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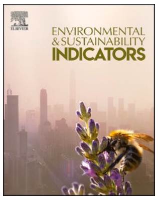

Agricultural production and biodiversity conservation: A typology of Swiss farmers' land use patterns

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ABSTRACT

Understanding farmers' land use behaviour is a prerequisite for designing effective policies that aim to protect and enhance biodiversity in agriculture. We develop a typology of Swiss farmers' land use patterns in terms of their agricultural production and biodiversity conservation. We contribute by adopting a comprehensive perspective encompassing not only EFAs (Ecological Focus Areas) but also non-EFAs. Relying on a sample of 2341 Swiss farm observations from the Farm Agri-Environmental and the Farm Accountancy Data Network, we conducted – for each agricultural region (plain, hill and mountain) – a K-means clustering to identify farmland use patterns. We considered four clustering variables, namely agricultural production intensity, the extent of a farm's participation in agri-environmental payment schemes and the impact of farm agricultural practices on the organismal biodiversity of 1) EFAs and 2) non-EFAs. The analysis reveals four distinct farmland use patterns beyond the classical dichotomy of low shares of EFAs and high agricultural production intensity versus high shares of EFAs and low agricultural production intensity. Three of the four land use patterns are similar across all agricultural regions. Our findings show that biodiversity enhancement is possible outside of EFA direct payment programmes. One cluster succeeded in exhibiting both a high agricultural production intensity and a high overall biodiversity score, which highlights that these dimensions are not mutually exclusive. The low or moderate use intensity of mineral fertilisers, pesticides and purchased feedstuffs in combination with a high use efficiency of these inputs seems to be the key to reconciling agricultural production and biodiversity conservation.

1. Introduction

Agriculture is the main driver of biodiversity loss (Dudley and Alexander, 2017; Kehoe et al., 2017). The world population growth and rising per capita income forecasted to take place in the next decades are expected to increase the demand for food, especially food from animal sources (Bodirsky et al., 2015; Crist et al., 2017; FAO, 2017). These developments are anticipated to result in the further conversion of natural ecosystems to farmland (Moore et al., 2012) and an intensification in farmland use, both of which may exacerbate biodiversity loss (Kehoe et al., 2017).

In response to growing concerns over the biodiversity loss caused by agriculture, agri-environmental policy instruments aimed at protecting and enhancing biodiversity were introduced in Switzerland in the 1990s (Badertscher, 2005). The most important instruments of the current Swiss agricultural policy for biodiversity conservation are the three area-based direct payments schemes for biodiversity conservation, namely the management-based Ecological Focus Area (EFA) payments,[1] the result-based EFA bonus payments and the EFA-agglomeration bonus payments (FOAG, 2020).

Understanding farmers' land use patterns is a prerequisite for designing effective policies aimed at protecting and enhancing biodiversity in agriculture. A strand in the literature on farmer's biodiversity preservation and enhancement behaviour focuses mainly on the factors that influence the uptake of agri-environmental payment schemes for biodiversity conservation (see, e.g., Mathijs, 2003; Polman and Slangen, 2008; Murphy et al., 2011; Russi et al., 2016; Mack et al., 2020). Even if these investigations provide highly valuable insights into farmers' attitudes towards biodiversity conservation schemes, they have two shortcomings. First, by focusing on EFAs, these investigations do not consider remaining farmland (i.e. non-EFAs), which is also important in terms of biodiversity conservation, and thus neglect a part of the whole-farm

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[1] Ecological Focus Areas are also synonymously referred to as Ecological Compensation Areas (ECAs).

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biodiversity picture. This issue is especially critical, as participation in agri-environmental payment schemes may be associated with spatial spillover effects in terms of land use intensity between EFA and non-EFA plots within a farm (Chakir and Thomas, 2022), which could lead to an intensification in non-EFA land use. This may in turn result in biodiversity decline in these areas and counterbalance – at the whole-farm level – the positive effects of EFA expansion in terms of biodiversity promotion.

The second shortcoming of the existing socioeconomic literature in this field is that, in most existing studies, the success or effectiveness of agri-environmental payment schemes is assessed using indicators of their uptake. Uptake indicators may be inappropriate for evaluating the effectiveness of management-oriented agri-environmental payment schemes because the link between land management and related benefits for biodiversity – that is, the environmental outcome – is rather weak and might lack scientific evidence (Rodríguez-Ortega et al., 2018). In the case of result-oriented schemes, uptake indicators may be relatively appropriate for evaluating the scheme's effectiveness. One should, however, be aware that windfall effects might occur with this type of scheme (Chabé-Ferret and Subervie, 2013; Bertoni et al., 2020; Wuepper and Huber, 2022). Indeed, the high abundance of a particular taxon on a farm does not necessarily result from the farm manager's efforts to provide more biodiversity. This may simply be due to the fact that the farm is located in a more biodiverse landscape and therefore fulfils the agri-environmental payment scheme requirements without making any additional efforts, such as changing farming practices (Matzdorf and Lorenz, 2010; Hodgson et al., 2010; Fleury et al., 2015).

Farm-level land use patterns at the interface between agricultural production and biodiversity conservation can be characterised according to three aspects: 1) the intensity of agricultural production, 2) the extent of farm participation in agri-environmental schemes for biodiversity conservation and 3) the biodiversity-friendliness of agricultural practices. Swiss farms show high heterogeneity regarding these three aspects, and to be effective in fostering a transformation towards sustainability, agri-environmental policy needs to be designed in a way that considers this heterogeneity in farm behaviour (Bartkowski et al., 2022).

The aim of the present article is to provide a better understanding of the heterogeneity of farm-level land use patterns in Swiss agriculture by adopting a comprehensive perspective that embraces the whole farm – that is, a perspective that encompasses both EFAs and non-EFAs. Furthermore, we aim to account for possible spatial spillover effects in terms of biodiversity friendliness of land use between EFA- and non-EFA-plots within a farm through a separate consideration of the biodiversity-friendliness of agricultural practices on these two land subcompartments. To identify existing land use patterns, we conducted a cluster analysis relying on a unique unbalanced panel dataset from the Swiss Agri-Environmental Data Network (AEDN) and Farm Accountancy Data Network (FADN) encompassing comprehensive economic and environmental farm-level data. We characterised the different farm clusters according to the clustering variables considered, their structural and managerial characteristics and the natural production conditions under which they operate. This analysis contributes to a better understanding of the interplay between the extent of participation in the agri-environmental payment schemes for biodiversity conservation, the biodiversity-friendliness of farm practices on EFAs and non-EFAs and agricultural production intensity. The typology, which reveals four different land use pattern types, three of which are similar across all three agricultural regions (plain, hill and mountain), serves as a starting point for further research on a better targeting of agri-environmental policies aimed at balancing agricultural production and biodiversity conservation.

The article proceeds as follows. Section 2 provides background information on agri-environmental payment schemes for biodiversity conservation, with a focus on the schemes in place in Switzerland. Section 3 describes our methodological approach, and Section 4 presents the data. The results of the clustering are provided in Section 5, and Section 6 concludes with a discussion of the results and their implications.

