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RESEARCH ARTICLE

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# Yield and cost–benefit analyses for apple scab sanitation practices in integrated and organic apple management systems

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**Societal Impact statement**

Reduced fungicide use lowers environmental pollution and enables safer food production. The usage of fungicides in apple orchards can be reduced through the application of sanitation practices which decrease the inoculum sources of apple scab disease on fallen leaves. This study found two non-chemical sanitation practices, namely the collection of fallen leaves (CFL) and CFL combined with straw mulch in tree rows, were beneficial. These two practices are not only biologically and environmentally valuable, as they reduce disease levels and can replace chemical fungicides, but they are also economically efficient options for integrated and organic orchards compared to non-sanitized ones.

**Summary**

- Severe fungicide use can be reduced by applications of sanitation practices in order to reduce scab incidence, yield and fruit quality losses in apple orchards. In a 5-year study, we aimed to investigate the effect of sanitation practices on biological and cost–benefit parameters in two sustainable apple management systems, and to find significant correlations among the parameters.
- We investigated the effect of five sanitation treatments (lime sulphur, leaf collection, mulching, lime sulphur + leaf collection, leaf collection + mulching) on four biological (scab incidence, fruit parameters: total yield, yield class I and II) and seven cost–benefit (three cost types, three annual revenue types, income surplus/deficit) parameters in integrated and organic apple orchards. Correlation, linear regression and principal component analyses (PCA) were performed to find correlations among biological and cost–benefit parameters.
- Results showed that fruit scab incidence was 3.4–8.1 times higher, while total yield was 1.4–1.8 times lower in the organic management system than in the integrated one. The treatment of leaf collection and/or leaf collection + mulching showed higher total cost (180.3 and 675.2 EUR ha$^{-1}$) but lower scab incidence (5.3 and 27.3%; 4.8 and 26.7%, integrated and organic, respectively) and higher yield with greater total revenues (10,235 and 10,329 EUR ha$^{-1}$; 8,136 and 8,230 EUR ha$^{-1}$, integrated and organic, respectively) and income surpluses (851 and 451 EUR ha$^{-1}$; 897 and 496 EUR ha$^{-1}$, integrated and organic, respectively)

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compared to non-sanitized control treatments in most cases. Other sanitation treatments provided fewer biological and/or no financial benefits. Results from correlation and linear regression analyses indicated strong relationships among the factors of total yield vs surplus, class I vs surplus, and fruit scab vs class II) in both management systems. Further relationships were detected among almost all parameters in the PCA.

- Overall, our study demonstrated that two non-chemical sanitation treatments could not only reduce scab incidence and increase fruit yield, but could show positive cost–benefit outcomes in both management systems.

**KEYWORDS**
apple scab, cost–benefit analyses, integrated and organic production, leaf collection, lime sulphur, mulch cover, sanitation, yield loss

## 1 | INTRODUCTION

Environmental and food safety strategies of the European Union (EU) promote a greater use of biological control agents and/or non-chemical methods in crop protection. Due to the increasing demand for healthy and affordable food production, further regulations will continue to shape farming systems and agricultural practices (Anon, 2022b). Among farming sectors, fruit production uses a major input of plant protection products and pesticides (Jackson et al., 2011; Tromp et al., 2005). In temperate fruit production, plant protection expenses constitute one of the highest cost components, for example, it accounts for 18–35% of the total production cost in apple production (e.g. Akdemir et al., 2012; Cheng et al., 2022; Glover et al., 2002; Goossens et al., 2017; Łakomiak & Zhichkin, 2020; Taylor & Granatstein, 2013).

Apple (*Malus x domestica* Borkh.) is one of the most common fruit species in Europe. Within the EU, approximately 12 million tons of apples were produced annually in around 520 thousand hectares from 2015 to 2019 (Anon, 2022b). The largest amount of apples in the EU is produced by Poland (around 25% of the EU apple production in the past five years). However, Poland's national average yield per hectare (approximately 19.4 t $ha^{-1}$) falls below the average yield per hectare of other leading EU producers such as Italy, Germany, and France (Anon, 2022a, 2022b).

The management of apple scab is an essential technological element in both conventional and sustainable apple production systems (Ekinci et al., 2020; Holb, 2009; Orpet et al., 2020; Reganold et al., 2001). Apple scab is a key polycyclic fungal disease caused by *Venturia inaequalis* Cooke (Winter). Insufficient scab control can result in severe scab epidemics by the time of harvest. The pathogen can cause severe scab lesions on both fruits and leaves with the potential for severe defoliation of the tree by early autumn (Belete & Boyraz, 2017; Bowen et al., 2011; MacHardy, 1996). Poor control of apple scab can lead to significant yield losses, ranging from 20 to 70%, in most apple-growing areas. This applies to conventional, integrated, and organic management systems. The most severe yield loss can result in economic losses of 70–100%, primarily in organic apple growing (e.g. Belete & Boyraz, 2017; Biggs & Stensvand, 2014; Hickey & Yoder, 1990; Holb et al., 2017; MacHardy et al., 1993). Yield loss caused by apple scab can be effectively controlled with fungicides, but the annual fungicide spray applications against apple scab can range between 12 and 25 depending on the weather conditions, cultivar susceptibility, growing regions and management approaches (e.g. Chatzidimopoulos et al., 2020; Gur et al., 2021; Holb, 2008, 2009; Holb et al., 2017; Holb & Kunz, 2016). Because of increasing production costs, environment concerns and resistance to fungicides, several non-chemical (e.g. cultural, physical and biological) control approaches have received great attention in order to reduce fungicide applications against apple scab (e.g. Belete & Boyraz, 2017; Caffi et al., 2017; Carisse & Dewdney, 2002; Didelot et al., 2016; Holb, 2006, 2007; Sutton et al., 2000; Vincent et al., 2004).

Sanitation practices are an essential non-chemical control approach that plays a crucial role in reducing the primary inoculum sources of *V. inaequalis*; therefore, they can effectively reduce the epidemic intensity of the disease development in the primary infection periods of the fungus. The most well-known sanitation practices include leaf shredding, leaf collecting, orchard floor covering (e.g. with mulch) and using lime sulphur/urea and their combinations. These sanitation practices suppressed the pseudothecial development and/or limited the discharge of *V. inaequalis* ascospores and/or reduced the number of scab infection by 23–92% in the primary infection period (e.g. Haynes, 1981; Holb, 2006, 2007, 2009; MacHardy et al., 1993; Niklas et al., 1979; Sutton et al., 2000; Vincent et al., 2004; von Diest et al., 2016). The possible effectiveness of orchard sanitation options and their combinations were confirmed in moderately infested (such as integrated) and/or severely infested (such as organic) commercial apple orchards on apple cultivars with different scab susceptibility (e.g. Didelot et al., 2016; Holb et al., 2017).

The investment and production costs of apples depend on the technological system (extensive, intensive, super-intensive), orchard size and production/management system (conventional, integrated

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pest management or organic) (e.g. Badiu et al., 2015; Beresford & Manktelow, 1994; Caffi et al., 2017; Cooley & Autio, 1997; Ellis et al., 1998; Håkansson et al., 2009; MacHardy, 2000; Nakyo et al., 2013; Sojkova & Adamickova, 2011; Taylor & Granatstein, 2013; Zhang et al., 2017). In conventional production, many synthetic pesticides and fertilizers are allowed for use. As environmental considerations have become essential components of fruit production, interest has turned from conventional to integrated and organic production systems, where management practices differ from those in the conventional one (e.g. Holb et al., 2017; Peck et al., 2006; Reganold et al., 2001). By definition 'integrated fruit production (IFP) in pome fruits is the economical production of high quality of fruit, giving priority to ecologically safer methods, minimizing the undesirable side effects and use of agrochemicals, to enhance the safeguards to the environment and human health' (Barzman et al., 2015; Cross & Dickler, 1994; Hendrickson et al., 2008). Organic production is defined as 'an approach where the aim is to create integrated, humane, and environmentally sustainable production system, which maximize reliance on farm-derived renewable resources and the management of ecological and biological processes and interactions' (Anon., 2019; Lampkin & Padel, 1994). According to these definitions, synthetic products are restricted in the integrated and banned in organic fruit growing. Only natural products, i.e. sulphur and copper compounds, fungicidal and botanical soaps, botanical insecticides, traps, and biological methods, are permitted in organic plant protection according to IFOAM (International Federation of Organic Agriculture Movements) standards (Anon., 2019). In the organic management system, spray costs against fungal diseases can even exceed half of the full production costs (Holb, 2008). In addition, the pesticides permitted in organic farming have lower efficacy against diseases compared to the chemicals used in conventional farming. This increases the importance and economic value of alternative defence strategies (Holb, 2009; Holb et al., 2017). Costs of apple disease and pest management account for 20–26% of the total direct production costs (Akdemir et al., 2012; Cheng et al., 2022; Glover et al., 2002; Goossens et al., 2017; Łakomiak & Zhichkin, 2020; Taylor & Granatstein, 2013). Some studies have focused on comparative economic analyses of apple disease management, including costs of fungicides, spraying equipment, application rates, cultivars and orchard sizes (Beresford & Manktelow, 1994; Ellis et al., 1998; Funt et al., 1990; Gül et al., 2014; Liang et al., 2021; Sedlar et al., 2013; Sotirov et al., 2018; Tona et al., 2018). However, previous studies have not evaluated the cost–benefit of orchard sanitation practices in sustainable (integrated and organic) apple production systems based on yield loss and scab-reducing abilities of these sanitation practices.

In this 5-year study, our aims were i) to investigate the effect of five sanitation treatments (lime sulphur, leaf collection, mulching, lime sulphur + leaf collection, leaf collection + mulching) on fruit scab incidence, yield, and cost–benefits in integrated and organic commercial apple orchards at harvest; ii) to find significant correlations among biological and cost–benefit parameters for both management systems and/or sanitation practices. Cost-benefits analyses were based on the determination of the measures of cost, revenue and income surplus/deficit.

## 2 | MATERIALS AND METHODS

### 2.1 | Plant material, experimental orchards and weather monitoring

A 5-year study was conducted in two sustainable (integrated and organic) apple orchards from 2015 to 2019. The organic apple orchard was located in Eperjeske, while the integrated one was in Nagykálló, Eastern Hungary, 89 km apart from each other.

