following major soil challenges: reducing sealing, reducing erosion, optimizing soil structure, soil organic carbon (SOC) conservation, reducing peat degradation, soil biodiversity conservation, increasing nutrient use efficiency (NUE), avoiding greenhouse gas (GHG) emissions and optimizing the water balance.
The Swiss Soil Strategy [1], the report on the State of Soils [2], the National Research Program 68 on sustainable soil use [3], a foresight study of the Swiss Soil Monitoring Network (NABO) [4] and a recent text book [91] summarize the knowledge on Swiss soils. A scientific framework to assess anthropogenic impacts on soil characteristics and functions was published in 2003 [5].

Sealing

From 1985 to 2009, Switzerland's agricultural area reduced by 5.4% (ca. 295 km^2). Two third of the lost land was converted into built-up areas [6]. Agricultural construction activities are strong drivers of soil sealing in the countryside [7]. It is possible to unseal soils, and these restored soils may develop favorable conditions for crop growth. However, restored soils have reduced functionality [8].
A nation-wide soil map as well as stringent spatial planning policies are crucial to protect the most valuable soils from sealing [9].

Erosion

The impact of soil management on erosion was determined in more than 200 arable fields over 20 years in the Swiss Midlands. The risk of soil erosion was significantly reduced by adapted crop rotation and tillage practice [10;11]. In managed alpine grasslands, erosion rates usually exceed soil formation rates; hence they are problematic [12].
According to V. Prashun, the state of knowledge is sufficient to address soil erosion risks. However, actual soil erosion rates outside case study areas are unknown [4].

Structure and compaction

The structure of agricultural soils is primarily influenced by the mineral composition [13] and the soil biological activity [14] and secondarily by structural deformation caused by tillage and traffic. SOC contents may increase the number of workable days per year, and are thus reducing the risk by tillage operation in wet soils [15]. The importance of assessing the effects of tillage and traffic on subsoil structure is known [16]. Regardless of operation scheduling, machine weights are likely to have exceeded the mechanical limit of soils, thus compaction is often unavoidable [17]. The prevalence of soil structural problems is widely unknown, just occasionally assessed at the Cantonal level [i.e. 18;19].
According to P. Weisskopf, the main knowledge gaps are: knowledge on processes that govern soil structural evolution [20], indicators for soil structural quality, quantification of natural and anthropogenic impacts on soil structure, spatial assessment of soil structural status, quantification of the site-specific soil structural damage risks and mitigation potential.

Soil organic carbon

A long-term study of 30 arable sites concluded that Swiss SOC levels were at or close to steady state since the 1980s. However, changes in the agricultural management triggered substantial changes in SOC contents for some sites [21]. A cantonal monitoring study made contradicting findings during the assessment of SOC levels on 240 sites over 6 years. Over time, SOC levels in integrated production systems were decreasing [18]. A review on Swiss long-term field trial results [22] found that most topsoils lost SOC, even though some of the treatments (no-till [23;24], reduced tillage [23;25], organic amendments [26;27], organic farming [28]) were expected to increase SOC.
According to P. Weisskopf and J. Leifeld, the knowledge gaps to address SOC depletion are substantial. Standards to measure and monitor SOC development on the field scale need to be established. The quantities of above- and belowground C inputs as well as the half-life time of typical organic amendments need better understanding to enhance SOC dynamics modelling. The knowledge on the effects of site characteristics, including soil hydrological status, on SOC dynamics remains limited. Additionally, the quantitative effects of SOC levels on soil function and soil fertility are understudied. Overall, the definition of site-specific SOC target levels as well as the strategies to attain and maintain these target levels remains a major challenge.

Peat degradation

Switzerland's peatland is mostly degraded due to large scale drainage and historical peat extraction. Since 1710 the peatland area has decreased by 70-80% [29;30]. The degradation status of the remaining peat can be assessed by a stoichiometric method [31]. The historical extent of peatlands and the C storage of the remaining peatland is connected to large uncertainty due to a lack of available data.

Biodiversity

The general consensus in Switzerland is that increased biodiversity supports a multitude of ecosystem services [32-38]. For example, there have been numerous studies highlighting the importance of soil microbial diversity for improving crop yields and NUE [35] as well as for improving overall system-multifunctionality [34].
According to F. Bender, one of the main knowledge gaps in this field is developing ways to make targeted use of soil organisms to provide ecosystem services at the field level [39]. Similarly, it is still not clear why certain practices improve soil biodiversity in some locations but not others. However, a recent NABO report introduced the effort for a national inventory of soil microbial populations and functions [40].

Contamination

The NABO started to assess diffuse contaminations in 1985. Since then, Zn and Cu levels increased due to contaminated slurry and manure application. In some sites U levels increased due to application of contaminated mineral P fertilizer. Pb, Hg and light PAHs levels decreased, among other due to lower air pollution and the ban of Pb fuel additives. Cd, Ni, Cr, Co and heavy PAHs levels did not change significantly. Low PCDD/F and PCB levels were observed in a one-time survey [41-44].
According to R. Meuli, the effects and the prevalence of soil contamination by pesticides and pesticide transformation products [45], antibiotics, flame retardants, and microplastic are widely unknown [4].

Nutrient use efficiency

Despite long-standing policies and helpful national fertilization guidelines [46], the latest estimates at the national scale show a net N, P and K surplus [47;48]. According to a policy evaluation study [49], regional problems exist chiefly in arable areas (nitrate leaching [50;51]) and in regions with high animal densities (ammonia emissions [52], eutrophication of soils [53] and water bodies [54-56]). At the plot level, N efficiency-sustainability dilemma has been identified: treatments with a high nitrogen use efficiency (NUE) lose more soil stock N than those with a lower NUE but higher N losses from the system [57].
According to F. Liebisch and E. Spiess, the main knowledge gaps are the quantification of nutrient pathways in livestock integrated farming systems. Further, the establishment of accepted and reliable methods to increase the NUE with site-specific fertilization is challenging.

N_2O & CH_4

To date, there has been extensive research devoted to understanding rates and drivers of N_2O and CH_4 emissions from Swiss agricultural systems [25;58-80]. In April 2020, all available greenhouse gas emission data was summarized in a national inventory report describing Switzerland's GHG inventory from 1990 to 2018 [77]. This report shows that overall GHG emissions, from the Agriculture sector amounted to 5,991 kt CO2-eq in 2018, which represents a decrease of 12.2% since 1990. Of these total emissions, 55% are from enteric fermentation, 25% are from agricultural soils in general, and 19% are from manure application to agricultural fields. Of these CO_2-equivalents, 6.2% are comprised of N_2O and 10.4% is comprised of CH_4.
According to D. Bretscher, the main knowledge gaps are not related to technical or policy-related aspects at all. Instead, our main challenge is understanding the various socio-economic and cultural barriers preventing practitioners from implementing practices aiming to reduce these potent greenhouse gas emissions.

Water balance

Switzerland's climate leads to the widespread soil water balance optimization by drainage and, in some locations, irrigation. At least a fifth of agricultural land is drained to make it suitable for cultivation and to prevent water logging [81;82]. Large parts of the drainage infrastructure have been in use for nearly a century and are close to the end of expected service life, raising the urgency of renovation [81]. At the same time, concerns about the environmental impact of the drainage systems have triggered research activities [82] and alternatives to drainage renovation are assessed [83].
Climate change will impact agricultural production [84] and may increase water use for irrigation [85-87]. Depending on the chosen adaptation strategies, increasing conflicts on water use during dry periods seem probable [88]. Nevertheless, today drainage and irrigation systems are subsidized [89]. For irrigation, subsidies are targeted to increase the water use efficiency, e.g. by sensor based irrigation scheduling [90].

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Switzerland's Management Strategies to address 9 major Soil Challenges

Environmental zones addressed: ALS, CON

This report addresses the Swiss management strategies of the following major soil challenges: reducing sealing, reducing erosion, optimizing soil structure, soil organic carbon (SOC) conservation, reducing peat degradation, soil biodiversity conservation, increasing nutrient use efficiency (NUE), avoiding greenhouse gas (GHG) emissions and optimizing the water balance. The Swiss Soil Strategy [1] lists measures and directions to counteract soil challenges. Further, many approaches are summarized in a recent text book [2].

Sealing

Soil sealing is addressed by three spatial planning instruments: The Federal Act on Spatial Planning that defines agricultural and building zones, the Sectoral Plan of Cropland Protection to preserve the quota of 438'460 ha prime cropland [3], and the regulations concerning construction activities outside the building zone [4]. A recent study indicates that these instruments might be more effective if they were legally binding at all administrative levels and, if planning authorities needed to compensate for the loss of the most fertile soils [5]. The synthesis of the National Research Project 68 on sustainable use of soil as a resource proposes a tool to integrate soil quality into spatial planning processes to avoid sealing of the high quality soils [6].
The potential and prerequisites of unsealing and restoring soils are understudied. In particular, the development of soils after restoration and their potential to provide ecosystem services need to be assessed [7].

Erosion

The Swiss Soil Protection Ordinance [8] limits tolerable soil erosion rate to 2 or 4 t DM yr^{-1} ha^{-1}, depending on soil rooting depth. The soil erosion risk maps for arable land [9] and grassland [10] support local authorities and farmers to identify areas prone to erosion. In such areas appropriate measures are to be taken [11-15]. A 20-year conservation tillage monitoring program on more than 200 fields showed a significant decrease in erosion rates due to changed tillage practices [16]. The farmer-to-farmer-extension approach has shown to be effective in the dissemination and adaptation of soil protection practices [17].
According to V. Prashun, the policy framework is sufficient to address soil erosion. However, policy implementation is below its potential, as different state levels and offices are involved causing inefficiencies and interface issues. Social barriers to adaptation of soil protection measures need to be better understood and addressed. Further, farmers' access to information needs to be improved to increase awareness of soil erosion.

Structure and compaction

Guidelines for authorities [11] and practitioners [18;19] to assess the risk of soil compaction by agricultural soil management and traffic are available. Tools to assess and optimize the compaction risks are the web-based model Terranimo [20] and a map displaying arable land prone to compaction at a scale 1:200,000 [21]. Recommendations of tire pressure [22] and construction [23] are published. Additionally, guidelines for soil protection during construction are available. They include information on soil stripping, storage and restoration as well as on the management after restoration and on traffic during construction [24]. An inter-cantonal network provides online soil moisture data to support decisions for agricultural and construction related soil management [25]. Defining national limit values for soil density and compaction is the target of the STRUDEL research project [26-29].
According to P. Weisskopf, the main knowledge gaps are the link of site-specific compaction risk assessment with machine control software. Further, there is need for a simple method for farmers to assess soil structural quality and consider the soil structural quality in field management decisions.

Soil organic carbon

The positive effect of SOC levels on soil quality and soil fertility is widely known. There are guidelines and tools to support farmers' efforts to maintain and increase SOC levels [30;31].
Nevertheless, according to Peter Weisskopf, evidence-based tools to assess and recommend site-specific soil management need to be developed. Such tools need to address all soil challenges linked to agricultural land use and integrate holistic knowledge on plant nutrition as well as on crop protection.

Peat degradation

No economically viable alternative to peatland restoration is known in Switzerland [32]. And even if restoration is considered, current carbon offsetting prices often cannot compensate for the lost

agricultural income [33]. Additional options and policy instruments are therefore necessary to protect the remaining peatlands. Additionally, a substantial part of the drainage infrastructure has come to the end of its expected lifetime and drainage renovation or peatland restoration increasingly becomes a political issue [34;35].
Some alternatives to peatland restoration are currently assessed. The «Feuchtackerprojekt» assesses the economic and environmental potential of wet arable cropping (e.g. wet rice cultivation) [36]. Other active projects evaluate the climate impact of covering organic soils with mineral soils and the conversion of organic soils to permanent grassland.