2. Background

In this section, we provide an overview of the two current agri-environmental policy instruments for biodiversity conservation in Switzerland: the 'Proof of Ecological Performance' (PEP) and the Swiss direct payments scheme for the promotion of biodiversity (FOAG, 2020).

(1) In order to qualify for direct payments, Swiss farms must comply with a set of environmental and animal welfare standards (PEP). As part of these cross-compliance requirements, farmers must manage at least 3.5% of the farm's utilised agricultural area (UAA) of special crops (wine, vegetables and fruits) and 7% of the remaining UAA as so-called EFAs (Direktzahlungsverordnung [DZV],[2] SR 910.13). The EFAs encompass a variety of biotopes, including grassland, arable land, permanent cropland and woody elements, for which different types of biodiversity direct payments may be granted as described hereafter. Beyond the minimum share of EFA, the PEP also makes requirements for nutrient budgets, crop rotation and pesticide use, which may also be beneficial for biodiversity (Aviron et al., 2009).

(2) The Swiss biodiversity direct payment scheme for the promotion of biodiversity currently includes the three following cumulative area-based payment types (FOAG, 2015; FOAG, 2020):
    i. Management-based EFA payments,[3] which are granted for land that fulfils the land use management requirements for EFA qualification.[4]
    ii. Result-based EFA bonus payments,[3] which are granted additionally when the EFA reaches a certain level of ecological quality. The measurement of ecological quality considers botanical diversity, which is assessed using plant indicator species, and the structural properties of the EFA.[5] With the exception of arable cropland biotopes, almost all EFA categories are eligible for result-oriented EFA payments.
    iii. EFA-agglomeration bonus payments, which follow a participatory-partnership, multi-actor-oriented and result-based approach. These are granted for EFAs enrolled in a regional project that aims to increase the biodiversity of animal and plant species by improving the agglomeration of EFAs at the regional landscape level. These payments are granted in addition to management- and result-based EFA payments for almost all the four biotope EFA categories (i.e. grassland, arable cropland, permanent cropland and woody elements) and are cofinanced by the cantons.

An overview of the different EFA categories and their eligibility for the three different EFA payment types is provided in Table A.1

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[2] Ordinance on direct payments in agriculture.

[3] Different terminologies are used for the two existing EFA payment types in the scientific literature. Management-based payment schemes are also referred to as action-, input-, and measure-based or action-oriented payment schemes. Result-based schemes are also called performance-, outcome-, output-, and success-based or - oriented payment schemes or as objective-driven or payment-by-result schemes (Bartkowski et al., 2021).

[4] For instance, for grassland EFAs, the requirements relate, among others, to fertilisation, pesticide use, earliest and latest date of harvest (mowing or grazing) and maximal yearly mow frequency. A comprehensive overview of the requirements that must be complied with for the different EFA categories is available in FOAG (2020).

[5] The minimum requirements that EFAs must fulfil to qualify for biodiversity quality payments are provided in the directives to Article 59 and Annex 4 of the ordinance on direct payments in agriculture (Direktzahlungsverordnung, DZV, SR 910.13).

(Appendix A).

In 2020, the share of management-oriented EFAs in the total UAA amounted to 19% (FOAG, 2021), increasing according to the unfavourableness of natural production conditions, from 14.7% in the plain zone to 45.1% in mountain zone IV (FOAG, 2021). On average, 43.3% of management-oriented EFAs (excluding trees) received result-based payments in 2020 (FOAG, 2021). The share of management-oriented EFAs enrolled in result-oriented biodiversity conservation programmes significantly varies between EFA categories, with the highest share (90%) observed for litter meadows and the lowest (26%) for less intensively used meadows (FOAG, 2021). The share of management-oriented EFAs that are part of a regional ecological network project that aims to improve the agglomeration of EFAs at the regional landscape level is also subject to substantial variability between the EFA categories (FOAG, 2021). It varies between 40% for riverside meadows and 91% for litter meadows (FOAG, 2021).

As is obvious from the previous description, the part of the Swiss agricultural policy that addresses biodiversity conservation relies on generic instruments and does not target specific groups of farms.

3. Methods

The objective of the present work is to use a comprehensive perspective that encompasses the whole farm to build a typology of farmland use according to agricultural production and biodiversity conservation. For this purpose, we used cluster analysis, which involves grouping a set of observations in such a way that observations in the same group, called a cluster, are more similar to each other than to observations in other clusters (James et al., 2013). This approach is particularly valuable for management and policy advice, not only because it reveals the structure behind data that depicts a complex and multidimensional phenomenon, but also because it is more convenient and effective for making decisions about a homogeneous set of objects that share similar characteristics than it is for a heterogeneous one (Khoshnevisan et al., 2015). As highlighted by Pedersen et al. (2012), in the agricultural economics and policy field, cluster analysis enables research 'to move from a tradition of analysing policy options based on an uni-modal to a multi-modal description of the regulated community, i.e., farmers, to pave the way for a more segmented and targeted approach to policy design' (p. 1095). The identification of farm behaviour types has been acknowledged as particularly useful in 'informing the design of targeted instruments to support transformation towards sustainable agriculture' (Bartkowski et al., 2022, p.1). We used two different clustering techniques: partitional and hierarchical clustering (Reddy and Vinzamuri, 2014). To account for (dis)similarities between observations, a distance measure was used. To ensure that the relative weight of each clustering variable was equal, we standardised all variables to have a zero mean and a standard deviation of 1.

3.1. K-means

The first algorithm that we used to find appropriate clusters was K-means clustering, which falls under the partitional techniques. For a predefined set of K clusters with initial means $\{m_1, m_2, \ldots m_K\}$, each observation was assigned to a cluster $\{1, 2, \ldots, K\}$ such that the (squared Euclidean) distance from $\{m_1, m_2, \ldots m_K\}$ was minimised (for a textbook description, see Hastie et al., 2009). This assignment procedure continued until no more changes occurred (for a graphical illustration, see Fig. 1).

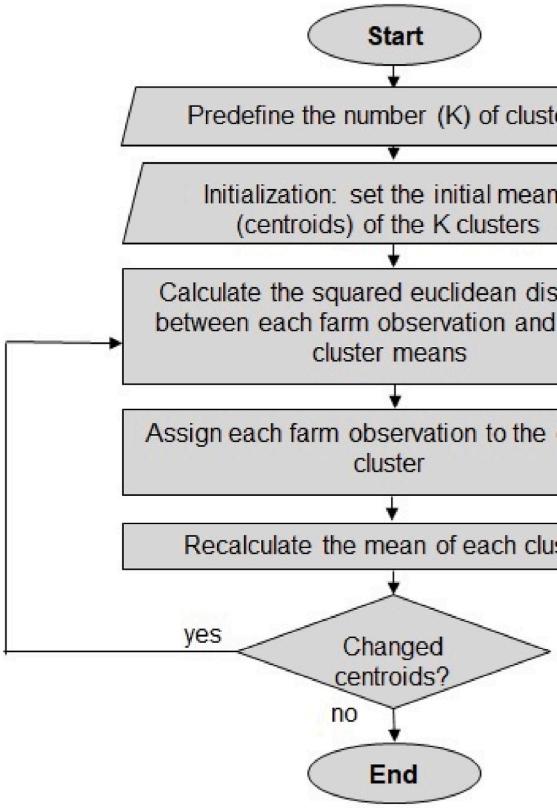

Fig. 1. Procedure of K-means clustering.

