Innovative agroecosystem goods and services: key profitability drivers in Swiss agroforestry

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Abstract Trees that characterized many agricultural landscapes across Europe are declining, despite the recent revival of agroforestry research and increasing direct payments for their maintenance. Therefore, in addition to field experiments, there is a need for transdisciplinary research in close alliance with local farmers. This paper proposes a three-step participatory design and assessment approach, incorporating local innovation and scientific evidence. To our knowledge, this is the first participatory and bioeconomic analysis of farmer-designed agroforestry systems in Europe. First, an exploratory survey of farmers' innovations in Switzerland was conducted together with a literature review. Based on the survey, 14 representative agroforestry practices were defined for the bioeconomic assessment, focusing on walnut (*Juglans hybr.*) and wild cherry (*Prunus avium*). The predictions of long-term yields were made with the Yield-SAFE model, and the profitability was assessed using the Farm-SAFE model. The survey results suggested a lack of local knowledge on key ecosystem services provided by agroforestry. It is therefore recommended to apply the concept of ecosystem services, in order to support the design of multifunctional agriculture and to increase the willingness to pay for its services.

According to our yield predictions, mixing trees and crops was commonly more productive (12 out of the 14 options, land equivalent ratio=0.95–1.30) than growing them in separate forestry or arable systems. This result contradicts the widespread view among modern Swiss farmers that agroforestry is unproductive. In terms of profitability, 68 % of the 56 financial scenarios for the agroforestry practices, particularly those linked to innovative marketing of fruit or receiving payments for ecosystem services, were found to be more profitable than the business as usual reference systems. These results demonstrate that there is a need and a value in bridging the gap between scientists and farmers, in order to coproduce applied knowledge for the design of productive agroforestry practices.

Keywords Agroenvironmental policy · Ecosystem services · Participatory research

1 Introduction

For much of human agricultural history, trees in agricultural landscapes have been used to provide a range of ecosystem services including physical products. However, agriculture has changed enormously in the second half of the last century, driven by agricultural policy and technological progress. Trees that characterized many agroecosystems across the globe have been lost to a large extent (Palang and Fry 2003; Kumar and Nair 2006).

Until the 1950s, Swiss landscapes have also been characterized by agroforestry practices (Bürgi and Stuber 2003). Silvopastoral and silvoarable practices called *Streuobst* have drastically declined similar to other European landscapes (Herzog 1998). The postwar policy of agricultural modernization discouraged the continued maintenance of trees on agricultural land and actively financed their felling (Ewald

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and Klaus 2010). Consequently, of the approximately 14 million trees standing in agricultural land in Switzerland in 1951, only 2.9 million trees were left in 2001 (BLW 2011). The simplification of agricultural landscapes resulted in a general impoverishment of ecosystem services that benefit society, namely habitat, regulation, and cultural ecosystem services (McAdam et al. 2009). A national vote in 1996 showed that 78 % of the Swiss public would support a transition towards low input and multifunctional agricultural landscapes. Consequently, in recent years, agricultural policy has increasingly made efforts to reduce agricultural externalities and improve the provision of ecosystem services. In this regard, a major challenge is the development of innovative farming systems, which can meet the demand for multifunctional service provision while remaining productive and profitable.

While tropical agroforestry research has enjoyed much attention (Nair 1993; Kumar and Nair 2006), it is only recently that temperate agroforestry research has gained some momentum. As part of this, experimental plots have been established on research stations in a number of European countries and these results have been instrumental in the development of agroforestry models that can simulate tree and crop interactions (van der Werf et al. 2007; Keesman et al. 2011). The preliminary results indicate that temperate agroforestry in Europe tends to be more productive than conventional arable and grassland systems and that it can be a profitable alternative to business as usual (Graves et al. 2007). Agroforestry can combine high productivity with a wide range of other ecosystem services (Palma et al. 2007a, b, and c; Kaeser et al. 2010; Briner and Lehmann 2011). Furthermore, trees in agricultural landscapes are popular (Schüpbach et al. 2009).

Despite the revival of research interest, and increasing direct payments for the maintenance of agroforestry practices, the decline of farm trees and hedgerows is still ongoing in many European landscapes (Eichhorn et al. 2006).

One way of increasing the adoption and maintenance of modern agroforestry systems is to ensure that research builds on local knowledge and cultural landscapes (Wettasinha and Waters-Bayer 2010). Farmers have their particular ways of designing agroforestry systems as well as marketing their goods and services. Therefore, in addition to field experiments, there is a need for transdisciplinary research in close alliance with local farmers. Little is known, for example, of farmers owning agroforestry innovations to solve current agronomic challenges.

This paper proposes a participatory farming system design and assessment approach, incorporating local innovation and scientific evidence. A case study is presented exploring the features, productivity, and profitability of modern agroforestry practices in Switzerland (Fig. 1). To our knowledge, this is the first participatory and bioeconomic analysis of farmer-designed agroforestry systems in Europe.

The objective of this study is to explore the productivity and profitability of Swiss agroforestry practices. Through a

transdisciplinary approach, building on local innovation and scientific understanding, the following questions were investigated:

1. What are the features of farmers' agroforestry innovations in Switzerland?
2. Are Swiss agroforestry systems productive?
3. Can agroforestry be profitable given current prices and payments for ecosystem services?

Prior to the present study, an integrated survey was conducted involving 50 randomly selected Swiss farmers, to explore their behavior and preferences with regard to adopting agroforestry (Sereke 2012). The results suggested that modern farmers often view agroforestry as difficult to manage as well as unproductive and unprofitable.

2 Material and methods

Methodologically, this study combined participatory field-based research with generation of scientific evidence. The following research steps were undertaken:

1. Classification of features and functions of Swiss agroforestry practices, building on the concept of ecosystem services (McAdam et al. 2009);
2. Simulation of long-term yields of representative agroforestry practices with the Yield-SAFE model (van der Werf et al. 2007);
3. Assessment of profitability using the Farm-SAFE model (Graves et al. 2007).

The main target region was the Swiss central lowland region (Swiss plateau), where the greatest loss of farm trees and biodiversity has been observed due to intensive agricultural practices (BAFU and BLW 2008).

2.1 Classification of Swiss agroforestry

The exploratory survey was conducted between 2007 and 2009. Farmers were identified at workshops and through contacts with experts. Twenty-one semi-structured interviews were conducted on-farm, and the questionnaire covered socioeconomic, technical, and agroecological aspects of the agroforestry practices.

For classifying the agroforestry practices, we modified and applied a European classification approach (McAdam et al. 2009). The classification categories were components, spatial and temporal arrangement, agroecological zone, socioeconomic features, and ecosystem services. Ecosystem services included production, habitat, regulation, and sociocultural benefits. Potential ecosystem services were identified on the

Fig. 1 Farmer agroforestry innovations in Switzerland, showing: (a) a silvopastoral agroforestry on grassland (pastured, haymaking) with additional shrubs for berry production in the tree line and occasional bee keeping (eastern Switzerland), and, (b) silvoarable agroforestry in central Switzerland with apple trees intercropped with strawberries, winter wheat, and flower strips

basis of national (where available) and other European publications on temperate agroforestry.

