Swiss National Soil Strategy

for sustainable soil management

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1 Key points in brief

The challenge

Both ecologically and economically, soil is a valuable, non-renewable resource. It provides vital services to Switzerland's population and economy, and is key to the production of foodstuffs, wood and other raw materials. It plays an important role for biodiversity and for a stable climate. It ensures clean drinking water and protects us from natural disasters. Soil is classified as a non-renewable resource because it takes around 100 years for a one-centimetre deep layer of soil to be created. Despite this, Switzerland is continuously losing soil: unsealed land area is shrinking all the time, soil is disappearing as a result of erosion and organic matter decline, and soil functions are being lost owing to compaction and contamination.

The vision

Here, this challenge is met with a vision in which soil use is managed to preserve soil functions for the long term, so that future generations are also able to benefit from the diverse services that soil provides.

Common soil strategy as a guiding framework

To bring this vision closer to fruition, the Federal Offices for the Environment (FOEN), Spatial Development (ARE) and Agriculture (FOAG) have joined forces to formulate this Strategy and to coordinate it with other federal agencies and cantonal experts. The National Soil Strategy is intended to serve the competent federal and cantonal authorities as a guiding framework and decision-making aid, and to highlight ways in which the challenges that have been identified can be tackled. The primary tasks here will be to obtain the necessary soil data and to coordinate current policies and instruments more effectively. Any new regulations will be considered only as a second step, following a comprehensive review of existing legislation.

Ecological soil functions

Soil is more than simply land area. The ability of soil to provide vital services for both humans and the environment is expressed by the term "soil functions". Three of these soil functions result directly from the ecological processes that are ongoing within the soil. These can be degraded irreversibly by inappropriate soil use. They are of central importance to the ecosystem services provided by soil:

- *Habitat function:* The ability of soil to sustain animals, plants and other organisms.
- *Regulating function:* The ability of soil to regulate, buffer or filter water and energy cycles, as well as to transform substances.
- *Production function:* The ability of soil to produce biomass, i. e. food and feedstuffs, as well as wood and other fibres.

Overarching objectives

Six overarching objectives should be pursued in the interests of preserving soil functions in the long term:

- Reduce soil consumption
- Manage soil consumption on the basis of an overall perspective
- Protect soil from harmful impacts
- Restore degraded soils
- Improve perceptions of the value and sensitivity of soil
- Strengthen international commitment.

Targets and strategic approaches

For eight fields which are deemed particularly relevant, the Soil Strategy sets out specific targets and strategic approaches that will be applied to reach the overarching objectives:

- The targets and focus areas relating to spatial planning are aimed at limiting soil use, and to factoring fundamental information and data on soil quality into decisions on space and land use both outside and within building zones.
- In the field of agriculture, the focus is on preventing soil compaction, erosion and organic matter decline. Particular attention will be paid to the risks associated with pesticides, fertilisers and other substances used in production.
- The two Soil Strategy targets set for forests focus on the input of substances from the atmosphere, and soil compaction. The strategic areas of focus broaden those relating to information and communication that are already contained in "*Waldpolitik. Ziele und Massnahmen 2030"* [Forests Policy. Objectives and Action to 2030].
- Physical soil degradations are to be avoided in the case of construction sites and remodelling of land. While suitable topsoil and subsoil that is removed must be reused as far as is possible, soils that have grown naturally should be protected from land remodelling works.
- "Greenfield" events such as open-air concerts, motocross races, Swiss wrestling festivals and tractor-pulling contests should not result in a lasting degradation of soil function. Procedures for issuing permits should be reviewed in order to achieve this.
- In settlement areas, new soils should be created in a way that allows them to fulfil their ecological functions. Furthermore, soil contamination should be avoided, and soils that have already been degraded by pollutants should be restored.
- There are differences in the way authorities have to deal with polluted soils and contaminated sites. These differences are the subject of some confusion at present. The various pieces of legislation must therefore be reviewed and, where necessary, aligned.
- At the international level, Switzerland should become a stronger advocate for soil preservation and sustainable soil use.

Three action areas

The total of 44 focus areas in the eight fields can be grouped into three action areas:

- *Information:* Switzerland lacks reliable, coherent nationwide information on its soils – a fact identified by the group of experts revising the crop rotation areas sectoral plan, and confirmed as a primary challenge by National Research Programme 68, "Sustainable Use of Soil as a Resource" (NRP 68). The absence of such information presents an obstacle to sustainable soil management. To close this gap swiftly, the establishment of the National Competence Centre for Soil (known by its German acronym, KOBO), as adopted by Parliament, is the top priority. The KOBO will have a key role to play in gathering the soil information that is needed.
- *Awareness-raising:* A central finding of NRP 68 was that many direct users of soil, and the general public, are little aware of the vital importance of soil as a basis of life, and of its sensitivity to degradation. There is therefore a need for information and awareness-raising measures among target groups whose decisions have a particular impact on soil.
- *Enforcement and legislation:* Although Swiss legal requirements for soil management are appropriate and practical, they are often insufficiently enforced. The federal and cantonal agencies responsible for soil-related issues should therefore together develop solutions to reinforce enforcement in this area. Existing regulations should be reviewed, aligned if possible, and amended and extended if necessary. The aim here is to achieve a coherent set of rules and regulations that is geared to preserving soil functions.

2 Introduction

Growing challenges and the need for a cross-sectoral soil strategy

Both ecologically and economically, soil is a valuable, non-renewable resource. It fulfils a whole range of functions and provides vital services for the Swiss population and Swiss economy. Just as varied as the functions of soil are the demands in terms of its use, however. This can lead to conflicts of use, as well as to conflicts between efforts to protect soil and to use or consume it. With a view to the sustainable use of soil in Switzerland, achieving a balance between the various demands and increasing the importance of soil as a resource in the environmental policy context will present key challenges for the future. These cannot be approached from a sectoral perspective.

Since its adoption in 2015, the 2030 Agenda for Switzerland's commitment to sustainable development at both national and international levels has provided a roadmap. At the heart of the 2030 Agenda for Sustainable Development are the 17 global Sustainable Development Goals (SDG), with their 169 targets. In this context, Goal 15 ("Protect, restore and promote sustainable use of terrestrial ecosystems") focuses specifically on the protection of soil, and especially on efforts to achieve a land degradation-neutral world, as formulated in target 15.3.

Soil as a resource is not being used sustainably at present

The continual loss of valuable arable land, experience in implementing soil-related environmental legislation, and recent scientific findings, all indicate that soil as a resource is not being used sustainably in Switzerland.

National Soil Strategy

To face this challenge, the Federal Office for the Environment FOEN has decided to join forces with other interested federal agencies (ARE, FEDRO, SFOE, FOAG and swisstopo) and the cantons to draw up a basis for a National Soil Strategy. At the centre of this work stands the vision of preserving soil functions for the long term so that future generations are also able to benefit from them. This vision, and the content of the Soil Strategy, are congruent with the Federal Council dispatch on legislative planning for 2015 – 2019, and the Sustainable Development Strategy 2016 – 2019. In view of the key role of soil in biodiversity, the drafting of a soil strategy was also included as measure 4.2.2 in the Action Plan to the Biodiversity Strategy that was adopted by the Federal Council on 6 September 2017.

Focus on soil functions: paradigm-shift for better decision-making

Sustainable, integrated management of soil as a resource is required to implement the objectives of the Soil Strategy. Switzerland has to date pursued a usage or sector-based approach in this field. The focus on soil functions thus represents a new and comprehensive perspective, no longer simply addressing the surface of soil, but rather its ability to fulfil a range of functions. The necessary, appropriate and economical use of soil – and the preservation of its many services – can be achieved only if all of these functions are factored into soil-related decisions. This type of holistic view enables both qualitative and quantitative aspects to be considered in decisions about soil use and soil

consumption. It takes into account the complexity of soil, and complements existing approaches to its management, without weakening them. As such, it offers the opportunity to address the need to both protect and use soil in a ore nuanced way than at present, and allows available land to be allocated to those different needs in the best possible manner. In this way, this overall, functional view encourages better decisions, such as those concerning the conflict surrounding the preservation of crop rotation areas and arable land. There is broad-based international support for the concept of soil functions, and it is already being applied successfully in other European countries.

Three action areas: soil information, enforcement and legislation, and awareness-raising

The knowledge currently available about the properties of soils in Switzerland is insufficient to establish soil functions as a basis for decision-making, and to apply them effectively. That said, better information is key to assessing soil functions, and thus to better decision-making processes in the interests of sustainable and integrated resource management. However, information alone is not enough to achieve the vision of the Soil Strategy. Existing legislative foundations, institutional frameworks and enforcement must also be reviewed and, where necessary, reoriented. Moreover, it is essential that the stakeholders concerned, and the general public, be made more aware of the value and the sensitivity of our soils, which are still too-little regarded as a valuable and finite resource.

The Soil Strategy takes a national view.
The Swiss National Soil Strategy sets out overarching objectives, targets in individual fields, and strategic approaches from a national perspective.

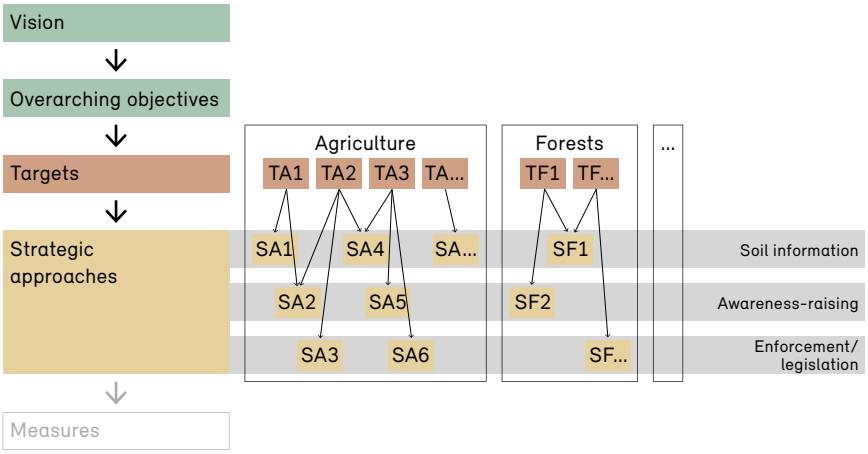
- The *overarching objectives* are derived from the principle of sustainability and the vision of the Soil Strategy. They do not relate to individual sectors or policy areas. These overarching objectives have a long time horizon of 20 to 30 years, i. e. a generation.
- The *targets* for individual fields (agriculture, forests, etc.) have been defined based on detailed analyses of the current situation and the challenges faced. These targets cover the eight fields in which action is most urgently needed, and relate in each case to one or more of the overarching objectives.
- *Strategic approaches,* meanwhile, have been formulated as a means of achieving these targets. They form a basis for drawing up specific measures and for nominating the actors responsible for implementation at a later date. Specific measures do not form part of the Soil Strategy itself, however.

The following figure explains the structure of the Soil Strategy:

Figure 1

Simplified graphical representation of the structure of the Swiss National Soil Strategy, showing the elements of vision, overarching objectives, targets and strategic approaches

The targets in the various fields are designated accordingly. For example, TA1 is the first target for agriculture, TA2 the second, etc. A similar nomenclature has been used for the strategic approaches derived from the targets (SA1, SA2, SA3, etc.). The grey bars show the three action areas.



Document structure

This document is structured as follows:

- Section 3, "Why a soil strategy?", introduces the concept of soil functions and discussed the most important over-arching aspects of soil issues.
- Section 4, "Vision and overarching objectives", describes the vision and overarching objectives.
- Section 5, "Targets and strategic approaches", derives targets and areas of strategic focus for the fields of spatial planning, agriculture, forests, construction sites and remodelling of land, greenfield events, the use of soils in urban areas, the management of degraded soils, and international cooperation. Underground planning and civil engineering forms part of the second stage of reforms to the Spatial Planning Act, and is not examined in the Soil Strategy.
- Section 6, "Action areas" allocates the strategic approaches derived in the previous section to the three action areas: *soil information, awareness-raising* and *enforcement and legislation,* summarises them, and also outlines the next steps towards implementation.

Development of a National Soil Strategy in cooperation with the cantons and other stakeholders

The National Soil Strategy is a collaborative effort between the FOEN, as lead agency, and other interested federal government agencies. It was discussed in depth, and additional content added, in a workshop attended by representatives of the specialist cantonal departments (environment, agriculture and spatial planning), and from the Swiss Conference of Directors of Public Works, Planning and Environmental Protection, DPPE. To understand the views and concerns of spatial planners even more fully, a total of seven interviews were also held with representatives of cantonal planning departments, and the president of the Swiss Conference of Cantonal Planners, KPK. Prior to its completion, the Soil Strategy went through a round of consultations with the relevant cantonal planner conferences, and other interested agencies.

The aim of this process was to achieve broad support for a National Soil Strategy, the targets and strategic approaches of which will be the joint responsibility of the federal government agencies concerned and the cantons.

Binding nature of the Strategy

The National Soil Strategy is intended to serve the competent federal government and cantonal authorities as a guiding framework and decision-making aid. It provides a roadmap for tackling the challenges that have been identified.

3 Why a soil strategy?

This section shows the benefits of a National Soil Strategy. It introduces the concept of soil functions and describes the principal challenges faced today with regard to the sustainable use of soil as a resource.

3.1 Soil is valuable and limited

A non-renewable resource, soil is an important part of the basis of our existence

Soil is the uppermost, unsealed layer of the earth's crust, characterised by living organisms. It is a highly valuable ecological and economic resource that cannot be renewed within a human time-scale, and along with water and air represents an essential basis of life. However, unlike water and air, soil is a finite resource bound to a specific place. Its protection, preservation and sustainable use is one of the tenets of the 2030 Agenda for Sustainable Development.

Soils fulfil a series of essential functions in the natural life cycle. They serve as natural habitats for plants and animals. In the event of heavy rainfall intact, non-compacted soils can absorb the water and thus help to mitigate flood-related damage while providing water over longer periods of time and during droughts. Soils regulate materials cycles, filter pollutants out of the air, and store carbon.

Furthermore, soils make a key contribution to providing many different ecosystem services, and thus to human well-being. They provide the basis for producing foodstuffs and wood, offer room for urban developments and infrastructures, and are the foundation for leisure, sporting, recreational and tourism uses. The long-term usability of our soils nonetheless demands that such use is sustainable, thereby maintaining their ecological performance.

Soil functions at the heart of the Strategy

Soil is thus at the heart of the National Soil Strategy not just as land area, but as a provider of services for humans and the environment. The ability of soil to provide these services is expressed by the term "soil functions". Reflecting the common international definitions, a distinction is drawn between the following soil functions:

- *Habitat function:* The ability of soil to sustain organisms and to maintain the diversity of ecosystems, species and their gene pool. The habitat function also covers soil's suitability as a habitat for organisms and as a location for plants.
- *Regulating function:* The ability of soil to regulate, buffer or filter water and energy cycles, and to transform substances.
- *Production function:* The ability of soil to produce biomass, i. e. food and feedstuffs, as well as wood and other fibres.

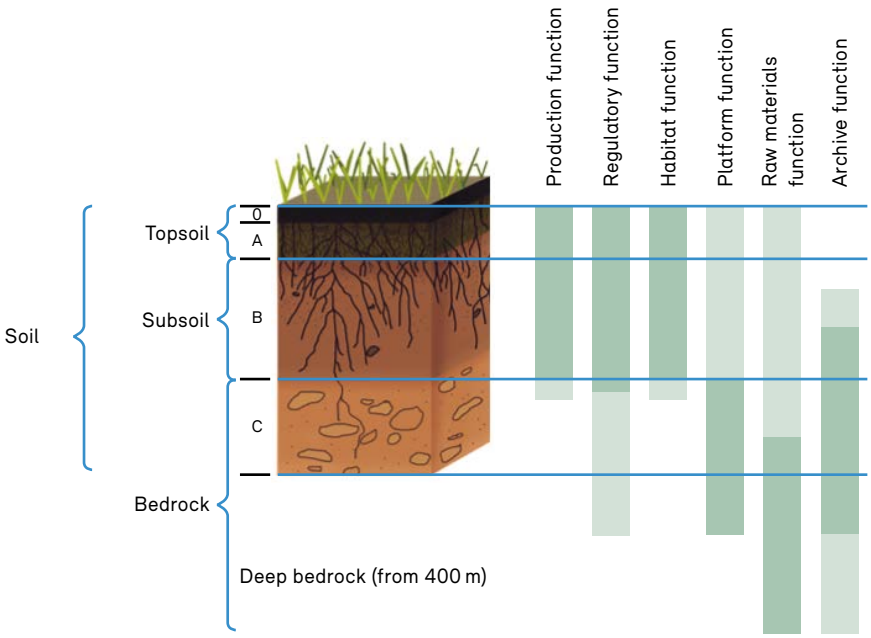
- *Platform function:* The ability of soil to provide a basis for man-made structures.
- *Raw materials function:* The ability of soil to store raw materials, water and geothermal energy.
- *Archive function:* The ability of soil to store information about natural and cultural heritage.

