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How to Assess the Agroecological Status of Swiss Farming Systems?

Application of the Tool for Agroecology Performance Evaluation (TAPE) and Further Development

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Summary

How to Assess the Agroecological Status of Swiss Farming Systems? – Application of the Tool for Agroecology Performance Evaluation (TAPE) and Further Development

The 'Tool for Agroecology Performance Evaluation' (TAPE) has been developed under the coordination of the Food and Agriculture Organisation of the United Nations (FAO) to assess the impact of agroecology with a globally applicable and comparable method. TAPE aims to measure the performance of agroecological systems in the different sustainability dimensions. The method includes a questionnaire to be filled in by an enumerator during or after a farm visit. So far, TAPE has predominantly been applied in low- and middle-income countries (LMICs).

In this study, we tested the applicability of TAPE in Switzerland. Furthermore, we developed a new biodiversity index for TAPE that takes into account unplanned biodiversity (e. g. the effect of management practices on wild species) in addition to planned biodiversity (e. g. the number of breeds, presence of trees), since the current tool only considers the latter.

Interviews were conducted on 21 farms throughout Switzerland covering different production systems. While generally applicable, the current version of TAPE proved inadequate for recording grassland-dominated farms, since many of the questions were designed for arable cropping systems. Furthermore, the effort required for data collection on Swiss farms considerably exceeded the target range of TAPE because the recording of pesticides, machinery, and information on plant and animal products was a more complex endeavour in Switzerland than in typical smallholder farming systems in LMICs.

Nevertheless, preliminary agroecological results (valid for the farms observed) were successfully derived with TAPE. The agroecological elements 'responsible governance' and 'social values' achieved the highest average scores, while we identified space room for improvement in other elements such as 'efficiency' or 'recycling'. No significant differences were found between the regions (valley/hill/mountain) for most elements, but (certified) organic farms performed considerably better than non-organic farms with regard to the transition to agroecology. It should be noted, however, that with only 8 organic farms and 13 non-organic farms, our sample was far too small to be representative for the Swiss farming sector.

Next to testing TAPE in Switzerland, we extended the method to include unplanned biodiversity, an important ecological aspect that has so far not been considered. The newly developed biodiversity index is based on the European BioBio method. The comparison of the new biodiversity index with a significantly more detailed and time-consuming method ('SALCA-BD') shows a positive correlation ($r = 0.56$, p-value=0.009). Based on our results, the new biodiversity index was implemented in TAPE and is freely available for other users as needed.

Zusammenfassung

Wie lässt sich der agrarökologische Zustand von Schweizer Landwirtschaftssystemen beurteilen? Anwendung und Weiterentwicklung des *Tool for Agroecological Performance Evaluation* (TAPE)

Das *Tool for Agroecology Performance Evaluation* (TAPE) wurde unter der Ägide der Ernährungs- und Landwirtschaftsorganisation (FAO) der Vereinten Nationen (UN) entwickelt. Dieses Werkzeug soll eine weltweit anwendbare und vergleichbare Bewertung agrarökologischer Auswirkungen ermöglichen. Dabei wird die Leistung von agrarökologischen Systemen in den verschiedenen Nachhaltigkeitsdimensionen gemessen. Zur Methode gehört ein Fragebogen, der von der erhebenden Person während oder nach einem Besuch auf dem Landwirtschaftsbetrieb ausgefüllt wird. Bisher wurde TAPE vor allem in Ländern mit niedrigem und mittlerem Einkommen (LMIC) eingesetzt.

In dieser Studie wurde die Anwendbarkeit von TAPE in der Schweiz getestet und ein neuer Biodiversitätsindex für TAPE entwickelt, der neben der geplanten Biodiversität (z. B. Anzahl der Rassen, Bäume), die bisher von TAPE berücksichtigt wird, zusätzlich auch die ungeplante Biodiversität (z. B. Auswirkungen von Bewirtschaftungspraktiken auf wildlebende Arten) miteinbezieht.

Die Befragungen wurden auf 21 Betrieben in der ganzen Schweiz durchgeführt, die verschiedene Produktionssysteme abdecken. Es hat sich gezeigt, dass sich das TAPE-Tool im Allgemeinen zwar gut anwenden lässt, aber in der aktuellen Version für Betriebe mit viel Grünland nicht geeignet ist, da sich viele Fragen auf Ackerkulturen beziehen. Zudem überstieg der Aufwand für die Datenerhebung auf Schweizer Betrieben den Zielbereich von TAPE deutlich, da die Erfassung der verwendeten Pflanzenschutzmittel und Maschinen sowie von Informationen zu pflanzlichen und tierischen Produkten komplexer war als in typischen kleinbäuerlichen Anbausystemen in LMIC.

Dennoch konnten mit TAPE erste agrarökologische Ergebnisse (gültig für die untersuchten Betriebe) abgeleitet werden. Die agrarökologischen Elemente «Verantwortungsvolle Betriebsführung» und «Soziale Werte» erreichten die höchsten Durchschnittswerte, während wir bei anderen Elementen wie «Effizienz» oder «Recycling» noch Verbesserungspotenzial sehen. Bei den meisten Elementen wurden keine signifikanten Unterschiede zwischen den Regionen (Mittelland/Jura/Voralpen/Alpen) festgestellt, aber die (zertifizierten) Biobetriebe schnitten bei den agrarökologischen Indikatoren deutlich besser ab als die Nicht-Biobetriebe. Allerdings ist zu beachten, dass unsere Stichprobe mit lediglich 8 Biobetrieben und 13 Nicht-Biobetrieben für den Schweizer Landwirtschaftssektor nicht repräsentativ ist.

Neben der Erprobung von TAPE in der Schweiz haben wir die Methode mit dem Bereich der ungeplanten Biodiversität erweitert, ein wichtiger, bisher nicht berücksichtigter ökologischer Aspekt. Der neu entwickelte Biodiversitätsindex basiert auf dem europäischen BioBio-Indikator-System. Der Vergleich des neuen Biodiversitätsindex mit einer wesentlich detaillierteren und aufwändigeren Methode (SALCA-BD) zeigt eine positive Korrelation ($r = 0{,}56$, p-Wert=0,009). Auf der Grundlage unserer Ergebnisse wurde der neue Biodiversitätsindex in TAPE implementiert und steht anderen Anwendern frei zur Verfügung.

Résumé

Comment évaluer le statut agroécologique des systèmes agricoles suisses? - Application de TAPE, un outil pour l'évaluation des performances agroécologiques

L'outil d'évaluation des performances agroécologiques, abrégé TAPE, de l'anglais «Tool for Agroecology Performance Evaluation», a été développé sous l'égide de l'Organisation des Nations Unies pour l'alimentation et l'agriculture (FAO) afin d'évaluer l'impact de l'agroécologie à l'aide d'une méthode applicable et comparable partout dans le monde. TAPE vise à mesurer la performance des systèmes agroécologiques en prenant en compte les différentes dimensions de la durabilité. La méthode comprend un formulaire à remplir par un enquêteur pendant ou après une visite d'exploitation. Jusqu'à présent, la méthode TAPE a surtout été appliquée dans les pays à faible revenu et à revenu intermédiaire (PRFI).

Dans cette étude, nous avons testé les possibilités d'application de TAPE en Suisse. En outre, nous avons développé un nouvel indice de biodiversité pour TAPE qui prend en compte la biodiversité non planifiée (par exemple, l'effet des pratiques de gestion sur les espèces sauvages) en plus de la biodiversité planifiée (par exemple, le nombre de races, la présence d'arbres), puisque la méthode TAPE actuelle ne prend en compte que cette dernière.

Des entretiens ont été menés dans 21 exploitations réparties dans toute la Suisse et couvrant différents systèmes de production. Bien que la méthode puisse en principe leur être appliquée, nous avons constaté que les exploitations à dominante herbagère ne pouvaient pas être enregistrées de manière adéquate dans la version actuelle de TAPE, car de nombreuses questions sont conçues pour les systèmes de culture arable. En outre, l'effort requis pour le relevé des données dans les exploitations agricoles suisses a considérablement dépassé la fourchette cible de TAPE, car l'enregistrement des pesticides, des machines et des informations sur les produits végétaux et animaux était plus complexe que dans les systèmes de petites exploitations agricoles typiques des PRFI.

Néanmoins, des résultats agroécologiques préliminaires (valables pour les exploitations observées) ont pu être obtenus avec la méthode TAPE. Les éléments agroécologiques «Gouvernance responsable» et «Valeurs sociales» ont obtenu les scores moyens les plus élevés, tandis que d'autres éléments tels que «Efficience» ou «Recyclage» peuvent encore être améliorés. Aucune différence significative n'a été constatée entre les régions (plaine/collines/montagne) pour la plupart des éléments, mais les exploitations biologiques (certifiées) ont obtenu de bien meilleurs résultats que les exploitations non biologiques en ce qui concerne la transition vers l'agroécologie. Il convient toutefois de noter qu'avec seulement huit exploitations biologiques et treize exploitations non biologiques, notre échantillon est beaucoup trop petit pour être représentatif du secteur agricole suisse.

Nous avons non seulement testé la méthode TAPE en Suisse, mais l'avons étendue pour inclure la biodiversité non planifiée, un aspect écologique important qui n'a pas été pris en compte jusqu'à présent. Le nouvel indice de biodiversité est basé sur la méthode européenne BioBio. La comparaison du nouvel indice de biodiversité avec une méthode beaucoup plus détaillée et chronophage («SALCA-BD») montre une corrélation positive ($r = 0,56$, valeur $p=0,009$). Sur la base de nos résultats, le nouvel indice de biodiversité a été mis en œuvre dans TAPE et est disponible gratuitement pour d'autres utilisateurs si nécessaire.

1 Introduction

1.1 Description of the Tool for Agroecology Performance Evaluation (TAPE)

1.1.1 General description of TAPE

The term “agroecology” covers different realities: it refers to a set of agricultural practices, a scientific discipline, and/or a political/social movement (Wezel et al., 2009). Agroecology as a set of practices promotes diversification of techniques that protect and respect local ecosystems and biodiversity, but also diversification of healthy food production (Sachet et al., 2021). Although growing evidence of the benefits of agroecology exists, the results remain fragmented because e. g. of different methods, data, and scales (Mottet et al., 2020; Silici, 2014). Therefore, the promotion of agroecology in research and policies has so far been limited (Silici, 2014). To assess the impact of it with a globally applicable and comparable method, the “Tool for Agroecology Performance Evaluation” (TAPE) has been developed under the coordination of the Food and Agriculture Organisation (FAO). The goal of TAPE is to produce evidence on (1) the use of agroecological practices and (2) the performance of agroecological systems on sustainability. The method was consolidated by the participation of different stakeholders and experts from an international community. The farm/household scale was chosen as assessment unit, but part of the collected data also refers to the regional scale. The method is characterized by its simplicity and a minimal, yet extendable data collection effort.

TAPE involves four steps. **Step 0** is a preliminary step, in which general information is collected with a desk review. It comprises basic information from territorial to national level. On the large scale (e. g. Switzerland), Step 0 includes e. g. descriptions of the demographic characteristics of the farms in the territory, of the ecological environment, and the market structure. On the farm level, general farm characteristics are collected within Step 0, such as the geolocation and the size of the farm.

Step 1 measures where the agricultural system stands in terms of its transition towards agroecology. It is based on the ten Elements of Agroecology defined by the FAO (Barrios et al., 2020). Each element is covered by three to four multiple-choice questions, the answers to which give 0 to 4 points (see Appendix, Section 8.1). The ten elements and their indices to **c**haracterize their **a**gro**e**cological **t**ransition (CAET indices) can be found in Table 1.

Step 2 measures the impact on five dimensions of sustainability using both qualitative and quantitative information. Each dimension is assessed using one or several core criteria of performance (Table 2). The indicators in Step 2 are more complex than in Step 1 and calculated with scoring systems and/or formulas (see Appendix, Section 8.2).

Step 1 and 2 are the core analytical steps, which can be carried out simultaneously during a maximum 3 h farm visit in most cases. They are used to reveal the strengths and weaknesses of the systems and territories assessed.

The final analysis and participatory interpretation of the results are covered in **Step 3**. The aims are to verify the framework, to put the results from Step 1 and Step 2 into context, and to discuss how to support the agroecological transition in the region with farmers and other stakeholders.

The questionnaire, the calculations, and the indicators/indices of TAPE are described in the study by Mottet et al. (2020) and its supplementary material. Since then, however, several changes have taken place. While Step 1 involves only minor reformulations in the multiple-choice answers, there have been important clarifications or changes in the calculation of some Step 2 indices (e. g. economic indices). Those changes were partially initiated by this study and partially by the FAO beforehand. In the Appendix, we provide an updated version of the calculations from Step 1 and Step 2.

Table 1: Structure of TAPE Step 1, the 10 Elements of Agroecology defined by the FAO and their corresponding CAET indices.

Element of Agroecology	CAET Indices
Diversity	Crops
	Animals, including fish and insects
	Trees and other perennials
	Diversity of activities, products, and services
Synergies	Crop-Livestock-Aquaculture integration
	Soil-Plants management system
	Integration with trees
	Connectivity between elements of agroecosystem and landscape
Efficiency	Use of external inputs
	Management of soil fertility
	Management of pests and diseases
	Productivity and household's needs
Recycling	Recycling of biomass and nutrients
	Water saving
	Management of seeds and breeds
	Renewable energy use and production
Resilience	Stability of income/production; capacity to recover
	Mechanisms to reduce vulnerability
	Environmental resilience; capacity to adapt to climate change
	Average diversity
Culture and food tradition	Appropriate diet and nutrition awareness
	Local or traditional identity awareness
	Use of local varieties/breeds; traditional knowledge for food preparation
Co-creation and sharing of knowledge	Platforms for horizontal creation; transfer of knowledge and good practices
	Access to agroecological knowledge and interest of producers in agroecology
	Participation of producers in networks and grassroot organisations
Human and social values	Women's empowerment
	Labour
	Youth employment and emigration
	Animal welfare
Circular and solidarity economy	Products and services marketed locally
	Networks of producers, relationship with consumers, presence of intermediaries
	Local food system
Responsible governance	Producers' empowerment
	Producers' organisations and associations
	Participation of producers in governance of land and natural resources

Table 2: Structure of TAPE Step 2, main sustainability dimensions and core criteria of performance.

Main dimension	Core criteria of performance
Governance	Secure land tenure
Economy	Productivity
	Income
	Value added
Health and nutrition	Exposure to pesticides
	Dietary diversity
Society and culture	Women's empowerment
	Youth employment opportunity
Environment	Agrobiodiversity
	Soil health

1.1.2 Coverage of agrobiodiversity in TAPE

In the following, we shortly describe how agrobiodiversity (or agricultural biodiversity) is currently covered in TAPE since this is one focus of this study. According to the Encyclopedia of Biodiversity (Jackson et al., 2013), agrobiodiversity encompasses the diverse range of living organisms, including plants and animals, which contribute to food and agriculture and are linked to the cultivation of crops and the raising of animals in complex ecological systems. In some cases, its scope is extended to incorporate all organisms within an agricultural landscape, e. g. crops and animal breeds, pollinators, symbionts, pests, and competitors. Croplands and fields, as well as habitats and species beyond farming systems that influence agricultural and ecosystem functions in the agricultural landscape are included as well (Jackson et al., 2013).

"Diversity" (going beyond agrobiodiversity) is one of the 10 elements of agroecology. Therefore, the diversity of crops, livestock, trees (and other perennials), and activities/products/services is assessed in Step 1 (see Section 8.1). Only the first three subcategories are directly linked to agrobiodiversity.