Each agroforestry practice was described in a factsheet and a database containing social, biophysical, and economic data. These factsheets have been subsequently used for extension workshops and practice-oriented publications. Based on this survey, 14 representative options were defined for the bioeconomic assessment, focusing on walnut (*Juglans* hybr.) and wild cherry (*Prunus avium*).

2.2 Biophysical assessment

Due to lack of field data in Switzerland, the equations for the Yield-SAFE model (van der Werf et al. 2007) previously implemented by Graves et al., (2011) in a spreadsheet-based Microsoft Excel© model called Plot-SAFE, were used to estimate long-term crop and tree yields for a full tree rotation.

The Yield-SAFE model is a daily time-step model and uses seven differential equations to describe the temporal dynamics of (1) tree biomass, (2) tree leaf area, (3) number of shoots per tree, (4) crop biomass, (5) crop leaf area index, (6) heat sum, and (7) soil water content. Daily weather data are required to drive the Yield-SAFE equations, including data on daily solar radiation (megajoules per square meter), mean daily temperature (degrees Celsius), and daily rainfall (millimeters). Crop and tree parameters were developed using a combination of literature and model calibrations, while soil parameters were provided from a classification of the hydraulic properties of European soils (Wösten et al. 1999). Further data required to run the model include data on management decisions, for example, concerning tree species, planting density, year of tree thinning, number of trees thinned, crop species, and crop rotation. The Yield-SAFE modeling method and application in various European countries has been described by Graves et al. (2007, 2010), Keesman et al. (2011), and Palma et al. (2007a, b, c).

The model was calibrated for the lowland plateau in Switzerland using the following steps. Daily weather data for Zurich (solar radiation (megajoules per square meter), mean daily temperature, and daily precipitation (millimeters)

were supplied by the Federal Office of Meteorology and Climatology (MeteoSwiss). The weather data showed that the area could expect an annual average precipitation of 1,086 mm. With an altitude of 556 m and a geographical position (8°34'/47°23'), these are typical site conditions for the Swiss plateau. Similarly, average soil conditions were assumed with a soil depth of 100 cm and medium-fine texture.

In a two-stage calibration process, the model was initially calibrated for “potential” yields of a range of crop and tree systems, which were limited by light and temperature (but not water) for the Atlantic and Mediterranean regions of Europe. Then, using these parameters for potential tree and crop growth, three parameters (management factor, harvest index, water use efficiency) were adjusted to calibrate the model against locally measured “reference” yields, but, this time, under water-limiting conditions. The final tree and crop parameters are shown in Graves and Sereke (2014).

Average lowland crop yields (Lips and Ammann 2006) were used for the reference crop calibrations, with 5.6 t ha⁻¹ for winter wheat and 3.0 t ha⁻¹ for oilseed (Table 1). Average grass yields were 12.0 t ha⁻¹ for high-input grassland and 4.0 t ha⁻¹ for low-input grassland (Dux 2008, Unpublished report).

Table 1 Average yields, costs, and revenues of the crop component

Input category	Unit	Wheat	Oilseed	Grassland	
				High input	Low input
Yield	t ha ⁻¹	5.6	3.0	12.0	4.0
Product value	SFr t ⁻¹	590	800	354	0
Direct costs	SFr ha ⁻¹	1,182	1,462	0	0
Labor costs	SFr ha ⁻¹	825	696	601	386
Overhead costs	SFr ha ⁻¹	3,100	2,868	4,190	1,884
Product revenue	SFr ha ⁻¹	3,302	2,400	4,250	0
Other revenues	SFr ha ⁻¹	524	47	0	0
Area payments	SFr ha ⁻¹	1,600	1,600	1,040	1,040
Specific crop payments	SFr ha ⁻¹	204	1,601	0	0

For calibrating the potential growth of wild cherry (Table 2), published tree growth tables were used from the nearby and climatically similar region of South Germany (Spiecker 1994). These data showed that a timber volume of $1.07 \text{ m}^3 \text{ tree}^{-1}$ for year 60 could be achieved for forestry trees. We assumed an initial planting density of $816 \text{ trees ha}^{-1}$, regularly thinned to a final density of 100 trees. For walnut (Table 2), the calibration for French yield data was used (Graves et al. 2007) as local data were not available. In this, the assumed tree volume was $0.99 \text{ m}^3 \text{ tree}^{-1}$ in year 60 for a walnut forestry system, planted at an initial density of 210 trees ha^{-1} and thinned twice by 55 trees.

Since the model did not include a fruit component, annual fruit yields were based on local fruit yield data, with average yields of 32 kg tree^{-1} (Maurer et al. 2008, Unpublished report) for walnut and 41 kg tree^{-1} for wild cherry (farmers data, not published). The management factor, pruning height, and tree line widths were adjusted to simulate the growth, shape, and management of fruit trees in order to determine their impact on intercrop growth and yield. Generally, lower tree densities result in higher timber and fruit yields per tree, as the trees have more space to grow larger.

The relative productive advantage of the agroforestry system in comparison to growing the annual and perennial systems separately was examined using the land equivalent ratio (LER). The LER has been defined by Ong (1996) as “the ratio of the area under sole cropping to the area under the agroforestry system, at the same level of management that gives an equal amount of yield.”

$$\text{LER} = \frac{\text{Tree yield agroforestry}}{\text{Tree yield forestry reference}} + \frac{\text{Crop yield agroforestry}}{\text{Crop yield agricultural reference}}$$

When the LER is calculated to be greater than 1, then there is a productive advantage to growing trees and crops in an agroforestry system. Where the LER is less than 1, the opposite is true, and there is a productive disadvantage to growing the trees and crops in an agroforestry system. Here, more than one crop was used in the rotation, and therefore, a time-based proportionally weighted ratio for each crop was developed over the 60-year rotation.

2.3 Economic assessment

Based on the predicted yields and local economic data, the profitability was calculated using the Farm-SAFE model (Graves et al. 2011). The Farm-SAFE model was developed in a Microsoft Excel spreadsheet using distinct worksheets to contain the key components of the economic analysis. For example, a primary worksheet called “Option and results” controls worksheet for selecting the scenarios and inputs and presenting the results. Input worksheets comprised physical yield data in worksheets labelled “Arablesystem,” “Forestrysystem,” and “Agroforestrysystem,” and also four financial data worksheets were labelled “Arablefinance,” “Treevalue,” “Treegrant,” and “Treecost.” For further details of the Farm-SAFE model, the reader is referred to Graves et al. (2011).