The first three soil functions result directly from the ecological processes that are ongoing within the soil, and are thus referred to as ecological soil functions. By contrast, the last three soil functions relate more to human activities, and are independent of those natural processes. They may be described as socio economic soil functions.

The following figure illustrates the depths at which the six soil functions are primarily fulfilled. Some clearly attain a certain depth, while others are fulfilled at quite different levels.

Figure 2

Systemic boundaries of the Soil Strategy



Focus on ecological soil functions

The platform, raw materials and archive functions are already the subject of other strategies and policies. This Strategy therefore deliberately omits any treatment of mineral raw materials provision and landfill management, as decision-making documents in these areas are already covered by other concepts and plans, as well as by other regulations. The Soil Strategy therefore fo cuses on maintaining the habitat, regulating and production functions of

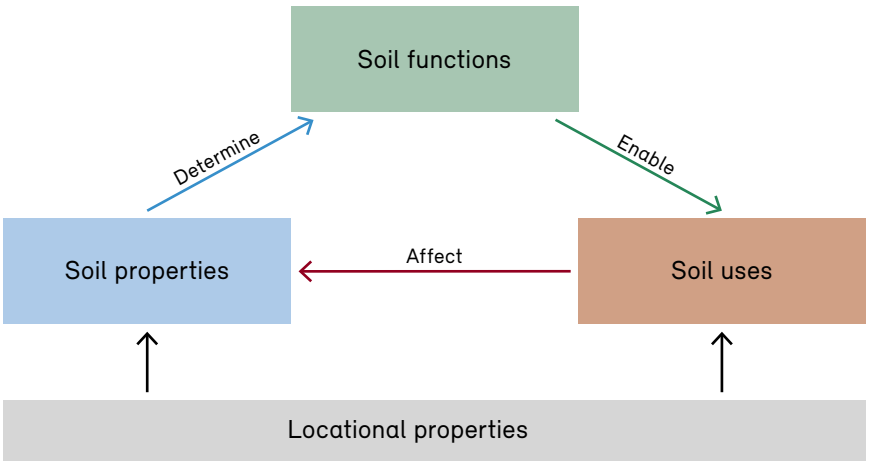
soils. These ecological functions can be degraded irreversibly by inappropriate soil use. They are of central importance to the ecosystem services provided by soil (see Section 3.3). That said, all soil functions must be taken into account when implementing the proposed strategic approaches (see Section 5).

Interrelations

Soil functions are interrelated with the qualities and uses of soil. This is illustrated below.

Figure 3

The interrelations on which the Soil Strategy is based



The physical, chemical and biological properties of soil determine its functions and thus permit it to be used in different ways. Meanwhile, soil use affects the properties of soil, and thus the way in which it fulfils its functions. Furthermore, both soil properties and soil use are shaped and influenced by locational properties, such as climate, relief, geology, anthropogenic degradation (e. g. air pollution), and socio economic factors, etc.

Soil functions not mentioned explicitly in laws and ordinances

Soil functions are not currently mentioned explicitly in Switzerland's primary and secondary legislation. The term "soil fertility" that was introduced in the Environmental Protection Act of 7 October 1983 (EPA; SR 814.01) and defined in greater detail in the Soil Pollution Ordinance of 1 July 1998 (SoilPO; SR 814.12) is nonetheless based on the functions of soil in the materials cycle[1], and is implicitly congruent with the production and habitat function as well as, to some extent, with the regulating function (see also Glossary of key terms in the Appendix).

1 Tschannen, P. (1999): *Kommentar zum Umweltschutzgesetz. Erläuterungen zum Bodenschutz.* [Commentary on the Environmental Protection Act. Notes on soil protection] Pub.: *Vereinigung für Umweltrecht* (vur/ade/ada) and Helen Keller. Zurich, 1999.

Unlike the definition of soil fertility in accordance with the SoilPO, the concept of soil functions can also be applied to soils which are not typical of their site, such as recultivated soils. The focus on soil functions should ensure within the context of the Soil Strategy that the functions of such soils are also preserved in the long term.

The concept of soil functions is already being applied successfully as part of spatial planning in several federal states in Germany, as well as in Austria[2].

3.2 The central role of soil for the climate

Soil is particularly important for the climate, as it stores more carbon than the atmosphere and vegetation combined[3]. Indeed, it is the second-largest active carbon reservoir after the oceans. In view of the enormous volumes of carbon it holds, any increased release of CO_2 from soil has measurable effects on the climate. On the other hand, according to the French-launched initiative "4 per 1000", if an additional 4‰ of soil organic matter could be stored in all soils around the world each year, it would be enough to largely offset anthropogenic greenhouse gas emissions.

In the fight against climate change, soil protection must thus encompass both measures to preserve and to increase the carbon stock in soil, and those to reduce greenhouse gases from it. Both can be achieved by means of adapted soil use (see Section 5.2.3).

At the same time, adaptive action is also required with regard to the already unavoidable consequences of climate change, as global warming is impairing important soil functions, for example through changes in groundwater levels. Furthermore, climate change – higher temperatures and longer droughts – may result in a loss of carbon from soil. Soils are therefore likely in future to release more CO_2 into the atmosphere and lose fertility. Adapted soil use, meanwhile, increases the resistance of soil to higher temperatures, increasing droughts, and a rise in the frequency of extreme weather events. This is because non-compacted soils which have a good structure and a root zone typical of their site are able to retain more water than compacted soils in the event of heavy rainfall. They thus protect against flooding and are able to provide plants with water for longer. This property will take on greater importance in the more frequent dry periods that are expected in the future.

2 E. g. Austria: *Bodenfunktionsbewertung: Methodische Umsetzung der ÖNORM L 1076* [An evaluation of soil function: methodological implementation of Austrian Norm L1076]. Brochure published by the Austrian *Fachbeirat für Bodenfruchtbarkeit und Bodenschutz* council for soil fertility and soil protection. E. g. Germany: LABO Project B 3.05: *Orientierungsrahmen Zusammenfassende Bodenfunktionsbewertung* [A reference framework for comprehensive soil function evaluation].

3 Schils R. et al. (2008): Review of existing information on the interrelations between soil and climate change; Climsoil Technical Report 2008. Final report 16 December 2008.

3.3 Soil is not being used sustainably in many places

Soil use can ultimately threaten the soil itself

All forms of soil use affect the properties of that soil, and thus influence the functions that soil can fulfil. Where soil use is adapted to soil conditions, these effects are desirable, and support the long-term preservation of soil's ecosystem services. Meanwhile, forms of soil use that are not adapted, as well as changes to the typical soil properties in a particular place, have undesirable effects on soil functions, in other words they are "soil threats". Drawing on common international categorisations[4], this text distinguishes between the following threats to soil: sealing, compaction, erosion and landslides, organic matter decline, soil biodiversity loss, contamination, acidification/eutrophication, salinisation and flooding.

When assessing the threats to soil that arise from the different types of use, particular consideration must be given to soil's regenerative capacity and potential long-term damage. Here, soil sealing for settlement areas and infrastructure, soil erosion, subsoil compaction and the infiltration into soil of persistent pollutants must be given special weight. These soil threats result in a loss of ecological soil functions that is practically irreversible[5].

A detailed analysis of soil threats (see Appendix A1) has shown that, based on current soil use in Switzerland, not all soil functions can be guaranteed in the long term. Indeed, this means that, in many cases, soil services are not fully available even now. This availability will decline further in the future without more sustainable soil use.

4 Arwyn J. et al. (2012): The state of soil in Europe. A contribution of the JRC to the European Environment Agency's Environment State and Outlook Report. SOER 2010. EU 2012.

5 Candinas T. et al. (2002): *Ein Bodenkonzept für die Landwirtschaft in der Schweiz. Grundlagen für die Beurteilung der nachhaltigen landwirtschaftlichen Bodennutzung* [A soil concept for agriculture in Switzerland. Basis for the evaluation of sustainable agricultural soil use]. *Bodenschutz* 3/02: p. 90-98.

3.4 Soil is an interdisciplinary issue

Quantitative and qualitative soil protection in the SPA and EPA

The Spatial Planning Act of 22 June 1979 (SPA; SR 700) and the EPA already contain provisions on soil management. Article 1 of the SPA, which sets out its aims, states that the Confederation, cantons and communes shall ensure "*that land is used economically*". There is a quantitative and a qualitative aspect to this remit. From the quantitative perspective, economical use requires the amount of land area used to be contained. Qualitatively, economical use is aimed at the optimum spatial distribution of the various types of use. The EPA is intended to protect "*in particular biological diversity and the fertility of the soil in the long term*". Although this technically provides the basis for sustainable soil management, the effect of conflicts with the implementation of other legal requirements often emerge in its enforcement.

Much soil-related legislation

The variety of uses that soil must satisfy (see Section 3.1) are reflected in the many items of legislation covering the protection and use of soil at all levels of government. However, since these have a wide range of backgrounds and objectives, there are overlaps, contradictions and conflicting objectives. This presents a challenge not only to soil users, but also for government. For example, the systematic inclusion of qualitative aspects in decisions on quantitative soil protection is currently hindered, among other things, by the fact that quantitative soil protection is governed primarily by spatial planning law, while the protection of soil quality is laid down mainly in the Environmental Protection Act. In addition, soil use for infrastructures is based on further statutory provisions put into action by a network of policies, implementing regulations and norms. Measures to protect rivers and lakes also have an effect on soil quality and soil preservation.

Many soil-related directives, strategies and instruments

The interdisciplinary nature of soil as an issue is also reflected in the large number of directives, strategies and instruments covering soil-related issues at the national level[6]. This may result in conflicts between the objectives of those individual strategies and instruments which make coherent soil protection programmes difficult. These conflicts must therefore be identified, analysed and, where possible, eliminated.

Collaboration and coordination challenges to enforcement

Tasks connected with soil protection and use demand collaboration or coordination between individual stakeholders, who are often drawn from different sectors. The large number of these stakeholders who are involved directly or indirectly in soil-related issues, as well as the distribution of authorities and

6 In alphabetical order, these are, specifically: Agricultural Policy 2018-2021; report on protecting arable land; Swiss Biodiversity Strategy; the soil protection concept for Swiss agriculture; guiding principles for soil protection in Switzerland; Strategy for Adapting to Climate Change in Switzerland; Green Economy Action Plan; Climate Policy from 2013 onwards; Climate Strategy for Agriculture; Landscape Concept; Agriculture and Food Production 2025; NRP 68: Sustainable Use of Soil as a Resource; Spatial Concept for Switzerland; Soil Resource Plan; strategic planning for the revitalisation of watercourses; the sectoral plans for crop rotation areas and transport; Sustainable Development Strategy; Natural Hazards Strategy; ecological targets for agriculture; guidance on environmental protection in agriculture; *Waldpolitik. Ziele und Massnahmen* 2030 [Forests Policy. Objectives and Action to 2030]); Soil Status Report.

responsibilities for soil management, present a challenge to enforcing the relevant acts and ordinances that should not be underestimated.

3.5 The importance of soil is underestimated

Increasing political weight given to quantitative soil protection

Increasing political weight is being given to quantitative soil protection at present, not least because of the shrinking area of arable land. This is reflected in both national and cantonal initiatives – such as the second home initiative *(Zweitwohnungsinitiative)*, agricultural land initiatives *(Kulturlandinitiativen)* in the cantons of Zurich and Bern, the landscape initiative *(Landschaftsinitiative)*, the popular initiative for food security *(Volksinitiative für Ernährungssicherheit)* and the *EcoPop* initiative to reduce overpopulation – as well as in parliamentary procedural requests of recent years. That said, most of these political activities centre on matters of landscape protection, or ensuring that there is a sufficient basis for food production. Among the population, the many other important services that soil provides are often underestimated, if they are known about at all. This is also true of the direct users of the soil, and even the authorities.

Lack of public knowledge about the services soil provides

Issues such as securing domestic food production, protections against flooding, protections against climate change and the provision of clean drinking water enjoy broad recognition. The contribution that soil makes to these and other ecosystem services goes largely unrecognised, however. One reason for this may be that soil is taken for granted as something that is always available. Generally, threats to the soil manifest only slowly, and are invisible to the layperson. It is therefore important to raise awareness among economic stakeholders and the general public of the value of soil and its functions, as well as of soil protection concerns.

The lack of public perception of the services soil provides is not limited to Switzerland, prompting the United Nations to declare 2015 the International Year of Soils. In recognition of this, many events and activities to raise awareness among users and the general public were held throughout Switzerland. The drafting of this National Soil Strategy may make a further, decisive contribution to improving knowledge about the importance and sensitivity of soils.

3.6 Lack of appropriate information as a basis for decision-making

Soil information as a key decision-making basis

Information on soil quality, as well as on the current condition of soil and its development potential is essential if soil is to be used economically and sustainably.

Data on the properties that essentially describe a soil, such as the nature, sequence and thickness of the soil horizons, or its water content, form the basis of an evaluation of soil functions. This knowledge of the quality of different soils should be considered specifically in decisions which result in quantitative soil loss, i. e. in spatial planning.

Contaminated soils must be identified so that risk mitigation measures can be instigated, such as remediation or restrictions on use. Information on the soil also forms the basis of this work.

Furthermore, where pollutants that have previously not been considered are concerned – examples include micro plastics and different organic compounds – there is a lack of the necessary knowledge not only about their prevalence, but also about their effects and dangers.

Only if soil properties are known can additional information about the current condition of the soil (such as current soil moisture or nutrient content, or the present risk of compaction) be put into its proper context. This information is important in making the right decisions about the adapted, sustainable use of soils in agriculture, for example.

Periodic measuring and collection of relevant soil data, in the sense of a monitoring programme on pollutant content, say, supplies the information that allows slow changes in soil properties and soil functions to be identified. Such monitoring programmes provide an essential foundation from which to initiate the necessary action – and evaluate its success.

No soil data for most of Switzerland

In Switzerland, precise information on soil quality is only sporadic, both geographically and in terms of change over time[7]. To date, detailed soil maps have been produced for less than a third of the land area that is used for agriculture[8]. Furthermore, many of these maps are over 30 years old, and there has been no national coordinating agency since 1996. The situation is even worse where

7 FOEN (2017): Boden in der Schweiz. Zustand und Entwicklung. Stand 2017 [Soil in Switzerland: status and developments as at 2017]. URL: *www.bafu.admin.ch/bafu/en/home/topics/soil/publications-studies/publications/boden-schweiz.html*

8 Rehbein K., Sprecher Ch., Keller A. (2019) : *Übersicht Stand Bodenkartierung in der Schweiz. Ergänzung des Bodenkartierkataloges Schweiz um Bodeninformationen aus Meliorationsprojekten, Bericht der Servicestelle NABODAT 2019* [Overview of the status of soil mapping in Switzerland. Addition to the Swiss soil map catalogue of information from soil improvement projects, report by the NABODAT National Soil Information System office]. URL: *www.are.admin.ch/dam/are/de/dokumente/raumplanung/dokumente/bericht/ubersicht-stand-bodenkartierung.pdf.download.pdf/ubersicht-stand-bodenkartierung.pdf*

forests and other areas are concerned. Thus, for the great majority of soils in Switzerland there is no basic information on which adapted usage or planning decisions can be made. Indeed, this fact was confirmed by the National Council Control Committee (GPK-N) on 24 November 2015 (see GPK-N media release of 24 November 2015 and postulate 15.4088[9]). The group of experts commissioned by the Federal Department of the Environment, Transport, Energy and Communications DETEC to conduct a critical analysis of the crop rotation areas sectoral plan also determined a need for action, especially with regard to obtaining a better data basis. Further complications are that there is no data standard at the cantonal level, and some of the data that is available no longer meets current methodological norms. The expert group deemed the production of soil maps essential.

National Competence Centre for Soil

By adopting the Müller-Altermatt motion, which tasked the Federal Council with establishing a National Competence Centre for Soil, both houses of the Swiss parliament recognised the importance of information on soil as a key basis for decision-making in the policy areas of food security, spatial planning and environmental protection.

NRP 68

Between 2012 and 2018, the National Research Programme entitled "Sustainable Use of Soil as a Resource" (NRP 68), run by the Swiss National Science Foundation (SNSF), drew up a basis for the sustainable use of soil in Switzerland. The project factored in both the ecological and economic services that soil provides. In five thematic syntheses, the authors present proposals for how soil quality might be incorporated into spatial planning and generally better integrated into soil policy. An overall synthesis summarises these recommendations[10].

A number of projects under the aegis of NRP 68 have addressed the collection of soil data and its alignment, as well as the development of new mapping and evaluation methods.

Establishing and operating a centre of competence, and providing data and knowledge about soil, are two of five key recommendations drawn up by an NRP 68 workshop[11] attended by 40 researchers and representatives of the federal and cantonal governments, associations and organisations.

