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Ecological–Economic Modelling of Traditional Agroforestry to Promote Farmland Biodiversity with Cost-Effective Payments

Takamasa Nishizawa [1,*], Sonja Kay [2], Johannes Schuler [1], Noëlle Klein [2,3], Felix Herzog [2], Joachim Aurbacher [4] and Peter Zander [1]

[1] Farm Economics and Ecosystem Services, Leibniz Centre for Agricultural Landscape Research (ZALF) e.V., Eberswalder Strasse 84, 15374 Muecheberg, Germany; schuler@zalf.de (J.S.); peter.zander@zalf.de (P.Z.)
[2] Department of Agroecology and Environment, Agroscope, Reckenholzstrasse 191, 8046 Zurich, Switzerland; sonja.kay@agroscope.admin.ch (S.K.); noelle.klein@agroscope.admin.ch (N.K.); felix.herzog@agroscope.admin.ch (F.H.)
[3] Planning of Landscape and Urban Systems (PLUS), ETH Zurich, Stefano-Franscini-Platz 5, 8093 Zurich, Switzerland
[4] Institute of Farm and Agribusiness Management, Justus-Liebig-University Giessen, Senckenbergstrasse 3, 35390 Giessen, Germany; joachim.aurbacher@agrar.uni-giessen.de
* Correspondence: takamasa.nishizawa@zalf.de; Tel.: +49-(0)33432-82-490

Abstract: Orchard meadows, a traditional agroforestry system in Switzerland combining the dual use fruit and fodder production, are declining, even though the farmland managed under agri-environmental schemes (AES) has been expanding. Despite increasing interest in agroforestry research for developing sustainable agriculture, it is poorly understood how subsidies contribute to the maintenance of trees on agricultural land and the promotion of farmland biodiversity. Therefore, the objective of the present study is to examine the effects of incentive-based AES on both farmers' decisions regarding trees and biodiversity by developing an ecological–economic assessment model. To explore cost-effective AES, we explicitly consider the heterogeneity of farm types. We apply this integrated model to the farms in Schwarzbubenland, a small hilly region in Northern Switzerland. Results show that the adoption of AES and the compliance costs of participating in AES considerably vary among farm types, and the current AES do not provide farmers with sufficient payments to maintain any type of orchard meadows, despite the ecological benefits of orchard meadows. The integrating modeling developed in this study enables us to better understand the relationship between subsidies and biodiversity through farmers' decisions on land use and facilitates the design of cost-effective payments for the maintenance of agroforestry.

Keywords: agroforestry; biodiversity; agri-environmental schemes; integrated ecological–economic modeling; cost effectiveness

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1. Introduction

Given the increasing awareness of biodiversity degradation in Switzerland [1,2], Swiss agricultural policies have developed agri-environmental schemes (AES) to promote biodiversity on farmland, including orchards, vineyards, vegetables, etc. [3]. AES are voluntary programs that provide financial incentives for farmers. In the case of Switzerland, AES are a part of direct payments. Considering the high share of direct payments to the total farm income in Switzerland (around 50% on average in 2018–2020 [4]), land-use decisions can be assumed to be highly dependent on public payments. One of the requirements for receiving direct payments is that at least 7% of a farm's production area needs to be managed under AES. These areas are referred to as ecological focus areas (EFA) [5], similar to EFA in the European Union, but related to different conditions, and focus on the provision of farmland biodiversity.

The majority of EFA are implemented on grassland and high-stem orchards, regarded as a traditional agroforestry system in Switzerland [6], combining the dual use for fruit and fodder production. Particularly, orchard meadows are likely to play a key role in biodiversity promotion as agrobiodiversity hotspots under AES [7,8]. Due to their diverse structure, they supply habitats for various species, including small mammals, reptiles and several insect groups [9]. Along with biological diversity, orchard meadows provide socio-cultural features, such as landscape aesthetics, recreation and regional identity [10,11]. However, maintaining orchard meadows has become increasingly challenging, due to higher production costs, mechanized farming, increasing quality requirements and the infestation of invasive fruit flies [12,13]. The decline in orchards may trigger the loss of not only the traditional characteristics of the regional landscape, but also the habitats for various species. Therefore, the recent decline in orchard meadows in Switzerland [14,15] is of great concern. It is vital to investigate to what extent AES have an impact on the maintenance of orchards and farmland biodiversity, given a certain level of AES payments. The cost of adopting AES is a critical factor in farmers' decisions of whether to participate [16]. Additionally, the different effects of AES across specific farm types should be considered, as varied adoption costs are expected due to the differences in farm management.

There is accumulating evidence that farm types influence the effects of AES differently [17,18]. Bamière et al. [19] argued that a detailed representation of farm management can provide us with valuable insights into designing agri-environmental policies and AES. Indeed, Mack et al. [5] revealed that the implementation of action-based AES was strongly influenced by farm types. Therefore, simplified AES can lead to less ecologically beneficial effects, failing their conservation potential [20], although they may be readily implemented by farmers [18]. However, more research is needed about the direct relationship between heterogeneous farm types and their consequences on the cost-effectiveness of AES. Fewer than 15% of studies evaluate cost-effectiveness when assessing AES [21]. Investigating the cost-effectiveness of payment programs can be a key to providing relevant implications for optimizing AES and ensuring the sustainability of agricultural policy [22]. Additionally, unless such programs prove to be cost effective, some legitimacy concerns may arise: governmental bodies, taxpayers and users of ecosystem services may be reluctant to pay [23].

To address this science-policy gap, we developed an ecological–economic assessment model by integrating the results of the expert system for farmland biodiversity assessment, SALCA-BD (Swiss Agricultural Life Cycle Assessment—Biodiversity), into an optimization-based bio-economic farm model (BEFM). The objective of this study is to provide policymakers with insight into the design of cost-effective AES, taking into account different farm types, for maintaining orchard meadows and promoting farmland biodiversity. To that end, we investigated the feedback mechanisms between AES and their subsequent ecological and economic effects per farm type, via farmers' decisions on land use. Our study can be distinguished from studies published to date in that we evaluated the cost-effectiveness of agri-environmental schemes while taking into account the impacts of both agroforestry and heterogeneous farms. We addressed the following research questions:

1. What role do AES play in land use and sustaining orchard meadows?
2. Which types of farms are more likely to implement AES and which measures?
3. How does the cost effectiveness of AES differ between farm types?
4. How would AES change the regional land use and affect the diversity of individual species?

2. Materials and Methods

Figure 1 illustrates our methodological approach for this study, in which we integrated the SALCA-BD and the BEFM, and describes the flow of model inputs and outputs. The following subsections explain each of these methodologies in depth.

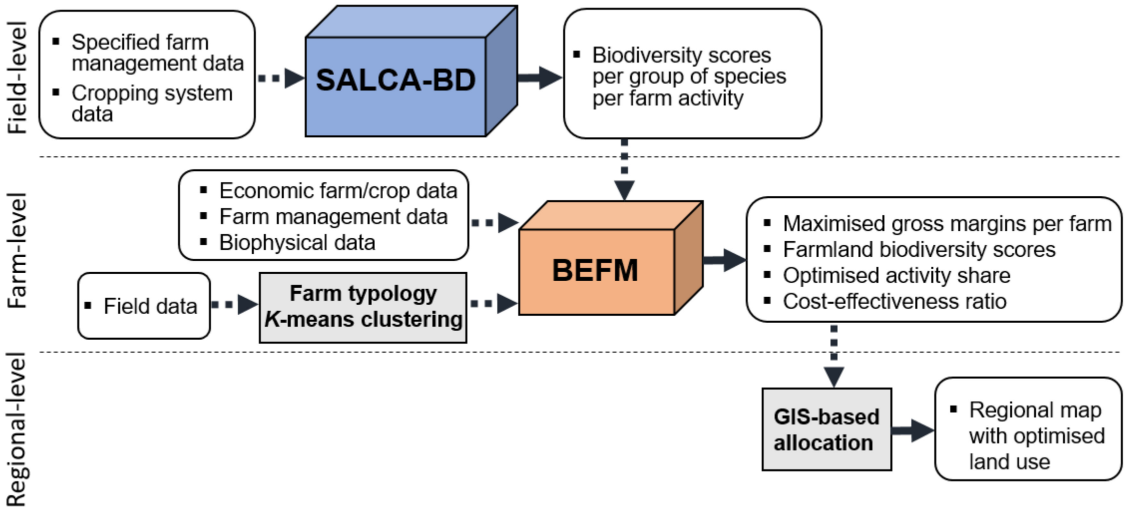

Figure 1. Structure of the ecological–economic model with the flow of inputs and outputs, integrated the results of each activity from the expert system for farmland biodiversity assessment (SALCA-BD) into the optimization-based bio-economic farm model (BEFM).