Biodiversity

Multiple national policies are currently in place to ensure that habitat for biodiversity is preserved in agricultural systems [37-39]. For example, it is well known that certain management practices such as reduced or no-tillage, incorporation of cover crops [40], and use of organic fertilizers [41] and organic farming [42-44] can increase soil microbial diversity. On the other hand, many intensive agricultural practices [45] and certain plant protection measures are known to negatively affect soil microbial communities [46], and thus care must be taken when choosing which management practices to employ. Several indicators and protocols have been developed to assess landscape-scale biodiversity of agricultural systems [47-49].
Although the management practices that promote biodiversity are relatively well known, many of these practices are not economically feasible for farmers. Therefore, more information regarding economically profitable, targeted and site-specific practices is needed.

Contamination

In Switzerland, sites with high contamination are identified and are to be renovated in accordance with the Contaminated Sites Ordinance [50]. Additionally, many cantons have published maps with potentially contaminated soils to avoid untraceable spreading of contaminated soils [e.g. 51]. The Swiss legislation relating to soil contamination was summarized in a short review [52].
Future contamination of agricultural soils can be avoided by appropriate fertilization with low Cd and U levels in mineral fertilizers [53], and uncontaminated manure and slurry [54;55].

Nutrient use efficiency

On the plot and farm level, balanced farm nutrient budgets are central to the reduction of excess nutrient levels and losses. For N, there are two site-specific fertilization methods [55]. The N_{opt}-method, correcting rates for the expected yield [56] and the N_{min}-method, correcting rates for the available N in the soil [57]. However, only if soil nutrient stocks are taken into account for fertilizer rate calculation, over-fertilized sites can return to an environmentally friendlier supply level [58;59]. These methods are further improved and linked to models for mineralization processes (SOC, N, P, K) and uptake capacity at the moment [e.g. 60].
According to F. Liebisch, the main challenges to site-specific fertilization are the establishment of accepted methods and digital tools for farmers and authorities.

N_2O & CH_4

In the past decades, management options for reducing greenhouse gas emissions from Swiss agricultural systems has been researched in detail [32;61-72]. GHG emissions were lowered by reduced and no-till management practices [71], replacing mineral fertilizers with organic sources and the use of composted farmyard manure instead of manure-based slurries [61], increasing the proportion of clover in the grass-clover mixture to promote biological nitrogen fixation and to reduce fertilizer input [70]. N taxes are an economic approach to reduce the N surplus, and thus the potential to produce N_2O emissions. However, a recent study showed that potential N taxes would likely have little effect on the N surplus [64]. The authors thus recommend further optimization of the direct payment scheme to motivate farmers to adopt better management practices aimed at reducing GHG emissions [64].
Thorough life-cycle assessments (LCA) of overall emissions are required to better understand impacts of multiple different organic fertilizer sources (e.g. composted manure) and crop types [71].
Additionally, there is still some uncertainty related to how practices aiming to reduce GHG emissions may impact yields, especially under a changing climate. More region-specific recommendations are thus needed.

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Description of policies

DPO - Direct Payments Ordinance (A1/1/2014) - Direktzahlungsverordnung (DZV)

The DPO regulates the 2.8 billion francs of direct payments to Swiss farmers. Farmers need to fulfil the proof of ecological performance (PEP) to be eligible for direct payments (cross compliance). The PEP includes minimal standards for soil protection (e.g. erosion). There are voluntary direct payment contributions for sustainable soil management (e.g. strip tillage).

SP-CP - Sectoral Plan for Prime Cropland Protection (A8/4/1992) - Sachplan Fruchtfolgeflächen (SP FFF)

The SP-CP is an active policy that aims to maintain Swiss food security in times of disturbed or disrupted international supply chains. The SP-CP obliges the federation and the cantons to sustain the quantity and quality of 438'460 ha of prime cropland.

AP22+ - Agricultural Policy 22+ (D12/2/2020) - Agrarpolitik 22+

The AP22+ is the proposition of the Federal Office for Agriculture for the agricultural policies beyond 2022. The proposition is to be discussed and agreed upon in the two chambers of the Swiss parliament. In recent years the agricultural policy were revised every 4 years (e.g. AP14-17, AP18-21). Within one agricultural policy revision many regulations (e.g. subsidies, animal welfare laws, tarifs) are changed.

AP-PPP - Action Plan Plant Protection Products (A6/9/2017) - Aktionsplan zur Risikoreduktion und nachhaltigen Anwendung von Pflanzenschutzmitteln (AP PSM)

The AP-PPP is a common action plan of the Federal Offices for Agriculture, the Environment, Food Safety and Veterinary as well as the State Secretariat of Economic Affairs to reduce the environmental risks plant protection practices by 50% and promote alternatives to chemical plant protection strategies.

SBS - Swiss Biodiversity Strategy (A6/9/2017) - Strategie der Biodiversität Schweiz

The SBS is a strategy of the Swiss governments Federal Office for the Environment to safeguard and increase biodiversity.

CSA - Climate Strategy for Agriculture (A31/5/2011) - Klimastrategie Landwirtschaft

The CSA is a strategy of the Federal Office for Agriculture to adapt the agricultural sector to a changing climate and mitigate the climate impact of Switzerlands agriculture.

EGA - Environmental Goals Agriculture (A2008) - Umweltziele Landwirtschaft

The EGA is a common set of environmental goals for the agricultural sector of the Federal Offices for Agriculture and the Environment. The EGA can be used to monitor the environmental impact of the agricultural sector and its policies. The EGA comprises goals related to biodiversity and landscape, climate and air, water as well as soil.

SSS - Soil Strategy Switzerland (A1/5/2020) - Bodenstrategie Schweiz

The SSS is a common strategy of the Federal Offices for Agriculture, the Environment and Spatial Development to align all soil related policies and strengthen the effort for soil protection.

NRP68 - National Research Programme NRP 68 'Overall Synthesis' (05/2018) - Nationale Forschungsprogramm NFP 68 'Gesamtsynthese'

The National Research Programme "Sustainable Use of Soil as a Resource" (NRP 68), with its 25 research projects, developed the scientific basis for political decisions. Both the ecological and the economic performance of the soil were taken into account. One overall synthesis and five thematic synthesis were created. The research phase lasted from 2013 to 2018.

SRS - Status Report on Soil in Switzerland (A30/11/2017) - Zustandsbericht Boden in der Schweiz

This SRS considers the condition of soils in Switzerland. The analysis of the Federal Office for the Environment shows that the soil is suffering both qualitative and quantitative damage. This suggests that it may be difficult to retain soil functions in the long-term. The 2017 report concludes that various measures have helped to prevent an increase or even decrease certain soil pollutions, Switzerland does not have a sustainable approach to dealing with soil, a basic natural resource. The SRS may have been a motivation to formulate the SSS (see above).

OFO - Organic Farming Ordinance (A1/1/1998) – Bioverordnung

The OFO is the Swiss regulation on organic Farming. The OFO is aligned with the international organic farming framework regulations by IFOAM.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 652615.

Description of Instruments

Table A1: Instruments

ID	Name DE	Name ENG	Description
ChemO	Chemikalienverordnung	Chemicals Ordinance	Substances in fertilizers or pesticides must fulfil the listed requirements
CPCal	CP-Faktor-Rechner	CP-Factor-calculator	This enables farmers to estimate how crop rotation, the tillage method and the tillage direction of a plot can change the risk of erosion.
CSO	Altlastenverordnung (AltlV)	Contaminated Sites Ordinance	Polluted sites are remediated if they cause harmful effects or nuisances, or if there is a real danger that such effects may arise (SS)
DPB	Biodiversitätsbeiträge	Direct payment for areas reserved for promoting biodiversity	Designating areas to promote biodiversity. Payments for quality (two levels) and connectivity of areas
DPPS	Produktionssystembeiträge (PSB)	Direct payment for Production System	e.g. promotion of organic farming and extensive production of arable crops ('Extenso' programme), e.g. promotion of soil fertility, production with reduced pesticide use, humus build-up to maintain soil fertility, reduction of nutrient losses, promotion of functional biodiversity, promotion of location-adapted LW, …
DPR	Ressourceneffizienzbeiträge (REB)	Direct payment for efficient use of resources	Application methods to reduce emissions Gentle tillage Precise application technology for pesticides N-reduced phase feeding Reduction of pesticides in fruit growing, viticulture and sugar beet
DPSI	Strukturverbesserungsbeiträge	Direct payments for structural improvement	Structural improvement in agriculture, such as soil improvement, drainages, upgrades to improve biodiversity, soil structure, water holding balance, restoration
EAEROOF	Verordnung des WBF über die biologische Landwirtschaft	EAER Ordinance on Organic Farming	List of fertilizers and substances allowed for Bio-certified farms.
GRUD2017	Grundlagen für die Düngung landwirtschaftlicher Kulturen in der Schweiz 2017	Principles for the fertilisation of agricultural crops in Switzerland 2017	the GRUD 2017 records the latest state of research in the field of fertilization and the development of cultivation techniques. It is a decision-making aid in connection with the fertilisation of agricultural crops, a tool for agricultural advisors and farms, and the basis for federal and cantonal enforcement instruments (e.g. Suisse balance sheet).
HODUFLU	HODUFLU	HODUFLU	HODUFLU is an internet programme for the uniform management of farm and recycled manure transfers in agriculture
OAPC	Luftreinhalteverordnung (LRV)	Ordinance on Air Pollution Control (A1/3/1986)	Protection of human beings, animals and plants, their biological communities and habitats, and the soil against harmful effects or nuisances caused by air pollution

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ID	Name DE	Name ENG	Description
PEP	Ökologischer Leistungsnachweis (ÖLN)	Proof of Ecological Performance	Contains an article on soil protection and regulates compliance with the minimum environmentally friendly standards. Mandatory, to qualify for other (optional) direct payments.
PPO	Pflanzenschutzmittelverordnung (PSMV)	Plant Protection Products Ordinance (A1/7/2011)	Regulation that addresses the registration, trade, application and control of soil protection products.
RP	Ressourcenprogramm	Resources programme	Within the framework of the available funding, the Federal Government supports the improvement of sustainability in the use of natural resources in agriculture with direct payments. The target areas are natural resources relevant to agriculture, such as soil, water, air, biodiversity or energy. The programme also supports the optimisation of the sustainable use of production resources such as pesticides or veterinary medicines, fertilisers, animal feed or energy.
SBil	Suisse-Bilanz	Suisse-Balance	An enforcement and planning instrument and serves to prove a balanced nitrogen and phosphorus balance. The reference method is described in the Suisse balance sheet guide
WBS	Wirkungskontrolle Biotopschutz Schweiz WBS	Monitoring the Effectiveness of Habitat Conservation in Switzerland (A2011)	To protect precious habitats and the biodiversity, Switzerland designated about 7000 sites of national importance. These sites are legally protected and include mires (fens and raised bogs), dry grasslands, and flood plain habitats as well as amphibian breeding sites. In 2011, the Federal Office for the Environment (FOEN) and the WSL Swiss Federal Research Institute launched the joint project "Monitoring the effectiveness of habitat conservation in Switzerland WBS" to observe developments and changes in these sites.