In 1996, 15 and 20 ha orchards were established in Nagykálló and Eperjeske, respectively. A slender spindle training system (4 × 1.5 m and 5 × 2 m distances) was implemented, including six and eight apple cultivars (min. 4,000 and 3,000 trees of each cultivar) in Nagykálló and Eperjeske, respectively. Trees were grown according to the Hungarian Integrated Fruit Production (HIFP) guidelines derived from international IFP standards and the Hungarian Organic Guidelines derived from International Federation of Organic Agriculture Movements (IFOAM) standards in Nagykálló and Eperjeske, respectively. Spray schedules against apple scab for both management systems were provided in Table S1. In both locations, trees were grafted on M.26 rootstocks and assessments were made on the scab-susceptible apple cultivar Jonagold.

In each year, a METOS agrometeorological station (Pessl Instrument GmbH, Weiz, Austria) was operated and Mills infection periods were calculated from 15 March until 10 October in each year.

### 2.2 | Sanitation treatments

Five treatments in four replicates were prepared in the experiment by a completely randomized block design (CRBD) in the autumn of 2014, 2015, 2016, 2017 and 2018. The size of the experimental plot (one replicate for each sanitation treatment) was 80 × 75 m in the organic and 50 × 50 m in the integrated orchard, containing a minimum of 250 trees per plot in both management systems. Treatments were:

i. one spray application to the tree in October and then an additional spray on the orchard floor with lime sulphur in November, Lime-S;
ii. fallen leaf collection in November, Collect-L;
iii. orchard floor mulching in February, Mulch-C;
iv. treatments i) and iii), i.e. lime sulphur application followed by mulching, Lime-S + Mulch-C;
v. treatments ii) and iii), i.e. leaf collection followed by mulching, Collect-L + Mulch-C;
vi. Non-sanitized control.

In treatments of Lime-S and Lime-S + Mulch-C, leaves on the trees were treated with 2% Tiosol (29% calcium polysulphide, Tiosol Ltd., Hungary) before leaf fall in October in both management systems and in all years. Then fallen leaves were treated with an additional 4% Tiosol in November in both systems and in all years. Sprays were applied with a Kertitox 2000 axial blower spray machine (Debreceni Gépgyár B.V., Debrecen, Hungary) in all years.

In treatments of Collect-L and Collect-L + Mulch-C, leaves were collected with a John Deere F-725 flail mower (Deere and Company, Moline, Illinois, USA) after defoliation in November in both systems and in all years.

In treatments of Mulch-C and Collect-L + Mulch-C, the full experimental area was covered with a 10 cm mulch-layer of winter wheat straw after leaf collection and before bud break. The mulching treatment was prepared only in February in all years in order to reduce favourable conditions for the swarming of voles during late autumn and winter.

In all years, a general spray schedule was applied in each integrated and organic plot against apple scab according to the HIFP and IFOAM guidelines, respectively. In both orchards, a Kertitox 2000 axial blower spray machine was used with a ceramic hollow cone (1.1–1.2 MP, 1000 L ha$^{-1}$).

## 2.3 | Assessment of fruit scab incidence and yield

Scab and yield assessments were made on fruits for all six sanitation treatments in all years (2015–2019) and in both management systems: integrated versus (vs) organic. For each treatment, four randomly selected plots including 10 trees per plot were selected for the assessments. Scab symptoms on fruit were assessed on all fruits of the 10 trees per plot at harvest each year. The scab incidence of fruits was calculated as the percentage of scabbed fruits.

In each year, the fruit yield at harvest was measured as fruit weight per tree, collected from the 10 trees per plot for each sanitation treatment in both the integrated and organic management systems. The harvested fruits were classified into two quality grades based on scab incidences: i) yield class I called dessert apples (fruits were not infected with scab) and ii) yield class II called apples for industrial processing (fruits were infected with scab).

## 2.4 | Methods of cost–benefit analyses

### 2.4.1 | Cost calculations of sanitation treatments

In order to calculate the cost of each sanitation treatment, various types of costs including material, mechanical, depreciation, labour and other costs were collected in the experimental years of 2015–2019 (Table 1). Cost values, excluding VAT, were given in EUR based on the monthly average exchange rates of Anonymous (2022a) for each year.

The material costs for the Lime-S treatment were based on the annual prices of Tiosol and fungicide annual price index (Anonymous, 2022d) separately for the applications of 2% Tiosol in October and 4% Tiosol in November, in every year and in both management systems.

**TABLE 1** Description and calculated expenditures/costs types for sanitation treatments in integrated and organic apple orchard (Nagykálló and Eperjeske, Hungary, 2015–2019). Lime-S: lime sulfur, collect-L: leaf collection, mulch-C: mulch covering, –: not applicable.

| Treatment type | Lime-S | Collect-L | Mulch-C |
|---|---|---|---|
| Applied treatment | Spray applications to leaves with lime Sulphur in autumn | Collection of fallen leaves in late autumn and compost them by open prismatic composting techniques | Mulching the orchard floor in late winter and collecting in late spring |
| Date and time of application | First in October on the tree, second in November on the orchard floor | In November, twice in one orchard row | In February and collect it in June |
| Material cost | 2% after 4% Tiosol, consequently (29% calcium polysulphide)[†] | - | 10 cm mulch-layer of winter wheat straw (approx. 13 t ha$^{-1}$)[‡] |
| Labour cost | employer's gross salary and taxes related to spray application | employers' gross salary and taxes related to the leaves collection and composting | employers' gross salary and taxes related to mulching in February and collection in June |
| Mechanical, depreciation cost[§] | Tractor with axial blower spray machine | Tractor and trailer with leaf collector vacuum sweeper | Tractor and trailer with bale shredder and spreader, after with swathers |
| Other cost | - | Collected leaves composting: Rotation and sifting of approx. 30 m$^3$ leaves ha$^{-1}$ (depending on the orchard) | - |
| Surplus revenue of sanitation | - | Price of the produced compost in NPK fertilizer active ingredient equivalent (approx. 16.5 m$^3$ in integrated, 13.5 m$^3$ in organic orchard)[¶] | - |

[†]Calculated by fungicide annual price index (Anonymous, 2022c).
[‡]Cost of winter wheat straw based on Anonymous (2022c).
[§]Costs were calculated by 41–75 kW tractor with appropriate machinery based on Anonymous (2022e).
[¶]Calculated by average price of Nitrosol (30% N content), Superphosphate (20% P content), and Potassium chloride granules (60% K content) based on Anonymous (2022c).

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The 10-cm mulch-layer of winter wheat straw (approx. 13 t $ha^{-1}$) was calculated as a material cost of Mulch-C treatment based on annual mean prices of cereal straw (Anonymous, 2022d).

There was no material cost for the Collect-L treatment; however, costs for composting were calculated as open prismatic composting costs (rotation, sifting) depending on the amount of average collected leaves of orchards (approx. 30 $m^3$ leaves $ha^{-1}$). The amount of produced compost was 16.5 $m^3$ in integrated and 13.5 $m^3$ in organic orchard $year^{-1}$ $ha^{-1}$. The produced composts were used as nutritional supply in the Collect-L treatment in both management systems; therefore, they were defined as the active ingredient equivalent of NPK fertilizers based on the calculation of NPK content of apple leaves (N: 2.0%, P: 0.15%, K: 1.5%). The annual prices of NPK fertilizers of Nitrosol (30% N content), Superphosphate (20% P content), and Potassium chloride granules (60% K content) were based on Anonymous (2022d). The price of the produced compost as NPK fertilizer active ingredient equivalent was added to our calculations as surplus revenues in the case of leaf collection treatments (Table 1).

In each sanitation treatment, mechanical, depreciation and labour costs were based on the calculation of the annual costs of agricultural machinery of the Institute of Agricultural Engineering, National Agricultural Research and Innovation Center, Hungary (Anonymous, 2022e, Table 1). The tractor cost was based on the performance of 41–75 kW tractor attached with specific machinery to the given treatment (Table 1).

Costs of the two combined treatments (Lime-S + Mulch-C and Collect-L + Mulch-C) were calculated as the sum of each single treatment component for example in the case of the cost of the combined treatment of Lime-S + Mulch-C was calculated as the cost of the Lime-S treatment plus the cost of the Mulch-C treatment.

### 2.4.2 | Calculation of harvested apple fruit prices

Fruit prices in the integrated management system were calculated as the monthly average prices (excluding VAT) for fruit yield classes I and II according to Anonymous (2022c). Fruit prices in the organic management system were calculated as 145% and 175% of the prices for fruit classes I and II of the integrated management system, respectively (Table 2). All values were given in EUR based on monthly average exchange rates according to Anonymous (2022a).

### 2.4.3 | Calculation of annual revenues and surplus income or deficit

The annual revenues (EUR $ha^{-1}$) of the five sanitation treatments and the non-sanitized control were calculated by multiplying corresponding yields and prices separately for each year and management system. Annual revenues were increased with revenues from leaf composting in the treatments of Collect-L and Collect-L + Mulch-C to obtain the corrected revenue values.

**TABLE 2** Calculated prices of dessert apples (class I) and apples for industrial processing (class II) excluding VAT in EUR $kg^{-1}$ in integrated and organic apple orchards (Nagykálló and Eperjeske, Hungary, 2015–2019).

| Classification grade of apples | Dessert apples (class I) | Apples for industrial processing (class II) |
|---|---|---|
| Integrated[†] | | |
| 2015 | 0.25 | 0.12 |
| 2016 | 0.21 | 0.06 |
| 2017 | 0.34 | 0.17 |
| 2018 | 0.20 | 0.05 |
| 2019 | 0.31 | 0.11 |
| Organic[†] | | |
| 2015 | 0.36[‡] | 0.21[§] |
| 2016 | 0.31[‡] | 0.11[§] |
| 2017 | 0.50[‡] | 0.29[§] |
| 2018 | 0.30[‡] | 0.09[§] |
| 2019 | 0.45[‡] | 0.20[§] |

[†]Based on average monthly production price (Anonymous, 2022c) and convert to EUR by Anonymous (2022a).
[‡]Prices were calculated as 145% of class I price in the corresponding year of integrated apple orchard.
[§]Prices were calculated as 175% of class II in the corresponding year of integrated apple orchard.

