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Research article

Sustainability analysis of apple orchards: Integrating environmental and economic perspectives

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ABSTRACT

The agricultural sector faces numerous challenges today, including the protection of biodiversity and the mitigation of environmental impact. Addressing these challenges require ensuring the stability of farmers' income, thus facilitating effective land management.

The present study aims to evaluate the environmental and economic sustainability of apple orchards under two distinct systems (integrated versus organic) and a scab-resistant variety. The Life Cycle Assessment method (LCA) was employed to evaluate environmental impact, while financial and economic aspects were analysed using metrics such as Net Present Value (NPV), Equivalent Annual Value (EAV), Benefit-Cost Ratio (B/C) and Discounted Payback Period (DPP).

Results analysis reveals that both inorganic fertilisation and pesticides usage have the greatest impacts in both integrated cultivation and scab-resistant orchards. In organic orchards, diesel usage emerges as a primary factor due to the substitution of chemical interventions with mechanical methods. For the same reason, labour constitutes 45 % of the organic production costs. Despite the lower environmental impact, organic treatments still contribute 22 % of the total production cost. Regarding the investment evaluation, the scab-resistant variety offers marginally lower costs than conventional varieties due to the reduction of required treatments; however, organic farming shows superior economic performance despite higher production costs, mainly attributed to higher market prices. This highlights the influence of market dynamics on business decisions in the apple sector, where farmers often have no direct control.

1. Introduction

Today's agricultural sector, and fruit production, are characterized by continuous challenges, encompassing environmental and socio-economic concerns such as biodiversity loss, greenhouse gas emissions, water pollution, low income for farmers, and rural abandonment [1]. In this context, the European Union and its member states are moving towards environmental, social, and economic sustainability. In fact, European agricultural policy increasingly encourages farmers to adopt sustainable practices, mitigating environmental impacts, and investing in rural development while also providing appropriate measures [2] to support their efforts. The ''Farm to fork'' strategy, published by the European Commission at the end of May 2020 [3] and set in the broader context of the *European Green Deal*, aims precisely to foster healthy, sustainable and cost-effective food production, while addressing issues such as

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climate change, environmental protection, biodiversity conservation, and farmers' income [4]. These key points were also highlighted by Mouron et al. [5] who stated that economic sustainability and reduced environmental impacts are core topics for modern fruit farming. Fruit growing is a sector that historically has a high input rate of plant protection products [6] and is therefore forced to change the current production system. As indicated by Antal et al. [7] the costs for the protection of fruit crops represent 18–35 % of the total cost of apple production.

In this regard, the agro-ecological approach can contribute to achieving more sustainable fruit production [8] with a focus on ecology, sociology, and economics [9], which are central to the European Union's future development strategies. Agroecological thinking has garnered widespread acclaim in recent years, emerging as a cornerstone of sustainable agricultural practices [10]. Rooted in ten fundamental principles [11] - including diversity, co-creation and knowledge sharing, synergies, efficiency, recycling, resilience, human and social values, food culture and traditions, responsible governance, and circular and solidarity economy - this approach adopts a holistic perspective [12] towards enhancing production efficiency and promoting economic, environmental, and social sustainability. Currently, various farming methods have been established to minimise the use of inorganic fertilisers, pesticides, and fungicides, thereby mitigating the environmental impact of the production process and reducing production costs, in line with the principles of organic farming [9]. Agro-ecological concepts fit well with fruit farms, representing a factor in their development and growth [13]. This need to find a production system with a lower environmental impact also derives from the evolution of demand from regular fruit consumers [14].

The production and consumption of organic products in Italy have undergone remarkable growth over the past decade, with sales soaring by +132 % between 2012 and 2022 [15]. Specifically, the market of organic apples is growing, with relatively sustained consumption in the last years [16] although the consumption of organic apples is only 3–4 % of total apple consumption [17]. This rapid expansion has encouraged a significant number of farmers to adopt organic farming practices, resulting in a remarkable increase in the proportion of Italian farms certified as organic, now standing at 7 % [18]. However, this transition to organic farming has often been haphazard, involving the mere substitution of traditional inputs with alternatives boasting lower energy impact, without entailing a comprehensive redesign of the production system [9].

In contrast, agroecology, a multidisciplinary field that integrates scientific and ecological principles into agricultural systems [19], seeks to blend traditional practices with innovative insights. This approach involves utilising resistant crop varieties -as the scab-resistant variety with the greatest resistance to a specific fungal disease, apple scab caused by the *Venturia inaequalis*, which causes deformations and the onset of black spots which cause damage to the peel and pulp, causing a significant production loss and depreciation of the product [7], adopting micro-dosing of fertilisers, and implementing integrated pest and weed management strategies, which are crucial factors for the orchard profitability [20,21], especially in a period characterized by significant climate changes and the development of new diseases which have important repercussions on the orchard [22]. Moreover, unlike organic farming, agroecology places a strong emphasis on economic considerations among its core principles, facilitating the production of high-quality products - a key aspect highly valued by consumers [23–27], by reducing reliance on external inputs and associated costs [28].