In Step 2, agrobiodiversity is one of the core criteria of performance. It is evaluated using the agrobiodiversity index, which is the average of the crop diversity index, the livestock diversity index, and the other-elements-index (see Section 8.2.5). Thus, more data are needed for this index than for the element "diversity" in Step 1.

1.2 Research goals of this study

So far, TAPE has been developed and used predominantly in low- and middle-income countries (LMICs; with data from over 40 countries to date, e. g. James et al., 2023; Lucantoni et al., 2023). Since TAPE claims to be applicable on a global level, it is important to test the questionnaire in high-income countries as well. Therefore, the first research objective was to test TAPE in Switzerland to suggest possible improvements for TAPE's applicability in high-income countries as well as to get first insights to where Switzerland stands in terms of agroecological transition.

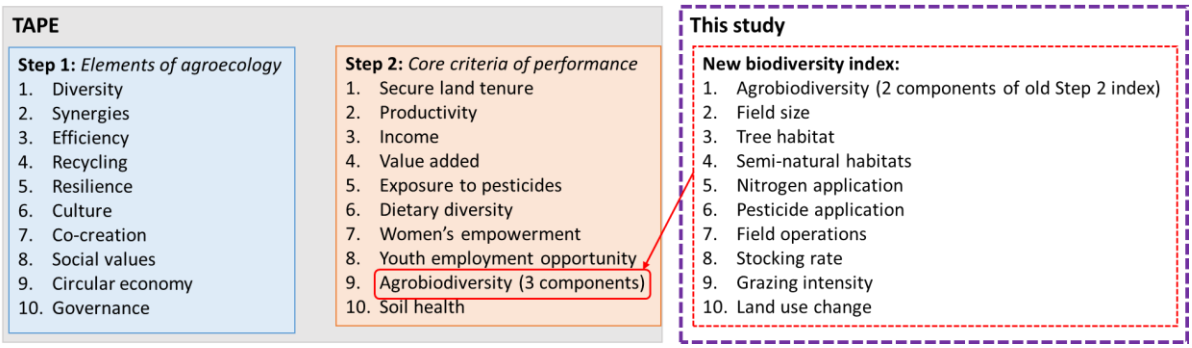

Figure 1: Embedding the new biodiversity index in the framework of TAPE. The two domains transferred to the new biodiversity index are the crop diversity index and the animal diversity index.

In TAPE, mainly planned agrobiodiversity is assessed in the agrobiodiversity index, i. e. the biodiversity of the crops, livestock, and semi-natural habitats (e. g. trees) chosen by the farmer. "Unplanned biodiversity" is so far hardly

addressed in TAPE; it includes the associated biota that colonize the agroecosystem and survive dependent on the local management and environment (Jackson et al., 2013). For example, fertilizer and pesticide applications have a large impact on biota such as vascular plants, farmland birds, and arthropods.

The second objective of this study was therefore to extend the TAPE agrobiodiversity index (Step 2) by incorporating unplanned biodiversity (Figure 1). This new biodiversity index should be applicable on the global scale, thus it was developed in Switzerland and then tested in an LMIC, namely Kenya. In this report, we focus on the TAPE results for Switzerland; the results for Kenya are provided in Merbold et al. (2023, in preparation).

2 Methods and data

The standard TAPE approach was slightly modified in this study and as follows. In Step 0, a desk review was not necessary since the enumerators were already very familiar with the Swiss agricultural and food system. Moreover, we did not draw a representative farm sample for Switzerland or a specific Swiss region/agricultural system. This seemed unnecessary since our primary intention was to verify whether TAPE is applicable in Switzerland at all. Furthermore, we relied on the assistance of farms from the Swiss Agri-Environmental Data Network (SAEDN; Gilgen et al., 2023) (see Section 2.1). Since these farms already provide detailed data for the SAEDN monitoring programme, it was challenging to motivate them for the TAPE interview for reasons of additional data recording effort.

Concerning Step 3, there was limited participatory exchange in this project because the applicability of TAPE, and not the final results, were the main focus. However, we sent an individual farm evaluation to each participating farm, which explained where the farm performed well and where potential for improvement exists. Instead of a thorough participatory approach, this study focused in Step 3 on data quality controls and plausibility checks of the results.

2.1 Recruited farms and interviews

Farmers for this study were recruited from the SAEDN. The SAEDN consists of around 300 farms that deliver structural and management data to Agroscope for the calculation of different agri-environmental indicators (Gilgen et al., 2023). Data are transmitted in an anonymised form via trustee agencies, therefore the recruitment process had to go through those. In total, 21 farms registered for participation (Figure 2). Due to the voluntary participation, the farms are not a representative sample of Swiss farms. However, they still represent a cross-section of different regions (Figure 2) and thus a variety of farming systems. Eleven, six, and four farms originated from the valley, hill, and mountain regions, respectively. Besides representing different regions, the farms surveyed also cover different concepts of farming, for example: (certified) organic (8) versus non-organic (13) farms; diversified versus specialised farms; farms which focus on direct marketing versus farms which sell their products to wholesalers.

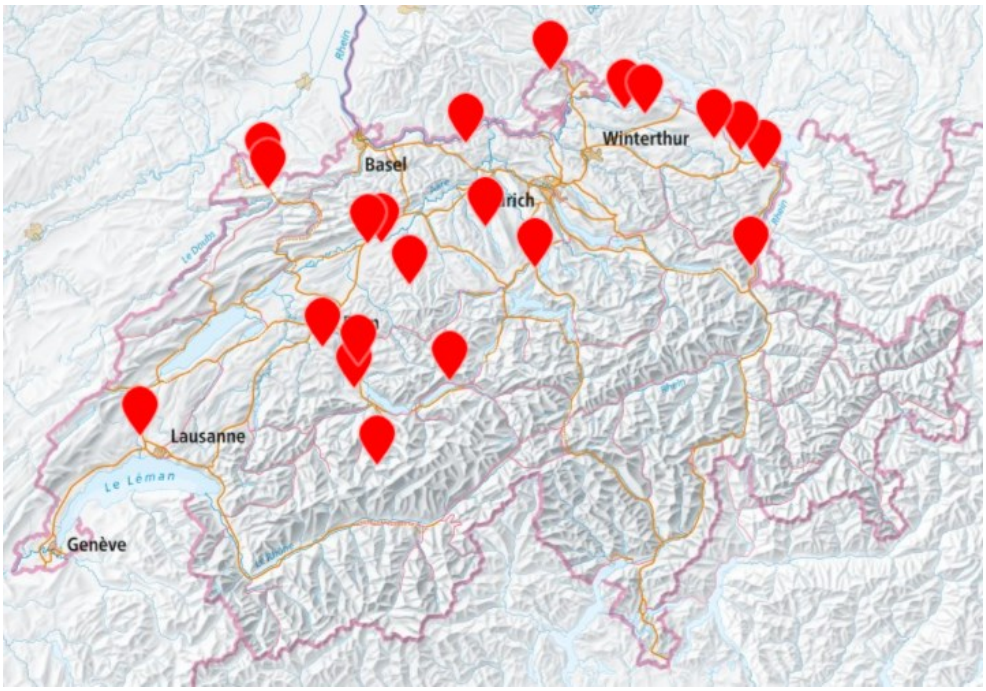

Figure 2: Approximate location of Swiss farms that participated in the TAPE survey.

We chose SAEDN farms because a large amount of data of these farms is already available in a standardized, digitalized form and could be integrated into the analysis. Furthermore, 19 of the farms that were surveyed with TAPE also participated in the Swiss Farm Accountancy Data Network (FADN), i. e. also accounting data were available in a standardized form. These data were used to answer some questions prior to the survey and allowed to shorten the interviews considerably. Moreover, using SAEDN and FADN data allowed to compare selected ecological and economic indicators from these networks (Swiss biodiversity indicator, productivity, and income) with the TAPE results. This made it possible to validate the robustness of TAPE results in Switzerland.

Due to data availability, SAEDN and FADN data of the year 2020 were used for this study, although the interviews were held in April and May 2022. For this reason, at the beginning of each interview the farmers were asked whether the farm structure had changed considerably in the last two years. If this was the case, the questions were asked to reflect the state in 2020.

On average, around ten hours were spent on data collection per farm: The interviews themselves lasted between 1.5 and 3 hours. Travel time required another 3-6 hours, depending on the farm location. Another 3-6 hours were needed for the pre- and post-data collection – although some simplifications were already made in the data collection to avoid exceeding the workload (see also Section 4.1.5). The data were transferred to the FAO through the online tool KOBO (https://www.kobotoolbox.org/).

The interviews were conducted by two Agroscope researchers. Before the interviews, the enumerators screened the existing SAEDN and FADN data to gain a first impression of the farm and to be able to ask more targeted questions. On the farm, the enumerators explained again the aim of the study and TAPE before commencing with the interview. Furthermore, farm walks were conducted and observations included in the data entry, for example for the soil assessment or the distribution of semi-natural habitats. The enumerators received training from the FAO before the interviews, coordinated before and during the interview phase, and conducted the first interview together in order to ensure the most uniform recording as possible.

2.2 Adaption of the TAPE questionnaire to Swiss conditions

Due to the open formulation of the questions, TAPE leaves some room to adapt the questions to local conditions, which is also envisaged to a certain extent (Mottet et al., 2020). Before the interviews, the TAPE questionnaire was therefore specified to Swiss conditions. In Table 3, we provide selected examples of adaptations made for questions in Steps 0, 1, and 2.

Table 3: Examples of how the TAPE questions were adapted to Swiss conditions.

Step, question	Original formulation in TAPE	Adaptation to Swiss conditions
Step 0, question 10	What is the main intended destination of the agricultural production? Sale / Mostly sale and a small part of self-consumption / Equally sale and self-consumption / Mostly self-consumption and a small part of sale / Self-consumption	The term «mostly» was defined as 80%.
Step 1, biodiversity of trees	0 - No trees (nor other perennials). 1 - Few trees (and/or other perennials) of one species only. 2 - Some trees (and/or other perennials) of more than one species. 3 - Significant number of trees (and/or other perennials) of different species. 4 - High number of trees (and/or other perennials) of different species integrated within the productive system	The two separate subcomponents “area share of trees (and other perennials)” and “number of tree (and other perennial) species/varieties” were derived and averaged to one component. Other perennials include e. g. grapevines or blueberry bushes. Forest outside the utilised agricultural area (UAA) was not considered. One tree was counted as 1 a, in line with the Swiss direct payment regulations. <u>Number of trees</u> 0 - 0% of UAA are covered with trees (and/or other perennials) 1 - >0%-1% of UAA 2 - >1-5% of UAA 3 - >5-10% of UAA 4 - More than 10% of UAA <u>Number of varieties</u> 0 - No species/varieties 1 - 1 species/varieties 2 - 2 species/varieties 3 - At least 3 species/varieties 4 - At least 3 species/varieties and agroforestry
Step 1, recycling of biomass and nutrients	0 – Residues and by-products are not recycled (e. g. left for decomposition or burnt). Large amounts of waste are discharged or burnt. 1 - A small part of the residues and by-products is recycled (e. g. crop residues as animal feed, use of manure as fertiliser, production of compost from manure and household waste, green manure). Waste is discharged or burnt. 2 - More than half of the residues and by-products is recycled. Some waste is discharged or burnt. 3 - Most of the residues and by-products are recycled. Only a little waste is discharged or burnt. 4 - All of the residues and by-products are recycled. No waste is discharged or burnt.	Burning of residues and by-products is forbidden in Switzerland. Crop residues are normally either incorporated into the soil or removed from the field and used as bedding. Farmyard manure is typically used for fertilisation. Therefore, no Swiss farm could receive only 0 or 1 point. ~~0 - no utilisation of residues and by-products~~ ~~1 - minimal utilisation of residues and by-products~~ 2 - utilisation of farmyard manure 3 - utilisation of farmyard manure and one further recycling measure* 4 - Utilisation of farmyard manure and two or more further recycling measures* *Examples of recycling measures: - Use of crop residues - Green manure - Composting - Biogas facility
Step 2, crops and fruits	How many crop/tree species do you grow? For each… - Name of the crop species or type of crop - Total production (kg) - Quantity sold (kg) - Price at the gate (per kg) - Quantity given for free (gift, present …) (Kg) - Land under production (ha) - Number of varieties produced	In Switzerland, the majority of UAA is used for fodder production. Most of the fodder produced is used by the farmers themselves. It was therefore necessary to determine a uniform approach on how to deal with these feeds. For example, amounts and prices are often not known exactly and it is difficult to determine "varieties" for grassland. The following crops were added together:

		- cheap fodder (e. g. grass, litter, grass silage, loose fodder) - Price: 0.002 CHF/kg - (for "varieties", we distinguished between intensive ley, extensive meadow, etc.) - expensive fodder (e. g. maize, fodder beet, fodder wheat) - Price: 0.20 CHF/kg - (for "varieties", we distinguished between silage maize, fodder beet, fodder wheat, etc.) - vegetables (except if listed separately in the accounts or if the area under cultivation is large) - berries (except if listed separately in the accounts or if the area under cultivation is large)
Step 2, machinery	How many different pieces of machinery/equipment do you own? For each: - Name of the machinery / equipment - Quantity owned - Price at purchase (per unit) - For how many years have you been using this machinery/equipment? - What is the remaining useful life of this machinery (on average)?	Machinery/equipment were grouped into four categories to reduce the effort of recording (50 machines per farm is not uncommon in Switzerland). The four categories are: - Machines - Tractive forces - Passenger cars - Fixed installations Per category, average prices and years of use were entered. Estimated life span of machines: 30 years Estimated prices at purchase, if information was not available: - Machine: 3'000 CHF - Tractive force: 40'000 CHF - Passenger car: 6'000 CHF - Fixed installation: 9'000 CHF

2.3 Procedure to develop biodiversity index

We followed the TAPE principles for the development of the new biodiversity index, which include: (1) building the index on existing indicator frameworks; (2) keeping it as simple as possible with low time expenditure; (3) choosing indicators that can be influenced by actors (farmers, landlords, politicians); (4) choosing a method that is globally applicable.

The aim was to extend the TAPE biodiversity index to better include unplanned biodiversity. There are two basic approaches to quantify unplanned biodiversity: Firstly, there is the possibility of surveying wildlife flora and fauna directly in the field. Secondly, the impact on biodiversity can be approximated with variables that have been shown to have an impact on wildlife biodiversity, such as fertilisation management.

Initially, it was planned to adapt the Swiss method by Jeanneret et al. (2014) – in the following called “Swiss biodiversity indicator” – for the context of TAPE. This Swiss biodiversity indicator is used within the SAEDN and thus calculated every year for approximately 300 Swiss farms. The indicator was designed as a lifecycle assessment impact category and assesses the potential impact of agriculture on biodiversity using a very comprehensive framework. The method considers eleven indicator-species groups including e. g. arable companion flora or snails. For each of those, a score is calculated on field level. The score accounts for both the suitability of the field as a habitat and the management conducted on this field. It is based on hundreds of studies from Switzerland and Western Europe. Subsequently, a weighted average is calculated over the different fields and over the different indicator-species groups. Results are given on a semi-quantitative point scale – the more points, the higher the expected biodiversity.

However, we found that the Swiss biodiversity indicator is currently not adaptable to LMICs as the data availability is often insufficient to estimate the influence of different management practices on different indicator-species groups. Moreover, the collection of field-specific information on management – albeit relevant for biodiversity – conflicts with TAPE's goal of keeping data collection as short as possible.

