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The Swiss agri-environmental data network (SAEDN): Description and critical review of the dataset

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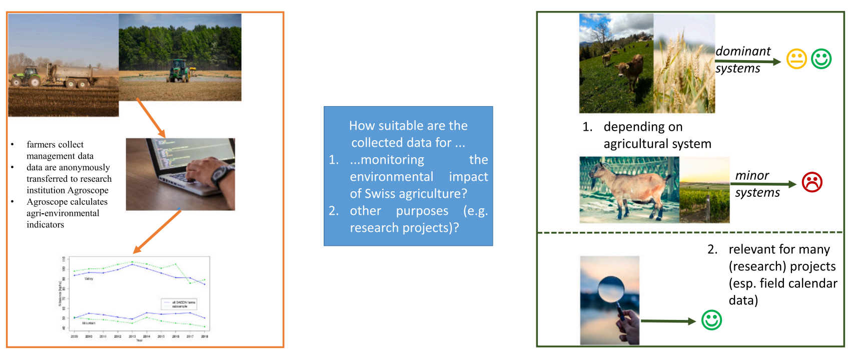
HIGHLIGHTS

- The Swiss agri-environmental data network (SAEDN) is presented in this paper.
- The suitability of the sampled data for agri-environmental monitoring and research projects is assessed.
- The farms participating in the SAEDN represent only the dominant agro-ecosystems of Switzerland reasonably well.
- The usefulness of the data for monitoring purposes is limited due to a rather small and time-varying sample.
- The data offers valuable insights into Swiss land use and farm management practices.

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: The Swiss agri-environmental data network (SAEDN) encompasses farm management data, which are collected and processed annually to calculate indicators such as greenhouse gas emissions, potential biodiversity impact, or erosion risk. These indicators are yearly published in the framework of an agri-environmental monitoring programme and serve as decision support for policy makers and other stakeholders. Furthermore, the collected data are frequently used for research projects.
OBJECTIVE: This paper compares the SAEDN farms with the whole of Switzerland. It addresses the question of how appropriate the data collected are for monitoring purposes as well as research projects.
METHODS: The data collection procedure of the SAEDN is described in detail, including automated tests that improve the data quality. Furthermore, key figures of the SAEDN farms are analysed and compared with the whole of Switzerland in order to assess the significance of the farm network.
RESULTS AND CONCLUSIONS: The time-consuming data collection has resulted in a relatively small, non-random sample of Swiss farms (approx. 300 farms per year). The farms participating in the SAEDN represent the dominant agroecosystems of Switzerland reasonably well, while certain crop specialisations (viticulture and field vegetable production) and small ruminant husbandry are only marginally represented. The latter can partially be explained by an underrepresentation of farms located in southern Switzerland and in the mountains.

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Another problem is the continuously changing composition of the farm network. Thus, robust time series cannot be produced for all desired farm classifications (e.g. special crops).
SIGNIFICANCE: The collected data offer valuable insights into Swiss land use and farm management practices. To our knowledge, the presented dataset is the most comprehensive source of agronomic data in Switzerland covering many aspects such as complete crop rotations, field-specific fertilisation, and plant protection product use. The data thus provide an important basis for research projects, decisions in the political and legal context, and the development of a future monitoring system.

1. Introduction

Current agricultural practices can cause environmental problems such as soil degradation, biodiversity loss, and global warming, which will impede agricultural production in the future (FAO, 2017; IPCC, 2019). In order to meet the increasing food demand, humanity therefore faces the challenge to improve agricultural production sustainably (FAO, 2017; Calicioglu et al., 2019).

According to the Federal Constitution, Swiss agriculture should make a significant contribution to the safe supply of food and simultaneously to the preservation of natural resources. This is a challenging task considering that the Swiss population has increased from 3.3 million to 8.6 million people between 1900 and 2019 (FSO, 2020a). At present, Switzerland's degree of self-sufficiency is approximately 60% (FOAG, 2020), while none of the environmental goals defined for the agricultural sector have been fully achieved (FOEN and FOAG, 2008; FOEN and FOAG, 2016).

The agri-environmental monitoring (AEM) programme was initiated by the Federal Office for Agriculture (FOAG) of Switzerland to assess the impact of agricultural policies on the environment over time. According to the "Ordinance concerning the Assessment of the Sustainability of Agriculture" (SR 919.118), quantitative as well as qualitative effects of agricultural policy should be assessed based on national, regional, and farm-level agri-environmental indicators (AEIs). Since one aim of the AEIs is to support international reporting, they should comply with international standards (e.g. OECD, Organisation for Economic Cooperation and Development).

The OECD defined several national AEIs such as greenhouse gas emissions, ammonia emissions, nutrient balances, or sales of plant protection products (OECD, 2019; OECD, 2021). European member states including Switzerland are encouraged to provide these AEIs to the OECD via Eurostat. The OECD AEIs allow the assessment of agri-environmental trends on an international level and comparison between countries. However, data use of real agricultural practices is limited in the calculation of these AEIs. As an example, information about applications of plant protection products is currently not considered as OECD indicator because such data is rarely available in most countries. Yet, knowledge of specific agricultural practices is crucial to estimate the environmental impact of agriculture. For example, the amount of plant protection products entering water bodies is determined, among others, by the location, timing, dosage, and technique of their applications (de Baan, 2020).