In Italy, however, there is no definition of agroecological practices. Nonetheless, there is a strong link between traditional agricultural knowledge and new production techniques, nowadays explicitly made manifest, particularly in organic farming [29]. Moreover, according to Van der Ploeg [30], an agroecological production system can potentially allow for a considerable increase in income.

Agroecology presents a versatile approach applicable to both annual herbaceous production and, notably, to poly-annual tree crops, such as orchards. Its potential impact on the Italian landscape, particularly in the Northwest – embodied by the Piedmont region - which is the subject of this study - is profound, given that agriculture occupies 36 % of the regional territory [31]. Whitin this agricultural area, 2.0 % is dedicated to orchards [32,33], of which 40 % of the surface are apple orchards [34], highlighting the significant relevance of agroecological prospectives within the region's agricultural framework.

Italian apple production surpassed 2.28 million tons annually in 2023, marking a 3 % increase compared to the previous year [35], covering an area of 54,081 ha under cultivation. This production contributes to the European context, which yields approximately 11 million tons [36].

Apples are extensively cultivated throughout Italy, with the cultivation traditionally concentrated in the mountainous and foothill regions of northern Italy, particularly in Piedmont, Veneto, and Trentino/Alto Adige-Süd Tirol. Specifically, the research focuses on apple production in Piedmont, which, after Trentino Alto Adige, is the second most suitable region, with production exceeding 0.15 million tons in 2023 [37].

Organic certified apple production in Italy amounted to 167,681 tons in 2023, marking a 13 % decrease compared to 2022, in stark contrast to the general trend of organic certifications mentioned earlier.

Overall, the apple market currently exhibits cautious optimism, driven both by the overall good quality of the product and the general reduction in orange and pear production in the European Union due to health and climatic factors [36].

In the current production context, consumer demands have evolved beyond mere ''quality-price'' evaluation. They now prioritise products that not only meet high-quality standards, but also promote health, protect workers, communities engaged in production, and the environment [38–41].

Agroecology, therefore, emerges as a pivotal aspect of agriculture in forthcoming years and it is imperative to identify environmentally friendly and economically viable production systems and varieties.

The Life Cycle Assessment (LCA) methodology may be used as tool for evaluating the environmental impact of a given agricultural system by comparing various production methods and the utilisation of resistant varieties, thus discerning the most environmentally sustainable products [42–44]. In addition, financial economic evaluation, including the Net Present Value (NPV) [45], Equivalent

Annual Value (EAV), Benefit-Cost ratio (BC) and Discounted Payback Period (DPP) analysis [46] can be utilised to assess the profitability of investments, integrating environmental sustainability assessment with the necessary economic considerations.

The research is part of a broad discourse related to the search for new production methods that are able to meet the challenges arising from global issues. The agricultural world is going through a period of strong and rapid economic, social, ethical and environmental challenges. Fruit production, given the long lead times between planting, start of production, full production and removal, is particularly affected by these dynamics. In this context, production systems increasingly aim to protect the environment, but sometimes call into question the possibility of guaranteeing a fair income for those working in agriculture. The authors decided to make their contribution by conducting research with the aim of comparing the economic and environmental sustainability of different apple cultivation models and a resistant variety.

1.1. Research questions

Considering that the agriculture of the future will have to ensure the reduction of the environmental impact of cultivation, with implications on both global and local scale, and at the same time protect and improve the income of farmers by introducing the principles of agroecology, this study poses the following research questions:

RQ1. What is the relationship between environmental and economic performance in apple orchards cultivation under traditional versus organic systems and scab-resistant varieties?

RQ2. What is the financial sustainability of investment for the three crop types of apple orchards cultivation: traditional, organic and scab-resistant varieties?

1.2. Objectives

Through environmental and economic assessments, drawn from collected data, informed judgments can be made regarding the real environmental and economic efficiency of the farm.

Nevertheless, it is often the case that comparisons between different management systems within the same orchard are overlooked [47]. Hence, the primary objective of this study is to analyse and evaluate in detail the environmental and economic sustainability of two different cropping systems, along with the implementation of a resistant variety, all within a single farm setting. This approach allows for a comprehensive assessment of farm efficiency and informs decision-making processes.

Moreover, we aim to assess the financial sustainability of the initial investment, examining a 20-year time frame, equivalent to the useful life of the orchard, for the three identified scenarios, also taking into account the significant variability in product selling prices with an approach applicable in other territorial contexts.

2. Methodology

The study took place in Piedmont, located in northwestern Italy. Thanks to optimal climatic and environmental conditions, this region is characterized by a high aptitude for cultivating various fruit species [48], with a particular emphasis on apples [49]. Traditionally, the cultivation methods employed here vary, reflecting the diverse range of apples varieties, from traditional to more modern cultivars.