Therefore, we examined other existing approaches that include unplanned biodiversity, but fit better within the context of TAPE. Specifically, we searched for simple methods that have successfully been tested also in LMICs. As there are many different methods to determine biodiversity, we relied on expert knowledge from Agroscope to narrow down the methods to be studied. Following this, it was decided to base the new biodiversity index on the BioBio method (biobio-indicator.org; Herzog et al. (2012)).

The goal of the BioBio research project was to identify farmland biodiversity indicators that are scientifically sound and practicable (Herzog et al., 2012). The BioBio method consists of eight indicators for habitat diversity, four indicators for species diversity, three indicators for genetic diversity, and eight indicators for farm-management practices. The indicators were tested in 12 different case study regions across Europe and – in addition – in Tunisia, Ukraine, and Uganda (Herzog et al., 2012).

3 Results

First, we describe the newly derived biodiversity index with its ten indicators and their normalizations. Second, results from the Swiss survey are presented, namely Step 1 and Step 2 of TAPE, a more thorough analysis of the economic indicators, and first results of the new biodiversity index (extended Step 2).

3.1 Derivation of the new biodiversity index

As described in Section 2.3, the BioBio method was chosen as basis for the new biodiversity index. Furthermore, we wanted to build on the existing TAPE questionnaire and therefore integrated TAPE's original agrobiodiversity index (Section 1.1.2) into the new biodiversity index. More precisely, the two domains crop diversity index and animal diversity index of the original agrobiodiversity index were used as the first element of the new composite biodiversity index (Figure 1). In the following, we describe which BioBio indicators were included in the new agrobiodiversity index in accordance with the TAPE requirements.

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 crop and livestock, e. g. the number and amount of different varieties and breeds. These aspects are already covered by the agrobiodiversity index 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 the BioBio indicators habitat diversity and agricultural management were considered and partly adapted for TAPE (Table 4). Habitat diversity is a good proxy for very mobile organisms, whereas management practices are good proxies for less mobile organisms.

Table 4: BioBio Indicators (Herzog et al., 2012) for habitat diversity and agricultural management. In the last column, their feasibility and adaptation for TAPE is described.

Indicator	Original BioBio indicators	Adaptation for TAPE
Habitat diversity		
Habitat Richness	«Number of habitat types, including linear habitats, occurring on a farm. Habitats considered are intensively farmed habitats as well as extensively farmed and semi-natural habitats. The unit of measurement is number of habitats per hectare of farm area.»	The indicators habitat richness and habitat diversity require mapping of the different habitat types. However, this is not straightforward for non-biodiversity experts. It is possible that the TAPE-enumerators would equate habitat with crop, but this is only partially true. Furthermore, crop diversity is already included in the TAPE indicator for agrobiodiversity. For this reason, we decided against these two indicators. Instead, only semi-natural habitats (e. g. hedgerows, wildflower strips) are taken into account because they are beneficial for biodiversity and hardly covered in TAPE. We consider both the overall (total) share of semi-natural habitats and the number of different semi-natural habitats. The relative shares of individual semi-natural habitats are not taken into account, as the areas depend strongly on the
Habitat Diversity	«Diversity of habitats available on the farm, including linear habitats, taking into account both the number of habitat types and their relative proportions of the total farm area. The unit of measurement is the Shannon Index, which will have a value of zero if there is only one habitat on the farm (no diversity) and will increase with increasing habitat	

	richness, in particular if their share of farm area is similar.»	type of semi-natural habitat (e. g. an extensive meadow has on average a much larger area than a hedge).
Semi-natural Habitats	«Share of semi-natural habitats on the farm. The unit of measurement is percent of Utilized Agricultural Area.»	
Linear Habitats	«Length of hedgerows, tree lines, scrub lines, grassy strips between fields, streams, rivers, stone walls and terrace walls which are on the farm or directly adjacent to fields of the farm (thus affected by farm management) in meters per hectare.»	We did not consider the indicator shrub habitats because its interpretation is not straightforward – it can be beneficial or detrimental for biodiversity, depending on the context. With regard to linear habitats and tree habitats, there is some overlap (hedges, trees in rows). We therefore restrict ourselves to the tree habitats indicator: This indicator is easier to collect (also possible with aerial photographs) and there are more synergies with TAPE, for which trees already have to be mapped. We slightly adapted the tree habitats indicator to exclude intensive orchards.
Shrub Habitats	«Percentage of the total farm area covered by shrubs. The unit of measurement is the percentage of the Utilized Agricultural Area (UAA).»	
Tree Habitats	«Relates to fruit trees, ornamental trees, vines and pastured forest as well as to hedgerows and semi-natural woodland elements on Utilised Agricultural Area (UAA). The unit of measurement is % of UAA.»	
Crop Richness	«Number of crops cultivated on a farm on a per hectare basis. Crops considered are arable crops (including forage and sown grassland), vegetables and tree crops. The indicator relates to the areal farm habitats, excluding woods and forest, permanent grassland, sparsely vegetated semi-natural habitats and all linear habitats. The unit of measurement is the number of crop types per hectare of farm area.»	Not considered separately since crop diversity index is already part of the agrobiodiversity index.
Patch Size	«Average size of habitat patches on a farm. The unit of measurement is hectares.»	Adapted to average field size instead of habitat patch since this is easier to collect (no expert knowledge required). Furthermore, there are several studies that show the positive effect of small field sizes for biodiversity (Sirami et al., 2019). Depending on the project and available data, the median field size can be taken as an alternative.
Agricultural management		
Total Direct and Indirect Energy Input	«Consumption of direct energy (fuel, electricity) and indirect energy (synthetic fertilisers, pesticides, feedstuff and machinery) for production of crops and livestock is a measure of the energy intensity for farms. Unit: GJ per ha Utilised Agricultural Area (UAA).»	Not considered. The calculation of indirect energy is too time-consuming, the calculation of direct energy is complicated by the distinction between farm and household.
Intensification / Extensification: Expenditure on inputs	«Annual expenditures on fertilizer, crop protection, pesticides and concentrate feed stuff. The unit of measurement is Euros (€) per ha utilized agricultural area (UAA).»	Not considered. More important than the expenditures are the usage of the inputs, which is considered through the indicators below.
Area with use of mineral nitrogen fertiliser	«Proportion of Utilised Agricultural Area (UAA) where mineral-based nitrogen fertilizer is applied. Unit of measurement: % UAA with use of mineral N fertilizer.»	Considered.
Nitrogen Input	«The unit of measurement is average input of nitrogen at the farm-level (kg N per ha UAA).»	Adapted to N input of manure, compost, and synthetic fertilizer. Biological fixation is not considered as it is difficult to quantify (e. g. highly dependent on clay content for pastures).
Pesticide Use	«This indicator measures the frequency of pesticide use on the farm. The unit of measurement is the area-weighted	The indicator summarises substances and thus does not consider the actual effect on species. We therefore extended the pesticide indicator to consider three aspects: 1) Share of the total farm area where pesticides

	average of numbers of pesticide applications on a farm.»	are applied. 2) The number of pesticide applications per ha UAA. 3) The ecotoxicity of the pesticides used. This is feasible because the individual pesticides and their human toxicity (among others) are already queried in TAPE. It is therefore not a great additional effort to also provide information about the ecotoxicity.
Field Operations	«Quantifies the number of mechanized field operations in crop fields and grassland. The unit of measurement is the total number of field operations. On farm-level the area-weighted average is calculated.»	Considered. Depending on the project and available data, either an area weighted average or a simple average (total number of applications divided by UAA) might be easier applicable.
Average Stocking Rate	«Livestock density on the farm, i. e. number of livestock in relation to the farm area. Unit of measurement: Number of livestock units (LU) per Utilized Agricultural Area (UAA).»	Considered.
Gazing Intensity	«This indicator evaluates the intensity of grazing on the pastures of the farm. Unit: Number of livestock units (LU) per hectare grazing area.»	Considered. Grazing area does not include communal land.

This resulted in a new biodiversity index (description in Table 5) based on the following ten indicators: (planned) agrobiodiversity, field size, tree 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 5), 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.

Table 5: The indicators of the new TAPE biodiversity index.

Indicator	Calculation	Normalisation
Agrobiodiversity	This is the average of the crop index and the animal index of the original TAPE agrobiodiversity index for planned biodiversity (see Sections 1.1.2, 3.2.2). The third domain of the original TAPE agrobiodiversity index ("index of other elements") 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 objectively determine (abundance of beneficial insects).	The Gini-Simpson-index is used, which takes values between 0% and 100%.
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 categorized (0% - 100%) according to the mean field size (fs): - fs < 0.5 ha → 100% - 0.5 ≤ fs < 3 ha → 75% - ≤ fs < 16 ha → 50% - 16 ≤ fs <100 ha → 25% - ≥ 100 ha → 0%
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 percentage of the area of tree habitats on the UAA.
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.
Nitrogen application	The nitrogen application indicator is calculated through two individual domains: 1) Area with 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 fertiliser (in percent). Domain 2 (calculated as kg N per ha) is classified as follows: - ≤ 1 kg N per ha → 100% - >1 – 30 kg N per ha → 75% - >30 – 100 kg N per ha → 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.
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 got 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 for fish (category I) and only slightly toxic for 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).
Field operations	The field operation indicator (FieldOP) is the area-weighted average of the number of mechanised field operations: $$FieldOP = \sum \frac{N_{FOi} * A_i}{A_{UAA}}$$ 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%
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%)
Grazing intensity	For the grazing intensity, all forage consuming animals are considered. To calculate the grazing intensity (GI) indicator, the livestock units are multiplied with the proportion of time in a year spent on the pastures of the farm (not including external pastures) and divided by the farm's pasture area: $$GI = \sum \frac{N_i * LU_i * t_i}{Ag}$$ N_i = number of animals by livestock category	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).

	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.	
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: $LUC = 100 - \frac{Area\ changed\ (ha)}{UAA\ (ha)} * 100$	The land use change indicator is the percentage of the total farm area that has not undergone LUC (in %) in the last year.

3.2 Results of Swiss survey

In Sections 3.2.1 and 3.2.2, we summarise the results from TAPE Step 1 and (the original) Step 2, respectively. We examined the data with regard to two categorizations: region and farming system. For the categorization by region, we distinguished between valley, hill, and mountain based on a Swiss regulation (see Gilgen et al., 2023 for more details). For the production system, we distinguished between organic and non-organic farms. The organic farms in this study are affiliated to an organic label and receive direct payments for organic farming.

The comparison between results from TAPE and FADN accountancy data (for productivity and income) is shown in Section 3.2.3. In Section 3.2.4, first results of the new biodiversity index are presented.

3.2.1 Step 1: Assessing agroecological transition with a multiple-choice questionnaire

As mentioned in Section 1.1.1, Step 1 provides information about the agroecological transitions of the farms. Each of the 10 elements of agroecology is assessed by several multiple-choice questions, with the answers resulting in point scores between 0 and 4 (Section 8.1).

The overall findings of Step 1 show that organic farms performed better for all 10 elements of agroecology except for responsible governance, where all farms in our sample received 100% (Figure 4). The absolute differences between organic and non-organic farms were most pronounced for efficiency (31 pp = percentage points), co-creation and knowledge (21 pp), synergies (19 pp), recycling (17 pp), and diversity (17 pp). The differences between regions were smaller (Figure 3). The diversity score of the mountain region was 10 pp smaller than the one of the valley regions. On the other hand, the mountain regions received 14-15 pp higher scores for the elements synergies, efficiency, and recycling. Below, we will analyze the results in more details for each of the 10 elements of agroecology.

Diversity

The diversity CAET index consists of four multiple-choice questions about crops, animals, trees, and economic activities. The diversity score was lower in farms from the mountain region because of a lower crop diversity (predominantly grassland) and a lower diversity of economic activities. It needs to be taken into account that only four mountain farms participated in the study and that one of those has grown unusual crops (blueberry shrubs and vegetables growing in a tunnel). Therefore, differences between regions might be larger with a representative sample of Swiss farms. The diversity of organic farms was 17 pp higher compared with non-organic farms, with all four multiple-choice questions receiving higher scores.

Synergies

The four synergies multiple-choice questions are related to crop-livestock-aquaculture integration, soil-plants system management, integration with trees, and connectivity between elements of the agroecosystem and the landscape. Mountain farms mainly performed better because of high scores for soil-plants system management and for connectivity. The high scores for soil-plants system management are related to the small soil disturbance and high soil cover of permanent grassland. The differences were also pronounced between organic and non-organic farms. The organic farms performed better; the largest differences occurred for the multiple-choice questions integration with trees and connectivity.

Efficiency

The efficiency CAET index considers the use of external inputs, management of soil fertility, management of pests and diseases, and productivity and household's needs. Organic farms performed somewhat worse for the question productivity and household's needs, but much better for the other three multiple-choice questions, resulting in a higher efficiency score by 31 pp. The management of soil fertility question considers how much synthetic fertilizer is used; since organic farms are not allowed to use synthetic fertilizer, they all received the highest score. For the question about management of pests and diseases, farms that apply chemical pesticides and drugs can receive between 0 and 2 points, while farms using organic pesticides can receive between 3 and 4 points. As a consequence, organic farms generally performed better than non-organic farms. The higher efficiency score of mountain farms compared to valley farms can also to a large extent be explained by the reduced usage of mineral fertilizer and pesticides.

Recycling

The recycling CAET index consists of four questions that focus on the recycling of biomass and nutrients, water saving, management of seeds and breeds, and renewable energy and production. Mountain farms had a higher recycling score than valley farms. The largest difference was found for the question about management of seeds and breeds, since mountain farms in many cases do not need to buy seeds and thus receive a higher score. Furthermore, organic farms performed clearly better than non-organic farms in all four questions, with no question standing out particularly.

Resilience

The resilience CAET index considers the stability of income, the mechanisms to reduce vulnerability, environmental resilience, and diversity (i. e. the diversity indicator described above). There were no pronounced differences for the three regions. The higher score of organic farms is related to the higher diversity as well as a somewhat higher environmental resilience.

Culture

The three questions of the culture CAET index address appropriate diet and nutrition awareness, local or traditional identity and awareness, and use of local varieties/breed and traditional knowledge for food preparation. There were no pronounced differences for either the regions or the farming systems.

Co-creation

The co-creation CAET index consists of questions related to existing platforms for horizontal creation and transfer of knowledge, access to agroecological knowledge and interest of producers in agroecology, and participation of producers in networks and grassroot organisations. Organic farms performed better than non-organic farms, mainly because they showed a larger interest and knowledge about agroecology. Moreover, valley farms performed somewhat better than mountain and hill farms in our sample because they participated more in grassroot organisations and because they educated themselves more and exchanged ideas with each other.

Social values

The social values CAET index considers questions regarding women's empowerment, labour, youth empowerment and emigration, and animal welfare. The overall score was similar for the different regions. Women's empowerment

and youth empowerment performed somewhat better in the valley region than in the hilly and mountain regions. Organic farms performed somewhat better in all multiple-choice questions, especially with regards to animal welfare.

Circular economy

The three questions of the circular economy CAET index refer to locally marketed products, networks of producers and relationship with consumers, and the local food system. Organic farms received a somewhat higher score because they did more direct marketing. The difference between the regions was not pronounced.

Responsible governance

The responsible governance CAET index consists of three multiple-choice questions about producers' empowerment, producers' organisations and associations, and participation of producers in governance of land and natural resources. These aspects were not asked on the farms, as they are regulated at national level. In Switzerland, a standardized and fully functional education system exists, human and fundamental rights are respected, there are several producer organisations, and farmers can get involved through direct democracy. For this reason, the maximum number of points was given to all farms. However, especially concerning gender equality, it is two different things whether equality is legally implemented or whether it is lived in society and in everyday life. More in-depth aspects of gender equality are discussed in Step 2 with the women's empowerment indicator.