2.1. Case Study Region and Data

The study region, Schwarzbubenland (Figure 2), is located in Canton Solothurn, characterized by gently rolling hills (elevation 430 to 670 m). The average temperature is between 7.7 °C and 9.1 °C with annual precipitation of 800 to 1000 mm. Forestry (44%) and farmland (43%) are the main land uses. The area size is approximately 50 km^2, of which 1783 hectares are used as farmland, consisting of 32% arable land, 20% grassland and 48% orchard meadows. The study region is characterized by traditional high-stem cherry orchards combined with permanent grasslands. They have been established for subsistence and commercial fruit production, and the permanent grasslands are grazed by cattle and occasionally mown. Orchard meadows are recognized as agro-biodiversity hotspots. However, the decline of orchard trees can also be observed in this region [14].

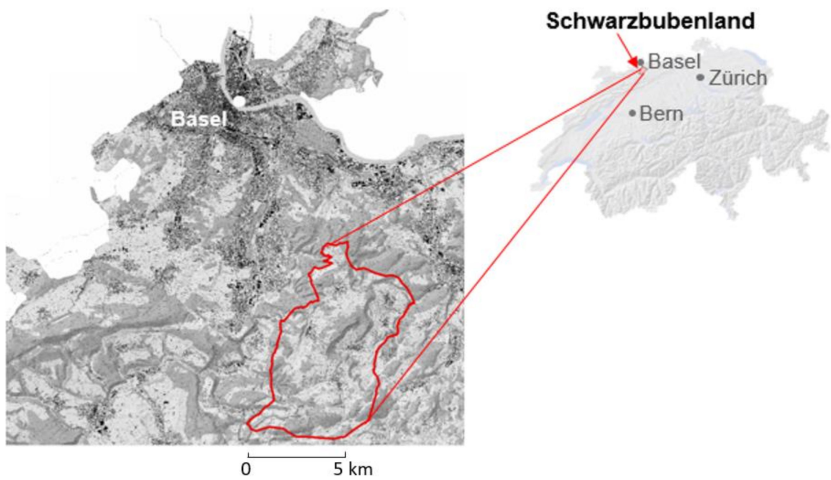

Figure 2. The study region: Schwarzbubenland (Switzerland) (Source: SwissImage ©Swisstopo).

Canton Solothurn provided 4698 spatially explicit field data spots in 2020 on the type of livestock, crops, management, the number of trees, area size, and the average slope degree [24]. Of the recorded 74 farms, over half of the farming enterprises are mixed farms, with combinations of arable crops, animal husbandry (mostly cattle for milk and meat production) and some fruit production. The average farm size is 24.1 ha, slightly larger than the average Swiss farm (21 ha, [25]), with approximately 0.77 livestock units per hectare.

2.2. SALCA-BD (Swiss Agricultural Life Cycle Assessment—Biodiversity)

The expert system SALCA-BD [26] evaluates the habitat suitability and favorable or adverse effects of agricultural activities on terrestrial species diversity at field scale [27]. Farmland biodiversity is represented by a set of indicator species groups (ISGs) that are sensitive to land use and farm management: vascular plants, birds, mammals, amphibians, snails, spiders, carabids, butterflies, wild bees, and grasshoppers. SALCA-BD assessed farm activities on both arable land and grassland as well as EFA. Along with the assessment of habitats' suitability on each ISG, management options, such as fertilizer and plant protection use, soil tillage, sowing, irrigation, the number and timing of mowing, etc., were explored. The SALCA-BD scores are calculated per ISG per farm activity and range between 0 and 50. The evaluation is non-spatially explicit. Results from the model have been validated in Switzerland and neighboring countries [27]. Jeanneret et al. [26] explain the method in more detail. Appendix A presents the biodiversity scores of the farm activities at a field-level evaluated with the model in this study.

For the aggregation of the habitats at a farm-level, we assumed a linear relationship between the biodiversity score of each farm activity and its area. Hence, we calculated the farmland biodiversity (FBD) score as follows:

$$\text{FBD score per farm type} = \sum_{i}^{n}\sum_{j}^{m} \text{BD score}_{ij} * \text{Area}_{ij} / \text{total farm size} \quad (1)$$

where BD score is the biodiversity estimated with SALCA-BD, i is a farm activity, and j is a management option. To obtain the biodiversity score at the regional level, the FBD scores of each farm type are aggregated by applying the weight of aggregation.

2.3. Farm Typology

We used a centroid-based clustering analysis, k-means clustering, to identify typical farm types in the study region. The number of clusters needs to be determined a priori. To determine the optimal number of centroids, we used the elbow method [28], while observing the performance of the cluster method at the same time. Supplementary Material S1 outlines the methods in detail. Based on the expert knowledge and the collected field data, we selected the following six explanatory variables for the identification of representative farms: the number of suckler cows and dairy cows (LSU), area of arable land, grassland, and orchard (ha) and stock intensity (LSU ha^{-1}). We considered the intensity of livestock and the area of extensive farmland habitats in the explanatory variables, as our typology of farms should reflect environmental impacts [29].

2.4. BEFM (the Bio-Economic Farm Model)

2.4.1. General Approach

The BEFM we developed can determine the optimal production pattern and level of land use by maximizing the total gross margin (GM), given the available resources and restrictions [30,31] and the assumption that the farm behaves as a profit maximizer. Therefore, it follows the general form of a linear programming model for n activities and m structural restrictions [32]:

$$\begin{aligned} &\text{maximize } Z = \textstyle\sum_{j=1}^{n} c_j x_j, \\ &\text{subject to}: \textstyle\sum_{j=1}^{n} a_j x_j \le b_i \\ &\text{and} \quad x_j \ge 0, \end{aligned} \quad (2)$$

where $i = 1, 2, \ldots, m$, $j = 1, 2, \ldots, n$, Z is the total GM at a farm level, x is the farm activities, c is the gross margins or costs per unit of activity, a is the technical coefficients, and b is the resource availability or upper/lower limits of activities. We developed the BEFM for each of the identified typical farm types with the same formula above. The add-in COIN-OR CBC linear solver (OpenSolver 2.9.3) in Excel was used to find the optimal solution in the linear programming model [33].

2.4.2. Farm Activities

The BEFM covers the main activities observed in the farm types that we identified: crop production (cash and fodder production), grassland production (meadows and pasture), livestock production and AES. Some of the activities belong to both fodder production and AES (e.g., less intensive meadows, extensive meadows and orchard meadows). In reality, farmers can choose any measures from the list of AES, but we selected the most relevant measures in our model (Table 1). We also considered different management options for each activity that distinguish the intensity level of inputs. Extensive management must be free of fungicides, plant growth regulators, insecticides, or chemical–synthetic stimulators of natural resistance [34].

Table 1. List of the production activities modeled in the bio-economic farm model.

Grassland (Fodder)		**Arable Land (Fodder)**		**Arable Land (Cash Crops)**	
Intensive	Meadow	Intensive	Fodder wheat	Intensive	Spelt wheat
	Pasture		Triticale		Winter Wheat
Less intensive	Meadow [1]		Oats		Spring wheat
Extensive	Meadow [1]		Winter barley		Rye
	Pasture [1]		Ley pasture	Extensive	Spelt wheat
	Orchard-	Extensive	Fodder wheat		Winter Wheat
	Meadow [1]		Triticale		Spring wheat
			Oats		Rye
Livestock			Winter barley		Flower strips [1]
	Dairy cow		Ley pasture		
	Suckler cow		White peas		
	Young stock		Silo-green corn		

Less intensive meadow [1], extensive meadow/pasture [1], orchard meadow [1] and flower strips [1] are eligible to receive the payments from AES.

To obtain crop yields across intensity levels, we referred to the yearly, average regional yield data (2003–2020) in Canton Solothurn [35] and the gross margin report of AGRIDEA: "Deckungsbeiträge DBKAT" [36]. For grass yields, we referred to the formula in GRUD [37] and estimated the yields of meadows and pastures at different intensities given the elevation in the study region. Supplementary Materials S2 (Table S2, 1,2) provides all activities modeled in this study, including their yields, variable costs, GMs, etc.