2.1. Data collection

The dataset, acquired through a structured questionnaire, encompasses to two distinct cultivation methodologies (integrated and organic) alongside the cultivation of a scab-resistant variety employing an integrated approach. This delineated a total of three distinct case studies: integrated (INT), scab-resistant (TR) and organic (ORG). The technical parameters utilised for both environmental and financial analyses summarise the entire lifecycle of the analysed orchards. Economic data are specific to year 2023. The environmental impact assessment is conducted at the maturity stage of the plant.

2.2. Life cycle assessment

The LCA analysis, conducted in accordance with ISO standards 14040 and 14044 [50], utilise a functional unit (FU) as the reference unit [51,52], facilitating a comparative analysis of the INT, ORG and TR cultivation methods. The FU was defined as 1 kg of apples produced, from cradle to gate, thus encompassing all inputs and outputs from the nursery stage through cultivation to harvesting.

Apples represent the sole output of this type of cultivation type, thus all impacts are referenced to the functional unit [53]. Impacts related to the woody biomass obtained during pruning at the end of the plant's life, upon decommissioning, were considered negligible.

Life cycle analysis, following the methodology outlined by Vinyes et al. [54], was performed employing the Recipe midpoint H method, with the Simapro 9.5 software.

In performing the LCA calculation, it was necessary to identify, for each case study, the entirety of inputs required by 1 ha of apple orchard, thereby determining the volume of apples yielded. Data were aggregated to represent the entire lifespan of the orchard (20 years) and are representative of an average year during the maturity stage [55].

The primary components of the life cycle inventory are reported in Table 1.

The components of the inventory are consistent with literature findings [56]. As indicated by Longo et al. [42], organic and integrated farming systems differ notably in weed control strategies: mechanical management is favoured in the former, while herbicides are utilised in the latter.

Within the organic approach, pest control relies on natural compounds and natural limiters. Environmental impacts associated with the use of microorganisms were not taken into account, aligning with the assertions made by Longo et al. [42] and Hanafizadeh et al. [57].

The production process analysed includes all inputs from nursery to field production as delineated in Table 2.

Four impact categories, as shown in Table 3, were used to return the results of the environmental study.

2.3. Economic analysis

The economic aspect of the study encompassed production costs and investment analysis. The production cost analysis accounts for both fixed and variable costs. Fixed costs pertain to depreciation, maintenance, insurance and interest on agricultural and land capital. Variable costs are contingent upon the cultivated area and yields achieved, covering expenses such as pesticides, fertilisers, labour, and fuels [58].

In further detail, the study incorporated the following economic data:

- Material costs, including fuel, lubricant, energy, fertilisers, phytosanitary treatments, irrigation water, and water needed for treatments;
- Labour costs: calculated at an opportunity cost of 15€ per hour for internal labour, to which was added the specific cost of the operating machine used (tractor with coupled machine or forklift). For the external labour was given an average hourly cost of 10€ [59]. The hours for each operation were provided by the farm through the questionnaire;
- For planting expenses (poles, hail net, trees, irrigation system, tillage and bottom fertilisation), the shares of depreciation were considered;
- Maintenance of machinery and equipment, as well as related insurance, have been included in the account as dues;
- Consulting services are included as services;
- Tributes were given a flat-rate value obtained from financial statements of homogeneous farms;
- Interest on land and working capital was calculated as 1.0 % of land endowment and gross saleable production.

In order to assess the profitability of the investment, it is also necessary to consider the gross saleable production (GPV) [58], obtained by the sale of apples and the contribution of public support (Common Agricultural Policy). Once all the different items were defined, the total production cost (€/kg of apples) was calculated for each case study.

Considering this, the *Net Present Value* (NPV) [60] and *Benefit/Cost ratio* (B/C) were then determined.

$$NPV = \sum_{t=n}^{0} \frac{R_t - C_t}{(1+i)^t}$$

where R_t is the income of year t (€/ha), C_t the costs of year t (€/ha), i is the interest rate and n are the reference years of the shift, which is 20 in this case.

The B/C is the ratio of the total of actualized incomes and the amount of actualized costs. It allows comparison of the investments based of their profitability: it is advantageous when the ratio is higher than 1.

As indicated by Blanc et al. [61], starting from the NPV, it was then possible to define the *Equivalent Annual Value* (EAV).

Table 1
Components of the life cycle inventory.

Item	Integrated	Scab resistant	Organic
Trees	X	X	X
Drip irrigation with pumping system	X	X	X
Hail net	X	X	X
Wood poles	X	X	X
Organic fertilisation	X	X	X
Synthetic inorganic fertilisation	X	X	
Chemical weeding	X	X	
Mechanical weeding			X
Synthetic insecticides and fungicides	X	X	
Natural compounds and natural limiters			X
Manual harvesting with forklifts	X	X	X
Fuel and lubricant	X	X	X
Electricity	X	X	X

Table 2
Cultivation process inputs referred to 1 kg of apples produced.