The lack of management data can be remedied by a farm-level monitoring: Since 2009, the Swiss Agri-Environmental Data Network (SAEDN) has collected management data and calculated several AEIs on farm or crop level. Historically, the SAEDN was initiated to supplement the national OECD AEIs at regional and farm type level. However, the SAEDN also includes AEIs for which no national equivalent exists, in particular for soil (Supplementary Fig. S1). The SAEDN was developed as an ecological counterpart to the Swiss Farm Accountancy Data Network (Swiss FADN; Renner et al., 2019), which has a strong focus on production and economic indicators. Originally, all SAEDN farms also supplied data to the Swiss FADN. However, the two data networks have diverged over time due to the excessive data requirements per farm. Therefore, nowadays only half of the SAEDN farms also provide data to the FADN.

The SAEDN covers a wide range of AEIs falling in the following thematic classes (Supplementary Fig. S1): i) nitrogen, ii) phosphor, iii) energy and climate, iv) water, v) soil, and vi) biodiversity. SAEDN's AEIs focus on the 'drivers' (e.g. N balance) and 'pressures' (e.g. ammonia emissions) components within the Driver-Pressure-State-Impact-Response framework (EEA, 1999; EEA, 2005), i.e. they are located at the beginning of the impact chain (e.g. human activities, emissions). This means that the SAEDN does not measure the state of the environment (e.g. greenhouse gas concentrations in the atmosphere) but that farm management activities and their potential environmental impacts are monitored (e.g. with model based calculations of greenhouse gas emissions). More on the DPSIR framework and the distinction of the SAEDN from other Swiss monitoring systems can be found in Supplementary Section 1. Furthermore, we compare the SAEDN with analogous data collection systems from selected other countries in Supplementary Section 2.

In this study, we will focus on the (raw) data collected in the farm network (e.g. fertiliser applications), the data collection system, and the farm sample. The aim of this paper is to present the strengths and weaknesses of the collected data, both for agri-environmental monitoring and for research purposes. Specifically, we will address the following research questions: 1. How does the SAEDN farm sample compare with Switzerland? (e.g. wheat area, valley farms, organic farms) 2. For which regions, crops, and animal species can the SAEDN sample provide meaningful results? 3. How suitable are the collected data for agri-environmental monitoring? 4. What is the potential use of the data for research projects? 5. What does the future of the AEM hold? However, we will *not* discuss the calculations and evaluations of the AEIs themselves; that will be covered in an upcoming publication.

In Section 2, we describe the collected data, the data flow, and data quality improvements. Information about how we compare our farm sample with Swiss national farm statistics and how we derive the error margins of the sampled data for different subsamples (e.g. different crop types) can be found in Supplementary Sections 7 and 8. In Section 3, we address each of the five research questions with its own subsection, before we summarise the findings in Section 4.

2. Material and methods

In the following, we describe the SAEDN's data collection system. More technical insights regarding data storage and processing can be found in Supplementary Section 5.

The SAEDN is a complex network, which involves a wide range of actors (Supplementary Table S2): around 300 farms, various agricultural trusteeships,[1] the Swiss agricultural extension centre Agridea, the Swiss centre of excellence for agricultural research Agroscope, and the FOAG. Farmers record their data with a software tool developed by Agridea and transmit them via trustees[2] to Agroscope (Fig. 1), where the AEIs are calculated and aggregated by region and farm type. The AEIs are finally published by the FOAG in the annual agricultural report. The (raw) data,

[1] Agricultural trustees support farmers in the field of trusteeship, taxation, and consultancy. Delivery via trusteeships has its origins in the initial joint delivery of environmental and accounting data.

[2] Since 2016, Agridea can also recruit SAEDN farms and transmit their data to Agroscope.

however, are not publicly available.

In the following, we first describe the collected data before we present the chronological sequence of data collection and the procedures for data quality control.

2.1. Sampled data

In Switzerland, data for cross-compliance (legal requirements for direct payments by the government; FOAG, 2021) are in most cases not collected centrally and are thus not available for monitoring purposes. For example, although farmers are obliged to keep a field calendar, in most cases they still make the records on paper (FSO, 2020b). To be able to use important management data for monitoring, these must be available in a digital and standardised form. Therefore, farmers record SAEDN data in the software tool AGRO-TECH (Agridea, 2000).

Not all data originally requested by Agroscope researchers could be collected due to time constraints of farmers. For this reason, it was decided that a large part of the collected data should also generate a benefit for the farmers beyond the participation in the SAEDN, for example for fertiliser planning or for collecting and processing the information needed for cross-compliance.

Although not all environmentally-relevant data can be collected (e.g. detailed data on stable systems), a large amount of data is nevertheless recorded. Hundreds of data entries are made per farmer, and often several pieces of information are needed per entry (e.g. date of the measure, type of the measure, product used, etc.). Most data are entered in the field register and calendar (including detailed information about measures on the field) as well as in the animal register (especially veterinary treatments). Supplementary Section 4 provides an overview of the sampled data.