Description if indicators

Table A2: Indicators

ID	Name DE	Name ENG	Description
AUI	Agrarumweltindikatoren	Agri-environmental indicators	Indicators to monitor the impact of the agricultural sector on the environment. The set of indicators includes nitrogen-balance, phosphorus-balance, ammonia emissions, humus-balance, N-loss, erosion risk, soil cover, biodiversity, GHG, use of energy/resources, energy/resource efficiency, pesticides, Zinc, Copper
Contamination		No indicator yet for new contaminants (I)	Risk of contamination: - general and proxy-indicators, used for scenario developments - Consumption and sales figures (E) - Cadastre of contaminated sites, test perimeter of soil displacement (E) - Balance/modelling on parcel, farm or regional level (E)
Contamination		No indicator yet for new contaminants (I)	Extent of contamination is monitored for 'established' compounds. Guide values are missing for 'new' compounds: - Micro plastic (I) - PPP (P) - Antibiotics - Trace elements (E)
Erosion		There are indicators for arable land, but none for grasslands (NABO) (I)	Guide values for maximum soil losses per time/event
RUSLE	Revised Universal Soil Loss Equation	Revised Universal Soil Loss Equation	Adapted for Swiss soils, for evaluation of erosion risk
Soil biodiversity		No indicator yet for soil biodiversity (I)	- Soil biomass (E) - Soil activity (E) - Molecular genetic methods (I)
Soil Compaction		No indicator yet (I)	Soil compaction: There are proposals for guide values (cantonal guides), but are not embodied in de law (I)
Soil quality		No indicator yet for soil quality(I)	- there is no scientific and political consensus on how to approach this

ID	Name DE	Name ENG	Description
Soil sealing		No indicator yet for area-wide soil sealing (I)	Area-Statistics monitors soil sealing in urban areas only (E)
SOM		No indicator yet (I)	Monitoring, guide values and evaluation intended for a 'SOM-guide value'

Table A3: Monitoring Tools

ID	Name DE	Name ENG	Description
agrammon	agrammon.ch	agrammon.ch	simulation model for ammonia emissions
ALL-EMA	Arten und Lebensräume Landwirtschaft (E)	Agricultural Species and Habitats' Monitoring Programme -	Area-wide random sampling in agricultural locations that are representative for Switzerland. They are monitoring a subset of the BDM. Monitoring of species and habitats
AUM	Agrarumweltmonitoring	Agri-environmental monitoring	N (water, emissions, balances), P (lakes, soils, balances), pesticides residues in water, soil cover/erosion/SOM balance/heavy metal/contaminants/quality, biodiversity Assembles an agriculture-specific report with data from GHGI
BDM	Biodiversitätsmonitoring (E)	Biodiversity Monitoring	Monitoring of species and habitats, area-wide.
ERM	Erosionsrisikokarte (ERK)	Erosion risk map	Modelling of the risk of erosion (no 'real' data monitoring)
GHGI	Treibhausgasinventar	Swiss GHG inventory	The Swiss Greenhouse Gas Inventory calculates all relevant climate gases and related carbon according to UN guidelines. The data acquisition is carried out by various official statistics
LABES	Landschaftsbeobachtung Schweiz	Landscape Observation Switzerland	Monitoring of quality of landscape: Soil sealing; Extensively used forest area; Building area outside the construction zones; Landscape quality in the residential environment; Landscape fragmentation; Landscape urban sprawl; Agricultural area; Light emissions; Variety of uses in the agricultural area; Summer pastures; Perceived beauty of the landscape;
MONET	Monitoring der Nachhaltigen Entwicklung	Sustainable development indicators	MONET is an indicator system to monitor sustainable development. It measures and comments on the current

ID	Name DE	Name ENG	Description
			situation and development in Switzerland with regard to the social, economic and ecological aspects of sustainable development. Available since 2003.
NABEL	Nationales Beobachtungsnetz für Luftfremdstoffe	The National Air Pollution Monitoring Network	Air pollution monitoring network.
NABO	Nationale Bodenbeobachtung	Swiss Soil Monitoring Network	SOM, compaction, water-holding capacity, microbial biomass, soil respiration, nutritional balance, contamination Soil monitoring since 1980 on reference network of around 100 locations (arable land, grassland, forests)
NAQUA	Nationale Grundwasserbeobachtung	National Groundwater Monitoring	Monitoring of pesticide residues from agricultural inputs in surface water NAWA/NAQUA measure the leaching and run-off of nutrients and pollutants from soil to water.
NAWA	Nationale Beobachtung Oberflächengewässerqualität	National Surface Water Quality Monitoring Programme	Monitoring of pesticide residues from agricultural inputs in surface water NAWA/NAQUA measure the leaching and run-off of nutrients and pollutants from soil to water.
OACP	Luftreinhalteverordnung (LRV) (E)	Ordinance on Air Pollution Control (A1/3/1986)	Protection of human beings, animals and plants, their biological communities and habitats, and the soil against harmful effects or nuisances caused by air pollution. Including emissions from agricultural practice.
WBS	Wirkungskontrolle Biotopschutz Schweiz WBS	Monitoring the Effectiveness of Habitat Conservation in Switzerland	To protect precious habitats and the biodiversity, Switzerland designated about 7000 sites of national importance. These sites are legally protected and include mires (fens and raised bogs), dry grasslands, and flood plain habitats as well as amphibian breeding sites. In 2011, the Federal Office for the Environment (FOEN) and the WSL Swiss Federal Research Institute launched the joint project "Monitoring the effectiveness of habitat conservation in Switzerland WBS" to observe developments and changes in these sites.

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Annex VIII: *Summary of policy analysis*.
Second priority policies are listed in italics and only the overarching target was extracted.

Target ID	Policy target	Indicators + current status	Policy monitoring tools	Other policy instruments
DPO-01	Balanced fertilizer use (SAS): - Close nutrient cycles as far as possible - adapt the number of livestock to the location	Farm-specific nutrient balance calculation, through PEP ('Swiss-Balance') (E) Cultivated soils have to be analysed according to DPO every 10 years to enable optimization of fertilization (E) + The min. 'good practice' standard of the GRUD is integrated in the PEP (through Swiss-Balance) and therefore legally binding. The GRUD also contains guidelines for site-specific 'best practice' for fertilization, but these are only recommendations and not legally binding. However, the AP22+ may recommend to enforce 'best practice' in critical regions	By BLW, 30% of farms are inspected/controlled	PEP (E), DPR (optional) (E) DPPS (optional) (E) GRUD2017 (E) Sbal ('Suisse-Bilanz') (E) HODUFLU (E)
DPO-02	Appropriate share of areas reserved for promoting biodiversity, promotion through direct payments (SS)	65'000ha of agriculturally productive areas in plains, 40% of specific quality as defined by DPO, 50% of areas are connected + Goal met concerning quantity and connectivity, but not concerning quality	ALL-EMA (E)	Implementation guidelines are available (E), direct payment through PEP: DPPS (optional) (E) DPB (optional) (E)
DPO-03	The crop rotations are to be determined in such a way that pests and diseases are prevented and that erosion, soil compaction and soil loss as well as leaching of fertilizers and PPPs[d] are avoided (SAS)	This target includes many sub-targets, various measures are promoted through PEP to reach these targets (E) + Strong focus on application measures and not on reaching targets PEP is well established, efforts for improvement are ongoing (P)	By BLW, 30% of farms are inspected/controlled	PEP (E), REB (optional) (E)
DPO-04	Appropriate soil protection (SAS): - Soil protection must be ensured by optimal soil cover and by measures to prevent soil erosion as well as chemical and physical impacts on soils (SAS)	According to SoilPO Annex 3 soil loss is considered to be relevant if it is higher than 2 to 4 t dm/ha*y, depending on the root penetration depth of a soil. Annex 2 and 3 contain guide values for organic and inorganic substances. + For erosion, there is no area-wide and systematic monitoring of effective status yet, except of one regional project (Frienisberg BE). Contaminants are monitored, but indicators for new compounds like micro-plastic are missing. Monitoring for soil compaction has started, but is not yet fully established. Development of biological parameters is also in progress (NABO) Generally, indicators that can be applied on farms are missing, development is ongoing	ERK2 (model based monitoring for erosion risks). NABO: For contamination (NABO, KABO) (E) Erosion Monitoring (I) Soil Compaction Monitoring (NABO) (I)	PEP (E), OSIA (E), DPSI (E)
DPO-05	Targeted selection and application of PPP[d] (SAS)	List of authorised PPP[d] in PPO + (N)	Cantonal implementation authorities	PEP (E)

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Target ID	Policy target	Indicators + current status	Policy monitoring tools	Other policy instruments
FAA-01	The Confederation shall ensure that, through sustainable, market-orientated production, the agricultural sector makes a significant contribution towards: - the reliable provision of the population with food (NS); - preserving natural resources (NS); - maintenance of the countryside (NS); -. encouraging decentralised settlement (NS) [...]	(N) + (N)	(N)	PEP (E), OSIA: Meliorations or soil improvements supported by the federal government
FAA-02	The Confederation supports the sustainable use of natural resources and promotes animal and climate-friendly production	(N) + (N)	(N)	PEP (mandatory), DPR (E), DPB (E), DPPS (E)
SP-CP-01	By the planning of cropland areas, the quality and quantity of the best Swiss arable soils will be protected in the long-term. For the whole of Switzerland a minimum of 438'460 ha has to be ensured (SS): This minimum area has to be permanently ensured by the cantons.	- High quality arable soils : Climatic Zones A/B/C/D1-4; ≤ 18% slope; ≥ 50 cm root penetration depth; contaminants ≤ guide value (SoilPO); min. of 1 ha coherent area, no long-term compaction (E) + Not all assigned areas meet the requirements or are still available, therefore mapping of inventory is ongoing (according to FAL 24+ method) (P)	The cantons are responsible, that their prime cropland contingent remains secured and available in the long term.	
SoilPO-01	Long-term preservation of soil fertility through regulating (SS): - the observation, monitoring and assessment of chemical, biological and physical impacts on soil - measures to prevent long-term soil compaction and erosion; - measures to be taken when manipulating excavated soil; - the further measures to be taken by the cantons in the case of impacted soils. - the requirements on soil management in case of impacted soils.	- Compaction: there are proposals for guide values, but they are not embodied in the law yet. Efforts to do so are ongoing (by BAFU) (I) - Erosion: max. total of 2t dm (for soils with top rooting layer of max 70cm) or 4t dm (for soils with more than 70cm) soil loss per ha and year - Max. content of PCDD and PCDF of 5 (ng I-TEQ/kg DM for soils up to 15 % SOM, ng I-TEQ/dm3 for soils with more than 15 % SOM) - Max. content of PAH of 1 (mg/kg DM for soils up to 15% SOM, mg/dm3 for soils with more than 15% SOM) - Max. content of PCB of 0.2 (mg/kg DM for soils up to 15% SOM, mg/dm3 for soils with more than 15% SOM) - Max. content of 50 CR, 50 Ni, 40 Cu, 150 Zn, 5 Mo, 0.5 Hg, 50 Pb, 700 F (mg/kg DM for soils up to 15% SOM, mg/dm3 for soils with more than 15% SOM) + Following monitoring tools are missing and their development is planned (BAFU/NABO): Erosion Map (I) Soil Compaction Monitoring (I) Soil Biodiversity and Activity Monitoring (I)	NABO (national level), cantonal services for soil protection (cantonal level)	ChemRRO (E), OPMF (E), EPA (E)
AP-22+-01	By 2025, reduction of P, N, GHG and ammonia losses and emissions of 10%, in comparison to 2014/2015	Emissions of N, P, GHG and NH3 (I) + 113 938 t N = 0.13% increase 6 122 t P = 0.5% increase 7 571 000 t CO2-eq = 0.2% decrease 42 300 t NH3-N = 0.5% decrease (2015/2017)	No monitoring tool yet (I)	