9 *www.parlament.ch/press-releases/Pages/2015/mm-gpk-n-2015-11-24.aspx?lang=1031*

10 Steiger U., Knüsel P., Rey L. (2018): *Die Ressource Boden nachhaltig nutzen. Gesamtsynthese des Nationalen Forschungsprogramms "Nachhaltige Nutzung der Ressource Boden" (NRP 68)* The sustainable use of soil as a resource. Overall synthesis of the National Research Programme "Sustainable Use of Soil as a Resource" (NRP 68). Pub.: NRP 68 steering committee. Bern

11 *www.nfp68.ch/en/News/Pages/171218-news-nfp68-intensive-exchange-of-information-using-syntegration.aspx*

3.7 Summary with a view to a National Soil Strategy

Preservation of soil functions jeopardised

Despite the enormous ecological and economic importance of soil, and the vital nature of the services it provides to the Swiss economy and Swiss society, it is not yet being used sustainably. The preservation of soil functions, i. e. soil's ecological performance, is therefore jeopardised in the long term. The reasons for this are complex and are not restricted to individual sectors or policy areas. Other factors, such as insufficient soil data or a lack of awareness among stakeholders also play a part in soil's current condition.

Soils must also be conserved for ethical reasons

For ethical reasons, too, the aim must be to protect and to use our soil in such a way that it is able to fulfil its multiple functions over time. However, the ethical perspective also requires ecological soil functions (habitat, production and regulating) to be given greater weight than, say, the archive function. These natural functions above all must be preserved in the interests of provi-sion for the future and thus long-term benefit[12].

Soil Strategy should set out comprehensive solutions

Given the claims on soil utilisation, absolute protection for soil and its functions is neither possible nor sensible. The aim must therefore be a balance between protection and use – something that can be achieved only with a nuanced approach.

The National Soil Strategy is intended to serve the competent federal government and cantonal authorities as a guiding framework and decision-making aid. It provides a roadmap for tackling the challenges that have been identified. The primary task here is to obtain the necessary soil data and to coordinate current policies and instruments more effectively. Any new regulations will be considered only as a second step, following a comprehensive review of existing legislation.

12 Bachmann A. (2018): *Ethische Bewertung der Bodenfunktionen* [An ethical evaluation of soil functions]. Internal Comité d'Ethique paper. FOEN 2014.

4 Vision and overarching objectives

The National Soil Strategy pursues the following vision:

Vision
The functions of soil are guaranteed in the long term so that future generations are also able to use this finite, non-renewable resource for their own needs.

To fulfil this vision, efforts must be made to achieve the following overarching objectives:

1. Reduce soil consumption
The objective is that, from 2050 onwards, net soil use in Switzerland will be zero.[13] It will still be possible to build on soil, but if this results in functions being lost, they must be offset elsewhere by improving the soil at that site.

2. Manage soil consumption on the basis of an overall perspective
Soil functions are factored into planning, and the associated balancing of interests, so that soil consumption can be managed in the interests of sustainable development. The soil data required to do so is available.

3. Protect soil from harmful impacts
Soil use does not result in any physical, chemical or biological impacts that might result in a lasting degradation of soil functions and thus soil fertility[14]. Soil use takes account of its current condition and sensitivity, so that ecological soil functions and thus soil fertility are preserved.

13 Drawing on SDG 15.3: "By 2030, [...] strive to achieve a land degradation-neutral world" and the European Union's 7th Environment Action Programme: "...with a view to making progress towards the objective of 'no net soil loss', by 2050". Please refer to the Glossary for a definition of "no net soil loss". Offsetting is based on qualitative requirements and does not relate to land area. Soil sealing (according to FSO land use statistics) will be used as an indicator until a nationwide soil function map is available.

14 In accordance with Art. 33 para. 2 EPA: The soil may be physically affected only to the extent that its fertility is not durably degraded; this does not apply to land used for building.

4. Restore degraded soils
Where possible and reasonable, degraded soils are restored and improved so that they are once again able to fulfil the functions typical of their site, and that their fertility is reinstated.

5. Improve awareness of the value and sensitivity of soil
Soil is seen as a valuable, sensitive and finite basis of existence, so that action surrounding sustainable soil management finds the necessary level of acceptance.

6. Strengthen international commitment
Switzerland's economic and social well-being depends not only on its own soil, but also on the preservation of soils abroad. Switzerland is thus an advocate for sustainable soil management at the global level.

The overarching objectives have a time horizon of 20 to 30 years, i. e. a generation. The following sections set out these objectives in greater detail for the most relevant fields, and formulate the corresponding strategic approaches.

5 Targets and strategic approaches

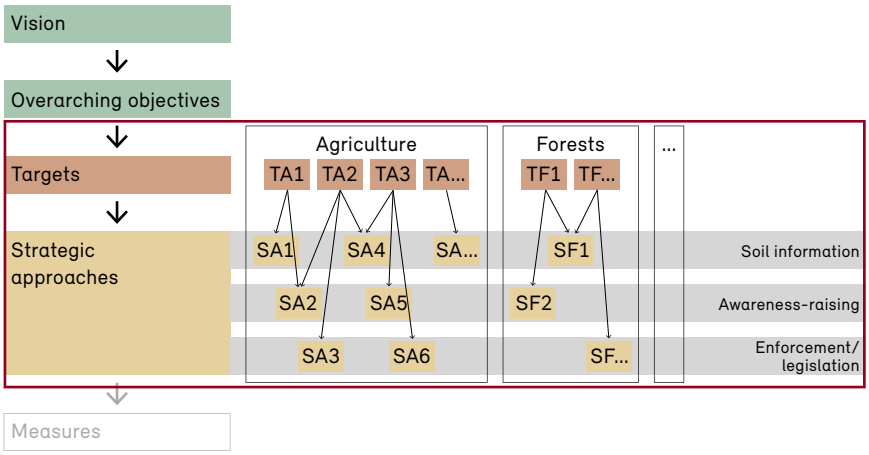
As explained in Section 2, unadapted soil use has a negative effect primarily on ecological soil functions. An analysis of these soil threats (see Appendix A1) has shown that, based on current soil use in Switzerland, not all soil functions can be guaranteed in the long term.

A detailed examination was conducted of the current situation and the prevailing challenges, resulting in the formulation of targets and strategic approaches for the fields that are deemed particularly relevant.

Figure 4

The red box shows the elements described in Section 5

The targets in the various fields are designated accordingly (TA1 is the first target for agriculture, TA2 the second, etc.). A similar nomenclature has been used for the strategic approaches derived from the targets (SA1, SA2, SA3, etc.). The grey bars show the three action areas.



5.1 Spatial planning

The economical use of soil is one of the central objectives of spatial planning in Switzerland. It covers both qualitative and quantitative aspects. Qualitative aspects relate to the appropriate spatial distribution of the various types of use, while quantitative aspects focus on stemming soil loss.

Economical soil use covers both qualitative and quantitative aspects

Urban area is a good indicator of soil loss[15]. Urban areas in Switzerland increased by 584 km² between the land use statistics surveys of 1979/85 and 2004/09. This corresponds to an expansion in urban area per capita of 5.2%. That said, a decline in urban area per capita has been observed in areas with a strong urbanisation and densification trend, or significant population growth.

Urban areas currently account for 7.5% of land area in Switzerland, with around 37% located outside of building zones. Some 60% of soils within urban areas are sealed, and thus no longer fulfil any ecological function (see Section 3.1). In addition to a poorer quality of life, this increases the risks attached to global warming, such as surface runoff and heat islands. According to the land use statistics, sealed soils in Switzerland increased by 29% in the 24 years from 1985 to 2009.

5.1.1 Building zones

Too little attention paid to soil functions when designating building zones

The designation of new building zones ultimately leads to the extensive sealing of the soils concerned, and therefore to a loss of their ecological soil functions. Given population growth, the pressure to develop land, and especially agricultural land, is likely to remain high, especially in Switzerland's agglomerations and the surrounding rural areas.

With the exception of the consideration given to soil's suitability for crop rotation areas, further information on soil quality or soil function is hardly ever factored into decisions on the designation of building zones. Only a few cantons in Switzerland currently use soil maps. In many cases, it is therefore impossible to ensure that other soils with important properties and functions will be preserved alongside the aforementioned designated crop rotation areas.

Maintaining soil functions also important in settlement areas

With its Sustainable Development Strategy 2016 – 2019, the Federal Council aims to curb urban sprawl. Indeed, the Federal Council enacted the partially revised Spatial Planning Act (SPA, SR 700) and the revised Spatial Planning Ordinance (SPO, SR 700.1) on 1 May 2014 with the same objective. The legislative reforms offer a range of new measures to combat urban sprawl. The amended Spatial Planning Ordinance of 28 June 2000, the technical guidelines for building zones, and additions to the guidelines for cantonal structural planning all demand that urban development be directed inward. In essence, this means that the development of urban areas must be concentrated on the area that has already been built on[16] (› SS1). The densification of existing urban areas tends to result in an increase in the degree of soil sealing within the building zone, although less land area will be designated within to this zone. The preservation of the various soil functions within urban areas, as

15 According to the nomenclature used in the land use statistics ("settlement and urban area"), urban area covers building area, building grounds, industrial buildings, industrial building grounds, special urban areas (e. g. landfill and building sites), recreation facilities and parks, and transport infrastructure (roads, railways and airfields/airports).

16 See Swiss Federal Council, CCG, DPPE, SSV, ASC (2012): *Raumkonzept Schweiz* [Spatial Strategy for Switzerland]. Revised version, Bern.

well as outside them, must be tackled as part of inward urban development. Efforts must be made to have as many overlapping uses as possible (› SS2).

However, in many places property rights present an obstacle to high-quality densification. Genuine high-density construction requires the selection of plots of the right size and shape to permit optimum development and usage. (› SS3)

The SPA and the Nature and Heritage Conservation Act of 1 July 1966 (NCA; SR 451) already require urban areas to include plenty of green space, or that steps must be taken to ensure an ecological balance. The cantons and communes are therefore tasked with preserving green areas or with designing and managing them to be as "natural" as possible. The legal requirements nonetheless permit enormous scope in their interpretation. At present, communes and private individuals in particular are often too little aware of the many functions that soil fulfils in urban areas, and of the synergies between preserving soil functions and high-quality inward urban development (› SS4).

Revision and strengthening of the crop rotation areas sectoral plan

Crop rotation areas make up a large part of the soils on Switzerland's central plateau. Revised between 2016 and 2020, the crop rotation area sectoral plan is intended to protect these soils, which offer the best conditions for agricultural production. It is currently the only spatial planning instrument which references the quality of soils and not simply their land area.

Focus on production function does not go far enough

Efforts to protect crop rotation areas centre on the production function of the soils in question. However, in the context of an holistic view of soil functions, this focus does not go far enough. To achieve improvements here and also to support the balancing of interests in spatial planning that is required by law, there is a need for methods and soil information which make it easier to factor all soil functions into spatial planning decisions, including those concerning soils outside of crop rotation areas (› SS5).

Targets

TS1: The aim is that soil consumption for urban areas, along with the necessary infrastructure, will be restricted in the long term to the settlement areas currently determined in the cantonal structure plans.

TS2: Fundamental information and data on soil quality are considered systematically in spatial planning decisions, e. g. the designation of building zones and inward urban development. The aim is to preserve as many soil functions as possible over time.

TS3: In urban areas, soils should be able to fulfil the soil functions that are important at their particular sites as effectively as possible, and they should contribute to quality of life, adaptation to climate change and biodiversity. The degree to which soils are sealed should be minimised.

Strategic approaches
SS1: Monitor the development of urban area and soil sealing.
SS2: Within the scope of existing instruments for planning and enforcement, processes (encouraging good practice) should be initiated that promote diverse soil functions and reduce soil sealing, while at the same time permitting compact urban areas.
SS3: Examine the degree to which incentives and conditions can be used to create optimum conditions for high-quality, high-density construction.
SS4: Raise awareness among commune governments, planners and private individuals of the value of unsealed soils in urban areas, specifically. The focus should be on illustrating the synergies between soil functions and high-quality, compact inward urban development that reflects local characteristics.
SS5: Provide methods and soil information enabling soil functions to be better taken into account in the designation of building zones.

5.1.2 Construction projects outside building zones

Structures and facilities outside building zones impair soil functions

There are many structures and facilities outside building zones which comply with zoning regulations or are tied to a particular site, but which may have a detrimental effect on soil functions. These effects are not limited solely to the soil that is impacted directly by the structure in question, but may also affect other soils which are being remodelled or used as temporary or permanent access roads or machinery tracks, etc. In some of these cases the soil is not sealed, but soil function is still impaired. Paddocks and gravel parking areas are two examples here.

Of Switzerland's total urban area, 37% is located outside building zones. Much of the soil loss in these areas is caused by agriculture and infrastructures (transport, leisure and tourism, energy, utilities and waste management). While soil consumption owing to agricultural needs continues to rise, the increase is less in the case of transport facilities, which occupy the largest share of land used for infrastructure outside construction zones[17].

Insufficient consideration given to soil functions in planning and building permit procedures

The federal government and various cantons have sectoral plans, directives and information sheets concerning the choice of site, and design, of structures and facilities outside building zones. Taking part in the planning processes, the competent authorities can influence the choice of site, and impose the corresponding conditions when authorising plans or issuing building permits (› SS8). As a rule, soil functions other than production (crop rotation areas) are hardly ever taken into consideration in planning and permit procedures, because, with the exception of nature conservation objects and groundwater protection zones, there is a lack of the relevant fundamental information (› SS6).

17 Data from the ARE's *Monitoring Bauen ausserhalb Bauzonen – Standbericht 2019* [Monitoring construction outside building zones – 2019 status report]: comparison of developments in 1992/97 with 2004/09 and 2013/18 (SFSO land use statistics), p. 12

The Federal Council dispatch on the second phase of the partial revision of the Spatial Planning Act (SPA 2) was submitted to Parliament on 31 October 2018. SPA 2 is concerned in particular with construction outside of building zones, and contains new proposals for how the number of structures and facilities might by stabilised, or even reduced, in the medium to long term (› SS7).

Targets

TS4: Fundamental information and data on soil quality are considered systematically in spatial planning decisions outside building zones. The aim is to preserve as many soil functions as possible for the long term.

TS5: When building outside building zones, soil sealing must be reduced to a minimum. Structures that are no longer required should be removed and the soil's natural state restored.

TS6: The federal government commits to an exemplary, economical use of soil in all of its activities having a spatial impact in Switzerland.

Strategic approaches

SS6: Provision of methods and soil information enabling soil functions to be better taken into account in planning and authorising new land uses or changes of land use outside building zones.

SS7: Review of the statutory framework and creation of incentives to reduce soil sealing outside building zones to a minimum.

SS8: In the case of infrastructure projects or other spatial planning on the part of the federal government, measures to reduce soil consumption are determined in the process of sectoral planning or as part of planning approval procedures or agreements.

5.2 Agriculture

According to the latest land use statistics for Switzerland, approximately 14,800 km² of land area was used for agriculture in 2009. Around 35% of this area was used for alpine agriculture, 34% was natural meadow and pasture, 28% was productive cropland, and 3% was occupied by orchards, vineyards and horticulture.

The use of soil as a platform for agricultural infrastructures such as barns and greenhouses, is examined in Section 5.1.

Agricultural use always impacts on the soil. In addition to positive effects, it may result in a variety of threats, and thus a loss of soil functions. The greatest challenges are caused by soil compaction, erosion, organic matter decline and contamination (see Appendix A1).

5.2.1 Soil compaction as a result of agricultural use

Machinery use the main cause of soil compaction

The use of heavy machinery in wet soil conditions is the main reason for soil compaction in agriculture (› SA6).

The problem of soil compaction often occurs in crop and (intensive) vegetable cultivation, especially in the case of high-yield cultures such as maize, sugar beet and potatoes on humid soils that are harvested late. Even the soil of meadows and pastures can be compacted if there is frequent tractor traffic for mowing or muckspreading in wet conditions, or damage caused by trampling by livestock. A further factor is that machinery must be used and harvests delivered at fixed times, forcing farmers to harvest their crops even when soil conditions are unfavourable (› SA3).

Organic matter decline can also accelerate soil compaction (see Section 5.2.3).

Lack of knowledge about the scale and progression of soil compaction

Switzerland has no precise, nationwide data on the scale of soil compaction, although experience from agricultural practices and findings from test areas indicate that many soils are compacted.

The trend towards larger farming operations and heavier machinery, on the one hand, and findings of climate research that suggest higher levels of soil moisture in the winter months, on the other,[18] point to soil compaction remaining a soil threat in the future.

18 CH2011 (2011): Swiss Climate Change Scenarios CH2011. Published by C2SM, MeteoSwiss, ETH, NCCR Climate and OcCC. Zurich, Switzerland. 88 pp.

No practicable enforcement system

Although soil compaction as a result of agricultural practices is mentioned both directly and indirectly in legal provisions connected with the federal government's financial aid programme – including in association with the proof of ecological performance and resource-efficiency subsidies in the Direct Payments Ordinance or the Structural Improvements Ordinance – there is still no practicable enforcement system in place. One of the gaps is that there are no statutory reference values by which to evaluate soil compaction (› SA4/SA5).