Since the optimal number of clusters K^* was a priori unknown, we decided on K^* using the so-called 'elbow method'. For the different values of K, we calculated the total within-cluster sum of squares and chose K^*, such that the decrease in the total within-cluster sum of squares between two successive values of K was much greater than for subsequent values. Ideally, this heuristic approach yields a kink in a graph that plots K against the total within-cluster sum of squares (see Figure A.1 in Appendix A). The advantage of the K-means clustering algorithm is that it is fast and yields the kinds of compact clusters in which we were interested.

3.2. Sensitivity analyses

Clustering results may be sensitive to the chosen clustering algorithm. For this reason, we carried out two sensitivity analyses, the first relying on hierarchical clustering and the second on the fuzzy K-means algorithm, to check the stability of the clusters with respect to the clustering algorithm. Further details on the sensitivity analyses conducted are available in Appendix B.

4. Data

In the following subsections, we present 1) the data source and sample investigated, 2) the clustering variables and their specification and 3) the FADN variables used to characterise the clusters.

4.1. Data source and sample investigated

Our investigation relies on unbalanced panel data from 410 farms included in the Swiss AEDN for the years 2009–2020; the farm observations were pooled over the years. The Swiss AEDN is the environmental counterpart of the Swiss FADN and is concerned with the environmental monitoring of Swiss agriculture based on environmental data collected at the farm level (Gilgen et al., 2023). The farms in the sample are not selected at random, as participation in the Swiss AEDN occurs on a voluntary basis. Only those farms that are willing and able to provide comprehensive and detailed data related to production and the environment take part in the monitoring, thus implying a sample selection bias. Furthermore, we considered only observations of the AEDN farms that also participated in the FADN. The sample investigated covers the three agricultural production regions (plain, hill and mountain) and all farm production types, as defined in Meier (2000), with the exception of farms with a strong focus on special crops (i.e. vegetable, fruit, wine growing, horticulture and other special crops), as special crops are not accounted for in the biodiversity impact assessment described in Section 4.2.[6] In total, 2341 farm observations were matched to the FADN data over the 12-year period considered. Statistics for the number of observations available per region, and farm production type as well as on the regional share of the different farm production types are provided in Table A.2 (Appendix A), which demonstrates that variation in natural production conditions substantially affects production orientation and, thus, the farm type distribution in different regions. We accounted for the different natural environments by implementing the clustering separately for each of the three production regions (i.e. plain, hill and mountain regions). In the preliminary explorative phase of our research, we implemented clustering using the Partitioning Around Medoids (PAM) approach, with regional affiliation as an additional cluster variable. PAM was chosen for its ability to handle mixed-type data. The clustering yielded three clusters that perfectly distinguished the regions; hence, we decided to divide our sample into three subsamples before running the K-means and hierarchical clustering algorithms.

In addition to detailed environmental AEDN data, our dataset also encompasses economic data from the Swiss FADN and, more precisely, detailed farm-level accountancy data. Beyond these economic data, the Swiss FADN also includes information about farm structure, production system and natural environment, which were used for cluster characterisation.

4.2. Clustering variables

Our typology relies on four clustering variables, which are specified in detail below.

4.2.1. Share of EFAs in the total UAA

To depict the extent of farm participation in agri-environmental payment schemes for biodiversity conservation, we chose the share of total EFAs in the total UAA as variable. For every farm, we have detailed plot-level data pertaining to its cultivated crops, including plot size, whether it was the main or a secondary crop and whether it was categorised as an EFA. Since the crop classification also included trees, an area of 100 square metres per tree was determined for these categories in accordance with direct payment regulations. Additionally, secondary crops and the associated main crop were given a weight of one-half. The share of EFAs in the total UAA was then calculated as the aggregated plot area, categorised as EFA, and divided by the total UAA.

4.2.2. Impact of farm practices on the biodiversity of EFAs and non-EFAs

For each farm observation in the sample, detailed data on the impact of a farm's agricultural practices on biodiversity and, more precisely, on organismal (species) diversity are available from the Swiss AEDN. The biodiversity impact assessment relies on the approach developed by Jeanneret et al. (2009, 2014) and is based on detailed and comprehensive production inventories collected for each farm. Regarding spatial system boundaries, the assessment focuses on the farm level and therefore does not consider the pre- or postfarm links in the food chain. Regarding temporal system boundaries, the assessment covers one cultural year. The biodiversity impact assessment approach used is an expert-based system that has been developed, parameterised and validated for use for grasslands, arable crops and seminatural habitats (SNHs)[7] in Switzerland and neighbouring countries. Special crops such as vegetables, fruit and grapes are not included in the assessment. The approach considers the eleven following indicator species groups (ISGs): flora of crops and grasslands (vascular plants, i.e., *Tracheophyta*), birds (*Aves*), small mammals (*Mammalia*), amphibians (*Amphibia*), snails (*Gastropoda*), spiders (*Araneae*), carabid beetles (*Carabidae*), butterflies (*Rhopalocera*), wild bees (*Apoidea*) and grasshoppers (*Orthoptera*) (Jeanneret et al., 2014). The assessment is based on a scoring system that estimates the suitability of farmland crops and SNHs as habitats for each ISG as well as the impact of the implemented field-management options (i.e. farming practices or farming activities, such as insecticide use, manuring and mowing) on each ISG.

The impact assessment on which our research relies focuses on the overall species diversity of each species group. The biodiversity impact estimate (R) of each management option for each ISG relies on expert knowledge and a highly comprehensive analysis of the scientific literature (about 900 scientific publications and reports). Biodiversity impact is rated on a relative scale from 1 to 5, with 1 being the most damaging management option and 5 being the most favourable one. This rating is weighted using the two coefficients $C_{habitat}$ and $C_{management}$, which both range from 0 to 10. $C_{habitat}$ reflects the suitability of the crop or SNH as a habitat for the ISG being considered, while $C_{management}$ quantifies, for each ISG, the relative importance of a management option occurring in a given crop or SNH. The final biodiversity impact score of a management option is the product of the rating R of the management option and the mean value of the two weighting coefficients, as shown in the following equation (1):

$$S = R \times \frac{(C_{habitat} + C_{management})}{2} \tag{1}$$

where.

