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SDEWES 2023: Barriers and Possibilities for the Development of Short-Rotation Coppice as an Agroforestry System for Adaptation to Climate Change in Central European Conditions

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Abstract: This article compares different production, economic, and selected environmental aspects of agroforestry systems in a standard (alley cropping) and a newly proposed design with fast-growing trees grown in short-rotation coppice. Our models of agroforestry systems (AFSs) are as follows: (i) alley cropping AFS with cherry and walnut trees in single rows (tree strips) with 28 m-wide arable fields between them (crop strips), and (ii) coppiced tree belt AFS with poplars and willows and 25 m-wide arable fields between them (crop strips). To evaluate the production characteristics of trees, we used yield curves from experimental plantations in conditions of the Czech Republic from previous research projects. Cost data were collected from long-term experimental plantations and combined with current operation and energy prices. The article presents an economic methodology for assessing the competitiveness of biomass production in AFSs under the current identified market conditions. Our results show that AFSs with short-rotation coppice can have similar economic and production results as annual crops if grown on suitable sites and with appropriate quality of agronomy. In comparison, alley cropping AFSs with fruit trees would not be economically viable for farmers without a significant subsidy for establishment and maintenance in the first years after establishment. Concerning the latest economic and political developments, the product from SRC (energy woodchips) can be evaluated as strategic, increasing the producer's independence from purchased energy fuels.

Keywords: agroforestry system; economic; fast-growing tree; short-rotation coppice; energy fuels; annual crops

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1. Introduction

Contemporary agriculture in the EU can be characterized as large-scale, industrial farming oriented towards economic profit and high yields of a few cash crops grown on large monocultural fields. Their size often exceeds 50–100 ha, which is typical in many Central–Eastern European (CEE) countries. Not only does this management approach provide sufficient food for the European population and profitable export incomes, especially from cereal products [1], but it also negatively impacts the environment and social situation in the countryside.

In the conditions of Central Europe, lowland areas previously known for the highest productivity will be more often threatened by the manifestations of climate change, especially extreme drought, which will have a significant negative impact on the production potential of these areas [2–5]. In these regions, looking for alternative farming practices is necessary to maintain agricultural production, increase the landscape's resilience, and improve water retention in the soil and landscape [6]. It can be assumed that significant changes in crop assortment and agrotechnological procedures for individual crops will occur in certain areas. One appropriate measure recommended as part of national action plans for adaptation to climate change [7] is to incorporate trees and their multifunctional stands into intensively managed landscapes, such as short-rotation coppices of fast-growing trees or agroforestry systems with a wide variety of tree species.

Agroforestry systems, i.e., combining tree cultivation with some form of annual agricultural production on one plot of farmland, can fundamentally contribute to making agriculture more sustainable and diverse. Therefore, in the new Common Agriculture Policy (CAP, 2022–2027), agroforestry systems are recommended for national strategic plans as a measure to fulfil multiple agricultural and environmental policy goals [8]. Unfortunately, agroforestry with fast-growing trees in short rotations (coppice), which can be an important source of biomass for energy and the bioeconomy, is often omitted from subsidy schemes, or there are legislative, economic, and nature protection limitations for their establishment.

The European Commission and Member states recently approved a new Renewable Energy Directive (RED 2+), which must respond to recent geopolitical changes in the availability of transitional fossil fuels (natural gas) and simultaneously enable the fulfilment of mitigation and adaptation measures to climate change, including reducing emissions of greenhouse gases and the transition to more resilient forms of landscape management. The Czech Republic, like some other landlocked and/or forest-rich countries, covers the largest share of renewable resources with various forms of biomass (69% in CZ)—mainly from forest and agricultural residues (e.g., smallwood, straw) [9]. However, the recent catastrophic bark beetle calamity affecting Norway spruce forests in CEE countries has been gradually reducing the potential of forest biomass; thus, searching for new and, at the same time, sustainable sources of biomass to cover current and future energy needs is required. Promising sources of biomass, especially in rural areas, could be agroforestry systems with fast-growing trees, which can be a win–win solution to both energy and environmental demands. In their research, Sperandio et al. evaluated the possible use and environmental sustainability of the local decentralized production chain producing SRC wood biomass and its subsequent local use for heat production [10]. The authors concluded that heat production from locally grown woody biomass leads to greenhouse gas (GHG) emissions savings of up to 77% compared to the use of fossil fuels. If the soil carbon sequestration over the lifetime of the SRC plantation is included these GHG emissions, savings would be over 90% [10].

Agroforestry, the intentional integration of trees and shrubs into annual crop and animal production systems, common in tropical and subtropical regions, has over the past few decades also been implemented in temperate climatic zones to enhance agricultural productivity and profitability while providing environmental benefits to agricultural systems and the cultural landscape [11,12].

The following categories of agroforestry systems are traditionally recognized: silvopastoral (trees on pastures), silvoarable (trees on arable fields), forest farming (multistory cropping on forest soil), windbreaks and shelterbelts (trees on the edges of fields), riparian-buffer strips (trees by water bodies), and home and community gardens.

As mentioned, many environmental and economic benefits are often connected with new agroforestry systems, often leading to them being recommended as adaptation measures to deal with the impacts of climate change on agriculture and the landscape [13]. Many authors have documented that agroforestry is a land-use system that allows for eco-intensification, meaning a production increase through the optimization of the use of natural resources and not through an increase in external inputs [14–16]. If AFSs are established in accordance with the individual site's production conditions and ecological requirements, they increase profitability and ecosystem service delivery per area, as was documented by authors using the land equivalent ratio (LER) approach [17–19]. (The LER coefficient focuses on evaluating the effectiveness of the combination of different crops from the point of view of land-use efficiency and does not evaluate the economic impacts of the combination of crops.) In our article, we analyzed the economic efficiency of AFSs from the farmers' decision-making point of view using principles of minimal-price methodology.

Agroforestry systems have important environmental benefits, especially compared to areas with intensive agriculture. The basic benefit of trees in agroforestry and other agricultural systems is their significant influence on the microclimate. In general, trees reduce soil and air temperature and mitigate their variability; they reduce wind speed and solar radiation and increase soil moisture [12–21]. A cooling effect is achieved through transpiration of trees and plants, which function as "heat valves" [22]. Larger areas with AFS systems can have a "cooling" effect on temperatures and affect the water regime similar to that of a forest or shrub stand ecosystem [20]. An essential component of the water regime in agricultural soils is the content of soil organic matter (SOC), on which AFSs have a positive effect [23,24]. However, the resulting microclimate in an agroforestry system is influenced by many factors, such as the system's design, orientation, and age, and the species grown there [25].

The benefit of AFS for improving the parameters of biodiversity, the sharp decline in which is recorded in areas with intensive agricultural production and anthropogenic activity [26], is based on the diversification of abiotic conditions described in the previous paragraph. AFS along with other stands of woody plants and perennial crops (short-rotation coppice, perennial energy crop plantations, hedges, windbreaks) in the landscape create a so-called transition ecosystem between dominant ecosystems—forest stands usually with low intensity of management and intensive agroecosystems [27,28]. They provide suitable conditions for many species of organisms adapted to these ecosystems and can benefit a species' migration, food needs, or reproduction. According to the results of various bioindicators, these stands increase biodiversity parameters 3–4× compared to locations with conventional intensive food crops [29].

Many authors agree that the main barriers to the development of agroforestry systems include (i) concerns of farmers about the complexity of growing trees with economic crops or animals, (ii) complicated bureaucracy to obtain permits and financial support, and (iii) loss of a certain percentage of land for main production [11,14,30]. These authors concluded that the complexity of the rules for establishing AFS (EU 1305/2013) thwarted many farmers from planting SRCs and caused many even to destroy the woody component in the arable lands because they were afraid to have any of their subsidy payments reduced or lost.

Short-rotation coppices (SRCs) are a new form of farming fast-growing trees (FGTs), especially poplars, willows, and other tree species, on agricultural land, which can also be used in agroforestry systems. Selected tree species (FGTs) with stump coppicing ability are effectively used to produce woody biomass for energy and also for material purposes and processing [31].