The income surplus or deficit (EUR $ha^{-1}$) of each sanitation treatment was also calculated for each year and management system. The cost of a sanitation treatment was subtracted from the corrected revenues of the sanitation treatment and then the revenue of the non-sanitized control was also subtracted from this value.

## 2.5 | Data analyses

### 2.5.1 | Analysis of variance

Data from the two locations were analysed separately. All parameters for each location were analysed using analysis of variance (Statistical Analysis System v. 8.1; SAS Institute Inc., Cary, NC) in order to determine the effect of year, sanitation treatment, and their interactions. Then, means were separated by a least significance difference (LSD) test using $LSD_{0.05}$ values. Significant F tests ($P = 0.05$) were followed by an LSD test for comparison of means of sanitation treatments using $LSD_{0.05}$ values. Prior to the analyses, scab incidence data were arcsine-square root transformed in order to make the data normally distributed.

A separate LSD test was performed for comparing the data of the two locations (i.e. integrated versus organic management systems) for each year and for the five years together (overall years). Significant F tests ($P = 0.05$) were followed by an LSD test for the comparison using $LSD_{0.05}$ values in order to determine the possible significant differences between the two management systems for the parameters

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of scab incidence, total yield, yield class I, yield class II, total annual revenue, revenue for yield class I, revenue for yield class II and income surplus/deficit.

### 2.5.2 | Correlation and linear regression analyses among parameters

Relationships among the parameters of scab incidence, total yield, yield class I, yield class II, total annual revenue, revenue for yield class I, revenue for yield class II and income surplus/deficit were analysed by Pearson correlation analyses. Integrated and organic management systems were separately analysed by calculating correlation coefficients (*r*) and their associated significance levels ($P \le 0.05$). In the correlation analyses, a multiple testing correction was used by the Bonferroni correction (Sedgwick, 2012). Beyond correlation analyses, boxplots [1.5xIQR (interquartile range), LQ (lower quartile), median, UQ (upper quartile), 1.5xIQR and outliers], density plots (Kernel density estimation), data plotting for correlation pairs and frequency distribution by management groups for all the parameters were prepared with statistical packages of R package GGally (Schloerke et al., 2021).

Then the strongest correlated pairs were selected for further analyses in both management systems. For the values of the strongest significantly correlated pairs, linear regression functions were fitted for integrated and organic management systems. Then, according to a t-test, the significantly different regression slopes were determined for integrated vs organic management systems. The statistical package of Genstat Release 9.1 (Lawes Agricultural Trust, IACR, Rothamsted, UK) was used for the analyses.

### 2.5.3 | Principal component analyses

The variables of scab incidence, total yield, yield class I, yield class II, total annual revenue, revenue for yield class I, revenue for yield class II and income surplus/deficit were used in a standardized Principal Component Analysis (PCA) using the correlation matrix with the above eight parameters. For standardizing the parameters, the values of variables were transformed to z-scores. During performing PCA, the values of Root Mean Square Residual (RMSR) were also used in the model fits (Basto & Pereira, 2012). Then biplot diagrams were prepared to visualise Principal Components (PCs). PCA was performed with statistical packages of R 4.2.2. (R Core Team, 2021) with the FactoMiner (Lê et al., 2008), psych (Revelle, 2022) and factoextra (Kassambara & Mundt, 2019).

## 3 | RESULTS

### 3.1 | Infection periods

Weather conditions were similar in both locations; however, the maximum and minimum values of temperature as well as the amount of precipitation were slightly larger at Eperjeske, compared to those at Nagykálló (Table S2). The numbers of infection periods were 19, 22, 24, 29, 30 and 37 at Nagykálló, and 20, 21, 25, 27, 32, and 35 at Eperjeske, in 2015, 2016, 2017, 2018, and 2019, respectively, from mid-March until mid-October.

### 3.2 | Apple scab incidences, yields and classification grades

Analysis of variance for scab incidence, total yield, classes I and II indicated significant ($P < 0.05$) differences among years and sanitation treatments in both management systems (Table 3).

The 'overall (treatment)' values of scab incidence were significantly lower in the integrated production system (6.1%) compared to the organic one (29.6%, Table 4). Values of fruit scab incidence ranged from 2.2 to 14.0% and from 19.1 to 46.1%, in the integrated and organic management systems, respectively (Table 4). Fruit scab incidence was 3.4–8.1 times higher in the organic production system compared to the integrated one in the corresponding treatments.

The lowest values of scab incidence were 2.2 and 19.1% for integrated and organic management systems, respectively, in the treatment of Collect-L + Mulch-C in 2018 (Table 4). The highest values were 14.0 and 46.1% for integrated and organic management systems, respectively, in the non-sanitized treatments in 2016. Treatment of Collect-L + Mulch-C and Collect-L showed significantly lower scab incidence compared to non-sanitized control in both management systems and in all years, with the exception of the organic production system in 2017 and 2019. Scab incidence values in the Lime-S or Mulch-C treatments were not significantly different from the non-sanitized control treatments in both management systems and in all years, with the exception of the integrated production system in 2016 (Table 4).

The 'overall (treatment)' total yield was significantly higher in the integrated production system (37.9 t $ha^{-1}$) compared to the organic one (23.8 t $ha^{-1}$, Table 5). Total yield was not affected by sanitation treatments in 2018 in the integrated, and in 2018 and 2019 in the organic management system (Table 5). Yield ranged from 34.2 to 43.7 t $ha^{-1}$ and from 20.1 to 29.8 t $ha^{-1}$, in the integrated and organic management systems, respectively (Table 5). The lowest value of total yield was obtained in the non-sanitized control treatment in 2018 for the integrated management system (34.2 t $ha^{-1}$), and in the Lime-S treatment in 2015 for the organic management system (20.1 t $ha^{-1}$). The highest yield values (29.8 and 43.7 t $ha^{-1}$) were measured in the Collect-L + Mulch-C treatment in 2016 in both management systems. Values in the treatment of Collect-L + Mulch-C showed significantly higher total yield in 2015, 2016, and 2019 in the integrated management system and 2016 in the organic one compared to the corresponding non-sanitized control treatments. Total yield values in the Lime-S or Mulch-C or Lime-S + Mulch-C treatments were not significantly different from the non-sanitized control treatments in both management systems and all years (Table 5).

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**TABLE 3** Analysis of variance for the effects of years (2015, 2016, 2017, 2018 and 2019) and sanitation treatments (lime sulfur, leaf collection, mulch covering, lime sulfur + mulch covering, leaf collection + mulch cover and non-sanitized control), on apple scab disease incidence (%), yield, dessert apples (class I), apples for industrial processing (class II), total revenue, revenue for class I, revenue for class II, surplus income/deficit (surplus inc./def.), total cost, material cost and labor + other costs for integrated and organic apple orchards (Nagykálló and Eperjeske, Hungary, 2015–2019). As the costs were the same for both integrated and organic orchards, ANOVA for costs types are not separated for the two orchard management systems..

| | | Scab incidence (%) | | Yield | | Class I | | Class II | |
|---|---|---|---|---|---|---|---|---|---|
| Source of variation | d.f.[†] | MS[‡] | P > F[§] | MS | P > F | MS | P > F | MS | P > F |
| *Integrated (Nagykálló)* | | | | | | | | | |
| Year (Y) | 4 | 64.8 | 0.001 | 88.5 | < 0.001 | 6.1 | 0.001 | 11.6 | 0.001 |
| Treatment (T) | 5 | 4.2 | < 0.001 | 22.2 | < 0.001 | 21.3 | 0.001 | 0.3 | 0.011 |
| Y x T | 20 | 0.4 | 0.089 | 0.2 | 0.047 | 0.4 | 0.172 | 0.1 | 0.395 |
| Total | 29 | 13.6 | | 9.1 | | 4.7 | | 1.3 | |
| *Organic (Eperjeske)* | | | | | | | | | |
| Year (Y) | 4 | 362.4 | < 0.001 | 14.6 | < 0.001 | 7.1 | 0.003 | 7.4 | < 0.001 |
| Treatment (T) | 5 | 22.9 | < 0.001 | 5.1 | 0.001 | 7.6 | 0.001 | 0.1 | 0.010 |
| Y x T | 20 | 0.7 | 0.049 | 0.1 | 0.124 | 0.8 | 0.247 | 0.2 | 0.292 |
| Total | 29 | 75.2 | | 4.1 | | 2.7 | | 5.1 | |

| | | Total revenue | | Revenue for class I | | Revenue for class II | | Surplus inc./def. | |
|---|---|---|---|---|---|---|---|---|---|
| Source of variation | d.f | MS | P > F | MS | P > F | MS | P > F | MS | P > F |
| *Integrated (Nagykálló)* | | | | | | | | | |
| Year (Y) | 4 | 31,662,511 | < 0.001 | 29,406,261 | < 0.001 | 74,276 | < 0.001 | 158,555 | 0.048 |
| Treatment (T) | 5 | 1,347,344 | < 0.001 | 1,465,575 | < 0.001 | 3,178 | 0.001 | 1,667,877 | < 0.001 |
| Y x T | 20 | 43,946 | 0.071 | 47,602 | 0.077 | 332 | 0.153 | 52,686 | 0.679 |
| Total | 29 | 463,103 | | 434,137 | | 11,022 | | 388,033 | |
| *Organic (Eperjeske)* | | | | | | | | | |
| Year (Y) | 4 | 19,966,301 | < 0.001 | 12,214,328 | < 0.001 | 1,581,344 | < 0.001 | 168,801 | 0.002 |
| Treatment (T) | 5 | 1,144,582 | 0.001 | 1,270,692 | < 0.001 | 4,890 | 0.007 | 1,240,141 | < 0.001 |
| Y x T | 20 | 22,449 | 0.196 | 19,539 | 0.092 | 1,096 | 0.399 | 23,298 | 0.175 |
| Total | 29 | 296,897 | | 190,758 | | 219,715 | | 286,121 | |

| | | Total cost | | Material cost | | Labour + other costs | |
|---|---|---|---|---|---|---|---|
| Source of variation | d.f. | MS | P > F | MS | P > F | MS | P > F |
| Year (Y) | 4 | 8,118 | 0.004 | 7,062 | 0.005 | 67.3 | 0.005 |
| Treatment (T) | 5 | 405,736 | < 0.001 | 276,063 | < 0.001 | 15,684 | < 0.001 |
| Y × T | 20 | 1,499 | 0.358 | 1,326 | 0.443 | 34.9 | 0.513 |
| Total | 29 | 852 | | 731 | | 22.5 | |

[†]d.f. = degree of freedom. (d.f. is 24 for surplus incidence/deficit).
[‡]MS = Mean squares.
[§]The probability values associated with the *F* tests.