2.4.3. Modules

The BEFM was constructed in a modular way. It is recommended that BEFMs should be modular to enhance the use of evidence in policymaking processes [38,39]. There are four modules exogenously given in the model (Figure 3). Each module is a subset of a larger section of the linear programming and comprises a set of constraints that serve to optimize the farm's gross margin.

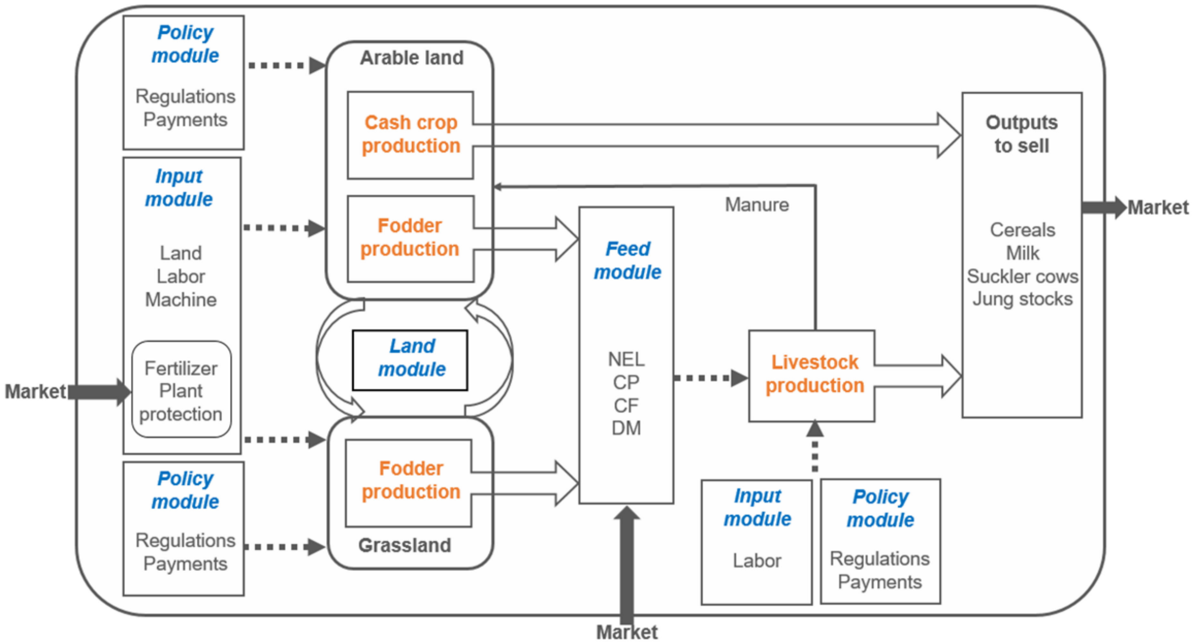

Figure 3. Activity flow inside the BEFM in the case of the dairy farm. NEL is net energy lactation; CP, crude protein; CF, crude fiber; and DM, dry matter.

Land module: We assumed that farmers could convert grassland into arable land depending on the payment level of direct payments as a result of maximizing the GM. Hence, this land module allows the model to convert the initial area of grassland into crop production and determines the optimal ratio of land use (i.e., the share of grassland, orchard and arable land). Under Swiss agri-environmental regulations, this conversion is possible as long as erosion events can be avoided. Nonetheless, we assumed that permanent grassland would remain on steep slopes (>24%), regardless of the payment level.

Input module: This module explicitly specifies the required labor hours and the level of input usage of different fertilizers and plant protection for each activity. For fertilizers, we considered N, P_2O_5, K_2O and Mg, and for plant protection, we included herbicides, fungicides, insecticides, growth regulators and trichogramma treatment. The costs of seeds, machinery and other miscellaneous items were also included [36]. Supplementary Materials S2 (Table S2, 3) details all the categories of variable costs included in this module for each farm activity. Note that we assumed manure to be used only within the farm without any exchanges with other farms.

Feed module: This feed module balances the supply and demand of livestock for feed in a nutritional form. We selected net energy lactation (NEL) in MJ DM-kg^{-1} (DM = dry matter), crude protein in kg DM-kg^{-1} and crude fiber in kg DM-kg^{-1}. We referred to the database of feed nutrition developed in Switzerland [40] to identify the nutritional values of the modeled crops and grasses. Supplement B describes these values per activity. To estimate the demand for livestock nutrition, we assumed the specific weight and performance of an adult milk cow: a 600 kg cow produces 8000 L of milk per year and young stocks (offspring of cows). We referred to the feed requirement tables [41] and determined the minimal requirement of the selected nutritional values as well as the maximum intake of dry matter per day per cow. For young stocks, we aggregated the nutritional requirements over different developmental phases of heifers, calves and bulls. Table 2 shows the results of the calculation for the nutritional constraints in the feed module.

Table 2. Nutritional constraints in the feed module to balance the supply and demand of livestock for nutrition.

	Dairy Cow		Suckler Cow	
	Adult Cow	**Youngstock**	**Adult Cow**	**Youngstock**
Maximum DM intake per day (kg)	16.8	12.5	14.0	7.8
Minimum NEL per day (MJ)	105.0	47.1	80.0	36.1
Minimum crude-protein per day (kg)	2.3	1.2	1.9	0.9
Minimum crude-fiber per day (kg)	3.4	2.4	2.8	1.4

Note that the unit kg is referred to the weight of dry matter (DM). NEL is net energy lactation.

Agricultural policy module: This module captures the role of direct payments, including the AES payments in farmers' land-use decisions by incorporating the obligatory measures and payments. We selected 14 different payment types [3]. Supplementary Materials S2 (Table S2, 4) details the total amount of direct payments that each activity receives and the breakdown of the sum. Table 3 lists all the restrictions that were implemented in the BEFM.

Table 3. List of the modeling restrictions.

Type of Restrictions	Explanation
Restrictions to qualify for direct payments	Crop rotation cereals (without corn and oats < 66% of AL), crop ration wheat, spelt and triticale (<50% of AL), crop rotation oats (<25% of AL), crop rotation corn (<40% of AL), crop rotation white peas (<15% of AL), flower strips (<50% of AL), biodiversity measure (>7% of total farmland), minimal livestock intensity, grassland-based milk and meat program [1]
Restrictions based on expert knowledge	Pasture limitation (less than 50% of grassland), nutritional balance (upper limit of DM intake, minimum NEL, crude protein and crude fiber), permanent GL (slope degree ≥ 24%), crop rotation limit cereals (<80% of AL)
Restrictions based on statistics	Total farm size, area of permanent GL, GL and AL, area of flexible land, labor hour, youngstock balance (share of offspring to adult cows), stable capacity

GL/AL are grassland and arable land. DM/NEL mean dry matter and net energy lactation. [1] The participation of the grassland-based milk and meat program was assumed to be subjected to only the large dairy farm and the suckler farm.

Table 4 shows the current payment level for EFA. While quality measures QI is an action-based measure rewarding farmers for adopting designated EFA, quality measures QII is a result-based measure for fulfilling specific goals [5]. For this study, we only considered the payment level of QI. This is because not all fields are eligible for QII, as they require specific site and biophysical conditions. Yet, for high-stem fruit trees, we considered both payments of QI and QII. This is because the payments for trees are primarily determined by the age of a tree (QI for 0 to 10 years and QII after 11 years) and additional measures (nesting boxes for birds, extensive grasslands, etc.). Thus, the extra costs to qualify for QII can be assumed to be negligible. Therefore, given an assumed tree's life of 60 years [42], we averaged the payments over 60 years per year and calculated the annual payment. In this study, we selected two types of orchard meadows, as explained in the next section.

Table 4. The current payments of AES in Switzerland and the payment level calculated for the model of this study.

Biodiversity Measures (EFA)	Quality Measure I	Quality Measure II	Modeled Payment
Extensive meadow (CHF ha^{-1})	860	1840	860
Less intensive meadow (CHF ha^{-1})	450	1200	450
Extensive pasture (CHF ha^{-1})	450	700	450
High-stem fruit trees (CHF $tree^{-1}$)	13.5	31.5	39.8
Orchard meadow Type A (CHF ha^{-1}) (CHF/ha)	-	-	1642
Orchard meadow Type B (CHF/ha^{-1})	-	-	2052
Flower strips (CHF ha^{-1})	2500	-	2500

Only high-stem fruits trees consider both QI and QII payments. Orchard meadows receive payments for the corresponding meadow production as well as payments for trees (assumed 30 trees ha^{-1}). Orchard meadow Types A and B are explained in the next subsection.

