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Regional and international farmland biodiversity monitoring programmes: biodiversity indicators in the FAO agroecology indicator framework

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1 Introduction

1.1 Types of farmland biodiversity monitoring programmes

Many farmland biodiversity monitoring programmes determine biodiversity by counting the number of different species (e.g. plants or birds) or different habitats in the field. One example of this is the Swiss monitoring programme ALL-EMA, in which field data on agricultural land are collected on 170 selected 1 km^2 squares in a five-year cycle (Agroscope, 2025a; Ecker et al., 2023). The advantage of field assessments is that (at least part of) biodiversity can be measured directly. However, this kind of assessment requires expert knowledge, a great deal of work – especially if the spatial and temporal resolution of the surveys is high for the sake of representativeness – and usually only provides reliable information on part of the biodiversity, as not all different species groups (e.g. grassland flora, snails, birds) can be determined due to resource constraints.

Therefore, there also exist monitoring programmes that calculate indirect biodiversity indicators, which estimate the impact of crop selection and

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agricultural management on biodiversity by using relationships derived from numerous field studies. In the Swiss monitoring programme SAEDN (Swiss Agri-Environmental Data Network; Gilgen et al., 2023a), the Swiss biodiversity indicator from Jeanneret et al. (2014) was calculated annually for 300 farms for which detailed, field-specific management data were available. The method can be applied to various habitats (e.g. grassland, arable land) and takes into account the following indicator species groups: grassland flora, arable companion flora, birds, small mammals, amphibians, molluscs, spiders, ground beetles, butterflies, wild bees, and grasshoppers. For each of these indicator species groups, the suitability of the grown crop as a habitat and the influence of management on biodiversity are taken into account. The indicator is expressed in points, with more points indicating higher biodiversity. The calculation is performed for each field and each indicator species group. For aggregation on the entire farm, the biodiversity points are averaged proportionally to the field areas. In addition, indicator species groups that serve as a food source for others and that are more species-rich in agricultural areas are given a higher weighting.

The Swiss biodiversity indicator requires significantly less effort than field measurements to produce results for many different indicator species groups. Nevertheless, it is still time-consuming in terms of data collection, as all management measures must be available in digital form for each field. The indicator was developed specifically for Switzerland and validated for neighbouring European countries (Knudsen et al., 2017; Lüscher et al., 2017). Conceptually, the method could also be applied to regions far away from Switzerland, but this may require very intensive literature research to determine the suitability of crops as habitats and the influence of management practices on the various indicator species groups, as these depend on environmental factors such as climate. Currently, the data basis in some regions (e.g. the tropics) is poor, which makes it even more difficult to transfer the method regionally.

There are also indirect biodiversity indicators which can be applied more widely across regions. As an example, the BioBio project (Agroscope, 2025b; Herzog et al., 2012) compiled biodiversity indicators that are scientifically sound and applicable at the pan-European level. These include habitat indicators, species diversity indicators, indicators for crop and livestock genetic diversity, and indicators for management-related diversity. The compilation also includes relatively straightforward indicators, such as the proportion of land under mineral fertiliser application or the average livestock unit density. The BioBio indicators were tested in 12 different case study regions across Europe and – in addition – in Tunisia, Ukraine, and Uganda.

The choice of which of the described monitoring approaches is used depends heavily on the objectives and resource capacities of the respective project.

1.2 Tool for Agroecology Performance Evaluation (TAPE)

The FAO (Food and Agriculture Organisation of the United Nations) has developed the Tool for Agroecology Performance Evaluation (TAPE; Mottet et al., 2020) in consultation with many partners to assess the impact of agroecology in a harmonised manner in different countries. The aim of TAPE is to quantify how agroecological a farm or region is and how this affects its sustainability. TAPE data are collected at the farm/household level in several steps, not all of which have to be performed on every farm. In the following, we will only describe steps 1 and 2, which are the core steps of TAPE.

Step 1 measures where the agricultural system stands in terms of its transition towards agroecology. It is based on the 10 Elements of Agroecology defined by the FAO (Barrios et al., 2020):

1. diversity;
2. synergies;
3. efficiency;
4. recycling;
5. resilience;
6. culture and food tradition;
7. co-creation and sharing of knowledge;
8. human and social values;
9. circular and solidarity economy; and
10. responsible governance.