Guidance on enforcement,[19] as well as other tools (such as Terranimo[20] and maps showing compaction risk), do already exist, however. There is also enormous potential in this regard in including soil protection practices more fully in basic and further agricultural training (› SA2). The extent to which the measures and instruments mentioned above reduce the risk of soil compaction in Switzerland must be reviewed (› SA1).

Target
TA1: Avoid the lasting compaction of soils used for agriculture.

Strategic approaches
SA1: Improve the available information on the (site-related and current) sensitivity of agricultural soils to compaction, and on the review of the measures that have been instituted.
SA2: Raise awareness of the issue of soil compaction among farmers and contractors.
SA3: Raise awareness among the buyers of produce of the impact of unfavourable harvest times (soil moisture levels) on soil compaction.
SA4: Develop evaluation and decision-making aids for farmers to promote the soil-friendly use of agricultural machinery.
SA5: Examine whether or not it is possible to define and lay down in law thresholds and methods to determine the structural status of soils.
SA6: Examine whether or not the permitted use of agricultural machinery might be tied to the load-bearing capacity of the soil.

19 FOEN and FOAG (2013): *Bodenschutz in der Landwirtschaft. Ein Modul der Vollzugshilfe Umweltschutz in der Landwirtschaft.* [Soil protection in agriculture. A module of the guidance on environmental protection in agriculture.] Federal Office for the Environment. Bern *Umwelt-Vollzug* no. 1313, 59 pp.

20 Simulation model for calculating the soil compaction risk when using agricultural vehicles, see *www.terranimo.ch*

5.2.2 Soil erosion as a result of agricultural use

Site-inappropriate farming chief cause of erosion in Switzerland

The primary cause of farming-related erosion in Switzerland is agricultural use that is inappropriate to the site in question: insufficient soil cover and root penetration during critical periods, overly intensive cultivation, excessive grazing on slopes, etc. Soil erosion is most commonly found at steep sites and on valley paths, especially where soil structure is weak and after there has been particularly heavy rainfall. Sloping sites are at particular risk, as is open cropland and areas used for intensive vegetable cultivation. Where infrastructure is concerned, a lack of – or insufficient – drainage from roads and paths may also cause erosion damage.

To date only sporadic surveys have been conducted on the incidence of soil erosion (› SA7). Model calculations indicate that approximately 20% of cropland in Switzerland should be classified as at risk of erosion[21], while a considerable risk has also been identified for grassland[22].

Although requirements for the proof of ecological performance (PEP) scheme demand measures to prevent erosion, food security subsidies for open cropland, and single culture subsidies,[23] may result in the extension of crop farming to sites susceptible to erosion, such as hillsides (› SA9). The future risk of soil erosion may be exacerbated by anticipated developments and trends, such as intensification and specialisation in field crop farming, but also the expected general increase in heavy rainfall as a result of climate change (› SA7, SA8).

Erosion risk map and agricultural guidance as a sound basis for enforcement

Soil erosion is mentioned directly or indirectly in a variety of statutory provisions[24]. The Agricultural Policy 2014 – 2017 introduced significant changes with regard to relevant erosion and farming-related soil loss from cropland, while also providing greater detail on existing requirements. For example, since 2017 erosion events have been monitored using a targeted, risk-based approach, and not – as in the past – in combination with regular PEP checks. The erosion risk map and the *Bodenschutz in der Landwirtschaft* guideline [Environmental Protection in Agriculture] (soil protection module) provide a sound foundation for enforcement (› SA9). The extent to which the measures and instruments mentioned above reduce the risk of soil erosion in Switzerland remains to be evaluated (› SA7).

21 Bircher P., Liniger H.P., Prasuhn V. (2019): *Aktualisierung und Optimierung der Erosionsrisikokarte (ERK2). Die neue ERK2 (2019) für das Ackerland der Schweiz. Schlussbericht 2019* [Update and optimisation of the erosion risk map (ERK2). The new ERK2 (2019) for cropland in Switzerland. Final report 2019].

22 Schmidt, S., Alewell, C., Meusburger, K. (2018): Mapping Spatio-Temporal Dynamics of the Cover and Management Factor (C-Factor) for Grasslands in Switzerland. Remote Sensing of Environment 211, p. 89-104.

23 This may lead to the extension of farming at sites susceptible to erosion, such as hillsides.

24 In the Direct Payments Ordinance (DPO, PEP Art. 17, resource-efficiency subsidies Art. 79), in the Structural Improvements Ordinance (SIO, Art. 14 para. 1 f), and in the Soil Pollution Ordinance (SoilPO), which contains reference values for the erosion of cropland.

Targets
TA2: No lasting degradation of soil functions as a result of the erosion of agricultural land.
TA3: No degradation of waterbodies, watercourses and near-natural habitats, or infrastructure, as a result of displaced soil material from agricultural land.

Strategic approaches
SA7: Improve the available information in order to assess the risk of erosion of agricultural soils (crop and grassland), and to review the measures that have been instituted.
SA8: Raise awareness among farmers of the problem of erosion, and draw their attention to the expected exacerbation of this risk as a result of climate change.
SA9: Review the operating framework, including the system of direct payments, to foster agriculture better adapted to the site in question and thereby prevent erosion more effectively, i. e. avoid false incentives and promote farming practices that mitigate erosion.

5.2.3 Decline in soil organic matter as a result of agricultural use

Soil organic matter is key to soil functions

Agricultural activity has a major effect on soil organic matter. Organic matter decline degrades all soil functions to a greater or lesser degree and poses a threat to all soils that are used for crop farming, especially vegetable cultivation, in which there are several crops per year.

Mineral soils

In contrast to organic soils, in the case of mineral soils the loss of organic carbon can be offset to some extent, for example by supplementing organic matter appropriately. A decline in organic carbon in mineral crop soils has been observed over the past 100 years, although its content appears to have stabilised over the past 20–30 years[25,26]. That said, new studies show that even with balanced crop rotations and despite organic fertilisers, organic carbon may continue to be lost[27,28] (› SA10, SA13).

Organic soils

The loss of soil organic matter is particularly severe in the case of organic soils used for the cultivation of crops. This use of organic soils is the cause

25 Maître V. (2014) : *Canton de Vaud. Indicateurs de développement durable. Matière organique et activité biologique dans les sols agricoles* [Canton of Vaud. Sustainable development indicators. Organic matter and bioactivity in agricultural soils].

26 Gubler A., Schwab P., Wächter D., Meuli R. G., Keller A. (2015): *Ergebnisse der Nationalen Bodenbeobachtung (NABO) 1985–2009. Zustand und Veränderungen der anorganischen Schadstoffe und Bodenbegleitparameter* [Findings of the NABO National Soil Monitoring Network 1985–2009. Status and changes in anorganic pollutants and soil monitoring parameters]. Federal Office for the Environment. Bern *Umwelt-Zustand* no. 1507: 81 pp

27 Oberholzer, H., Leifeld, J., Mayer, J. (2014): Changes in soil carbon and crop yield over 60 years in the Zurich Organic Fertilization Experiment, following land-use change from grassland to cropland. Journal of Plant Nutrition and Soil Science 177 (5).

28 Leifeld, J., Reiser, R., Oberholzer, H., (2009): Consequences of Conventional versus Organic farming on Soil Carbon: Results from a 27-Year Field Experiment. Agronomy Journal, Volume 101, Issue 5.

of most of the CO_2 emissions from Swiss agriculture. Organic soils cannot be farmed without a progressive loss of soil organic matter, which goes hand in hand with subsidence in peat soil levels.[29] Most drained peatlands have been used for agriculture for approx. 50 to 150 years now. Peat layers have declined by approx. 50 – 200 cm during this period. Furthermore, with the exception of rewetting there are currently no effective, sustainable regeneration methods (› SA10). One way of continuing to use subsided organic soils for agriculture is to incorporate mineral soil matter that has been removed from elsewhere. Intervention must be planned and supported by qualified experts if such work is to achieve the desired improvement (see strategic approaches in Section 5.4). In addition, such projects must always be planned in the knowledge of the soil's composition (› SB5), and taking into account the full range of interests: in addition to food security, nature conservation, climate, water and flood protection considerations must all be factored in to deliberations.

Use drainage renovation as an opportunity

In many areas where agricultural land has undergone improvement measures, drainage systems are now reaching the end of their useful lives and must be replaced or renovated. As part of this, it is advisable to rethink the future use of these soils, taking into account all of the various aspects such as agriculture, nature, climate and water protections, and natural hazards (› SA14).

Information about Switzerland's soils is not currently sufficient to permit any reliable nationwide forecast of how the organic matter content of mineral and organic soils will develop (› SA13). It is also impossible to assess at present how the proportion of organic matter in soils will alter as a result of climate change.

No practicable enforcement system

The loss of soil organic matter is mentioned directly or indirectly in a variety of statutory provisions, such as PEP regulations and the DPO. These provisions are not set out in sufficient detail, however, and there is no practicable system for their enforcement (› SA11/SA12).

Targets
TA4: Offset the loss of soil organic matter as a result of the agricultural use of mineral soils.
TA5: Minimise the loss of soil organic matter as a result of the agricultural use of mineral soils.

29 Hagedorn, A., Krause, H-M., Studer, M., Schellenberger, A., Gattinger, A. (2018): *Thematische Synthese TS2 des Nationalen Forschungsprogramms "Nachhaltige Nutzung der Ressouce Boden" (NFP 68)* [Thematic synthesis TS2 of the "Sustainable Use of Soil as a Resource" National Research Programme (NRP 68)]. Bern

Strategic approaches
SA10: Draw up recommendations to preserve soil organic matter in agricultural production.
SA11: Develop evaluation and decision-making aids for farmers to avoid the loss of soil organic matter as a result of agricultural use.
SA12: Review the operating framework, including the system of direct payments, to foster agricultural practices better adapted to the site in question, and thereby better preserve soil organic matter.
SA13: Improve the available information to assess the organic matter content of agricultural soils, and to review of the measures that have been instituted. Draw up target and reference values for soil organic matter content.
SA14: Develop guidelines for the future use of organic agricultural soils, in particular where drainage systems are due to be renewed. These should take into account not only agricultural aspects, but also those relating to biodiversity and to climate, water and flood protections.

5.2.4 Pollution from agriculture

Intense, long-term use of critical products especially problematic

The use of mineral fertilisers and pesticides, cosubstrates in biogas plants and composting facilities, as well as other recycled fertilisers and adjuvants, can cause considerable damage to soil functions. The use of feed additives and medications is viewed as similarly problematic because they can contaminate the soil indirectly through the spreading of manure and recycled fertilisers (› SA17). (Micro) plastic is a recently recognised problem. It can enter the soil via the spreading of substrates from biogas plants, or via mulch film which is not fully removed after use, and thus remains in the soil to some extent (› SA18). The risk of an accumulation of pollutants in the soil is particularly high where critical products have been used intensively for many years.

Grassland sites that are heavily used, as well as soils used for intensive crops such as vegetables and fruit, as well as vineyards, are particularly prone to pollution.

The precise extent to which Swiss soils are contaminated is not known, however[30] (› SA15).

Economic pressure as a driver of contamination

The economic pressure on agriculture to increase income leads to more intensive production, which may also result in the use of greater quantities of pesticides and fertilisers. This in turn leads to the undesirable release of these substances from agricultural operations, and thus to emissions into near-natural ecosystems.

30 It is often stated that 90% of soils in Switzerland are polluted to a minor degree, while 10% suffer moderate to heavy contamination. This statement cannot be proven, however.

Confusing regulations hinder enforcement

Pollutants in the soil are the subject of a large number of regulations laid down in a variety of ordinances[31]. Their sheer number makes them difficult to navigate, thereby hindering enforcement (› SA16). Switzerland depends on international law (particularly that of the EU) with regard to current pollutant thresholds and the authorisation of agricultural adjuvants.

Pesticide action plan being drawn up

In connection with the use of pesticides, the Federal Council responded to the Moser postulate (12.3299) by instructing the FONES to work with the FDHA and DETEC to draw up an action plan to reduce risk and to promote the sustainable use of pesticides by the end of 2016. The Federal Council adopted this action plan in September 2017. Initiatives promoting the efficient and sustainable use of manure and recycled fertilisers already exist (Hoduflu), and should be reinforced.

Targets

TA6: No lasting degradation of soil functions, and thus no degradation of waterbodies and watercourses, or near-natural habitats, by pollutants from agriculture.

TA7: Substantial reduction of the risk to humans, animals, plants and waterbodies and watercourses as a result of the infiltration of pollutants and foreign matter from pesticides, fertilisers and other agricultural adjuvants.

Strategic approaches

SA15: Improve the available information to permit the early detection, or risk assessment, of the input of pollutants and foreign matter in connection with agricultural production.

SA16: Harmonise and simplify the rules on using adjuvants in agriculture.

SA17: Review statutory regulations on reducing the risk of pollution from pesticides and fertilisers, and on promoting their sustainable application, taking into account the pesticides action plan.

SA18: Review statutory regulations on preventing the deposit of plastics and microplastics into the soil, and on promoting good agricultural practices, specifically in connection with mulch films and substrates from biogas plants.

31 The SoilPO defines reference, test and remediation values for anorganic and organic pollutants; the Chemical Risk Reduction Ordinance (ORRChem) sets out thresholds for heavy metals in all fertilisers, as well as additional reference values for organic pollutants in manure, organic and recycled fertiliser; further legislation includes the Air Pollution Control Ordinance (OAPC), the Waste Ordinance (ADWO), and the Waters Protection Ordinance (WPO). Others include the Plant Protection Products Ordinance (PlantPPO), the Fertiliser Ordinance (FertO, with a reference to the values laid down in the ORRChem), the EAER Fertiliser Book Ordinance (FertBO, minimal nutrient values for declaration, with the instruction that reads: “only where absolutely necessary”), the Feedstuffs Ordinance (FeedO, on feedstuffs checks), the EAER Ordinance of 26 October 2011 on the Production and Marketing of Feedstuffs, Feed Additives and Dietary Feed (FADO, thresholds for the heavy metals Cu and Zn), the Direct Payments Ordinance (DPO, referencing the PEP, resource-efficiency subsidies and production system subsidies), and the Agriculture Act (AgricA) Art. 77a/b (resource programme).

5.2.5 Biodiversity loss as a result of agricultural use

Intensification of agriculture results in decline in biodiversity

The intensification of agriculture causes a decline in biodiversity and in the activity of organisms in the soil, and thus results in a deterioration in its habitat function. This may subsequently lead to a weakening of the other ecological soil functions, the production and regulating functions (water content and the turnover of organic matter). Various current studies[32,33,34] provide evidence of a correlation between intensive farming and a reduction in bioactivity in the soil. Larger organisms (earthworms, macroarthropods and nematodes) are more heavily affected than microorganisms (bacteria and fungi). The decline in the availability of organic matter from arable crops (harvest residues) and organic fertilisers is particularly relevant in the latter case.

Over the past 50 years, the intensification of agriculture has facilitated massive increases in revenue. This has been made possible primarily by the industrialisation and mechanisation of the farming industry, as well as the use of large quantities of agricultural adjuvants. It has moreover had the effect of harming soil organisms. To date, this decline in biodiversity and bioactivity has not yet resulted in any decline in crop yields, because farmers have been able to offset impairments to soil's production function by using fertilisers and pesticides. If bioactivity in soil cannot be maintained or restored, degradation in soil functions are unavoidable, and this may be felt in the future in the form of declining agricultural yields[32] (› SA20, SA21).

Ammonia deposition from agriculture a problem for biodiversity

An oversupply of nitrogen results in a reduction in above-ground biodiversity because vulnerable species are crowded out by nutrient-loving species, thereby depleting the quality and diversity of the plant community. For example, in Switzerland 95% of forests, 100% of raised bogs, 84% of fens and 42% of dry meadows and pastures suffer from excess nitrogen deposition from the air[35]. Around two-thirds of these depositions originate from ammonia emissions, from agriculture above all (› SA22).

No reliable data available on the status of soil biodiversity in Switzerland

By contrast, in Switzerland there are no studies whose findings would permit statements to be made about the nationwide status of soil biodiversity (› SA19). Although microbiological parameters for soil have been measured on plots of agricultural cropland and permanent pasture since 2012, as part of the NABObio pilot programme, it is not yet possible at present to predict their development or to make any statements concerning Switzerland as a whole. In other countries, monitoring has identified a deterioration in soil biodiversi-

32 Ponge J.-F. et al. (2013): The impact of agricultural practices on soil biota. A regional study. Soil Biology & Biochemistry 67, p. 271–284.

33 Tsiafouli M. A. et al. (2015): Intensive agriculture reduces soil biodiversity across Europe. Global Change Biology 21 (2), p. 973–985.

34 Postma-Blaauw M. B. et al. (2010): Soil biota community structure and abundance under agricultural intensification and extensification. Ecology 91.

35 Info Flora et al. (2015): *Zustand der Biodiversität in der Schweiz 2014* [Status of biodiversity in Switzer-

ty that is linked to the intensity of agricultural use and the associated decline in soil organic matter.