The owner of the data collected is the Confederation, represented by Agroscope and the FOAG, who may use the data for research and publications. The results have to be published in a way that persons and farms cannot be identified and conclusions cannot be drawn about the behaviour of individual farms. Since Agroscope receives the data anonymously via the trustees, this is guaranteed in most cases anyway. Due to the anonymity clause, the data is not georeferenced. Data from the SAEDN may be passed on to Swiss universities and their research institutes for study and research purposes as well as to third parties that act on behalf of the Confederation.

2.2. From data collection to analysis

In the following, we describe the data collection and evaluation process divided into the three consecutive steps "data collection", "AEI calculation", and "publication" (Fig. 1).

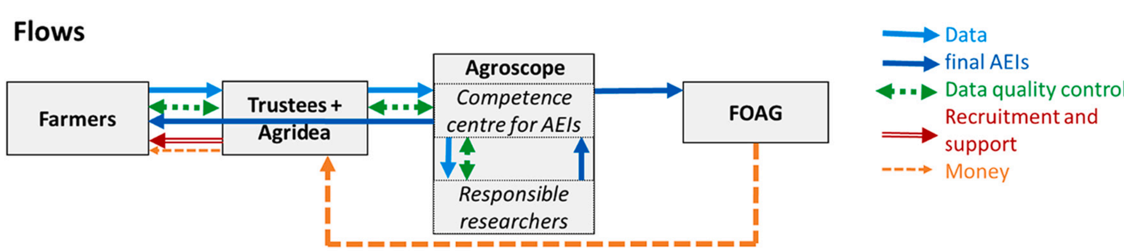
2.2.1. Phase 1

The farmers, recruited by the trustees, enter the data for the year *t* in AGRO-TECH. They are supported by the trustees in case they require assistance. The data collection process varies from farm to farm: sometimes paper records are transferred to the computer, sometimes the records are made with a mobile application. Once the data have been finalised, they are transferred to the corresponding trustees. The trustees make a first quality check and can request a correction if data seem incomplete or erroneous. Subsequently, the trustees transfer the data to the competence centre for AEIs at Agroscope.

The competence centre for AEIs conducts the second stage of data quality control. Automated tests (called plausibility tests in the following) detect potential errors that were not recognised by the trustees (see Section 2.3 for details). The results of these plausibility tests are automatically sent by e-mail to the trustees, who re-check and process the data again if necessary. In the event of ambiguities, the trustees contact the competence centre for AEIs for clarification. The official deadline for the final delivery of data from year *t* is end of August $t + 1$.

2.2.2. Phase 2

After data delivery, the competence centre for AEIs calculates the compensation payments for each farm, which depends on the number and completeness of entered measures. These payments compensate farmers for the additional effort involved in data collection. They are *not* related to direct payments or the environmental performance of the farms, as the SAEDN should not steer the farmers' actions. The minimum and the maximum payments per farm are fixed at CHF 500 and CHF



Time line

Phase 1: Data collection ***Jan t to Aug t+1***	**Phase 2: AEI calculation** ***Sep t+1 to Aug t+2***	**Phase 3: Publication** ***Sep t+2 to Nov t+2***
Farmers collect data for year *t* and send them to trustees	Competence centre for AEIs calculates financial compensations for every farm, which is paid by FOAG to trustees	Competence centre for AEIs sends the final AEIs to FOAG
Trustees check data quality and forward data to competence centre for AEIs	Competence centre for AEIs and responsible researchers calculate the AEIs	FOAG published the AEIs in the agricultural report
Competence centre for AEIs controls data quality further; correction of data by trustees or (via trustees) by farmers	Responsible researchers check the AEIs for plausibility	Competence centre for AEIs compiles an individual compilation for each farm, which is distributed by trustees to farmers

Fig. 1. Flow chart and time frame of data to calculate the AEIs for year t. Since 2016, Agridea has also taken on the role of a trustee agency. AEIs = Agri-environmental indicators, FOAG = Federal office of agriculture.

1800, respectively; the average compensation per farm accounts to approximately CHF 1200. For reasons of anonymity, the FOAG pays each trustee the sum of compensations for all the farms delivered. It is left to the trustees and the farmers to divide the compensations between themselves. Together with other expenses for the SAEDN (Supplementary Table S2), the FOAG thus incurs annual costs of CHF 400,000 to 500,000. Labour costs of Agroscope and FOAG are not included in this number.

During the following months, the AEIs are calculated. Depending on the AEI, the responsible researchers further improve the data quality before the calculation, e.g. in the area of plant protection products where a certain expert knowledge is required.

2.2.3. Phase 3

The AEIs are aggregated in the form of descriptive statistics (mean, median, and standard deviation), which are calculated over all 300 farms, different agricultural zones (valley, hill, mountain), different farm types (special crops, arable farming, livestock farming, mixed systems), and different crops (for AEIs related to plant protection products). The aggregated AEIs are published by the FOAG as part of the annual agriculture report (November $t + 2$; e.g. FOAG, 2019) in the form of both an interactive web application and an Excel file.

Many of the participating farmers are interested in their indicator values. Therefore, since 2017, farmers have received their calculated AEIs ("individual compilation") annually as an incentive for participating in the network. The individual compilation allows the farmers to compare their AEIs to the AEIs of other farms of the same type.