Yield values for the 'overall (treatment)' class I were significantly higher in the integrated management system in all years than class I values in the organic one, while class II values were the opposite (Table 5). Similar to total yield data, Collect-L + Mulch-C treatment showed the highest values for class I, for example, in 2015, 2016, 2018 and 2019 in both management systems (Table 5). For both classification grades, Lime-S or Mulch-C or Lime-S + Mulch-C treatments were not significantly different from the non-sanitized control treatments in both management systems and all years (Table 5).

### 3.3 | Costs of sanitation treatments and compost of collecting leaves

Analysis of variance for total cost, material cost and labour + other costs indicated significant ($P < 0.05$) differences among years and sanitation treatments (Table 3). There were no significant interactions among treatment factors for the three cost types.

Each treatment was prepared equally in integrated and organic management systems, therefore, the costs of the treatments were the

**TABLE 4** Apple scab incidence on fruit (%) of cultivar 'Jonagold' in six orchard sanitation treatments (lime sulfur -lime-S, leaf collection-collect-L, mulch covering – mulch-C, lime-S + mulch-C, collect-L + mulch-C and non-sanitized control) in two orchard management systems (integrated and organic) assessed at the harvest of years from 2015 until 2019 (Nagykálló and Eperjeske, Hungary).

| Management and treatment/year | 2015 | 2016 | 2017 | 2018 | 2019 | Overall (year) |
|---|---|---|---|---|---|---|
| *Integrated (Nagykálló)* | | | | | | |
| Lime-S | 5.1 b[†] | 11.8 bc | 6.1 bc | 3.2 cd | 7.3 b | 6.7 cd |
| Collect-L | 3.9 a | 10.2 ab | 4.7 a | 2.7 abc | 4.9 a | 5.3 ab |
| Mulch-C | 4.4 ab | 12.2 bcd | 5.3 abc | 2.9 bcd | 7.1 b | 6.4 bcd |
| Lime-S + mulch-C | 4.2 ab | 11.8 bc | 5.2 ab | 2.5 ab | 6.4 b | 6.0 abc |
| Collect-L + mulch-C | 3.6 a | 8.9 a | 4.6 a | 2.2 a | 4.8 a | 4.8 a |
| Non-sanitized control | 5.0 b | 14.0 d | 6.5 c | 3.5 d | 7.5 b | 7.3 d |
| $LSD_{0.05}$[‡] | 1.0 | 2.1 | 1.2 | 0.6 | 1.3 | 1.2 |
| *Organic (Eperjeske)* | | | | | | |
| Lime-S | 27.2 bc | 44.3 bc | 31.2 c | 22.5 bc | 31.2 c | 31.3c |
| Collect-L | 23.3 a | 38.9 ab | 27.3 ab | 19.9 ab | 27.3 ab | 27.3 ab |
| Mulch-C | 27.1 bc | 44.2 bc | 30.1 abc | 21.6 abc | 30.1 abc | 30.6 bc |
| Lime-S + mulch-C | 26.7 abc | 43.2 bc | 28.7 abc | 21.9 abc | 28.7 abc | 29.8 abc |
| Collect-L + mulch-C | 23.8 ab | 37.6 a | 26.5 a | 19.1 a | 26.5 a | 26.7 a |
| Non-sanitized control | 27.5 c | 46.1 c | 30.8 bc | 24.5 c | 30.8 bc | 31.9 c |
| $LSD_{0.05}$ | 3.4 | 4.8 | 3.8 | 3.2 | 3.7 | 3.8 |
| Overall (treatment) | | | | | | |
| Integrated | 4.4 a | 11.5 a | 5.4 a | 2.8 a | 6.3 a | 6.1 a |
| Organic | 25.9 b | 42.4 b | 29.1 b | 21.6 b | 29.1 b | 29.6 b |
| $LSD_{0.05}$ | 2.4 | 3.4 | 2.3 | 1.9 | 2.3 | 2.2 |

[†]Values followed by the same letter are not significantly different according to LSD test ($P = 0.05$).
[‡]$LSD_{0.05}$ = least significant differences at $P = 0.05$ level.

same in both management systems. Material costs covered most of the total costs and were significantly higher than the labour + other costs (Table 6).

The total costs were the highest in the Collect-L + Mulch-C treatment ranging from 550.3 to 736.6 EUR $ha^{-1}$ (Table 6). The total cost of Collect-L + Mulch-C treatment was significantly higher than all other treatments with the exception of Lime-S + Mulch-C treatment.

Materials costs were the highest in the Lime-S + Mulch-C treatment ranging from 436.6 to 600.9 EUR $ha^{-1}$ (Table 6) but the material cost of this treatment was not significantly different from the Collect-L + Mulch-C treatment. The material cost of the Lime-S + Mulch-C treatment was significantly higher than all other, not combined, treatments (Lime-S, Collect-L, Mulch-C, Non-sanitized control).

Labour + other costs were the highest in the Collect-L + Mulch-C treatment ranging from 144.7 to 162.0 EUR $ha^{-1}$ (Table 6). The labour + other costs in the Collect-L + Mulch-C treatment were significantly higher than all other treatments.

Values of the revenues of compost from the leaf collection treatments were lower in the organic management system compared to the integrated one (Table 7). The lowest values were in 2017 (30.34 and 37.08 EUR $ha^{-1}$) and the highest in 2015 (35.33 and 43.18 EUR $ha^{-1}$) in the two management systems, and these values were significantly different from each other (Table 7).

## 3.4 | Corrected revenues

Analysis of variance for total revenue, revenue for class I, and revenue of class II indicated significant ($P < 0.05$) differences among years and sanitation treatments in both management systems (Table 3). There were no significant interactions among treatment factors.

Similarly to total yield, the 'overall (treatment)' total annual revenues were significantly higher in the integrated management system (9,626 EUR $ha^{-1}$) compared to the organic one (7,593 EUR $ha^{-1}$, Table 8). The total annual revenue and the revenues for fruit quality categories of class I and II were not affected by sanitation treatments in 2018 in the integrated management system (Table 8). The lowest values of total annual revenue were obtained in the non-sanitized control in 2018 for the organic management system (5,418 EUR $ha^{-1}$), while the highest one (13,127 EUR $ha^{-1}$) were measured in the Collect-L treatment in 2017 in the integrated management system. Total annual revenues in the Lime-S or Mulch-C or Lime-S + Mulch-C treatments were not significantly different from the non-sanitized control treatments in both management systems (Table 8).

Revenues for the fruit quality category of class I were significantly higher in the integrated management system in all years than

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**TABLE 5** Total yield – Yt, yield class I – Cl-1 and yield class II – Cl-2 (t $ha^{-1}$) of cultivar 'Jonagold' in six orchard sanitation treatments (lime sulfur -lime-S, leaf collection-collect-L, mulch covering – mulch-C, lime-S + mulch-C, collect-L + mulch-C and non-sanitized control) in two orchard management systems (integrated and organic) assessed at the harvest of years from 2015 until 2019 (Nagykálló and Eperjeske, Hungary). Yield class I called as dessert apples (fruits were not infected with apple scab disease) and II) yield class II called as apples for industrial processing (fruits were infected with apple scab disease).