Unlike annual agricultural crops grown on arable land, SRCs have an extensive root system [32] that efficiently uses nutrients and, at the same time, improves soil properties such as organic matter content and soil structure [33]. SRCs improve erosion control and the drainage conditions of the site after creating a crown canopy [34]. Agroforestry shelterbelts or buffer strips have significantly higher infiltration capacity than arable or pasture land [35]. Selected species and genotypes, especially of willows—namely, the "Rokyta" variety, can be used in vegetation filters for soils contaminated with heavy metals [36–38], wastewater, or sludge [39]. Riparian buffers with SRCs retain 30–99% nitrate N and 20–100% phosphorus from runoff and shallow groundwater and are also effective for pesticide removal [35].

According to the recent results, SRCs are also CO_2 negative during the lifetime of the plantation. They store more carbon, especially in the soil, than is released by growing them. From the point of view of the subsequent energy use of biomass, SRC stands are then evaluated as CO_2 neutral—the amount of carbon released by burning biomass is accumulated again in the growing wood in a very short time (within a 3–6-year rotation). The longer the vegetation exists in an area, the larger it becomes and thus, the more carbon it absorbs from atmospheric CO_2 [40,41].

Task of Our Article

The main goal of our article is to compare different production, economic, and selected environmental aspects of agroforestry systems in traditional alley cropping with fruit trees and a newly proposed design with fast-growing trees grown in short-rotation coppice. Using the conditions of the Czech Republic and two model case studies, we aim to identify the barriers and potentials of these new management methods. We analyzed the economic efficiency of AFSs from farmers' decision-making point of view using principles of minimal-price methodology.

2. Materials and Methods

2.1. Crops and Trees in Agroforestry and Their Yields

Annual food crops, fast-growing trees, and fruit trees were used in our economic models of two case studies of agroforestry systems, described in more detail in Section 3, resp. Section 3.2 (AFS with coppiced fast-growing trees) and Section 3.3 (AFS with fruit trees). Their main parameters and design features are shown in Table 1.

Table 1. Main parameters of two AFSs analyzed in the case studies.

Parameter	AFS with Coppiced Tree Belts (AFS-CTB)	AFS with Fruit Trees
Planting scheme	4 triple rows ((3 × 1.8 m) × 0.5 m)	4 single rows (5 m × 30.5 m)
Tree density and cover	2024 pc/ha (16.7% of ha)	100 pc/ha (9% of ha)
Tree assortment	FGT: poplar, willow	50% walnut 50% cherry
Annual cash crops	Barley, wheat, rapeseed, maize	Barley, wheat, rapeseed, maize
Width of crops strips	26 m	28 m
Width of tree strips	5.6 m	2.5 m
Subsidy (per area, SAPS)	Yes	Yes + subsidy for the establishment of AFS

A 4-year rotation of annual crops of winter wheat, winter rape, maize, and spring barley was used in both case studies to represent the most typical combination of crops in the Czech Republic. The yields of individual annual crops are based on analyses by the Institute of Agricultural Economics and Information [42], specified for agricultural production areas of the Czech Republic. Yields are entered into the models according to the agricultural production conditions of individual land plots, described in the valuated soil-ecological unit (BPEJ) [43]. Yields of annual crops may be affected positively or negatively due to interaction with trees (shade, moisture, temperature, etc.), and thus, yields should be adjusted using the correction coefficient.

The following fast-growing trees were used in the case study of an AFS with a coppiced tree belt: poplar clone Max-4 (*Populus nigra* × *P. maximowiczii*) and the willow varieties *Salix* 'Tora', *Salix* 'Rokyta', and *Salix* 'Stvola'. Yields of their biomass (resp. woodchips) are also derived from production conditions of individual land plots described in the valuated soil ecological unit (BPEJ), specifically from the hardiness zones for fast-growing trees in the Czech Republic [43]. In the second case study of an AFS with fruit trees, the common walnut (*Juglans regia*) and cherry (*Prunus avium*) were used. Yields of their fruits and nuts harvested as a by-product of an alley-cropping AFS can be modelled in two basic productivity variants reflecting different conditions and influences—the so-called minimum and optimal variants.

2.2. Valuated Soil Ecological Units (BPEJ) for Yield Estimation

BPEJ units from the Czech agricultural land valuation system are used to apply the bottom-up principle to the methodology in the conditions of the Czech Republic. The following are included in this system: 10 climatic regions, 72 soil-type units, 5 slope categories, 4 exposures to the cardinal directions, and 4 depths of the soil profile. There are more than 2000 BPEJ units total, which can be bundled into several groups with similar characteristics, e.g., hardiness growth zones for individual crops. In particular, the parameters of the climatic region and soil type are key to estimating the yield of both conventional and energy crops. The actual modelling of crop yields is carried out using a GIS (geographic information system), which links information on the geographical location of the land, area, climatic region, and soil type. The GIS can then be used to analyze the expected variability in crop yields, the geographical distribution, and the economic characteristics of production. The modelling of yields of both cash and energy crops is described in detail in, e.g., [44].

2.3. Methodology of Economic Evaluation

To evaluate the economic efficiency of each type of AFS, a methodology based on modelling the cash flows generated by a given type of AFS was proposed. The methodology is based on the following basic principles:

- The model for a given type of AFS always captures the entire life cycle of the AFS and all the processes required for its establishment, maintenance, and disposal at the end of its useful life.
- Respecting opportunity land use for annual agricultural crops (i.e., the economic loss from not growing conventional crops on the land dedicated to trees in AFSs).
- Yields of both types of crop, i.e., annual agricultural crops and trees, are derived from the soil and climatic conditions of the location, according to the valuated soil ecological units (BPEJ in Czech) [44].
- Costs of growing annual crops are according to the respective agricultural production area (e.g., the Czech Republic is divided into six major agriculture production areas according to the site conditions, e.g., agropastoral costs will vary between lowland areas with large soil patches and foothill areas with smaller soil patches and temporally sloping terrain.
- Conventional (annual) food crops are assumed to be rotated according to the conditions of the agricultural production area.
- The lifetime of the AFS is correctly respected (based on the expected lifetime of a given stand of trees).
- Real business conditions are considered, i.e., the costs of agrotechnologies, including seeds and seedlings, are valued at market prices; similarly, the production of cash crops and the production of biomass (e.g., the thinning of tree stands) are valued at market prices.
- The cost-effectiveness of a given type of AFS (in a given location) is evaluated using cash flow modelling with respect to the time value of money (discount).

The basic logic of the proposed methodology is described in Figure 1.

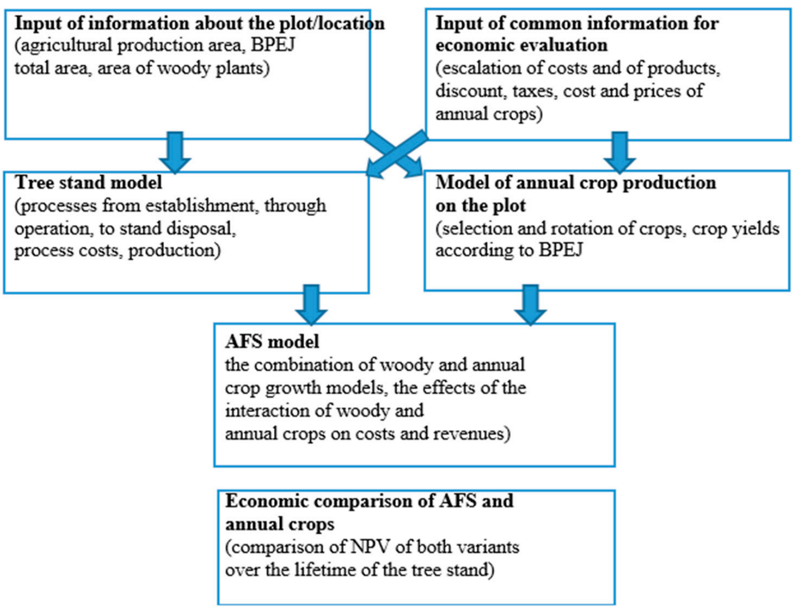

Figure 1. Scheme of the general economic model.

The AFS general economic model works with the general methodological assumptions outlined above.