As tree planting is a long-term enterprise, future income and expenditure was discounted and aggregated to obtain the net present value (NPV). This is described by the following equation:

$$\text{NPV} = \sum_{t=0}^{t=T} \frac{R_t - V_t - A_t}{(1+i)^t} \quad (1)$$

where NPV was the net present value (Swiss francs (SFr) per hectare) of the agricultural reference or the agroforestry land

Table 2 Yields, costs, and revenues of the tree component

Input category	Units	Wild cherry				Walnut			
		Timber		Fruits		Timber		Fruits	
		40	70	40	70	40	70	40	70
Yield	Yield ha^{-1}	53.9 m^3	79.8 m^3	1.8 t	2.9 t	57.8 m^3	80.6 m^3	1.3 t	2.0 t
Product value	SFr	800 m^{-3}		2,750 €^{-1}		1,168 m^{-3}		5,000 €^{-1}	
Establishment costs	SFr ha^{-1}	2,716	3,898	3,030	4,447	2,698	3,477	4,789	7,838
Maintenance costs	SFr ha^{-1}	574	917	2,462	3,992	427	521	2,318	3,511
Harvest costs	SFr ha^{-1}	114	200	900	1,450	114	200	2,860	4,400
Area payments	SFr ha^{-1}	1,040	1,040	1,040	1,040	1,040	1,040	1,040	1,040
(1) Common 15 SFr tree^{-1}	SFr ha^{-1}	600	1,050	600	1,050	600	1,050	600	1,050
(2) Ecological 45 SFr tree^{-1}	SFr ha^{-1}	1,800	3,150	1,800	3,150	1,800	3,150	1,800	3,150

For timber yield, the final tree volume harvested in year 60 is shown. As the cost and revenue values change within the 60-year tree rotation, the values in year 30 are presented. Depending on the agroenvironmental scheme the farmer participates in, 15 or 45 SFr tree^{-1} is currently available in Switzerland

use options, R_t is the profit from the enterprise (including subsidies) in year t (SFr per hectare), V_t is the variable costs in year t (SFr per hectare), A_t is the assignable fixed costs in year t (SFr per hectare), T is the time horizon (years), and i was the discount rate. A discount rate of 3.5 % was used, as this has been the opportunity cost of capital assumed for previous economic studies on Swiss orchards (Alder 2007).

In order to compare tree species with different rotations, the model was also developed to calculate an infinite NPV (NPV_{Infinite}, unit: euros per hectare), this being the NPV defined over an infinite time horizon, in which each replication has a rotation of n years (Eq. 2):

$$\text{NPV}_{\text{Infinite}} = \text{NPV} \frac{(1+i)^n}{(1+i)^n - 1} \quad (2)$$

NPV was also expressed as an annuity value, the “equivalent annual value” (EAV, units: euros per hectare per annum) (Eq. 3):

$$\text{EAV} = \text{NPV}_{\text{Infinite}} \times i \quad (3)$$

For the economic assessment, a database based on the field survey and published literature was established, describing local crop and tree management, costs, revenues, and direct-payment regimes. The data for the arable cropping system (Lips and Ammann 2006) and the grassland system (Dux 2008, Unpublished report) were supplied by the local research station for agricultural economics (Table 1). The reference scenario for grassland is natural grassland, including two intensities: round bale silage for high input and fresh grass harvesting for low input. In both systems, no direct costs are involved such as for seeds, fertilizer, and phytosanitary. As fertilizer, we assumed liquid manure, which has no financial value.

Data for walnut production were provided by the local research station for fruit production (Maurer et al. 2008, Unpublished report), with a reference walnut fruit price of 5 SFr kg⁻¹ (Table 2). Based on the field survey, a cherry fruit price of 2.75 SFr kg⁻¹ was assumed. The price for high-value walnut timber varies considerably, with an average price of 1,168 SFr m⁻³ (WVZ 2010). The reference value recommended for high-quality wild cherry timber was 800 SFr m⁻³ (WALDSG 2011).

The following direct payments were considered for the bioeconomic calculations. General direct payments are paid as flat rates for the agricultural area. For our crop rotation, these were 1,600 SFr ha⁻¹ for wheat and oilseed rape (Lips and Ammann 2006), with additional crop-specific payments of 204 SFr ha⁻¹ for wheat and 1,601 SFr ha⁻¹ for oilseed rape.

The grassland areas received basic payments of 1,040 SFr ha⁻¹ (BLW 2008).

The ecological direct payments for standard trees consist of a basic payment of 15 SFr tree⁻¹. Additional payments of 30 SFr tree⁻¹ are available if the farmer complies with ecological quality demands, such as tree densities between 30 and 100 trees ha⁻¹, trees well maintained, and specific ecological quality standards met. The extra labor and material costs to meet the habitat quality criteria were considered in the NPV calculations. Hence, our direct-payment scenarios compared the basic tree direct payments (15 SFr tree⁻¹) with the accumulated ecological payments for trees (45 SFr tree⁻¹).

2.3.1 Definition of scenarios

Scenarios were defined to reflect, to some extent, the uncertainty of future prices as well as possible strategies of agroforestry farmers. One pessimistic price scenario was defined as low fruit prices are a main risk for the profitability of Swiss agroforestry practices (Alder 2007). Similarly, the price of high-value timber depends on the timber quality and on changing consumer trends. The survey identified two marketing strategies followed by the farmers. The first was the product innovation strategy, with direct marketing of innovative regional specialties. The second approach was the upcoming ecosystem services strategy where the farmers aimed to market ecosystem services through participation in the ecological direct-payment scheme. Some farmers managed to more or less combine both strategies, but still they were assessed separately to analyze their specific cash flow performance. Additionally, hence, the following scenarios were defined:

1. BASIC_A: Baseline scenario, with basic direct payments (15 SFr tree⁻¹) and average tree product prices;
2. BASIC_P: Basic direct payments and pessimist tree product price (−10 %);
3. BASIC_O: Basic direct payments and optimist tree product price (+10 %), representing the tree product innovation strategy;
4. ECO: Ecological innovation scenario, with payments for ecosystems services (45 SFr tree⁻¹) and average tree product price, representing the ecosystem services strategy.

3 Results and discussion

3.1 Classification of Swiss agroforestry

Our exploratory survey and literature review yielded an inventory of 21 tree-crop or tree-grass combinations (Table 3).