2.3. Quality check of data

The huge amount and the high complexity of the data do not allow to thoroughly check each entry manually in a reasonable time. Tens of thousands of measures are entered into the field calendar alone every year. Therefore, the competence centre for AEIs started programming plausibility tests in 2014 to detect missing and/or suspicious data. For example, the tests detect imbalances in the produced and applied manure amount or missing information in field calendar measures (see also Supplementary Section 6). To show the effect of these tests on data quality, we run all plausibility tests over the final data for 2009 (initial year of data delivery), 2013 (last year before introduction of first plausibility tests), and 2018 (year after the implementation of all plausibility tests). The comparison between the years 2013 and 2009 allows to quantify the gain in data quality that was achieved *without* the plausibility tests, i.e. through communication between the different actors. The comparison between the years 2018 and 2013 shows the improvement in data quality that we attribute to the plausibility tests alone. We quantify data quality by using the "error rate", which we define as the percentage of farms that have at least one suspicious or missing data entry for each specific plausibility test.

Some data issues could be significantly reduced without plausibility tests (i.e. compare years 2009 and 2013 in Fig. 2), including missing information about the altitude and slope of fields, missing product amount (e.g. products for seeds or fertilisers), and incomplete pasture entries. The introduction of the plausibility tests further improved the data quality of these entries (i.e. compare years 2013 and 2018 in Fig. 2). Moreover, many error rates were *only* reduced by the introduction of the plausibility tests, e.g. missing preceding crops and harvest dates, too generic data entries, and manure imbalances. Thus, the plausibility tests considerably improved the data quality.

For data entries about slurry dilution and product amount, the error rate remains relatively high in 2018 despite the introduction of the plausibility tests. This can be explained by the conservative thresholds set in the plausibility tests. As an example, the plausibility test produces an error/warning when the slurry dilution exceeds a ratio of 5:1 (water to slurry). However, higher dilutions can sometimes occur in practice. In such a case, the trustees/farmers confirm the high dilution rate and the data entry is accepted manually. The plausibility tests for which rectifications by the farmers are possible are marked in Supplementary Table S3.

Although data quality has improved in recent years, the plausibility tests obviously do not detect all data errors. Furthermore, the data are still self-declared and cannot be completely verified. For example, we cannot detect missing entries of fertiliser applications because it is difficult to assign a lower limit for the amount of fertiliser applied – a farmer can indeed not fertilise certain fields, depending on the crop type and the situation. Another example is that farmers import data from the previous year (e.g. data on certain biodiversity promotion areas, such as the number of large fruit trees) and sometimes forget to enter possible changes. Such data are plausible in many cases and errors are therefore often noticed rather by coincidence.

3. Results and discussion

3.1. Comparison of SAEDN sample with Swiss farm statistics

Recruitment of farms for the SAEDN has always been challenging, partly due to the time-consuming data collection. As a consequence, the SAEDN farms recruited by the trustees are *not* randomly selected. It is therefore important to compare the SAEDN sample with national scale Swiss farm statistics (described in Supplementary Section 7) to assess the validity of the collected data and the calculated AEIs. In this section, we therefore show how key features of the SAEDN farms compare to the rest of Switzerland before we draw conclusions about their representativeness in Section 3.2. A more detailed comparison and explanations for the observed patterns can be found in Supplementary Section 9.

The annually averaged number of farms that participate in the SAEDN varies between the Swiss cantons (Fig. 3), with participation rates between 0.25% and 1% of all farms for most cantons. It is striking that in Southern Switzerland, only a very small proportion of farms participate in the SAEDN (GE = 0.07%, VS = 0.02%, TI = 0.04%, GR = 0.24%). Furthermore, a relatively small number of farms from the mountain region participate in the SAEDN (Supplementary Fig. S5).

In terms of utilised agricultural area (UAA), large farms are over-represented[3] whereas small farms are under-represented compared to the national distribution (Supplementary Fig. S6).

On average over the whole period, the SAEDN farms cover between 0.31% and 1.46% of the total Swiss crop areas, depending on the crop type (Supplementary Table S4). In the SAEDN data, the share of grassland is lower and that of arable crops is higher compared to the whole of Switzerland: While 59% and 31% of the Swiss UAA are covered by permanent grassland and the five most important arable crops (ley,[4] wheat, maize, barley, rapeseed), respectively, the SAEDN contributions to the UAA amount to 48% and 40%. Vine and field vegetables are less well represented in the SAEDN, with 1.2% and 1.1% for Switzerland and only 0.5% and 0.7% for the SAEDN, respectively.

In terms of animals (given in livestock unit = LU), SAEDN farms include between 0.16% and 1.18% of Swiss animals, depending on the animal category (Supplementary Table S5). Cattle account by far for the largest share of total livestock, for both Switzerland (72.4%) and the SAEDN (79.4%). Next in importance are pigs and commercial poultry with 15.2% and 5.0% for Switzerland and 10.1% and 8.3% for the SAEDN, respectively. Small ruminants still represent 3.1% (sheep) and 0.9% (goats) of Swiss livestock, while their shares for the SAEDN are significantly smaller at 0.7% and 0.4%.