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Target ID	Policy target	Indicators + current status	Policy monitoring tools	Other policy instruments
AP-22+-02	Agricultural sector has to contribute 20-25 % (1,5-2 Mio t) to the reduction of GHG emissions by 2030, in comparison to the base year 1990 (SAS)	Emissions of GHG from agriculture (I) + Total GHG emissions of agriculture in 1990: 7.56 Mio t CO2-ep	No monitoring tool yet (I)	
AP-22+-03	Protection of prime cropland is important. Besides the quantitative aspect of soil protection in the cropland area, conservation of soil quality becomes more important. Prime croplands (according to SP-CP) have to be protected from sealing and its soil quality has to be maintained (SS)	No indicator yet (I) + (N)	No monitoring tool yet (I)	
AP-22+-04	The scarce cropland area shall primarily be used for direct human nutrition (not animal feed) (SAS)	No indicator yet (I) + (N)	No monitoring tool yet (I)	
AP-22+-05	The dependency of agricultural production from non-renewable resources like fossil energy or phosphate has to be reduced. The consumption of non-renewable resources (fossile energy, phosphorus, soils, etc.) has to be reduced (SAS)	No indicator yet (I) + (N)	No monitoring tool yet (I)	
AP-22+-06	Payments for innovative technologies to increase animal welfare and health and to prevent negative environmental effects (SAS)	No indicator yet (I) + (N)	No monitoring tool yet (I)	
AP-22+-07	A sustainable management shall ensure soil fertility. Promotion of humus formation and encouragement of management techniques to increase soil fertility (SAS)	Humus balance calculator (P) + Development of guide values ongoing	No monitoring tool yet (I)	
AP-22+-08	Environmental impacts by agriculture have to be reduced. The strategic focus is on environmental risks by plant nutrients N and P as well as by GHG, PPPs[d] and antibiotics (SAS)	No indicator yet (I) + (N)	No monitoring tool yet (I)	
AP-22+-09	A minimum percentage of arable land shall be managed as biodiversity promotion areas. This percentage shall be fixed at 3.5 % and will be taken into account for the necessary 7 % of over all biodiversity areas. (SS)	Status of biodiversity, quality of species and habitat on the entire agriculturally used area (E) + First cycle of monitoring ongoing	ALL-EMA (E)	
AP-22+-10	Promotion of a site-adapted agriculture, fertilization plans for individual fields, improved use of permanent grasslands, adapted stocking rates. (SAS)	No indicator yet (I) + (N)	No monitoring tool yet (I)	

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Target ID	Policy target	Indicators + current status	Policy monitoring tools	Other policy instruments
AP-22+-11	Adaptation of the water protection act: reduction of the maximum allowable amount of farm manure usage from 3 to 2.5 LMU[a]/ha (SAS)	Status of and nitrogen input into watercourses (E) + First cycle of monitoring ongoing	No monitoring tool yet (I)	Extension of WPO (I)
AP-22+-12	To reduce the occurrence of subsoil compaction, the load capacity of soils shall be considered for soil management in the (SAS)	Software to monitor soil-compaction risk (Terranimo) for agricultural contracting business (P) - Compaction: there are proposals for guide values, bit they are not embodied in the law yet. Efforts to do so are ongoing (by NABO) (I) + (N)	No monitoring tool yet (I)	Extension of PEP (I)
AP-22+-13	Promotion of functional biodiversity (NS)	Status of biodiversity, quality of species and habitat on the entire agriculturally used area (E) + First cycle of monitoring ongoing	No monitoring tool yet (I)	
AP-22+-14	In the PEP, PPPs[d] with a high environmental risk won't be allowed, and the abandonment of PPPs[d] will be promoted by direct payments (SAS)	(N) + Testing and compilation of list is ongoing according to AP-PPP[d] (P)	No monitoring tool yet (I)	
AP-22+-15	Ensuring an area-wide management by maintaining and improving soil fertility and yield potential (SAS)	(N) + Development of guide values ongoing	No monitoring tool yet (I)	
AP-PPP-01	The risks of PPPs[d] are reduced by half through reduction and limitation of applications and by reducing emissions (NS)	According to sales figures (P) Proposal for development of specific indicators (P) + First evaluation planned for 2023	FAOG (for sales figures) (P) area-wide monitoring of crop-specific use (I)	PEP (E)
AP-PPP-02	By 2027, reduction of specific PPPs[d] (according to AP PPPs by 30%, in comparison to 2012-1015 (NS)	According to sales figures (P) + First evaluation planned for 2023	FAOG (P) AUM (for crop-specific use) (P)	WPO (E)
AP-PPP-03	The application of PPPs[d] has no long-term adverse effects on soil fertility and the use of such products with high risk potential for the soil is reduced (SS)	no indicator yet (P) + Process has been started to find methods and values to evaluate soil fertility (P)	Agroscope and The Ecotox Centre (P)	WPO (E)
AP-PPP-04	By 2027, the use of PPPs[d] with persistence in the soil (DT50> 6 months) will be reduced by 50%, in comparison to 2012-2015 (SS)	According to sales figures (P) + First evaluation planned for 2023	FAOG (P)	PEP (E)
AP-PPP-05	Residues of relevant PPPs[d] in soils and their degradation products are known until 2020 and will be regularly monitored from 2020 (SS)	no indicator yet (P) + First measurements are ongoing	NABO (E)	SoilPO (E)
SBS-01	Proof of ecological performance shall - as planned for agricultural policy 2014-2017 - be optimized as prerequisite for direct payments regarding fertilization, soil protection, plant protection and ecological compensation. (NS)	Amount of payments for biodiversity per time (E) + Process ongoing through AP22+, which under development	by BLW (E)	

Target ID	Policy target	Indicators + current status	Policy monitoring tools	Other policy instruments
SBS-02	Various instruments and incentive systems are to be used in combination to reduce ammonia emissions. As an important instrument, additional incentives for resource efficiency in the context of direct payments are to be used to promote targeted technical measures.	Ammonia emissions (E) + Decreasing trend between 1990 and 2018 (Switzerland's Informative Inventory Report 2020)	GHGI	
SBS-03	By 2020, the use of natural resources and interventions involving them are sustainable so that the conservation of ecosystems and their services as well as species and their genetic diversity is ensured	No indicators for soil biodiversity yet, there are research projects working on it (P) Various indicator for non soil-specific factors exist + There are efforts to develop monitoring for soil biodiversity (NABO) (I)	No monitoring tool yet for soil-biodiversity (NABO) (I)	
SBS-04	By 2020, an ecological infrastructure consisting of protected and connected areas will be developed to protect the area necessary for maintaining biodiversity. The state of endangered habitats will be improved. (NS)	No indicators for soil biodiversity yet, there are research projects working on it (P) + Goals are specific for above ground soil factors	BDM, ALL-EMA, 'Wirkungskontrolle 'Biotopschutz Schweiz' (for natural reserves)	
SBS-05	By 2020, ecosystem services are recorded quantitatively. This enables their consideration in the measurement of welfare, as complementary indicators to gross domestic production and in regulatory impact assessments	No indicator for ecosystem services yet (I) + Not clear yet, which indicators would be measured. Research necessary	no monitoring tool yet (I)	
CSA-01	By 2050, GHG emissions by agriculture will be reduced by at least one third, compared to 1990. (NS)	Emissions from agriculture + Reduction of 13% until 2017 (AUI)	GHGI and AUM	
EGA-01	Avoiding permanent compaction of agricultural soils (SAS)	There are proposals for guide values, bit they are not embodied in the law yet. Efforts to do so are ongoing (by NABO) (I) + Goal not met, respective ordinances are not properly executed yet	no area-wide monitoring yet. Responsibility of cantonal authorities AUM (E) ?	Several leaflets with recommendations, but no guidelines. Regulated on regional level
EGA-02	Promotion of extensive management practices in watercourse corridors and for species-rich alpine pastures (SS)	Use of management practices + (N)	(N)	DPO (E)
EGA-03	Promotion of low-emission slurry application, thrift-reduced PPP[d] application, and soil conserving management techniques. (SAS)	Use of application techniques + there is an increase in use of precise application techniques[e]	AUM?	DPO (E)
EGA-04	Reduction of loss of arable land in alpine zones due to forest ingrowth (NS)	Reduction of loss + (N)	(N)	
EGA-05	Ammonia emissions amount to a maximum of 25 000 t N/year (SAS)	Emissions from agriculture + Goal not met yet, currently it's at 43'000 t N.	GHGI	
EGA-06	A maximum of 25 mg nitrate per litre in waters that serve as or are intended to be used for drinking water and whose inflow area is mainly used by agriculture (NS)	Amount of nitrate in waters + Goal not met yet, 45% or arable- and 15% of grassland exceeded limit in 2016	NAQUA/NAWA (E)	

Target ID	Policy target	Indicators + current status	Policy monitoring tools	Other policy instruments
EGA-07	Reduction of agricultural nitrogen emissions into the water by 50% compared to 1985 (NS)	Emissions from agriculture + Goal not met, 2016, a reduction of 25% was measured	NAQUA/NAWA (E)	
EGA-08	Maximum total P content of 20ug P/L in lakes whose P input derives mainly from agriculture. (SAS)	Emissions from agriculture + Goal met for most large lakes. Not met for 6 medium lakes. No measurements present for small lakes	NAWA (E)	
EGA-09	No impairment of soil fertility and health due to inorganic or organic contaminants from agriculture (SS)	development of indicators for soil fertility ongoing (NABO) (P) + Goal not met. Guide value missing for soils. Goal met for most of groundwater, but not for small and medium surface water in highly cultivated areas	NAQUA/NAWA (E) (for water) NABO/AUM (E) (soils). No area-wide monitoring yet.	
EGA-10	The environmental risk from PPPs[d] must be reduced as much as possible. Natural conditions must be taken into account. (SS)	0.1 µg/l per individual substance unless regulated otherwise (see WPO Annex 2) + (N)	various (cantonal regulation)	
EGA-11	Input of individual contaminants from agriculture in soils is smaller than their output and degradation. (SAS)	List of contaminants available in SoilPO + No area-wide monitoring yet. Reference-measurements through NABO do not show a systematic accumulation of contaminants in the upper soil	(N)	SoilPO (E)
EGA-12	No impairment of soil fertility through erosion (SAS) - Erosion values have to stay below threshold in agricultural soils - Prevention of talweg erosion on arable soils soils	Max. total of 2t dm (for soils with top rooting layer of max 70cm) or 4t dm (for soils with more than 70cm) soil loss per ha and year + Goal not met, respective ordinances are not properly executed yet	Erosion Map (ERK2) and area-wide monitoring (NABO) (I) Regional monitoring in Frienisberg (Bern), as representative location for hilly areas	ERM (P), CPCal (E)
EGA-13	Agriculture makes a considerable contribution to maintain and promote biodiversity regarding species and habitat diversity, genetic diversity within species, and functional biodiversity (SAS).	65'000ha of prime cropland in plains, 50% or areas are connected. + Goal met for connectivity, but not for quality. Soil biodiversity is not included, development of indicators for soil biodiversity and ecosystem services are planned	BDM, ALL-EMA	DPO (E)
EGA-14	By 2050, reduction of agricultural carbon dioxide, methane and nitrous oxide emissions by at least one third, in comparison to 1990 (corresponds to a reduction of around 0.6% per year under a linear reduction path). (SAS)	Emissions from agriculture + Reduction of 13% until 2017 (AUI)	GHGI and AUM (E)	
EGA-15	Soil fertility is not affected by soil compaction (SS)	Emissions from agriculture + Development of guide values ongoing	no area-wide monitoring yet (NABO) (I) Responsibility of cantonal authorities	Extension of in PEP (I)
SSS-01	From 2050 onwards, no more soils shall be used. Building on soils will still be possible. If soil functions are lost by construction work, they have to be compensated for by upgrading soils on other places. (SS)	soil use (E) soil functions (N) + (N)	currently monitored by the land-use statistics of The Federal Statistical Office. In future, NABO will take over	*SP-CP*