2.4.4. Orchard Meadows

The orchards in the study region are mainly high-stem cherry trees (Kay et al., 2018). To model orchard meadows in the BEFM, we made several assumptions. First, we assumed two types of orchard meadows available in the model: orchard meadows with and without commercial cherry production. For orchard meadows with commercial cherry production (orchard meadow Type A), we assumed that they were managed on less intensive meadows. The gross margin of Type A is based on three price levels (low, medium, and high). For orchard meadows without commercial cherry production (orchard meadow Type B), we assumed that farmers did not harvest cherries, but kept the trees only to receive subsidies. We also assumed that orchard meadow Type B is managed on extensive meadows. Based on our available data, we assumed that 30 trees were planted per hectare for both types of orchard meadows. In the model, both types of orchard meadows are available for all farm types. Table 5 describes the detailed gross margin calculation for the modeled orchard meadows. Supplementary Materials S2 (Table S2, 5) contains comprehensive gross margin calculations of orchard meadows with further disaggregated items.

Table 5. GM calculation for the modeled orchard meadows.

	Orchard Meadow Type A	Orchard Meadow Type B	Source
Description	Commercial cherry production	No cherry production (maintaining trees for AES)	
Trees	30 trees ha^{-1}	30 trees ha^{-1}	Own source
Cherry yield	30 kg $tree^{-1}$	-	Giannitsopoulos 2020
Cherry price	1.5/1.2/0.7 CHF kg^{-1}	-	Giannitsopoulos 2020
Meadow management	Less intensive (2 cuts $year^{-1}$)	Extensive (1 cut $year^{-1}$, no fertilizer)	
Forage yield loss	−15% less (yield: 54 dt ha^{-1})	−10% less (yield: 23 dt ha^{-1})	According to a local expert
Annual replanting	0.5 tree ha^{-1}	0.5 tree ha^{-1}	Schönhart 2011a
Establishment cost	140 CHF $tree^{-1}$	140 CHF $tree^{-1}$	Giannitsopoulos 2020
Maintenance cost [2]	6585 CHF ha^{-1}	630 CHF ha^{-1}	Giannitsopoulos 2020
Clearing cost [1]	60 CHF $tree^{-1}$	60 CHF $tree^{-1}$	Giannitsopoulos 2020
Labor	44 h ha^{-1}	27 h ha^{-1}	Giannitsopoulos 2020
Subsidy for trees	39.8 CHF $tree^{-1}$	39.8 CHF $tree^{-1}$	Bundesrat 2016
Total subsidy	2393 CHF ha^{-1}	2803 CHF ha^{-1}	Bundesrat 2016
Total revenues	3743 CHF ha^{-1} (1.5 CHF kg^{-1}) 3473 CHF ha^{-1} (1.2 CHF kg^{-1}) 3050 CHF ha^{-1} (0.7 CHF kg^{-1})	2803 CHF ha^{-1}	
Total costs [1]	6837 CHF ha^{-1}	882 CHF ha^{-1}	
GM with subsidy	−3094 CHF ha^{-1} (1.5 CHF/kg) −3364 CHF ha^{-1} (1.2 CHF/kg) −3787 CHF ha^{-1} (0.7 CHF/kg)	1921 CHF ha^{-1}	

Establishing cost [1], clearing cost [1] and total costs [1] are converted into annual equivalent costs based on a discount rate of 4% [42] and the average inflation rate over the last 30 years in Switzerland (0.9%). Maintenance cost [2] includes input use, harvesting and machinery for orchard meadow Type A and machinery and miscellaneous costs for orchard meadow Type B.

2.5. Policy Scenarios

Figure 4 illustrates how we ran the model with the baseline scenario and the policy scenarios. We first ran the model to retrieve the optimal baseline solution given the current payment level and the fixed land assumption. Next, we ran the model, while increasing the payment level from the current level to 200% by 10% increments. For this policy scenario, we applied the flexible land assumption. Therefore, the model can determine the optimal share of grassland and arable land at each level of payments of AES and corresponding cropping patterns.

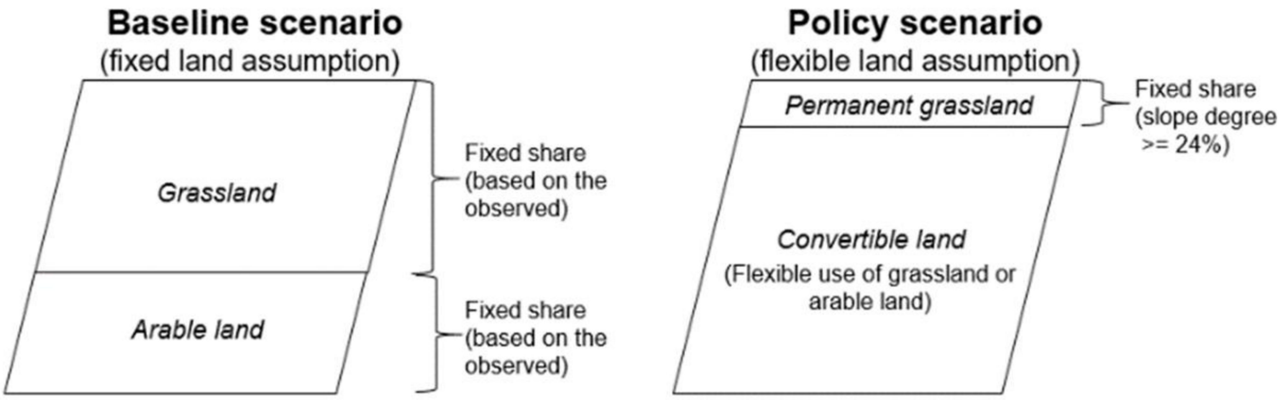

Figure 4. Land use determined under the land module with the baseline and policy scenarios. Note that both grassland and permanent grassland can be also used as orchard meadows in the model.

2.6. Evaluation of Cost Effectiveness

We measured the cost effectiveness of AES using the following two indicators: the cost-effectiveness ratio (CER) [43] and the producer rent. The CER represents the maximum FBD (farmland biodiversity) score that each farm can obtain per CHF 1000 of AES payments. To compare the CERs among farm types, the amount of payments paid out from AES is divided by EFA. Thus, the CER (unit: FBD score/CHF 1000) is computed per hectare as follows:

$$\text{CER} = (\text{FBD score}/(\text{payout from AES}/\text{EFA})) * 1000. \quad (3)$$

The producer rent quantifies how much the implementation of AES forgoes the income of farms [44]. It indicates the opportunity costs associated with impending AES. The producer rent (unit: CHF ha^{-1}) is calculated as follows:

$$\text{producer rent} = (\text{GM with AES} - \text{GM without AES})/\text{total farm size}. \quad (4)$$

Both CER and the producer rent were calculated per farm type and were also aggregated for the regional scale with the weights.

2.7. Map Regional Change of Orchard Meadows

To map the farm-level modeling results to each of the fields, we first identified which farm type was located in which field. Then, we assigned either of the land-use options in shares obtained with the model (grassland, orchard meadows or arable land) per farm type to each of the fields. Second, to determine which fields were most likely to belong to which land-use option, we assumed that fields with lower slope degrees would be covered by arable land for lower production costs, while on fields with higher slope degrees, trees would be planted on meadows to prevent erosion. This is consistent with a finding by Huber et al. [16] that fields with steeper slopes are more likely to enter the agglomeration scheme, which is a part of Swiss AES. The remaining fields were assigned as grassland.

3. Results

3.1. Farm Typology

We identified the following five representative farm types in the study region with the k-means clustering and the elbow methods in R (Version 1.2.1335) (Figure 5): 1. orchard farm without livestock (high-value trees and commercial cherry production, mainly cherries); 2. small-scale dairy farm; 3. large-scale dairy farm; 4. suckler farm; and 5. small-scale farms without livestock. Table 6 outlines the characteristics of these five farm types and their management. Given the number of farms and their farm size, large dairy and suckler farms are found to be the most prevalent farm types in the region. However, their management is contrastingly different. Large dairy farms tend to adopt intensive farming, as they own more arable land and less extensive grassland, whereas suckler farms utilize more extensive grassland. These results were confirmed by regional stakeholders.