Each element is covered by three to four questions, the answers to which give 0 to 4 points. As an example, one question refers to the diversity of trees, where a ‘farm with no trees’ receives 0 points and a ‘farm with a high number of trees of different species integrated within the productive system’ receives 4 points.

Step 2 measures the impact on five dimensions of sustainability (governance, economy, health and nutrition, society and culture, environment). Each dimension is assessed using one or several indicators. The indicators in Step 2 are more complex than in Step 1 and are calculated with scoring systems and/or formulas. For example, the farm income is the sum of various revenues and expenses, taking into account depreciation of agricultural machinery.

Despite covering five sustainability dimensions, TAPE was deliberately designed so that data collection requires little time. Accordingly, data collection for Steps 1 and 2 should not take more than approximately 3 hours per farm.

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In the following, we describe how biodiversity is assessed in the original TAPE version of Mottet et al. (2020). In Step 1, individual questions are used to roughly assess the diversity of the crops grown, the animals kept, and the trees (or other perennials) on the farm. In Step 2, a more quantitative agrobiodiversity index is calculated, which is the average over the three domains GSI_{crops} (GSI stands for Gini-Simpson Index), $GSI_{animals}$, and I_{other}, described below:

***GSI*$_{crops}$**

$$shannon_{crops} = \sum_{i=1}^{S_c} \frac{\left(\frac{area_i}{area_{total}}\right)^2}{varieties_i}$$

$$GSI_{crops} = 100 \times \left(1 - shannon_{crops}\right)$$

where S_c is the number of different crop species produced on the farm, $area_i$ is the area on which the crop species i is produced, $area_{total}$ is the farm's total crop production area, and $varieties_i$ is the number of varieties grown of each species i.

***GSI*$_{animals}$**

$$shannon_{animals} = \sum_{i=1}^{S_a} \frac{\left(\frac{animal_i}{animal_{total}}\right)^2}{breed_i}$$

$$GSI_{animals} = 100 \times \left(1 - shannon_{animals}\right)$$

where S_a is the number of different animal species on the farm, $animal_i$ is the number of animal species i converted to livestock units (country-specific conversion factors), $animal_{total}$ represents the farm's total livestock unit (i.e. over all animal species), and $breed_i$ is the number of breeds of species i.

***I*$_{other}$**

I_{other} is the average over the three sub-scores natural/diverse vegetation, bees, and presence of beneficial insects, which are listed in Table 1.

This agrobiodiversity index has several shortcomings:

1) It is unclear how farms with 20–25% natural or diverse vegetation should be scored, as they cannot be assigned to any category in Table 1.
2) For the calculation, the number of breeds and varieties is indicated, and it is assumed that each breed or variety occurs equally often. Farms with different breeds (or varieties) are therefore better off than farms with different animal categories (or crops). Example: A farm with 12 livestock units (LU) of cows of three different breeds obtains a score of 67%

Table 1 Rating for the three sub-scores of I_{other}

Category	Answer	Score
Natural or diverse vegetation	Absent: area covered with natural or diverse vegetation is negligible.	**0**
	Small: less than 10% of the system is covered with natural or diverse vegetation.	**3**
	Significant: at least 20% of the system is covered with natural or diverse vegetation.	**66**
	Abundant: more than 25% of the system is covered with natural or diverse vegetation.	**100**
Bees	No, bees are not raised and are rare within the agroecosystem.	**0**
	No, bees are not raised but are widespread within the agroecosystem.	**5**
	Yes, bees are raised within the agroecosystem.	**100**
Presence of beneficial insects	Absent	**0**
	Little	**33**
	Significant	**66**
	Abundant	**100**

because it is automatically assumed that it has four cows of each breed – even if in reality, the farm has 10 animals of one breed and one animal of each of the other breeds. In contrast, a farm keeping cows, pigs, and poultry of one breed each must keep exactly the same number of LU of the different animals to achieve the same score. Another challenge is how to deal with grasslands: Grassland is theoretically one crop, but its diversity is not low, as grassland usually consists of various plant species. One possibility is to consider different grassland intensities as different crop types (e.g. extensive versus intensive grassland).