Input	Integrated	Scab resistant	Organic
Water (m^3)	0.0344	0.0344	0.0358
Diesel (MJ)	0.6601	0.6601	0.6865
Poles (m^3)	1.97E-05	1.97E-05	2.05E-05
Plastics (kg)	0.0010	0.0010	0.0010
Fertilisers (kg)	0.0040	0.0040	
Oil (kg)	0.0002	0.0002	0.0002
Manure (kg)	0.1027	0.1027	0.1068
Electricity (MJ)	0.0038	0.0038	0.0039
Pesticides (g)	0.1167	0.1150	0.0856
Trees (unit)	0.0029	0.0029	0.0030

Table 3
Impact categories selected in the LCA calculation.

Category	Acronym	Units of measurement
Climate Change	CC	kg CO2 eq
Freshwater EcoToxicity	FET	kg 1.4-DCB
Human Carcinogenic Toxicity	HTC	kg 1.4-DCB
Water Consumption	WD	m3

$$\text{EAV} = \text{NPV}\,\frac{i\,(1+i)^n}{(1+i)^n - 1}$$

Another way of evaluating the investment is through the employment of the *Discount Payback Period* (DPP). The DPP is the time (years) that allows the revenue to cover the costs incurred to start the investment [62].

The Discount Payback Period is determined as:

$$DPP = \sum_{i=0}^{n} (DR_i - DC_i)$$

where *DR* represents discount incomes and *DC* represents discount costs. In fact, the DPP is calculated as cumulative cash flow, obtained from the net cash flows for the considered year and previous years.

In agreement with Stillitano et al. [58] e Pergola et al. [63], an interest rate of 2.0 % was considered. Given the volatility of product liquidation prices, three possible sales scenarios were sought to be analysed, investigating the change in the hypothetical annual cash flow for each case study. Prices, collected in November 2023, were obtained from the ISMEA website [64].

Three prices were recorded for each case study, as outlined in Table 4.

3. Results

The life cycle impact results and the production cost results for 1 kg of apples are presented in Figs. 1 and 2.

Remembering that CC stands for Climate Change, FET for Freshwater EcoToxicity, HTC for Human Carcinogenic Toxicity, and WD for Water Consumption.

In the LCA analysis, diesel consumption emerges as the most impactful input across all case studies for the CC, FET and HTC categories.

In the INT scenario, it is evident that pesticides constitute the input with the highest impact on FET after fuel. At the same time, however, they rank as the fourth most impactful cost item per unit of product. The INT scenario necessitates the use of synthetic fertilisers, which have a limited impact on total cost, but contribute significantly to the impact on CC, FET and HTC. The WD impact is mainly associated with the source of electricity consumed. The company relies on electricity from the public grid, which predominantly originates from non-renewable sources: this type of supply causes the impact to be high for all case studies.

The integrated cultivation method of TR varieties shows very similar impacts to the integrated cultivation of traditional varieties. The main difference, attributed to the distinct apple varieties used, lies in reduced usage of pesticides used: in TR varieties, the cost

Table 4
Price variability in estimating scenario cash flows.

	INT and TR	ORG
Minimum price (€/kg)	0.38	0.61
Average price (€/kg)	0.47	0.91
Maximum price (€/kg)	0.68	1.09

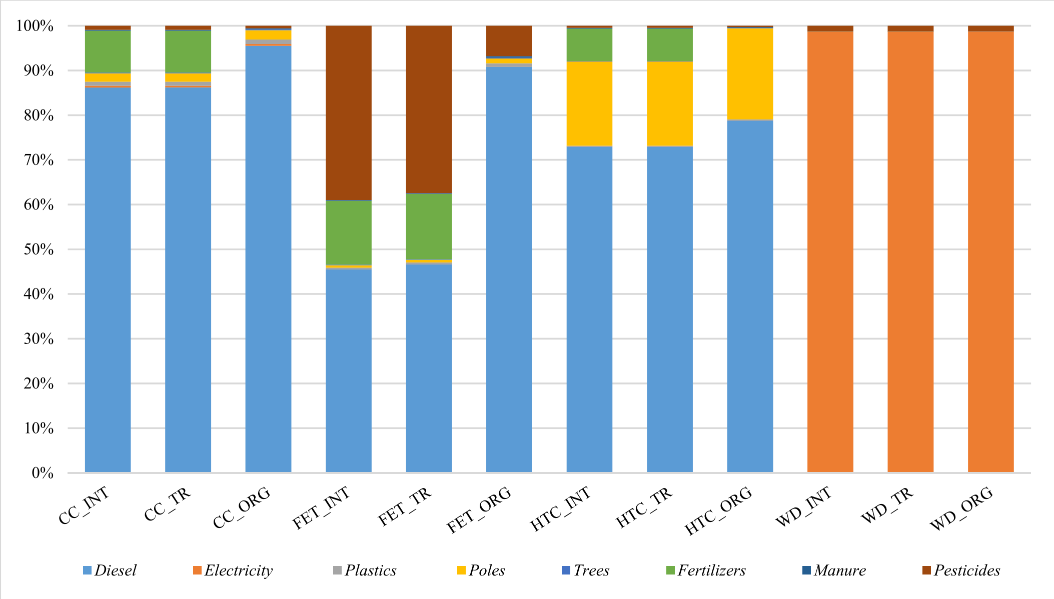

Fig. 1. Environmental impacts of 1 kg of apples for INT, ORG and TR scenarios.