Given the lack of reliable data, it is almost impossible to say anything about the potential development of soil biodiversity in Switzerland. That said, the soil organic matter content (humus content) of soil is directly correlated to soil biodiversity and its activity (see Section 5.2.3).

Target
TA8: No lasting loss of soil biodiversity and activity owing to agricultural use.

Strategic approaches
SA19: Improve the available information on the biodiversity and bioactivity of soils used for agriculture. Draw up target and reference values for soil biodiversity.
SA20: Promote farming methods that ensure an active biotic community that is typical of the site in question.
SA21: Factor soil biodiversity and bioactivity into the planning and designation of ecological networking structures.
SA22: Consistently implementat all possible measures to minimise the discharge of substances such as ammonia from agriculture.

5.3 Forests

According to the land use statistics for 2013, 31.3% of Switzerland's land area is wooded[36].

The greatest challenges in the forests arise from the eutrophication and acidification of forest soils as a result of nitrogen deposition from the air. Forest management can also result in a loss of soil function, however: the compaction of forest soils is a problem that must be taken seriously (see Appendix A1).

5.3.1 Eutrophication and acidification of forest soils

Deposition of nitrogen compounds from the air the main cause

The deposition of nitrogen compounds from the atmosphere causes the overfertilisation and acidification of forest soils. These nitrogen compounds originate mainly from agriculture and traffic. Around two-thirds of nitrogen entering soil from the air originates from agriculture (ammonia), while around a third results from combustion processes (nitrogen oxide). With their large surface area, forest trees filter the nitrogen compounds out of the air, meaning that

36 SFSO (2013): Land use in Switzerland. Results of the Swiss land use statistics. Swiss Federal Statistical Office. Neuchâtel. 24 pp

deposition in forests is higher than in unforested areas[37]. If the levels of these compounds rise too high, forest soils become overfertilised and acidified, and lose important nutrients (calcium [Ca], magnesium [Mg] and potassium [K]). This results in an imbalance of nutrients over the long term[38]. The problem of nutrient removal is further exacerbated by the common practice of whole-tree logging (whole-tree harvesting).

Better soil information required

Current information on the eutrophication and acidification of forest soils is insufficient. Establishing the extent of at-risk forests and forest sites (i. e. producing an inventory), as required by the Forests Policy,[39] therefore also involves recording information about soils. The corresponding surveys and analysis should be coordinated as part of a comprehensive soil information strategy (› SF1).

Further reduction in air pollutant emissions required

National and international standards on air pollution control are the authoritative instruments for limiting substance depositions. Despite these standards, the critical load for nitrogen is exceeded in 90% of Swiss forests, which can lead to unwanted changes[40].

In addition to the inventory it requires, the Forests Policy states that the federal government must work with the stakeholders concerned to draw up a strategy to improve the nutrient balance in forests (recommendations for cantons and forest owners). In view of the fact that critical loads for eutrophying nitrogen depositions in forests are continuously exceeded, all technically possible measures to reduce ammonia emissions must be implemented consistently (› SA22 see Section 5.2.5).

Target

TF1: No lasting degradation of the soil functions of forest soils as a result of substance depositions from the atmosphere.

37 Swiss Agency for the Environment, Forests and Landscape, SAEFL (2005): *Stickstoffhaltige Luftschadstoffe in der Schweiz. Status-Bericht der Eidg. Kommission für Lufthygiene (EKL)* [Nitrogenous air pollutants in Switzerland. Status report of the Federal Commission for Air Hygiene (FCAH)]. Umwelt publication series, no. 384.

38 Forum für Wissen (2013): *Bodenschutz im Wald – Ziele – Konflikte – Umsetzung* [Soil protection in forests – objectives – conflicts – implementation]. WSL reports. p. 23-28, ISSN 2296-3448. URL: *www.wsl.ch/dienstleistungen/publikationen/pdf/13083.pdf* (German)

39 *Waldpolitik. Ziele und Massnahmen 2030* [Forests Policy. Objectives and Action to 2030].

40 Rihm B., Künzle T. (2019): Mapping Nitrogen Deposition 2015 for Switzerland, Technical Report on the Update of Critical Loads and Exceedance, including the years 1990, 2000, 2005 and 2010. Report commissioned by the Federal Office for the Environment (FOEN).

Strategic approaches
For the Soil Strategy, the following strategic approaches emerge as a complement to the measures already defined in the Forests Policy:
SF1: Improve the available information about the extent and development, as well as the impact, of the eutrophication and acidification of forest soils.

5.3.2 Compaction of forest soils

Use of heavy forestry machinery results in soil compaction in forests

Heavy machinery driving across forest soils reduces their pore volume and therefore air and water circulation and the volume of soil that roots can penetrate. Plant growth and the regulating and habitat functions of forest soils are impaired as a result.

Climate change likely to exacerbate compaction problem

The increase in soil moisture during the winter half of the year that is expected as a result of climate change[41] is likely to exacerbate the compaction problem still further.

Sustainable forest management requires soil information and better communication

In 2010, the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) published a fact sheet for practitioners on physical soil protection in forests. In 2016, the FOEN published the handbook entitled *"Physikalischer Bodenschutz im Wald"* ["Physical soil protection in forests"], which sets out the principles of driving on forest soils in a way that minimises damage[42]. Meanwhile, *"Waldpolitik. Ziele und Massnahmen 2030"* [Forests Policy. Objectives and Action to 2030] addresses further knowledge transfer to practitioners about sustainable forest management. The federal government, cantons and forest associations are responsible for this (› SF2).

Target
TF2: Avoid the lasting compaction of forest soils.

Strategic approaches
For the Soil Strategy, the following strategic approaches emerge as a complement to the measures already defined in the Forests Policy:
SF2: Improve the available information, and knowledge-transfer to practitioners, with the aim of encouraging sustainable forest management. Factor in the cantons' existing fundamental information.

41 CH2011 (2011): Swiss Climate Change Scenarios CH2011. Published by C2SM, MeteoSwiss, ETH, NCCR Climate, and OcCC. Zurich, Switzerland. 88 pp.

42 Lüscher P., Frutig F., Thees O. (2016): *Physikalischer Bodenschutz im Wald. Waldbewirtschaftung im Spannungsfeld zwischen Wirtschaftlichkeit und Erhaltung der physikalischen Bodeneigenschaften* [Physical soil protection in forests. Forest management as a balancing act between economy and the preservation of physical soil properties]. Federal Office for the Environment, Bern. *Umwelt-Wissen* no. 1607. 159 pp

5.4 Construction sites and remodelling of land

The ongoing use of land for the construction of infrastructures (soil sealing) is the subject of Section 5.1, Spatial planning. This section addresses the temporary use of soils in connection with construction sites, as well as soils on which land is being remodelled[43].

Improper handling of removed soil can result in a loss of soil functions

In most cases concerning construction sites, soil is removed, stored temporarily, transported, and some returned to its original site. If this is not done properly, it can result in a loss of soil functions, in particular as a result of compaction, organic matter decline, and the loss of soil biodiversity (see Appendix A1). Simply driving across the soil with heavy construction machinery can result in compaction, which causes permanent soil damage. Moving soil from one site to another is also one of the main ways in which invasive species are spread.

Construction sites which involve excavation almost always produce a surplus of soil which, as a valuable resource, should be re-used. However, a lack of space means that the on-site storage of soil that has been removed is often impossible, as is returning it once construction is complete. It is therefore dumped as waste, even though it is not polluted.

Remodelling of land represents severe interference in natural soils

One way of re-using unpolluted soil from construction sites is to remodel agricultural land to improve the soil, i. e. to increase productivity. Such measures always represent severe interference in natural soils, however: the structure of the soil may be damaged, and its layer composition may be adversely affected. Both of these result in a reduction in ecological soil functions.

Measures to improve natural soils prohibited

The term soil *improvement* is sometimes abused as justification for disposing cheaply of unpolluted soil by spreading it on natural, shallow soils. This is prohibited, because the principles of soil protection demand that typical local soils be preserved regardless of their quality from the agricultural perspective[44]. Furthermore, such shallow soils often fulfil important functions for biodiversity. By contrast, anthropogenically degraded soils can be candidates for such improvement by remodelling, although in many places there is a lack of information on the location and size of suitable sites (› SB5).

What are anthropogenically degraded soils?

"Anthropogenically degraded" soils refers to all soils whose structure (sequence and thickness of layers) has been changed significantly owing to construction, specifically as the result of spreading soils or excavated material removed from elsewhere, or compaction. Subsided organic soils or those which have become degraded over and above the analysis values laid down in the SoilPO

43 In accordance with Art. 33 para. 2 EPA: "The soil may be physically affected only to the extent that its fertility is not durably degraded; this does not apply to land used for building."

44 Art. 2 para. 1 SoilPO defines soil fertility according to whether or not the active biotic community, soil structure and composition, and depth, are typical of its site. Spreading soil on top of soil that has grown naturally generally changes the original typical local structure, soil composition, and biotic communities.

are also classified as being anthropogenically degraded. This contrasts with changes to soil structure caused by normal crop farming, which is not classified as anthropogenic degradation because ploughing only mixes the top layer (the A horizon) within itself.

Illegal soil improvement a growing problem

Degraded or unsuitable soil or excavated material is also sometimes used to "improve" soil. Under applicable environmental legislation[45], this practice is illegal. It results in a lasting degradation of ecological soil functions and is a growing problem.

Huge volumes of soil available every year

In Switzerland, there are an estimated 4 million m^3 of clean topsoil and 11 million m^3 of clean subsoil available for re-use every year[46]. Together, they represent just under twice the volume of the Great Pyramid of Giza. The topsoil alone would be enough to cover the surface of Lake Sils to a depth of one metre.

The sectoral plan for crop rotation areas requires the cantons to designate a sufficiently large quota of land for crop rotation areas (crop-sustaining arable land). This results in steadily increasing pressure on the cantons to improve soil for use for crop rotation. An increase in the number of relevant initiatives can therefore be expected. Furthermore, soil improvement programmes can receive financial support from the federal government via measures laid down in the Structural Improvements Ordinance to preserve and improve the structure and water content of soil.

No formalised review of the environmental impact on small construction sites

The SoilPO already determines how soil is to be handled on construction sites to avoid compaction and erosion. Furthermore, nowadays pedological site support is usually required on sites that must produce an environmental impact assessment (EIA). These support personnel are responsible for compliance with the provisions of soil protection legislation, as well as the project-specific conditions imposed as part of the permit process. This means that soil protection targets on construction sites subject to an EIA are generally well met. Projects which are not obliged to undergo an EIA are subject to the same legal requirements, but in most cases there will be no formalised review of environmental impact, and soil protection measures will be forgotten (› SB1, SB3).

The obligation to re-use soil that has been removed has been laid down since 1 January 2016 in the Ordinance of 4 December 2015 on the Avoidance and Disposal of Waste (ADWO; SR 814.600)[47]. To avoid this re-use obligation becoming a conflict of interest, it must be focused primarily on anthropogenically degraded soils. Knowledge of suitable soils must be improved by producing the relevant maps at cantonal level (› SB5).

45 SoilPO Art. 7 para. 2.

46 Fry P., Liechti K. (2009): *Wiederverwendung von abgetragenem, sauberem Boden in der Landwirtschaft. Erarbeitung der Grundlagen für die Entwicklung eines akteurorientierten Lösungsansatzes. Abschlussbericht* [Re-use of removed, clean soil in agriculture. Draft principles for developing a stakeholder-based approach. Final report].

47 Art. 18 para. 1 of the Waste Ordinance codifies the obligation to re-use both topsoil and subsoil.

Land remodelling and soil improvements are often approved in processes in which there is no formalised review of environmental impact. Although the necessary information and guidance are actually available[48], effective soil protection measures are often forgotten. In addition, circumventing regulations on the re-use of excavated materials can save significant sums of money. The problems associated with land remodelling and soil improvements can therefore be tackled primarily by strengthening the enforcement of existing law (› SB2). Furthermore, some of the affected stakeholders are not sufficiently aware of the potential negative impact of remodelling works on ecological soil functions (› SB4).

Targets

TB1: No lasting degradation of soil functions as a result of physical, chemical or biological soil degradation owing to construction or the remodelling of land.

TB2: Suitable removed topsoil and subsoil are to be re-used to the fullest extent possible.

TB3: Natural, untouched soils displaying typical local properties are protected from land remodelling.

Strategic approaches

SB1: Strengthen the enforcement of physical and biological soil protections, in particular for construction projects not subject to an EIA.

SB2: Strengthen the enforcement by reviewing permit practices for remodelling land, and for soil improvement programmes.

SB3: Raise awareness among the competent authorities and building contractors of how to handle soil properly in construction projects.

SB4: Raise awareness among the relevant stakeholders of physical soil protection where land is remodelled.

SB5: Identify and map soils that have been subject to anthropogenic degradation and are candidates for soil improvement programmes. These should take into account not only agricultural aspects, but also those relating to biodiversity and to climate and water protection.

48 Fact sheet issued by the cantons of AG, AI, BE, BL, BS, FR, GR, JU, LU, SG, SO, TG, VD, ZG, ZH and the Principality of Liechtenstein (no year given): *Bodenschutz beim Bau von Golfanlagen* [Soil protection in the construction of golf courses]. Various cantonal guidance documents on land remodelling also exist.

5.5 "Greenfield" events

Soil compaction the main problem

The number of greenfield leisure events such as open-air concerts, motocross races, Swiss wrestling festivals, tractor-pulling contests and the like have increased significantly in recent years, posing an ever-greater challenge for the competent cantonal authorities. Alongside small-scale events, more and more large, professionally organised events are also being staged. Such events are often held on flat soils that are well suited to agriculture. The erection and operation of the related infrastructures, including car parks or trucks driving across unprotected soil, can result in soil compaction. The extent of this compaction depends heavily on the type of event and the current condition of the soil. Land is also remodelled for certain events, such as motocross races (see Section 5.4).

Soil protection measures are forgotten

As a rule, greenfield events require trading or road traffic permits, but no building permit. Environmental agencies are not usually involved, and soil protection measures are ordered only in exceptional cases.

To avoid lasting soil degradation as a result of greenfield events, the existing rules on soil protection must be applied consistently. This requires permit processes which ensure that soil-related concerns are taken into account (› SE1).

New legal foundations and enforcement aids available

A number of cantons have joined forces with the FOEN to publish a fact sheet entitled *"Freizeitveranstaltungen auf der Grünen Wiese"* ["Leisure events on greenfield sites"], aimed at event organisers, farmers and local authorities. It contains measures to protect the soil at the preparation, implementation and restoration stages[49]. Several years ago the SoilPO was also amended in connection with the revision of the Technical Ordinance on Waste (now known as the Waste Ordinance, ADWO). To avoid soil degradation from major events and temporary installations on greenfield sites, Art. 6 para. 1 SoilPO now apples not only to the erection of facilities and to farming, but also generally to any form of soil use.

Target
TE1: No lasting degradation of soil functions as a result of soil degradation from greenfield events.

Strategic focus area
SE1: Review the practice for granting permits for greenfield events with a view to better consideration of environmental and soil protections.

49 Fact sheet issued by the cantons of AG, AI, BE, BL, BS, FR, GR, JU, LU, SG, SO, TG, VD, ZG, ZH and the Principality of Liechtenstein (2004): *Freizeitveranstaltungen auf der Grünen Wiese* [Leisure events on greenfield sites]. Fact sheet. 6 p

5.6 Soil use in urban areas

Unsealed soils in urban areas fulfil special regulating functions. They retain rainwater and let it seep away slowly, thereby actively easing the strain on the sewerage system and helping to protect against flooding. Together with plants, they provide diverse habitats and recreation areas, and ensure a stable local climate. These important soil functions are increasingly at risk, however.

Soils in settlement areas often heavily contaminated

Soils in settlement areas often contain pollutants as a result of many years of use. Harmful depositions from the air, as well as the use of adjuvants such as ash, mineral fertilisers and pesticides, result in unwanted substances infiltrating the soil and accumulating there. The improper use of pesticides and fertilisers by private individuals further adds to the problem. Nowadays, gardens and parks are among the most heavily polluted soils in Switzerland[50] (› SU4).

Many unsealed soils in settlement areas have been shaped by anthropogenic activity. They consist of a mix of redistributed natural and anthropogenic substrates. They are frequently poorly laid down, have too little organic matter, and are too shallow (› SB4 see Section 5.4).

Regulations highly fragmented and confusing

A whole range of provisions govern the approval and use of fertilisers and pesticides in Switzerland. Relevant regulations can be found in particular in the Plant Protection Products Ordinance of 12 May 2010 (PlantPPO; SR 916.161), the Chemicals Ordinance of 5 June 2015 (ChemO; SR 813.11) and the Chemical Risk Reduction Ordinance of 18 May 2005 (ORRChem; SR 814.81). These regulations are nonetheless highly fragmented, not to mention confusing in some areas. This leads to problems both for users and for enforcement (› SU2). In September 2017, the Federal Council adopted the action plan to reduce risk and to promote the sustainable use of phytosanitary products *(Aktionsplan Pflanzenschutzmittel)*. Restrictions on the sale of pesticides to private users are integrated as specific measures into this action plan (› SU1).