The economic efficiency of a given type of AFS can be assessed for a specific project implemented in a specific location (characterized by soil and climatic conditions and rotation of specific annual crops) or it can be assessed generally, e.g., for a given type of agricultural production area characterized by typical crops and conditions for their cultivation. In the following two case studies, four main crops are considered: barley, wheat, rapeseed, and maize, which are the dominant crops in Czech agriculture.

The methodology for the economic evaluation of AFSs is based on the logic of combining two products—conventional agricultural production (wheat, barley, etc.) and tree-related production (biomass in the form of woodchips, and fruits). The economic efficiency of AFSs can then be evaluated in two different ways:

1. Prices of conventional agricultural (food) crops are exogenous variables (many critical crops are global commodities—e.g., wheat, corn, barley, and rapeseed—and their price is set by the global market regardless of the conditions and costs of cultivation in a given location), while prices of tree-related production are endogenous variables (results of modelling). Biomass in the form of woodchips is a typical "local" product, where there are logistical constraints for transport over longer distances. In this case, the analysis of the economic efficiency of AFSs can be based on the calculation of the so-called minimum price of production (biomass in the form of woodchips) that will provide the producer with the desired economic return from the business. The minimum biomass price can then be compared to the limit of the price the market is willing to accept (compared to substitutes such as natural gas or conventional solid fossil fuels). If the minimum price of a given product is higher than the price accepted by the market, the decision-maker (farmer) looks for other uses for his land.
2. The prices of both products (i.e., conventional annual food crops and tree-related production) are exogenous variables (determined by the market), and the economic evaluation of AFSs is carried out by calculating the net present value (NPV) of the cash flows generated over the lifetime of the AFS (total cash flows from the combination of both activities on a given land plot). If the NPV of AFSs (i.e., the combination of conventional farming and tree plantations) is higher than (over the lifetime of AFSs) the NPV of conventional production, the farmer will prefer AFSs. Otherwise, he will stick to growing conventional food crops.

When AFSs are implemented, part of the land that would have originally been used for conventional agricultural production is used to grow trees (tree strips). The part of the land that is not used for conventional food crops must also include any land taken for mechanization access corridors or manipulation areas, because the land allocated to these corridors would otherwise be used for conventional crops. The original land area h (100%) allocated to conventional crops is thus divided into the area used for conventional crops (h_{conv}) and the area used for tree production, including access corridors and tree strips (h_{tree}):

$$h = h_{i,conv} + h_{i,tree} \tag{1}$$

and

$$h_{i,tree} = h_{i,dir} + h_{i,cor} \tag{2}$$

where

$h_{i,conv}$: relative share of land for conventional crops in the *i-th* AFS type [-];
$h_{i,tree}$: relative share of land for tree cover in an AFS, incl. corridors in the *i-th* AFS type [-];
$h_{i,dir}$: relative share of land directly used for trees on total land in the *i-th* AFS type [-];
$h_{i,cor}$: relative share of land used for corridors on total land in the *i-th* AFS type [-].

The minimum cost of production is the price that provides the required return on capital employed and the useful life of the AFS, and its value shall be determined from the basic condition that the net present value of the project of a given type of AFS is zero. In other words, this means that the present value of the income (from the sale of the products and any subsidies) and the present value of the project expenditure (for the establishment, maintenance, harvesting, and disposal of the AFS) are equal (their difference is zero):

$$NPV_{tree} = \sum_{t=1}^{Tl} (pmin_{tree,i,t} \cdot q_{tree,i,t} \cdot k_{i,ALS} \cdot h_{i,dir} + S_{tree,t} \cdot h_{i,tree} - E_{tree,i,t} \cdot h_{i,dir} - E_{land} \cdot h_{i,cor}) \cdot (1 + r_{n,tree,i})^{-t} = 0 \quad (3)$$

where

t: sequential year of AFS lifetime;
$pmin_{tree,i,t}$: minimum price of the *i-th* product (fruit, woodchips) in year t [EUR/t, EUR/GJ];
$q_{tree,i,t}$: specific yields of the *i-th* product (fruit, woodchips) in standard conditions (plantation conditions) in year t from land lost for conventional crop [t/year,ha];
T_l: expected lifetime of a given AFS type [year];
$k_{i,ALS}$: relative increase/decrease in specific yields of the *i-th* product (fruit, woodchips) due to the location of trees in the AFS [-];
$S_{tree,t}$: specific subsidy for the AFS (tree area/numbers) in year t [EUR/ha];
$E_{tree,i,t}$: specific expenditures related to the *i-th* product (fruit, woodchips) from the trees in year t [EUR/ha, year];
E_{land}: specific expenditures for the land (land rent, land tax) [EUR/ha,year];
$r_{n,tree,i}$: nominal discount for the business activities related to the *i-th* product (fruit, woodchips) [-].

The second approach to assessing the economic efficiency of a given type of AFS compares, in principle, the NPV of growing conventional annual crops on a given plot with the NPV of combining conventional crops with trees on that plot.

The NPV of the variant without ALS (conventional annual crops only) is calculated according to the following relationship:

$$NPV_{conv} = \sum_{t=1}^{Tl} (p_{conv,j,t} \cdot q_{conv,j,t} + S_{conv,j,t} - E_{conv,j,t}) \cdot (1 + r_{n,conv})^{-t}, \quad j = 1, \ldots, m \quad (4)$$

where

m: number of conventional crop types in rotation for a given production area;
j: type of conventional crops included in the crop rotation in a given production area;
$p_{conv,j,t}$: specific price of the *j-th* conventional crop included in the crop rotation in given soil and climate conditions (production area) [EUR/t];
$q_{conv,j,t}$: specific yield of the *j-th* conventional crop on a given land plot in year t [t/ha];
$S_{conv,j,t}$: specific subsidy for the *j-th* type of conventional crop in year t [EUR/ha,year];
$E_{conv,j,t}$: specific production costs of the *j-th* conventional crop in a given production area and in year t [EUR/ha];
$r_{n,conv}$: nominal discount for the business activities related to producing the conventional crop [-].

Note:

- All the prices and expenditures are in nominal values—i.e., they are assumed to increase annually by the expected inflation/escalation of the type of prices or cost inputs.
- The cost of growing convection crops varies according to the conditions of the (agricultural) production areas. These areas are defined by soil and climatic conditions.
- Crop rotations corresponding to the growing conditions are used for each production area.
- Crop yields are also derived from the soil and climatic conditions of the individual plots.

In the case of the implementation of the *i-th* type of AFS, there is a combination of annual crops and production linked to tree plantations. The NPV of this type of AFS is then calculated according to the following equation:

$$NPV_{i,AFS} = \sum_{t=1}^{Tl} (p_{conv,j,t} \cdot q_{conv,j,t} \cdot \ k_{j,i} + S_{conv,j,t} - E_{conv,j,t}) \cdot h_{conv} \cdot (1 + r_{n,conv})^{-t} + \sum_{t=1}^{Tl} (p_{tree,i,t} \cdot q_{tree,i,t} \cdot k_{i,ALS} \cdot \ h_{i,dir} + S_{tree,t} \cdot h_{i,tree} - E_{tree,i,t} \cdot h_{i,dir} - E_{land} \cdot h_{i,cor}) \cdot (1 + r_{n,tree,i})^{-t} \quad (5)$$

where

$k_{j,i}$: relative increase/decrease in the *j-th* crop yield due to the effect of the *i-th* AFS type (beneficial cooling effect of the crop in hot summers, soil erosion protection);
$p_{tree,i,t}$: market price of the product from the *i-th* AFS type in year t [EUR/t, EUR/GJ].

If the $NPV_{i,AFS} - NPV_{conv}$ difference is positive, then (on a given plot characterized by soil and climate parameters determining the yields of both types of production) the given type of AFS is economically more profitable for the farmer than growing only conventional crops.

A number of authors emphasize both the higher level of risk associated with perennial energy crops compared to conventional agricultural production [45–47] and the opportunity cost principle when modelling the price of biomass from energy crops on agricultural land. Higher business risk is due to the high cost of establishing the tree plantation and the higher risks of losing both production (e.g., fruit) and the entire plantation (e.g., in case of bad weather in the first years after the establishment of the AFS). The higher business risk is then reflected in the higher value of the discount used to discount the cash flows associated with the tree plantation. At the same time, different types of tree plantations (i.e., different AFS types) generally have different business risk. For example, fruit trees will be riskier in terms of loss of production yield (due to inclement weather) compared to SRC plantations. Thus, SRC plantations generally have less sensitivity to weather fluctuations.