Table 3 Classification of Swiss agroforestry practice. Classification scheme developed according to McAdam et al. (2009)

ID	Location	Components			Local name	Main tree species	Intercrop	Arrangement	Ecosystem services
		Site	AF System						
SP1	Gempen (SO)	M	Silvopastoral		Streubstwiesen	<i>Prunus avium</i>	Pasture	Mixed sparse	P1 (P2), H1, H2, S
SP2	Oberflachs (AG)	M	Silvopastoral		Streubstwiesen	<i>Prunus avium</i> , <i>Juglans regia</i> , <i>Castanea sativa</i> , <i>Malus domestica</i> , <i>Prunus avium</i> , <i>Juglans regia</i> , <i>Castanea sativa</i> , <i>Malus domestica</i>	Pasture	Mixed sparse	P1, H1, H2, S
SP3	Nendaz (VS)	M	Silvopastoral		Pré-verger	<i>Prunus armeniaca</i>	Pasture	Mixed sparse	P1, H1, H2, S
SP4	Zeiningen (AG)	M	Silvopastoral		Streubstwiesen	<i>Morus alba</i>	Pasture	Mixed sparse	P1, H1, H2, S
SP5	Frick (AG)	M	Silvopastoral		Streubstwiesen	<i>Prunus avium</i> , <i>Mespilus germanica</i> , <i>Pyrus pyracantha</i> , <i>Rosa canina</i> , <i>Sorbus aucuparia</i> , <i>Sorbus torminalis</i> , <i>Sorbus domestica</i> , <i>Cornus</i> , <i>Sorbus domestica</i>	Fodder	Strip planting	P1, H1, S
SP6	Truttkon (SH)	B	Silvopastoral		Streubstwiesen	<i>Juglans regia</i>	Fodder	Strip planting	P1, H1, S
SP7	Muri (AG)	M	Silvopastoral		Streubstwiesen	<i>Prunus domestica</i> , <i>Juglans regia</i> , <i>Pyrus communis</i> , <i>Prunus avium</i> , <i>Sorbus aucuparia</i> , <i>Castanea sativa</i> , <i>Malus domestica</i> , <i>Sorbus domestica</i>	Fodder	Strip planting	P1, H1, S
SP8	Steinmaur (ZH)	B	Silvopastoral		Streubstwiesen	<i>Malus domestica</i> , <i>Prunus avium</i> , <i>Pyrus communis</i> , <i>Cydonia oblonga</i> , <i>Pyrus pyrifolia</i> , <i>Mespilus germanica</i>	Fodder	Strip planting	P1, H1, S
SP9	Hauptwil (SG)	M	Silvopastoral		Streubstwiesen	<i>Juglans regia</i>	Pasture	Strip planting	P1, H1, H2, S
WB	Toggenburg (SG)	M	Windbreak		Baumhecken	<i>Prunus</i> spp., <i>Pyrus</i> spp., <i>Malus</i> spp., <i>Corylus avellana</i> , <i>Acer</i> spp., <i>Fraxinus excelsior</i> , <i>Sambucus nigra</i> , <i>Prunus padus</i> , <i>Prunus spinosa</i> , <i>Crataegus monogyna</i> , <i>Cornus mas</i>	Fodder	Boundary	P1, H1, R1, S
SA1	Möhlín (TG)	B	Silvoarable		Streubstäckler	<i>Prunus avium</i> , <i>Malus domestica</i> , <i>Pyrus communis</i>	Arable	Strip planting	P1, H1, S, R2
SA2	Sursee (LU)	B	Silvoarable		Streubstäckler	<i>Malus domestica</i>	Arable	Strip planting	P1, H1, S, R2
SA3	Steinmaur (ZH)	B	Silvoarable		Streubstäckler	<i>Pyrus pyracantha</i>	Arable	Strip planting	P1 (P2), H1, S, R2
FG1	Breno (TI)	M	Forest grazing		Selva	<i>Castanea sativa</i>	Pasture	Mixed sparse	P1, H1, H2, S
FG2	Arosio (TI)	M	Forest grazing		Selva	<i>Castanea sativa</i>	Pasture	Mixed sparse	P1, H1, H2, S
FG3	Brontallo (TI)	M	Forest grazing		Selva	<i>Castanea sativa</i>	Pasture	Mixed sparse	P1, H1, H2, S
FG4	Veizio (TI)	M	Forest grazing		Selva	<i>Castanea sativa</i>	Pasture	Mixed sparse	P1, H1, H2, S
FG5	Chaux-des-Breuleux (JU)	M	Forest grazing		Pâturage boisé	<i>Abies alba</i> , <i>Picea abies</i> , <i>Acer pseudoplatanus</i> , <i>Fagus sylvatica</i>	Pasture	Mixed sparse	P2, H1, H2, S
FG6	Bettwiesen (SG)	M	Forest grazing		Tannenweid	<i>Abies nordmanniana</i> , <i>Abies koreana</i> , <i>Picea pungens glauca</i>	Pasture	Strip planting	P2, H1, H2, S
FG7	Wildenstein (BL)	M	Forest grazing		Eichenwitwald	<i>Quercus robur</i>	Pasture	Mixed sparse	P1 (P2), H1, H2, S
FGA	Toggenburg (SG)	M	Forest garden		Waldgarten	<i>Prunus domestica</i> , <i>Pyrus communis</i> , <i>Malus domestica</i> , <i>Prunus domestica</i> , <i>Fraxinus excelsior</i> , <i>Acer</i> spp., <i>Alnus</i> spp., <i>Populus</i> spp., <i>Frangula alnus</i> , <i>Ulmus</i> spp., <i>Sorbus aucuparia</i> , <i>Salix</i> spp.	Horticulture	Successional	P1 (P2), H1, H2, S

Site: best plain land (B) and marginal sloping land (M). Agroforestry systems: silvopastoral (SP), windbreak (WB), silvoarable (SA), forest grazing (FG), and forest garden (FGA). Ecosystem services include production: fruit (P1) and timber (P2); habitat: biodiversity (H1) and shelter for livestock (H2); regulation: windbreak (R1) and soil/water conservation (R2); and sociocultural functions (S)

Traditional orchards are characterized by widely spaced standard fruit trees of old varieties. They are commonly located in the lowland and hilly regions of Switzerland.

In the silvopastoral group (SP1 to SP9), trees are intercropped with fodder grass which is grazed or cut for haymaking. The silvoarable case (SA1 to SA3) is hardly found nowadays. There, trees are intercropped by arable crops (vegetables, winter wheat, winter barley, oilseed, grain maize, forage maize, and sunflower).

The hedgerow or windbreak (WB) systems are typical examples of diverse landscapes of the pre-alps. However, today remnant hedgerows are often not actually part of the farm holding which may explain their neglect by farmers.

Forest-grazing systems (FG1 to FG7) mainly occur in the (lower) mountainous regions. Some of these (FG1 to FG4) are revitalized traditional chestnut orchards, which mainly occur on the south facing slope of the alps. Others (FG5 to FG6) are representative of the Jura Mountains (where Switzerland and France share borders), where free-ranging cattle and horses graze in a semi-open landscape with characteristic, free-standing (mostly coniferous) trees. The forest-grazing practice FG7 is a 500-year-old remnant of the formerly widespread oak forest-grazing system and is now protected for cultural and natural heritage. In contrast, “forest garden” FGA is a recent innovation and combines crops, shrubs, and tall trees (Vogt 1999).