Target ID	Policy target	Indicators + current status	Policy monitoring tools	Other policy instruments
SSS-02	In order to control soil consumption in terms of sustainable development, soil functions are considered in planning and in weighing interests. The necessary soil information is available (SS)	(N) + (N)	NABO (P)	*SP-CP*
SSS-03	For its economic and social welfare Switzerland is depending on both the conservation of the country's own soils and the soils abroad. Therefore Switzerland is pleading for a more sustainable soil use on global level. (SS)	(N) + (N)	(N)	
SSS-04	In construction work outside of the construction zones the degree of soil sealing must be reduced. Buildings no longer used shall be removed and the natural state must be re-established. (SS)	(N) + (N)	(N)	Provision of methods and soil information to better take soil functions into account when defining construction zones (I) Review of the legal framework and creation of incentives to reduce soil sealing outside the construction zones to a minimum (I) In the case of infrastructure projects or other space-related activities by the federal government, measures to reduce soil loss are specified within the framework of the property planning, the planning approval or agreements (I).
SSS-05	Avoidance of permanent compaction in agricultural soils (SAS)	- Compaction: there are proposals for guide values, bit they are not embodied in the law yet. Efforts to do so are ongoing (by NABO) (I) + Development of monitoring tools to evaluate measures (P) Development of guide values and methods to evaluate state of soil structure (I) Revision and adaptation of current indicators and regulations for heavy machinery (I)	NABO (P)	Amelioration of available information on local/current risk of soil compaction risk through agricultural practices (I) Raising awareness along the value chain for the sensitivity of soils to compaction (I) Development of evaluation and decision making tools for farmers (I)
SSS-06	No permanent impairment of soil functions through erosion on agricultural land (SAS)	see SoilPO for guide values (E) + (N)	Cantonal implementing authorities for direct payments (I)	G-SPA (E)
SSS-07	No impairment of water bodies and semi-natural habitats due to soil material washed away from agricultural areas (NS)	Guide values according to SoilPO (E) + (N)	Cantonal implementing authorities for environmental protection	

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Target ID	Policy target	Indicators + current status	Policy monitoring tools	Other policy instruments
SSS-08	Compensation of soil organic matter losses due to agricultural use of mineral soils. (SAS)	(I) + Development of guide and target values for SOM (I) Development of guidelines for renewal of drainage systems, including biodiversity, climate-, water- protection (I)	NABO (P) Swiss climate reporting under the UNFCCC (P)	Development of recommendation on how to maintain soil organic matter (I) Development of evaluation and decision making tools for farmers (I) Review of the general conditions including the direct payment system for an agriculture adapted to the location in order to better maintain soil organic matter (I) Amelioration of available information (I)
SSS-09	Minimizing the loss of soil organic matter due to agricultural use of organic soil (SAS)	(N) + Development of guide and target values for SOM ((I) Development of guidelines for renewal of drainage systems, including biodiversity, climate-, water- protection (I)	NABO (P)	Development of recommendation on how to maintain soil organic matter (I) Development of evaluation and decision making tools for farmers (I) Review of the general conditions including the direct payment system for an agriculture adapted to the location in order to better maintain soil organic matter (I) Amelioration of available information (I)
SSS-10	No permanent loss of soil biodiversity and activity due to agricultural soil use (SAS)	(I) + Development of guide- and target values (I)	NABO (P)	Amelioration of available information on soil biodiversity and activity (I) Promotion of agricultural cultivation methods that guarantee a biologically active community typical of the location (I) Consideration of soil biodiversity and activity when planning and selecting 'ecosystems' ('ökol. Vernetzungsstruktur') (I) Consistent implementation of the possible measures to minimize emission of substances, such as ammonia from agriculture (I)

Target ID	Policy target	Indicators + current status	Policy monitoring tools	Other policy instruments
SSS-11	Review of measures and financing options for the remediation and use restriction of contaminated soils and brownfield sites with the aim of possible harmonization. (SS)	(N) + (N)	(N)	
ADWO-01	*Protection of humans, animals, plants, their communities as well as water bodies, soil and air from harmful effects or nuisances caused by wastes. (NS)*	(N) + (N)	*NAWA/NAQUA for water (E)* *NABEL/GHGI for air (E)* *NABO/AUM for soils (E)*	
ADWO-02	*Limitation of environmental pollution by waste through precautionary measures (NS)*	(N) + (N)	*NAWA/NAQUA for water (E)* *NABEL/GHGI for air (E)* *NABO/AUM for soils (E)*	
ADWO-03	*Promotion of the sustainable use of natural resources through environmentally friendly recycling of waste (NS)*	(N) + (N)	*(N)*	
ADWO-04	*By January 2026, phosphorous must be materially recycled from phosphorous rich wastes, such as sewage sludge of central wastewater treatment plants or from the ashes of the thermal treatment of sewage sludge. (NS)*	(N) + (N)	no monitoring tool yet	
AP-GE-01	*The improvement of resource efficiency and the long-term reduction of resource consumption to an environmentally-friendly level (SS)*	no indicators yet (I) + (N)	*(N)*	
ChemRRO-01	*This Ordinance prohibits or restricts the use of particularly dangerous substances, preparations and articles; Annex 2.6 regulates the contents and application of fertilizers (SAS)*	Annexes ChemRRO (long list of substances) + (N)	*various (cantonal level)*	
ChemRRO-02	*Ban of direct application of sewage sludge on agricultural land (SAS)*	no indicator + (N)	*various (cantonal level)*	
NCHA-01	*Particular protection amongst others for sites which have a compensational function in ecosystems and offer particularly favourable conditions for communities. (NS)*	According to WBS (E) + Goals not met	*WBS (E)*	
G-NFA-01	*... for the protection of water and air due to the management of nutrients and the use of fertilizers in agriculture (SAS)*	(N) + (N)	*(N)*	
G-PPP-A-01	*This enforcement aid explains the legal basis in water and environmental protection, in chemicals legislation and, in part, in agricultural legislation, which are decisive for the handling of PPPs[d] on farms. It concretizes undefined legal terms in particular with regard to the storage and application of PPP[d] and the cleaning of spray equipment. (SS)*	(N) + (N)	*NAWA/NAQUA for water (E)* *NABEL/GHGI for air (E)* *NABO/AUM for soils (E)*	

Target ID	Policy target	Indicators + current status	Policy monitoring tools	Other policy instruments
G-SPA-01	*The enforcement aid explains the legal basis for the soil protection module with the two areas erosion and soil compaction (SAS)*	Guide values according to SoilPO + (N)	*(N)*	*PEP (E)*
NRP68-01	The NRP 68 is recommending: when dealing with soils give prevention priority. (SS)	(N) + (N)	(N)	
NRP68-02	The NRP 68 is recommending: soil quality should be integrated into the spacial planning act as a decisive decision-making factor. This also applies to soils that are not classified as prime croplands. (SS)	no indicator yet (NABO) (I) + development of guide values ongoing	(I)	
NRP68-03	The NRP 68 is recommending: soil management has to be further developed as a site-appropriate, regionally adapted agriculture and forestry that uses soil functions and services provided by the soil optimally and avoids soil damage such as erosion, compaction, pollutants and losses of soil organic matter. (SS)	no indicator yet (NABO) (I) + Development of guide values ongoing	(I)	
NRP68-04	The NRP 68 is recommending: soil organic matter content and soil compaction should be essential indicators for soil quality in the direct payment system of agricultural policy (SS)	(I) + (N)	SOM Map and area-wide monitoring (NABO) (I)	
NRP68-05	The NRP 68 is recommending: from the perspective of climate protection and considering costs of climate change for society, further agricultural use of organic soils should be avoided. (SAS)	(N) + (N)	(N)	
NRP68-06	The NRP 68 is recommending: strengthen the efforts to reduce nitrogen pollution (SS)	(N) + (N)	GHGI and AUM (E) ?	
OFLN-01	*Preservation and protection of landscapes and natural monuments of national importance, including biotopes like peat bogs. These objects must remain intact in their landscape character related to natural and cultural aspects and their formative elements.*	AUI + (N)	*AUM* *Regulated by cantonal authorities, under supervision of the FOEN.*	
OISA-01	*This Ordinance regulates the processing of data in the field of agriculture, i.a. in the information system on nutrient shifts (NS)*	HODUFLU (web app) contains a list of guide values for different types of farm manure + (N)	(N)	
OPMF-01	*Commercial fertilizers are only admitted if (SAS):* *- there are no unacceptable side effects and no danger for neither environment nor indirectly for humans, if used according to the official prescriptions*	(N) + (N)	various (cantonal regulation)	ChemO (E)

Target ID	Policy target	Indicators + current status	Policy monitoring tools	Other policy instruments
OSIA-01	*Contributions are granted for: ... measures to maintain or improve structure and water regime of soils; Contributions are given to the periodic repair and maintenance of: ... agricultural drainage systems: cleaning and repair of drainage pipes, drains and drainage ditches; (SAS)*	(N) + (N)	*various (cantonal regulation)*	*DPSI (E)*
OSME-01	*THE FOAG authorizes a livestock size, so that the amount farm manure produced per farm allows a phosphorus balance to be maintained in accordance with the requirements of points 2.1.4 and 2.1.5 of Annex 1 to the DPO (NS)*	The phosphorus balance of the completed nutrient balance may have an error range of at most plus 10% of the crop's requirements (E) + (N)	various (cantonal regulation)	*DPO (E)*
SRS-01	No exceeding of threshold values for erosion and prevention of talweg erosion on arable land (SS)	SoilPO: Max. total of 2t dm (for soils with top rooting layer of max 70cm) or 4t dm (for soils with more than 70cm) soil loss per ha and year + ERK2 is a model based monitoring for erosion risks. No monitoring for effective status yet (I)	Erosion Map (ERK2) and area-wide monitoring (NABO) (I) Regional monitoring in Frienisberg (Bern), as representative location for hilly areas	DPO, G-SPA, Agricultural Policy 2014-15
SRS-02	Erosion on agricultural land does not damage soil fertility (SAS)	No indicator yet for soil fertility yet (I) + Soil fertility' is defined in SoilPO, development of indicators in progress (P)	Erosion Map (ERK2) and area-wide monitoring (NABO) (I) Regional monitoring in Frienisberg (Bern), as representative location for hilly areas	DPO, G-SPA, Agricultural Policy 2014-16
SRS-03	No impairment of water bodies and semi-natural habitats due to soil material washed away from agriculturally used land (NS)	List for guide values of individual substances available in WPO (E) + ERK2 is a model based monitoring for erosion risks. No monitoring for effective status yet (I)	NAWA/NAQUA (source: NRP68TS4) various (cantonal regulation)	DPO, G-SPA, Agricultural Policy 2014-17
SRS-04	No impairment of soil fertility through soil compaction. Avoidance of permanent compaction of agricultural soils. (SS)	No indicator yet (NABO) (P) + there is no overview yet, but processes to develop indicators, methods and monitoring tools are ongoing	no monitoring tool yet (NABO) (I)	Several leaflets with recommendations, but no guidelines. Regulated on regional level
SRS-05	No impairment of soil fertility and health through inorganic or organic pollutants (SS)	Development of risk based indicators (oekotoxzentrum) for PPP[d] (P) + (N)	NABO and cantonal services (P)	G-NFA
SRS-06	Reduce the use of mineral phosphorus fertilizers as much as possible to the actual need in order to close the national P cycle using recycling measures. (SAS)	Development of national P-cycle is ongoing (P) Cultivated soils have to be analysed according to DPO every 10 years to enable optimization of fertilization (E) + Surplus phosphorous has been reduced from 12 kg/ha in 1990 to around 4kg/ha in 2018c Since 2016, the ADWO Art 15 demands, that by 2026, phosphorous has to be recycled from different wastes.	BLW	