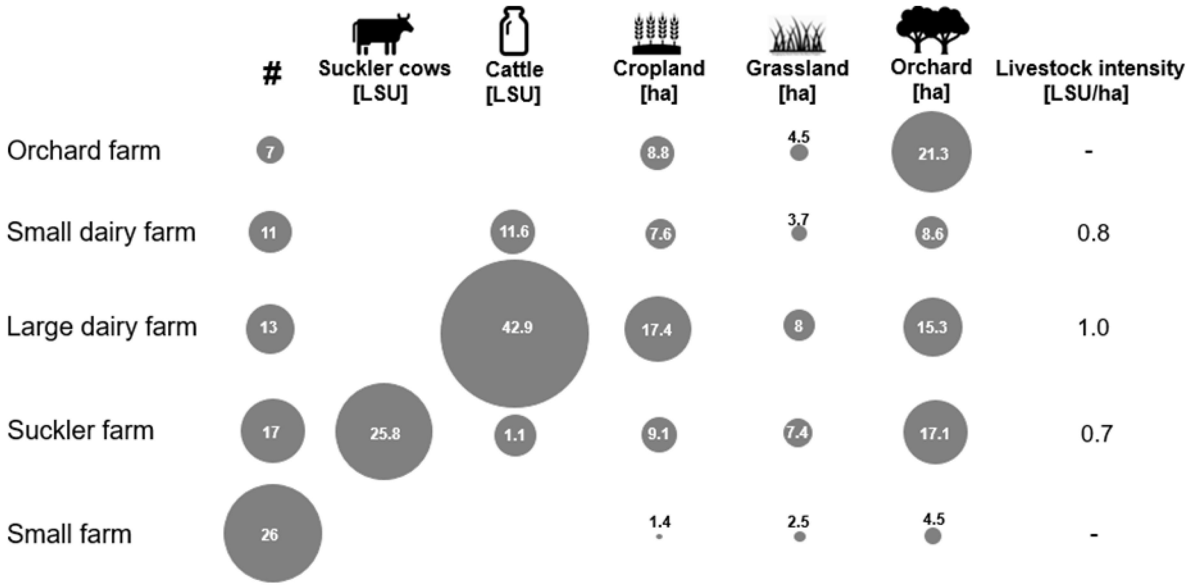

Figure 5. Identified representative farm types (left column) with k-means clustering in the study region and the average value of each explanatory variable. LSU: Livestock units. # indicates the number of farms found in each farm type.

Table 6. Modelled farm types and their characteristics.

	Orchard	Small Dairy	Large Dairy	Suckler Farm	Small Farm
Farm size (ha)	34.8	19.9	40.7	33.6	8.5
Weight for aggregation	14%	12%	30%	32%	12%
Initial grassland share	72%	60%	56%	70%	81%
Of which extensive grassland	41%	29%	19%	31%	46%
Permanent grassland	9.4%	10.5%	8.1%	5.9%	24.8%
Livestock	no	yes	yes	yes	No
Livestock intensity (LSU ha^{-1})	-	0.6	1.1	0.8	-
Capacity of livestock (LSU)	-	12	43	26	-
Labor availability in AWU	0.5	1.34	1.9	1.34	0.2
Grassland-based milk and meat program [1]	-	no	yes	yes	-

AWU stands for the annual working unit (1 AWU = 1800 h). We assumed that the orchard and small farms were part-time farms due to the small-scale farming. Grassland-based milk and meat program [1] provides farmers with an extra subsidy if they keep more than 75% of the share of fodder produced from grassland and less than 10% of the share of concentration (in weight of dry matter).

3.2. Orchard Meadows with the Baseline Scenario

Under this baseline scenario, the EFA of all farm types exceeds the obligatory level (7% of the total farmland) (Table 7). All farm types, except for the large dairy farm, chose orchard meadows for more than 50% of the total farmland. In particular, farm types without livestock (orchard and small farms) resulted in a higher share of orchard meadows. This led to a higher share of subsidy to the GM, which was more than 100%. By contrast, the large dairy farm resulted in the lowest share of orchard meadows. Regarding the FBD scores, orchard and small farms obtained higher values than the other farm types because of a relatively large share of orchard meadows and a lower share of arable land. Accordingly, their CERs were relatively high.

Table 7. Optimal baseline results per farm type with the current payments given the assumption that the area of grassland cannot be converted into arable land.

	GM	Subsidy to GM	EFA (%)	Trees	FBD Score	CER	Producer-Rent	Grass Land	Orchard	Arable Land
Orchard	73,322	113%	72%	755	12.2	6.0	541	0%	72%	28%
Small dairy	83,414	51%	52%	313	10.6	5.2	589	8%	52%	40%
Large dairy	236,446	31%	29%	350	9.4	4.6	256	28%	29%	44%
Suckler farm	101,440	77%	65%	659	11.8	5.8	702	5%	65%	30%
Small farm	17,048	122%	81%	206	13.2	6.4	605	0%	81%	19%

GM is gross margin and subsidy to GM indicates the share of the total amount of subsidies to the GM. EFA/FBD/CER indicate, ecological focused areas, farmland biodiversity (score), and cost-effectiveness ratio.

3.3. Policy Scenario

3.3.1. Role of AES in Land-Use and Sustaining Orchard Meadows

Regional land-use result: The regional result revealed that the share of grassland and orchard meadows at the current payment level was just under 20%, while arable land covered 80% of the land (Figure 6). Given the flexible land assumption, the arable land expanded considerably for all farm types at the current premium level, compared to the baseline result. As a result, the share of EFA dropped to 14%. However, as the payment level increased, the share of arable land decreased to 20% at 150% of the current AES premium, while EFA increased. This increase in EFA is mostly attributed to the expansion of the area of orchard meadow Type B.

Land-use differences across farm types: The EFA of the small and large dairy farms dropped just to the obligatory level, whereas the EFA of the suckler and small farms remained relatively high. Nonetheless, for all farm types, the arable land expanded considerably. Given the flexible land assumption, the difference in how much the arable land expands depends on the share of the permanent grassland. At the current payment level, all farm types except for large dairy farms expanded the arable land to the maximum possible area. Therefore, the share of land use at the current level would not change, even if the payment level was lowered from the current level.

Change in orchard meadows: The regional change in the number of trees is shown in Figure 7. The number of trees at the baseline is shown by a dot at 100%. In the policy scenario, the number of trees fell to 7627 from 29,847 at the current premium level. In the baseline scenario, where the conversion of land was not permitted, there was enough incentive to maintain orchards as shown in Table 7. However, if allowed, the arable land took over a large area of orchard meadows as they became less profitable. Increasing the payment level to 150%, however, restored the profitability of orchard meadows enough, allowing them to expand the area comparable to the baseline. The payment for orchard meadows at this level is around 1000 CHF ha^{-1}, higher than the current AES payments.