These findings for Switzerland echo the situation in much of Europe, where only remnants of formerly widespread temperate agroforestry practices continue to exist in a declining state (Herzog 1998; Eichhorn et al. 2006).

The interviewed farmers were generally more interested in fruit than in timber production. Timber was also produced but mainly in the forest-grazing systems. The understory was also a source of revenues through arable crops or fodder production as well as through livestock products.

A promising example for product innovation was the wild cherry innovation (SP1). The farmer produces high-value wild cherries for the local processing and liquor industry, while the intercropped pasture is mown and grazed by livestock. The walnut silvopastoral system (SP6) was another promising innovation. In both cases, farmers managed to sell their tree products at well above the average prices. Hence, various design options of these two promising innovations were further assessed with the bioeconomic models.

The habitat function provided by agroforestry is the main ecosystem service scientifically recognized in Switzerland (BAFU and BLW 2008; Kaeser et al. 2010) and other parts of Europe (McAdam et al. 2009). With regard to shelter for livestock, obtaining this service is the main motivation why Swiss farmers plant trees (Sereke 2012).

Notably, no studies were found on the soil and groundwater conservation potential of agroforestry in Switzerland.

However, in European studies, the potential of agroforestry to tackle these issues has been highlighted (Lehmann et al. 1999; Palma et al. 2007). The potential to help counter climate change by sequestering atmospheric carbon (C) in Switzerland has hardly been explored (Briner and Lehmann 2011), whereas in Europe, studies have examined the possible role of farmland trees in this context (Palma et al. 2007).

The deep connection of Swiss people with trees is illustrated by the tradition of planting a tree for each newborn child (Lurker 1976). The tree of life park (SP7) offers this service. The price is 50 SFr⁻¹ with a 20-year contract; afterwards, the child decides how to proceed. *Streuobst* landscapes with native fruit trees and hedges are the most popular components of Swiss cultural landscapes (Schüpbach et al. 2009).

According to our review, the most recognized ecosystem service provided by agroforestry was biodiversity. Lack of local data was identified for other ecosystem services, such as soil conservation and groundwater protection. The first strategy to incorporate ecosystem services has been suggested recently (Staub and Ott 2011). Hence, a systematic valuation of ecosystem services in the agricultural economy is needed, which would recognize the benefits of multifunctional farming systems. The importance of valuing ecosystem services is a matter of international concern (Termorshuizen and Opdam 2009).

3.2 Biophysical assessment

3.2.1 Definition of representative agroforestry practices

The survey yielded diverse agroforestry designs with various tree species. In order to assess their productivity and profitability, we established a typology, focusing on *Juglans* hybr. and *P. avium* as two of the most popular tree species, which can be used for both nut/fruit and timber production. Both tree species were planted by seven and four surveyed farmers, respectively. Their suitability for agroforestry has been assessed in other temperate regions of Europe (Graves 2007; Dupraz and Liagre 2008). For both tree species, various design options and direct-payment scenarios were assessed, following the main design strategies identified by the survey.

According to our observations, most farmers' choice is fruit production combined with fodder production or pastures. In contrast, recent agroforestry research in temperate European regions indicates that high-value timber production and silvoarable agroforestry can also be profitable (Graves 2007; Dupraz and Liagre 2008). Hence, the two tree management options were considered for the assessment. The intercrop options were silvopastoral and silvoarable intercropping.

Regarding tree density, farmers planted trees in low and high densities. Therefore, low-density (40 trees ha⁻¹) and high-density (70 trees ha⁻¹) options were defined. In mechanized agroforestry, trees are planted in rows and the row

distance should fit the maximum machinery width (12 m in Switzerland). We assumed a tree strip width of 2 m for pruned timber trees and of 4 m for fruit trees, due to their larger crowns. A tree distance within the rows of 10 m was assumed, which is suitable for both production systems.

This results in eight alley cropping schemes for a given tree species, representing both the widespread silvopastoral and the less frequent silvoarable systems. For cherry, the combination of fruit production with arable crops was discarded, due to conflicting harvest periods. A typical crop rotation was assumed with oilseed/winter wheat/rotational grassland/winter wheat. The grassland was managed through a common mechanized cut and carry system, where silage bales are produced for high-quality forage.

3.2.2 Yield assessment

The four assessed tree-crop combinations were timber-arable (TA), fruit-arable (FA), timber-grassland (TG), and fruit-grassland (FG) with either 40 or 70 trees ha^{-1} . Figure 2 shows four silvopastoral combinations with wild cherry trees and four silvoarable combinations with walnut trees. These examples show how the relative intercrop yields steadily declined during the 60-year cropping cycle under wild cherry (Fig. 2a) and walnut trees (Fig. 2c). The corresponding timber (T) yields are demonstrated in Fig. 2b, d. The high-density options (70 trees ha^{-1}) had a stronger impact on the intercrop than the low-density options (40 trees ha^{-1}). Under the high-density conditions, continuous cropping for 60 years was not feasible. Hence, according to the NPV calculations, low-input silvopastoralism was assumed when the profitability of high-input intercropping was not profitable anymore. Similar results were found by Dupraz and Liagre (2008) who recommend a low tree density (<50 trees ha^{-1}) if continuous intercropping is planned. Similarly, fruit trees had a greater impact on the intercrop than timber trees which are pruned to achieve long straight stems. The pruning reduces light competition and also allows a minimum tree line width (of 2 m).

Of the 14 simulated agroforestry options, 12 had a land equivalent ratio greater than 1 (Fig. 2e), indicating that the trees and intercrops of most of the agroforestry options were more productive when grown together than separately ($\text{LER} > 1$). The LER was systematically higher for the cherry systems, timber options, and high tree densities. The two practices with an LER of less than 1 were walnut FG40 ($\text{LER}=0.95$) and walnut FA40 ($\text{LER}=0.99$). The highest LER was achieved by the cherry options FG70, TA70, and TG70 with 1.30, 1.30, and 1.29, respectively.

The predicted LERs indicate that combining tree and crop production increases the overall productivity of the land. Higher levels of productivity in agroforestry systems compared with cropping or forestry systems were also found for other European countries (Graves et al. 2007). Thus, a farmer

wishing to produce both a tree and intercrop component from his land would achieve greater productivity using an agroforestry system than by separating crops from trees. This contradicts the average farmer's view that agroforestry is less productive than crop or grass production in pure stands (Sereke 2012).