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Target ID	Policy target	Indicators + current status	Policy monitoring tools	Other policy instruments
SRS-07	Preventive limitation of the emission of nitrogenous air pollutants (ammonia) as far as technically and operationally feasible and economically viable (SS)	max. ammonia emissions of agriculture of 25 000 t N/year (EGA) (E) + Goal not met. See EGA-05.	agrammon.ch	Project 'Instrumente-Evaluation Stickstoff'
SRS-08	No excessive immission (ammonium), i.e. no exceedance of critical limits such as immission limits, critical loads, critical levels and ‹Air Quality Guidelines›. (SS)	Critical Loads' and 'Critical Levels' for ammonium compounds acc. to CLRTAP + Goal not met (see Report 'Critical Loads of Nitrogen and their Exceedances')	agrammon.ch for emission FOEN for immission	OAPC (E)
WPO-01	*This Ordinance is intended to protect surface and underground waters against harmful effects and to enable their sustainable use. To this end, all measures taken under this Ordinance must take account of the ecological objectives for water bodies (NS)*	Annexes WPO + (N)	NAQUA/NAWA	
WPO-02	*Waste water from farm manure processing, from hors-sol production and similar crop production techniques must be reused in an environmentally compatible manner, according to the state of the art in agriculture or in horticulture (SAS)*	(N) + (N)	*(N)*	
PAL-01	*The protection of agriculturally suitable soils is given greater priority in spatial planning; the principle is emphasized, that arable land lost as a result of spatial planning must be compensated. (NS)*	(N) + (N)	*LABES*	*SP-CP*
PAL-02	*Prime cropland has to be compensated real, e.g..* *- by re-zoning prime cropland in undeveloped building zones, and assigning them to the agricultural zone* *- by improving soils which have been damaged by human activities, or (iii) assigning soils in agricultural zones which have not yet been assigned to the cropland area. (SAS)*	(N) + (N)	*(N)*	*SP-CP*
SCCS-01	*Switzerland tries to benefit from the chances resulting from climate change by minimizing the risks of climate change, protecting the population, assets and natural resources and improves the adaptive capacity of society, the economy and the environment (NS)*	(N) + (N)	*(N)*	
SCP-01	*With its climate policy, Switzerland aims to reduce its national greenhouse gas emissions by 20 percent as compared with 1990 levels by 2020*	GHG emissions (E) + Reduction of 13% until 2019 (Federal Statistical Office)	*GHGI*	

Target ID	Policy target	Indicators + current status	Policy monitoring tools	Other policy instruments
SSD-01	*By 2030, the quantitative and qualitative planetary resilience and use limits of natural resources (e.g. biodiversity, landscape, soil, air, water, forest and renewable and non-renewable raw materials for energetic or material use) are complied with. The pressure on the ecosystems is limited so that they can continue to perform their functions, remain resilient and the conservation of species populations is guaranteed. The area required to maintain the resources is secured. The environmental pollution caused by Switzerland nationally and abroad has been reduced to a level that is compatible with nature.*	(N) + (N)	MONET	*SP-CP*
SSfS-01	*Switzerland minimizes the loss of agricultural land through new settlements and thus permanently guarantees the highest possible share of food production.*	(N) + Implementation of goals is ongoing	LABES	*SP-CP*
EPA-01	*Protection of humans, animals and plants, their communities and habitats against harmful effects or nuisances and to preserve the natural resources sustainably, in particular biological diversity and the fertility of the soil*	(N) + (N)	*(N)*	*CSO (E)*
EPA-02	*The soil may be physically affected only to the extent that its fertility is not permanently impaired; this does not apply to land used for construction. The Federal Council may issue regulations or recommendations on measures against physical impacts such as erosion or compaction (SS)*	(N) + (N)	*(N)*	*CSO (E)*
EPA-03	*If soil fertility in specific areas is no longer guaranteed in the long term, the cantons must, in agreement with the Confederation, tighten the regulations on requirements for sewage infiltration, limitation of emissions for facilities, the use of substances and organisms or physical impacts on soil to the necessary extent.*	(N) + (N)	*(N)*	*CSO (E)*

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Target ID	Policy target	Indicators + current status	Policy monitoring tools	Other policy instruments
OFO-01	The fertility and biological activity of the soil shall be maintained and, if possible, increased. To this end, the following measures in particular must be taken (SAS): a. the soil shall be cultivated in such a way that its physical, chemical and biological properties enable it to achieve sustainable productivity; b. biological diversity shall be promoted; c. crop rotation, crop shares, use of pastures and soil management shall be planned to avoid crop rotation problems, soil erosion, runoff and leaching of nutrients and plant protection products; d. in arable land use, soil cover must be so high that soil erosion and losses of nutrients and plant protection products are kept to the minimum; e. the intensity of forage production must be differentiated and adapted to the site.	This ordinance does not contain measurable indicators but tries to provide a framework to aim at the described state of soils + The OFO is based on restrictions concerning products and practices. Compliance results in approaching the described state of soils	Certified private inspection bodies (E)	DPO (E)
OFO-02	The quantity of nutrients applied per hectare (own farmyard manure and manure from other farms, bought in fertilizers) may, under the most favourable valley conditions, correspond to no more than 2.5 LMU[a]. It shall be graded according to soil load capacity, altitude and topographical conditions. If maximum values defined by the Canton according to water protection legislation are lower, these values are valid (SAS)	max. 2,5 LMU[a] per ha + (N)	Certified private inspection bodies (E)	DPO (E)
OFO-03	The EAER[b] authorizes the fertilisers that are permissible and the instructions for their use. Mineral nitrogen fertilisers are not allowed for use (SAS)	EAER OOF[f] contains a long list of authorised substances + (N)	Certified private inspection bodies (E)	

SS: soil specific; **SAS**: specific for agricultural soils only; **NS**: non-soil specific, the target includes soils but is broader than agricultural soils only

E: already established (already or nearly operational); **P**: in progress (it is already (quite) well known how to develop and development is in progress); **I:** initial development phase or development or research phase still has to start; **N**: not available/planned

[a] (livestock manure unit) equals 105 kg total N (without losses), 15 kg P

[b] Federal Department of Economic Affairs, Education and Research

[c] Phosphorus balance of the Federal Statistical Office

[d] plant protection product

[e] Monitoring des Direktzahlungssystem', May 2020

[f] EAER Ordinance on Organic Farming

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Annex IX: *Overview of management practices, grouped into seven management categories, listed in the policy packages (Management practices adapted from Catch-C project D5534)*

	Maintain/ increase SOC	**Avoid N_2O/CH_4 emissions**	**Avoid peat degradation**	**Avoid soil erosion**	**Avoid contamination**	**Optimal soil structure**	**Enhance soil biodiversity**	**Enhance nutrient retention/use efficiency**	**Enhance water storage capacity**	**Other environmental stakes**
Crops/rotations										
More legume crops	NRP68							NRP68		DPO (increase biodiversity)
More grassland	CSA									DPO (increase biodiversity), EGA
Intercropping/multiple cropping		OFO		NRP68, OFO		NRP68		NRP68		
Cover/catch crops					AP-PPP (catch crop),					
Perennial crops										DPO (food security)
Other:	DPO (Smart/adapted rotation)	DPO (Smart/adapted rotation), NRP68 (smart/adapted rotation)	DPO (Smart/adapted rotation)	SoilPO (smart/adapted rotation)	AP-PPP (smart/adapted rotation), DPO (smart/adapted rotation)	SoilPO (smart/adapted rotation), CSA (smart/adapted rotation), NRP68 (smart/adapted rotation)	NRP68 (smart/adapted rotation)	DPO (Smart/adapted rotation)	DPO (Smart/adapted rotation), CSA (smart/adapted rotation)	CSA (smart/adapted rotation to avoid pests), OFO (smart/adapted rotation to avoid pests)
Tillage and traffic										
No till						DPO				
Non-inversion/reduced tillage				NRP68		DPO (strip-till, strip milling), NRP68	NRP68		CSA (gentle management), NRP68	
Low pressure (in) tires						CSA				
Other:				SoilPO		DPO (direct sowing, mulch sowing), SoilPO, NRP68 (timeliness of traffic)				
Organic matter/nutrient management										

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	Maintain/ increase SOC	Avoid N_2O/CH_4 emissions	Avoid peat degradation	Avoid soil erosion	Avoid contamination	Optimal soil structure	Enhance soil biodiversity	Enhance nutrient retention/use efficiency	Enhance water storage capacity	Other environmental stakes
Reduced/more precise mineral fertiliser application		CSA, DPO, EGA								DPO (ban of mineral fertilizer on pastures)
Appropriate compost application	CSA	DPO							CSA	
Appropriate farmyard manure application	CSA	DPO							CSA	
Biochar application	CSA					CSA	CSA	CSA	CSA	
Incorporation of crop residues	CSA									
Fertilisation plan/advice	NRP68 (closed nutrient cycle), OFO (closed nutrient cycle), DPO (balanced use of fertilizer, closed nutrient cycle), CSA									
Better manure storage		CSA								
Crop protection										
Mechanical weeding					AP PSM - for cereals, rapeseed, maize and potato, replace herbicide application by mechanical weeding					OFO (avoid pests)
Precision herbicide application					AP-PPP (specific for berries and sugar beet), DPO					
Other					DPO (reduce leaching of pesticide residues), AP-PPP (reduced use of pesticides in vineyards and sugar beet)	NRP68 (green manure)				OFO (thermal treatment against pests)
Water management										

EJP SOIL European Joint Programme
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	Maintain/ increase SOC	Avoid N_2O/CH_4 emissions	Avoid peat degradation	Avoid soil erosion	Avoid contamination	Optimal soil structure	Enhance soil biodiversity	Enhance nutrient retention/use efficiency	Enhance water storage capacity	Other environmental stakes
Subsurface drainage	CSA									
Increasing water tables	CSA (restoration of peat-soils)	CSA								
Buffer strips/small landscape elements										
Other buffer strips										CSA (avoid pests), EGA
Hedges					AP-PPP					
Agricultural systems										
Organic farming										DPO
Agroforestry	CSA									
Conservation agriculture	CSA				AP-PPP			EGA		
Other:	SSS (adapted agriculture)	SSS (adapted agriculture)								

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Annex X: Current policy realisations and aspirational goals per soil challenge.