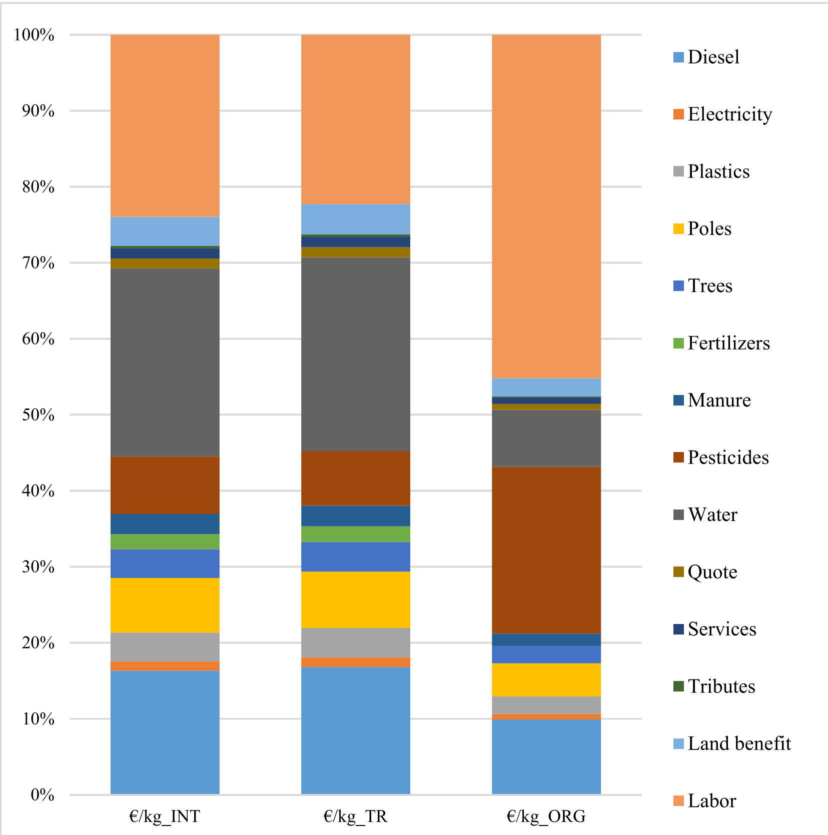

Fig. 2. Percentage composition of the production cost of 1 kg of apples for INT, ORG and TR scenarios.

associated with products used for treatments is lowered by approximately 8.2 %.

Regarding FET, the impact of pesticides decreases from 39.0 % in integrated cultivation to 37.5 % in the cultivation of scab-resistant varieties.

The organic orchard presents different conditions for LCA and costs. In this agricultural approach, the impact of pesticides on FET is significantly reduced compared to integrated farming and TR varieties.

On the other hand, however, the percentage total production cost attributed to pesticide in ORG scenario is 22.0 %, compared to 7.6 % and 7.2 % in the INT and TR scenarios, respectively. Regarding the life cycle of organic orchards, diesel remains the most influential input, exhibiting a higher impact for the CC, FET and HTC impact categories compared to the other two case studies. Specifically, in FET for organic orchards, the fuel-related component accounts for more than 90.0 % of the impact, unlike in integrated and TR scenarios, where pesticides also contribute significantly.

Examining the production costs of the three case studies, it become evident that water has a greater impact on the production cost for the integrated crop and the scab resistant variety compared to the organic orchard. This finding is expected, given that in organic cultivation the number of treatments is lower (30 interventions in INT versus 28 in ORG), while watering volumes remain constant. Economic assessments regarding the return on investment, as presented by NPV, EAV, B/C and DPP, are detailed in Table 5.

It is evident that two out of three liquidation prices of the organic product yield a positive NPV and thus a B/C ratio greater than one for the medium and maximum prices indicated by ISMEA.

The higher price of organic apples, compared to non-organic ones, is indeed more than proportional to the higher costs incurred in organic cultivation.

A completely opposite scenario is observed in the comparison between integrated farming and TR varieties. In these two cases, only the current maximum price on the Italian market results in a positive NPV value. The difference between INT and TR is minimal, as evidenced by the B/C ratio and Fig. 3 e 4, although scab-resistant varieties require less use of plant protection products.

These two graphs depict the cash flows for each year, spanning from year 0 of orchard planting to year 20 marking the end of production.

The disparity between TR and traditional varieties in integrated cultivation is reaffirmed. The trends over the different years of orchard development are almost identical, with TR's cash flow consistently € 70–90 higher per year.

Comparing the cash flow generated by the INT and TR scenarios with that of the ORG scenario (Fig. 5), it becomes evident that the latter yields the best economic results.

The cash flow pattern in organic cultivation mirrors that of the INT and TR scenarios. However, the first positive flow occurs in the fifth year, irrespective of the three sales prices (minimum, average and maximum), while in integrated cultivation and with TR varieties, values greater than zero are observed as early as the fourth year for the average and maximum prices considered.