3) The Gini-Simpson index gives implausible values if the shares show pronounced differences. Example: A farm that keeps 50 cows of the same breed (=50 LU) receives a Gini-Simpson index of 10; the number of cows is not included in the calculation, but only the share of animals of one animal category/breed (in this case 1). If the farm now buys 10 chickens (=0.1 LU), the Gini-Simpson index drops from 10 to 0.4 – although the farm has actually increased its agrobiodiversity.
4) The main drawback of the TAPE agrobiodiversity index is that it almost exclusively considers planned agrobiodiversity, i.e. the biodiversity of the crops and livestock chosen by the farmer. ‘Unplanned biodiversity’ is hardly addressed in TAPE so far; it includes the associated biota that colonise the agroecosystem and survive depending on local management and the environment (Jackson et al., 2013). For example,

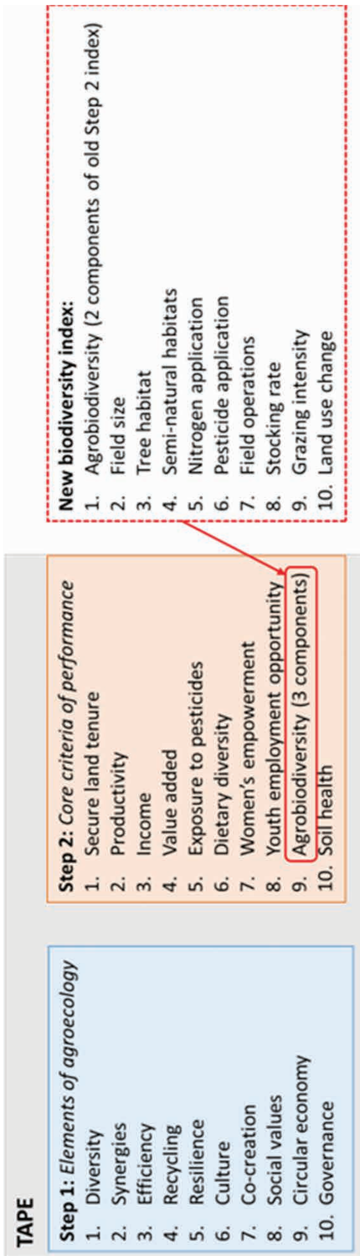

Figure 1 Embedding the new biodiversity index in the framework of TAPE. The two domains transferred to the new biodiversity index are the crop diversity index and the animal diversity index described in Section 1.2.

fertiliser and pesticide applications have a large impact on biota such as vascular plants, farmland birds, and arthropods. For this reason, a new biodiversity index for TAPE (Step 2; see Fig. 1) was developed (described in Gilgen et al., 2023b), which also takes unplanned biodiversity into account. This index is described in the next section.

2 The improved biodiversity index developed for Tool of Agroecology Performance Evaluation

The following objectives had to be considered when developing the improved biodiversity index for TAPE: The index should (1) integrate the existing TAPE data and calculations as far as possible, (2) be applicable to farms in different countries and climates, (3) be influenceable by farmers and other stakeholders, and (4) be calculable using data that can be collected within a reasonable timeframe.

To integrate the existing TAPE calculations, the two domains crop diversity index (GSI_{crops}) and animal diversity index ($GSI_{animals}$) of the original agrobiodiversity index were used as the first element/indicator of the new composite biodiversity index, despite the problems described in Section 1.2. Concerning the third domain (I_{other}) of the original agrobiodiversity index, the aspect of natural/diverse vegetation was integrated as a separate, improved indicator ('semi-natural habitats' in Table 2) in the new biodiversity index, while the aspects of 'bees' and 'presence of beneficial insects' were removed. This was because the presence of bees or other beneficial insects, as queried in TAPE, depends heavily on subjective perception of farmers.

Following consultation with experts, it was decided to base the rest of the new biodiversity index on the BioBio method, which largely fulfils the requirements for TAPE. The BioBio indicators are divided into the categories genetic diversity, (wildlife) species diversity, habitat diversity, and agricultural management. The genetic diversity indicators of BioBio refer to the genetic diversity of crops and livestock, e.g. the number and amount of different varieties and breeds. These aspects are already covered by GSI_{crops} and $GSI_{animals}$ and therefore not considered twice. The indicators of (wildlife) species diversity comprise direct measurements of vascular plants, spiders, earthworms, and wild bees. They were excluded for reasons of data collection time, required expert knowledge, and dependence on weather conditions. Therefore, only some BioBio indicators of habitat diversity (Herzog et al., 2017) and agricultural management were considered and partly adapted for TAPE. Habitat diversity is a good proxy for very mobile organisms, whereas management practices are good proxies for less mobile organisms.