2.4. Planting and Cultivation Costs

The cultivation costs of perennial energy crops generally vary according to the conditions of the site, mainly determined by the type of soil, the slope of the soil, and the climatic conditions of the site. The combination of these parameters determines the type of (agricultural) production area. Within the same farming area, the farming conditions on different plots of land can be considered similar and therefore the cultivation costs comparable. This can be documented, for example, in the example of the Czech Republic, where agricultural land is divided traditionally into five basic crop-production regions, three of which (grain, maize, and sugar beet regions) make up more than 90% of agricultural land [48]. It is possible to survey cultivation costs, e.g., by means of a sample survey among farmers.

In order to estimate the minimum price of production (woodchips, fruit) providing the required return on invested capital (for the establishment and operation of the AFS) according to Formula (3), economic models capturing the entire life cycle of a stand of trees from the establishment of the stand, through maintenance and the harvesting of the production, to disposal can be used. The following basic principles apply to the development of these models (see [43]):

- The whole life cycle and all necessary agro-operations for the tree stand (plantation) are captured.
- All processes are valued at market prices at the place and time. For the valuation of individual agro-operations, typical costs in the year and location (region, state) for which the valuation is carried out are used; similarly, land rents and overhead activities associated with both the AFS and the farm as a whole (accounting, business management, etc.) should be valued at market prices.
- The opportunity cost principle is consistently applied, i.e., even the processes provided by a single farmer are valued at market prices (including land-related costs).
- The economic modelling is based on the simulation of nominal net cash flows (after income tax), and the costs (of individual agro-operations and activities) and benefits of the project are escalated by an estimate of inflation (price development of single-consumption items).

- Only eligible subsidies (e.g., area subsidy per unit area of agricultural land) are counted towards project income.
- A discount value is used to discount the cash flows to reflect the specific risk of the business (which is generally different for conventional crops and different types of AFS) [48].

Yields from tree plantations (fruit, woodchips, etc.) depend on the growing conditions in a given location (for the same agrotechnologies and growing material used), similar to yields from conventional crops. Also, part of the costs depends on the location (land rent) and the level of production (harvesting costs). It is therefore appropriate to relate the minimum production cost to several typical scenarios of production levels (esp. for SRCs).

Similar to energy crops, the costs of agro-operations for conventional crops vary according to site conditions (slope and terrain, size of continuous field areas) and are also influenced by the level of crop yields (e.g., costs of transporting the harvest from the field). At the same time, land costs (land rent) typically vary according to the quality of the site, with higher yielding land typically paying higher rents. Statistical observations of the agricultural sector can be used to determine the costs of agro-operations and for land rents There is, for example, a robust set of long-term data on the cost of cultivating conventional crops in contrast to that available for SRC plantations.

3. Case Studies of Economic Evaluation of AFSs

For our task—to evaluate the production and economic aspects of a newly proposed design of an AFS with coppiced fast-growing trees—we used data from existing experimental and commercial tree plantations—fruit trees and short-rotation coppice plantations, which represent two types of AFSs. Their parametes are described in the following chapter.

The analysis used data on soil and climatic conditions in the Czech Republic, as well as data on the cost of growing conventional food crops and tree crops. Yields of both types of crops in different AFS types were derived using crop yield modelling according to soil and climate parameters (see Sections 2.1 and 2.2) based on long-term crop yield observations, including data from experimental and pilot SRC plantations.

3.1. General Input Data

The cost of production as well as yields of individual annual crops are based on economic analyses by the Institute of Agricultural Economics and Information [42], which are specified for agricultural production areas of the Czech Republic. The prices of annual agricultural crops were taken from the market reports [49] produced by the State Agricultural Intervention Fund (SZIF in Czech). To prepare the case studies, commodity prices determined as averages for the years 2016–2020 were used. Yields were entered into the models according to the production conditions of the individual land plots.

The economic evaluation did not include the possible economic effects resulting from the beneficial effect of AFSs on annual crops, e.g., cooling the crop in hot summers, better absorption of rainfall, soil erosion protection, etc. [50]—see Formulas (3) and (5). These beneficial effects can then lead to an increase in or less variation in the specific production of annual crops in AFSs compared to conventional farming and can substantially increase the attractiveness of combining annual crops with trees. Another, albeit indirect, economic effect resulting from the combination of annual crops and SRCs is the significant diversification of production and the reduced dependence on both market fluctuations and weather conditions.

Yields of woodchips (as a by-product of coppiced tree belt AFSs) were also derived from the valuated soil ecological unit (BPEJ) from the hardiness growth zones of fast-growing trees for the Czech Republic [51].

To model the economic efficiency of both types of AFS with coppiced tree belts, five scenarios of typical yields of SRCs and main conventional crops were considered—see Table 2.

Table 2. Typical expected average yields of biomass from coppiced tree belts and grain from annual crops in AFSs for SRC production regions of the Czech Republic.

	Expected Average Yields of SRC Strips in t_{DM}/ha/year				
Crops/SRC	6.78	9.04	11.3	13.56	15.82
	Expected Average Yield of Annual Crops in t/ha/year				
Barley	5.73	5.78	5.71	5.64	6.09
Wheat	6.02	6.13	6.05	6.04	6.65
Rapeseed—grain	3.35	3.38	3.3	3.21	3.47
Maize for silage	37.74	37.29	37.58	36.92	41.25

The modelling system uses market prices for agronomic services/operations, with costs and product prices indexed to average expected long-term inflation. The two case studies are based on the cost and price level of 2020. An inflation rate of 2% was used, based on the Czech National Bank's [52] long-term inflation target. A nominal discount of 10% was used to discount future cash flows generated by AFSs. The determination of the discount rate for biomass produced for energy purposes, e.g., from plantations of perennial energy crops or from AFSs, considers both the inherent risks associated with the establishment of the plantation and the market risks. To derive the discount rate for AFSs for the Czech Republic, the discount rate used under the support scheme for electricity and heat from renewable energy sources (6.3% until 2022) was used as a lower limit [53]. The upper value of the discount rate was set with reference to the values of the agricultural sector's profitability for 2018 and 2019 (9.94% and 9.29%, respectively) [54].

The costs of growing tree species in AFSs were derived from plantation economic models (SRCs) from a cost analysis of fruit tree plantations (cherry, walnut) in a given spatial configuration. Costs were monitored for the three basic phases of an AFS—establishment, cultivation, and liquidation of trees.

In both case studies, a EUR 240/ha subsidy for agricultural land was considered. In the case study of the AFS with fruit trees, an establishment subsidy of EUR 4350/ha of AFS land and a maintenance subsidy during the first five years of the AFS (EUR 750/ha AFS) were also considered.

Economic models were calculated in CZK and for this article converted into EUR at the exchange rate of CZK 23.55 (the exchange rate of Central Bank of the Czech Republic valid for 30 March 2023).

3.2. A Case Study of AFS with Coppiced Tree Belts (AFS-CTB)

A newly proposed variant of an AFS in Czech agricultural practice in which a plot of land with an annual crop is divided by narrow strips (belts) with multiple rows of trees harvested/coppiced in very short rotations (usually 3–6 years) is presented. The study assumes the use of suitable varieties of fast-growing trees, e.g., Max-4, AF-28, and 'Monviso' poplars, and 'Tora', 'Rokyta', and 'Stvola' willows. However, if other broadleaved species that can be grown in coppice (hazel, alder, oak, lime, maple, etc.) are used, the model input data on the expected yields (yield curves) must be adjusted.

Results from our experimental plantations show that trees in narrow coppiced tree belts have increased biomass production per area compared to SRC plantations because of the positive marginal effect (increased tree growth on the edges due to better access to sun, water, etc.) [55]. Therefore, we recommend setting a correction coefficient to be used when calculating yields in the economic analysis (Formula (3)) at a conservative level of 1.13.

It is assumed that a large field of the annual crop is divided by 5.5 m-wide tree strips, according to the basic scheme shown in Figure 2 and pictures in Figure 3.