Soil Challenge	Target ID	Policy document	Current policy target	Current status of policy targets (when Indicators are available) *Policy indicator + status extracted from table 2*
Maintain/increase SOC	SSS-08	Soil Strategy Switzerland (A1/5/2020) - Bodenstrategie Schweiz	Compensation of soil organic matter losses due to agricultural use of mineral soils. (SAS)	Development of guide and target values for SOM, of guidelines for renewal of drainage systems, including biodiversity, climate-, water- protection is planned
	SSS-09		Minimizing the loss of soil organic matter due to agricultural use of organic soil (SAS)	
	NRP68-05	National Research Programme NRP 68 'Overall Synthesis' (05/2018) - Nationale Forschungsprogramm NFP 68 'Gesamtsynthese'	The NRP 68 is recommending: from the perspective of climate protection and considering costs of climate change for society, further agricultural use of organic soils should be avoided. (SAS)	**Status unknown**
Avoiding N2O, CH4 emissions from soils	CSA-01	Climate Strategy for Agriculture (A31/5/2011) - Klimastrategie Landwirtschaft	By 2050, GHG emissions by agriculture will be reduced by at least one third, compared to 1990. (NS)	Reduction of 13% was measured in 2017 (AUI)
	EGA-07	Environmental Goals Agriculture (A2008) - Umweltziele Landwirtschaft	Reduction of agricultural nitrogen emissions into the water by 50% compared to 1985 (NS)	Goal not met, 2016, a reduction of 25% was measured (EGA Status Report 2016)
	EGA-14		By 2050, reduction of agricultural carbon dioxide, methane and nitrous oxide emissions by at least one third, in comparison to 1990 (corresponds to a reduction of around 0.6% per year under a linear reduction path). (SAS)	Reduction of 13% was measured in 2017 (AUI)
	SRS-07	Status Report on Soil in Switzerland (A30/11/2017) - Zustandsbericht Boden in der Schweiz	Preventive limitation of the emission of nitrogenous air pollutants (ammonia) as far as technically and operationally feasible and economically viable (SS)	Goal not met yet, see EGA-05

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Soil Challenge	Target ID	Policy document	Current policy target	Current status of policy targets (when Indicators are available) *Policy indicator + status extracted from table 2*
Avoid soil erosion	EGA-12	Environmental Goals Agriculture (A2008) - Umweltziele Landwirtschaft	No impairment of soil fertility through erosion (SAS) - Erosion values have to stay below threshold in agricultural soils - Prevention of talweg erosion on arable soils soils	Max soil loss per ha and year according to SoilPO. Status unknown, there is no monitoring tool yet. Development of area-wide monitoring ongoing (NABO)
	SSS-06	Soil Strategy Switzerland (A1/5/2020) - Bodenstrategie Schweiz	No permanent impairment of soil functions through erosion on agricultural land (SAS)	
	SRS-01	Status Report on Soil in Switzerland (A30/11/2017) - Zustandsbericht Boden in der Schweiz	No exceeding of threshold values for erosion and prevention of talweg erosion on arable land (SS)	Guide values according to SoilPO. Monitoring through ERK2, which is a model based monitoring for erosion risks. No monitoring for effective status yet
	SRS-02		Erosion on agricultural land does not damage soil fertility (SAS)	No indicator yet for soil fertility yet. 'Soil fertility' is defined in SoilPO, development of indicators in progress (NABO)
	SRS-03		No impairment of water bodies and semi-natural habitats due to soil material washed away from agriculturally used land (NS)	List for guide values of individual substances available in WPO. Model based monitoring through ERK2. No monitoring for effective status yet
Avoid soil sealing	SP-CP-01	Sectoral Plan for Prime Cropland Protection (A8/4/1992) - Sachplan Fruchtfolgeflächen (SP FFF)	By the planning of cropland areas, the quality and quantity of the best Swiss arable soils will be protected in the long-term. For the whole of Switzerland a minimum of 438'460 ha has to be ensured (SS): This minimum area has to be permanently ensured by the cantons.	- High quality arable soils : Climatic Zones A/B/C/D1-4; ≤ 18% slope; ≥ 50 cm root penetration depth; contaminants ≤ guide value (SoilPO); min. of 1 ha coherent area, no long-term compaction (E). Not all assigned areas meet the requirements or are still available, therefore mapping of inventory is ongoing (according to FAL 24+ method)
	SSS-01	Soil Strategy Switzerland (A1/5/2020) - Bodenstrategie Schweiz	From 2050 onwards, no more soils shall be used. Building on soils will still be possible. If soil functions are lost by construction work, they have to be compensated for by upgrading soils on other places. (SS)	soil use and soil functions + status not available yet. Currently monitored by the land-use statistics of The Federal Statistical Office. In future, NABO will take over
	SSS-02		In order to control soil consumption in terms of sustainable development, soil functions are considered in planning and in weighing interests. The necessary soil information is available (SS)	No monitoring tool available

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Soil Challenge	Target ID	Policy document	Current policy target	Current status of policy targets (when Indicators are available) *Policy indicator + status extracted from table 2*
Avoid soil sealing	NRP68-04	National Research Programme NRP 68 'Overall Synthesis' (05/2018) - Nationale Forschungsprogramm NFP 68 'Gesamtsynthese'	The NRP 68 is recommending: soil organic matter content and soil compaction should be essential indicators for soil quality in the direct payment system of agricultural policy (SS)	**Status unknown**
Avoid contamination	DPO-05	Direct Payments Ordinance (A1/1/2014) - Direktzahlungsverordnung (DZV)	Targeted selection and application of PPP[d] (SAS)	**List of authorised PPP[d] in PPO. Status unknown**
	AP-PPP-01	Action Plan Plant Protection Products (A6/9/2017) - Aktionsplan zur Risikoreduktion und nachhaltigen Anwendung von Pflanzenschutzmitteln (AP PSM)	The risks of PPPs[d] are reduced by half through reduction and limitation of applications and by reducing emissions (NS)	Monitoring so far according to sales figures. Proposal for development of specific indicators is in progress. First evaluation period planned for 2023.
	AP-PPP-02		By 2027, reduction of specific PPPs[d] (according to AP PPPs[d] by 30%, in comparison to 2012-1015 (NS)	
	AP-PPP-03		The application of PPPs[d] has no long-term adverse effects on soil fertility and the use of such products with high risk potential for the soil is reduced (SS)	No indicator for soil fertility yet. Process has started to find methods and values to evaluate soil fertility
	AP-PPP-04		By 2027, the use of PPPs[d] with persistence in the soil (DT50> 6 months) will be reduced by 50%, in comparison to 2012-2015 (SS)	Monitoring so far according to sales figures. First evaluation period planned for 2023
	AP-PPP-05		Residues of relevant PPPs[d] in soils and their degradation products are known until 2020 and will be regularly monitored from 2020 (SS)	Development of indicators in progress. First measurements are ongoing
	EGA-06	Environmental Goals Agriculture (A2008) - Umweltziele Landwirtschaft	A maximum of 25 mg nitrate per litre in waters that serve as or are intended to be used for drinking water and whose inflow area is mainly used by agriculture (NS)	Goal not met yet, 45% or arable- and 15% of grassland exceeded limits in 2016
	EGA-08		Maximum total P content of 20ug P/L in lakes whose P input derives mainly from agriculture. (SAS)	Goal met for most large lakes. Not met for 6 medium lakes. No measurements present for small lakes
	EGA-09		No impairment of soil fertility and health due to inorganic or organic contaminants from agriculture (SS)	Goal not met. Development of indicators for soil fertility ongoing (NABO) Guide value missing for soils. Goal met for most of groundwater, but not for small and medium surface water in highly cultivated areas

EJP SOIL European Joint Programme

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Agroscope

Soil Challenge	Target ID	Policy document	Current policy target	Current status of policy targets (when Indicators are available) *Policy indicator + status extracted from table 2*
Avoid contamination	EGA-10	Environmental Goals Agriculture (A2008) - Umweltziele Landwirtschaft	The environmental risk from PPPs[d] must be reduced as much as possible. Natural conditions must be taken into account. (SS)	**0.1 µg/l per individual substance unless regulated otherwise (see WPO Annex 2). Status unknown**
	EGA-11		Input of individual contaminants from agriculture in soils is smaller than their output and degradation. (SAS)	List of contaminants available in SoilPO. There is no area-wide monitoring yet. Reference-measurements through NABO do not show a systematic accumulation of contaminants in the upper soil
	SSS-07	Soil Strategy Switzerland (A1/5/2020) - Bodenstrategie Schweiz	No impairment of water bodies and semi-natural habitats due to soil material washed away from agricultural areas (NS)	**Guide values according to SoilPO, status not known**
	SSS-11		Review of measures and financing options for the remediation and use restriction of contaminated soils and brownfield sites with the aim of possible harmonization. (SS)	not available yet
	SRS-05		No impairment of soil fertility and health through inorganic or organic pollutants (SS)	No official definition of soil fertility and soil health yet. Therefore no indicators/monitoring tools available.
Optimal soil structure	DPO-04	Direct Payments Ordinance (A1/1/2014) - Direktzahlungsverordnung (DZV)	Appropriate soil protection (SAS): - Soil protection must be ensured by optimal soil cover and by measures to prevent soil erosion as well as chemical and physical impacts on soils (SAS)	Annexes of SoilPO contain guide values for erosion, organic and inorganic contaminants. For erosion there is no area-wide and systematic monitoring of effective status yet, except of one regional project (Frienisberg BE). The ERK2 serves as a model based erosion risk monitoring only. Contaminants are monitored, but indicators for new compounds like micro-plastic are missing (NABO, KABO). Monitoring for soil compaction has started, but is not yet fully established (NABO). Development of biological parameters is also in progress (NABO). Generally, indicators that can be applied on farms are missing, development is ongoing.
	EGA-01	Environmental Goals Agriculture (A2008) - Umweltziele Landwirtschaft	Avoiding permanent compaction of agricultural soils (SAS)	Goal not met. There are proposals for guide values, but they are not embodied in the law yet. Efforts to do so are ongoing (NABO)
	EGA-15		Soil fertility is not affected by soil compaction (SS)	Development of guide values ongoing
	SSS-05	Soil Strategy Switzerland (A1/5/2020) - Bodenstrategie Schweiz	Avoidance of permanent compaction in agricultural soils (SAS)	Ongoing processes: Development of monitoring tools to evaluate measures Planned processes: Development of guide values and methods to evaluate state of soil structure and revision and adaptation of current indicators and regulations for heavy machinery

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Agroscope

Annex X

Soil Challenge	Target ID	Policy document	Current policy target	Current status of policy targets (when Indicators are available) *Policy indicator + status extracted from table 2*
Optimal soil structure	SRS-04	Status Report on Soil in Switzerland (A30/11/2017) - Zustandsbericht Boden in der Schweiz	No impairment of soil fertility through soil compaction. Avoidance of permanent compaction of agricultural soils. (SS)	Development of indicators, methods and monitoring tools is ongoing (NABO)
Enhance soil biodiversity	DPO-02	Direct Payments Ordinance (A1/1/2014) - Direktzahlungsverordnung (DZV)	Appropriate share of areas reserved for promoting biodiversity, promotion through direct payments (SS)	65'000ha of agriculturally productive areas in plains, 40% of specific quality as defined by DPO, 50% of areas are connected + Goal met concerning quantity and connectivity, but not concerning quality
	DPO-03		The crop rotations are to be determined in such a way that pests and diseases are prevented and that erosion, soil compaction and soil loss as well as leaching of fertilizers and PPPs[d] are avoided (SAS)	This target includes many sub-targets, various measures are promoted through PEP to reach these targets. Strong focus on application measures and not on reaching targets. PEP is well established, efforts for improvement are ongoing
	FAA-02	Federal Act on Agriculture (A1/1/1999) - Landwirtschaftsgesetz (LWG)	The Confederation supports the sustainable use of natural resources and promotes animal and climate-friendly production	**Status unknown**
	SBS-01	Swiss Biodiversity Strategy (A6/9/2017) - Strategie der Biodiversität Schweiz	Proof of ecological performance shall - as planned for agricultural policy 2014-2017 - be optimized as prerequisite for direct payments regarding fertilization, soil protection, plant protection and ecological compensation. (NS)	Process ongoing through AP22+, which is under development
	SBS-02		Various instruments and incentive systems are to be used in combination to reduce ammonia emissions. As an important instrument, additional incentives for resource efficiency in the context of direct payments are to be used to promote targeted technical measures.	Decreasing trend between 1990 and 2018 (Switzerland's Informative Inventory Report 2020)
	SBS-03		By 2020, the use of natural resources and interventions involving them are sustainable so that the conservation of ecosystems and their services as well as species and their genetic diversity is ensured	No indicators for soil biodiversity yet. Various indicator for non soil-specific factors exist. There are efforts to develop such indicators and monitoring (NABO)
	SBS-04		By 2020, an ecological infrastructure consisting of protected and connected areas will be developed to protect the area necessary for maintaining biodiversity. The state of endangered habitats will be improved. (NS)	