In many cases, the market controls[51] conducted regularly by the federal government and the cantons reveal shortcomings in labelling, safety data sheets, and classification. This indicates that the current requirements must be put into practice even more effectively than is the case at present (› SU3).

50 FOEN (2017): *Boden in der Schweiz. Zustand und Entwicklung. Stand 2017* [Soil in Switzerland: status and developments as at 2017]. URL: *www.bafu.admin.ch/bafu/en/home/topics/soil/publications-studies/publications/boden-schweiz.html*

51 *www.anmeldestelle.admin.ch/chem/en/home/themen/recht-wegleitungen/marktkontrolle.html*

Targets

TU1: New (anthropogenic) soils in urban areas are created in a way that allows them to fulfil their ecological functions[52].

TU2: No lasting degradation of soil function as a result of organic and inorganic pollutants in urban soils.

TU3: Restoration of soil functions of unsealed soils within urban areas that have been subject to physical degradation and contamination.

Strategic approaches

SU1: Monitor the impact of the phytosanitary products action plan.

SU2: Promote communication and education measures for private and public users on banned substances and the proper use of pesticides and fertilisers.

SU3: Review the market controls conducted by the federal government and the cantons and, where necessary, reinforce them based on risk assessments.

SU4: Review the operating framework for restoring soil functions of soils in urban areas (planning foundations, incentives, etc.).

5.7 Handling of degraded soils

Current regulations on handling degraded soils result in enforcement problems

Soils can be contaminated with pollutants from a variety of sources. Depending on the origin of those pollutants, different statutory provisions apply to their assessment and handling.

If the degradation results from the deposit of waste within a confined area, such as a landfill site, or the location of an industrial plant or an accident, it is assessed in accordance with the provisions of the Contaminated Sites Ordinance of 26 August 1998 (CSO; SR 814.680): if any of the concentration values are exceeded, remediation is mandatory, with the costs paid by the polluter, in accordance with the EPA. If the polluter is unknown or is unable to pay, an application for compensation for the remediation work may be made under the Ordinance of 26 September 2008 on the Charge for the Remediation of Contaminated Sites (CRSCO; SR 814.681).

However, if the pollution originates from diffuse sources, it is dealt with not under the CSO, but under the SoilPO. This Ordinance provides for a range of measures depending on the type of soil use and the level of contamination. In settlement areas, restrictions on use are imposed, but no remediation work is undertaken. If remediation work outside a settlement area is necessary[53], it cannot be co-financed via the CRSCO contaminated sites fund.

52 For strategic approaches please refer to Section 5.4.

53 In the case of horticultural, agricultural or forestry use as determined in the context of spatial planning (Art. 10 para. 2 SoilPO).

Depending on its origin, the same degree of contamination therefore either carries an obligation to remediate, or use of the soil need only be forbidden or restricted. There is no objective justification for this, and it results in confusion in the enforcement of the law. The FOEN is currently working with the cantons to draft proposals for the harmonisation of the CSO and the SoilPO. Since the revisions are also likely to necessitate amendments to the EPA, this work is not expected to be completed before 2022 (› SH1).

Target
TH1: Review the measures and financing options for remediating and restricting the use of polluted soils and contaminated sites, with the aim of a possible harmonisation.

Strategic focus area
SH1: Necessary revision of legal texts in accordance with the recommendations of the ongoing evaluation.

5.8 International commitment

Fertile soils are a scarce resource world-wide

Soil is a finite resource, and land use therefore represents one of the limits to the carrying capacity of our planet[54]. Unsustainable soil use around the world – deforestation, extension of settlement areas as a result of population growth, and changes to land use, etc. – contribute to soil degradation. More than 24 billion tonnes of fertile soil are lost every year through erosion alone.

A large proportion of the food and feedstuffs consumed in Switzerland, as well as other consumer goods, originates from production on foreign soil. There is a limit to the volume of fertile soil world-wide, and soil that can be used for agricultural purposes covers only 12% of the earth's surface. In addition, soil use abroad has an indirect impact on Switzerland, as it affects the climate, for example. For these reasons, the preservation, improvement, restoration and sustainable use of soil at the global level is also in Swiss interests.

Megatrends resulting in more intensive soil use around the globe

Megatrends such as climate change, population growth, new dietary habits and the increasing cultivation of bioenergy are further intensifying soil use, and thus the loss of soil biodiversity and progressive soil degradation around the world.

54 Steffen W. et al. (2015): Planetary boundaries: Guiding human development on a changing planet. Science 13 February 2015, Vol 347, Issue 6223.

Switzerland's international commitment

Switzerland also uses its bilateral development cooperation programmes as a means of targeting support for the fight against land degradation and for efforts to promote sustainable farming. Equitable access to soil is an important factor here. Furthermore, Switzerland supports a variety of international initiatives aimed at sustainable soil use – as a member of the UN Convention to Combat Desertification (UNCCD), with financial support for and contributions in kind to the FAO's Global Soil Partnership, and as a member of the European Environment Agency and part of EIONET, the associated European Environment Information and Observation Network, which is a network of experts sharing knowledge and experience between the European authorities responsible for enforcing soil protections. The UNCCD explicitly pursues sustainable soil use and land degradation neutrality as the key elements of its work, but it focuses in particular on the arid, semi-arid and dry sub-humid zones of the world. Countries located outside of these zones are nonetheless invited to engage at the international level and become advocates of land degradation neutrality. Goal 15 of the 2030 Agenda for Sustainable Development is the restoration and sustainable use of soil and land[55]. Target 15.3 focuses on soil protection and land degradation neutrality. Switzerland, too, has committed to help achieve these targets.

No instrument for global soil protection exists

As things stand, however, there is no specific instrument aimed at protecting soils and their multifunctionality in all parts of the world. Soil protection does not play a large enough part in other current instruments, such as the UN Convention on Biodiversity (UNCBD) or the UN Framework Convention on Climate Change (UNFCCC) (› SI1).

For changes in soil status and the effectiveness of soil protection measures to be monitored at an international as well as national level, there must be standard methods for collecting soil data, as well as multilateral, harmonised formats for international data exchange (› SI1).

Target:
TI1: Switzerland is an advocate at the international level for the preservation and sustainable use of soils.

Strategic focus area
SI1: Better integration of the issues of soil and soil protection in international instruments. Engagement in international bodies to improve methods for monitoring changes in soil status, and the effectiveness of the measures that have been instituted.

55 Specifically in targets 2.4, 3.9, 12.4, 14.1 and 15.3. (see *https://sustainabledevelopment.un.org/post2015/transformingourworld*)

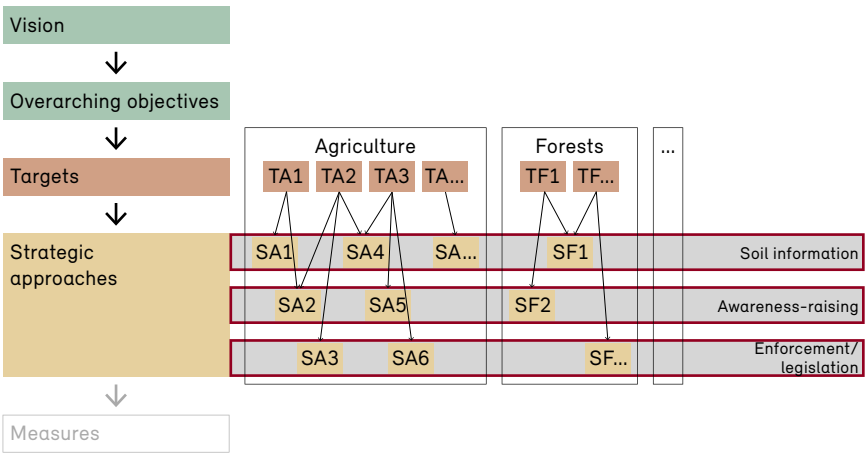
6 Action areas

The strategic approaches developed in this document identify a need for action in particular where *soil information, awareness-raising* and *enforcement and legislation* are concerned. The following section describes these three action areas, and outlines the next steps towards implementing the strategic approaches.

Figure 5

Section 6 summarises the strategic approaches and sketches out the next steps towards implementation in the three action areas of soil information, awareness-raising and enforcement and legislation

The targets in the various fields are designated accordingly (TA1 is the first target for agriculture, TA2 the second, etc.). A similar nomenclature has been used for the strategic approaches derived from the targets (SA1, SA2, SA3, etc.). The grey bars outlined in red show the three action areas.



6.1 Soil information

Many of the strategic approaches defined to achieve the targets can be allocated to the soil information action area. This is unsurprising, given that a lack of information on Switzerland's soils was identified as one of the key overarching challenges (see Section 3.6).

Soil information must be collected and made available as a vital basis for decision making

To achieve the targets identified in Section 5, there is a need for standardised, reliable, nationwide information on the condition and sensitivity of Switzerland's soils. Fact-based decisions that are congruent with the defined targets cannot be made without sufficiently detailed knowledge of soil properties, which may differ considerably at the local level. As already established in Section 3.6, the available soil data for Switzerland is in some cases outdated or only sporadic, and thus largely unusable as an important basis for current

decisions on soil use. However, nationwide soil information, in the form of soil maps, for example, is essential for better decision-making processes in the interests of sustainable, integrated resource management. Work to close the corresponding gaps must therefore be treated as a priority.

Data gathering and analysis methods must be refined and harmonised

The primary aim of the first soil mapping programmes in Switzerland was to evaluate the suitability of soils for agricultural production. Implementing the strategic approaches defined in this document requires additional soil information, however, as is now being gathered by current soil mapping initiatives in the cantons of Solothurn, Basel-Landschaft and Lucerne, for example.

In some instances, the necessary data gathering and analysis methods for soil properties, as well as pedotransfer functions to estimate soil functions, still have to be developed or calibrated for Swiss soils. The extent to which supplementary methods such as remote sensing, GIS modelling and geostatistics can support this work must be examined. It must also be taken into account that methods are being adapted all the time to new technologies. Furthermore, methodological standards and reference values must be secured over the long term to ensure that data can be compared across extended periods.

Both the gathering and analysis of soil data, and the evaluation of soil threats and of soil functions, should follow standardised methods so that findings can be compared with those of other cantons. Since the disbanding of the national mapping service in 1996, there has been no national institution to maintain and develop a standard working basis for implementation that is available to both the federal government and the cantons. As a result, Switzerland currently has no up-to-date, standardised national foundation documents or methods for evaluating soils. This hinders the implementation of measures and sustainable soil use.

Expanded soil monitoring

Expanded soil monitoring is a central strategic approach alongside the more widespread use of soil information as a basis for decision-making, as well as the refinement of data gathering and analysis methods. At the national level, NABO monitors the state of pollution of 100 representative sites, as well as their physical, biological and chemical conditions. Some cantons run additional monitoring programmes, such as KABO (cantonal soil monitoring), and the *Interkantonale Walddauerbeobachtung* (long-term intercantonal forest observation) initiative. In addition, in its Long-Term Forest Ecosystem Research (LWF) programme, the Federal Institute for Forest, Snow and Landscape Research WSL has for decades been observing the development of eight selected forest ecosystems that are subject to anthropogenic influence. Soil analyses linked to the Proof of Ecological Performance in agriculture are not currently assessed in any further detail, and are not used for soil monitoring purposes.

Existing monitoring programmes are not enough to achieve the set targets. It is therefore vital that monitoring be expanded to provide data on the relevant issues.

Cooperation between federal government and cantons on data management and processing

Soil information is gathered by public and private-sector stakeholders for a variety of purposes. To date in Switzerland there has been neither a standard data model nor any coordinated, shared data storage system to manage this data – with the exception of those cantons which manage their datasets using NABODAT. If soil data is not migrated to NABODAT and aligned with the other data in the system, cantonal data sets are more difficult to compare, and are often extremely time-consuming to compile and synthesise[56]. To generate maximum benefit from both existing and future soil data, it must be held in harmonised, digital form, and be accessible via a central interface. This cannot be achieved without close cooperation between the federal government and the cantons. Work that is currently ongoing to process older soil data is a first step in this direction.

National Competence Centre for Soil as service point

The soil information gathered in the field and in the lab is highly specialised and, in itself, does not give the direct answers that politicians, decision-making and enforcement authorities and soil users need. The data must be linked and processed before it can help to achieve the set targets. Many of the issues or enforcement measures demand bespoke analyses that, at present, cannot be delivered without significant effort. In the future, the National Competence Centre for Soil adopted in fulfilment of the Müller-Altermatt motion 12.4230 and established in 2019 will serve as the national service point. It will prepare the necessary soil information for all of the individual stakeholder groups specifically, and offer it as needed.

The targets and strategic approaches determined in this document already provide specific indications of what needs to be done to improve the situation with regard to soil information in Switzerland. The FOEN and other agencies have already provided an overview and the technical details of the necessary tasks on the soil information front.[57] NRP 68 also recommends establishing and operating the Competence Centre,[58] and has drawn up four important principles for it as part of its thematic synthesis 4[59].

56 NABODAT already provides an overview of cantonal data: Rehbein K., Sprecher, Ch. & Keller, A. (2019): *"Übersicht Stand Bodenkartierung in der Schweiz. Ergänzung des Bodenkartierungskataloges Schweiz um Bodeninformationen aus Meliorationsprojekten"* [Overview of the status of soil mapping in Switzerland. Addition to the Swiss soil map catalogue of information from soil improvement projects], Agroscope, NABODAT National Soil Information System office, Zurich.

57 See Tobias, S. (2012): *Brainstorming Zukunft Bodeninformation Schweiz, Projektabschlussbericht* [Brainstorming session on the future of soil data in Switzerland. Concluding project report], WSL, Swiss Soil Science Society.

58 Steiger U., Knüsel P., Rey L. (2018): *Die Ressource Boden nachhaltig nutzen. Gesamtsynthese des Nationalen Forschungsprogramms "Nachhaltige Nutzung der Ressource Boden" (NRP 68)* [The sustainable use of soil as a resource. Overall synthesis of the National Research Programme "Sustainable Use of Soil as a Resource" (NRP 68)]. Pub.: NRP 68 steering committee. Bern

59 Keller A., Franzen J., Knüsel P., Papritz A., Zürrer M. (2018): *Bodeninformations-Plattform Schweiz (BIP-CH). Thematische Synthese TS4 des Nationalen Forschungsprogramms "Nachhaltige Nutzung der Ressouce Boden" (NFP 68)* [Swiss soil information platform (BIP-CH). Thematic synthesis TS4 of the "Sustainable Use of Soil as a Resource" National Research Programme (NRP 68)]. Bern

Steps towards implementation
The federal government works with the cantons to establish the **National Competence Centre for Soil.** With the involvement of research institutions, the following issues will have to be addressed, in particular:

- **Norms and standards:** Update and develop the methodological principles for gathering, classifying, measuring and analysing soil data.
- **Gather soil data:** Design and implement a nationwide soil mapping programme using updated methods. Prioritise the inventory according to region, time, level of detail and the type of soil data that is to be gathered.
- **Data management:** Establish a national platform to provide harmonised soil information to experts and other user groups on the basis of NABODAT.
- **Analysis and interpretation:** Create a central service point offering professional analysis and interpretation of soil information that is oriented towards the needs of individual target groups.

6.2 Awareness-raising

Too little known about the value and sensitivity of soils

One challenge mentioned frequently by researchers and practitioners is the lack of awareness of the importance and sensitivity of soils among direct users (farmers, construction companies, communes, etc.), the business community, and the general public alike. This is reflected not least in the many strategic approaches which provide for communication and education measures to raise awareness among these target groups.

The concept of soil functions offers an approach by which clearly to explain the potential of soil to provide certain services for the environment, the economy and society.

The development of this National Soil Strategy is a first step towards a better understanding of the importance and sensitivity of soils. Experience from other fields such as natural disaster prevention shows that the provision of information to all of those affected by the issue both directly and indirectly is best planned and implemented holistically. In this way, target-group-specific communication and education programmes, and other measures (such as strengthening enforcement) can be designed to complement each other. For such programmes to have a lasting impact, the specific factors which are inhibiting the desired behaviours on the part of businesses and society must be identified in advance, so that targeted action can be taken to break down those inhibitions. Modern behavioural science offers the necessary tools for this work. If it is not done, there is a considerable risk that awareness-raising measures will have little effect.

Steps towards implementation
Develop a programme to raise awareness among target groups whose actions and decisions have a particularly significant effect on soil functions. This programme should cover the following issues, in particular:
- Identify the factors which inhibit sustainable behaviours with regard to soil
- Identify and prioritise target groups
- Develop target group-specific awareness-raising measures
- Develop a concept to evaluate the measures that have been instituted.