- S = the final impact score (S) of the management option for a given ISG and for a given crop or SNH; its range is between 0 and 50;
- R = the impact rating of the management option for the given ISG and the given crop or SNH (from 1 to 5);
- $C_{habitat}$ = the weighting coefficient reflecting the suitability of the crop or SNH as a habitat for the ISG being considered (from 0 to 10);
- $C_{management}$ = the weighting coefficient quantifying the relative importance, for the ISG being considered, of the farming activity under consideration in relation to the crop or SNH in question (from 0 to 10).

Usually, several management options take place within a given crop or SNH; thus, as the first step to obtaining a final crop or SNH ISG score across all management options occurring in the crop or SNH, the individual scores of the different management options implemented are aggregated through averaging. In the second step, the ISG scores are aggregated across all ISGs to obtain the overall biodiversity impact score of the crop or SNH. Aggregation occurs by weighting each ISG score (including those equal to zero) on the basis of trophic links between the ISGs and ISG species richness. The more important an ISG is as a basic food for other ISGs, and the more species-rich it is in the agricultural landscapes, the higher its assigned weight. In the third and last step, the biodiversity impact scores are aggregated across the crops and SNHs to derive the farm-level biodiversity impact score. Aggregation occurs by

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[6] The agricultural region classification is based on criteria regarding 1) climatic situation (especially the length of the growing season), 2) topography and 3) accessibility (FOAG, 2008).The farm production typology is an a priori typology aimed at classifying the farms based on the importance of their activities (e.g. arable cropping, dairy farming, pig farming, etc.).Farms with a strong focus on special crops are defined as those farms with a share of special crops in the UAA above 10% or with a share of special crops in the farm monetary agricultural output (excluding direct payments) above 33%. This is the case for 195 observations.

[7] Seminatural habitats are defined as those habitats not primarily devoted to agricultural production (e.g. extensively managed meadows, wildflower strips, hedges, etc.).

weighting each crop or SNH biodiversity impact score according to the respective crop or SNH area. In the present study, we computed for each farm observation two separate aggregate biodiversity impact scores, one for the whole-farm EFAs and one for the whole-farm non-EFAs.

4.2.3. Farm agricultural production intensity

The extent of the orientation of a farm towards agricultural production was assessed using an indicator of agricultural production intensity. For that purpose, we used a biophysical variable, namely the nitrogen output per hectare of UAA, which is defined as the nitrogen removed with the harvested crop (including fodder crops) or with the grazed fodder crop or grass and can therefore be considered as the nitrogen yield per hectare of UAA. This value is derived from soil-surface nitrogen balancing according to the approach explained briefly in Jan et al. (2017) and in more detail in Spiess (2010). We preferred a biophysical variable over a monetary one due to our focus on the primary function of agriculture from a biophysical perspective: agricultural commodity production.

Compared to other possible biophysical variables, such as human digestible energy output, nitrogen output has two major advantages. First, it enables the researcher to capture the whole agricultural output from land use independently of whether the harvested agricultural commodities are used for food, feed, fibre or fuel. Second, it is directly related to land use, as it is assessed according to a soil-surface nitrogen balancing approach, the system boundaries of which are, as stated in its name, the soil surface. Compared to monetary variables, nitrogen output has the advantage of being directly related to the nutrition function of agriculture, as nitrogen is a core component of amino acids, which are the molecular building blocks of proteins.

Table 1 summarizes the clustering variable statistics. The average EFA share of the farms in the sample amounts to 15.1% of the UAA. The mountain region shows a significantly higher EFA share (21.9%) compared to the plain and hill regions (12.4% and 14.0%, respectively). The average biodiversity impact score of the EFAs is 17.1 and is slightly higher in the hill than in the plain and mountain regions (17.7 compared to 17.0 and 16.5, respectively).[8]

The average biodiversity impact score of the non-EFAs is 9.6, and it increases from the plain to the mountain regions (8.4, 9.7 and 12.0, respectively); in other words, the less favourable the natural production conditions are, the higher the biodiversity impact score of the non-EFAs. Additional detailed statistics on the biodiversity score of (i) the non-EFAs decomposed into arable land and grassland and (ii) the different EFA categories can be found in Table A.3 in the appendix. As is obvious from these detailed statistics, within the non-EFA, arable cropland shows a substantially smaller biodiversity score than grassland (on average 7.4 and 10.5, respectively). This is one of the reasons why the impact score of the non-EFAs increases from the plain region to the mountain region. Substantial differences in terms of biodiversity scores are also observed among EFAs, depending on the habitat. The highest average biodiversity scores are observed for (i) hedges, field, and riparian shrubs (28.5), (ii) riverside meadows (27.7), and (iii) litter meadows (24.0). Conversely, (i) native individual trees and tree alleys, (ii) less intensively used meadows, (iii) extensively used pastures, and (iv) extensively used meadows show the lowest average biodiversity scores among all EFA categories (13.6, 14.0, 14.7, and 15.5, respectively).

The 2341 farm observations in the sample revealed an average nitrogen output of 166 kg per hectare of UAA. The plain and hill regions are characterised by a significantly higher nitrogen output per hectare of UAA compared to the mountain region (181, 185 and 111 kg of nitrogen per hectare, respectively). These numbers reflect the more adverse natural production conditions, especially the shorter vegetation period, at higher elevations.

4.3. FADN and AEDN variables selected to further characterise the clusters

As recommended by Alvarez et al. (2018), we characterised the clusters according to the clustering variables and the different farm variables that were hypothesised to drive the observed heterogeneity of land use patterns. These variables were selected from the FADN dataset and include characteristics of a farm's structure, its production system and orientation and its economic performance. We also considered additional variables from the AEDN related to nitrogen use. A full list of the variables of interest and their abbreviations is provided in Table 2, and the descriptive statistics of the FADN and AEDN variables used for cluster characterisation are available in Table A.4 (Appendix A).

5. Results

We now turn to the main results of our cluster analysis for the plain, hill and mountain regions. The results of the Hopkins test, which aims to test the cluster tendency, and whose null hypothesis states that the data are uniformly distributed, revealed the existence of meaningful clusters (test statistic >0.8). Based on the elbow method, we found that the optimal number of clusters was equal to four in the plain region and three in the hill and mountain regions (see Figure A1 in Appendix A). Since we used unbalanced panel data, any given farm could be assigned to several clusters. For the 170 (112, 82) farms with repeated observations in the plain (hill, mountain) region, 106 (86, 57) are part of only one cluster, while 56 (32, 21) farms belong to two clusters and 8 (4, 4) to three clusters. The farm cluster assignment is therefore more stable across time in the hill and mountain regions than in the plain region, with 77%, 70%, and 62% of the mountain, hill, and plain farms, respectively, being part of only one cluster. Despite the farm switches between clusters, the identified land use patterns and their interpretation are not substantially affected by the time dimension, as shown by a preliminary analysis in which the last two years (2019 and 2020) of the investigated period were not considered and which yielded similar land use patterns. Furthermore, the sensitivity analyses we carried out reveal that the clustering results are robust to the chosen clustering algorithm (for more details on the sensitivity analyses, see Appendix B).