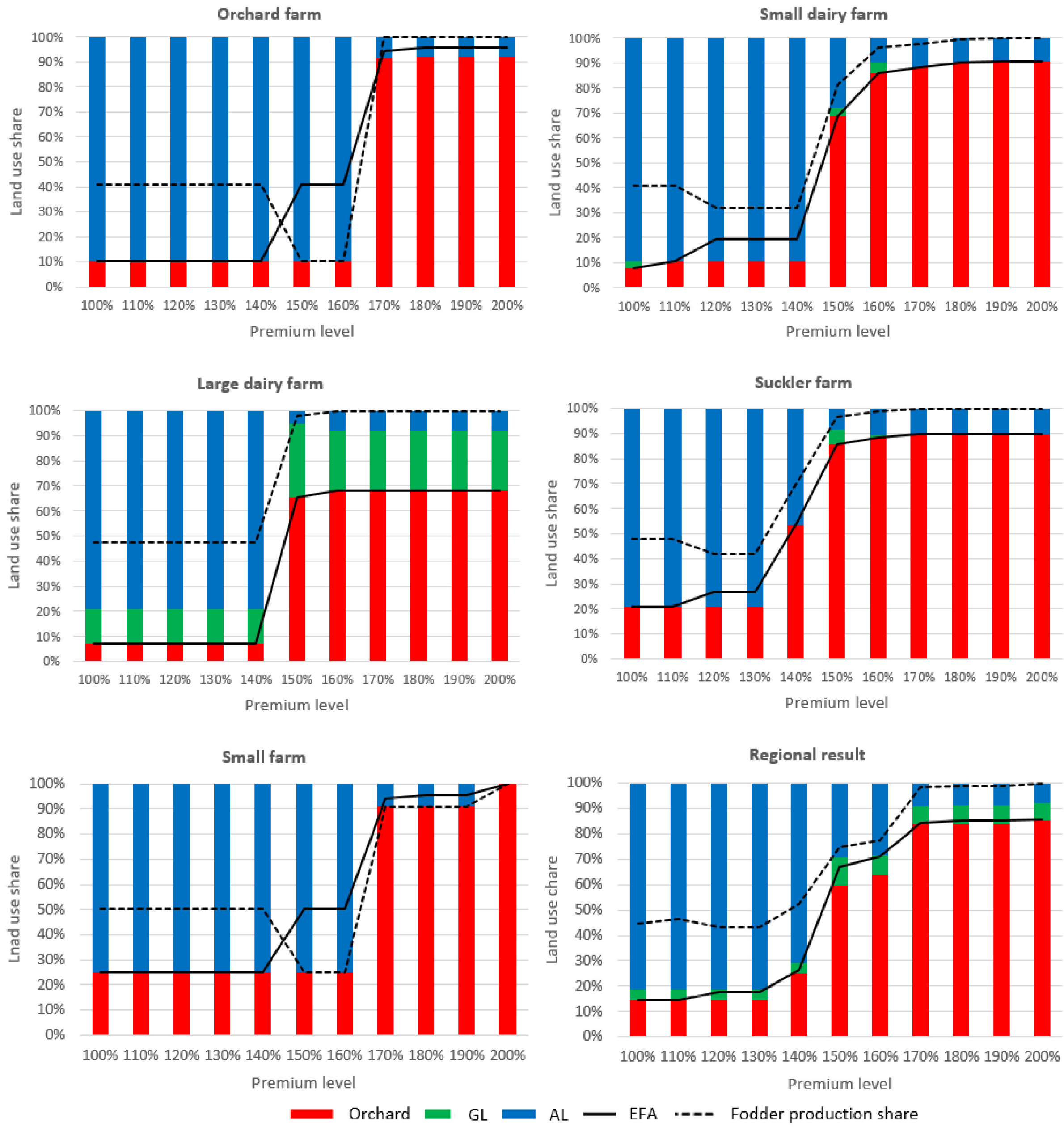

Figure 6. Policy scenario results with the increments of the payments from the current level up to 200%. The *X*-axis indicates the payment level compared to the current level. The *Y*-axis indicates land-use share. GL/AL/EFA designate grassland, arable land and ecologically focused area.

3.3.2. Difference in the Adoption of AES and the CER among Farm Types

The difference in the producer rents over farm types indicates the difference in the adoption costs of AES (Figure 8). The producer rent of large dairy farms stayed negative at lower payment levels, unlike other farm types. This reveals that for large dairy farms, the current AES payments cannot compensate for the cost of the mandatory implementation of the AES. The opportunity cost of adopting AES is the highest among all farm types due to the larger number of profitable dairy cows. Contrary to this result, all the other farm types had a positive producer rent with the current payment level. Among these farm types, the producer rent of the suckler farms was the highest: the opportunity cost of the suckler farm was the lowest. Nonetheless, the producer rents in the policy scenario are much less than the baseline producer rents.

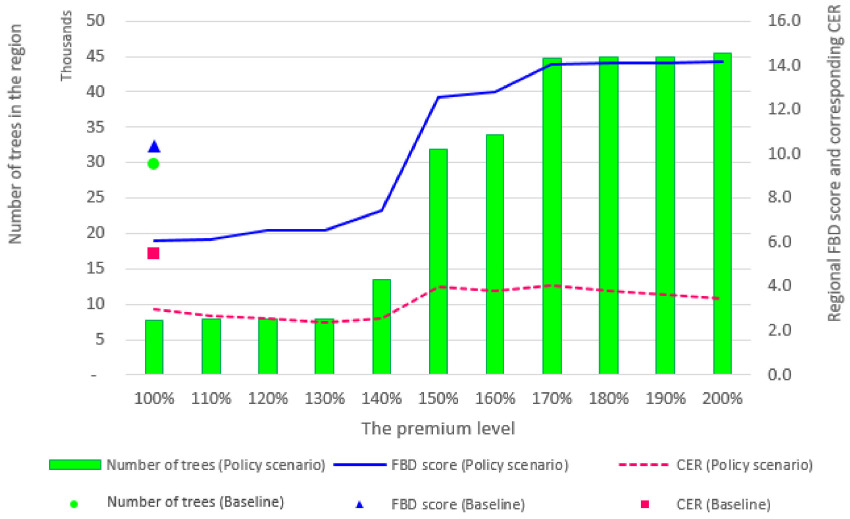

Figure 7. The regional change in the number of trees, regional farmland biodiversity score and the CER depending on the payment level (100% = the current level). FBD is farmland biodiversity.

All FBD scores at the initial level were approximately halved, despite the same level of payment, compared to the baseline scenario. The FBD scores of the orchard, large dairy and small farms remained the same until 140% of the current level. At a premium level of 150% premium, FBD scores increased sharply, as the area of orchard meadows tended to expand considerably.

The change of CER showed a similar trend. Up to a level of 140% premium, CERs tended to slightly decrease as the FBD score remained the same. However, due to the sharp increase in FBD scores above the 140% premium, CERs increased accordingly. For the regional level, it reached a maximum at 150% premium. Yet, they decreased eventually because there was little improvement in the FBD scores at higher payment levels. The highest CER in the policy scenario was even lower than the baseline CER.

3.3.3. Change in the Regional Land Use and Individual Species Suitability with AES

On the map of the case study region (Figure 9) with the baseline result, orchard meadows appeared more in the east and south, where the suckler, orchard and small farms tend to be located. On the other hand, more arable land and grassland appeared in the north and east, where the small and large dairy farms are more prevalent. The grassland mapped here is mostly with intensive pasture. The fields in the north and east area are relatively large and the slopes are flatter than the other areas. Thus, these fields are more suited to crop production and intensive grass production.

In the policy scenario at 100% premium (current level), most of the fields covered by orchard meadows disappeared, as Figure 7 shows that the number of trees is about one-quarter of the baseline number. When the premium was increased to 150%, the fields with orchard meadows appeared almost evenly on the map. However, 150% of the premium level is insufficient to sustain orchard meadows for orchard and small farms. Therefore, the fields belonging to these farm types remained as arable land, despite the increase in the payments. Figure 10 presents the variations in species suitability as a result of these regional-level results. Birds, butterflies, wild bees and grasshoppers are projected to be the most harmed by the expansion of arable land. All of these species groups are strongly linked to extensive grasslands.