In each case study, it is possible to see how organic fertilisation, carried out every three years, from the third or fourth year, has a significant impact on cash flow, leading to a sharp decrease.

Where a positive NPV value is found and thus a B/C ratio greater than 1, the discount payback period can be calculated. As for INT and TR, the DPP is the same. This means that between traditional and scab-resistant cultivars there is no difference in years for which revenues cover costs. The case of organic is different; the DPP has two distinct values for medium and maximum selling price, especially the latter is characterized by a lower number of years than INT and TR. This aspect is even more relevant when related to EAV obtained in organic with the maximum selling price. This assumes a key role when it is necessary to make the assessment of the investment in the study phase.

4. Discussion

Life cycle assessment can help in studying the environmental impacts of agricultural production systems with the aim of optimizing their management by reducing inputs [65,66]. Specifically, in apple orchards the highest energy consumption is related to the use of machinery, as also identified by Alaphilippe [67]. Our results indicate that fuel is the item with the greatest impact in the cultivation phase and this finding is in agreement with the results of Milà i Canals et al. [66] and Sessa et al. [68].

Table 5
NPV, EAV, B/C and DPP for INT, ORG and TR scenarios.

	Selling price (€/kg)	*NPV (€/ha)*	*EAV (€/ha)*	*B/C*	*DPP*
Integrated					
Minimum	0.38	−144,043	−8,809	0.63	–
Medium	0.47	−85,222	−5,212	0.78	–
Maximum	0.68	52,026	3,182	1.13	11
Resistant scab					
Minimum	0.38	−142,395	−8,708	0.64	–
Medium	0.47	−83,574	−5,111	0.79	–
Maximum	0.68	53,674	3,283	1.14	11
Organic					
Minimum	0.61	−88,193	−4,410	0.80	–
Medium	0.91	82,089	4,104	1.19	10
Maximum	1.09	184,259	9,213	1.42	7

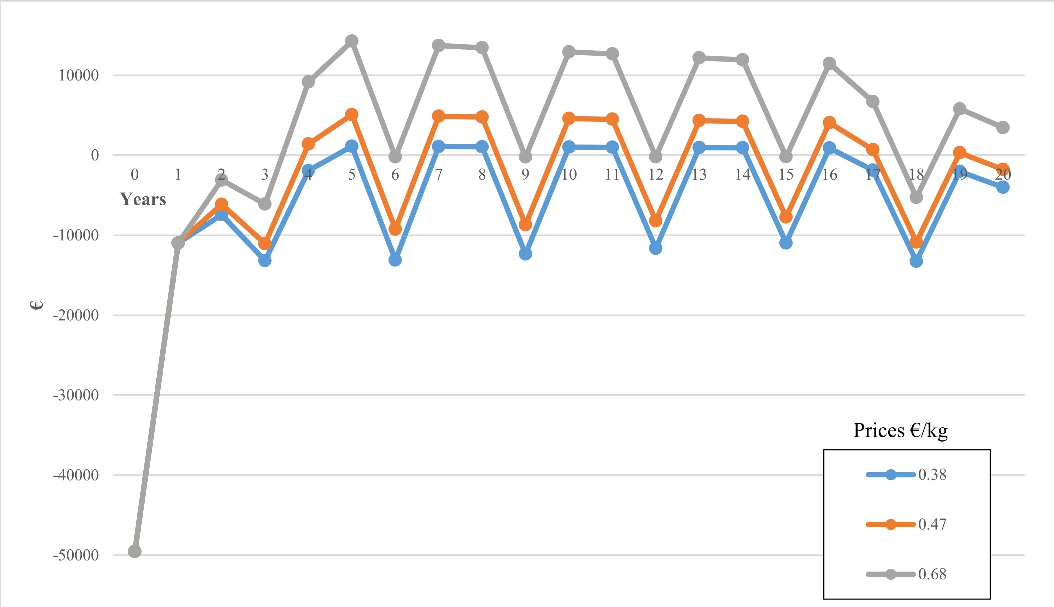

Fig. 3. Cash flow of the INT scenario.