5.1. Cluster characterisation regarding the clustering variables

Table 3 summarizes the results in the form of mean values for all clustering variables by region and cluster membership. We have also provided the mean values of the overall biodiversity impact score, which encompasses both EFAs and non-EFAs and provides therefore an overall picture of farm biodiversity. Additionally, the distribution of the clustering variables by region and cluster is displayed graphically in several violin plots available in Appendix A (see Figures A.2a, A.2b and A.2c).

We found three distinct clusters showing – across all regions (plain, hill and mountain) – quite similar basic land use patterns in terms of agricultural production intensity and biodiversity conservation. These clusters were labelled as follows: 'extensive farms with a strong focus on EFA production', 'intensive farms with biodiversity-friendly practices' and 'intensive farms with less biodiversity-friendly practices'. In the plain region, we found an additional cluster, which we called 'neither highly intensive nor particularly biodiversity-friendly farms'. Even though the other clusters revealed strong basic similarities across all three regions, they also showed some regional particularities. In the following section, we describe the clusters and compare the average values of the clustering variables to the respective regional averages.

The **extensive farms with a strong focus on EFA production** cluster has the highest EFA share of all the clusters, ranging from 21% to 28% in the hill and mountain regions, respectively, to 47% in the plain region. Evidently, EFA or, more precisely, biodiversity conservation

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[8] To correctly interpret this score, recall that the higher the biodiversity impact score, the more biodiversity-friendly the farm practice.

Table 1
Descriptive statistics of the clustering variables.

Clustering variable	Variable specification *(variable abbreviation)*	All regions		Plain region		Hill region		Mountain region	
		Mean	CV	Mean	CV	Mean	CV	Mean	CV
Extent of farm participation in the agri-environmental payment schemes for biodiversity conservation	Share of EFAs in the total UAA *(share_efa_uaa)*	15.1	0.65	12.4	0.59	14.0	0.55	21.9	0.59
Impact of farm practices on the biodiversity of EFAs	Biodiversity impact score of the EFAs *(score_efa)*	17.1	0.12	17.0	0.12	17.7	0.12	16.5	0.13
Impact of farm practices on the biodiversity of non-EFAs	Biodiversity impact score of the non-EFAs *(score_nonefa)*	9.6	0.20	8.4	0.13	9.7	0.17	12.0	0.10
Agricultural production intensity	Nitrogen output per hectare of UAA *(n_output)*	166.5	0.34	180.6	0.29	184.9	0.26	111.0	0.38

Notes: Total number of observations (N) = 2341; CV = coefficient of variation.
Source: Authors' calculations based on AEDN (2009–2020).

within the EFA agri-environmental payment schemes, is an important production branch of these farms. In addition, the production intensity is the lowest in this cluster across all regions and amounts to 90, 137 and 84 kg of nitrogen output per hectare for the plain, hill and mountain regions, respectively, compared to 181, 185 and 111 kg nitrogen output for the respective regional averages across all clusters. Interestingly, the above-average EFA share does not translate to higher EFA biodiversity impact scores. In all three regions, the EFA biodiversity impact score of this cluster (16.0, 16.5, and 16.1 points for the plain, hill and mountain regions, respectively) is below the respective regional average (17.0, 17.7, and 16.5 points for the plain, hill and mountain regions, respectively). Conversely, the non-EFA biodiversity impact scores of this cluster (9.3, 10.3 and 12.6 in the plain, hill and mountain regions, respectively) exceed the regional averages (8.4, 9.7 and 12.0 in the plain, hill and mountain regions, respectively). The overall biodiversity impact score of this cluster (i.e. the impact score across the whole UAA, including EFAs and non-EFAs) is higher than the respective regional average, which is attributable to the fact that compared to other clusters, this cluster has a substantially higher share of EFAs, the biodiversity impact scores of which are almost twice as high as those of non-EFAs. With the exception of the hill region, this cluster has the highest overall biodiversity impact score of all the clusters. Most farm observations (56%) in the mountain region belong to this cluster, compared to only 27 farm observations (3%) in the plain region. In the hill region, 30% of the farm observations fell into this cluster.

The **intensive farms with biodiversity-friendly practices** cluster is characterised by an above-average production intensity (207, 211 and 136 kg of nitrogen for the plain, hill and mountain regions, respectively) compared to the respective regional means (181, 185 and 111 kg of nitrogen, respectively). This cluster has the highest EFA biodiversity impact score of all the clusters (18.8, 18.8 and 20.4 for the plain, hill and mountain regions, respectively, compared to 17.0, 17.7 and 16.5 for the respective regional means). The non-EFA biodiversity impact scores of this cluster are 9.8, 11.2 and 11.9 for the plain, hill and mountain regions, respectively, which are higher than or close to the respective regional averages of 8.4, 9.7 and 12.0. The average EFA share of this cluster differs by region. In the plain and hill regions, the EFA shares of this cluster (12.1% and 12.4%, respectively) are close to the regional averages (12.4% and 14.0%, respectively). For the mountain region, the EFA share is 11.5%, which is about half as much as the regional average (21.9%).

The intensive farms with biodiversity-friendly practices cluster is the second-best performing cluster in the plain and mountain regions in terms of overall biodiversity impact scores. In the hill region, this cluster has the highest overall biodiversity score, outperforming even the extensive farms with a strong focus on EFA production cluster in this regard. The above-average overall biodiversity performance of this cluster is attributable to the fact that in all regions and in all clusters, it has not only the highest EFA biodiversity impact score but also – for the plain and hill regions – the highest non-EFA biodiversity score. The intensive farms with biodiversity-friendly practices cluster was found in all regions, but most commonly in the hill region, where 29% of the farms belong to this cluster. The share of this cluster in the plain and mountain regions was significantly lower at 19% and 13%, respectively.

The **intensive farms with less biodiversity-friendly practices** cluster also reveals an above-average production intensity. The nitrogen output per hectare of UAA of the farms in this cluster amounts, on average, to 214, 202 and 149 kg per hectare of UAA in the plain, hill and mountain regions, respectively, which is 18%, 9% and 35% higher than the respective regional averages. This cluster is further characterised by EFA shares (9.4%, 10.0% and 15.8% for the plain, hill and mountain regions, respectively) that are lower than the respective regional averages (12.4%, 14.0% and 21.9% for the plain, hill and mountain regions, respectively). Additionally, this cluster has the lowest non-EFA biodiversity impact scores (7.7, 8.2 and 10.9 for the plain, hill and mountain regions, respectively) of all the clusters. In terms of the EFA biodiversity impact scores, the picture differs according to region. In the plain and hill regions, the EFA biodiversity impact scores of this cluster (17.2 and 17.7, respectively) are quite close to or equal to the regional averages (17.0 and 17.7, respectively). In the mountain region, the score is lower than the regional average (15.7 compared to 16.5). This cluster exhibits the lowest overall biodiversity impact score of all the clusters, which is attributable to the fact that it has the lowest non-EFA biodiversity impact score in combination with the lowest EFA shares, at least for the plain and hill regions. These types of farms are commonly present in all three regions; however, their presence is slightly more common in the plain and hill regions (39% and 40%, respectively) than in the mountain region (31%).