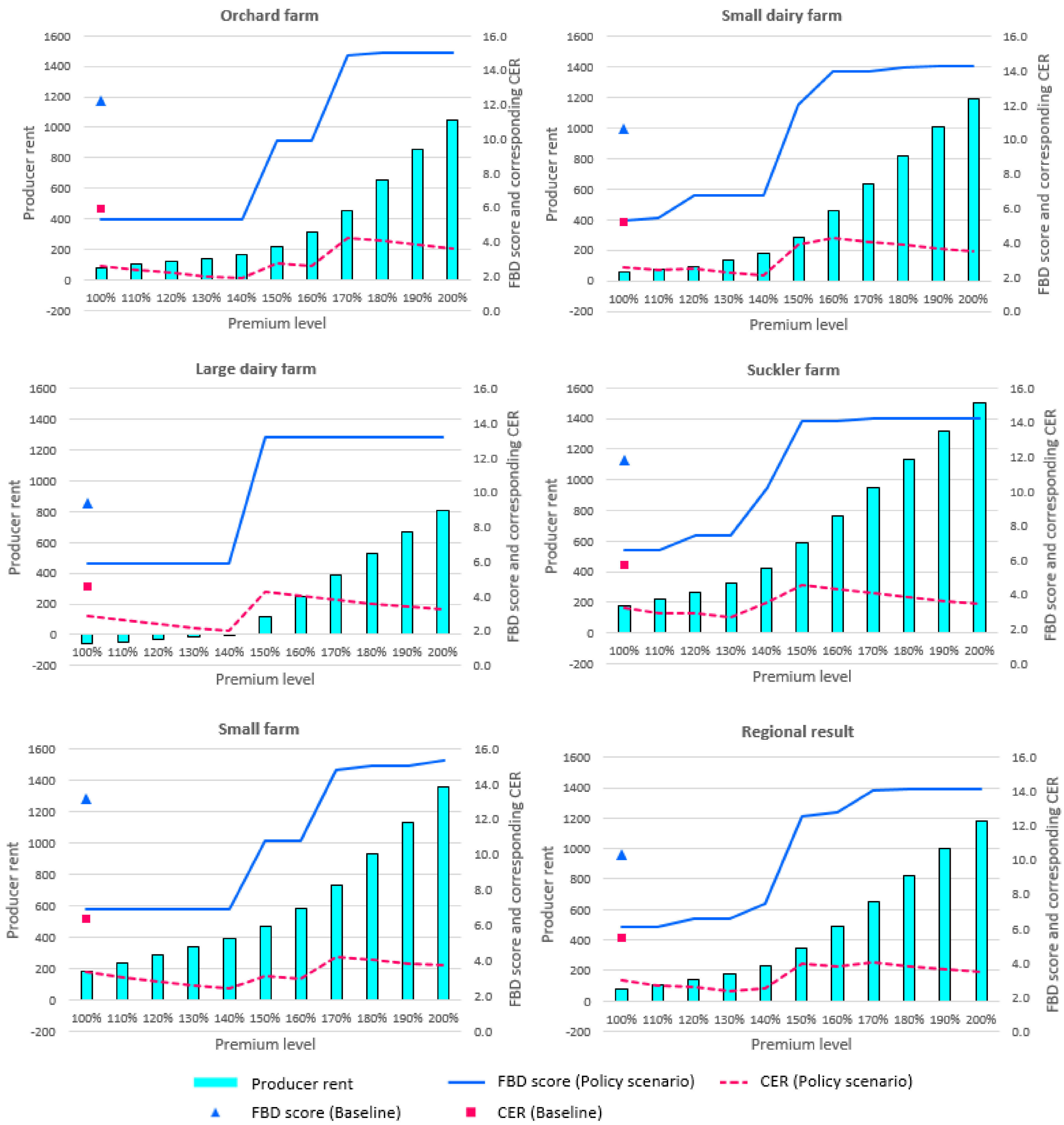

Figure 8. Policy scenario results with the increments of the payments from the current level up to 200%. The $X-$axis indicates the payment level compared to the current level. The $Y-$axis indicates producer rent in CHF per hectare. The $Z-$axis indicates the FBD (farmland biodiversity) scores and the CER (cost-effectiveness ratio). The triangle symbol in the graph indicates the level of FBD scores at the baseline, while the square symbol indicates the corresponding CER at the baseline.

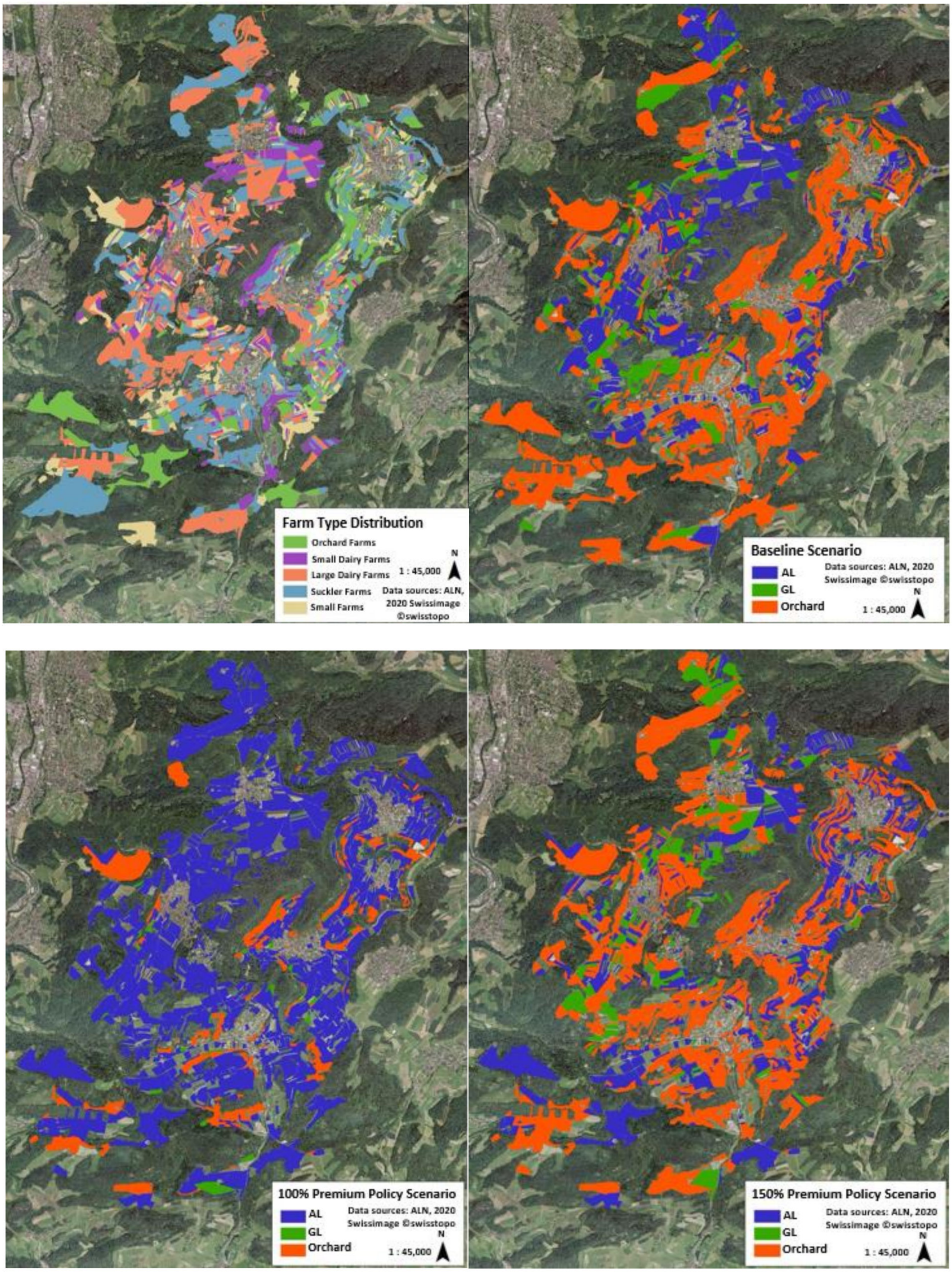

Figure 9. Maps of farm type distribution (above left) and the regional land use under the baseline scenario (above right) and policy scenarios—100% and 150% of the current premium level (bottom). AL/GL designate arable land and grassland.

	Flora of crops	Flora of grasslands	Birds	Small mammals	Amphibia	Molluscs
Baseline	4.2	9.1	17.3	12.5	5.0	4.9
100%	10.5	3.0	10.6	6.4	2.6	3.0
150%	5.3	9.0	18.5	13.5	5.1	5.1

	Spiders	Carabids	Butterflies	Wild bees	Grasshoppers
Baseline	16.0	15.1	13.3	16.2	13.6
100%	9.2	10.5	4.3	8.1	4.4
150%	17.5	16.5	14.6	17.4	14.4

Figure 10. Biodiversity scores of each species indicator group in the regional level with the baseline scenario and the policy scenario (100% and 150% premium levels).

4. Discussion

4.1. Orchard Meadows and Land-Use Change

We discovered that all farm types benefit from existing AES [34], and orchard meadows were well maintained in the baseline. Particularly, orchard and small farms favored orchard meadows to a large extent because the total gross margin for orchard meadows of Type B, including tree payments, was higher than the gross margins of pure meadows, due to the expected low selling price of hay (6 CHF dt^{-1}) [45]. Therefore, orchard and small farms rely on AES for a higher share of their income than the other farm types. This is also the case for suckler farms, which require less intensive meadows or pastures, compared to dairy [5]. Having dairy cows with high livestock intensity brings farms relatively high profits. Therefore, the share of orchard meadows on large dairy farms was the lowest of all farm types, as orchard meadows cannot provide the protein-rich fodder needed for dairy production.

In comparison, orchard meadow Type A was not chosen at any payment level. The sensitivity analysis with increasing cherry prices showed that it becomes only economically viable when the price of cherries exceeds 7 CHF kg^{-1}. The high production costs of cherries are mostly due to the high labor cost for harvesting. In reality, however, some orchard farms continue to produce cherries for profits. The discrepancy between our model's predictions and reality can be explained by traditional, family labor-based cherry production in the region: opportunity costs of labor may be low, and the local marketing of homemade products can be attractive. Nonetheless, the ecological benefits of trees alone justify public financial support.