3.3 Economic assessment

3.3.1 Tree component

The interviewed farmers developed two main strategies to improve the profitability of their agroforestry practices: innovative marketing of tree products and/or profiting from maximum payments for ecosystem services. Under the baseline condition (BASIC_A), 8 out of 14 of the agroforestry practices were economically competitive after 60 years, compared to the respective non-agroforestry references (Table 4). Under the pessimistic assumption (BASIC_P), the reduction of the tree product price by 10 % had a significant impact on the profitability, particularly for the fruit-producing systems. A premium product price increase by 10 % (BASIC_O) turned ten agroforestry practices more competitive. The ecological innovation scenario (ECO) was the only strategy where 100 % of the agroforestry practices were more profitable than the monoculture.

Most interviewed farmers were interested in fruit production. This finding contrasts with most recent research publications, which focused on high-value timber (van der Werf et al. 2007; Graves 2007; Dupraz and Liagre 2008). According to our results, both systems have advantages and disadvantages.

The advantages for the timber system are lower investment costs and more space below the tree canopies, which is critical today with regard to the large farming machines. In contrast, the fruit option provides regular income, which makes the high-density fruit agroforestry practices more profitable. The disadvantage is that mechanization is still underdeveloped for such intercropped orchard systems. Another risk for the fruit system is the low average fruit prices for tree products (Alder 2007). However, the product innovation strategy shows that farmers can find niche markets such as high-quality premium products or local specialties. For this reason, walnut production currently has a great potential in Switzerland due to high market prices for the fruits and the high-value timber.

The long and expensive establishment phase of trees is a major disadvantage of agroforestry systems. This is particularly the case with fruit production, due to higher planting and maintenance costs. Therefore, we recommend introducing establishment payments to create incentives for planting trees.

In most cases, the simulated silvoarable options were more profitable than the corresponding silvopastoral options. This is surprising as silvoarable practices are largely abandoned today

Fig. 2 Relative crop yield and timber volume predictions for the wild cherry silvopastoral (**a**, **b**) and walnut silvoarable (**c**, **d**) practices. The silvopastoral tree-crop combinations are timber-grassland (TG) and fruit-grassland (FG), and the silvoarable combinations are timber-arable (TA) and fruit-arable (FA). The crop yield development under the wild cherry silvopastoral practices (**a**) and the walnut silvoarable practices (**c**) is

shown relative to the pure grassland and arable (rotation: oilseed/winter wheat/rotational grassland/winter wheat) systems. The associated timber volumes (cubic meters per hectare) for wild cherry silvopastoral (**b**) and walnut silvoarable (**d**) practices are also shown for the two tree densities (40 and 70 trees ha^{-1}). The land equivalent ratios (LERs) for the 14 agroforestry practices (**e**)

(see classification results above). Other European studies have confirmed that silvoarable practices can fit into modern farming schemes in a productive and profitable way (Graves et al. 2007; Dupraz and Liagre 2008).

The economic analysis showed the importance of payments for ecosystem services. With a payment of 15 SRF tree^{-1} , agroforestry practices are likely to be unprofitable, particularly with low tree product prices (Alder 2007). The recently introduced ecological payment scheme of 45 SRF tree^{-1} is needed to help farmers to cover the tree maintenance costs.

However, how effective are payments for ecosystem services, given the ongoing levels of payments for production?

Historically, direct-payment systems of many European countries, including Switzerland, supported specialization in agricultural production and, thus, are considered to have resulted in the abandonment of multifunctional agroforestry practices (Eichhorn et al. 2006). Currently, the balance remains in favor of payments for conventional cropping and livestock production, which in Switzerland is approximately 80 % of the total direct payments (Bosshard et al. 2010).

Interestingly, our research found that Swiss farmers do not often make use of the increased payments available for ecosystem services. In the case of agroforestry, most farmers only received a minimum of 15 SRF tree^{-1} (Sereke 2012). Modern farmers often argued that they preferred to be food producers

Table 4 Net present value (SFr per hectare, 3.5 % discount rate) 10, 30, and 60 years after tree planting for the four scenarios: (a) baseline (BASIC_A), (b) pessimist (BASIC_P), (c) optimist (BASIC_O), and (c) ecological innovation (ECO)

Agroforestry practices Timber (T)/fruits (F)	BASIC_A SFr ha ⁻¹ in a year			BASIC_P SFr ha ⁻¹ in a year			BASIC_O SFr ha ⁻¹ in a year			ECO SFr ha ⁻¹ in a year		
	10	30	60	10	30	60	10	30	60	10	30	60
Arable (A)/grassland (G)	10	30	60	10	30	60	10	30	60	10	30	60
Arable monoculture	13,533	29,510	41,008	13,533	29,510	41,008	13,533	29,510	41,008	13,533	29,510	41,008
Wild cherry (TA40)	10,182	24,579	35,763	10,182	24,579	35,212	10,182	24,579	36,315	14,128	33,827	47,258
Wild cherry (TA70)	11,001	27,328	40,019	11,001	27,328	39,207	11,001	27,328	40,831	13,805	35,261	51,411
Walnut (TA40)	11,352	21,298	38,751	11,352	21,298	37,863	11,352	21,298	39,638	15,581	30,467	48,465
Walnut (TA70)	13,113	23,487	46,920	13,112	23,487	45,683	13,112	23,487	48,156	15,183	32,091	60,020
Walnut (FA40)	-1,661	23,442	38,049	-2,214	17,820	28,990	-1,246	27,658	44,844	5,027	32,491	48,265
Walnut (FA70)	-7,089	27,909	48,280	-7,969	18,965	33,867	-6,429	34,616	59,089	1,136	38,847	61,360
Grassland monoculture	10,542	23,554	32,469	10,542	23,554	32,469	10,542	23,554	32,469	10,542	23,554	32,469
Wild cherry (TG40)	7,903	23,106	36,629	7,903	23,106	35,212	7,903	23,106	37,196	12,095	32,333	47,285
Wild cherry (TG70)	8,642	26,618	43,435	8,642	26,618	42,599	8,642	26,618	44,271	9,815	30,251	50,095
Walnut (TG40)	8,051	11,561	26,264	8,051	11,561	25,376	8,051	11,561	27,152	12,574	22,598	40,513
Walnut (TG70)	8,978	17,271	40,525	8,978	17,271	39,289	8,978	17,271	41,761	6,679	25,652	51,596
Wildcherry (FG40)	-5,426	16,893	33,973	-5,526	14,602	29,603	-5,338	18,914	37,829	1,880	27,842	45,371
Wildcherry (FG70)	-12,383	16,678	40,539	-12,542	13,033	33,586	-12,242	19,894	46,674	-4,468	26,643	49,867
Walnut (FG40)	-4,439	16,322	29,361	-4,992	10,701	20,302	-4,024	20,539	36,155	2,361	26,029	41,141
Walnut (FG70)	-10,826	20,941	41,158	-11,706	11,997	26,746	-10,166	27,648	51,968	-3,698	31,452	53,131

For the tree-crop combinations timber-arable (TA), fruit-arable (FA), timber-grassland (TG), and fruit-grassland (FG) with 40/70 trees ha⁻¹. The references are the arable rotation (oilseed/winter wheat/rotational grassland/winter wheat) and pure grassland stands

rather than to be (ecological) direct-payment receivers. However, it is worth noting that until the 1950s trees were popular components of Swiss agriculture (as their fruits were valued by the local population).