| Managements and | 2015 | | | 2016 | | | 2017 | | | 2018 | | | 2019 | | | Overall years | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Treatment/year | Yt | Cl-1 | Cl-2 | Yt | Cl-1 | Cl-2 | Yt | Cl-1 | Cl-2 | Yt | Cl-1 | Cl-2 | Yt | Cl-1 | Cl-2 | Yt | Cl-1 | Cl-2 |
| *Integrated (Nagykálló)* | | | | | | | | | | | | | | | | | | |
| Lime-S | 34.3a[†] | 32.5a | 1.7 | 40.1ab | 35.2ab | 4.7ab | 36.2ab | 34.0a | 2.2ab | 34.3 | 33.2ab | 1.1 | 36.8a | 34.1a | 2.7ab | 36.3a | 33.8a | 2.5ab |
| Collect-L | 39.0bc | 37.5bc | 1.5 | 43.0ab | 38.7b | 4.3a | 39.4b | 37.6b | 2.8b | 37.1 | 36.1ab | 1.0 | 41.9bc | 39.9bc | 2.0a | 40.1ab | 38.0bc | 2.3ab |
| Mulch-C | 34.9a | 33.4a | 1.5 | 40.3ab | 35.4ab | 4.9ab | 35.9a | 34.0a | 1.9a | 34.7 | 33.7ab | 1.0 | 38.1ab | 35.4ab | 2.7ab | 36.8ab | 34.4ab | 2.4ab |
| Lime-S + mulch-C | 35.3abc | 33.8ab | 1.5 | 41.2ab | 36.3abc | 4.8ab | 37.4ab | 35.5ab | 1.9a | 35.1 | 34.2ab | 0.9 | 37.9ab | 35.5ab | 2.4ab | 37.4ab | 35.1abc | 2.3ab |
| Collect-L + mulch-C | 39.6c | 38.2c | 1.4 | 43.7b | 39.9c | 3.8a | 39.2ab | 37.4b | 1.8a | 37.2 | 36.4b | 0.8 | 42.2c | 40.2c | 2.0a | 40.4b | 38.4c | 2.0a |
| Non-sanitized control | 35.3ab | 33.5a | 1.8 | 39.2a | 33.8a | 5.4b | 36.7ab | 34.3ab | 2.4ab | 34.2 | 33.0a | 1.2 | 37.9ab | 35.1ab | 2.8b | 36.7ab | 33.9a | 2.7b |
| $LSD_{0.05}$[‡] | 3.9 | 3.7 | Ns | 3.8 | 3.6 | 1.0 | 3.0 | 3.3 | 0.8 | Ns | 3.2 | Ns | 4.0 | 4.5 | 0.7 | 3.8 | 3.7 | 0.6 |
| *Organic (Eperjeske)* | | | | | | | | | | | | | | | | | | |
| Lime-S | 20.1a | 14.6a | 5.5 | 26.2ab | 14.6a | 11.6 | 21.1ab | 14.6 | 6.6 | 22.2 | 17.2ab | 5.0ab | 24.5 | 16.9ab | 7.6b | 22.8ab | 15.6a | 7.3 |
| Collect-L | 22.9ab | 17.6abc | 5.3 | 29.1ab | 17.8ab | 11.3 | 23.7b | 17.2 | 6.5 | 24.2 | 19.4ab | 4.8ab | 25.9 | 18.8ab | 7.1ab | 25.2ab | 18.2ab | 7.0 |
| Mulch-C | 21.2ab | 15.5ab | 5.7 | 26.2ab | 14.6a | 11.6 | 22.4ab | 15.6 | 6.7 | 22.7 | 17.8ab | 4.9ab | 24.9 | 17.4ab | 7.5ab | 23.5ab | 16.2ab | 7.3 |
| Lime-S + mulch-C | 20.5ab | 15.0ab | 5.5 | 26.4ab | 15.0ab | 11.4 | 22.1ab | 15.8 | 6.3 | 22.9 | 17.9ab | 5.0ab | 24.6 | 17.6ab | 7.0ab | 23.3ab | 16.3ab | 7.0 |
| Collect-L + mulch-C | 23.6b | 18.0b | 5.6 | 29.8b | 18.6b | 11.2 | 23.1ab | 17.0 | 6.1 | 24.5 | 19.8b | 4.6a | 26.1 | 19.2b | 6.9a | 25.4b | 18.5b | 6.9 |
| Non-sanitized control | 20.7ab | 15.0ab | 5.7 | 25.7a | 13.9a | 11.8 | 20.9a | 14.5 | 6.4 | 21.9 | 16.5a | 5.3b | 23.7 | 16.4a | 7.3ab | 22.6a | 16.0ab | 7.3 |
| $LSD_{0.05}$ | 3.3 | 3.0 | Ns | 3.7 | 3.9 | Ns | 2.6 | Ns | Ns | Ns | 3.2 | 0.5 | Ns | 2.7 | 0.6 | 2.7 | 2.8 | Ns |
| Overall (treatment) | | | | | | | | | | | | | | | | | | |
| Integrated | 36.4b | 34.8b | 1.6a | 41.3b | 36.6b | 4.7a | 37.5b | 35.5b | 2.2a | 35.4b | 34.4b | 1.0a | 39.1b | 36.7b | 2.4a | 37.9b | 35.6b | 2.4a |
| Organic | 21.5a | 16.6a | 5.6b | 27.2a | 15.8a | 11.5b | 22.2a | 15.8a | 6.4b | 23.1a | 18.1a | 4.9b | 25.0a | 17.7a | 7.2b | 23.8a | 16.8a | 7.1b |
| $LSD_{0.05}$ | 4.2 | 4.0 | 1.5 | 4.0 | 4.1 | 1.8 | 3.2 | 3.5 | 1.6 | 5.1 | 3.8 | 0.9 | 4.3 | 5.0 | 1.4 | 4.2 | 4.0 | 1.4 |

[†]Values followed by the same letter are not significantly different according to LSD test ($P = 0.05$).

[‡]$LSD_{0.05}$ = least significant differences at $P = 0.05$ level.b.

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**TABLE 6** Total costs of various orchard sanitation methods (EUR $ha^{-1}$) and cost types divided into material cost and labour cost with mechanical, depreciation and other costs in both integrated and organic orchards (2015–2019, Nagykálló and Eperjeske, Hungary). The costs were the same in both integrated and organic management systems in a hectare as the same sanitation treatments were prepared for both orchards.

| Costs and treatment/year | 2015 | 2016 | 2017 | 2018 | 2019 | Overall (year) |
|---|---|---|---|---|---|---|
| Total cost | | | | | | |
| Lime-S | 155.1 ab[†] | 154.3b | 157.4b | 158.5ab | 157.5b | 156.6b |
| Collect-L | 169.9 b | 172.8b | 181.0b | 187.3b | 190.6b | 180.3b |
| Mulch-C | 544.4c | 377.5c | 486.3c | 549.3c | 516.8c | 494.9c |
| Lime-S + mulch-C | 699.5 cd | 531.8d | 643.7d | 707.8 cd | 674.3d | 651.4d |
| Collect-L + mulch-C | 714.3d | 550.3d | 667.3d | 736.6d | 707.5d | 675.2d |
| Non-sanitized control | 0.0a | 0.0a | 0.0a | 0.0a | 0.0a | 0.0a |
| $LSD_{0.05}$[‡] | 157.1 | 137.9 | 150.3 | 159.7 | 155.6 | 152.3 |
| Material cost | | | | | | |
| Lime-S | 134.6b | 134.4b | 136.6b | 137.1b | 136.1b | 135.8b |
| Collect-L | 97.7ab | 103.3ab | 108.8ab | 112.9ab | 116.3ab | 107.8ab |
| Mulch-C | 465.5c | 302.4c | 402.2c | 464.2c | 429.5c | 412.7c |
| Lime-S + mulch-C | 600.2d | 436.6d | 538.8d | 600.9d | 565.1d | 548.3d |
| Collect-L + mulch-C | 563.6 cd | 405.6 cd | 511.2 cd | 577.5 cd | 545.5 cd | 520.7 cd |
| Non-sanitized control | 0.0a | 0.0a | 0.0a | 0.0a | 0.0a | 0.0a |
| $LSD_{0.05}$ | 121.1 | 115.3 | 122.2 | 125.7 | 119.1 | 120.2 |
| Labour cost + mechanical, depreciation cost + other cost | | | | | | |
| Lime-S | 20.5a | 19.9a | 20.8a | 21.4a | 21.4a | 20.8a |
| Collect-L | 72.2b | 69.5b | 72.2b | 74.4b | 74.3b | 72.5b |
| Mulch-C | 78.9b | 75.1b | 84.1b | 85.1b | 87.3b | 82.1b |
| Lime-S + mulch-C | 99.3b | 95.2b | 104.9b | 106.9b | 109.2b | 103.1b |
| Collect-L + mulch-C | 150.7c | 144.7c | 156.1c | 159.1c | 162.0c | 154.5c |
| Non-sanitized control | 0.0a | 0.0a | 0.0a | 0.0a | 0.0a | 0.0a |
| $LSD_{0.05}$ | 42.1 | 38.2 | 45.8 | 40.3 | 44.7 | 42.2 |
| Overall (treatment) | | | | | | |
| Total cost | 380.5b | 243.3b | 299.6c | 332.3c | 316.4c | 314.4b |
| Material cost | 310.3b | 155.3b | 190.5b | 212.4b | 201.0b | 213.9b |
| Labour + other costs | 70.3a | 67.4a | 73.0a | 74.5a | 75.7a | 72.2a |
| $LSD_{0.05}$ | 100.3 | 95.3 | 102.7 | 106.2 | 104.2 | 101.6 |

[†]Values followed by the same letter are not significantly different according to LSD test ($P = 0.05$).
[‡]$LSD_{0.05}$ = least significant differences at $P = 0.05$ level.

revenues for the fruit quality category of class I in the organic one, while class II was the opposite (Table 8). Collect-L + Mulch-C treatment showed the highest values for revenues for class I in most cases, for example, in 2015, 2016, 2018 and 2019 in both management systems (Table 8). On the other hand, Collect-L + Mulch-C treatment showed the lowest values for revenues for class II in both management systems in all years (except for 2015 in the organic management system).

For both classification categories, Lime-S or Mulch-C or Lime-S + Mulch-C treatments were not significantly different from the non-sanitized control treatments in both management systems and in all years with the exception of class II in 2017 for integrated management systems (Table 8).

## 3.5 | Income surplus or deficit of sanitations compared to the non-sanitized control

Analysis of variance for surplus income/deficit indicated significant ($P < 0.05$) differences among years and sanitation treatments in both management systems (Table 3). There were no significant interactions among treatment factors.

The highest surplus income (1,238 EUR $ha^{-1}$) was obtained in the Collect-L treatment in 2019 while the highest surplus deficit (−593 EUR $ha^{-1}$) in the Lime-S + Mulch-C treatment in 2019 in the integrated management system. Surplus income was obtained in the treatments of Collect-L and Collect-L + Mulch-C in all years and both management systems, with the exception of Collect-L + Mulch-C

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**TABLE 7** Revenues of compost from leaf collection treatments (EUR $ha^{-1}$) in integrated and organic orchards between 2015 and 2019 (Nagykálló and Eperjeske, Hungary).[†]

| Year/management system | Integrated orchard | Organic orchard |
|---|---|---|
| 2015 | 43.18b[‡] | 35.33b |
| 2016 | 38.76ab | 31.71ab |
| 2017 | 37.08a | 30.34a |
| 2018 | 37.95ab | 31.05ab |
| 2019 | 40.70ab | 33.30ab |
| $LSD_{0.05}$[§] | 5.91 | 4.95 |
| *Overall years* | *39.53* | *32.35* |

[†]Calculated by the average prices of Nitrosol 30%, Superphosphate 20%, Potassium chloride granules 60% based on HCSO (2020c) multiplied the amounts of producible equivalent NPK active ingredient of compost from collecting leaves.
[‡]Values followed by the same letter are not significantly different according to LSD test ($P$= 0.05).
[§]$LSD_{0.05}$ = least significant differences at $P = 0.05$ level.

treatment in 2018 in the integrated system (Table 9). Treatments of Collect-L and Collect-L + Mulch-C were significantly higher compared to all other treatments in all years and in both management systems, with the exceptions of 2018 in the integrated management system, and of 2017 and 2018 in the organic one.

## 3.6 | Correlation and linear regression analyses among parameters

### 3.6.1 | Correlation among parameters

Descriptive statistics showed that IQRs, Kernel density estimations and frequency distributions were the widest for the parameters of total revenue, revenue for class I and surplus for both management systems (Figure 1). The Pearson correlation coefficient ($r$) was the highest ($r = 0.999$) between total annual revenue (Rt) and revenue for yield class I (Rcl1) within the integrated management system (Figure 1). Seven correlation pairs were significant (P = 0.05) for both management systems; and all these parameter pairs correlated positively (total yield vs yield class I, total yield vs surplus, yield class I vs surplus, fruit scab incidence scab vs yield class II, revenue for class II vs total revenue, revenue for class II vs revenue for class I and total revenue vs revenue for class I; Figure 1).