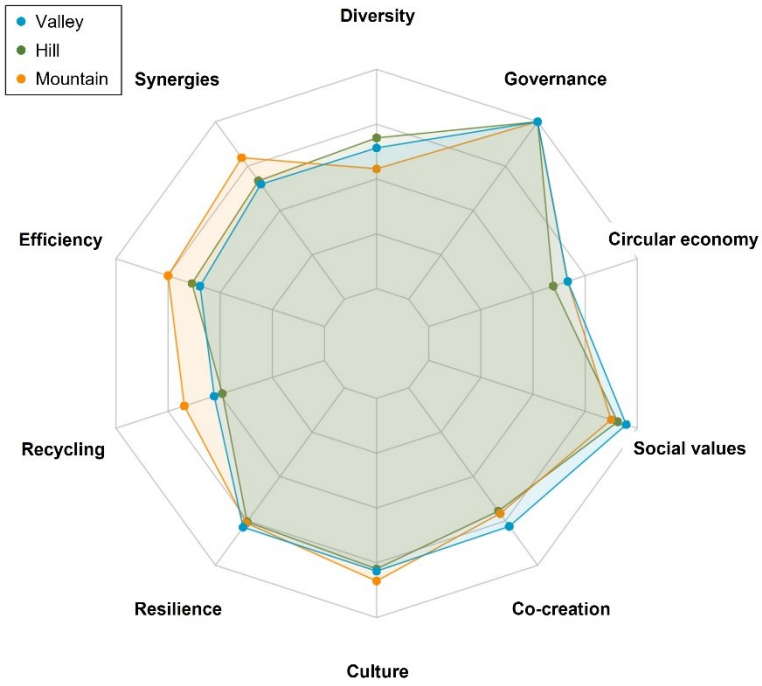

Figure 3: TAPE Step 1 results categorised by region for the 21 farms surveyed.

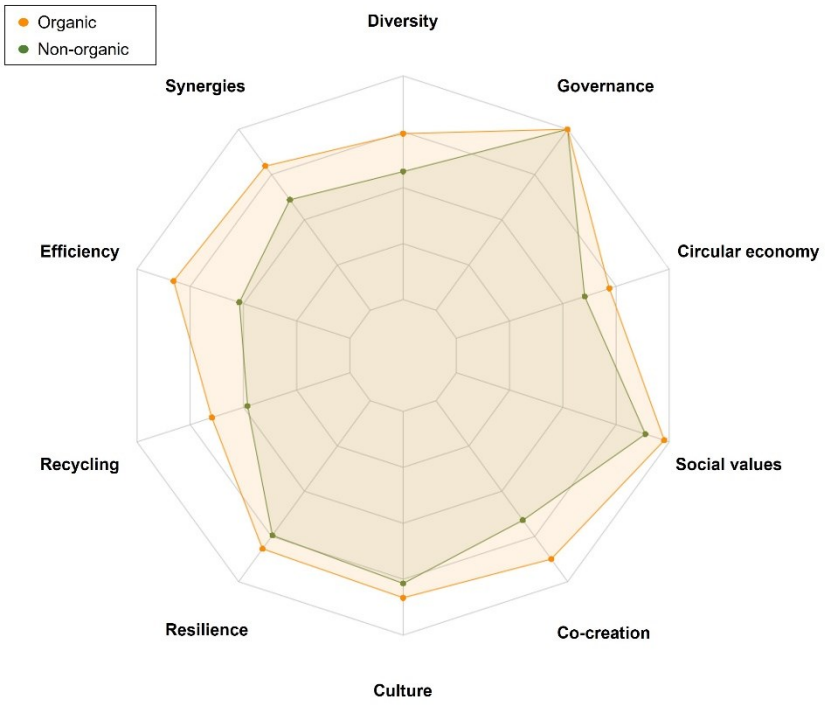

Figure 4: TAPE Step 1 results categorised by farming system for the 21 farms surveyed.

3.2.2 Step 2: Assessing the impact on sustainability using indices

Step 2 of TAPE considers significantly more data for the sustainability assessment. These data include e. g. information on the harvested production, including the quantities sold, donated or self-consumed, and information on all pesticides used. With these data, several indicators are calculated that cover the five sustainability dimensions governance, economy, health and nutrition, society and culture, and environment. The TAPE indicators that did not already refer to a scale between 0% and 100% were converted accordingly in this study (see Section 8.2). This allowed the results for Step 2 to be presented in a spider diagram as for Step 1.

Overall, the analysis revealed clear differences for the economic indicators as well as for the pesticide indicator (Figure 5, Figure 6). Mountain and organic farms received higher (i. e. better) values for the pesticide indicator, but lower values for the economic indicators.

Governance

Governance is covered in TAPE by the land tenure indicator, which was calculated as the mean of the land tenure indicator for men and the land tenure indicator for women. Overall, the score is high because farmers in Switzerland have recognized title deeds to their land and they feel safe crossing their land (Section 8.2.1). The land tenure indicator value for men was 100% throughout, whereas the score for women was either 100% or 50%. The latter was the case if the land did not belong to the women. This was relatively often the case on the farms visited, because many times the man had inherited the land.

Economy

Values of the three economic indicators productivity, income, and value added ranged from 0% to 100%, with large standard deviations between 35% and 44%. These values and ranges are influenced by the scaling (see Section 8.2.2), but also the unscaled values span a large range (Figure 7). The values for the economic indicators were smaller in the mountain region than in the hilly and valley regions (Figure 5) and smaller for organic farms than for non-organic farms (Figure 6).

Health and nutrition

The pesticide scores of the farms ranged between 44% and 100%, with a rather large standard deviation (24%). This is due to the very different amounts and types of pesticides used, which are related to the different regions (less pesticides in mountainous areas than in valley areas, Figure 5) and the different farming systems (less pesticides on organic farms compared to non-organic farms, Figure 6).

All farms reached comparably high dietary diversity scores, ranging between 70% and 100%. This means that farmers consume between 7 and 10 of the 10 food groups surveyed (e. g. dairy). There were no large differences between regions or farming systems.

Society and culture

The youth indicator consists of the two domains youth employment and youth emigration. For youth employment, the full score is only achieved if all children in the age of 15 to 34 are in education or working in the agricultural production of the farm. Considering emigration, the full score is only given if all children want to continue the agricultural activities of their parents.

12 out of the 21 farms had children aged 15 to 34 and were thus included in the calculation. The youth scores ranged between 25% and 100% and showed a relatively large standard deviation (29%). The differences between regions and farming systems were not pronounced.

The women's empowerment indicator comprises the five domains productive decision making, access to productivity inputs, income decision making, leadership, and time use. The women's empowerment indicator achieved overall high values, ranging between 60% and 100% for the individual farms. Except for the domain leadership (83%), all average domains reached scores over 90%. Some farms received a low score in leadership because the woman had no agricultural training, worked mainly outside the farm, and only helped out on the farm from time to time.

Environment

The agrobiodiversity index consists of the three domains crop diversity index, animal diversity index, and other elements of agrobiodiversity (Section 8.2.5). The crop diversity index showed the largest average score (86%), followed by the other elements (59%) and the animal diversity index (47%). There were no clear differences for the agrobiodiversity index between the regions or the farming systems.

The soil health indicator is determined by looking at the soil on a field and evaluating it according to criteria such as soil structure or soil compaction. Because of problems with the soil inspections (Section 4.1.2), we gave a default value of 4 points for each criterion (points range from 1 to 5). If the soil performed particularly well/badly in a criterion, we gave plus/minus 1 point. In addition to the visual inspection, the farmer's statements were also taken into account. Not surprisingly, the soil health scores thus only ranged between 3.9 points (72%) and 5 points (100%). A standard deviation larger than 0.5 only occurred for the categories water retention, soil cover, and erosion. There were no pronounced differences between regions and farming systems.

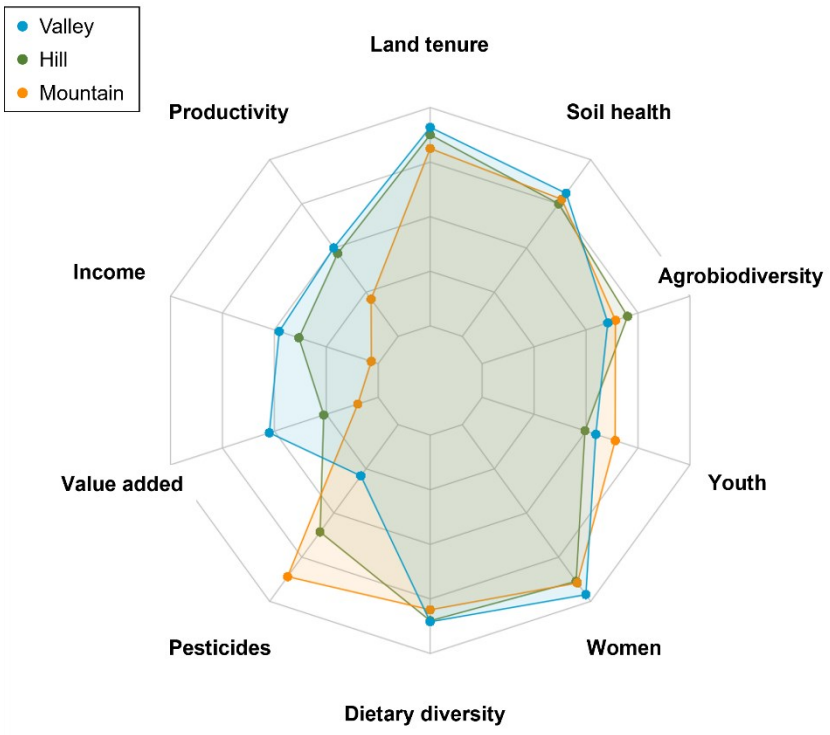

Figure 5: TAPE Step 2 results categorised by region for the 21 farms surveyed.

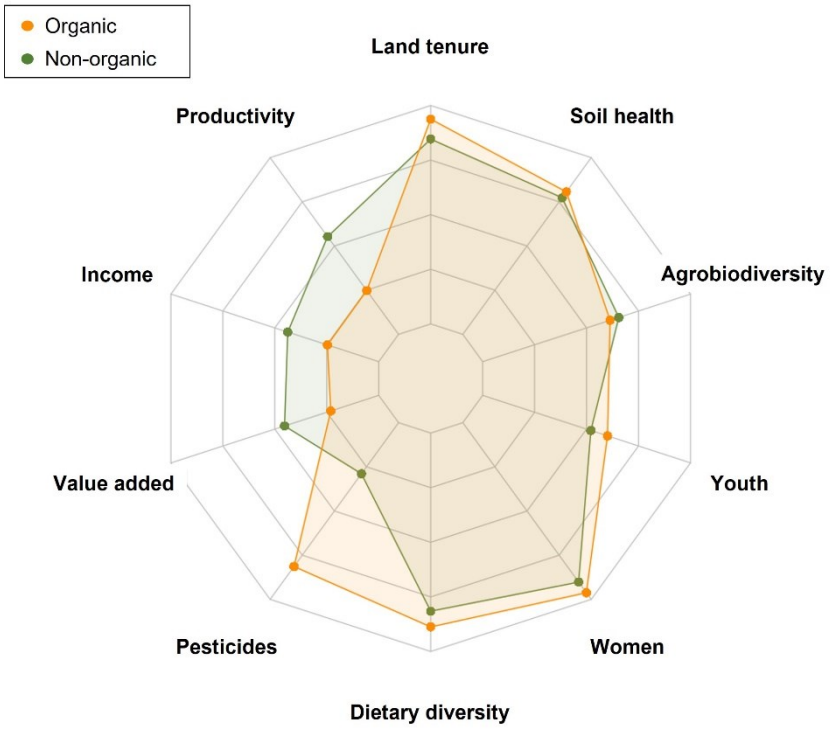

Figure 6: TAPE Step 2 results categorised by farming system for the 21 farms surveyed.

3.2.3 Comparing the economic indicators of Step 2 with FADN results

Using the accounting data provided by the farms, we compared TAPE's productivity and net income with the calculated values from the accounts (FADN). For a meaningful comparison, the following changes were performed:

- For the calculation of productivity, direct payments were subtracted from the agricultural revenue of the accounting data.
- Private taxes were added to TAPE's income, since taxes are not subtracted from income in Switzerland and not only related to agricultural income.
- We added the social security expenses to the FADN's income, because these are not subtracted in the calculation of TAPE's income. (Thus, according to Swiss terminology, it is not a net income, but a gross income.)

Both the productivity and the income correlate very well (Figure 7), with significant correlation coefficients over 0.9 for productivity ($r = 0.92$ for Pearson, $r = 0.96$ for Spearman rank) and around 0.8 for income ($r = 0.81$ for Pearson, $r = 0.77$ for Spearman rank). It is worth mentioning that the correlation coefficients were initially much lower, motivating us to have a closer look at the input data as well as the calculation. Errors were found and eliminated in both the data collected and the code for the calculations, resulting in the significantly higher correlation. The remaining differences between the TAPE indicators and the accounting data are due to simplifications in TAPE's calculations as well as due to different approaches to calculate depreciation (the latter is only relevant for income calculation). For example, animals cannot be recorded by age in TAPE and some financial items are not included (e. g. insemination costs, office/digitization costs).

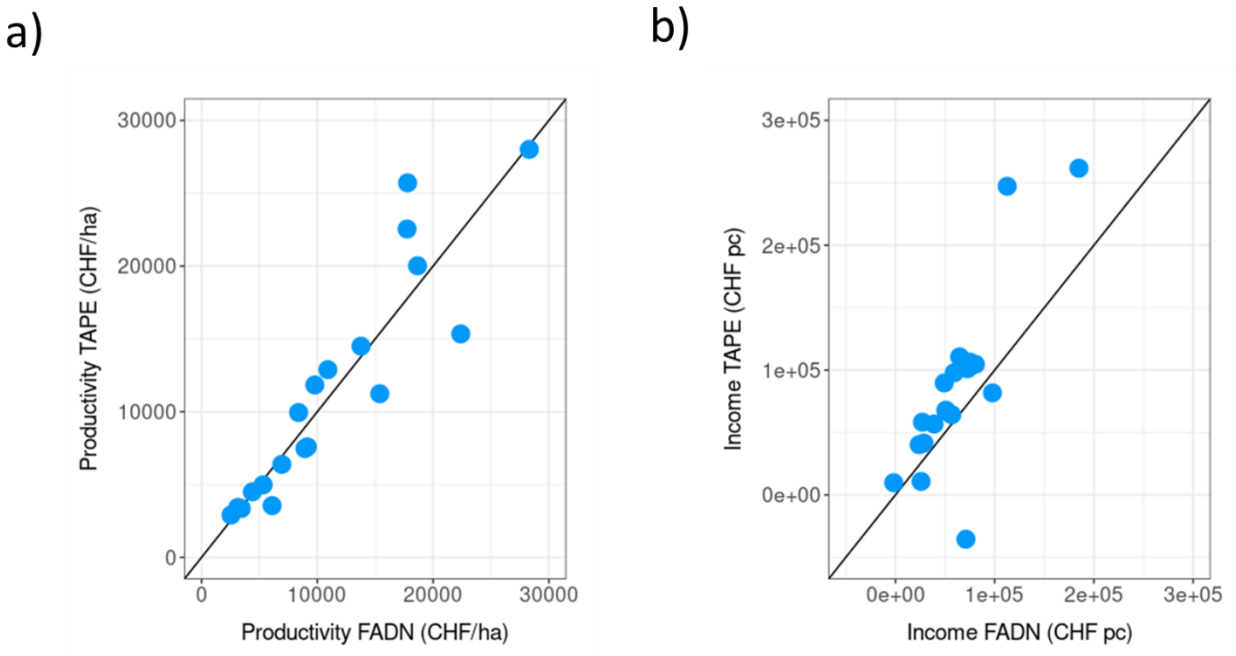

Figure 7: Comparison between data from the farm accountancy data network (FADN) and the TAPE indicators for (a) productivity per agricultural area and (b) income per capita. Each blue dot represents one farm. The black line represents the 1:1-line.