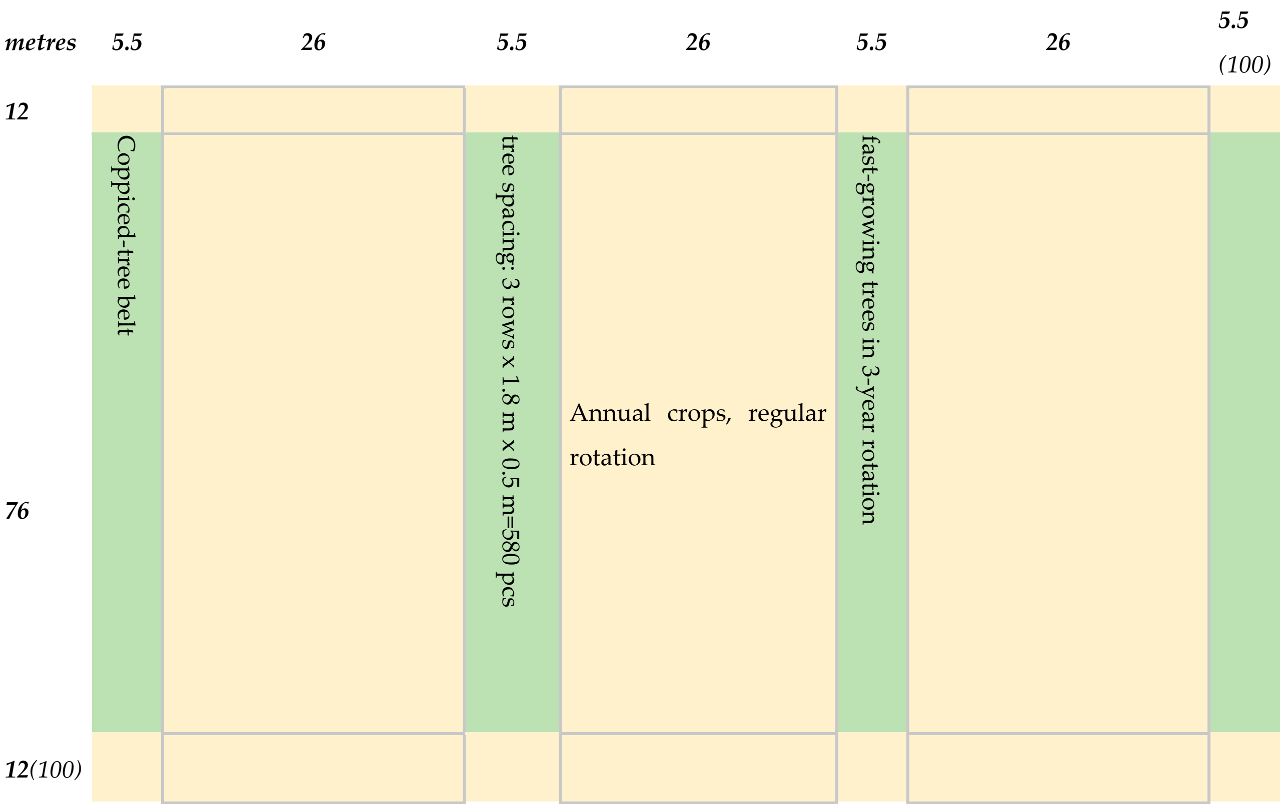

Figure 2. Scheme of 1 ha coppiced tree belt AFS (SRC strips in annual agriculture).

Figure 3. Pictures of two AFS types: AFS with coppiced tree belts (in winter after planting, December 2020) and alley cropping AFS with fruit trees (in summer 2022 with wheat) (both at Michovky experimental site, Central Bohemian Region).

The basic scheme represents the division of 1 ha of farmland (100 m × 100 m) into:

- Four tree strip (coppiced tree belt with fast-growing trees): (76 m × 5.5 m) × 4 =1672 m^2 (16.7%);
- Three crop strips (area of annual crops) and manipulation areas: (26 m × 76 m) × 3 + (100 m × 12 m) × 2 = 8328 m^2 (83.3%).

On larger fields, this pattern is expected to be repeated so that the strips of trees and annual crops are well connected to each other for easy movement of the machinery used. The total area of the coppiced tree belt strips is thus determined by a coefficient of 0.167 and the total area of the AFS.

In the case study, a 25 ha agroforestry system with 4.2 ha of coppiced trees belts is considered to optimize the deployment of technology for the establishment and harvesting of trees. For instance, a modern harvesting machine can harvest about 7–10 ha of coppiced trees in one day. The existing economic model of a 10 ha SRC is used to determine the cost items related to coppiced trees belts [56]. Certain items are reduced proportionally for a tree area of 4.2 ha.

Conversely, some items are left at the level used for the SRC plantation (10 ha). These items are:

- Project preparation—although the 25 ha AFS has only 4.2 ha of coppiced trees, the project preparation will be as demanding as in the case of a 10 ha project of a conventional SRC plantation.
- The harvesting costs are assumed to be the same as for a standard 10 ha SRC plantation. Although a smaller area is harvested, the harvesting is more demanding due to transfers between tree belts. Only the diesel fuel consumption is adequately reduced.
- The overhead is assumed to be the same as in the case of a standard SRC plantation of 10 ha—thanks to, e.g., a higher level of control [57].
- The land rents are assumed to be the average value of the range of rents.
- The value of the subsidy per area is considered at the 2020 level (EUR 420/ha of the whole AFS area).

The number of cuttings used to plant each AFS tree belt is 580, equaling a theoretical density of 13,875 cuttings per hectare of tree belt. The price of one cutting is considered at EUR 0.12/pc + EUR 0.04/pc for mechanized planting.

Yields and yield curves of fast-growing trees for different hardiness growing zones (BPEJ groups) used in the case study are those used for modelling biomass potential in the Czech Republic [44,51] and are presented in Table 2. The expected yields of the annual crops used in the model rotation (wheat, barley, rapeseed, and maize) are then calculated for the same BPEJ groups (yield scenarios) as trees according to the annual crop hardiness growing zones.

In addition to the above input values, another input used in the model was the life of the coppiced tree strip of 22 years.

3.3. A Case Study of AFS with Fruit Trees

A model of a silvoarable alley cropping system (1 ha in total) consists of 2.5 m-wide tree strips with fruit trees (walnuts and cherries) in combination with annual crops in strips 28 m wide. Similar to the AFS-CTB, the most typical annual crops in the Czech Republic are considered (barley, wheat, rapeseed, and maize). An example of the geometric layout of the AFS is shown in Figure 4. The area of annual crops is 0.79 ha, and 0.12 ha is an access road and handling area. The area of fruit trees is 4 tree strips $\times$ 220 m^2 = 0.09 ha.

The species of fruit trees are 50% walnut and 50% cherry, i.e., 50 walnut trees and 50 cherry trees. An average tree line spacing is approximately 3.5 m. The design of the AFS is based on input from the Research and Breeding Institute of Pomology in Holovousy and corresponds to the upcoming agroforestry measure in the Czech CAP Strategic Plan for the period 2023–2027 [58].

Other environmental effects of the AFS are not taken into account in the economic modelling, similar to the previous AFS (with coppiced tree belts).

In contrast to the CTB system, there is no (economic) requirement for a minimum plot or swath size for the use of harvesting machinery to be efficient. In the model of this AFS, the same annual crops are assumed to be used as in the case of the CTB system, and similarly, the cultivation costs and yields of these crops are assumed to be the same in relation to the agricultural production area.

As with the AFS-CTB, land rent and subsidy amounts are considered. The individual identified processes of an AFS with fruit trees that are directly related to stand establishment are presented below. The physical extents of the processes are derived from recommended growing practices, and the valuations are based on the 2019–2020 price level.