### 3.6.2 | Linear regression analyses among parameters

The linear regression analysis showed significant relationships for all seven pair-variables with $r = 0.721–0.985$, P = 0.04–0.001 and with $r = 0.702–0.982$, P = 0.045–0.001 for the integrated and organic management systems, respectively. The slopes of the seven pair variables differed significantly (P = 0.05) between the integrated and organic management systems, except for the total yield vs yield class I, fruit scab incidence vs yield class II, and total revenue vs revenue for class I. In the case of the total yield vs yield class I relationship, values were clustered separately for integrated and organic management systems (Figure 2a). In the cases of total yield vs surplus and yield class I vs surplus relationships, a wide range of surplus was determined for both management systems but the two systems were separately grouped (Figure 2b,c). In the case of fruit scab incidence vs yield class II, the increase in scab incidence was directly proportional to the increase of yield class II in both management systems (Figure 2d). In the case of revenue for class II vs total revenue and revenue for class II vs revenue for class I relationships, similar patterns were detected across the two management systems (Figures 2e,f). An increase in total revenue corresponded linearly to an increase in revenue for class I in both management systems (Figure 2g).

### 3.6.3 | Principal component analyses among parameters

PCA explained 95% of the total variance and PCA was confirmed by three PCs according to the RMSR. RSMR was 0.03, which indicated a good fit. PC1 accounted for 53% of the total variance and correlated with scab incidence, total yield, yield class I, yield class II, and revenue for yield class II (Figures 3a,b). PC2 accounted for 29% of the total variance and correlated with the total annual revenue and revenue for yield class I. PC3 accounted for 13% of the total variance and correlated only with the surplus variable (Figures 3a,b).

In the biplot figure representing the management systems, the PC1 and PC2 axes played discernible roles for both integrated and organic management systems (Figure 3a). However, the biplot figure indicated a greater dominance of the PC2 axis for the organic management system, in contrast to the more pronounced influence of the PC1 axis for the integrated system (Figure 3a).

According to the biplot figure for sanitation treatments, the PC1 and PC2 axes played considerable roles across the six sanitation treatments (Figure 3b). Both PC1 and PC2 axes were dominant for the treatments of Lime-S, Mulch-C, Lime-S + Mulch-C, and non-sanitized control, whereas the PC2 axis was more dominant for the treatments of Collect-L and Collect-L + Mulch-C (Figure 3b).

The long arrows' length and proximity of the variables of scab incidence, total yield, yield class I, yield class II, total annual revenue, revenue for yield class I, revenue for yield class II and surplus indicated a strong decisive role primarily for PC2. All these findings highlighted robust associations among biological and cost–benefit parameters (Figure 3a,b).

## 4 | DISCUSSION

In this 5-year study, we determined the yield amount, yield classification categories, costs, annual revenues and income surplus or deficit

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**TABLE 8** Total annual revenues ($R_{Tot}$) and revenues for fruit quality categories of class I and II ($R_{Cl\text{-}1}$ and $R_{Cl\text{-}2}$) in EUR ha$^{-1}$ of apple cultivar 'Jonagold' in six orchard sanitation treatments (lime sulfur – lime-S, leaf collection – collect-L, mulch covering – mulch-C, lime-S + mulch-C, collect-L + mulch-C and non-sanitized control) after harvest (October–November) in integrated and organic orchards between 2015 and 2019 (Nagykálló and Eperjeske, Hungary). Yield class I called as dessert apples (fruits were not infected with apple scab disease) and II) yield class II called as apples for industrial processing (fruits were infected with apple scab disease).

| Managements and | 2015 | | | 2016 | | | 2017 | | | 2018 | | | 2019 | | | Overall years | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Treatment/year | $R_{Tot}$ | $R_{Cl\text{-}1}$ | $R_{Cl\text{-}2}$ | $R_{Tot}$ | $R_{Cl\text{-}1}$ | $R_{Cl\text{-}2}$ | $R_{Tot}$ | $R_{Cl\text{-}1}$ | $R_{Cl\text{-}2}$ | $R_{Tot}$ | $R_{Cl\text{-}1}$ | $R_{Cl\text{-}2}$ | $R_{Tot}$ | $R_{Cl\text{-}1}$ | $R_{Cl\text{-}2}$ | $R_{Tot}$ | $R_{Cl\text{-}1}$ | $R_{Cl\text{-}2}$ |
| *Integrated (Nagykálló)* | | | | | | | | | | | | | | | | | | |
| Lime-S | 8378a[†] | 8166a | 212ab | 7808ab | 7520ab | 288abc | 11972a | 11605a | 367bc | 6,861 | 6,802 | 59 | 10837a | 10529a | 308bc | 9171a | 8924a | 247ab |
| Collect-L | 9586bc | 9402bc | 184ab | 8477b | 8210bc | 267ab | 13127c | 12819b | 308ab | 7,449 | 7,395 | 54 | 12534b | 12299b | 235ab | 10235bc | 10025b | 210a |
| Mulch-C | 8556a | 8370a | 186ab | 7823ab | 7524ab | 299bc | 11923a | 11607a | 316a | 6,957 | 6,903 | 54 | 11235a | 10925a | 310bc | 9299ab | 9066a | 233ab |
| Lime-S + mulch-C | 8663ab | 8483ab | 180ab | 8022ab | 7726abc | 296bc | 12428abc | 12105ab | 323a | 7,058 | 7,011 | 47 | 11227a | 10949a | 278abc | 9480abc | 9255ab | 225ab |
| Collect-L + mulch-C | 9749c | 9576c | 173a | 8701b | 8464c | 237a | 13067bc | 12767b | 300a | 7,498 | 7,454 | 44 | 12632b | 12400b | 232a | 10329c | 10132b | 197a |
| Non-sanitized control | 8627a | 8413a | 214b | 7502a | 7168a | 334c | 12112a | 11715a | 397c | 6,826 | 6,762 | 64 | 11147a | 10821a | 326c | 9243ab | 8976a | 267b |
| $LSD_{0.05}$[‡] | 960 | 927 | 40 | 911 | 905 | 56 | 1,090 | 1,020 | 61 | Ns[§] | Ns | Ns | 1,010 | 1,001 | 75 | 942 | 917 | 50 |
| *Organic (Eperjeske)* | | | | | | | | | | | | | | | | | | |
| Lime-S | 6482a | 5322a | 1,160 | 5735a | 4499b | 1,236 | 9145ab | 7220a | 1925b | 5582a | 5111a | 471 | 9078ab | 7544a | 1534b | 7204a | 5939a | 1265bc |
| Collect-L | 7521bc | 6389b | 1,132 | 6687b | 5482b | 1,205 | 10412c | 8529c | 1883ab | 6212bc | 5758b | 454 | 9846b | 8427b | 1419ab | 8136bc | 6917b | 1219ab |
| Mulch-C | 6840ab | 5622a | 1,218 | 5741a | 4508b | 1,233 | 9713abc | 7751ab | 1962b | 5749abc | 5287ab | 462 | 9294ab | 7790ab | 1504ab | 7467abc | 6192a | 1276c |
| Lime-S + mulch-C | 6627a | 5466a | 1,161 | 5838a | 4624b | 1,214 | 9646abc | 7800ab | 1846ab | 5786abc | 5313abc | 473 | 9267ab | 7850ab | 1417ab | 7433ab | 6211a | 1222ab |
| Collect-L + mulch-C | 7733c | 6542b | 1,191 | 6926b | 5733b | 1,193 | 10187bc | 8405bc | 1782a | 6329c | 5888c | 441 | 9974b | 8586b | 1388a | 8230c | 7031b | 1199a |
| Non-sanitized control | 6666a | 5459a | 1,207 | 5532a | 4270b | 1,262 | 9033a | 7159a | 1874ab | 5418a | 4912a | 506 | 8805a | 7340a | 1465ab | 7091a | 5828a | 1263bc |
| $LSD_{0.05}$ | 739 | 540 | Ns | 610 | 491 | Ns | 988 | 708 | 135 | 593 | 530 | Ns | 981 | 832 | 128 | 782 | 514 | 53 |
| Overall (treatment) | | | | | | | | | | | | | | | | | | |
| Integrated | 8927b | 8735b | 192a | 8056b | 7769b | 287a | 12438b | 12103b | 335a | 7108a | 7055b | 54a | 11227a | 11321b | 282a | 9626b | 9396b | 230a |
| Organic | 6978a | 5800a | 1178b | 6077a | 4853a | 1224b | 9689a | 7811a | 1879b | 5846b | 5378a | 468b | 12632b | 7923a | 1455b | 7593a | 6353a | 1241b |
| $LSD_{0.05}$ | 853 | 774 | 52 | 811 | 732 | 63 | 1,052 | 1,032 | 152 | 644 | 621 | 124 | 999 | 1,021 | 132 | 822 | 615 | 52 |

[†]Values followed by the same letter are not significantly different according to LSD test ($P = 0.05$).

[‡]$LSD_{0.05}$ = least significant differences at $P$= 0.05 level.

[§]ns = nonsignificant.