This resulted in a new biodiversity index (description in Table 2) consisting of the following ten indicators: (planned) agrobiodiversity, field size, tree

Table 2 The indicators of the new TAPE biodiversity index

Indicator	Calculation	Normalisation
1) Agrobiodiversity	This is the average of the first two components of the original TAPE agrobiodiversity index, i.e. GSI_{crops} and $GSI_{animals}$ (see Section 1.2). The third domain of the original TAPE agrobiodiversity index (GSI_{other}) was excluded because part of it is covered in indicator 4 (see below, area of semi-natural habitats) and part of it is difficult to determine objectively (abundance of beneficial insects).	The Gini-Simpson index is used, which takes values between 0% and 100%.
2) Field size	Field size is calculated as the mean field size of the farm, the UAA of each farm divided by the number of fields.	The field size indicator is categorised (0–100%) according to the mean field size (fs): • fs < 0.5 ha 100% • 0.5 ≤ fs < 3 ha 75% • 3 ≤ fs < 16 ha 50% • 16 ≤ fs < 100 ha 25% • ≥ 100 ha 0%
3) Tree habitat	Forest that is not used for agricultural purposes is excluded. Tree habitats are not quantified by the number of trees, but refer to the area on which (enough) trees grow. Example: If there are standard fruit trees in an extensive meadow, the entire area of the meadow counts as tree habitat.	The tree habitat indicator is calculated as a percentage of the area of tree habitats on the UAA.

4)	Semi-natural habitats	The semi-natural habitats indicator is defined through two domains: 1) The share of semi-natural habitat on UAA 2) The diversity (number of different types of semi-natural habitats) of the semi-natural habitats that are present on the farm Semi-natural habitats are, for example: • Hedges • Trees • Small woods • Extensive managed orchards • Extensive permanent grassland • Extensive permanent grassland interspersed with trees (silvopastoral agroforestry) • Small structures, i.e. walls, unpaved paths, cairns • Field margins, i.e. flower strips, wildflower strips, arable strips, etc. • Aquatic habitats	Domain 1 is normalised as follows: Linear value in % between 100% (≥25% semi-natural habitats of UAA) and 0% (0% semi-natural habitats) The diversity (n = number of different types of habitats) of the semi-natural habitats (domain 2) is defined as follows: • n ≥ 5 100% • n = 4 75% • n = 3 50% • n = 2 25% • n < 2 0% The total semi-natural habitat indicator is calculated as the average of domain 1 and domain 2.
5)	Nitrogen application	The nitrogen application indicator is calculated through two individual domains: 1) Area with N mineral fertiliser application as percentage of the UAA 2) Amount of (total) N input through mineral and organic fertilisation, defined as kg N per hectare. The N amount in manure is defined as the total N excreted.	Domain 1 is the share of the UAA that has not been fertilised with mineral N fertiliser (in per cent). Domain 2 (calculated as kg N per hectare) is classified as follows: • ≤ 1 kg N per hectare 100% • > 1–30 kg N per hectare 75% • > 30–100 kg N per hectare 50% • > 100–200 kg N per ha 25% • > 200 kg N per ha 0% The total nitrogen application indicator is the average of domain 1 and domain 2.

(*Continued*)