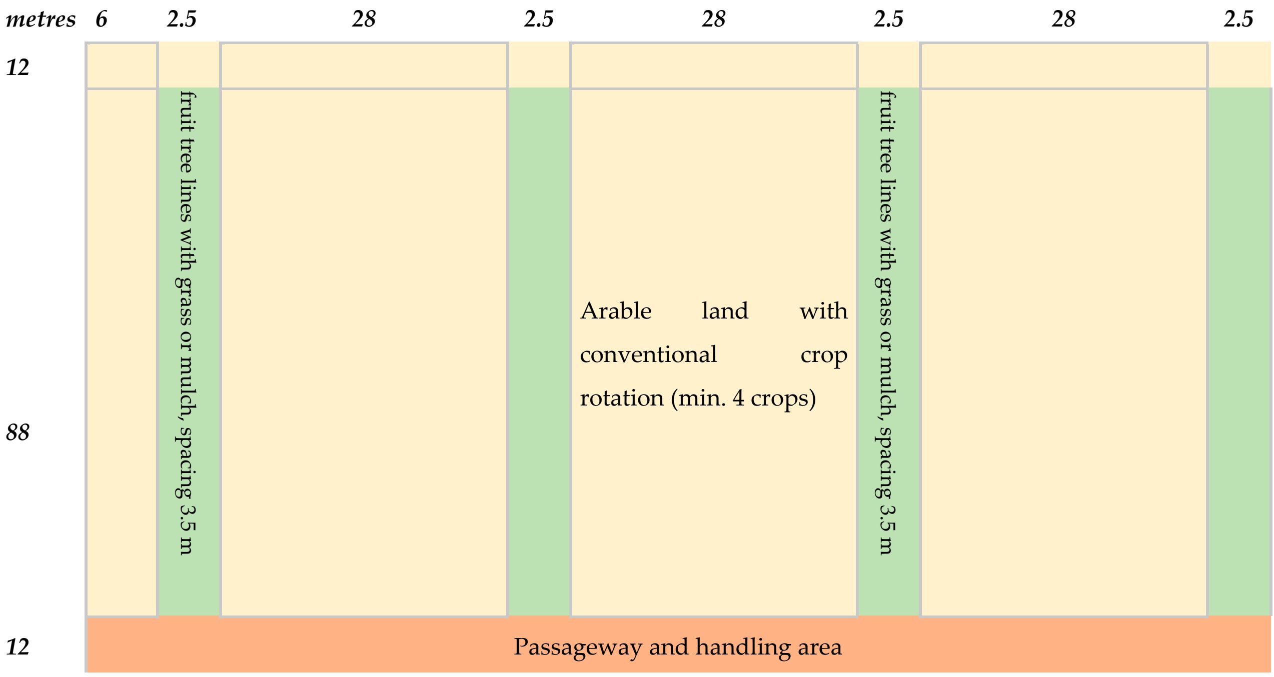

Figure 4. Scheme of the division of a 1 ha AFS stand with fruit trees into conventional farming, fruit tree lines (25 trees per line, 100 trees per ha), passageway, and handling area.

A recapitulation of the costs associated with the fruit tree plantation (0.09 ha of trees, 100 trees, 50% cherry, 50% walnut) over the entire AFS life cycle of 30 years is:

One-off costs:

- Planting material (100 pcs/ha): EUR 1700/ha AFS;
- Cost of preparing the land for planting fruit trees: EUR 276/ha AFS;
- Cost of planting fruit trees (100 pcs/ha): EUR 4550/ha AFS.

Costs in years 1–3 after planting:

- Irrigation: EUR 765/ha AFS.

Costs in years 1–4 after planting:

- Formative pruning: EUR 425/ha AFS.

Costs in years 5–30 after planting:

- Maintenance pruning: EUR 850/ha AFS.

Ongoing costs over the lifetime of the AFS:

- Weed-free strip maintenance costs: EUR 70/ha AFS per year;
- Fertilizer costs: EUR 161/ha AFS per year;
- Disease and pest control: EUR 43/ha AFS per year;
- Stem treatment: EUR 47/ha AFS per year.

The cost of the disposal and removal of trees is EUR 15,685. The total proceeds from the sale of wood and woodchips from the disposal of trees are EUR 11,340.

Yields of fruit trees are considered at an average level according to the age of the fruit trees (the source of the data is statistics from the Research and Breeding Institute of Pomology in Holovousy):

- Fruit cherry (50 trees assumed in AFS):
  - Years 3–7: 100 kg;
  - Years 8–15: 750 kg;
  - Years 16–30: 2000 kg.
- Walnut (50 trees assumed in AFS):

- ○ Years 8–15: 100 kg;
- ○ Years 16–30: 350 kg.
- ○ The same crop yield scenarios as for the AFS with coppiced tree belts were used to model the "dropped" production from conventional crops due to land taken for fruit trees and service corridors.

The price of fruit is considered at the 2020 price level. For cherries, this corresponds to around EUR 2.68/kg (assuming that 70% of the cherries produced is of table quality for direct consumption and 30% is for processing), while for nuts a selling price of EUR 3/kg is considered [59].

4. Results

4.1. An Economic Case Study of AFS with Coppiced Tree Belts (AFS-CTB)

The economic efficiency of the AFS-CTB was evaluated using Formulas (4) and (5) which calculate NPV_{conv}. and $NPV_{i,AFS}$, respectively. The analysis showed that the level of woodchip yield has a major impact on its economic efficiency. As shown in Figure 5, at low chip yields (6.9 t (DM)/ha/year), the cumulative discounted net cash flow over the lifetime of the AFS-CTB does not reach the cumulative discounted cash flow from annual crops grown in the same area (for a selling chip price of EUR 50.96/t (FM). This result indicates that from a purely economic point of view, the AFS-CTB is not profitable for farmers for this biomass yield. An AFS with coppiced tree belts with a yield of 9 t (DM)/ha/year is slightly more profitable than just growing annual crops. If even higher yields from coppiced tree belts are reached, then the advantage of this type of AFS substantially increases. In addition to the biomass yield itself, the price at which the produced woodchips can be sold on the market plays a significant role. An increase in the price of woodchips has the same impact on economic efficiency as an equally large relative increase in biomass yields.

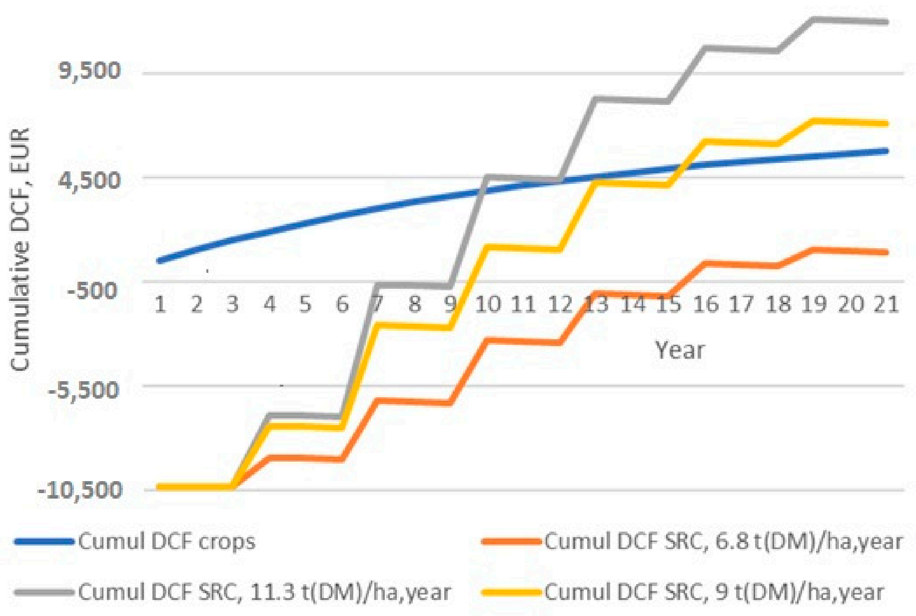

Figure 5. Cumulative discounted cash flows (DCFs) for the three variants of SRC (CTB) biomass yield and for annual crops produced in the same area as the SRC; crop yields for grain, maize, and sugar beet regions and biomass price of EUR 50.96/t (FM).

The efficiency of the AFS-CTB can also be assessed indirectly using the so-called minimum price of the woodchip produced (see Formula (3)). The results of the calculation of the minimum chip price for each yield curve and the three discount rate values are shown in Table 3.

Table 3. Results of the calculation of the minimum price of woodchips produced within the AFS.