[3] With the term «under-representation» («over-representation»), we mean lower (higher) values compared to the average of all SAEDN farms. If, for example, 0.52% of all Swiss farms participate in SAEDN, but only 0.36% of all Swiss mountain farms, we say that mountain farms are under-represented.

[4] A ley is an area sown as a meadow that is cultivated within a crop rotation for at least one growing season.

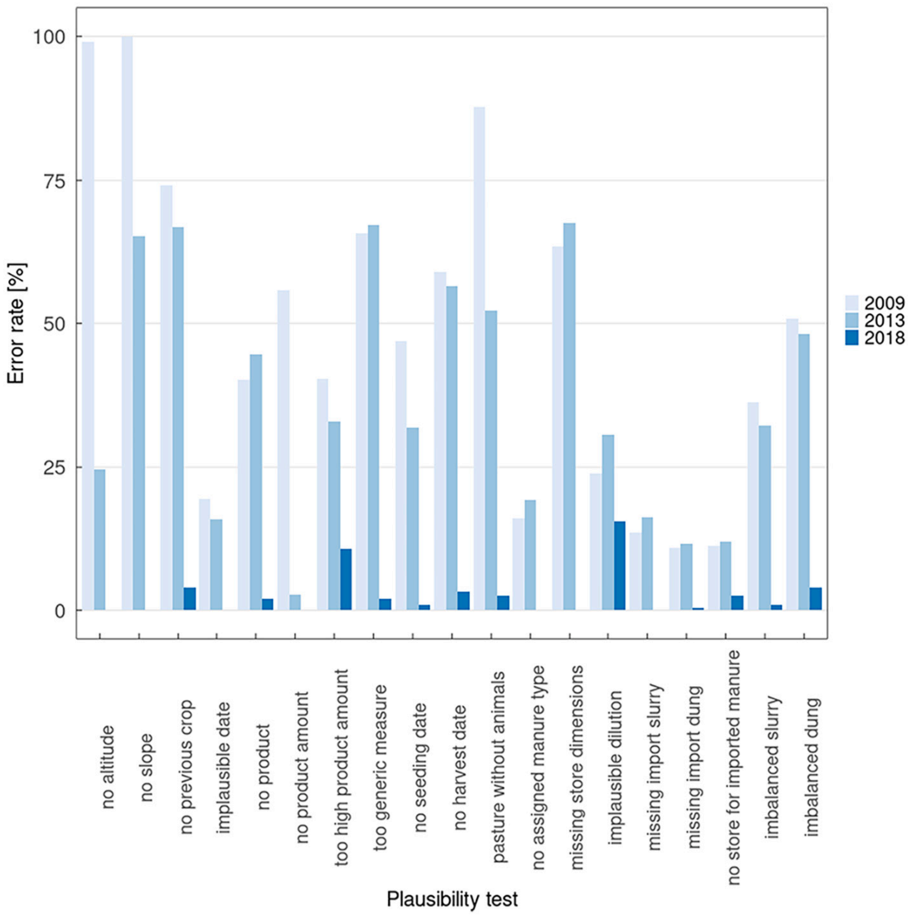


Fig. 2. Percentage of farms showing suspicious/missing data for the years 2009, 2013, and 2018. The meaning of the different entries is explained in Supplementary Table S3. Only plausibility tests with a large effect, i.e. with >10% of farms delivering erroneous data in 2009, are shown.

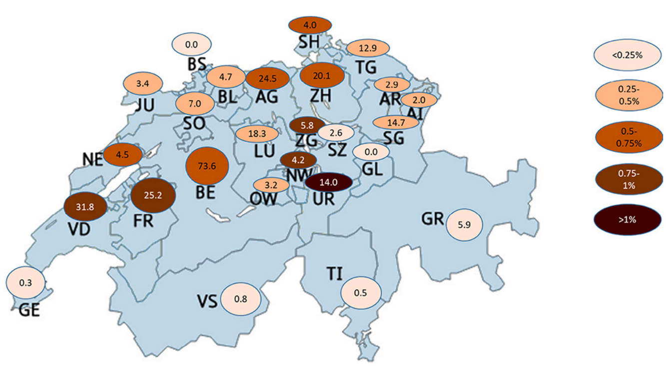


Fig. 3. The number and percentage (colour) of farms participating in the SAEDN per canton of Switzerland. Shown is the average over the years 2009 to 2018.

72% of the Swiss farms keep cattle and this proportion is with 89% in the SAEDN even higher (Supplementary Fig. S7). Similarly, more SAEDN farms keep pigs when compared to the overall number of farms in Switzerland (CH: 15%; SAEDN: 22%). An opposite picture is shown for other animal categories, for which the proportions for Switzerland are larger than the proportions for the SAEDN, especially for sheep (CH: 16%; SAEDN: 9%).

The distributions of animal densities (in LU per UAA) look similar for Switzerland and the SAEDN farms (Fig. 4a). Among the SAEDN farms, the proportion of farms with little or no open arable land[5] (<20%) is considerably lower compared to Switzerland as a whole (Fig. 4b). The proportion of organic farms is very similar for Switzerland and the SAEDN, with 10.7% and 11.3%, respectively.