For the plain region, we found an additional cluster, which we called the **neither highly intensive nor particularly biodiversity-friendly farm** cluster. This cluster includes farms with below-average agricultural production intensities (140 kg of nitrogen output per hectare compared to the regional plain average of 181 kg). The EFA share of these farms (13.3%) is quite close to the average observed for all farms in the plain region (12.4%). This cluster is further characterised by a below-average EFA biodiversity impact score (15.9 compared to 17.0), whereas its non-EFA biodiversity score is almost equal to the regional means (8.3 compared to 8.4). The average overall biodiversity impact score of this cluster is slightly lower than that of the regional plain average. In terms of presence frequency, this cluster includes 39% of farms in the plain region.

For a better understanding of the differences between clusters in terms of the biodiversity score of the EFA, we provide detailed information on the average EFA composition of each cluster in Appendix A (see Figures A.3a, A.3b, and A.3c). We found that the two plain and hill clusters with the highest average EFA biodiversity scores have a higher share of permanent cropland and woody EFA elements, especially of (i) traditional orchard trees as well as (ii) hedges, field, and riparian shrubs, compared to other clusters. They also show a lower share of grassland EFA. In the mountain region, the cluster with the highest EFA

Table 2
FADN and AEDN variables used for cluster characterisation.

Category	Variable	Abbreviation
Structural characteristics of the farm	Farm size: UAA in hectares	*uaa*
	Farming form	*fulltime*
	1 Individual farm, full-time farming	*fulltime_second*
	2 Individual farm, full-time farming with secondary activity	*part_time*
	3 Individual farm, part-time farming	*farm_collective*
	4 Farming collective	
Production system	Production form	*conv_farm*
	1 Conventional farming, fulfilling the cross-compliance requirements (PEP)	*organic_farming*
	2 Organic farming	*conv_to_organic*
	3 In conversion to organic farming	
Production orientation	Farm type in terms of production orientation according to the FADN typology	*arable_crop*
	1 Arable crops	*dairy_cows*
	2 Dairy cows	*suckler_cows*
	3 Suckler cows	*other_cattle*
	4 Other cattle	*horses/sheep/goats*
	5 Horses/sheep/goats	*granivores*
	6 Granivores (pig and poultry)	*comb_dairy_arable*
	7 Combined dairy cows/arable crops	*comb_suckler*
	8 Combined suckler cows	*comb_granivores*
	9 Combined granivores	*comb_others*
	10 Combined others	
	Livestock density in livestock units per hectare	*lu_uaa*
	Share of arable crops in the UAA (in %)	*arable_uaa*
	Share of arable crops in farm's agricultural monetary market output[a] (in %)	*arable_output*
	Share of milk and milk products in farm's agricultural monetary market output[a] (in %)	*milk_output*
	Share of cattle (cattle breeding and fattening, including dairy cattle culling) in farm's agricultural monetary market output[a] (in %)	*cattle_output*
	Share of granivores (pigs and poultry) in farm's agricultural monetary market output[a] (in %)	*granivores_output*
	Share of direct payments in farm's total monetary output (in %)	*dp_output*
	Share of para-agricultural activities in farm's total monetary output (in %)	*para_output*
Economic performance	Gross land productivity (farm's total monetary output in Swiss Francs per hectare of UAA)	*prod_land*
	Labour intensity (in labour units per hectare of UAA)	*lab_int*
	Capital intensity (in Swiss Francs fixed assets per hectare of UAA)	*cap_int*
	Intensity of use of mineral fertilisers (costs for mineral fertilisers per hectare of UAA)	*intens_fert*
	Intensity of pesticide use (costs for pesticides per hectare of UAA)	*intens_pest*
	Intensity of purchased feedstuff use (costs for purchased feedstuffs per hectare of UAA)	*intens_feed*
	Work income per family labour unit[b] (in Swiss Francs)	*income*
Environmental performance regarding nitrogen use	Nitrogen balance (in kg of nitrogen per hectare of UAA)	*n_balance*
	Nitrogen use intensity (in kg of nitrogen per hectare of UAA)	*n_intensity*
	Nitrogen use efficiency (in %)	*n_efficiency*
Natural environment of the farm	Altitude of production site (in metres above sea level)	*altitude*

[a] Agricultural output without any direct payments.

[b] The work income per family labour unit corresponds to the agricultural income available per full-time equivalent family labour unit after deducting all external factor costs and after the remuneration of equity capital at its opportunity costs.

biodiversity score shows a higher share of wooded pastures and litter meadows in combination with a lower share of extensively used meadows and pastures, as well as less intensively used meadows compared to the two other clusters. Thus, across all regions, the clusters with the highest average EFA biodiversity score show a higher share of EFA types characterised by a high biodiversity score and a lower share of EFA types with a low biodiversity score.

5.2. Cluster characterisation regarding additional variables

After describing the farm types in terms of the clustering variables, we subsequently characterised them in relation to the additional variables listed in Table 2. The clusters were found in all regions to differ significantly in terms of several characteristics related to farm structure, production system and orientation, economic performance, and environmental performance regarding nitrogen use (see also Table A.5 in Appendix A). In what follows, we focus on the key results of this characterisation, especially the common patterns found across all three regions.

The **extensive farms with a strong focus on EFA production** cluster is characterized in all regions by the lowest livestock density among all clusters. Among all the clusters, this cluster has the highest share of direct payments in the farm monetary output (around one-third for the hill region and one-half for the plain and mountain regions). This is attributable, among other things, to the farms in this cluster having strong involvement in agri-environmental payment schemes for biodiversity conservation. In the plain and hill regions, this cluster further features the highest work income per family labour unit of all the clusters. This superior economic performance results from a particularly low input use intensity (labour, capital, and intermediate consumption) and scale effects, both of which overcompensate for the lower gross land productivity of this cluster. In the mountain region, the economic performance of this cluster does not differ from the regional average. Similar to the plain and hill regions, the lower gross land productivity observed for this cluster in the mountain region is counteracted by its lower capital and intermediate consumption use intensity. However, as opposed to the plain and hill clusters, this cluster does not benefit from scale effects. In terms of nitrogen balance, this cluster has the lowest nitrogen surplus per hectare across all regions, which is attributable to its significantly lower nitrogen use intensity. In the mountain region, the farms in this cluster operate at a higher average altitude and thus under less favourable natural production conditions than those in the other

Table 3
Results of K-means clustering, including the mean values of clustering variables and the statistical significance of the differences between clusters.