	Expected Yields of the SRC Strip in t (DM)/ha/year				
Discount rate	6.78	9.04	11.3	13.56	15.82
	Minimum Price of Woodchips in EUR/t FM				
10%	66.24	50.62	40.98	34.06	16.86
13.2%	76.43	57.54	46.54	38.47	19.66
16.3%	88.70	65.73	53.12	43.74	23.10

Table 3 shows the significant effect of SRC yields on the minimum price of woodchips. In favorable sites, higher yields of woodchips substantially reduce the price needed to reach the economic break-even point for this type of AFS. The required minimum price of woodchips is influenced by the price level of annual crops. This can be demonstrated in the results of the calculation if the commodity prices are not taken as the average for the years 2016–2020 but rather the situation in December 2021, when commodity prices were 1.23 to 1.5 times higher—see Table 4.

Table 4. Increase in commodity prices in December 2021 compared to average prices (in EUR) in 2016–2020 [49].

Crop	Increase %
Wheat	62.00
Barley	53.08
Rapeseed	63.69
Maize for silage	52.23

Assuming an average increase in the cost of growing crops between 2020 and 2021 of about 7%, then there is an increase in minimum prices for woodchips of about 50–66%—see Table 5.

Table 5. Comparison of the minimum price of woodchips from the AFS-CTB for two commodity price scenarios.

	Expected Yields of the SRC Strip in t (DM)/ha/year				
Price scenario	**6.78**	**9.04**	**11.3**	**13.56**	**15.82**
	Minimum Price of Woodchips in EUR/t FM				
Average 2016–2020	66.24	50.62	40.98	34.06	16.86
December 2021	109.98	82.76	66.37	54.52	26.03
% increase	66%	63%	62%	60%	54%

It is also interesting to compare the minimum price from a standard SRC plantation implemented independently in the same location as the AFS-CTB. There is a drop in the marginal effect (see Section 3.2) and at the same time a lower density of cuttings per hectare (8000 pcs/ha and thus lower cost of plantation establishment). Otherwise, the costs of the other activities are the same as for the SRC implemented under the AFS, except for a slight drop in harvesting costs. Combining individual parameters finally leads to a minor reduction in the minimum price of about 5–6% (effect of the marginal effect in AFS is not able to compensate for the lower cost of the SRC plantation).

4.2. An Economic Case Study of AFS with Fruit Trees

In terms of the economic efficiency of this type of AFS, the following factors play the most crucial role:

- CF distribution—similar to the AFS-CTB, but the CF profile is disadvantageous in terms of overall NPV. There are large upfront costs for land preparation, planting materials, and actual planting of fruit trees. Of the total cost (escalated by an inflation of 2% and discounted by the value of the specified discount of 10%), the total one-off cost of establishing the stand is then about 24%. In contrast, income accrues with a long lag, peaking only in the 15th year after the fruit trees are planted.

- Discount value—given the distribution of CF (high expenditure at the beginning of the period under assessment, full revenue availability only from around year 15), the amount of the discount plays a crucial role. The higher the value of the discount, the lower the contribution of future cash flows to the NPV of the option under evaluation. Given the expected expenditure and the establishment and operation of the fruit tree AFS, and, at the same time, given the expected sales, even very low discount values (4%) do not lead to a positive cumulative discounted cash flow value before 15–20 years after the establishment of the AFS (without a subsidy for the establishment of the AFS). The subsidy for the establishment of the AFS significantly improves the economics of the AFS project, but even so, a positive cumulative discounted cash flow is only achieved between 12 and 15 years after the establishment of this type of AFS.
- The amount of revenue for annual crops—due to the chosen design of the AFS, approximately 9% (fruit tree strips) and 12% (handling area) are taken away from food crops. The fruit trees must therefore not only cover the costs of setting up and maintaining the fruit tree plantation with their production but also the positive economic effect of annual crop production over the lifetime of the fruit tree plantation. The higher the fallout from the production of annual crops, the higher the price of fruit tree production must be.

The economic efficiency of the model AFS with fruit trees was analyzed using Formula (3), where the price of production (i.e., price of fruits) was not the output value but was the input value.

Figures 6 and 7 show the large impact of the initial capital investment on the establishment of the AFS and its maintenance in the first five years after establishment. There is a significant improvement in the path of cumulative discounted flows. The lower the value of the nominal discount (r), the greater this effect.

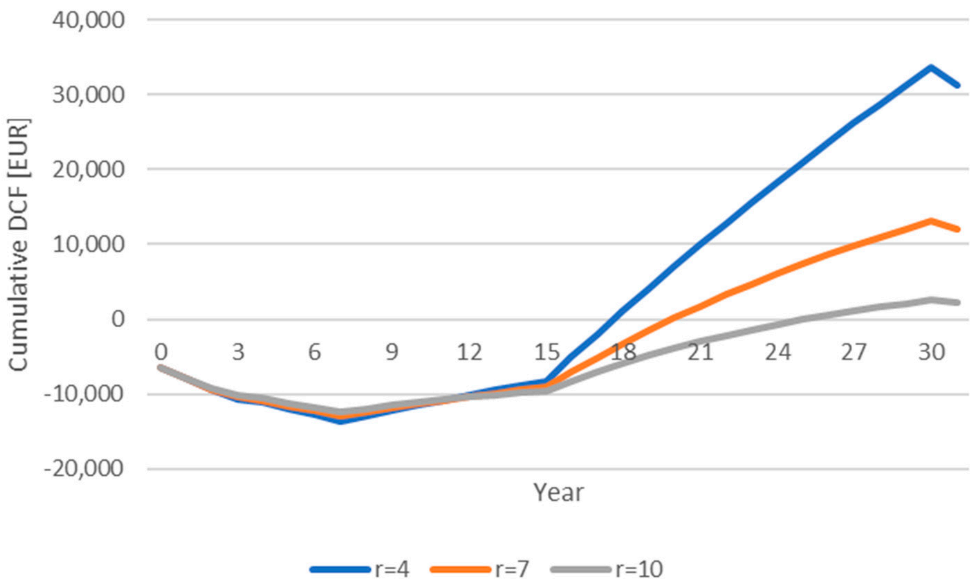

Figure 6. Cumulative discounted cash flows (excluding the effect of taxes) of the AFS model with fruit trees at constant prices from 2020, excluding subsidies for establishment and maintenance for the first five years after establishment.

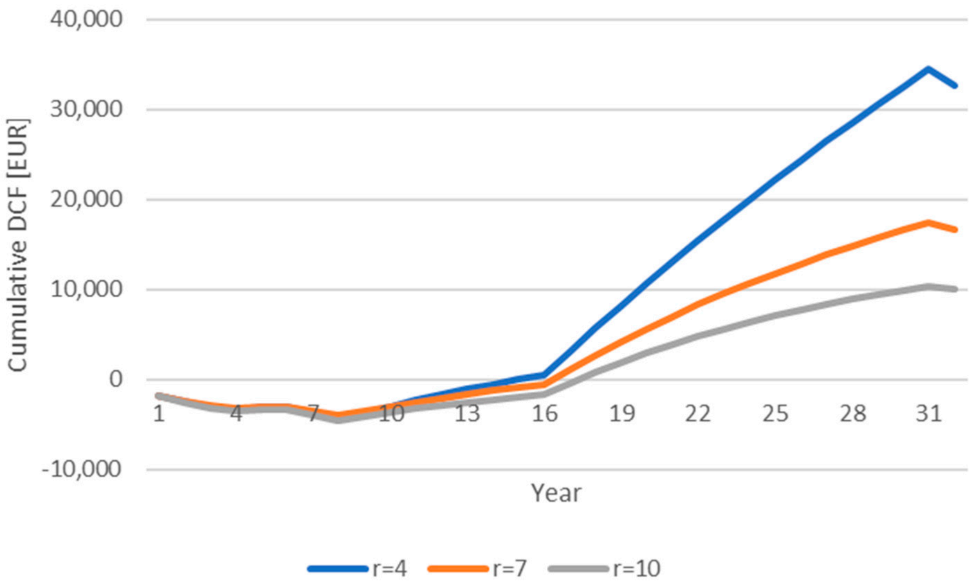

Figure 7. Cumulative discounted cash flows (excluding the effect of taxes) of the AFS model with fruit trees at constant prices from 2020—including subsidies for establishment and maintenance for the first five years after establishment.