6.3 Enforcement and legislation

Action needed to strengthen enforcement

In many cases it has become clear that, although the legal requirements are fit for purpose, they are not sufficiently enforced. Action is needed in particular with regard to construction projects both inside and outside building zones, permit practices and checks on land remodelling, the implementation of measures to reduce ammonia in agriculture and, last but not least, with regard to events on greenfield sites. The main causes of shortcomings in enforcement are generally a lack of (especially political) acceptance of the regulations and a lack of resources within the enforcement authorities. The latter is often a result of the former. Alongside substantiated facts and awareness-raising among stakeholders, it is important in order to gain acceptance for soil protection measures to have a set of rules and regulations that is easy for all concerned to understand, and that is aligned with their varying needs. There must also be a clear allocation of authorities. A lack of resources can be offset in particular by concerted efforts, experience-sharing and efficient enforcement instruments, such as risk-based controls. Prioritising enforcement also creates acceptance in turn. In view of the differing interests in soil as a resource, it will be essential for the competent authorities in the fields of environment, agriculture and spatial planning to coordinate and share information with each other on a regular basis. Appropriate networks could be established to this end, and innovative instruments such as benchmarking or peer reviews deployed – as specified in the process to strengthen enforcement and supervision.

Action needed on legislation

Of the total of 44 strategic approaches, 17 provide for the review of existing regulations, or the development of new aids and instruments. Action with regard to legislation is needed especially where agriculture (accounting for just under half of the strategic approaches for agriculture) and spatial planning (accounting for a third of strategic approaches for spatial planning) are concerned. Almost all of these regulations aim to improve environmental protection. Requirements concerning greenfield events, the handling of contaminated soils and soil use in urban areas should also be reviewed and revised where necessary. The requirements in individual areas that are given in Section 5 should be examined for overlaps, contradictions and conflicting objectives,

and then improvement proposals drafted. The objective must be to produce a coherent and enforceable set of rules and regulations for soil which is geared to the overarching objectives and soil functions, and which permits a flexible response to new challenges.

Steps towards implementation

The agencies responsible for soil-related issues at federal and cantonal levels are drawing up joint programmes to strengthen enforcement in the fields identified in Section 5, and regularly set priorities for implementation on the basis of the current status of enforcement.

The agencies responsible for soil-related issues at federal and cantonal levels

- review the relevant requirements in the light of the strategic approaches determined in Section 5
- examine existing regulations to identify overlaps, contradictions and conflicting objectives, and make proposals for how they might be remedied
- join forces to develop enforceable changes to laws and ordinances to achieve a coherent set of rules and regulations for soil that is geared to cross-sectoral targets and soil functions

The agencies responsible for soil-related issues at federal and cantonal levels share knowledge and experience at regular intervals and coordinate their activities with each other.

Appendix

A1 Soil threats

Soil threats caused by land use

The different types of land use affect the properties of soil, and thus also soil functions. While the expansion of urban areas results in progressive soil consumption, a range of uses have specific effects which lead to the impairment of ecological soil functions in particular.

Sealing

Definition

Soil sealing describes the man-made covering of soils by construction and tarmac, concrete or similar materials, as well as any other coverage of soil using impermeable substances. Soil sealing results primarily from the construction of residential and commercial property, as well as road-building.

Effects

Water and gas exchange are largely halted in sealed soils. As a result, these soils lose their function as a habitat for plants, soil animals and other organisms, as well as their filter and absorption capacity. Biologically, they all but cease to be active. It is not possible to restore soil functions within a human time-frame. Recultivating sealed soil requires soil matter from elsewhere, thereby reducing the functional capacity of the soil at the source location.

Consequences for Switzerland

In Switzerland, soil sealing has by far the most significant quantitative effect on soil. According to the federal government's land use statistics, urban areas grew by almost a quarter between 1985 and 2009. The degree of soil sealing (the proportion of impermeable soils, i. e. buildings, tarmac and concrete surfaces) within an urban area amounts to just over 60% overall. The increase in urban areas was greater than population growth during the same 1985 – 2009 period, with agglomeration belts most heavily affected.

Sealing is addressed specifically in the following sections:

- *Building zones (p. 25)*
- *Construction projects outside building zones (p. 27)*

Soil compaction

Definition

Soil compaction describes where the pores in the soil that conduct air and water are compressed by weight on the surface of the soil in a manner that results in a permanent plastic deformation. The main cause of soil compaction is the use of heavy machinery working or driving across the soil, or the improper treatment of the soil when conditions are too wet.

Effects

Compaction destroys the soil's structure and reduces pore volume, thereby lessening its permeability to water (resulting in surface runoff and erosion), weakening aeration, and impairing the biological processes within the soil. Compacted soils are therefore unable adequately to fulfil their ecolog-

ical functions (habitat, regulating and production). Since compaction also diminishes soil's capacity to store water, the risk of erosion and flooding is increased. Subsoil compaction is particularly damaging because it is gener-ally impossible to reverse.

Consequences for Switzerland

It may be assumed that soil compaction will be a growing problem in the future, especially where crop farming is concerned, owing to the use of increasingly large and heavy machinery (harvesters with sizeable bunkers or tanks). Quantitative information on the scale of soil compaction in Switzerland is only very sporadic at present, and in most cases there is no broad basis of data

Compaction is addressed specifically in the following sections:

- *Soil compaction as a result of agricultural use (p. 29)*
- *Compaction of forest soils (p. 39)*
- *Construction sites and remodelling of land (p. 40)*
- *"Greenfield" events (p. 43)*

Erosion and landslides

Definition

The term "erosion" summarises the wearing away of soil matter by wind, surface and subterranean water runoff, and abrasion from snow and avalanches. "Landslides" is used here as the collective term for the downslope movement of solid and loose earth and rock, and covers earthslides, rockfalls, and open-slope debris flow.

Causes

Erosion in itself is a natural process, but it is often affected by human soil use such as tilling, choice of culture, grazing and excavation work. It remains a relevant problem, especially in areas with intensive farming. Recent decades have seen an increase in the erosion risk faced by many Alpine valleys, as farmers abandon higher pastures or use them more extensively, thereby necessitating the more intensive use of lower-lying grasslands[60].

Landslides are generally triggered by heavy rain and the resulting seeping of water between soil layers that were previously bound firmly together. An increase in such events is expected as the permafrost continues to thaw.

Effects

Soil loss from use-related erosion diminishes soil fertility because the humus-rich topsoil horizon is the first to be degraded. Soil erosion doesn't just damage the soil, however. The nutrients and crop-treatment products that are carried away by erosion pollute rivers and lakes, and may harm neighbouring protected areas.

60 Alewell, C., Egli, M., Meusburger K. (2014): An attempt to estimate tolerable soil erosion rates by matching soil formation with denudation in Alpine grasslands. Journal of Soils and Sediments: Volume 15, Issue 6 (2015).

Where a landslide causes the displacement of soil material, most soil functions will be impaired for many years both where the landslide originated and where it came to rest.

Consequences for Switzerland

Nowadays, soil erosion by wind and water is seen globally as one of the most significant forms of soil degradation altogether. In Switzerland, widespread soil erosion threatens around 20% of open cropland, with mean current soil loss amounting to 840,000 tonnes per year, or 2.1 t/ha annually. Average figures of 1.2 t/ha have been recorded for Alpine grassland, while soil loss of over 30 t/ha has been measured in heavily affected areas[60].

Erosion is addressed specifically in the following section:

- *Soil erosion as a result of agricultural use (p. 31)*

Organic matter decline

Definition

Organic matter consists of living biomass, i. e. all of the organisms living in the soil, including plant roots and the remains of organisms that have died, at their various stages of decomposition. Soil organic matter forms an important part of fertile soil because it improves structural stability and water retention capacity, and stores nutrients in a way that enables them to be absorbed by plants and other organisms. It is also central to buffer, degradation and filter processes, and helps to bind climate-relevant CO_2 into soil.

Effect

If topsoil is placed under heavy stress by intensive land use, the result is often a decline in soil organic matter. This destabilises soil structure and makes soil more susceptible to compaction and erosion. The decline in soil organic matter also lessens bioactivity, and reduces soil's water content and nutrient levels.

Diminishing reserves of organic matter in soil are associated with the net release of CO_2, thus having a warming effect on the planet.

Consequences for Switzerland

The findings of the NABO's long-term monitoring project (1985 – 2009) did not determine any general trend towards an increase or decrease in the carbon content of the topsoil of the mineral soils studied. It is a different picture for intensively used organic soils and drained wetlands. Here, the decline in organic matter is hugely significant because peat subsidence in some fields in the Bernese *Seeland* region is more than 1 cm per year.[61]

Organic matter decline is addressed specifically in the following sections:

- *Decline in soil organic matter as a result of agricultural use (p. 32)*
- *Construction sites and remodelling of land (p. 40)*

61 Krebs, R. et al. (2011) : *Jahresbericht des Amts für Wasser und Abfall des Kantons Bern 2011* [Annual report of the Canton of Bern Office for Water and Waste 2011]

Soil biodiversity loss

Definition

Soil biodiversity refers to the wealth and variety of life in the soil, from genes to biotic communities, and to the variety of soil habitats, from microaggregates to entire landscapes. Active soil organisms are crucial to the ecological functions of soil – habitat, regulating and production. Soil biodiversity is thus central to the provision of these ecosystem services. Soil biodiversity loss is caused by chemical pollution and the physical degradation of soils, as well as by land use changes, specifically the intensification of farming and the expansion of urban areas.

Effect

Since active soil organisms are of key importance to soil formation and ecological soil functions, soil biodiversity loss necessarily diminishes these vital functions.

Consequences for Switzerland

It is not known how much biodiversity in Switzerland's farmed soils has changed in recent decades. Various foreign studies have nonetheless shown that intensive agricultural use – specifically crop farming – reduces biodiversity in the soil (see Section 5.2.5). Moreover, it is known that in many places nitrogen depositions in forests limit the mycorrhizal spectrum of forest trees, with the corresponding negative effects on nutrient uptake.

- *Biodiversity loss as a result of agricultural use (p. 36)*
- *Eutrophication and acidification of forest soils (p. 37)*

Contamination

Definition

Soil contamination refers to the local or dispersed deposition and infiltration of pollutants into soil. These substances are found on top of and within soil as a result of polluted air, rainfall and dust deposits, mineral fertilisers and manure, the re-use and illegal disposal of waste, and pesticides, etc. Furthermore, biological soil degradation can result from genetically modified, pathogenic or introduced non-native organisms (neobiota).

Effect

Some of the pollutants are retained in the soil, where they accumulate over decades. Via soil, pollutants also enter water, the air, or (through plants) the food chain. Pollutants in the soil can damage soil life and thus ecological soil functions.

Consequences for Switzerland

Contamination as a result of pollutant deposition is one of the priority threats to soil. There are no longer any soils in Switzerland that are completely free of pollution.

Contamination is addressed specifically in the following sections:

- *Pollution from agriculture (p. 34)*
- *Soil use in urban areas (p. 44)*

Acidification/eutrophication

Definition

Soil acidification is a process in which the concentration of protons in groundwater increases, causing cations (the nutrient cations potassium [K], calcium [Ca] and magnesium [Mg], and where pH < 4.5 increasingly also aluminium [Al] and manganese [Mn]) to mobilise and be washed out along with the retained anions sulphate (SO_4^{2-}) and nitrate (NO_3^-).

Soil acidification has a range of causes. For example, burning sulphurous fossil fuels such as coal or oil creates sulphur compounds. Nitrogen oxides (NO_x) are created by combustion processes (car engines) from the elemental nitrogen in the air, and ammonia (NH_3) is generated primarily by livestock farming.

However, there are also natural acidification processes, such as those in sediments that were not covered with fresh moraine material during the last ice ages. The great length of time that it takes for soils to develop, and the associated natural acidification processes, have resulted in very acidic soils, such as *Deckenschotter* (gravel coverage) on the Irchel plateau. Any evaluation of the extent of soil acidification must always consider and weigh its various causes.

Eutrophication refers to an oversupply of nutrients in soil or water.

Effect

Widespread, soil acidification can damage both soil organisms and plants. Acidification may also impair ecological soil functions because the soil's buffer capacity declines.

An oversupply of nitrogen results in vulnerable species being crowded out by nutrient-loving species and therefore in the depletion of the quality and diversity of the plant community. For example, in Switzerland 95% of forests, 100% of upland moors, 84% of lowland moors and 42% of dry grasslands and pastures suffer from excessive depositions of nitrogen from the air[62]. By contrast, cultivated plants and cropland are not affected by eutrophication from nitrogen depositions.

Consequences for Switzerland

Where eutrophication is concerned, nitrogen depositions are the main problem in Switzerland at present. Each year, an average of 23 kg/ha infiltrate the country's forests – representing five to ten times the natural level. Just under two thirds of these nitrogen depositions originate from agriculture, primarily in the form of ammonia (NH_3) from livestock farming. The remainder consists of nitrogen oxides (NO_x) from furnaces and car engines.

Acidification/eutrophication is addressed specifically in the following action area:

- *Eutrophication and acidification of forest soils (p. 37)*

62 Fischer M. et al. (2015): Zustand der Biodiversität in der Schweiz 2014 [Status of biodiversity in Switzerland 2014]. Pub.: Swiss Biodiversity Forum et al., Bern

Salinisation

Salinisation describes the accumulation of soluble salts in the soil. **Definition**

Essentially, salinisation is only a problem if the water balance for the year as a whole (including winter) is negative. Therefore, salinisation will normally be observed only under arid climatic conditions, or on the seashores of areas with humid climates. In Switzerland, fertilisation, irrigation or the use of road salt may lead to artificial salinisation in isolated cases. **Consequences for Switzerland**

Flooding

Where flooding occurs, normally dry soils will be entirely covered in water, usually as a result of waterbodies and watercourses breaking their banks. **Definition**

Water retention areas created specifically as flood defences, as well as the renaturalisation of waterbodies and watercourses are the chief land uses that result in flooding. They do, however, use the regulation function of soil, i. e. its storage effect. This is not impaired by the soil's use as a retention area, as long as there is no erosion. **Effect**

The extent to which soil and its functions are degraded by flooding depends on how long the water remains on the flooded area, as well as the nature and volume of material that is deposited on the soil by the flood. A protracted lack of oxygen as a result of flooding can cause significant harm to soil life.

Switzerland regularly experiences flooding. Large areas of the country may be affected by extreme weather events (please refer to the hazard map and the hazard index map). **Consequences for Switzerland**

A2 Glossary of key terms

Arable land

Arable land is defined as all soils and land area that can be used and farmed by the agricultural sector. According to the classifications applied in Switzerland's land use statistics (compiled by the Swiss Federal Statistical Office SFSO), they include meadow and cropland, pasture, fruit farms, vineyards, horticulture and land area usable for Alpine farming. Under agricultural law, a distinction is made between arable land and usable agricultural land area. The most valuable components of agricultural land area are what are known as crop rotation areas, i. e. the best crop-sustaining arable land. Arable land covers just over a third of Switzerland's entire land area – a total of around 1,500,000 hectares.

Building zone
The term "building zone" is governed by Art. 15 of the Spatial Planning Act (SPA). It is to be used for construction, and must meet anticipated needs for the following 15 years. Building zone regulations are binding on property owners.

Crop rotation areas
By definition, crop rotation areas encompass the highest-yielding agricultural soils in Switzerland. They comprise crop-sustaining arable land, primarily cropland, and temporary grassland in rotation, as well as crop-sustaining natural grasslands, and are secured by measures under spatial planning legislation (Art. 26 para. 1 Spatial Planning Ordinance (SPO)). Crop rotation areas form part of arable land and comprise approximately 444,000 hectares. The great majority of these areas are located on Switzerland's central plateau.

Degraded soils
"Anthropogenically degraded" soils are all those soils whose structure (sequence and thickness of layers) has undergone significant change as a result of construction – specifically as the result of the spreading of soils or excavated material removed from elsewhere. In contrast, soils whose structure has been changed by normal crop cultivation are not classified as anthropogenically degraded because ploughing only mixes the top layer (the A horizon) within itself.

Subsided organic soils are also considered "anthropogenically degraded", as are soils that are contaminated over and above the soil values laid down in the SoilPO, or whose subsoil is irreversibly compacted.

Ecosystem services
Differing definitions of the term "ecosystem services" can be found in some sections of the relevant literature. Some definitions equate ecosystem services with the benefit that people get from ecosystems. By contrast, more recent literature distinguishes between services, on the one hand, and their benefit, on the other. Ecosystem services are thus not a benefit in themselves, but they provide benefits. The "The Economics of Ecosystems and Biodiversity (TEEB)" research programme defines ecosystem services as the direct and indirect contributions of ecosystems to human well-being (see also C. Staub, W. Ott et al. (2011): *Indikatoren für Ökosystemleistungen* [Indicators for ecosystem services]. Federal Office for the Environment. Bern).

Land degradation neutrality
Land degradation neutrality is a state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remains stable or increases within specified temporal and spatial scales and ecosystems.[63]

63 Definition of the Inter-Agency and Expert Group on Sustainable Development Goal Indicators 2016.

No net soil loss
No net soil loss is the result where soil functions that are lost at one site as a result of construction are restored, i. e. offset, at another site by removed soil being spread. With the focus on soil functions, this indicator takes into account not simply the affected land area, but also the difference in quality between different soils.