Because of the resistance to payments for ecosystem services, the recovery of markets for fruits may provide a more sustainable way of encouraging farmers to plant trees. However, we also suggest that it is important to show farmers how agroenvironmental development programs can meet their expectations and needs. In this way, farmers will then be motivated to make use of agroenvironment payments, such as those available for trees, because they will recognize that multifunctional agroecosystems lead to improved profitability and sustainability of their farming systems as well as provide benefits for the environment and the rest of society (Altieri 1999).

3.3.2 Crop component

In the previous section, we examined the sensitivity of the agroforestry system to changes of the tree component revenues in a series of scenarios. Here, the sensitivity of crop revenue changes in the agroforestry and non-agroforestry reference systems is assessed using sensitivity analysis. The impact of declining or increasing crop revenues on the net present value was undertaken by altering the original revenue

values by plus or minus 10–50 % (Fig. 3). The arable reference was compared to the walnut timber (TA) silvoarable practices for 40 and 70 trees ha⁻¹. The high sensitivity of the arable reference to changing crop revenues is shown, compared to the agroforestry practices. The sensitivity analysis indicates that mixing trees and crops helps mitigate the financial risks associated with production if crop prices fall, as the

Fig. 3 Sensitivity to changes in crop revenues: net present value of the walnut timber (TA) silvoarable practices with 40 and 70 trees ha⁻¹. NPV (1000×SFr ha⁻¹)

revenue sources are diversified. This is not only valid for cropping agriculture but also for other strategies which are based on a single product such as timber or fruit plantations.

The results suggest that crop revenues would have to increase by approximately 10 % before the non-agroforestry reference becomes as profitable as the more densely planted (70 trees ha⁻¹) agroforestry system. In Switzerland, however, the increasing free trade policy is expected to significantly decrease the crop production revenues (Mack and Flury 2006). In this context, the analysis suggests that the more widely spaced (40 trees ha⁻¹) agroforestry system will become more profitable if crop prices decrease by approximately 10 %. These and other risk reduction potentials of agroforestry practices have also been identified by other authors (Kumar and Nair 2006).

4 Conclusion

The three-step participatory design and assessment approach presented in this paper identified living examples of productive and profitable agroforestry practices. However, we also identified agroecological and economic challenges which may explain why agroforestry is not popular anymore. Based on our agroforestry design and bioeconomic assessment exercise, the following recommendations can be made. There is need for the following:

- Promoting the concept of ecosystem services, to better understand the diverse ecosystem services provided by agroforests and to increase the willingness to pay for these services;
- Coproducing agroecological knowledge, including both farmer and scientific perspectives, to support the design of productive and multifunctional farming systems. For example, most interviewed farmers only considered fruit production combined with grassland, despite recent scientific evidence that high-value timber combined with arable crops represents further productive options;
- Recovering the markets for tree products to encourage farmers to plant trees, and the introduction of establishment payments to cover the long establishment phase.

Still, the unanswered question is why most farmers in Switzerland still resist the adoption of agroecological measures, such as restoring farm trees, despite the availability of competitive ecological direct payments. Hence, further in-depth surveys should be undertaken to fully understand the multiple drivers of farmers' behavior.

This is one of the few participatory studies of modern agroforestry systems in Europe, based on a limited number of agroforestry practices and on model estimations. Hence,

long-term field experiments to further validate our model predictions are needed. After decades of neglect, there is a need for a wide range of research and development to promote the development of profitable and sustainable agroforestry systems.

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References

- Alder T (2007) Vollkostenkalkulation für die Mostobstproduktion. Vergleich der Produktionskosten von Mostobst zwischen der Ostschweiz und Baden-Württemberg. ART-Berichte 691:8
- Altieri M (1999) The ecological role of biodiversity in agroecosystems. *Agric Ecosyst Environ* 74(1–3):19–31. doi:10.1016/S0167-8809(99)00028-6
- BAFU, BLW (2008) Umweltziele Landwirtschaft. Hergeleitet aus bestehenden rechtlichen Grundlagen. Umwelt-Wissen Nr. 0820. Bundesamt für Umwelt, Bern, 221 S. <http://www.bafu.admin.ch/publikationen/publikation/00097/index.html?lang=de>. Accessed Feb 2014
- BLW (2008) Direktzahlungen an die Landwirtschaft im Überblick 2009. Bundesamt für Landwirtschaft, Bern
- BLW (2011) Agrarbericht. Bundesamt für Landwirtschaft, Bern
- Bosshard A, Schläpfer F, Jenny M (2010) Weissbuch Landwirtschaft Schweiz – Analysen und Vorschläge zur Reform der Agrarpolitik. Haupt Verlag, Bern
- Briner S, Lehmann B (2011) Is agroforestry an economic opportunity for carbon-neutral animal production? *Agrarforschung Schweiz* 2(1): 12–19
- Bürgi M, Stuber M (2003) Agrarische Waldnutzungen in der Schweiz 1800–1950. *Waldfeldbau, Waldfrüchte und Harz. Schweiz. Z. Forstwes.* 154: 360–375
- Dupraz C, Liagre F (2008) *Agroforesterie: Des arbres et des cultures*. La France Agricole, Paris
- Eichhorn M, Paris P, Herzog F, Incoll L, Liagre F, Mantzanas K, Mayus M, Moreno G, Papanastasis V, Pilbream D, Pisanelli A, Dupraz C (2006) Silvoarable systems in Europe: past, present and future prospects. *Agrofor Syst* 67:29–50. doi:10.1007/s10457-005-1111-7
- Ewald KC, Klaus G (2010) Die ausgewechselte Landschaft – Vom Umgang der Schweiz mit ihrer wichtigsten natürlichen Ressource. Bern/Stuttgart/Wien, Haupt, 2. Aufl. pp. 660
- Graves AR, Sereke F (2014) List of tree and crop parameters identified for the YieldSAFE model in lowland Switzerland. Unpublished Report. Cranfield University, Bedford, p 4
- Graves AR, Burgess PJ, Palma JHN, Herzog F, Moreno G, Bertomeu M, Dupraz C, Liagre F, Keesman K, van der Werf W, Koeffeman de Nooy A, van den Briel JP (2007) Development and application of bio-economic modelling to compare silvoarable, arable and forestry systems in three European countries. *Ecol Eng* 29:434–449. doi:10.1016/j.ecoleng.2006.09.018
- Graves AR, Burgess PJ, Palma J, Keesman K, van der Werf W, Dupraz C, van Keulen H, Herzog F, Mayus M (2010) Implementation and calibration of the parameter-sparse Yield-SAFE model to predict production and land equivalent ratio in mixed tree and crop systems under two contrasting production situations in Europe. *Ecol Model* 221:1744–1756. doi:10.1016/j.ecolmodel.2010.03.008