3.2. *Informative value of the SAEDN sample*

We have so far analysed how the SAEDN sample compares with the whole of Switzerland. In the following, we will determine how meaningful the sample is for certain environmentally relevant aspects by calculating margins of error (Supplementary Material, Section 8). The lower the error margin, the higher the informative value for the environmentally relevant aspect. We make however no statement about the sample size necessary to identify a significant trend for each AEI because this would go beyond the scope of this paper.

We limit our analysis to the environmentally relevant aspects of crop type, animal category, and region since these can be determined for the whole of Switzerland, are central for extrapolations to the national level, and strongly influence the AEIs. For example, the AEIs for plant protection product use, erosion risk, or biodiversity depend very strongly on the crop type. In addition, we show results for the Swiss national scale.

The SAEDN sample is associated with a margin of error of <5% for the populations "Switzerland" and "Farms possessing permanent grassland" (Table 1). Margins of error between 5 and 10% are achieved for the regions valley and hill, the main arable crops (including ley), and the

[5] Open arable land = arable land minus ley

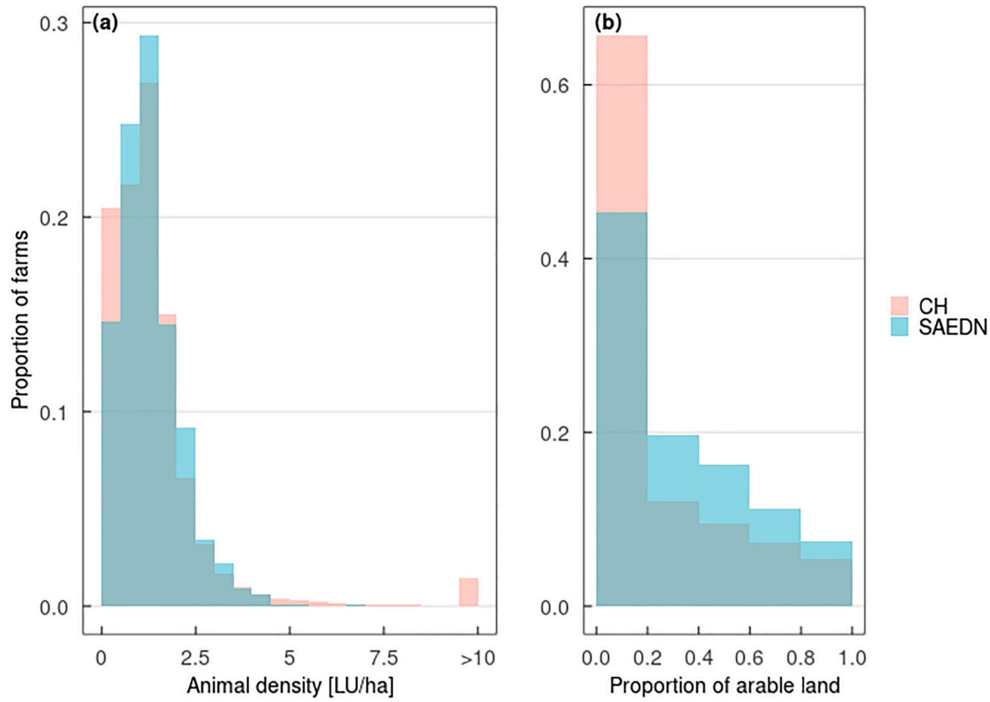


Fig. 4. (a) Animals densities in livestock unit per ha for all Swiss farms and the SAEDN farms. (b) Proportion of (open) arable land per farm for all Swiss farms and the SAEDN farms. All farms of the years 2009 to 2018 are included (except for Swiss farms having no utilised agricultural area in b). Note that the y-axes have different scales.

Table 1
Margins of error for the SAEDN sample. The lower the margin of error, the higher the informative value for the respective farm category. Values above 10% are in italics.

Farm categories		Margin of error (%)
Region: Farms located in the ...	Valley	6.9
	Hill	8.6
	Mountain	*11.1*
Crops: Farms cultivating...	Permanent grassland	4.9
	Temporary ley	5.9
	Wheat	6.4
	Maize	6.5
	Barley	7.9
	Rape seed (canola)	9.6
	Sugar and fodder beet	9.9
	Vine	*18.8*
	Fruit	*13.7*
	Potato	*10.8*
	Field vegetables	*15.2*
	Triticale	*13.4*
	Spelts, oats, rye	*13.6*
	Legumes	*14.5*
	Sunflowers	*18.8*
Livestock: Farms having...	Cattle	5.1
	Pigs	*10.3*
	Comm. Poultry	*10.6*
	Sheep	*16.2*
	Goats	*17.8*
All farms		4.9

animal category cattle. Sunflowers, vine, field vegetables, and small ruminants perform worst with values above 15%. The high margin of error for sunflowers is related to the small number of Swiss farms growing sunflowers, which outweighs the relatively high share of SAEDN farms (Supplementary Table 4).