3.2.4 Results of the new biodiversity index of Step 2

Figure 8 shows the results for the new biodiversity index, including the mean value as well as the minimum and maximum values of the 21 farms. All farms scored well on the field size indicator; this is not surprising as the mean field size is small in Switzerland compared to other high-income countries (e. g. Germany) due to the heterogeneous landscape. The land use change indicator received also very high scores for all farms; in Switzerland, the slow decline of UAA is more of a problem than the conversion of (semi-)natural habitats to agricultural land, as is the case in the tropics through deforestation, for example. The agrobiodiversity indicator is based on the original TAPE step 2 agrobiodiversity index. A certain range is visible, 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 (Figure 9), which is in agreement with Swiss biodiversity measurements (Meier et al., 2020). Largest differences occurred for the indicators semi-natural habitats, pesticide application, and grazing intensity. Furthermore, organic farms received higher scores than non-organic farms (Figure 10). Similarly, the differences for the indicators pesticide application, grazing intensity, and nitrogen application were most pronounced.

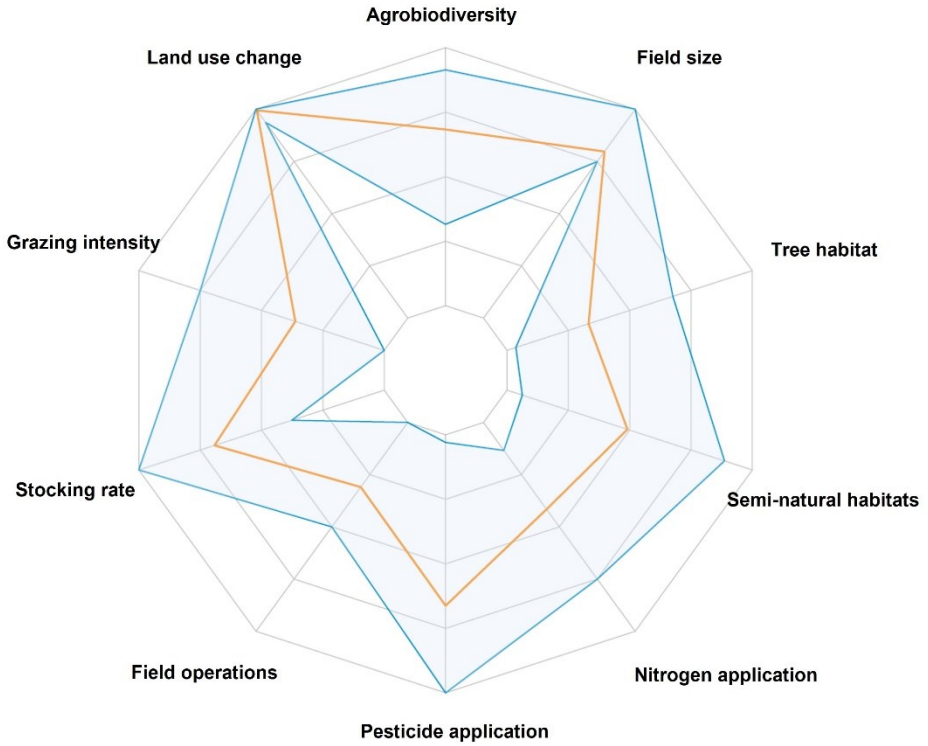

Figure 8: New biodiversity index. Mean (orange line), minimum, and maximum (blue lines) value of the 21 farms.

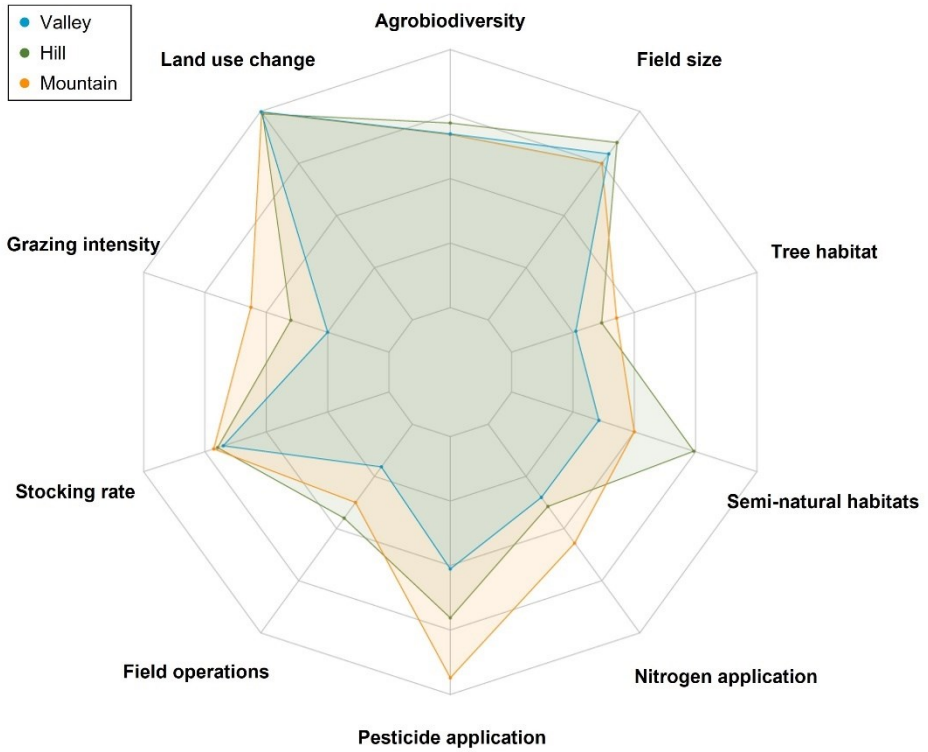

Figure 9: New biodiversity index categorised by region (mean values) for the 21 farms surveyed.

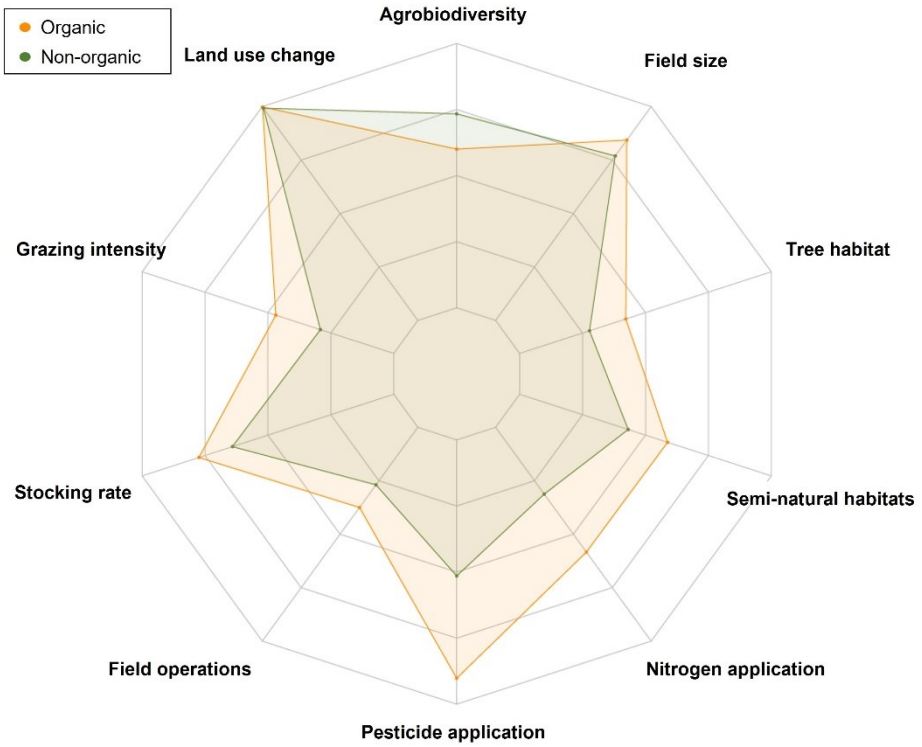

Figure 10: New biodiversity index categorised by farm type (mean values) for the 21 farms surveyed.

4 Discussion

In this chapter we discuss possible adaptions of the TAPE questionnaire for high-income countries, the newly developed biodiversity index, and limitations of the study.

4.1 Suggestions for further developments of the TAPE questionnaire

The first objective of this study – testing the applicability of the TAPE questionnaire in a high-income country – was reached and overall, plausible results have been obtained. Yet, there is room for improvement and further adaptations, some of which would also improve the application in LMICs.

4.1.1 Structure of the questions

In Step 1, sometimes two or more aspects per item are asked (Section 8.1). As an example, in the question about integration with trees, the number and usage of trees are intermixed in the answers. Therefore, farms with a low number of trees that fulfil many services and farms with many trees that fulfil only one service are not covered. The enumerators thus need to decide how to balance these two aspects, which makes it difficult to arrive at consistent results. A reformulation of the multiple-choice answers would remedy this problem.

4.1.2 Expert knowledge

Without expert knowledge, the answers to some TAPE questions strongly depend on the subjective perception of the enumerator and/or the farmer. The two most important ones are the following:

1) the Swiss enumerators struggled to assess soil health in the field. As an example, soil structure should be evaluated by the soil aggregates – minimal score is given for loose, powdery soil without visible aggregates and maximal score is given for well-formed aggregates that are difficult to break. However, the breakability of the aggregates largely depends on soil moisture and the soil properties. Without expert knowledge, it is difficult to assess what proportion of the soil structure is due to management and what proportion is due to conditions that the farmer cannot influence (e. g. rain, clay content). In addition, plots of the same farm can differ greatly from each other due to different management and topography.

2) For the agrobiodiversity index, the abundance of beneficial insects is queried. However, the enumerators lacked the expertise to differentiate insects according to pollinators, beneficial animals, pathogens, etc. Even the total number of insects could hardly be determined, as this is highly dependent on the weather. The enumerators therefore also asked the farmers for their opinion. It seemed that especially older and organic farmers stated that there are nowadays significantly fewer insects than in the past. The answers thus seem to depend very much on subjective perception. For these reasons, the question about the abundance of beneficial insects is not considered in the new biodiversity index.

4.1.3 Coverage of ecological aspects

It is perfectly clear that TAPE cannot cover all ecological aspects due to its simplicity. Nevertheless, the restriction to soil health and agrobiodiversity should be discussed. Some of the largest environmental problems of agriculture are a result of high animal numbers (e. g. eutrophication, climate change; FAO, 2006; Manale, 2006). However, in the current TAPE questionnaire, the negative impact of high animal numbers on the environment is not captured. Farms with (potentially many) animals tend to score better on the TAPE environmental indicators than farms without animals because they achieve higher agrobiodiversity scores. We therefore recommend including at least one additional environmental issue whose main driver are high animal numbers to show these trade-offs. The use of the new biodiversity index already reduces this problem since the detrimental effect of high animal numbers is included. Alternatively, TAPE could provide a list of environmental indicators from which those identified as priority environmental issues in the system should be selected (e. g. water, greenhouse gas emissions, soil degradation, etc.).

4.1.4 Agrobiodiversity index

The fact that TAPE's current agrobiodiversity index focuses on planned biodiversity and is thus not sufficient to adequately describe biodiversity aspects has already been mentioned before. After all, this was the motivation for the development of the new biodiversity index. However, there are additional shortcomings in the current agrobiodiversity index, which are discussed below.

For the calculation of the animal diversity index (and the plant diversity index), one has to indicate the number of animals per animal category (areas per crop) as well as the number of breeds (varieties) of the respective animal category (crop). In the calculation, it is assumed that each breed (variety) occurs equally often. The ratios of the different animals and breeds (crops and varieties) are then considered in the Gini-Simpson index, which is calculated as the sum over the squared ratios (Section 8.2.5).

The following problems are associated with this calculation:

1) Farms with different breeds (or varieties) are better off than farms with different animal categories (or crops). Example: A farm with 12 livestock units (LU) of cows of 3 different breeds obtains a score of 67% because it is automatically assumed that it has 4 cows of each breed – even if in reality, the farm has 10 animals of one breed and 1 animal of each of the other breeds. On the other hand, a farm that keeps 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. For crops, there is the added difficulty that it is unclear how to indicate the number of varieties in grassland. Furthermore, it is also important to be aware that in Switzerland private vegetable gardens are generally not considered as utilized agricultural area (UAA) and that these data are therefore not collected, which might lead to a smaller crop diversity index compared to other countries.

2) The Gini-Simpson index gives implausible values if the shares show large differences. Example: A farm that keeps 50 cows of the same breed (=50 LU) gets 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.

4.1.5 Transferability to Swiss conditions

While TAPE was generally applicable in Swiss farms after regionalisation of the questionnaire (Table 3), we still encountered some obstacles in the application. We recommend that these be addressed before the tool is applied on a larger scale in high income countries.

Location

Due to topographic and climatic conditions, the majority of Switzerland's agricultural land consists of grassland. However, TAPE seems to be predominantly targeted towards arable and/or mixed farms but not adapted sufficiently to grassland dominated farms. This fact also reduces TAPE’s applicability in the other regions of the world, e. g. those dominated by pastoral communities.

For example, the different crops including varieties must be indicated. Grassland, however, does not appear as a crop in TAPE’s drop-down-list. It is unclear how grassland should be recorded – whether it should all be recorded as one crop or whether and how grassland should be differentiated (e. g. extensive versus intensive, temporary versus permanent). Harvest volume and price are also more difficult to specify than for arable products, as most grass is consumed by own animals.

Another example is soil management: the question on soil-plants system management under Step 1 is very clearly designed for arable farming. Rotational grazing is mentioned in brackets, but not differentiated enough for the 5-point scale. The soil quality analysis in Step 2 is also designed for arable soil. On dense grassland, the soil is not visible, so that the colour of the soil or the thickness of the topsoil cannot directly be evaluated.

Furthermore, Step 1 includes a question about water saving. It is assessed how many devices and practices for water saving/harvesting exist. However, in several regions of Switzerland, water scarcity is not an issue and rain is (yet) sufficient to irrigate the fields. Therefore, there should be the option in TAPE to indicate that water saving/harvesting is not necessary.

Note that a special version of TAPE for pastoral systems is being developed by FAO and partners, which should address the challenges we identified in our study.

Data collection effort

The aim of TAPE is that the questionnaire including Step 2 can be completed within 3 hours. For Switzerland, this is currently not possible, especially because of the following two points:

- Pesticides: It is not uncommon that 30 different products are used on intensively managed farms. It is very time-consuming to record all of them individually with the required information (especially human toxicological values). The online tool (KOBO) is furthermore not designed for so many items and takes several minutes to load the input masks.
- Machinery: On most Swiss farms there are dozens of machines that have to be recorded in TAPE. Furthermore, the question of the remaining lifetime of the machines is uncertain.