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Soil Challenge	Target ID	Policy document	Current policy target	Current status of policy targets (when Indicators are available) *Policy indicator + status extracted from table 2*
Enhance soil biodiversity	SBS-05	Swiss Biodiversity Strategy (A6/9/2017) - Strategie der Biodiversität Schweiz	By 2020, ecosystem services are recorded quantitatively. This enables their consideration in the measurement of welfare, as complementary indicators to gross domestic production and in regulatory impact assessments	No indicator for ecosystem services yet. Not clear yet, which indicators would be measured. Research necessary
	EGA-02	Environmental Goals Agriculture (A2008) - Umweltziele Landwirtschaft	Promotion of extensive management practices in watercourse corridors and for species-rich alpine pastures (SS)	**Status unknown**
	EGA-13		Agriculture makes a considerable contribution to maintain and promote biodiversity regarding species and habitat diversity, genetic diversity within species, and functional biodiversity (SAS).	65'000ha of prime cropland in plains, 50% or areas are connected. Goal met for connectivity, but not for quality. Soil biodiversity is not included, development of indicators for soil biodiversity and ecosystem services are planned
	SSS-10	Soil Strategy Switzerland (A1/5/2020) - Bodenstrategie Schweiz	No permanent loss of soil biodiversity and activity due to agricultural soil use (SAS)	Development of guide values ongoing (NABO)
	OFO-01	Organic Farming Ordinance (A1/1/1998) - Bioverordnung	The fertility and biological activity of the soil shall be maintained and, if possible, increased. To this end, the following measures in particular must be taken (SAS): a. the soil shall be cultivated in such a way that its physical, chemical and biological properties enable it to achieve sustainable productivity; b. biological diversity shall be promoted; c. crop rotation, crop shares, use of pastures and soil management shall be planned to avoid crop rotation problems, soil erosion, runoff and leaching of nutrients and plant protection products; d. in arable land use, soil cover must be so high that soil erosion and losses of nutrients and plant protection products are kept to the minimum; e. the intensity of forage production must be differentiated and adapted to the site.	This ordinance does not contain measurable indicators but tries to provide a framework thorough restricting products and practices, to aim at the described state of soils

Soil Challenge	Target ID	Policy document	Current policy target	Current status of policy targets (when Indicators are available) *Policy indicator + status extracted from table 2*
Enhance soil nutrient retention/use efficiency	DPO-01	Direct Payments Ordinance (A1/1/2014) - Direktzahlungsverordnung (DZV)	Balanced fertilizer use (SAS): - Close nutrient cycles as far as possible - adapt the number of livestock to the location	Swiss-Balance: The min. 'good practice standard of the GRUD is integrated in the PEP (Swiss-Balance) and therefore legally binding. The GRUD also contains guidelines for site-specific 'best practice' for fertilization, but these are only recommendations and not legally binding. However, the AP22+ may recommend to enforce 'best practice' in critical regions. Cultivated soils have to be analysed according to DPO every 10 years to enable optimization of fertilization
	EGA-05	Environmental Goals Agriculture (A2008) - Umweltziele Landwirtschaft	Ammonia emissions amount to a maximum of 25 000 t N/year (SAS)	42'200 kt N were measured in 2015 (AUI)
	EGA-03	Environmental Goals Agriculture (A2008) - Umweltziele Landwirtschaft	Promotion of low-emission slurry application, thrift-reduced PPP[d] application, and soil conserving management techniques. (SAS)	There is an increase in use of precise application techniques[e]
	SRS-06	Status Report on Soil in Switzerland (A30/11/2017) - Zustandsbericht Boden in der Schweiz	Reduce the use of mineral phosphorus fertilizers as much as possible to the actual need in order to close the national P cycle using recycling measures. (SAS)	Development of national P-cycle is ongoing. Cultivated soils have to be analysed according to DPO every 10 years to enable optimization of fertilization Surplus phosphorous has been reduced from 12 kg/ha in 1990 to around 4kg/ha in 2018[c] Since 2016, the VVEA Art 15 demands, that by 2026, phosphorous has to be recycled from different wastes.
	SRS-08		No excessive immissions (ammonia), i.e. no exceedance of critical limits such as immission limits, critical loads, critical levels and ‹Air Quality Guidelines›. (SS)	Goal not met (see Report 'Critical Loads of Nitrogen and their Exceedances')
	NRP68-06	National Research Programme NRP 68 'Overall Synthesis' (05/2018) - Nationale Forschungsprogramm NFP 68 'Gesamtsynthese'	The NRP 68 is recommending: strengthen the efforts to reduce nitrogen pollution (SS)	**Status unknown**

Soil Challenge	Target ID	Policy document	Current policy target	Current status of policy targets (when Indicators are available) *Policy indicator + status extracted from table 2*
Enhance soil nutrient retention/use efficiency	OFO-02	Organic Farming Ordinance (A1/1/1998) - Bioverordnung	The quantity of nutrients applied per hectare (own farmyard manure and manure from other farms, bought in fertilizers) may, under the most favourable valley conditions, correspond to no more than 2.5 LMU[a]. It shall be graded according to soil load capacity, altitude and topographical conditions. If maximum values defined by the Canton according to water protection legislation are lower, these values are valid (SAS)	LMU unit is not adapted to current livestock breeds, therefore it is an approximation.
	OFO-03	Organic Farming Ordinance (A1/1/1998) - Bioverordnung	The EAER[b] authorizes the fertilisers that are permissible and the instructions for their use. Mineral nitrogen fertilisers are not allowed for use (SAS)	WBF OOF[f] contains a long list of authorised substances
Preserve soil functions	FAA-01	Federal Act on Agriculture (A1/1/1999) - Landwirtschaftsgesetz (LWG)	The Confederation shall ensure that, through sustainable, market-orientated production, the agricultural sector makes a significant contribution towards: - the reliable provision of the population with food (NS); - preserving natural resources (NS); - maintenance of the countryside (NS); -. encouraging decentralised settlement (NS) [...]	**Status unknown**
	SoilPO-01	Soil Pollution Ordinance (A1/10/1998) - Verordnung über Belastung des Bodens (VBBo)	Long-term preservation of soil fertility through regulating (SS): - the observation, monitoring and assessment of chemical, biological and physical impacts on soil - measures to prevent long-term soil compaction and erosion; - measures to be taken when manipulating excavated soil; - the further measures to be taken by the cantons in the case of impacted soils. - the requirements on soil management in case of impacted soils.	SoilPO contains various guide values for erosion and contaminants. Development of indicators and monitoring tools for soil compaction, for soil biodiversity and activity and for erosion are planned (by BAFU/NABO)
	EGA-04	Environmental Goals Agriculture (A2008) - Umweltziele Landwirtschaft	Reduction of loss of arable land in alpine zones due to forest ingrowth (NS)	**Status unknown**

Soil Challenge	Target ID	Policy document	Current policy target	Current status of policy targets (when Indicators are available) *Policy indicator + status extracted from table 2*
Preserve soil functions	SSS-03	Soil Strategy Switzerland (A1/5/2020) - Bodenstrategie Schweiz	For its economic and social welfare Switzerland is depending on both the conservation of the country's own soils and the soils abroad. Therefore Switzerland is pleading for a more sustainable soil use on global level. (SS)	**Status unknown**
	SSS-04		In construction work outside of the construction zones the degree of soil sealing must be reduced. Buildings no longer used shall be removed and the natural state must be re-established. (SS)	**Status unknown**
	NRP68-01	National Research Programme NRP 68 'Overall Synthesis' (05/2018) - Nationale Forschungsprogramm NFP 68 'Gesamtsynthese'	The NRP 68 is recommending: when dealing with soils give prevention priority. (SS)	**Status unknown**
	NRP68-02		The NRP 68 is recommending: soil quality should be integrated into the spacial planning act as a decisive decision-making factor. This also applies to soils that are not classified as prime croplands. (SS)	Development of guide values ongoing (NABO)
	NRP68-03		The NRP 68 is recommending: soil management has to be further developed as a site-appropriate, regionally adapted agriculture and forestry that uses soil functions and services provided by the soil optimally and avoids soil damage such as erosion, compaction, pollutants and losses of soil organic matter. (SS)	Development of guide values ongoing (NABO)

SS: soil specific;

SAS: specific for agricultural soils only;

NS: non-soil specific, the target includes soils but is broader than agricultural soils only

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Annex XI: Other instruments to achieve aspirational goals per soil challenge.

Soil challenge	Possible instruments to achieve aspirational goal (short explanation)
Maintain/increase SOC	- 'Bio-Suisse', the swiss organic label promotes maintenance and increase in SOM - 'CarboCert GmbH', a market based initiative, promotes projects for humus formation - 'AgroCO2ncept', a regional initiative to reduce CO2 emissions - 'Klimaschutz durch Humusaufbau' a project where a local bank compensates GHG emissions by supporting local measures to increase humus formation. - 'My Climate', an international, but Swiss-based initiative for voluntary CO2-compensation measures
Avoid soil erosion	- The online 'CP-Factor Calculator' can be used as decision making aid, to estimate how the crop rotation system, tillage method and direction of tillage of a plot of land can change the risk of erosion. - The 'Erosion risk map of Switzerland (ERK2)' shows the potential risk of erosion (acc. to RUSLE). To determine the current erosion risk, the factors for soil cover and tillage method and direction of tillage are necessary. These two factors can strongly influence farmers. - the NFP68 recommends the use of soil index points as a control instrument limit the progressive loss of high-quality soils
Avoid soil sealing	- NFP68-PS4, recommends the use of soil indicators as a decision aid for spatial planning
Avoid contamination	- The 'Bio-Suisse' label, which extends the regulations of the OFO, prohibits the use of pesticides and mineral fertilizer - In the framework of the 'NFP68', a regional soil monitoring tool for sustainable cycles of sustances on agricultural soils ('Frühwarnsystem') was developped. This could be used as decision aid for sustainable soil management.
Optimal soil structure	- The 'Bio-Suisse' label also contains many regulations that promote conservation agriculture (e.g. plough-less tillage, direct sowing, mulch sowing) - The 'IP-Suisse' label recommends the use of soil-conserving practices, optimal crop rotation and permanent soil cover. Most swiss farms cultivate - 'bodenmessnetz.ch': The soil monitoring network of the cantons of Solothurn, Aargau, Baselland, Zug, Geneva, Vaud, Fribourg and Berne provides information on the current state of the soil and decision-making aids for soil-conserving work. - Regional Programms like 'Förderprogramm Boden' of the canton Berne, to create a network for promotion of practices promiting soil health - Terranimo® is a model for prediction of the risk of soil compaction due to agricultural field traffic.

Enhance soil biodiversity	- 'Bio-Suisse' label: fertilization and soil management has to promote soil life. Prohibition of synthetic fertilizers, promotion of conservation tillage
Enhance soil nutrient retention/use efficiency	- Bio-Suisse: Nutrient balance has to be reduced to a minimum and has to be adapted to the specific location. - The simulation model 'Agrammon' allows ammonia emissions to be calculated, and shows how changes in structure and production methods at the farm level affect emissions.
Enhance water storage capacity	- 'bewässerungsnetz.ch': The soil probe measuring network via soil probes helps to determine the optimal time and amount of irrigation.
No specific challange	- The NFP68 recommends: - to consider soil quality, the individual soil functions and ecosystem services for future land use decisions - a comprehensive mapping of Swiss soils - The establishment of a Swiss Soil Information Platform, which develops standardized sampling methods, ensures the nationwide harmonisation of soil information, makes interactive products such user and soil function maps available and ensures access to them for science, authorities and practice. - to provide consumers with information on sustainable use of soil in Switzerland and abroad - Cooperation between the various stakeholders - in particular between environmental, agricultural and spatial planning experts - should be deepened and coordinated at all levels of government - to promote the implementation of the Swiss Soil Strategy and to raise awareness of soil issues in society