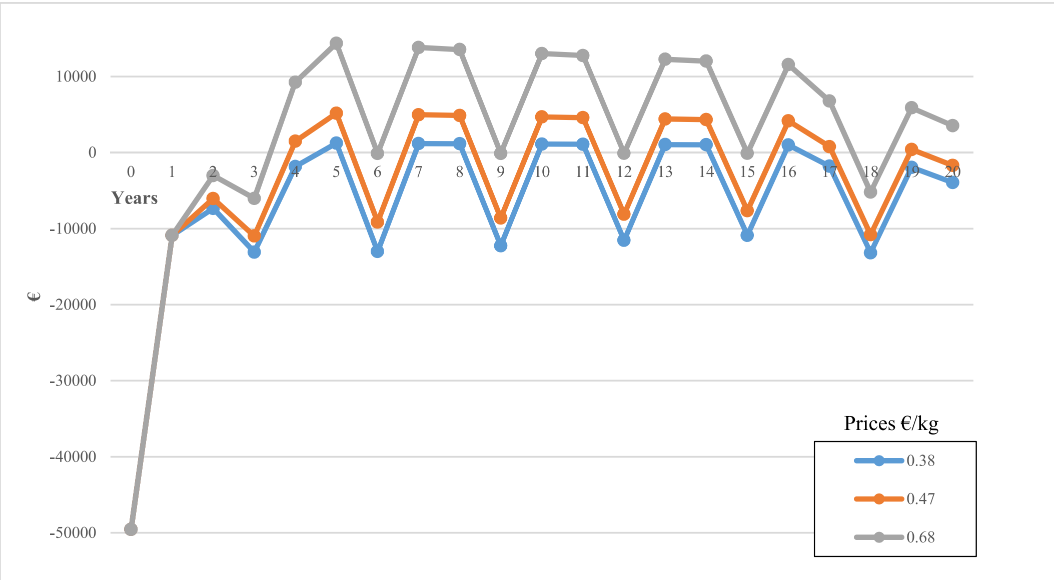

Fig. 4. Cash flow of the TR scenario.

In the specifics of the ORG case study, it can be seen that fuel has a significant impact, in agreement with other studies by Longo et al. [42] and Goossens et al. [69]. As stated by Alaphilippe et al. [67], this is due to the increased use of mechanical operations to replace chemical protection products, as in the case of weeding replaced by mechanical tillage between rows. These results confirm what the farmer indicated in the initial questionnaire. It was then observed how the use of pesticides for crop defence has direct consequences both economically and environmentally. In organic farming, in accordance with the statements of Zhu et al. [70], pesticides derived from plant species or from microorganisms such as fungi and bacteria are used: this results achieve a reduced environmental impact.

At the same time, on the economic aspect, in agreement with Doria et al. [71] and Meng et al. [72], it is noted that these products are much more expensive than the products used in integrated orchard production. A relevant aspect related to the use of these biological products is the possible contamination of the soil [67], mainly related to the quantities used and the repeated interventions required to ensure good vegetation cover throughout the season. The study by Alaphilippe et al. [67] also determined how replacing

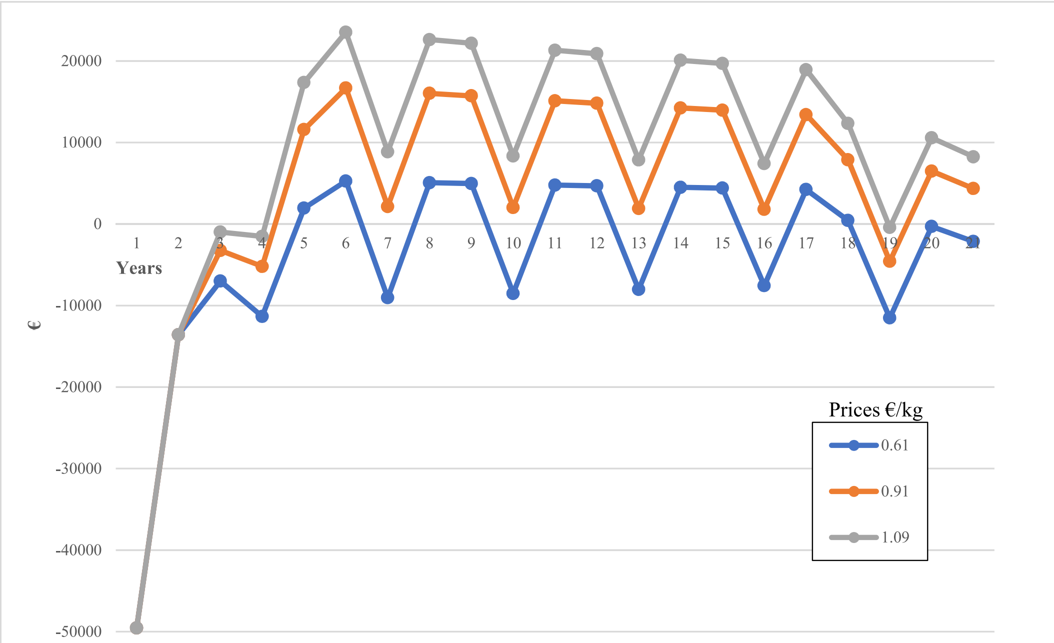

Fig. 5. Cash flow of the ORG scenario.

some chemical interventions with mechanical operations does not result in a greater impact related to energy consumed, as the emissions occurring in the field during operations are lower than the indirect emissions due to the production process of the different inputs. Other authors [67,70] then place attention on the cultivation of resistant (TR) cultivars, highlighting the greater resistance of this cultivar to scab and thus a lower need for treatments to obtain a product with a suitable commercial quality. In our study, the same scenario is presented, with farmer reporting less pesticide use for the protection of TR orchards.