Table 2 *Continued*

Indicator	Calculation	Normalisation
6) Pesticide application	The pesticide application indicator is calculated through three individual domains: 1) The total number of pesticide applications on the farm per hectare of UAA 2) The share of UAA with pesticide applications in percent 3) Ecotoxicology. The ecotoxicology of each applied pesticide was categorised (I = extremely toxic; II = moderately toxic; III = slightly toxic/non-toxic) for the toxicology for fish (LC50), aquatic invertebrates (EC50), and algae/water plants (EC50) ***Fish LC50*** I: < 0.1 mg l^{-1} II: 0.1–100 mg l^{-1} III: > 100 mg l^{-1} ***Aquatic invertebrates EC50 (mg l^{-1})*** I: < 0.1 mg l^{-1} II: 0.1–100 mg l^{-1} III: > 100 mg l^{-1} ***Algae/water plants EC50 (mg l^{-1})*** I: < 0.01 mg l^{-1} II: 0.01–10 mg l^{-1} III: > 10 mg l^{-1}	Domain 1 is normalised as follows: Linear value in % between 100% (≤1 application per ha) and 0% (≥10 applications per ha) Domain 2 is the share of the total farm area with **no** pesticide applications in percent. Each pesticide was assigned the highest toxicity among the three groups of organisms. For example, if one pesticide is highly toxic to fish (category I) and only slightly toxic to aquatic invertebrates and algae (category III), the overall ecotoxicology of the pesticide is highly toxic (category I). **The most toxic** pesticide that each farmer used defines domain 3. An ecotoxicology of category I of the most toxic pesticide used results in a score of 0%, category II in a score of 33%, and category III in a score of 67%. If no pesticide was used, a score of 100% was achieved. The total pesticide application indicator is the average of the pesticide application number (domain 1), the application area (domain 2), and the ecotoxicology (domain 3).
7) Field operations	The field operation indicator (FieldOP) is the area-weighted average of the number of mechanised field operations: $FieldOP = \sum \frac{N_{FOi} \times A_i}{A_{UAA}}$ with: N_{FOi} = Number of mechanised field operations on field i A_i = Area of field i A_{UAA} = UAA	The categorisation of the field operations indicator is as follows: • FieldOP < 1 100% • 1 ≤ FieldOP < 2 75% • 2 ≤ FieldOP < 10 50% • 10 ≤ FieldOP < 20 25% • 20 ≤ FieldOP 0%

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8)	Stocking rate	For the stocking rate, the number of animals (converted to livestock units — LU) are divided by the UAA.	Stocking rates are calculated as livestock units per hectare (LU/ha). The stocking rate indicator takes linear values between the worst value (stocking rate ≥ 4 LU/ha 0%) and the best value (stocking rate = 0 LU/ha 100%).
9)	Grazing intensity	For grazing intensity, all forage-consuming animals are considered. To calculate the grazing intensity (GI) indicator, the livestock units are multiplied by the proportion of time in a year spent on the farm's pastures (not including external pastures) and divided by the farm's pasture area: $GI = \sum \frac{N_i \times LU_i \times t_i}{Ag}$ N_i = number of animals by livestock category LU_i = livestock unit by livestock category t_i = time fraction of livestock spent on own farm pastures (considering pasture days and hours) Ag = grazing area on the farm, only area that has been used for grazing is considered.	The categorisation of the grazing intensity indicator is as follows: • GI ≤ 0.25 100% • 0.25 < GI ≤ 0.5 75% • 0.5 < GI ≤ 1 50% • 1 < GI ≤ 2 25% • GI > 2 0% For farms that do not have any grazing area, the grazing intensity indicator is not calculated (NA value).
10)	Land use change	For the land use change indicator, the natural or semi-natural area that was converted to agricultural land within the last year is considered. The indicator is the percentage of the converted land to the UAA: $LUC = 100 - \frac{Areachanged(ha)}{UAA(ha)} \times 100$	The land use change indicator is the percentage of the total farm area that has not undergone LUC (in %) in the last year.

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habitat, semi-natural habitats, nitrogen application, pesticide application, field operations, stocking rate, grazing intensity, and land use change. The ten indicators were normalised to a scale between 0% and 100% (see Table 2), representing the worst and best case, respectively. By this, the indicators can be shown in a spider diagram and/or be aggregated to a single biodiversity score.

3 Case study in Switzerland using the improved Tool of Agroecology Performance Evaluation biodiversity index

The new biodiversity index was tested on 21 Swiss farms covering different regions (valley, hills, mountains) and production systems (organic/conventional, different animals and crops; Gilgen et al., 2023a). Figure 2 a shows the average as well as the minimum and maximum values of the 21 farms. All farms scored well on the field size indicator, which is not surprising since fields in Switzerland are typically small (1–2 ha) due to the heterogeneous landscape. The land use change indicator also received very high scores for all farms because conversion of (semi-)natural habitats to agricultural land (e.g. through deforestation) does not occur often in Switzerland. The agrobiodiversity indicator shows a certain range, but neither very low nor very high values are achieved. The other seven indicators – tree habitat, semi-natural habitats, nitrogen application, pesticide application, field operations, stocking rate, and grazing intensity – all showed a large range in values, indicating that the thresholds defined are (at least for Switzerland) well chosen to differentiate between farms.

Farms located in the mountain and hill region obtained higher scores than the valley farms (Fig. 2b), which is in agreement with Swiss biodiversity measurements (Meier et al., 2020). The largest differences occurred for the indicators semi-natural habitats, pesticide application, and grazing intensity. Furthermore, organic farms received higher scores than non-organic farms (Fig. 2c). Similarly, the differences for the indicators pesticide application, grazing intensity, and nitrogen application were most pronounced.