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TABLE 9 Surplus income or deficit (EUR $ha^{-1}$) of apple cultivar 'Jonagold' in five orchard sanitation treatments (lime sulfur -lime-S, leaf collection-collect-L, mulch covering – mulch-C, lime-S + mulch-C, collect-L + mulch-C) after harvest (October–November) in integrated and organic orchards between 2015 and 2019 (Nagykálló and Eperjeske, Hungary). The surplus income or deficit (EUR $ha^{-1}$) of each sanitation treatment was calculated as follows: the cost of a sanitation treatment was subtracted from the corrected revenues of the sanitation treatment and then the revenue of the non-sanitized control was also subtracted from this value.

| Management and treatment/year | 2015 | 2016 | 2017 | 2018 | 2019 | Overall (year) |
|---|---|---|---|---|---|---|
| *Integrated (Nagykálló)* | | | | | | |
| Lime-S | -404a[†] | 152a | -297b | -123b | -466a | -228a |
| Collect-L | 833c | 841b | 871d | 474c | 1238c | 851c |
| Mulch-C | -615a | -57a | -675a | -418a | -428a | -439a |
| Lime-S + mulch-C | -663a | -11a | -328b | -475a | -593a | -414a |
| Collect-L + mulch-C | 452b | 688b | 325c | -27b | 819b | 451b |
| $LSD_{0.05}$[‡] | 340 | 236 | 332 | 299 | 407 | 323 |
| *Organic (Eperjeske)* | | | | | | |
| Lime-S | -339b | 48a | -45a | 6bc | 116a | -43a |
| Collect-L | 720d | 1014b | 1229c | 638d | 884c | 897c |
| Mulch-C | -371b | -169a | 194ab | -218ab | -28a | -118a |
| Lime-S + mulch-C | -739a | -227a | -30a | -340a | -212a | -310a |
| Collect-L + mulch-C | 387c | 875b | 516b | 206c | 495b | 496b |
| $LSD_{0.05}$ | 332 | 395 | 416 | 326 | 352 | 364 |

[†]Values followed by the same letter are not significantly different according to LSD test ($P = 0.05$).
[‡]$LSD_{0.05}$ = least significant differences at $P = 0.05$ level.

of five non-chemical sanitation treatments (Lime-S, Collect-L, Mulch-C, Lime-S + Collect-L, Collect-L + Mulch-C) in integrated and organic commercial apple orchards. Furthermore, we established significant correlations among biological and cost–benefit parameters for the sanitation practices in both management systems.

The differences in yield and disease/pest damage between integrated and organic management systems were extensively documented in previous studies and it was concluded that the production risk was higher in the organic orchards than in the integrated ones (e.g. Holb et al., 2012, 2017, 2022; Reganold et al., 2001). Relatively few studies evaluated the differences in cost, income and revenue among various apple management systems (e.g. Glover et al., 2002; Goossens et al., 2017; Taylor & Granatstein, 2013). In agreement with this study, authors concluded that the differences among apple management systems were dependent upon the greater yield and the better fruit quality in the integrated or conventional management system compared to the organic one (e.g. Ekinci et al., 2020; Glover et al., 2002; Orpet et al., 2020; Reganold et al., 2001; Taylor & Granatstein, 2013). Furthermore, the nutritional and crop protection efficacy is lower and costs are higher in organic orchards compared to integrated ones. To mitigate the production risk in the organic management system, substantial governmental subsidies are provided, and higher sales prices exist for organic products, albeit varying by growing regions (Lampkin & Padel, 1994; Sudheer, 2015). However, the implementation of improved production technology elements, such as the efficient use of sanitation practices, can help to reduce costs and augment surplus revenue (Table 9). This study confirmed that some sanitation practices helped to increase the income in organic apple production throughout the increase of total yield, class I fruit and income surplus in the Collect L and/or Collect-L + Mulch treatments compared to the non-sanitized control (Tables 5 and 9).

This study demonstrates a notable increase in the proportion of lower-grade (class II) fruits in the organic management system when compared to the integrated one (Table 5). Due to the reduced efficacy of pest control in organic orchards, the incidence of pest and disease damage is also higher, leading to yield losses (Caffi et al., 2017; Holb et al., 2017; Reganold et al., 2001). However, in this study, not only the total yield was reduced considerably but the proportion of lower-grade (class II) fruits increased in the organic system when compared to the integrated one (Table 5). These findings significantly impact financial returns, too; as although the income derived from class II fruits was greater in the organic system than in the integrated one; the income derived from the higher-grade (class I) fruits was greatly higher in the integrated system due to higher fruit prices and the higher proportion of class I fruit when compared to the organic one. Consequently, this led to a markedly higher total revenue in the integrated system compared to the organic one. This clearly underscores that crop quality aspects can play a decisive role in the profitability of apple production (Cheng et al., 2022; Goossens et al., 2017; Łakomiak & Zhichkin, 2020; Taylor & Granatstein, 2013).

In 2015 and 2019, the Collect L and Collect-L + Mulch treatments yielded a greater surplus income in the integrated system as opposed to the organic one (Table 9). Conversely, surplus income was higher in the organic system during the remaining years (2016, 2017, and 2018). This discrepancy may arise because the organic system is more sensitive to environmental and annual fluctuations in terms of yield quantity and quality, in contrast to the integrated one (e.g. Goossens et al., 2017; Reganold et al., 2001; Taylor &

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**FIGURE 1** The effect of apple orchard sanitation management strategies on yield, incidence of the fungal disease apple scab, and orchard revenue. Pearson correlation coefficients (Corr), boxplots (1.5xIQR, LQ, median, UQ, 1.5xIQR and outliers), density plots (kernel density estimation), data plotting for correlation pairs (red and blue pints) and frequency distribution by management groups (integrated and organic) among six orchard sanitation treatments (lime sulfur -lime-S, leaf collection-collect-L, mulch covering – mulch-C, lime-S + mulch-C, collect-L + mulch-C and non-sanitized control) in integrated (int, red colour) and organic (org, blue colour) orchards (Nagykálló and Eperjeske, Hungary, 2015–2019). *, **, *** represent significant correlations at P = 0.05, 0.01, and 0.001 levels, respectively. Scab: apple scab disease incidence, yield: total yield, clas.1: yield class I, clas.2: yield class II, Rt: total annual revenue, Rcl1: revenue for yield class I, Rcl2: revenue for yield class II and surp: income surplus/deficit. Yield class I called as dessert apples (fruits were not infected with apple scab disease) and II) yield class II called as apples for industrial processing (fruits were infected with apple scab disease). In the correlation analyses, the Bonferroni correction test was used.

Granatstein, 2013). Therefore, despite higher product prices in the organic system compared to the integrated one, the income surplus may vary significantly from one year to another, occasionally falling below that of the integrated system.

The applicability of other sanitation treatments (Mulch, Lime-S, Lime S + Mulch) within the integrated system raises questions, primarily due to the demonstrated income deficit associated with these practices. However, the applicability of these treatments is less questionable in the organic system, despite the income deficit of these sanitation treatments. The reason is that the value of such sanitation practices cannot be solely assessed from a financial standpoint as they may have positive effects on environmental integrity,

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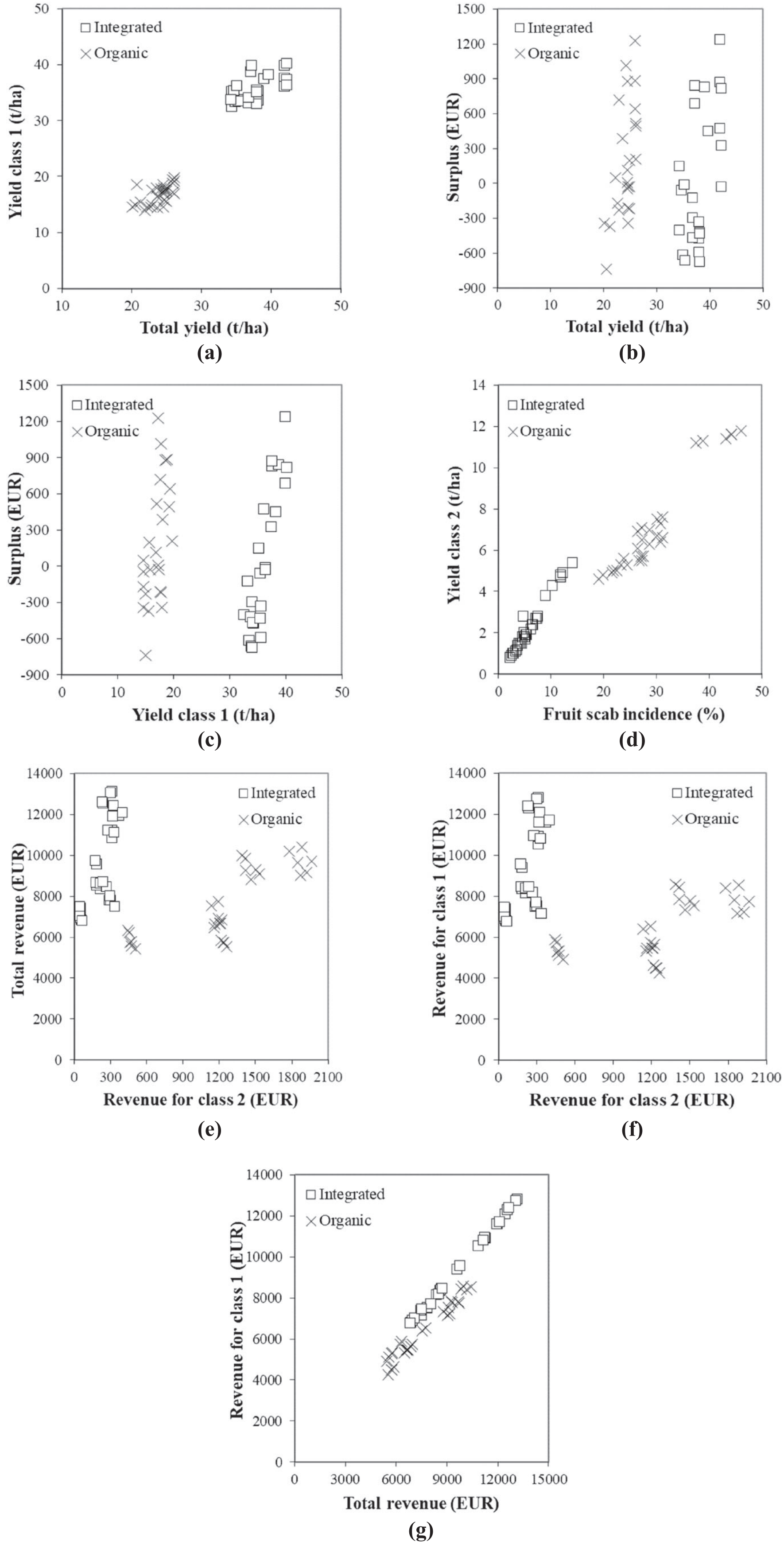


**FIGURE 2** Relationship between total yield and yield class I (a), total yield and surplus (b), yield class I and surplus (c), fruit scab incidence and yield class II (d), revenue for class II and total revenue (e), revenue for class II andrevenue for class I (f), and total revenue and revenue for class I (g) of six orchard sanitation treatments (lime sulfur, Lime-S; leaf collection-Collect-L; mulch covering, Mulch-C; Lime-S + Mulch-C, Collect-L + Mulch-C, and non-sanitizedcontrol) in integrated and organic management systems (Nagykálló and Eperjeske, Hungary, 2015–2019).