For this study, we did not record these data during the interviews due to time constraints. Instead, we looked it up in the SAEDN and FADN databases. However, most Swiss farms do not provide data to these monitoring databases, which increases the interview duration for general applications of TAPE.

For the pesticides, we recommend asking farmers for the 5-10 most frequently applied products they use and restrict the data collection to those products. The information on machinery is only needed for the economic indicators. We recommend the possibility to enter the economic key figures directly (see also below) instead of recording numerous data (including machinery).

Social aspects

TAPE's youth indicator asks, among other things, whether the young people want to emigrate (including moving within country) and whether they want to continue working on a farm (Section 8.2.4). This can be used to ascertain whether an urbanization process is taking place caused by lack of employment in rural regions. Rural exodus can also occur and be a problem in high-income countries (Llorent-Bedmar et al., 2021). However, in today's Switzerland, rural exodus is not a major problem and in recent years there has even been a reverse trend with a spatially expanded peri-urbanization (Lerch, 2023). Due to the good infrastructure (e. g. public transport, internet access) and the small size of Switzerland, commuting from rural to urban regions is possible. A change of residence is therefore not automatically associated with a lack of employment. Regarding the agricultural sector, the number of farms and farmers in Switzerland has been decreasing in the last years, while the average farm size has increased (Federal Office for Agriculture, 2022). Most farms are still family-run (Federal Office for Agriculture, 2022).

Against this special context, the youth indicator cannot provide a meaningful value for all Swiss farms. As an example, in the case of a family with four adult children, one son has joined the farm and thus a family succession is certain. The other three children decided to pursue another occupational activity. From a Swiss perspective, this is a good scenario: in order to keep the number of Swiss farms stable, it is sufficient for one person/one family to take over the farm. Furthermore, the other three children have also found good jobs outside agriculture. Nevertheless, this farm only achieved a partial youth score of 25% in TAPE because "only" one of the four children works on the farm.

Concerning nutrition, one must be aware that a farmer's nutritional habits are not directly related to a farm's agricultural production in Switzerland, which might be different to LMICs. While the current nutrition indicator provides a good overview of whether individuals consume enough of major food groups, it does not take into account problematic dietary habits of high-income countries (e. g. high sugar and meat consumption). Data on these are partly collected, but are not (yet) included in the nutrition indicator.

The TAPE questions on animal welfare, hunger, land ownership and, to some extent, women are less of a problem in Switzerland compared to other countries. Most of these questions are regulated by law and generally enforced in Switzerland. However, this does not mean that the problem areas do not exist in Switzerland. It would be possible to identify the need for further action by asking more detailed questions. Examples of this are: 1) With regard to animal welfare, questions about the housing system and the time spent outdoors could be taken into account. 2) The inclusion of women in the social security system could be queried. For example, women from Swiss farmer families often do not adhere to a social security insurance, which creates dependencies from the husband in case of separation or divorce.

Regarding data collection, TAPE's requirement to interview the woman separately and ask the man to leave was not implemented. This is perceived as impolite by many Swiss people.

Economic aspects

In Switzerland, all agricultural holdings have an accounting system. The bookkeeping shows the financial situation of a farm (e. g. income). Revenues and expenditures are also recorded in TAPE. From a Swiss point of view, the recording of revenues in TAPE is tedious and prone to errors, because the quantity produced, the quantity sold, and the price per kg (which is an unusual unit in Switzerland for most crops) have to be indicated for each crop (similar for animals). As an example, it has to be calculated back from the money received from the sale of winter wheat, how high the price and the production/sales quantities were. Furthermore, the revenues and expenditures recorded in TAPE are incomplete for Swiss farms. Not queried in TAPE are for example insurances or software and office expenses.

We therefore suggest to provide the opportunity to directly enter bookkeeping results or the TAPE indicators (e. g. income) in the questionnaire. For farms without bookkeeping, the entry of finances would proceed as before. This would greatly simplify the recording for Swiss farms and make the results more precise.

4.2 The new agrobiodiversity index

4.2.1 Comparison of the new agrobiodiversity index and the Swiss biodiversity indicator

Validating the new biodiversity index with biodiversity measurements on farms (e. g. flowers, insects) is out of the scope of this study. However, the new biodiversity index is based on a published method for Europe (Herzog et al. 2012, BioBio-indicators.org). Therefore, we expect a positive correlation with biodiversity measurements in the field. Furthermore, we can compare the new biodiversity index with the Swiss biodiversity indicator, which is available for all sampled farms. For this comparison, the new biodiversity index is expressed as the average over its ten indicators. We do not expect a perfect correlation between the Swiss biodiversity indicator and the new biodiversity index since the two have different methods and partly different scopes: in the Swiss biodiversity indicator, each habitat is assessed for its quality for 11 terrestrial indicator-species groups. In addition, detailed management practices are incorporated at the field level, and the method is defined specifically for Switzerland. The new biodiversity index, on the other hand, consists of 10 different indicators, none of which requires plot-specific data. Most of the indicators relate to management (e. g. applied nitrogen, pesticides) or habitats (e. g. semi-natural habitats, trees) on the farm and are thus linked to the data included in the Swiss biodiversity indicator. However, the aspects of (planned) agrobiodiversity, field size, and land use change are not included in the calculation of the Swiss biodiversity indicator.

Despite the differences, there was a significant positive correlation between the Swiss biodiversity indicator and the new biodiversity index (Figure 11a; $r = 0.56$, 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. It scores very well in the Swiss biodiversity indicator (18 points) but not particularly well in the new biodiversity index (0.46 or 46%). This is due to the fact that orchards are not yet included in the Swiss biodiversity indicator and the high score of the farm thus only refers to the (small) biodiversity promotion area without fruit trees. For this particular farm, the values of the two methods can therefore not be directly compared.

For comparison, we also calculated the correlation of the Swiss biodiversity indicator with the agrobiodiversity index, i. e. the original TAPE biodiversity index with three indicators (Figure 11b). Here, no positive correlation was found ($r = 0.09$, p-value = 0.71) since the agrobiodiversity index does not consider unplanned biodiversity.

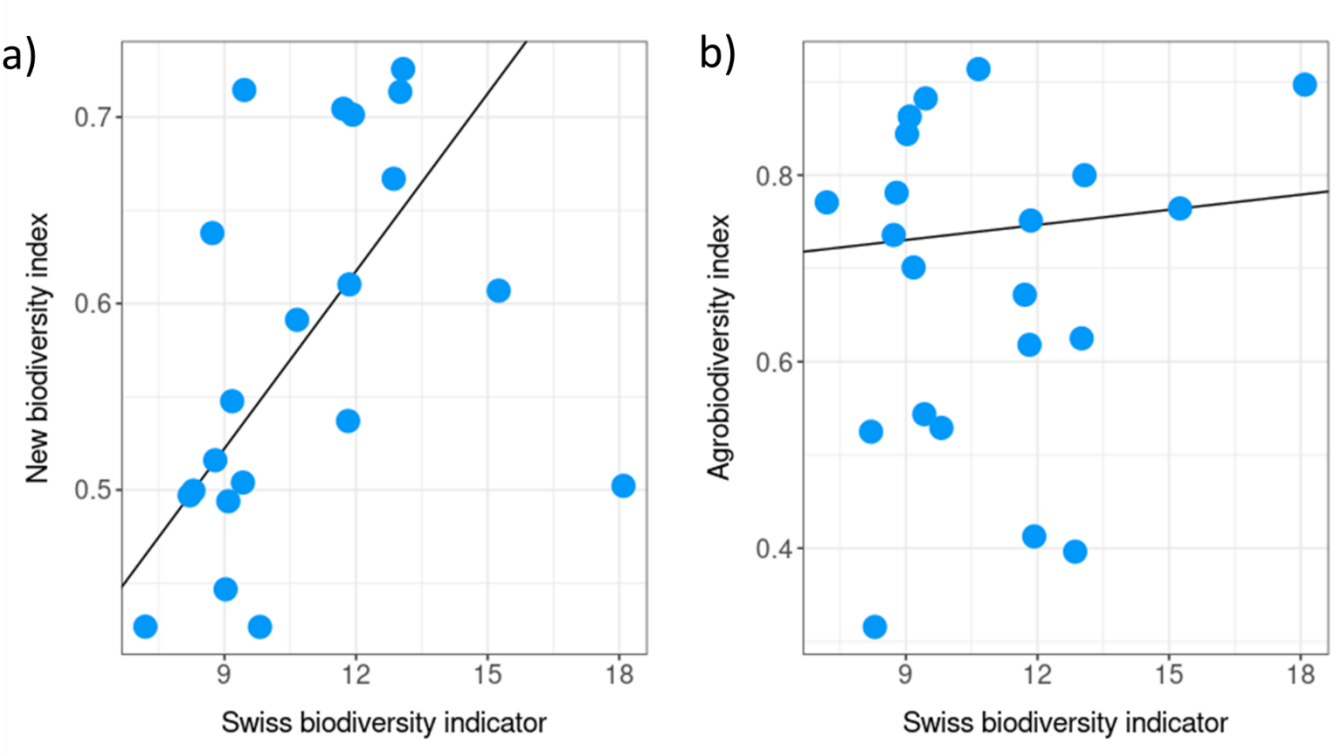

Figure 11: Theil-Sen regression of a) the Swiss biodiversity indicator and the new biodiversity index and b) the Swiss biodiversity indicator and the agrobiodiversity index (current TAPE biodiversity index with three domains). Note the different dimensions of the y-axis.

4.2.2 Strengths and weaknesses of the new agrobiodiversity index

The new biodiversity index is a valuable addition to TAPE because many more biodiversity aspects are now taken into account. Another strength is that it can be presented in a spider diagram/on a scale from 0% to 100%, which facilitates communication.

The proposed scaling thresholds were chosen to be able to describe the pressure on biodiversity as well as the diversity of different farms on the global scale. For Switzerland, a high variability is shown at the individual farm level, which speaks in favour of the choice of thresholds. It still needs to be examined whether the thresholds are also meaningful at the international level or whether they may need to be adapted to specific regions.

The indicator for grazing intensity does not yet take into account that in some regions low grazing intensity leads to higher biodiversity than no grazing, while high grazing pressure decreases biodiversity again (Ingty, 2021). Such a non-linear relationship could theoretically be mapped through a different allocation of points. However, this has to be done specifically for the respective biotope, because there is no globally valid function to describe this relationship.

One criticism of the new biodiversity index is that the selected indicators are not completely independent. For example, some of the tree habitats also belong to the semi-natural habitats. There are also correlations between nitrogen application, stocking rate, and grazing intensity. Nevertheless, each of the ten indicators has a unique aspect, so none is redundant. Furthermore, the suggested indicators are easier to understand for farmers than an abstract variable eliminating correlations.

4.3 Limitations of the study

A major limitation of the study is the small and non-random sample of 21 heterogeneous farms. It is possible that a disproportionately large number of farms interested in the topic of agroecology participated in the TAPE interview. For example, 8 of the 21 farms (38%) are organic, which is significantly higher than the proportion of organic farms in the SAEDN network and in Switzerland (both around 15%, see Gilgen et al., 2023).

Consequently, the results are not representative for the farming sector in Switzerland, which is partly reflected in the comparison of the TAPE results with national figures: for example, the economic indicators of non-organic farms showed higher values than those of organic farms. This is not the case for whole Switzerland, for which the income of organic farms is similar to that of non-organic farms or even slightly higher (Hoop et al., 2022). However, the economic indicators were smaller in the mountain region than in the hill and valley regions, which is in qualitative agreement with national values (Hoop et al., 2022).

Although not representative, we would like to emphasize that the sample not only included flagship farms from an agroecological perspective. Rather, the sample also included farms with a high mineral fertiliser and pesticide use as well as intensive animal husbandry. The heterogenous sample thus allowed the applicability of the TAPE approach to be evaluated in a wide range of Swiss farming systems.

5 Conclusions and outlook

This was one of the first applications of TAPE in a high-income country of the Northern Hemisphere. It showed the potential of TAPE for evaluating and monitoring the agroecological status of farms and national agricultural and food systems also in this region of the world. Yet, some improvements and adaptations are proposed, which would also improve the TAPE approach in general. To summarise, we suggest to create a different version of the questionnaire for high-income countries. This allows, for example, a different focus for the social indicators and simplifies the data collection. Furthermore, it is recommended to make the answer options in the multiple-choice questions (Step 1) clearer.

In this study, a new TAPE biodiversity index was developed. This new index also takes unplanned diversity into account and thus represents a valuable extension. A version of the TAPE questionnaire to collect the necessary data for this new index has already been implemented. In the future, this version will be made available on a voluntary basis, i. e. users can choose between the old and the new TAPE biodiversity index. Agroscope will also provide an R script via git with which the new biodiversity index and the other TAPE results can be calculated automatically. In the meantime, the new biodiversity index has already been tested on Kenyan farms; a publication is in progress (Merbold et al., 2023, in preparation).

If the adapted TAPE questionnaire is available for high-income countries, it can be used for studies describing the agroecological transformation of these countries' agricultural and food systems. For Switzerland, for example, the differences between non-organic and organic farms could be investigated. In this study, a higher agroecology was generally found on organic farms than on non-organic farms, but due to the small sample size, no reliable statement can be made about the robustness of this result.

6 Acknowledgements

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8 Appendix

Here we describe TAPE to better understand the content of this publication. Since the publication of the method (Mottet et al., 2020), changes in Step 2 have been substantial, while changes in Step 1 comprise only some rewordings and extensions. We further describe in this chapter how we converted all Step 2 results in this study to a 0-100% scale to homogenously assess them. For the conversion of the economic indicators, Swiss-specific values have been considered.

8.1 Step 1

The description of Step 1 (Table 6 to 15) was taken from Mottet et al. (2020).