The 21 sampled farms were part of the Swiss Agri-Environmental Data Network (Gilgen et al., 2023a) and therefore the Swiss biodiversity indicator by Jeanneret et al. (2014) was already available for them. This enabled it to compare the newly developed biodiversity index with the more comprehensive method of Jeanneret et al. (2014) on these 21 farms (Gilgen et al., 2023b). For the comparison, the new biodiversity index is expressed as the average over its 10 indicators.

No perfect correlation was expected because the two methods differ in terms of the detail level of data collection and the scope (TAPE: global; Jeanneret et al. (2014): Switzerland). Nevertheless, there was a significant

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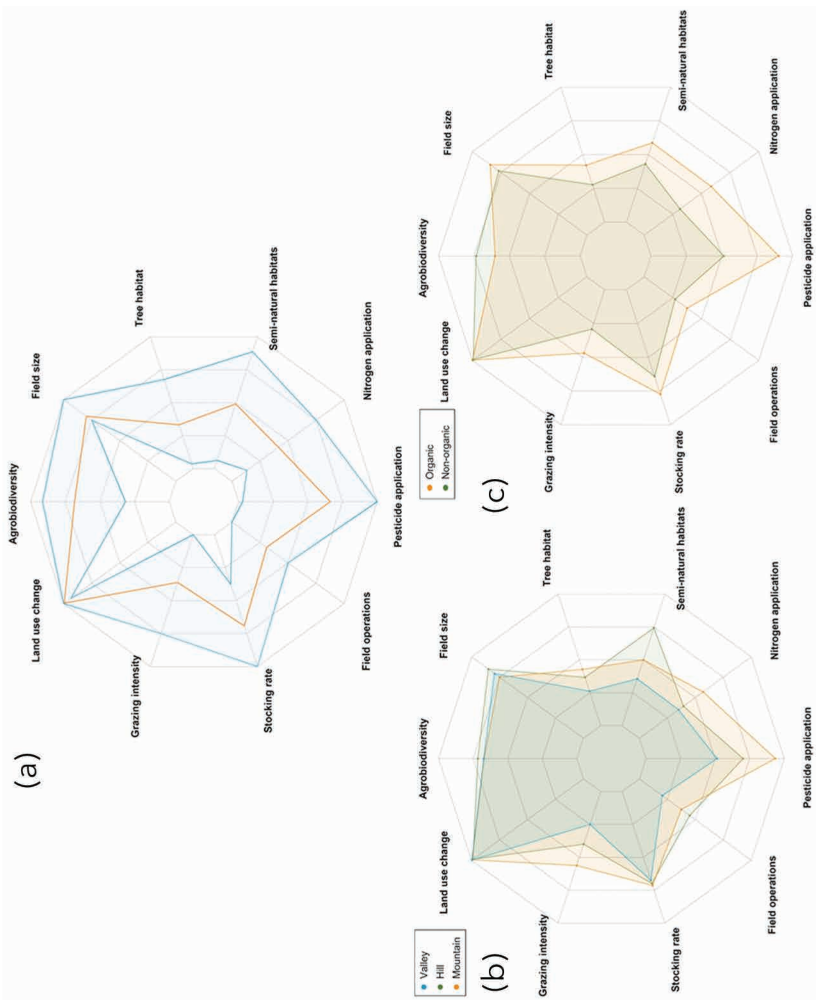

Figure 2 New biodiversity index for the 21 Swiss farms. In (a), the mean (orange line) as well as the minimum and the maximum (blue lines) values are shown. In (b), the farms are categorised by region, and in (c), they are categorised by farm type.