If the fruit trees were to be economically efficient on their own (i.e., without covering the dropped economic effects from annual crop production) and without subsidies for AFS establishment and maintenance in the first five years, this would require a significant increase in the price of the fruit produced. At a discount of 10%, the initial price of the fruit would need to be increased by about 52%. At a discount of 7%, the required increase would be 25%, and at a discount of 4% the required increase would be only 8%.

5. Discussion

Similar to our results of field monitoring of yields of poplars and willows in SRCs, Lasch et al. conclude that it will be possible to allocate plantations of fast-growing trees to agricultural land, especially where fertility is low, for cash crop food production [60]. They also expect that higher yields will be achieved even under the effects of climate change because trees with deeper root systems will be able to respond better to the uneven supply of precipitation throughout the year compared to annual crops and grasses. According to Orság [61], reduced water availability from precipitation does not proportionally reduce biomass yield because some varieties/clones of fast-growing trees are sufficiently resistant to water-limited conditions.

The economic efficiency of AFSs with coppiced tree belts is significantly influenced by local production conditions, which are then reflected in the yields of annual crops (in relation to the costs of their cultivation, including land rent) and in the amount of harvested biomass of woodchips. The conditions then translate significantly into the production price of the woodchips, at which point the farmer needs to sell the woodchips to compensate for the shortfall in annual crop production. Rising commodity (annual crop) prices lead to the need to increase the production price of woodchips. Using commodity prices from December 2021 (compared with the average commodity prices for 2016–2020), the production price of woodchips increases by 54–66% depending on the level of modelled SRC yields. The economic efficiency of an AFS compared to an annual crop system is negatively affected by the cash flow profile, where there are significantly large expenditures at the beginning of AFS implementation (planting of CTBs), but income is only received from the third year after establishment (first cropping season), with the cash flow optimum only being reached between 8 and 12 years after AFS establishment. Income from the sale of the woodchips, therefore, has a lower weight in the NPV due to discounting than the one-off income associated with the establishment of the SRC. Compared to an AFS with fruit or forest timber trees, an AFS with CTBs has the advantage that the by-product income (woodchips) comes significantly earlier than the full income from fruit or timber production.

AFSs with fruit trees are characterized by high expenditure on land preparation and planting of fruit trees early in the life of the AFS. Maximum fruit production is not reached until about the 15th year after planting, which significantly reduces the contribution from fruit sale revenue in the total NPV. The implementation of this type of AFS leads to a loss of part of the economic effect from annual crops, and this loss has to be compensated by the revenue from fruit sales to achieve the same economic effect for the farmers. Annual crops, unlike fruit trees, have a completely different cash flow generation profile, which is significantly more advantageous in terms of purely economic decision-making for the farmer. The case study of this type of AFS shows that from a purely economic point of view, at current commodity prices and the costs of growing annual crops and fruit trees, this type of AFS is not profitable without a significant subsidy for establishment and maintenance in the early years after establishment. Without these subsidies, at a 10% discount, fruit prices (at 2020 price levels) would need to be increased by up to about 55%. Although a reduction in the discount leads to lower values for the required increase in fruit prices, such low discount values do not correspond to the (current) profitability of annual crops. A further risk associated with this type of AFS is ensuring the sale of the produce and, at the same time, the share of manual labor in harvesting the fruit. It creates risks both with the realization (sale) of production and with the increase in costs associated with fruit trees.

Other factors that increase the business risk of AFS compared to conventional farming are, on the one hand, the higher business risk associated with the risk of damage to or destruction of trees in the first years after the establishment of the AFS due to bad weather and, on the other hand, the uncertainty in the price of AFS production in the future. In general, the more distant the time horizon, the more uncertain the production figures and, in particular, the market prices. The higher business risk of an AFS compared to conventional farming should then be compensated by the higher value of the discount used in the calculation of the economic efficiency of the AFS. Consequently, this then leads to an increase in the required minimum price for tree-related production (woodchips, fruit, etc.) or a reduction in the economic efficiency of the AFS compared to conventional farming.

Case studies were used to model the economics of AFSs and to discuss the economic efficiency of AFSs using data from the Czech Republic (as representative of Central and Eastern European countries with similar soil and climatic conditions). As most of the input data for the case studies are based on market prices (which are similar in these countries—e.g., commodity prices, prices of main agricultural inputs such as machinery, fertilizer, fuel, seeds, etc.) the conclusions of the study can be largely transferred to other countries in the region. The conclusion of higher risks associated with perennial crops compared to conventional agricultural production is supported by other studies [46,47].

Some multifunctional agroforestry systems like windbreaks offer the possibility to prolong the production period (and required function) for quite a long period of time by continuing to harvest and replant trees, thus improving the economic efficiency of the AFS by postponing or even avoiding the expensive step of liquidating the tree stumps [62].

On the other hand, the implementation of an AFS diversifies farmers' activities and generates significant cash flows after about 15 years of tree planting. The cost-effectiveness of this type of AFS can be significantly supported by targeted subsidies for the establishment and the care of trees in the first three years after planting. This is documented in the evaluation results for a 30-year lifetime and a discount of 10%. If the actual costs of planting this AFS are fully covered (approx. EUR 6150/ha, AFS), then a slight increase in prices of approx. 11% is sufficient to achieve the overall advantage of this type of AFS compared to a similarly sized plot with only annual crops. The current subsidy for establishing and maintaining an agroforestry system is EUR 4353/ha and EUR 754/ha/year (for 5 years), respectively, in the Czech Republic. It seems to be set well to support the establishment of AFSs with fruit trees. Subsidy parameters include a mandatory total of 100 planted trees per hectare, of which no tree should have a share higher than 50% and a minimum of half of them must be forest trees. Therefore, the subsidy is not available for the proposed AFS with coppiced tree belts, mainly due to the mandatory number of planted trees.

6. Conclusions

From our analyses and economic modeling of two agroforestry systems, it is possible to conclude that:

- An agroforestry system with coppiced fast-growing trees (coppiced tree belts) can have similar economic and production results as annual crops if grown on very suitable sites and with appropriate quality of agronomy. For less productive/suitable sites, a subsidy to establish an AFS would need to be implemented to improve the economic efficiency of the AFS.
- The agroforestry system with fruit trees would not be profitable without a significant subsidy for establishment and maintenance. Without these subsidies, fruit prices (at 2020 price levels) would need to be increased by up to about 55%.
- A newly introduced subsidy for establishing and maintaining an AFS, which is EUR 4353/ha and EUR 754/ha/year (5 years), respectively, in the Czech Republic since 2023, seems to be well set to support AFS establishment with fruit (and forest) trees, whereas for an AFS with coppiced tree belts the level of the subsidy, if introduced, should be set proportionally for different production in hardiness growing zones.
- The multiple environmental effects and functions of fast-growing trees in modern agricultural systems and landscapes justify subsidies for the AFS-CTB model.
- Incorporating AFSs with coppiced tree belts into modern and CAP-supported types of agroforestry would bring economic and environmental benefits for farmers, bioenergy, and landscape more quickly than with standard agroforestry systems; however, to develop them, it would be necessary to remove legislative barriers and appropriately diversify the subsidy parameters.
- The results achieved in our analysis are applicable and transferable to neighboring countries with similar growing conditions, such as Slovakia and Poland. The analysis of legislative barriers and possible ways to support the cultivation of the AFS-CTB are also applicable in other Western European countries.
- Concerning the latest economic and political developments in Europe, the product from the AFS-CTB (energy woodchips) can be evaluated as strategic for the energy security of the EU, which can increase producers' independence from purchased (fossil) fuels.

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

Nomenclature

Abbreviations	
AFS	Agroforestry systems
BPEJ	Valuated soil ecological units of agricultural land in the Czech Republic
CAP	Common Agricultural Policy of the EU
CTB	Coppiced tree belt (agroforestry system)
C_{alt}	Minimum acceptable price of biomass by farmers
CR	Czech Republic
DM	Dry matter
DCF	Discounted cash flow
GIS	Geographic information system
EU	European Union
FM	Fresh matter
ha	Hectare
NPV	Net present value
SRC	Short-rotation coppice
Indices	
t	Year of perennial plantation lifetime
q	q-th conventional crop in the crop rotation
lf	Lifetime of planting of perennial crops
Units	
EUR	Euro
GJ	Gigajoule
PJ	Petajoule
t	Ton

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