The calculated margins of error give a good first impression of the representativeness of certain aspects of the SAEDN farms but cannot cover all relevant aspects. The method cannot account for possible biases that exist within the sample under consideration. For example, it is theoretically possible that wheat is fertilised significantly differently in the canton of Ticino than in the canton of Bern. In such a case, it would be problematic that hardly any farms from Ticino participate in the SAEDN. Furthermore, the applied method does not take into account the size of the farms, including the crop areas and number of animals per farm. Consequently, SAEDN arable crops are more likely to be better represented than what the calculated margins of error suggest, since the SAEDN farms are larger than the average Swiss farm. Moreover, we cannot account for the variability of farm management within the different populations: Since the variability differs depending on the measure and we have no information on this at national level, we have assumed the worst case (p =0.5).

3.3. Suitability of the SAEDN data for agri-environmental monitoring

In an ideal case, data used for agri-environmental monitoring would fulfil the following conditions:

- Complete data: record all relevant data or variables (e.g. field-specific plant protection product applications, milk yields) that have an impact on the environmental topics under consideration respectively are required for the modelling of meaningful AEIs
- Reliable data: good quality, no false declarations
- Representative data: stratified random sample, with which reliable extrapolations can be made and temporal trends can be reliably recognised
- Time consistency of data collection: using the same method and sample over time

In reality, it is very challenging to fulfil all these conditions optimally. Especially between complete data (high data depth) and representative data (large sample) there is a trade-off today as the scope of data collection is linked with time and thus financial resources. In the following, we will discuss how well the SAEDN data performs in these four criteria.

Of the data collected, the field calendar data (see Supplementary Section 4.2) are the most valuable because of their high resolution and relevance to many environmental issues. They allow, for example, to account for parcel-specific heterogeneous soil properties in the calculations or to make crop-specific evaluations. On the other hand, there is a lack of certain animal-related data, which is important for topics such as greenhouse gas or ammonia emissions. Data are missing especially in the area of concentrate feeds and animal housing. The data situation is therefore different depending on the environmental topic. While the variables collected are sufficient for topics such as biodiversity, plant protection product use, or heavy metal balance, standard assumptions have to be made in some cases for other topics such as greenhouse gas or ammonia emissions.

As highlighted in Section 2.3, many resources are devoted to data quality. This has made it possible to improve data quality in recent years. However, there are certainly still undetected errors in the data, which is due to their very large amount and high complexity. Such errors are especially problematic when they show clear biases. It is possible that some variables are slightly underestimated, since it seems more likely that a data entry (e.g. a fertilisation measure) is forgotten than that it is entered twice. What we can probably rule out is deliberate misreporting: The farmers can be sure that they will not face any financial (with regard to direct payments) or legal consequences if they do not (actually) fulfil the respective requirements. This is enabled by the anonymous data delivery and the contractual assurance that the data will not be used for control purposes.

As discussed in Section 3.2, the SAEDN data set is only moderate in terms of representativeness since the SAEDN sample is with 0.52% of Swiss farms and 0.75% of Swiss UAA rather small. The time-consuming data collection and the necessity to deliver the data via AGRO-TECH prevents farms from being recruited with a stratified random sample or even compulsory participation. Instead, data collection depends on supporting trustees and motivated farmers, but their number is limited: not all trustee offices participate in the SAEDN because the expertise required to provide environmental data is outside the core business of most offices. Furthermore, the majority of Swiss farmers still record data such as field calendar entries on paper, and for many participating farmers it is an additional effort to enter their data in AGRO-TECH.

Over the years, the same software (AGRO-TECH) has always been used, which provides temporal consistency in data collection. However, the composition of participating farms changes to some extent every year since some farms step out while other farms enter. In 2018, approximately 50% of the original cohort from 2009 was still remaining

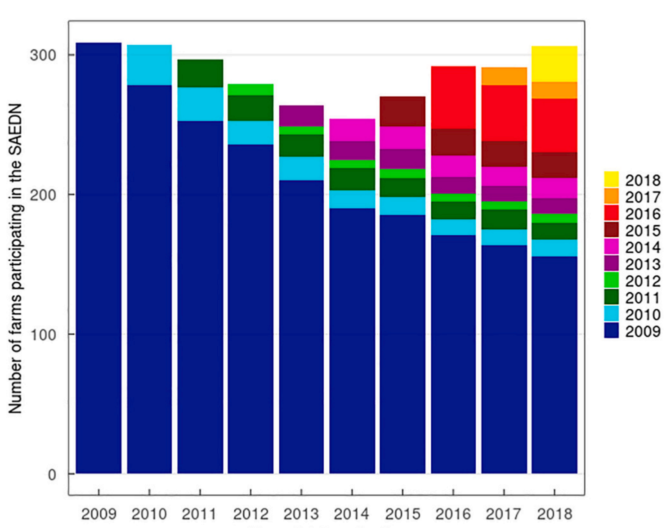


Fig. 5. The number of farms particpiating in the SAEDN over the years 2009–2018. The colour shows the entrance year of the farms.

(Fig. 5). This turnover makes the calculation of robust trends for the AEIs more challenging, as changes may be partly due to changes in the participating farms rather than actual changes in agricultural practices. We have conducted some analyses comparing the time series over all farms with the time series over the farms participating from the beginning (subsample). The extent of the differences depends on both the AEI and the object of aggregation (e.g. region versus culture), as shown for two examples in Supplementary Fig. S8: The time series of the biodiversity indicator, aggregated for different crop types, are essentially the same for all farms and the subsample (Supplementary Fig. S8b). On the other hand, the time series of the nitrogen balance, aggregated for the valley and mountain region, differ somewhat for all farms and the subsample (Supplementary Fig. S8a).