This also leads to differences in economics and financial results: for the same selling price between TR and INT, the NPV and B/C ratio are slightly higher for the scab-resistant variety. Our work highlights how fertilisers also play an important role in terms of environmental impacts, in agreement with the findings of Milà i Canals et al. [66], Wang et al. [65] and Sessa et al. [68]. It is examined how the impact of fertilisers is more relevant in integrated cultivation and for the TR variety than in organic cultivation, since this latter cultivation method the use of synthetic fertilisers is not allowed [69]. At the same time, this type of agriculture allows the employment of organic fertilisers, such as manure. However, Zhu et al. [70] highlighted how the use of manure could have impacts on soil, water eutrophication and energy consumption.

Focusing on the economic outcomes, Zhang et al. [65] defined that the adoption of sustainable and efficient cultivation allows for the reduction of fertilisers and pesticides usage, thus generating higher net income. Our study shows that this assumption is confirmed for the TR variety and for ORG scenario, considering the latter's also the higher selling price. As stated by Stillitano et al. [58] and Badiu et al. [73], and as observed in this study, the amount of the initial investment for planting the orchard (such as masts, poles, labour, etc.) is decisive for the profitability of the investment.

Badiu et al. [73] confirms how the annual income generated by the orchard is related to the annual production yield, which is higher in the integrated and scab-resistant case, and the quality of the harvested products, which guarantees a higher selling price, as in the organic case. Badiu et al. [73] also state how an intensive orchard achieves better values for NPV. Considering this and agreeing with what was presented by Jalić et al. [74], orchards with higher production potential have a drip irrigation system, an anti-hail system and targeted fertilisation. This situation is also true for our orchard and confirms that for the first years the investment incurs expenses greater than income [74,75]. Despite this, net cash flow in our case study shows positive values earlier than in other studies [74], thanks to the production yield, the quality of the product obtained, and thus the selling price [73,76].

Our study confirms what Lordan et al. [76] have also found: the selling price of the apple is crucial in assessing financial performance, especially when investing in a high-density orchard, the return of which is closely linked to the trend in the price of the product sold. Cost also plays a factor in the choice when making an investment: for the same NPV, it is preferable to opt for a system that allows for lower initial investment demands [76]. The economic return is therefore related to planting density, which varies for each cultivar, production yield, selling price of the final product, and labour cost [68,76]. Analysing the different cost items emerges that labour was one of the most impactful costs, especially in organic farming. This is also found in other studies [58], where harvesting and pruning are identified as the most costly cultivation operations.

Picking up on what was stated at the beginning, it is possible to confirm how in agroecology it is essential to combine tradition, land and technological innovation in order to achieve economic sustainability for the farmer as well as environmental sustainability. As pointed out by Milà i Canals et al. [66], the economic aspect of the investment is what drives the farmer's choices, and by observing the strong link between the financial and ecological aspects of the orchard system [77], it is clear how farmers have at their hands a high potential to influence the environment and thus change the environmental impacts of production systems, especially with regard to energy use.

5. Conclusions

This work considered three different case studies: two cultivation methods (integrated and organic) and a scab-resistant variety.

The study shows that for organic cultivation, fuel is the item with the greatest environmental impact, unlike in the integrated system and scab-resistant variety, where fertilisers and pesticides are the most impactful. These results can be explained by the replacement of mechanical operations with respect to chemical interventions.

One aspect that is common to all the scenarios analysed and can be considered typical of orchard management is the high demand for labour that this type of cultivation requires. Indeed, manual labour is essential for carrying out pruning and harvesting, whatever the method of management. Therefore, maintaining this type of cultivation can ensure the demand for specialised labour in rural areas, while at the same time guaranteeing the preservation of fragile territories.

Economically, the orchard investment requires a significant upfront expense, which will result in negative cash flow in the first few years of planting. Added to this aspect is the apple selling price, which is closely related to the quality of the product sold, and which is discriminating in assessing the profitability of the investment. In the analysed case, the organic apple allows for a higher liquidation price, ensuring positive financial results.

The principles of agroecology are embraced by businesses with the introduction of organic production systems to replace conventional schemes and with the choice of resistant varieties. However, business choices are strongly influenced by market dynamics, over which the farmer has no influence.

In the future, large commercial players and large organised distribution will play a central role in shaping production choices and the eventual adoption of production schemes that adhere to agroecology principles. In this sense, consumer awareness can also be decisive in the processes of choice and purchase and thus support sustainable production.

Data availability statement

The data used are confidential and have not been deposited in a public archive.

Data used and/or analysed in the current study are available from the corresponding author upon reasonable request.

CRediT authorship contribution statement

Lorenzo Baima: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation. **Luca Nari:** Writing – review & editing, Validation, Data curation. **Davide Nari:** Writing – review & editing, Validation, Data curation. **Andrea Bossolasco:** Writing – review & editing, Validation, Data curation. **Simone Blanc:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Data curation, Conceptualization. **Filippo Brun:** Writing – review & editing, Validation, Supervision.

Declaration of competing interest

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

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