Table 6: Step 1 – Diversity

	Index	0	1	2	3	4
DIVERSITY	Crops	Monoculture (or no crops cultivated)	One crop covering more than 80% of cultivated area	Two or three crops	More than 3 crops adapted to local and changing climatic conditions	More than 3 crops and varieties adapted to local conditions. Spatially diversified farm by multi-, poly- or inter-cropping
	Animals (including fish and insects)	No animals raised	One species only	Two or three species, with few animals	More than 3 species with significant number of animals	High number of species with different breeds well adapted to local climatic conditions
	Trees (and other perennials)	No trees (nor other perennials)	Few trees (and/or other perennials) of one species only	Some trees (and/or other perennials) of more than one species	Significant number of trees (and/or other perennials) of different species	High number of trees (and/or other perennials) of different species integrated within the farm land
	Diversity of activities, products and services	One productive activity only (e. g. selling only one crop)	Two or three activities producing income (e. g. selling 2 crops or one crop and one type of animals)	More than 3 activities producing income	More than 3 activities producing income and one service (e. g. processing products on the farm, ecotourism, transport of agricultural goods, training etc.)	More than 3 activities producing income and several services

Table 7: Step 1 – Synergies

	Index	0	1	2	3	4
SYNERGIES	Crop-livestock-aquaculture integration	No integration: animals, including fish, are fed with purchased feed and their manure is not used for soil fertility; or no animal in the agroecosystem.	Low integration: animals are mostly fed with purchased feed, their manure is used as fertilizer.	Medium integration: animals are mostly fed with feed produced on the farm and/or grazing, their manure is used as fertilizer.	High integration: animals are mostly fed with feed produced on the farm, crop residues and by-products and/or grazing, their manure is used as fertilizer and they provide traction.	Complete integration: animals are exclusively fed with feed produced on the farm, crop residues and by-products and/or grazing, all their manure is recycled as fertilizer and they provide more than one service (food, products, traction, etc.).
	Soil-plants system management	Soil is bare after harvest. No intercropping. No crop rotations (or rotational grazing systems). Heavy soil disturbance (biological, chemical or mechanical).	Less than 20% of the arable land is covered with residues or cover crops. More than 80% of the crops are produced in mono and continuous cropping (or no rotational grazing).	50% of soil is covered with residues or cover crops. Some crops are rotated or intercropped (or some rotational grazing is carried out).	More than 80% of soil is covered with residues or cover crops. Crops are rotated regularly or intercropped (or rotational grazing is systematic). Soil disturbance is minimized.	All the soil is covered with residues or cover crops. Crops are rotated regularly and intercropping is common (or rotational grazing is systematic). Little or no soil disturbance.
	Integration with trees (agroforestry, silvopastoralism, agrosilvopastoralism)	No integration: trees (and other perennials) don't have a role for humans or in crop or animal production.	Low integration: small number of trees (and other perennials) only provide one product (e. g. fruits, timber, forage, medicinal or biopesticides substances…) or service (e. g. shade for animals, increased soil fertility, water retention, barrier to soil erosion…) for humans crops and/or animals.	Medium integration: significant number of trees (and other perennials) provide at least one product or service.	High integration: significant number of trees (and other perennials) provide several products and services.	Complete integration: many trees (and other perennials) provide several products and services.
	Connectivity between elements of the agroecosystem and the landscape	No connectivity: high uniformity within and outside the agroecosystem, no semi-natural environments, no zones of ecological compensation.	Low connectivity: a few isolated elements can be found in the agroecosystem, such as trees, shrubs, natural fences, a pond or a small zone of ecological compensation.	Medium connectivity: several elements are adjacent to crops and/or pastures or a large zone of ecological compensation.	Significant connectivity: several elements can be found in between plots of crops and/or pastures or several zones of ecological compensation (trees, shrubs, natural vegetation, pastures, hedges, channels, etc.).	High connectivity: the agroecosystem presents a mosaic and diversified landscape, many elements such as trees, shrubs, fences or ponds can be found in between each plot of cropland or pasture, or several zones of ecological compensation.

Table 8: Step 1 – Efficiency

	Index	0	1	2	3	4
EFFICIENCY	Use of external inputs	All inputs are purchased from the market.	The majority of the inputs is purchased from the market.	Some inputs are produced on farm/within the agroecosystem or exchanged with other members of the community.	The majority of the inputs is produced on farm/within the agroecosystem or exchanged with other members of the community.	All inputs are produced on farm/within the agroecosystem or exchanged with other members of the community.
	Management of soil fertility	Synthetic fertilisers are used regularly on all crops and/or grasslands (or no fertilizers are used for lack of access, but no other management system is used).	Synthetic fertilizers are used regularly on most crops and some organic practices (e. g. manure or compost) are applied to some crops and/or grasslands.	Synthetic fertilisers are used on a few specific crops only. Organic practices are applied to the other crops and/or grasslands.	Synthetic fertilisers are only used exceptionally. A variety of organic practices are the norm.	No synthetic fertilisers are used, soil fertility is managed only through a variety of organic practices.
	Management of pests & diseases	Chemical pesticides and drugs are used regularly for pest and disease management. No other management is used.	Chemical pesticides and drugs are used for a specific crop/animal only. Some biological substances and organic practices are applied sporadically.	Pests and diseases are managed through organic practices but chemical pesticides are used only in specific and very limited cases.	No chemical pesticides and drugs are used. Biological substances are the norm.	No chemical pesticides and drugs are used. Pests and diseases are managed through a variety of biological substances and prevention measures.
	Productivity and household's needs	Household's needs are not met for food nor for other essentials.	Production covers only household's needs for food. No surplus to generate income.	Production covers household's needs for food and surplus generates cash to buy essentials but doesn't allow savings.	Production covers household's needs for food and surplus generates cash to buy essentials and to have sporadic savings.	All household's needs are met both for food and for cash to buy all essentials needed and to have regular savings.

Table 9: Step 1 – Recycling

	Index	0	1	2	3	4
RECYCLING	Recycling of biomass and nutrients	Residues and by-products are not recycled (e. g. left for decomposition or burnt). Large amounts of waste are discharged or burnt.	A small part of the residues and by-products is recycled (e. g. crop residues as animal feed, use of manure as fertilizer, production of compost from manure and household waste, green manure). Waste is discharged or burnt.	More than half of the residues and by-products is recycled. Some waste is discharged or burnt.	Most of the residues and by-products are recycled. Only a little waste is discharged or burnt.	All of the residues and by-products are recycled. No waste is discharged or burnt.
	Water saving	No equipment nor techniques for water harvesting or saving.	One type of equipment for water harvesting or saving (e. g. drip irrigation, tank).	One type of equipment for water harvesting or saving and use of one practice to limit water use (e. g. timing irrigation, cover crops).	One type of equipment for water harvesting or saving and various practices to limit water use.	Several types of equipment for water harvesting or saving and various practices to limit water use.
	Management of seeds and breeds	All seeds and/or animal genetic resources (e. g. chicks, young animals, semen) are purchased from the market.	More than 80% of seeds/animal genetic resources are purchased from the market.	About half of the seeds are self-produced or exchanged, the other half is purchased from the market. About half of the breeding is done with neighbouring farms.	The majority of seeds/animal genetic resources are self-produced or exchanged. Some specific seeds are purchased from the market.	All seeds/animal genetic resources are self-produced, exchanged with other farmers or managed collectively, ensuring enough renewal and diversity.
	Renewable energy and production	No renewable energy is used nor produced.	The majority of the energy is purchased from the market. A small amount is self-produced (animal traction, wind, turbine, hydraulic, biogas, wood…).	Half of the energy used is self-produced, the other half is purchased.	Significant production of renewable energy, negligible use of fuel and other non-renewable sources.	All of the energy used is renewable and/or self-produced. Household is self-sufficient for energy supply, which is guaranteed at every time. Use of fossil fuel is negligible.

Table 10: Step 1 – Resilience

	Index	0	1	2	3	4
RESILIENCE	Stability of income/production and capacity to recover from perturbations	Income is decreasing year after year, production is highly variable despite constant level of inputs and there is no capacity to recover after shocks/perturbations.	Income is on decreasing trend, production is variable from year to year (with constant inputs) and there is little capacity to recover after shocks/perturbations.	Income is overall stable, but production is variable from year to year (with constant inputs) or vice versa. Income and production mostly recover after shocks/perturbations.	Income is stable and production varies little from year to year (with constant inputs). Income and production mostly recover after shocks/perturbations.	Income and production are stable and increasing over time. They fully and quickly recover after shocks/perturbations.
	Mechanisms to reduce vulnerability	No access to credit, no insurance, no community support mechanisms.	Community is not very supportive and its capacity to help after shocks is very limited. And/or access to credit and insurance is limited.	Community is supportive but its capacity to help after shocks is limited. And/or access to credit is available but hard to obtain in practice. Insurance is rare and does not allow for complete coverage from risks.	Community is very supportive for both men and women but its capacity to help after shocks is limited. And/or access to credit is available and insurance covers only specific products/risks.	Community is highly supportive for both men and women and can significantly help after shocks. And/or access to credit is almost systematic and insurance covers most of production.
	Environmental resilience and capacity to adapt to climate change	Local environment is highly prone to climatic shocks and the system has little capacity to adapt to climate change	Local environment suffers from climatic shocks and the system has little capacity to adapt to climate change	Local environment can suffer from climatic shocks but the system has a good capacity to adapt to climate change	Local environment can suffer from climatic shocks but the system has a strong capacity to adapt to climate change	Local environment has a strong natural capital base, climatic shocks are rare and the system has a strong capacity to adapt to climate change
	Diversity	This index is the average score for the element of Diversity already assessed.				

Table 11: Step 1 – Culture and food tradition

	Index	0	1	2	3	4
CULTURE & FOOD TRADITION	**Appropriate diet and nutrition awareness**	Systematic insufficient food to meet nutritional needs and lack of awareness of good nutritional practices.	Periodic insufficient food to meet nutritional needs and/or diet is based on a limited number of food groups. Lack of awareness of good nutritional practices.	Overall food security over time, but insufficient diversity in food groups. Good nutritional practices are known but not always enforced.	Food is sufficient and diverse. Good nutritional practices are known but not always enforced.	Healthy, nutritious, diversified diet. Good nutritional practices are well known and enforced.
	Local or traditional (peasant / indigenous) identity and awareness	No local or traditional (peasant / indigenous) identity felt.	Little awareness of local or traditional identity.	Local or traditional identity felt in part, or that concerns only part of the household.	Good awareness of local or traditional identity and respect of traditions or rituals overall.	Local or traditional identity strongly felt and protected, high respect for traditions and/or rituals.
	Use of local varieties/breeds and traditional (peasant & indigenous) knowledge for food preparation	No use of local varieties/breeds nor traditional knowledge for food preparation.	A majority of exotic/introduced varieties/breeds are consumed, or there is little use of traditional knowledge and practices for food preparation.	Both local and exotic/introduced varieties/breeds are produced and consumed. Local or traditional knowledge and practices for food preparation are identified but not always applied.	The majority of the food consumed comes from local varieties/breeds and traditional knowledge and practices for food preparation are implemented.	A number of local varieties/breeds are produced and consumed. Traditional knowledge and practices for food preparation are identified, applied and recognised in official frameworks and/or specific events.

Table 12: Step 1 – Co-creation and sharing of knowledge

	Index	0	1	2	3	4
CO-CREATION & SHARING OF KNOWLEDGE	**Platforms for the horizontal creation and transfer of knowledge and good practices**	No platforms for co-creation and transfer of knowledge are available to producers.	At least one platform for the co-creation and transfer of knowledge exists but does not function well and/or is not used in practices.	At least one platform for the co-creation and transfer of knowledge exists and is functioning but is not used to share knowledge on agroecology specifically.	One or several platforms for the co-creation and transfer of knowledge exist, are functioning and are used to share knowledge on agroecology, including women.	Several well established and functioning platforms for the co-creation and transfer of knowledge are available and widespread within the community, including women.
	Access to agroecological knowledge and interest of producers in agroecology	Lack of access to agroecological knowledge: principles of agroecology are unknown to producers.	Principles of agroecology are mostly unknown to producers and/or there is little trust in them.	Some agroecological principles are known to producers and there is interest in spreading the innovation, facilitating knowledge sharing within and between communities and involving younger generations.	Agroecology is well known and producers are willing to implement innovations, facilitating knowledge sharing within and between communities and involving younger generations, including women and younger generations.	Widespread access to agroecological knowledge of both men and women: producers are well aware of the principles of agroecology and eager to apply them, facilitating knowledge sharing within and between communities and involving younger generations.
	Participation of producers in networks and grassroot organisations	Producers are isolated, have almost no relations with their local community and do not participate in meetings and grass-root organisations.	Producers have sporadic relations with their local community and rarely participate in meetings and grass-root organisations.	Producers have regular relations with their local community and sometimes participate in the events of their grass-root organisations but not as much for women.	Producers are well interconnected with their local community and often participate in the events of their grass-root organisations, including women.	Producers (with equal participation of men and women) are highly interconnected and supportive and show a very high engagement and participation in all the events of their local.

Table 13: Step 1 – Human and social values

	Index	0	1	2	3	4
HUMAN & SOCIAL VALUES	**Women's empowerment**	Women do not normally have a voice in decision making, not in the household nor in the community. No organisation for women empowerment exists.	Women may have a voice in their household but not in the community. And/or one form of women association exists but is not fully functional.	Women can influence decision making, both at household and community level, but are not decision makers. They don't have access to resources. And/or some forms of women associations exist but are not fully functional.	Women take full part in decision making processes but still don't have full access to resources. And/or women organisations exist and are used.	Women are completely empowered in terms of decision making and access to resources. And/or women organisations exist, are functional and operational.
	Labour (productive conditions, social inequalities)	Agricultural supply chains are integrated and managed by agribusiness. There is a social and economic distance between landowners and workers. And/or workers don't have decent working conditions, make low wages and are highly exposed to risks.	Working conditions are hard, workers have average wages for the local context and may be exposed to risks.	Agriculture is mostly based on family farming but producers have limited access to capital and decision-making processes. Workers have the minimum decent labour conditions.	Agriculture is mostly based on family farming and producers (both men and women) have access to capital and decision-making processes. Workers have decent labour conditions.	Agriculture is based on family farmers which have full access to capital and decision-making processes in gender equity. There is a social and economic proximity between farmers and employees.
	Youth empowerment and emigration	Young people see no future in agriculture and are eager to emigrate.	Most young people think that agriculture is too hard and many wish to emigrate.	Most young people do not want to emigrate, despite hard working conditions, and wish to improve their livelihoods and living conditions within their community.	Most young people (both boys and girls) are satisfied with working conditions and do not want to emigrate.	Young people (both boys and girls) see their future in agriculture and are eager to continue and improve the activity of their parents.
	Animal welfare [if applicable]	Animals suffer from hunger and thirst, stress and diseases all year long, and are slaughtered without avoiding unnecessary pain.	Animals suffer periodically/seasonally from hunger and thirst, stress or diseases, and are slaughtered without avoiding unnecessary pain or they are not free to express their natural behaviour.	Animals do not suffer from hunger or thirst, but suffer from stress, may be prone to diseases and can suffer from pain at slaughter.	Animals do not suffer from hunger, thirst or diseases but can experience stress, especially at slaughter.	Animals do not suffer from stress, hunger, thirst, pain, or diseases, and are slaughtered in a way to avoid unnecessary pain.

Table 14: Step 1 - Circular and solidarity economy

	Index	0	1	2	3	4
CIRCULAR & SOLIDARITY ECONOMY	Products and services marketed locally	No product/service is marketed locally (or not enough surplus produced), or no local market exist.	Local markets exist but hardly any of the products/services are marketed locally.	Local markets exist. Some products/services are marketed locally.	Most products/services are marketed locally.	All products and services are marketed locally.
	Networks of producers, relationship with consumers and presence of intermediaries	No networks of producers for marketing agricultural production exist. No relationship with consumers. Intermediaries manage the whole marketing process.	Networks exist but do not work properly. Little relationship with consumers. Intermediaries manage most of the marketing process.	Networks exist and are operational, but don't include women. Direct relationship with consumers exists. Intermediaries manage part of the marketing process.	Networks exist and are operational, including women. Direct relationship with consumers exists. Intermediaries manage part of the marketing process.	Well established and operational networks exist with equal women participation. Strong and stable relationship with consumers. No intermediaries.
	Local food system	Community is totally dependent on the outside for purchasing food supply and agricultural inputs and for the marketing and processing of products.	The majority of food supply and agricultural inputs are purchased from outside and products are processed and marketed outside the local community. Very few goods and services are exchanged/sold between local producers.	Food supply and inputs are purchased from outside the community and/or products are processed locally. Some goods and services are exchanged/sold between local producers.	Equal shares of food supply and inputs are locally available and purchased from outside the community and products are processed locally. Exchanges/trade between producers are regular.	Community is almost completely self-sufficient for agricultural and food production. High level of exchange/trade of products and services between producers.