To summarise, the data collected is only partially suitable for agri-environmental monitoring. This is primarily due to the rather small, non-random sample, but also to some missing environmentally relevant variables.

3.4. *Usefulness of the SAEDN data for research projects*

Data on agricultural practices are needed for many research projects but are scarce in Switzerland. The information collected in our network is thus of high value for agricultural research. Most of the collected data are not available to this extent in other Swiss data sources, or at least not for research purposes. The only comparable data network that we know of was organised by the Research Institute of Organic Agriculture (FiBL), being restricted in time (2005 to 2009) and the number of farms involved (around 60). Besides, all of these were organic farms (FiBL, 2021). In addition to farm networks, some national surveys are conducted by the FSO, agristat, and the University of Agricultural, Forest and Food Sciences HAFL (FSO, 2022; Agristat, 2022; Kupper et al., 2018). However, these surveys do not provide field specific information and focus on selected topics only (e.g. ammonia emissions in case of HAFL).

Therefore, our data is frequently used in research projects (e.g. Wettstein et al., 2016; Möhring et al., 2019; Spycher et al., 2020). We process about ten data requests per year from Swiss universities and their research institutions as well as instances working on behalf of the Swiss government. The most requested data are on the use of plant protection products, derived from the field calendars. Due to the breadth of the SAEDN data, however, it can also be used for overarching studies that focus on various environmental issues. This allows to assess synergies and trade-offs of different farm structures and agricultural measures. A publication on this aspect is currently in preparation.

Still, there are limits to the use of SAEDN data. Depending on the research project, the depth of the data collected may not be sufficient. Furthermore, the lack of georeferencing limits the potential of data use in some cases, for example for calibrations or validations in remote sensing studies.

3.5. *Development opportunities of the AEM*

The SAEDN will be stopped in the next years. The experience gained so far will be used to create a new agri-environmental monitoring programme without its own farm network. The new AEM should rely more on established data sources, such as data from national surveys and other government data. Furthermore, the FOAG is running a project called “digiFlux” independently of the AEM. The aim of digiFlux is to establish gradually an overall system for nutrient and plant protection product management based on individual farm data. As recording will be mandatory for all Swiss farms, the digiFlux data can provide a representative data basis for plant protection product and nutrient indicators of the future AEM.

Within the framework of the future AEM, additional individual farm data collection will still be possible but in a more targeted form to complement existing data sources. One possibility is to use data that are available in Farm Management Information Systems but to which no legal and technical access exists yet. Other possibilities are additional national surveys and remote sensing data. As all of these data sources have their advantages and disadvantages, a combination is likely to lead to the best results, i.e. to the calculation of representative, robust, and meaningful indicators.

4. Conclusions

The Swiss agri-environmental data network (SAEDN) collects a large set of farm management data anonymously and with the participation of several actors. Originally, the SAEDN was set up for the purpose of agri-environmental monitoring (AEM). Based on the collected data, agri-environmental indicators (AEIs) are calculated every year to show the development of agricultural impact on the environment over time. However, as data collection is time-consuming, only comparatively few farms in Switzerland participate in the programme (about 300 per year), despite financial reimbursements. The SAEDN data allows relatively robust conclusions to be drawn for the most important crop types and animal categories such as permanent grassland, wheat, or cattle. However, the sample size for crops and animal categories that are minor in terms of areas and LU (such as viticulture or sheep) remains small which is associated with high margins of error (>15%) and a correspondingly lower robustness of the results. In some cases, calculating robust trends thus remains challenging due to insufficient sample size as well as lack of information on some key variables. The farm network is therefore only moderately suitable for monitoring purposes. On the other hand, the farm network currently provides by far the best database for many research projects. In particular, data from the field calendar are in demand.

Due to its limited usefulness for monitoring, the SAEDN will be replaced in the next years by a new monitoring system, which should better incorporate existing data sources and conduct data collection in a more targeted manner. This should not only reduce the multiple data entries that many Swiss farmers face today, but also improve the sample size and in some cases the spatial resolution of the AEM data. Consequently, more robust AEIs should become available in the future. However, a number of challenges in the exploitation, linkage, and quality control of data sources need to be mastered to achieve this.

Availability of data and materials

The here presented SAEDN data may be passed on to Swiss universities and their research institutes for study and research purposes as well as to third parties that act on behalf of the Confederation. A data contract must be signed in this case. The AGIS data from the FOAG is not publically available. Data from the FSO can be found at https://www.bfs.admin.ch/bfs/de/home/statistiken/kataloge-datenbanken/daten.html?dyn_prodima=900106.

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Contributions

AG: conception and design, analysis and interpretation of data, and drafting of article. SB: support on data analysis, interpretation of data, feedback on the text. JS: support on data analysis, interpretation of data, feedback on the text. FL: interpretation of data, revising critically for important intellectual content, feedback on the text. LM: conception and design, interpretation of data, feedback on the text.

Ethics approval

Not applicable.

Consent to participate

Not applicable.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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