	Extensive farms with a strong focus on EFA production	Neither highly intensive nor particularly biodiversity-friendly farms	Intensive farms with biodiversity-friendly practices	Intensive farms with less biodiversity-friendly practices	All farms	F- or Welch-test statistics[2]
Plain region	**Cluster 1**	**Cluster 2**	**Cluster 3**	**Cluster 4**		
share_efa_uaa	46.931^{a}	13.301^{b}	12.111^{c}	9.357^{d}	12.427	291.335***
score_efa	16.005^{c}	15.856^{c}	18.822^{a}	17.238^{b}	16.972	156.14***
score_nonefa	9.35^{a}	8.29^{b}	9.764^{a}	7.726^{c}	8.380	261.084***
overall_score[1]	12.465^{a}	9.306^{c}	10.868^{b}	8.62^{d}	9.421	394.71***
n_output	90.018^{c}	140.275^{b}	207.144^{a}	213.726^{a}	180.595	498.403***
n	8	101	55	101	193	
N	27	391	193	395	1006	
Hill region	**Cluster 2**		**Cluster 1**	**Cluster 3**		
share_efa_uaa	20.908^{a}		12.351^{b}	10.035^{c}	14.016	167.172***
score_efa	16.502^{c}		18.843^{a}	17.739^{b}	17.689	89.041***
score_nonefa	10.317^{b}		11.174^{a}	8.15^{c}	9.698	934.773***
overall_score [1]	11.625^{b}		12.154^{a}	9.118^{c}	10.773	845.049***
n_output	137.23^{c}		210.925^{a}	201.736^{b}	184.877	322.987***
N	55		49	67	131	
N	246		239	326	811	
Mountain region	**Cluster 2**		**Cluster 1**	**Cluster 3**		
share_efa_uaa	27.643^{a}		11.483^{c}	15.83^{b}	21.888	140.336***
score_efa	16.119^{b}		20.375^{a}	15.742^{c}	16.5364	106.27***
score_nonefa	12.632^{a}		11.884^{b}	10.921^{c}	11.999	150.384***
overall_score [1]	13.658^{a}		12.859^{b}	11.725^{c}	12.949	203.76***
n_output	83.839^{c}		135.631^{b}	149.303^{a}	110.976	262.835***
n	57		21	47	96	
N	293		66	165	524	

Notes: n = number of farms; N = total number of observations; the same farm can be assigned to several clusters, and the number of clusters is based on the elbow method.

[1] *Overall_score* refers to the overall biodiversity impact score of the UAA, encompassing both EFAs and non-EFAs. It has not been included as an input in the clustering. Its two components – the biodiversity impact scores of EFAs and non-EFAs – were considered as separate clustering variables.

[2] The overall differences between clusters were investigated using an ANOVA, also called an F-test, or Welch's ANOVA, also called Welch's F-test, if the variance homogeneity assumption (Levene's test) was not met. Pairwise differences between clusters were subsequently analysed using Scheffé's test.

Statistical significance levels provided for the F- and Welch-tests: $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$; n.s. = not statistically significant at the 5% level.

$^{a,\ b,\ c,\ d}$ Means followed by a common letter were not significantly different at the 5% level of significance, according to Scheffé's test.

Source: Authors' calculations based on AEDN and FADN (2009–2020).

two clusters.

The **intensive farms with biodiversity-friendly practices** cluster shows a lower share of organic farms in the plain and mountain regions than its counterpart with less biodiversity-friendly practices, while the opposite applies in the hill region. Of all the plain and hill clusters, the intensive farms with biodiversity-friendly practices are the most highly specialised in milk production while having the lowest shares of arable cropland and thus the highest grassland share. In the plain and hill regions, the average livestock density of this cluster does not significantly differ from that of its less biodiversity-friendly counterpart whereas it is lower in the mountain region. In the plain and hill regions, this cluster further demonstrates a higher gross land productivity compared to the regional average. In both regions, the average mineral fertiliser and pesticide costs per hectare of this cluster are lower than the respective regional averages and are almost half of (in the plain region) or two-thirds (in the hill region) lower than the average value observed for the intensive farms with less biodiversity-friendly practices cluster, which shows a similar production orientation. Quite interestingly, unlike in the plain and hill regions, this cluster shows an average gross land productivity lower than the regional average in the mountain region. In the mountain region, the costs for purchased feedstuffs per hectare of UAA in this cluster are 60% lower than those in the intensive farms with less biodiversity-friendly practices cluster. Compared to its less biodiversity-friendly counterpart, this cluster also has a lower nitrogen input per hectare, which, combined with a higher nitrogen use efficiency, leads to a lower nitrogen balance per hectare of UAA. This lower nitrogen use intensity is, in the plain and hill regions, ascribable to the much lower mineral fertiliser use intensity and, in the mountain region, to the lower livestock density and purchased feedstuff use intensity. Notably, in the hill and mountain regions, the nitrogen surplus per hectare of UAA in this cluster does not differ in a statistically significant way from the value observed for the 'extensive farms with a strong focus on EFA production' cluster.

The **intensive farms with less biodiversity-friendly practices** cluster is characterised by above-regional average livestock densities across all three regions. Compared to their biodiversity-friendly counterparts, these farms show a significantly higher arable cropland share in the plain and hill regions. In both regions, this cluster demonstrates above-regional average gross land productivity. Regarding intermediate consumption use intensity, this cluster exhibits a substantially higher fertiliser and pesticide use intensity in the plain and hill regions compared to the values observed for its biodiversity-friendly counterpart. In the mountain region, this cluster shows the highest gross land productivity and purchased feedstuff use intensity among all clusters. As a consequence of its substantially higher nitrogen use intensity and, in the plain and hill regions, lower nitrogen use efficiency, this cluster has the highest nitrogen surplus per hectare among all clusters and in all three regions.

The **neither highly intensive nor particularly biodiversity-friendly** farm cluster is characterised by having the highest arable cropland share in the UAA. As a consequence of its strong focus on arable crops, this cluster shows the highest mineral fertiliser and pesticide costs per hectare of UAA. Regarding nitrogen use, this cluster has the second lowest nitrogen balance of the four plain clusters, which is attributable to a significantly lower nitrogen input per hectare of UAA compared to the regional average.

6. Discussion and conclusions

Our study offers a better understanding of farm-level land use patterns regarding agricultural production and biodiversity conservation in Swiss agriculture. In particular, we adopted a comprehensive perspective that embraces the whole farm (i.e. encompassing both EFAs and non-EFAs). This comprehensive approach represents one of the main contributions of our research, especially since the focus of the existing empirical literature in this research field and regarding agricultural policy debates on biodiversity conservation in European agriculture (see, e.g., Pe'er et al., 2017) has previously been restricted to EFAs.

We identified four farmland use pattern types. In each region (plain, hill, and mountain), we identified three clusters showing similar land use patterns in terms of agricultural production intensity and biodiversity conservation: extensive farms with a strong focus on EFA production, intensive farms with biodiversity-friendly practices, and intensive farms with less biodiversity-friendly practices. In the plain region, we found an additional cluster described as neither highly intensive nor particularly biodiversity-friendly farms. The fact that similar clusters were found in the plain, hill and mountain region further supports the validity of the typology. However, any interpretation of these results should consider that the similarity of the observed land use patterns across regions applies in relative but not absolute terms. For instance, the clusters "intensive farms with biodiversity-friendly practices" and "intensive farms with less biodiversity-friendly practices" are both—in absolute terms—substantially less intensive in the mountain region than in the hill and plain regions. Conversely, the biodiversity friendliness of farm practices is substantially higher in the mountain than in the hill and plain regions for all clusters.