Table 15: Step 1 – Responsible governance

	Index	0	1	2	3	4
RESPONSIBLE GOVERNANCE	**Producers' empowerment**	Producers' rights are not respected. They have no bargaining power and lack the means to improve their livelihoods and develop their skills.	Producers' rights are recognized but not always respected. They have small bargaining power and little means to improve their livelihoods and/or to develop their skills.	Producers' rights are recognised and respected for both men and women. They have small bargaining power but are not stimulated to improve their livelihoods and/or to develop their skills.	Producers' rights are recognised and respected for both men and women. They have the capacity and the means to improve their livelihoods and are sometimes stimulated to develop their skills.	Producers' rights are recognised and respected for both men and women. They have the capacity and the means to improve their livelihoods and to develop their skills.
	Producers' organisations and associations	Cooperation among producers is non-transparent, corrupted or non-existent. No existing organisation or they do not to distribute profits transparently and/or equally nor do they support producers.	One organisation of producers exists but its role is marginal and support to producers limited to market access.	One organisation of producers exists and provides support to producers for market access and other services (e. g. information, capacity development, incentives…), but women don't have access.	One organisation of producers exists and provides support to producers for market access and other services with equal access to men and women.	More than one organisation exists. They provide market access and other services, with equal access to men and women.
	Participation of producers in governance of land and natural resources	Producers are completely excluded from the governance of land and natural resources. There is no gender equity in the governance of land and natural resources.	Producers participate in the governance of land and natural resources but their influence on decisions is limited. Gender equity is not always respected.	Mechanisms allowing producers to participate in the governance of land and natural resources exist but are not fully operational. Their influence on decisions is limited. Gender equity is not always respected.	Mechanisms allowing producers to participate in the governance of land and natural resources exist and are fully operational. They can influence decisions. Gender equity is not always respected.	Mechanisms allowing producers to participate in the governance of land and natural resources exist and are fully operational. Both women and men can influence decisions.

8.2 Step 2

8.2.1 Governance

Table 16: Land tenure indicator.

Legal recognition	Name on document	Perceive access is secure	Sell/bequeath/inherit	Score
1	1	1	>0	**3**
1	0	-	-	**2**
1	1	0	-	**2**
0	-	1	>0	**2**
0	-	0	-	**1**
0	-	-	0	**1**

The land tenure indicator ranges from 1-3. It is driven by whether farmers have legal documentation of the farm, whether their names are listed as owners, if they perceive the access to the land as secure, and whether they have the right to sell, bequeath or inherit the land (Table 16). If the first three questions are affirmed (and at least one of the conditions: sell, bequeath or inherit) then the score is 3. The score 2 is reached by either having legal recognition or perceiving the access as secure and being able to sell bequeath or inherit the land. The score 1 was given if there was no legal recognition and the before mentioned statement was not the case. The land tenure indicator is calculated separately for men and women. We calculated the average of the two and scaled the values from 1-3 points to 0-100%.

8.2.2 Economy

Step 2 considers the economic indicators “productivity” ($Prod$), “income” (Inc), and “value added” (VA), which are based on the handbook for the evaluation of agroecology (Levard et al., 2019). The indicators are calculated the following way:

$$Prod = M_{prod\_crop} * P_{crop} + M_{prod\_cfp} * P_{cfp} + M_{prod\_anim} * P_{anim} + M_{prod\_ap} * P_{ap}$$

$$Inc = M_{sale_{crop}} * P_{crop} + M_{sale_{cfp}} * P_{cfp} + M_{sale_{anim}} * P_{anim} + M_{sale_{ap}} * P_{ap} + subs - ex - workers - interest - taxes - rent - depr$$

$$VA = Prod - ex - depr$$

M_{prod} stands for the produced quantity and P for the price at the gate of crops ($crop$, e. g. wheat), crop and forestry products (cfp, e. g. wood), animals ($anim$, e. g. cow), and animal products (ap, e. g. milk).

M_{sale} stands for the sold quantity of the respective products, $subs$ for subsidises by the government, ex for the expenditures of seeds, fertilisers, pesticides, livestock, feed, veterinary products/services, energy, transport, rental of agricultural machinery services (contractors were included), and pesticides, $workers$ for the wages of external workers, $interest$ for interest on loans, $taxes$ for taxes (private taxes included), $rent$ for cost of renting land, and $depr$ for depreciation of machineries and equipment. Depreciation is calculated using an arithmetic-degressive approach with a residual value of 10%.

To compare different farms, we divided the productivity by agricultural area and the income and value added by capita. We used (inter)national surveys (FDFA, 2023; FSO, 2023; OWID, 2023) and the data set from this study as a guide for the threshold values needed for scaling the values to 0-100% (Table 17).

Table 17: Chosen thresholds for the economic indicators in this study. Values ≤ minimal threshold correspond to 0%, values ≥ maximal threshold correspond to 100%. Values in-between are linearly interpolated. FTE stands for full-time equivalent.

Economic indicator	Minimal threshold	Maximal threshold
Productivity	25'000 CHF / (FTE * yr)	100'000 CHF / (FTE * yr)
Income	48'000 CHF / (FTE * yr)	108'000 CHF / (FTE * yr)
Value added	2000 CHF / (ha * yr)	20'000 CHF / (ha * yr)

8.2.3 Health & Nutrition

The final indicator for exposure to pesticides can take values between 0% and 100%. For farms using no pesticides, the score is 100%. For other farms, the score is the mean of the following four domains:

- **Pesticide type**: is 0 if only chemical pesticides were used, 50% if chemical and organic pesticides were used, and 100% if only organic pesticides were used.
- **Toxicity**: the pesticides are allocated to 3 different toxicity levels. If extremely/highly toxic pesticides are used the score is 0%, moderately toxic pesticides give the score of 50%, and pesticides with slight or no toxicity get a score of 100%. The pesticide with the highest toxicity level is being considered for the score.
- **Mitigation measures**: different mitigation strategies for when applying pesticides (e. g. wearing masks) increase the score by 25%. 4 or more strategies give the maximum value of 100%.
- **Ecological management measures**: different ecological management strategies for pests (e. g. Trichogramma) increase the score by 25%. 4 or more strategies give the maximum value of 100%.

The dietary diversity indicator is based on the food groups listed in Table 18. The number of food groups consumed in the last 24 h is multiplied by 10.

Table 18: Ten food groups of the Minimum Dietary Diversity for Women indicator (FAO, 2016).

Food source	Value
Foods made from grains White roots and tubers or plantains	1
PULSES (beans, peas, fresh or dried seed, lentils or bean / pea products, including hummus, tofu and tempeh)	1
NUTS and SEEDS (Tree nut, groundnut/peanut or certain seeds, or nut / seed "butters" or pastes)	1
Milk Cheese or yoghurt	1
Organ meats Red flesh meat from mammals Processed meat Poultry and other white meats Fish and seafood	1
EGGS	1
DARK GREEN leafy VEGETABLES (any medium to-dark green leafy vegetables, including wild / foraged leaves)	1
Vitamin A-rich vegetables or roots Vitamin A-rich fruits	1
other VEGETABLES (cucumber, eggplant, mushroom, onion, tomato, etc.)	1
other FRUITS (avocado, apple, pineapple, etc.)	1

8.2.4 Society & Culture

The youth indicator considers farmers' children between 15 and 34 years. It is calculated by averaging over the two domains "employment" and "emigration" (see Table 19) as well as overall youngsters.

The women empowerment indicator is the average over 5 domains listed in Table 20 (multiplied by 100), which in turn represent the average over subdomains (except for the domain leadership, where the greater value of the two answers is the domain score).

Table 19: Points for youth indicator.

Domains	Indicators	Score
Employment	Working in the agricultural production within the system assessed Both working in the agricultural production within the system and also enrolled in formal education Enrolled in formal education Working in his/her own farm	**100**
	Both working in the agricultural production within the system and also employed outside the system	**50**
	Not working nor studying Employed outside the system assessed	**0**
Emigration	Would like to stay at the farm	**100**
	Wants a farm but also wants to emigrate Neither wants a farm nor wants to emigrate	**50**
	wants to emigrate and doesn't want a future farm.	**0**

Table 20: Points for women empowerment indicator. "- "means that in this case the variable does not impact the answer.

Domains	Subdomain	Questions	Answers	Score
Productive Decisions	Crops, animals & economic activities	When decisions are taken about CROP PRODUCTION, who normally takes these decisions?	*Myself* *My husband* *Both of us* *Someone else*	**1** **0** **1** **0**
		When decisions are taken about ANIMAL PRODUCTION, who normally takes these decisions?	*Myself* *My husband* *Both of us* *Someone else*	**1** **0** **1** **0**
		When decisions are taken about other economic activities within the household, who normally takes these decisions?	*Myself* *My husband* *Both of us* *Someone else*	**1** **0** **1** **0**
	Minor & major household expenditures	When decisions are taken about MAJOR HOUSEHOLD ASSETS, who normally takes these decisions?	*Myself* *My husband* *Both of us* *Someone else*	**1** **0** **1** **0**
		When decisions are taken about MINOR HOUSEHOLD ASSETS, who normally takes these decisions?	*Myself* *My husband* *Both of us* *Someone else*	**1** **0** **1** **0**
	Perception for animal crops economic activities	If you wanted, do you feel that you can take decisions about CROP PRODUCTION?	*I think that I cannot take any decision* *Just little decisions* *Some decisions* *In great part / totally*	**0** **0.33** **0.66** **1**
		If you wanted, do you feel that you can take decisions about ANIMAL HUSBANDRY?	*I think that I cannot take any decision* *Just little decisions* *Some decisions* *In great part / totally*	**0** **0.33** **0.66** **1**
		If you wanted, do you feel that you can take decisions about OTHER ECONOMIC ACTIVITIES?	*I think that I cannot take any decision* *Just little decisions* *Some decisions* *In great part / totally*	**0** **0.33** **0.66** **1**
	Perception of major & minor household expenditures	If you wanted, do you feel that you can take decisions about MAJOR HOUSEHOLD EXPENDITURES?	*I think that I cannot take any decision* *Just little decisions* *Some decisions* *In great part / totally*	**0** **0.33** **0.66** **1**

		If you wanted, do you feel that you can take decisions about MINOR HOUSEHOLD EXPENDITURES?	*I think that I cannot take any decision* *Just little decisions* *Some decisions* *In great part / totally*		**0** **0.33** **0.66** **1**
Decision Making	Land tenure	See land tenure indicator	*Land tenure = 1* *Land tenure = 2* *Land tenure = 3*		**0** **0.5** **1**
	Credit	Do you have access to credit?	Women	Men	
			Official channels	-	**1**
			Non-official channels	*Not possible*	**0.8**
			Non-official channels	*Non-official channels*	**0.75**
			Non-official channels	*Official channels*	**0.5**
			Not possible	*Not possible*	**0.25**
			Not possible	*Non-official channels*	**0.1**
			Not possible	*Official channels*	**0**
			Non-official channels	*NA*	**0.5**
			Not possible	*NA*	**0**
	Ownership Crops, animals & assets	Who is the owner of the CROPS and the SEEDS?	*Myself* *My husband* *Both of us* *Someone else*		**1** **0** **1** **0**
		Who is the owner of the ANIMALS?	*Myself* *My husband* *Both of us* *Someone else*		**1** **0** **1** **0**
		Who is the owner of the assets for other economic activities within the household?	*Myself* *My husband* *Both of us* *Someone else*		**1** **0** **1** **0**
	Ownership Major & minor household assets	Who is the owner of the MAJOR HOUSEHOLD ASSETS?	*Myself* *My husband* *Both of us* *Someone else*		**1** **0** **1** **0**
		Who is the owner of the MINOR HOUSEHOLD ASSETS?	*Myself* *My husband* *Both of us* *Someone else*		**1** **0** **1** **0**
Income Use		Who makes decisions about the use of income generated by crop production?	*Myself* *My husband* *Both of us* *Someone else*		**1** **0** **1** **0**
		Who makes decisions about the use of income generated by animal production?	*Myself* *My husband* *Both of us* *Someone else*		**1** **0** **1** **0**
		Who makes decisions about the use of income generated by other economic activities?	*Myself* *My husband* *Both of us* *Someone else*		**1** **0** **1** **0**

Leadership	The greater value of the two involvement questions is chosen.	Involvement in agriculture related organisations	*I do not participate in such organisations*	0
			I rarely participate in such meetings / organisations	**0.25**
			I participate often but I rarely speak in the meetings	**0.5**
			I am an active member of such organisation sometimes I speak in the meetings	**0.75**
			I often speak in the meetings and participate in the decisions making processes	**1**
		Involvement in other organisations	*I do not participate in such organisations*	**0**
			I rarely participate in such meetings / organisations	**0.25**
			I participate often but I rarely speak in the meetings	**0.5**
			I am an active member of such organisation sometimes I speak in the meetings	**0.75**
			I often speak in the meetings and participate in the decisions making processes	**1**
Time use		Sum of the hours per day spent working on AGRICULTURAL PRODUCTION within the system assessed, FOOD PREPARATION and other DOMESTIC WORKS or OTHER GAINFUL ACTIVITIES	*Working-hours > 10.5* *Working-hours =< 10.5*	**0** **1**
			Women>Men *Women<=Men*	**0** **1**

8.2.5 Environment

The Soil Health assessment is done by rating the listed categories by their characteristics on a scale from 1-5 (Table 21). After that the mean of all the ratings is taken. The range from 1 to 5 was converted to a scale from 0% to 100% for this study.

Table 21: Scoring system for soil health assessment.

Indicators	Characteristics	Score
Structure	Loose, powdery soil without visible aggregates	**1**
	Few aggregates that break with little pressure	**3**
	Well-formed aggregates – difficult to break	**5**
Compaction	Compacted soil, flag bends readily	**1**
	Thin compacted layer, some restrictions to a penetrating wire	**3**
	No compaction, flag can penetrate all the way into the soil	**5**
Soil depth	Exposed subsoil	**1**
	Thin superficial soil	**3**
	Superficial soil (> 10 cm)	**5**

Status of residues	Slowly decomposing organic residues	**1**
	Presence of last year's decomposing residues	**3**
	Residues in various stages of decomposition, most residues well-decomposed	**5**
Color, odor and organic matter	Pale, chemical odor, and no presence of humus	**1**
	Light brown, odorless, and some presence of humus	**3**
	Dark brown, fresh door, and abundant humus	**5**
Water retention (moisture level after irrigation or rain)	Dry soil, does not hold water	**1**
	Limited moisture level available for short time	**3**
	Reasonable moisture level for a reasonable period of time	**5**
Soil cover	Bare soil	**1**
	Less than 50% soil covered by residues or live cover	**3**
	More than 50% soil covered by residues or live cover	**5**
Erosion	Severe erosion, presence of small gullies	**1**
	Evident, but low erosion signs	**3**
	No visible signs of erosion	**5**
Presence of invertebrates	No signs of invertebrate presence or activity	**1**
	A few earthworms and arthropods present	**3**
	Abundant presence of invertebrate organisms	**5**
Microbiological activity	Very little effervescence after application of water peroxide	**1**
	Light to medium effervescence	**3**
	Abundant effervescence	**5**

The agrobiodiversity index is the average over the three domains GSI_{crops}, $GSI_{animals}$, and GSI_{other}.

GSI$_{crops}$

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

$$GSI_{crops} = 100 * (1 - shannon_{crops})$$

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 system's total crop production area, and $varieties_i$ is the number of varieties grown of each species i.

GSI$_{animals}$

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

$$GSI_{animals} = 100 * (1 - shannon_{animals})$$

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.

GSI_{other}

GSI_{other} is the mean over the three sub-scores natural vegetation, bees, and pollinators (see Table 22).

Table 22: Rating for the three sub-scores of GSI_{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.	**33**
	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.	**50**
	Yes, bees are raised within the agroecosystem.	**100**
Presence of beneficial insects	Absent	**0**
	Little	**33**
	Significant	**66**
	Abundant	**100**