A validity check of the modeling results with reality shows that the model tends toward orchard meadows, where, in reality, we find intensive meadows for dairy. As our model is a static comparative, it includes investments such as a dairy herd and its related infrastructure or planting of trees only as an annual average gross margin. Switching the production system between trees and cows is almost a once-in-a-lifetime decision, which does not depend on actual gross margins, as in our model. So, farmers, in general, have high resistance against such changes and can overcome smaller periods of lower gross margins in part of their production systems by compensating with income from other parts. Only if it becomes obvious that in the long run, the system will have low or even negative returns, do farmers change their production system. Often, this decision goes along with a generational change of ownership of the farm. Additionally, the timing of orchard-related labor peaks may play a role. Tree pruning can be done in winter, when labor pressure is low and the cherry harvest is in early summer, mostly after the labor peak of first hay making and before the start of crop harvesting. Nevertheless, our model shows this tendency under current circumstances. Should the performance relations between orchard meadows and dairy production remain the same for a longer period, we expect to see production shifts as projected in our model runs.

The policy scenario demonstrated that at the current payment level, regional biodiversity was considerably degraded as grassland and in particular, orchard meadows were often replaced by crop production. This implies that crop production in Switzerland is highly financially attractive if subsidies are considered [42]. Farmers receive a guaranteed payment of 1400 CHF ha^{-1} for crop production in addition to 120 CHF ha^{-1} as price support for supplying cereals [46], while a guaranteed premium for cultivating grassland is 1000 CHF ha^{-1} in the hilly regions [3].

4.2. Cost-Effectiveness and Its Difference over Farm Types

While the baseline maintains the current ratio of grassland and arable land, the policy scenarios allow flexible use of more than 75% of the land. With the current payment levels, this leads to lower biodiversity scores and also lower cost effectiveness. However, with increasing payments, the policy scenarios lead to high biodiversity impacts (see Figure 8). This is only possible as farmers are allowed to convert arable land into grassland, which goes along with decreasing cost effectiveness. This trade-off occurs as a result of higher payments, which reduce the cost effectiveness of AES.

Additionally, our results indicated that the producer rents over different farm types largely varied due to the different compliance costs of AES. Among the livestock farms, livestock intensity and type determine the producer rent. Large dairy farms still need to keep sufficient high-yield grassland to sustain high livestock intensity and fulfil the conditions of the grassland-based milk and meat program, which results in lower implementation rates from AES. In contrast, suckler farms gained relatively high implementation rates of AES. Mack et al. [5] verified these findings: the adoption of action-based EFA, which this study examined, is substantially influenced by farm type. Dairy farms are negatively correlated and suckler farms are positively correlated to the adoption rate. Our study demonstrated that farms with a higher implementation rate of AES tended to gain higher CER.

4.3. Methodological Limitations

We assumed that farmers would maintain or abandon orchard meadows depending on the economic profits in relation to the profitability of the other activities. However, we did not consider their non-market benefits, i.e., externalities, such as reduced soil erosion risk, carbon sequestration or regional identity, in the calculation of the economic profit. Although capturing the real value of orchard meadows is a core challenge in the economic assessment [11], accounting for such non-market benefits of orchard meadows in the decision process will improve the validity of results and help to determine a more appropriate level of financial support [42,47].

Another possible limitation of this study is that the evaluation of farmland biodiversity was neither contingent on the complexity of landscapes, such as the spatial configuration of semi-natural habitats [48], nor connectivity at different scales [49]. AES can be ineffective unless the ecological effects are observable at the landscape scale [50–52]. Spatial planning of biodiversity measures can enhance their benefits and reduce the opportunity cost for food production [53]. Understanding species dynamics and their relationships to landscape complexity, using a broader spatial scale and landscape indicators, could help improve biodiversity conservation in agricultural landscapes [43,54].

4.4. Policy Implications

Under the current situation, where it is possible to convert grassland into arable land, expanding arable land will increase the profitability of farms, especially for competitive farms, such as larger-scale dairy farms. The fact that these farms have a negative product rent at the present premium level implies that they will lose income and have no incentive to adopt AES beyond the obligatory level [55]. In contrast, extensively managed farms, such as suckler farms, are likely to profit from AES due to the lower compliance costs. They have more incentives to adopt biodiversity measures [56,57]. When the adoption rate of AES is high, the cost effectiveness tends to be higher. It can be more cost efficient to provide farm-type-specific payments rather than providing all farm types with the same payment level. This way of payments is in line with the claim of Armsworth et al. [18] that the inefficiency of the simplification of AES derives from their inability to address variation within and between farms in terms of private costs associated with providing biodiversity. Additionally, our study recommends a regulatory framework that incentivizes farmers to preserve the existing area of grassland. Under the current direct payments, crop production is far more financially attractive.

5. Conclusions

The purpose of this study is to provide policymakers with insight into the design of cost-effective AES for maintaining agroforestry systems and promoting farmland biodiversity by considering different farm types, using orchard meadows as an example. Based upon our results, the following can be concluded: 1. Higher AES payments increase orchard meadows and biodiversity scores. However, excessive payments would impede the improvement and lower the cost-effectiveness. 2. Farmers would maintain orchard meadows only with higher payments as compared to the current level, under the assumption that they can convert any grassland to arable land for maximizing their profit. However, if the conversion from grassland into arable land was not permitted, all farm types would maintain current orchard meadows. 3. Compliance costs and the adoption of AES vary considerably among farm types. Suckler farms and farms without livestock largely economically benefit from AES, while large dairy farms lose income under the flexible land-use assumption.

These findings can carry the following policy implications. First, AES can be more cost effective in targeting specific farm types and offer them the payments reflecting the compliance costs rather than paying all farm types with the same payments. Second, whether the current AES can contribute to the maintenance of orchard meadows is contingent on how far the conversion of land can be prevented. Under the current direct payments, crop production is significantly more profitable, which may encourage farmers to expand arable land. Therefore, this study recommends establishing a regulatory framework that incentivizes farmers to preserve existing grassland.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su14095615/s1, Supplementary Materials S1: Documentation of the cluster analysis, Supplementary Materials S2: List of the parameters in the modeling.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. SALCA-BD Results

Farm activities	Total score	Flora of crops	Flora of grasslands	Birds	Small mammals	Amphibia
Intensive meadows	10.4	0.0	9.4	13.6	11.9	4.0
Intensive pasture	11.7	0.0	12.6	17.4	11.5	6.3
Less intensive meadow*	11.6	0.0	12.2	14.4	12.4	5.1
Extensive meadows*	13.9	0.0	13.9	18.2	13.0	6.4
Extensive pasture*	11.8	0.0	13.9	17.4	11.5	6.5
Orchard meadows Type A*	13.4	0.0	12.2	18.7	16.3	5.4
Orchard meadows Type B*	15.6	0.0	13.4	22.7	17.8	6.7
Intensive crops	4.7	14.3	0.5	7.9	4.1	1.8
Extensive crops	5.1	14.4	0.5	9.2	4.0	1.9
Flower strips*	19.7	30.0	0.0	40.0	12.0	6.0

Farm activities	Molluscs	Spiders	Carabids	Butterflies	Wild bees	Grasshoppers
Intensive meadows	5.3	11.1	12.7	14.9	16.3	14.8
Intensive pasture	4.9	12.3	10.8	17.4	18.6	17.2
Less intensive meadows*	6.2	13.0	14.6	15.9	17.6	16.5
Extensive meadows*	6.6	15.4	17.8	21.2	19.8	21.2
Extensive pasture*	4.7	11.9	10.8	17.4	18.6	17.2
Orchard meadows Type A*	6.1	19.0	16.8	16.1	20.1	16.8
Orchard meadows Type B*	6.4	22.2	19.7	20.0	22.4	20.4
Intensive crops	2.3	6.4	8.6	0.6	5.1	0.6
Extensive crops	2.4	7.5	9.6	0.5	5.4	0.5
Flower strips*	3.0	36.0	27.0	25.0	23.0	15.0

Figure A1. Biodiversity scores (0–50) of modelled farm activities per hectare estimated with SALCA-BD. The total score is the average of the scores of each ISG. * indicates the biodiversity measures under AES (ecological focused areas). Orchard meadow Type A corresponds to orchard meadows with commercial cherry production on less intensively managed meadows, while orchard meadows Type B orchard meadows without commercial cherry production on extensively managed meadows. The scores of intensive and extensive crops are aggregated over individual crops with the same weight. Online Resource 2 (Table S2, 6) provides the biodiversity scores of all of the modeled farm activities.

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