The clustering revealed that in terms of agricultural production and biodiversity conservation, farm-level land use patterns are not only heterogeneous but also more complex than the implicit classical dichotomy adopted in many socioeconomic investigations that associates low shares of EFAs with high agricultural production and high shares of EFAs with low agricultural production. We found that farms with the highest EFA shares did not necessarily have the highest EFA biodiversity impact scores or the highest overall biodiversity scores. Conversely, farms with the lowest EFA shares did not necessarily have the lowest EFA biodiversity impact scores. A disaggregation of the EFA into its two subcomponents – the action- and result-oriented EFA – would have helped to better contextualise the two previous findings, but the data were unavailable. The study would have benefitted specifically from the ability to check whether the two previous findings were related to the fact that, compared to farms with a low EFA share, farms with a high EFA share have a lower share of result-oriented EFAs in their total EFA. In general, result-oriented EFAs have demonstrated better ecological performance compared to their action-oriented counterparts (e.g., Meier et al., 2021; Saint-Cyr et al., 2023).

Although the agricultural production intensity and the overall biodiversity impact score tended to be negatively related, we found among the intensive farms two different subtypes, one with a lower overall biodiversity impact score and one with a higher overall biodiversity impact score. In terms of EFA, non-EFA and overall biodiversity impact scores, in the hill region, the farms with the highest agricultural production intensity outperformed the extensive farms with a strong focus on EFA production. This finding suggests that agricultural production and biodiversity conservation do not per se involve tradeoffs and may be synergetic. The intensive farms with biodiversity-friendly practices are characterised in the plain and hill regions by lower arable land shares, significantly lower mineral fertiliser and pesticide use intensities and higher nitrogen use efficiencies compared to the intensive farms with less biodiversity-friendly practices. In the mountain region, intensive farms with biodiversity-friendly practices were associated with significantly lower livestock densities and purchased feedstuff use intensities compared to their less biodiversity-friendly counterparts. As a result, it seems that a key element of reconciling agricultural production and biodiversity conservation may be to combine a low or moderate use intensity of mineral fertilisers, pesticides and purchased feedstuffs with a high use efficiency of these inputs. These results align with Storkey et al.'s (2012) finding that fertiliser and pesticide use intensity are the main factors affecting biodiversity in European arable habitats, as well as Herrero-Jáuregui and Oesterheld's (2018) finding that species richness in grassland is negatively affected by the stocking rate. Quite interestingly, the intensive farms with biodiversity-friendly practices cluster has a higher organic farm share than its less biodiversity-friendly counterpart only in the hill region. No significant differences were observed in this regard in the plain and hill regions in either cluster, which suggests that production type is not a key factor in reconciling agricultural production and biodiversity conservation.

In terms of non-EFA biodiversity scores, we found substantial differences between clusters. Additionally, we found that the highest non-EFA biodiversity scores in the plain and hill regions were not observed in the cluster with a strong focus on EFA production. Taken together, these two findings suggest that it is possible for biodiversity conservation to take place outside EFA direct payment programmes to a certain extent.

With regard to the interactions between EFA and non-EFA, we did not identify any cluster with an above-average EFA share and a below-average non-EFA biodiversity score, which suggests no negative spatial within-farm spillover effect. In other words, we found no evidence to suggest that a high EFA share may lead to an intensification of production on non-EFA. This finding contradicts Uthes and Matzdorf's (2013) literature review and Chakir and Thomas (2022) empirical investigation of French farmers. However, we emphasise that our results are descriptive and merely constitute a starting point for further analyses using the methods of causal inference.

That the clusters differ significantly in terms of several characteristics related to farm structure, as well as production system and orientation, highlights the need to consider farm systems holistically to better understand the farming strategies associated with different land use pattern types. This finding aligns with Jan et al. (2017), who found that most of these characteristics were significant determinants of farm-level nitrogen surpluses in Swiss agriculture. The fact that the EFA and non-EFA compositions differ among clusters indicates that the different farm-level land use patterns identified are attributable not only to management but also to the habitat composition and thus, to a certain extent, to the natural endowment. This finding is corroborated by the differences observed between some clusters in terms of average farm altitude, which suggests that site conditions and thus structural differences may have, to a certain extent, played a role in the cluster building process. Controlling for site conditions and natural endowment is therefore of crucial importance for future studies that infer causal effects.

The clusters showed significant differences in terms of environmental performance regarding nitrogen use and economic performance, which suggests that different farm-level land use patterns impact the dimensions of environmental and economic performance. In this regard, our research and, more precisely, the identification of the extensive farms with a strong focus on EFA production cluster suggests that on large-scale farms and under the current Swiss agricultural policy, an extensive land use strategy combined with 1) strong involvement in agri-environmental programmes for biodiversity conservation and 2) low capital, labour and intermediate consumption use intensities is very promising. Indeed, this approach not only offers benefits in terms of biodiversity preservation but may be the most successful economic strategy for the plain and hill regions. However, this strategy is associated with significantly lower agricultural production per hectare and thus presents a tradeoff between biodiversity conservation and agricultural production.

With respect to their implications for agri-environmental biodiversity conservation policies, our findings call for a shift from the implicit classical dichotomy of low versus high EFA share and acknowledging the greater complexity of biodiversity by considering not only EFAs but also non-EFAs, especially the biodiversity impact of farm practices on non-EFAs.

In terms of future research, there remains a need to better understand the overall farm strategies that underpin each land use pattern type identified in this study. For this purpose, we suggest that future studies conduct qualitative social research capable of obtaining in-depth insights into the farm management decision-making process, considering the socioeconomic and biophysical contexts of farming, especially the biodiversity endowment of a farm's natural environment. The focus of such research should be placed on behavioural factors and opportunity costs, which have been identified as key drivers of farmer participation in agri-environmental payment schemes for biodiversity conservation (Schaub et al., 2023). A particular attention should be thereby paid to a better understanding of the determinants of farm switches between clusters. The findings of this proposed research can then be used to derive recommendations for more tailored agri-environmental policies that seek to balance agricultural production and biodiversity conservation.

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Data statement

The single farm data on which our research relies are confidential and cannot be made publicly available. The data may, however, be used by Swiss higher education institutions and research institutes for study and research purposes. Temporary data access may be granted upon signature of a data transfer and use agreement. Further information about the data access procedure and conditions can be found online at the following link.

CRediT authorship contribution statement

Pierrick Jan: Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing, Data curation. **Franziska Zimmert:** Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Dunja Dux:** Conceptualization, Data curation, Writing – review & editing. **Silvio Blaser:** Conceptualization, Data curation. **Anina Gilgen:** Conceptualization, Data curation, Writing – review & editing.

Declaration of competing interest

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

Data availability

The data that has been used is confidential.

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Appendix A. Supplementary data

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