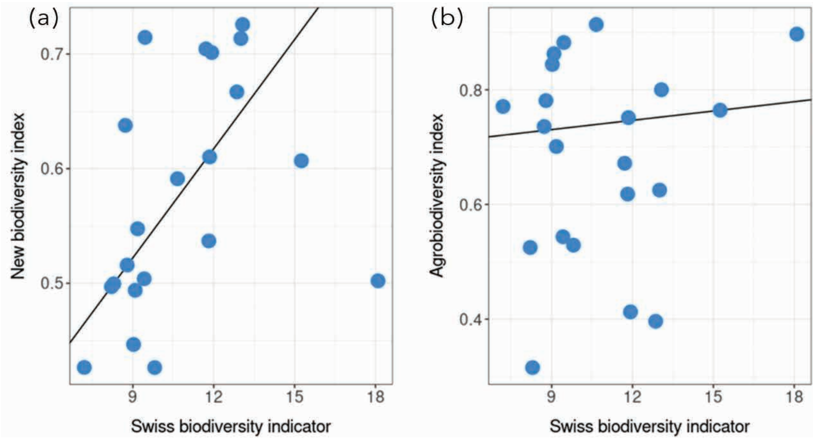

Figure 3 Theil-Sen regression of (a) the Swiss biodiversity indicator (Jeanneret et al., 2014) and the new biodiversity index (Gilgen et al., 2023b) and (b) the Swiss biodiversity indicator and the original TAPE agrobiodiversity index (Mottet et al., 2020).

positive correlation between the Swiss biodiversity indicator and the new biodiversity index (Fig. 3a; r = 0.56, p-value = 0.009 with Spearman rank). It needs to be considered that the absolute values are not comparable because the Swiss biodiversity indicator is expressed in terms of biodiversity points (between 7 and 18 for the selected farms), whereas the new biodiversity index is expressed in terms of percent/range between 0 and 1.

One of the sampled farms – an intensive orchard – is a clear outlier (Fig. 3a). It scores very well in the Swiss biodiversity indicator (18 points) because trees are a good habitat for most indicator species groups. In the new biodiversity index, however, the farm does not score particularly well (0.46% or 46%), because the planned agrobiodiversity is low (e.g. no animals), the semi-natural area is low, and the management (pesticides, fertilisation) is intensive.

For comparison, we also calculated the correlation of the Swiss biodiversity indicator with the original TAPE agrobiodiversity index (Fig. 3b). Here, no positive correlation was found (r = 0.09, p-value = 0.71). Accordingly, the goal of improving the old TAPE biodiversity index by including unplanned biodiversity was clearly achieved.

4 Conclusion

Reflecting the complexity of biodiversity in monitoring programmes is a major challenge. The challenge is even greater when few resources are available for data collection and when the method is to be applied internationally. For the Tool of Agroecology Performance Evaluation (TAPE), which has been developed by the FAO and used in many different countries, a new biodiversity index has been designed that attempts to strike a balance between simplification and information content. The index is based on the indicator compilation of the BioBio project (Agroscope, 2025b). The new biodiversity index was compared with a more comprehensive biodiversity indicator on 21 Swiss farms and showed a good correlation.

4.1 Future projects using the improved TAPE biodiversity index

The newly developed TAPE biodiversity index was tested for western Kenya in 2022, where 50 farms in each of two counties (Nandi and Bomet) were surveyed. The results will be published soon. It was found that some changes had to be made to the data collection process, since farms in Kenya are less regulated by the state than in Switzerland. For example, the grazing area in Kenya is often less clearly defined than in Switzerland because animals partially graze on the edges of fields. Furthermore, all cultivated land was taken into account in Kenya. In contrast, private vegetable or fruit gardens in Switzerland were excluded from the survey because they are not classified as 'agricultural areas', which are subject to stricter regulations and eligible for direct payments.

Furthermore, the TAPE version with the new biodiversity index was applied on 600 farms each in Kenia and Uganda in 2025. Difficulties arose in data collection and quality, hindering the derivation of reliable results not only for the TAPE biodiversity index but TAPE step 2 in general. Examples include missing data on breeds and pesticides, highly diverse systems difficult to classify (e.g. as semi-natural habitat), and uncertain expenditures. Applying TAPE Step 2 and the new biodiversity index to a large sample of farms in regions with poor data availability, therefore appears very challenging. In such cases, an (even) simpler version of the biodiversity index could be derived by omitting individual aspects and/or working with proxies. For example, the number of breeds could be disregarded, or the typical use of plant protection products could be derived from the crops grown and expertise from the region.

The code for calculating the biodiversity indicator is available on GitHub. However, the calculation has not yet been transferred to the standard TAPE tool. It is possible that the FAO will make changes during the transfer to TAPE in order to further simplify data collection.

5 Where to look for further information

- TAPE – General information and contact form: Tools | Agroecology Knowledge Hub | Food and Agriculture Organization of the United Nations.
- TAPE R code including new biodiversity index: GitHub – MAUS-team/tape_calculator.

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