Settlement area
The term "settlement area" is based on the remit of the cantons to determine settlement development in their cantonal structure plan (Art. 8*a* SPA). Settlement areas also form part of the content of the cantonal structure plan, which sets out the canton's target for the areas in which settlements should grow over the next 20 to 30 years. Unlike the building zone boundaries, which are clearly outlined, the borders that apply to settlement areas are shown only approximately.

Soil
Soil is the uppermost layer of the earth's crust, characterised by living organisms. Soil hosts an active exchange of substances and energy between the air, water and rocks. As part of the ecosystem, soil occupies a key position in local and global materials cycles.[64]

Soil consumption
Soil consumption in the narrower sense is understood to mean the destruction of soil by means of sealing or removing soil. With it, soil loses all of its ecological functions. *Soil consumption in the broader sense* describes the loss of soils in order to extend urban areas.

Soil fertility
The term "soil fertility" was introduced in the Environmental Protection Act (EPA) and subsequently set out in greater detail in the Soil Protection Ordinance (SoilPO). According to the latter, soil is deemed fertile if:

a. the active biotic community, soil structure and composition, and soil depth, are typical of its site, and its degradation capabilities have been unaffected;
b. natural plants and plant communities, and those that have been subject to human influence, are able to grow and develop unhindered with their characteristic properties intact;
c. plant products are of good quality and do not endanger the health of humans or animals;
d. Humans and animals who ingest soil directly are not at risk.

64 Definition of soil used by the Soil Science Society of Switzerland.

According to the commentary to the Environmental Protection Act,[65] the term "soil fertility" is based "on the ecological functions of soil".

Soil functions
Soil functions describe the *ability of soil to provide services for humans and the environment.* They are derived directly from the properties of soil and the processes that are ongoing within it. Soil functions therefore represent *a potential* that exists regardless of whether the services are actually used or not. This becomes clear using the example of groundwater. In total, much more groundwater in Swiss soils is purified to drinking water standard than drinking water is actually consumed.

The great majority of soils are multifunctional – in other words, their properties enable them to fulfil several functions at the same time. For example, the same soil may be a habitat for flora and fauna (the habitat function), may transform substances and store water (the regulating function) and thereby produce biomass (the production function). In its stratification, it also stores information about the site's cultural heritage and past climatic periods (the archive function). The degree to which the individual functions are fulfilled may vary from site to site.

The Soil Strategy distinguishes between "ecological" soil functions (habitat, production and regulating functions) and socio-economic soil functions (platform, raw materials and archive functions).

Soil improvement
In this document, "soil improvement" refers to all measures to improve the agricultural productivity of a soil, i. e. to boost its production function. In many cases, this will be achieved by taking soil that has been removed from elsewhere and spreading it across and/or working it into existing soils.

Soil protection, quantitative and qualitative
Quantitative soil protection aims to preserve open areas of land in the long term. It chiefly falls within the remit of spatial planning, which is responsible for the economical use of soil.

Qualitative soil protection is intended to preserve soil functions – and soil fertility – in the long term. This aim falls mainly within the sphere of influence of environmental protection, which implements measures to protect soil against chemical, physical or biological degradation.

The Soil Strategy calls for *quantitative and qualitative soil protections to be linked.* This will be achieved by adopting a nuanced view in spatial planning of

65 Tschannen, P. (1999): *Kommentar zum Umweltschutzgesetz; Erläuterungen zum Bodenschutz* [Commentary on the Environmental Protection Act. Notes on soil protection]. Pub.: *Vereinigung für Umweltrecht* (vur/ade/ada) and Helen Keller. Zurich 1999.

soil functions as an expression of soil quality. Here, soils which fulfil several functions to a high degree (multifunctional soils) are to be attributed a higher value, and protecting them against sealing thus made a greater priority, than soils which fulfil only a few functions.

Soil sealing
Soil sealing describes the man-made covering of soils by buildings, construction and layers of tarmac, concrete or similar materials, as well as any other coverage of soil using impermeable substances. Water and gas exchange are largely halted by sealing. As a result, these soils lose their function as a habitat for plants, soil animals and organisms, as well as their filter and absorption capacity. Biologically, they all but cease to be active.

Urban area
"Urban area" corresponds to the "settlement and urban area" classification found in the official land use statistics. It covers industrial and commercial complexes, building complexes, transport infrastructure, special urban areas, and recreation facilities and parks. The degree of soil sealing, consisting of the proportion of buildings and hardened surfaces within urban areas, was 61.8% in the most recent land use statistics survey (2004/09)[66]. Unsealed soils in urban areas fulfil valuable functions, especially with regard to biodiversity, water content and the local climate.

66 Swiss Federal Statistical Office, Swiss land use statistics. SFSO number: gr-d-02.02.04lulc001

Acronyms

ADWO
Waste Ordinance of 4 December 2015 (SR 814.600)

AgricA
Agriculture Act of 29 April 1998 (SR 910.1)

ARE
Federal Office for Spatial Development

CCG
Conference of Cantonal Governments

ChemO
Chemicals Ordinance of 5 June 2015 (SR 813.11)

DPO
Direct Payments Ordinance of 23 October 2013 (SR 910.13)

DPPE
Swiss Conference of Directors of Public Works, Planning and Environmental Protection

EAER
Federal Department of Economic Affairs, Education and Research

EIA
Environmental Impact Assessment

EIONET
European Environment Information and Observation Network

EPA
Environmental Protection Act of 7 October 1983 (SR 814.01)

FADO
EAER Ordinance on the Production and Marketing of Feedstuffs, Feed Additives and Dietary Feed of 26 October 2011 (SR 916.307.1)

FAO
Food and Agriculture Organization of the United Nations

FCHA
Federal Commission for Air Hygiene

FEDRO
Swiss Federal Roads Authority

FeedO
Ordinance on the Production and Marketing of Feedstuffs of 26 October 2011 (SR 916.307)

FertBO
EAER Fertiliser Book Ordinance of 16 November 2007 (SR 916.171.1)

FertO
Fertiliser Ordinance of 10 January 2001 (SR 916.171)

FOAG
Federal Office for Agriculture

FOEN
Federal Office for the Environment

IASS
Institute for Advanced Sustainability Studies in Potsdam

NABODAT
Switzerland's National Soil Information System

NCCR
National Centre of Competence in Research

NCHA
Nature and Cultural Heritage Act of 1 July 1966 (SR 451)

OAPC
Air Pollution Control Ordinance of 16 December 1985 (SR 814.318.142.1)

OcCC
Advisory Body on Climate Change

ORRChem
Chemical Risk Reduction Ordinance of 18 May 2005 (SR 814.81)

PEP
Proof of Ecological Performance

PlantPPO
Plant Protection Products Ordinance of 12 May 2010 (SR 916.161)

SIO
Structural Improvements Ordinance of 7 December 1998 (SR 913.1)

SGV
Association of Swiss Communes

SoilPO
Soil Pollution Ordinance of 1 July 1998 (SR 814.12)

SPA
Spatial Planning Act of 22 June 1979 (SR 700)

SPO
Spatial Planning Ordinance of 28 June 2000 (SR 700.1)

SSV
Swiss Cities Association

swisstopo
Federal Office of Topography

TOW
Technical Ordinance on Waste of 10 December 1990 (SR 814.600)

UNCCD
United Nations Convention to Combat Desertification

WPO
Waters Protection Ordinance of 28 October 1998 (SR 814.201)

WSL
Swiss Federal Institute for Forest, Snow and Landscape Research

References

Alewell, C., Egli, M., Meusburger K. (2014): An attempt to estimate tolerable soil erosion rates by matching soil formation with denudation in Alpine grasslands. Journal of Soils and Sediments: Volume 15, Issue 6 (2015).

Arwyn J. et al. (2012): The state of soil in Europe. A contribution of the JRC to the European Environment Agency's Environment State and Outlook Report. SOER 2010. EU 2012.

Bachmann A. (2018): *Ethische Bewertung der Bodenfunktionen* [An ethical evaluation of soil functions]. Internal Comité d'Ethique paper. FOEN 2014.

Bircher P., Liniger H.P., Prasuhn V. (2019): *Aktualisierung und Optimierung der Erosionsrisikokarte (ERK2). Die neue ERK2 (2019) für das Ackerland der Schweiz. Schlussbericht 2019* [Update and optimisation of the erosion risk map (ERK2). The new ERK2 (2019) for cropland in Switzerland. Final report 2019].

Candinas T. et al. (2002): *Ein Bodenkonzept für die Landwirtschaft in der Schweiz. Grundlagen für die Beurteilung der nachhaltigen landwirtschaftlichen Bodennutzung* [A soil concept for agriculture in Switzerland. Basis for the evaluation of sustainable agricultural soil use]. *Bodenschutz* 3/02: p. 90-98.

CH2011 (2011): Swiss Climate Change Scenarios CH2011. Published by C2SM, MeteoSwiss, ETH, NCCR Climate, and OcCC. Zurich, Switzerland. 88 pp. ISBN: 978-3-033-03065-7

Federal Office for Spatial Development ARE (2019): *Monitoring Bauen ausserhalb Bauzonen – Standbericht 2019 des ARE: Vergleich Entwicklung 1992/97 mit 2004/09 und 2013/18 (Arealstatistik BFS)* [Monitoring construction outside building zones – 2019 status report from the ARE: comparison of developments in 1992/97 with 2004/09 and 2013/18 (SFSO land use statistics)], p. 12

Fischer M. et al. (2015): *Zustand der Biodiversität in der Schweiz 2014* [Status of biodiversity in Switzerland 2014]. Pub.: Swiss Biodiversity Forum. Bern.

FOEN (2017): *Boden in der Schweiz. Zustand und Entwicklung. Stand 2017* [Soil in Switzerland: status and developments as at 2017]. URL: *www.bafu.admin.ch/bafu/en/home/topics/soil/publications-studies/publications/boden-schweiz.html*

FOEN and FOAG (2013): *Bodenschutz in der Landwirtschaft. Ein Modul der Vollzugshilfe Umweltschutz in der Landwirtschaft.* [Soil protection in agriculture. A module of the guidance on environmental protection in agriculture.] Federal Office for the Environment. Bern. *Umwelt-Vollzug* no. 1313, 59 pp.

Forum für Wissen (2013): Bodenschutz im Wald – Ziele – Konflikte – Umsetzung [Soil protection in forests – objectives – conflicts – implementation]. WSL reports. p. 23-28, ISSN 2296-3448. URL: *www.wsl.ch/dienstleistungen/publikationen/pdf/13083.pdf* (German).

Fry P., Liechti K. (2009): *Wiederverwendung von abgetragenem, sauberem Boden in der Landwirtschaft. Erarbeitung der Grundlagen für die Entwicklung eines akteurorientierten Lösungsansatzes. Abschlussbericht* [Re-use of removed, clean soil in agriculture. Draft principles for developing a stakeholder-based approach. Final report].

Gubler A., Schwab P., Wächter D., Meuli R. G., Keller A. (2015): *Ergebnisse der Nationalen Bodenbeobachtung (NABO) 1985 – 2009. Zustand und Veränderungen der anorganischen Schadstoffe und Bodenbegleitparameter*

[Findings of the NABO National Soil Monitoring Network 1985 – 2009. Status and changes in inorganic pollutants and soil monitoring parameters]. Federal Office for the Environment. Bern. *Umwelt-Zustand* no. 1507: 81 pp

Hagedorn, A., Krause, H-M., Studer, M., Schellenberger, A., Gattinger, A. (2018): *Thematische Synthese TS2 des Nationalen Forschungsprogramms "Nachhaltige Nutzung der Ressouce Boden" (NFP 68)* [Thematic synthesis TS2 of the "Sustainable Use of Soil as a Resource" National Research Programme (NRP 68)]. Bern.

Keller A., Franzen J., Knüsel P., Papritz A., Zürrer M. (2018): *Bodeninformations-Plattform Schweiz (BIP-CH). Thematische Synthese TS4 des Nationalen Forschungsprogramms "Nachhaltige Nutzung der Ressouce Boden" (NFP 68)* [Swiss soil information platform (BIP-CH). Thematic synthesis TS4 of the "Sustainable Use of Soil as a Resource" National Research Programme (NRP 68)]. Bern.

Krebs, R. et al. (2011) : *Jahresbericht des Amts für Wasser und Abfall des Kantons Bern 2011* [Annual report of the Canton of Bern Office for Water and Waste 2011)

Leifeld, J., Reiser, R., Oberholzer, H., (2009): Consequences of Conventional versus Organic Farming on Soil Carbon: Results from a 27-Year Field Experiment. Agronomy Journal, Volume 101, Issue 5.

Lüscher P., Frutig F., Thees O. (2016): *Physikalischer Bodenschutz im Wald. Waldbewirtschaftung im Spannungsfeld zwischen Wirtschaftlichkeit und Erhaltung der physikalischen Bodeneigenschaften* [Physical soil protection in forests. Forest management as a balancing act between economy and the preservation of physical soil properties]. Federal Office for the Environment, Bern. *Umwelt-Wissen* no. 1607. 159 pp

Maître V. (2014) : *Canton de Vaud. Indicateurs de développement durable. Matière organique et activité biologique dans les sols agricoles* [Canton of Vaud. Sustainable development indicators. Organic matter and bioactivity in agricultural soils].

Oberholzer, H., Leifeld, J., Mayer, J. (2014): Changes in soil carbon and crop yield over 60 years in the Zurich Organic Fertilization Experiment, following land-use change from grassland to cropland. Journal of Plant Nutrition and Soil Science 177 (5).

Ponge J.-F. et al. (2013): The impact of agricultural practices on soil biota. A regional study. Soil Biology & Biochemistry 67, p. 271–284.

Postma-Blaauw M. B. et al. (2010): Soil biota community structure and abundance under agricultural intensification and extensification. Ecology 91.

Rehbein K., Sprecher Ch., Keller A. (2019): *Übersicht Stand Bodenkartierung in der Schweiz. Ergänzung des Bodenkartierkataloges Schweiz um Bodeninformationen aus Meliorationsprojekten, Bericht der Servicestelle NABODAT 2019* [Overview of the status of soil mapping in Switzerland. Addition to the Swiss soil map catalogue of information from soil improvement projects, report by the NABODAT National Soil Information System office] URL: *www.are.admin.ch/dam/are/de/dokumente/raumplanung/dokumente/bericht/ubersicht-stand-bodenkartierung.pdf.download.pdf/ubersicht-stand-bodenkartierung.pdf*

Rihm B., Künzle T. (2019): Mapping Nitrogen Deposition 2015 for Switzerland, Technical Report on the Update of Critical Loads and Exceedance, including the years 1990, 2000, 2005 and 2010. Report commissioned by the Federal Office for the Environment FOEN.

Schils R. et al. (2008): Review of existing information on the interrelations between soil and climate change; Climsoil Technical Report 2008. Final report 16 December 2008.

Schmidt, S., Alewell, C., Meusburger, K. (2018): Mapping Spatio-Temporal Dynamics of the Cover and Management Factor (C-Factor) for Grasslands in Switzerland. Remote Sensing of Environment 211, p. 89-104.

Steffen W. et al. (2015): Planetary boundaries: Guiding human development on a changing planet. Science 13 February 2015, Vol 347, Issue 6223.

Steiger U., Knüsel P., Rey L. (2018): *Die Ressource Boden nachhaltig nutzen. Gesamtsynthese des Nationalen Forschungsprogramms "Nachhaltige Nutzung der Ressource Boden" (NRP 68)* [The sustainable use of soil as a resource. Overall synthesis of the National Research Programme "Sustainable Use of Soil as a Resource" (NRP 68)]. Pub.: NRP 68 Steering Committee. Bern.

Swiss Agency for the Environment, Forests and Landscape SAEFL (2005): *Stickstoffhaltige Luftschadstoffe in der Schweiz. Status-Bericht der Eidg. Kommission für Lufthygiene (EKL)* [Nitrogenous air pollutants in Switzerland. Status report of the Federal Commission for Air Hygiene (FCAH)]. *Umwelt* publication series, no. 384.

Swiss Federal Council, CCG, DPPE, SSV, ASC (2012): *Raumkonzept Schweiz* [Spatial Strategy for Switzerland]. Revised version, Bern.

Swiss Federal Statistical Office SFSO (2013): Land use in Switzerland. Results of the Swiss land use statistics. Neuchâtel. 24 pp

Swiss Federal Statistical Office, Swiss land use statistics. SFSO number: gr-d-02.02.04lulc001

Tobias, S. (2012): *Brainstorming Zukunft Bodeninformation Schweiz, Projektabschlussbericht* [Brainstorming on the future of soil data in Switzerland. Concluding project report], WSL, Swiss Soil Science Society.

Tschannen, P. (1999): *Kommentar zum Umweltschutzgesetz. Erläuterungen zum Bodenschutz.* [Commentary on the Environmental Protection Act. Notes on soil protection] Pub.: Vereinigung für Umweltrecht (vur/ade/ada) and Helen Keller. Zurich 1999.

Tsiafouli M. A. et al. (2015): Intensive agriculture reduces soil biodiversity across Europe. Global Change Biology 21 (2), p. 973–985.