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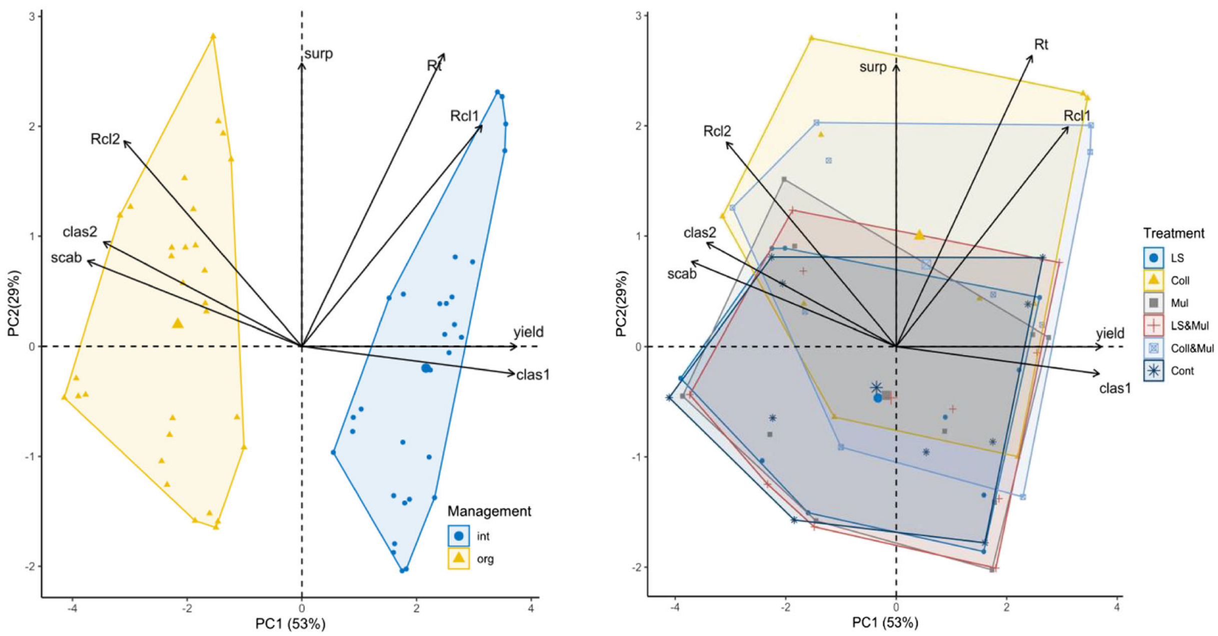


(a) (b)

**FIGURE 3** The effect of apple orchard sanitation management strategies on yield, incidence of the fungal disease apple scab, and orchard revenue. Biplot diagram of principal component analyses (PCA) prepared on biological and economic measures (scab: apple scab disease incidence, yield: total yield, clas1: yield class I, clas2: yield class II, Rt: total annual revenue, Rcl1: revenue for yield class I, Rcl2: revenue for yield class II and surp: income surplus/deficit) in six orchard sanitation treatments (LS: lime sulfur, Coll: leaf collection, Mul: mulch covering, Cont: non-sanitized control, LS&Mul and Coll&Mul) in integrated (int) and organic (org) management systems (Nagykálló and Eperjeske, Hungary, 2015–2019). Yield class I called as dessert apples (fruits were not infected with apple scab disease) and II) yield class II called as apples for industrial processing (fruits were infected with apple scab disease). A: 95% confidence intervals were separated for the two management systems and B: 95% confidence intervals were separated for the six sanitation treatments.

biodiversity, and nutrient return (e.g. Marliac et al., 2015; Pfiffner et al., 2019; Teravest et al., 2010).

In this study, the utilization of mulch cover did not result in significant economic benefits. Furthermore, the residual mulch must be removed later in the season and treated (i.e. composting costs and the nutrient ingredients of mulch compost are less favourable than leaf composting). Additionally, mulch cover exhibits several drawbacks, including i) its potential to attract pests detrimental to cultivated crops (Merwin et al., 1999; Merwin & Stiles, 1994), ii) its adverse impact on soil microbial communities, and iii) its potential to increase the severity of apple replant disease (e.g. St Laurent et al., 2008; Yao et al., 2009). Nonetheless, mulch cover also confers certain biological advantages, such as i) offering habitat and refuge for natural predators (e.g. Marliac et al., 2015; Miñarro & Dapena, 2003; Pfiffner et al., 2019; Yan et al., 1997), enhancing soil carbon-to-nitrogen ratios, and iii) increasing essential plant nutrients in the soil (Atucha et al., 2011; Teravest et al., 2010). These biological roles must be assessed prior to determining the suitability of employing mulch cover in an organic orchard. If biological arguments are strong enough for mulch cover utilization, its value may be synergistically combined with Collect-L. This combination has the potential to economically enhance the biological efficacy of the mulch cover treatment, which was confirmed by this study (Table 9).

In this study, the utilization of lime sulphur was proved economically in specific years (Table 9). Furthermore, lime sulphur can serve as a source of sulphur nutrition and is also known as a post-infection fungicide against various fungal diseases (Holb et al., 2003; Jamar et al., 2008). Additionally, it has an excellent disinfectant activity on disease inoculum present on fallen leaves (Cromwell et al., 2011; DeLong et al., 2018), which can be a valuable option if there is no possibility to collect and compost fallen leaves. Nevertheless, it needs to be noted that the use of lime sulphur raises significant environmental concerns and current regulations are advised to restrict the use of lime sulphur in apple orchards.

Leaf collection is one of the most successful sanitation methods both economically and biologically (Tables 5, 8 and 9). This treatment not only generates surplus income (Table 9) but also facilitates nutrient recycling through the composting of collected fallen leaves (Ekinci et al., 2021; Holb, 2006). As these leaves originate from the same orchard, the plant organic matter is reintegrated back into the same area, thereby serving as an environmentally benign nutrient source. Consequently, this organic nutrient contributes to a reduction in the total nutrient costs of the orchard. These issues can bear particular significance in an organic orchard, where a balanced nutrient return can be a challenging endeavour. Thus, leaf collection not only provides disease and cost reduction but also results in a surplus

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income, which can be valuable, especially for biologically and economically sensible production systems, such as the organic one.

In this study, we observed that the integrated system consistently had higher yield and fruit quality than the organic system, as previous studies also confirmed (e.g. Glover et al., 2002; Goossens et al., 2017; Holb et al., 2012, 2017; Reganold et al., 2001). Furthermore, the integrated management system performed better not only in yield and quality but also in surplus revenues. While our data strongly supports better overall production and integration advantages for the integrated system, it is essential to note that the organic system offers economically not expressible valuable benefits, such as positive impacts on the environment and biodiversity. These aspects need to be taken into consideration in the case of organic production systems. This is particularly relevant for the combined treatments, where the costs were universally elevated (Table 6) and economic benefit could not be justified for all combined cases (Tables 8 and 9). Hence, combined cases should be handled more carefully from a cost–benefit perspective, as they can cause economic deficit or modest surplus income. However, from a biological and environmental standpoint, they may result in additional positive effects. In light of this, especially in organic apple orchards, it is worthwhile to carefully assess the potential application of combined sanitation treatments based on their broader spectrum of benefits.

Some previous apple studies showed that cost–benefit data sets corresponded with certain biological values, such as yield amount and quality (Glover et al., 2002; Wani et al., 2021); however, they did not show correlation effects among biological and cost–benefit parameters. In this study, several significant pairwise correlations indicated a strong relationship among biological and cost–benefit factors (e.g. total yield vs surplus, class I vs surplus, and fruit scab vs class II) in both management systems, particularly when treatment and year data set were combined (Figures 1 and 2). Further relationships were detected among nearly all parameters in the PC1 and PC2 of the PCA (Figure 3). These findings underscore that the potential marketing positions of the sanitation treatments are predominantly dependent on the joined relationships among biological and financial factors.

Overall, this work clearly demonstrated that irrespective of the year or management system, Collect-L and Collect-L + Mulch-C treatments ensured a consistent surplus income under the given fruit price categories and treatment costs (Table 9). Thus, this study not only affirms significant scab reduction of these sanitation practices, in agreement with previous studies of Holb (2006, 2007) but also showed increased financial advantages for both management systems. Nevertheless, one of the key questions on cost–benefits is which reductions in fruit price and/or treatment cost increasement could reduce the surplus income of these sanitation practices to zero, i.e. whether the future fruit prices can cope with the unpredictable rises of energy prices, which are reflected in production costs. Consequently, the stability of surplus income arising from sanitation practices is contingent on a multitude of factors, warranting further in-depth research.

## 5 | CONCLUSIONS

Our study demonstrated that orchard sanitation treatments could not only reduce scab incidence, and enhance the quality of fruit yield, but also showed positive cost–benefit outcomes in both integrated and organic apple orchards.

Specifically, our findings clearly showed that Collect-L and Collect-L + Mulch-C treatments can be effectively used across all years and in both management systems, from both biological (yield amount, fruit quality, disease reduction) and cost–benefit (cost, revenue and income surplus) point of views. However, it needs to be noted that the combined sanitation treatment is more sensitive and less stable to seasonal effects compared to the treatment applied alone.

Other sanitation treatments cannot be recommended for the integrated management system either from a cost–benefit or biological standpoint. Nonetheless, the application of sanitation treatments, within the organic management system, may be worth considering, even if economically is not justified. This is due to i) hard to judge the financial value of the positive environmental effects and ii) due to the limited availability of effective biological plant protection options. As such, sanitation practices can be an inevitable option to reduce scab incidences in organic apple orchards.

## AUTHOR CONTRIBUTION

**Gabriella Antal:** Data curation; methodology; investigation; writing—original draft; visualization; investigation. **Szilárd Szabó:** Methodology; formal analysis; software; writing—review and editing. **Péter Szarvas:** Data collectio; writing—review and editing; investigation. **Imre J. Holb:** Conceptualization; methodology; software; validation; writing—original draft; writing—review and editing; resources; supervision; project administration; funding acquisition.

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## CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in the Dataverse Project, University of Debrecen, Hungary (2023). The data set was deposited in the following link including data repository doi number: https://doi.org/10.48428/ADATTAR/HK7ZGC.

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