- Graves AR, Burgess PJ, Liagre F, Terreaux J-P, Borrel T, Dupraz C, Palma J, Herzog F (2011) Farm-SAFE: the process of developing a plot- and farmscale model of arable, forestry, and silvoarable economics. *Agrofor Syst* 81, 2:93–108
- Herzog F (1998) Streuobst: a traditional agroforestry system as a model for agroforestry development in temperate Europe. *Agrofor Syst* 42: 61–80. doi:10.1023/A:1006152127824
- Kaesler A, Palma J, Sereke F, Herzog F (2010) Umweltleistungen von Agroforstwirtschaft. Die Bedeutung von Bäumen in der Landwirtschaft für Gewässer- und Bodenschutz, Klima, Biodiversität und Landschaftsbild. ART-Bericht 736:1–12
- Keesman K, Graves AR, van der Werf W, Burgess PJ, Palma J, Dupraz C, Van Keulen H (2011) System identification approach for developing and parameterising an agroforestry system model under constrained availability of data. *Environ Model Softw* 26(12):1540–1553. doi:10.1016/j.envsoft.2011.07.020
- Kumar BM, Nair PKR (2006) Tropical homegardens: a time-tested example of sustainable agroforestry. Springer, Dordrecht
- Lehmann J, Weigl D, Droppelmann K, Huwe B, Zech W (1999) Nutrient cycling in agroforestry with runoff irrigation. *Agrofor Syst* 43:49–70. doi:10.1023/A:1026447119829
- Lips M, Ammann H (2006) Vollkostenkalkulationen für Ackerkulturen. *AGRARF Orschung* 13(5):210–214
- Lurker M (1976) Der Baum in Glauben und Kunst. 2. Auflage, mit Bibliographie zum Baum-Thema, Schriften zur Deutschen Kunstgeschichte Band 328, Verlag Koerner, Baden-Baden
- Mack G, Flury C (2006) Auswirkungen der Agrarpolitik 2011. Modellrechnungen für den Agrarsektor mit Hilfe des Prognosesystems SILAS. Bundesamt für Landwirtschaft, Bern
- McAdam JH, Burgess PJ, Graves AR, Mosquera-Losada MR, Rigueiro-Rodríguez A (2009) Classifications and functions of agroforestry systems in Europe. In: Rigueiro-Rodríguez A, McAdam JH, Mosquera-Losada MR (eds) *Advances in agroforestry*, vol 6, Agroforestry in Europe: current status and future prospects. Springer, New York, pp 21–41. doi:10.1007/978-1-4020-8272-6_2
- Nair PKR (1993) *An Introduction to agroforestry*. Kluwer, Dordrecht, 499 pp
- Ong CK (1996) A framework for quantifying the various effects of tree-crop interactions. In: Ong CK, Huxley P (eds) *Tree-crop interactions a physiological approach*. CAB International, Wallingford, pp 1–23
- Palang H, Fry G (eds) (2003) *Landscape interfaces: cultural heritage in changing landscapes*. Kluwer, Dordrecht, p 420
- Palma JHN, Graves AR, Burgess PJ, van der Werf W, Herzog F (2007a) Integrating environmental and economic performance to assess modern silvoarable agroforestry in Europe. *Ecol Econ* 63:759–767. doi:10.1016/j.ecolecon.2007.01.011
- Palma JHN, Graves AR, Bunce RGH, Burgess PJ, de Filippi F, Keesman KJ, van Keulen H, Liagre F, Mayus M, Moreno G, Reisner Y, Herzog H (2007b) Modeling environmental benefits of silvoarable agroforestry in Europe. *Agric Ecosyst Environ* 119:320–334. doi:10.1016/j.agee.2006.07.021
- Palma JHN, Graves AR, Burgess PJ, Keesman KJ, van Keulen H, Mayus M, Reisner Y, Herzog F (2007c) Methodological approach for the assessment of environment effects of agroforestry at the landscape scale. *Ecol Eng* 29:450–462. doi:10.1016/j.ecoleng.2006.09.016
- Schüpbach B, Junge X, Briegel R, Lindemann-Matthes P, Walter T (2009) Ästhetische Bewertung landwirtschaftlicher Kulturen durch die Bevölkerung. ART-Schriftenreihe 10, Agroscope Reckenholz-Tänikon Research Station ART, Zürich
- Sereke F (2012) Transdisciplinary development of agroforestry systems. Diss ETH-Zürich. doi:10.3929/ethz-a-009753126
- Spiecker M (1994) Wachstum und Erziehung wertvoller Waldkirschen. Mitt. d. Forstl. Vers. u. Forschungsanstalt Baden-Württemberg, Heft, 181
- Staub C, Ott W (2011) Indikatoren für Ökosystemleistungen: Systematik, Methodik und Umsetzungsempfehlungen für eine wohlfahrtsbezogene Umweltberichterstattung. Bundesamt für Umwelt, Bern, p 113
- Termorshuizen JW, Opdam P (2009) Landscape services as a bridge between landscape ecology and sustainable development. *Landsc Ecol* 24:1037–1052. doi:10.1007/s10980-008-9314-8
- van der Werf W, Keesman K, Burgess PJ, Graves AR, Pilbeam D, Incoll LD, Metselaar K, Mayus M, Stappers R, van Keulen H, Palma J, Dupraz C (2007) Yield-SAFE: a parameter-sparse process-based dynamic model for predicting resource capture, growth and production in agroforestry systems. *Ecol Eng* 29:419–433. doi:10.1016/j.ecoleng.2006.09.017
- Vogt J (1999) Agroforstwirtschaft – eine mögliche Bereicherung der Landnutzungsformen in zwei ausgewählten Regionen. Diplomarbeit an der ETH Zürich, Institut für Pflanzenwissenschaften
- WALDSG (2011) Rundholzpreise Stand Januar 2010. <http://www.waldsg.ch/index.php/holzmarkt/richtpreisempfehlungen>. Accessed Jan 2011
- Wettasinha C, Waters-Bayer A (eds) (2010) Farmer-led joint research: experiences of PROLINNOVA partners. IIRR / Leusden: PROLINNOVA International Secretariat, ETC. EcoCulture, Silang
- WVZ (2010) Wertholzsubmissionen Waldbirtschaftsverband Kt. Zürich, <http://www.zueriwald.ch/>. Accessed Mar 2010
- Wösten JHM, Lilly A, Nemes A, Le Bas C (1999) Development and use of a database of hydraulic properties of European soils. *Geoderma* 90:169–185