

## Effects of Inorganic Substances Used in Late-Season Apple Scab Management on Disease Incidence and Productivity in Two Orchard Systems of cv. ‘Ligol’

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**Abstract.** In apple production, reducing the use of synthetic pesticides may be possible by using inorganic substances in the second part of the season against secondary scab infections. An investigation was conducted to evaluate strategies for controlling apple scab. The trial comprised the following treatments: synthetic fungicides applied to manually pruned slender-spindle canopy trees; synthetic fungicides applied during the primary scab infection period and inorganic substances during the secondary period; and synthetic fungicides applied only during the early stages of apple scab infection for mechanically pruned trees with a vertical axis canopy. The incidence of apple scab in ‘Ligol’ was strongly influenced by season, treatment, and canopy management, with secondary infection periods being critical for disease control. Combining synthetic fungicides in the primary period with inorganic substances in the secondary period effectively reduced fruit infection while limiting chemical use. Vertical-axis orchard systems showed higher yield efficiency per canopy volume. Overall, integrated management strategies, including pruning, canopy design, and targeted fungicide application are essential for optimising yield and fruit health under variable seasonal conditions.

**Key words:** *Malus*, *Venturia*, susceptible cultivar, synthetic fungicides, canopy.

### Introductions

The life cycle of *Venturia inaequalis* includes a phase where it survives the winter in fallen leaves as pseudothecia, which are its sexual fruiting structures. In the spring, these structures release ascospores, which serve as the primary source of infection (Biggs & Stensvand, 2014). Preventing these initial infections caused by ascospores is essential for controlling subsequent infections on leaves and fruit, which is the main target of chemical treatments for apple scab (Belete & Boyraz, 2017). Monitoring the onset of ascospore release is a key part of effectively managing the disease, as it enables timely measures to control primary infections (Phillion *et al.*, 2019; Turan *et al.*, 2018).

After sexual reproduction, the fungus produces conidia, which serve as secondary sources of infection. These asexual spores are generated sequentially at the tips of specialised short hyphae known as conidiophores (Biggs & Stensvand, 2014; Belete & Boyraz, 2017). Conidiophores form within dense

fungal growth located between the plant’s cuticle and epidermis, eventually breaking through the leaf surface (Bowen *et al.*, 2011). Young scab lesions often have a velvety texture due to the presence of conidia and conidiophores.

Conidia production is influenced by environmental conditions, particularly temperature and humidity. Optimal development occurs at temperatures between 15 – 20 °C and relative humidity of 90% or higher (Belete & Boyraz, 2017; González-Domínguez *et al.*, 2017). Rain helps disperse the conidia, which then adhere to the surfaces of young apple or pear tissue, germinate, and penetrate the cuticle to initiate infection. Cool, wet conditions during spring, summer, and autumn are ideal for secondary infections, leading to multiple cycles of conidial production and disease spread (Biggs & Stensvand, 2014).

Pruning is an essential cultural practice that can help manage *Venturia inaequalis*, as it improves light penetration and air circulation within the tree canopy. This, in turn, reduces humidity levels and lowers

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the chances of infection and spore production by the fungus (Holb, 2005). The removal of shoots that show signs of wood scab also decreases the amount of infectious material present in the orchard (Holb, 2005; Rancāne *et al.*, 2023a). Additionally, proper orchard design, particularly regarding tree spacing, plays a key role in disease management. Planting trees with sufficient (larger) distance between them helps reduce infection risk by limiting the spread of spores and promoting faster drying after rainfall or irrigation (Majeed *et al.*, 2017).

Effective management of apple scab is critical in both conventional and sustainable apple production systems (Ekinici *et al.*, 2020; Holb *et al.*, 2009; Orpet *et al.*, 2020). As a major disease affecting apple crops, scab poses significant economic challenges and typically requires frequent fungicide applications for effective control (Carisse *et al.*, 2007; 2009). Fungicides remain the most widely used method for managing the disease and generally provide reliable results (Fiaccadori, 2018). However, the success of fungicide treatments heavily depends on proper timing, especially during the initial phase of *V. inaequalis* infections. If these early applications fail, the pathogen produces secondary spores (conidia) on the infected plant tissue, leading to repeated infection cycles throughout the season. This polycyclic nature of the disease may demand numerous additional fungicide applications (Carisse *et al.*, 2009). Although chemical fungicides are effective, their repeated use – often exceeding ten sprays per season – raises concerns over the cost, sustainability, and environmental impact (Stewart *et al.*, 2023; Valiūškaitė *et al.*, 2017).

Concerns are increasing regarding the continued use of synthetic pesticides on food crops due to their potential negative impact on both human health and the environment (Holb *et al.*, 2009; Holb & Kunz, 2016; Jamar *et al.*, 2007; Wightwick *et al.*, 2009). To promote more sustainable farming practices and reduce biodiversity loss, the European Union introduced the “Farm to Fork Strategy,” which aims to cut pesticide use and associated risks by 50% by 2030, using 2015–2017 levels as a baseline (European Commission, 2020). Another challenge with synthetic fungicides is the increasing occurrence of fungicide resistance (Cox, 2015; Rancāne *et al.*, 2023b; Stević *et al.*, 2010).

As a result, global efforts are underway to explore effective alternatives to synthetic fungicides for managing plant diseases. Farmers are encouraged to modify their spraying strategies, particularly during the period when secondary infections are most likely to spread (Paušič *et al.*, 2023). In the latter part of the growing season, organic apple production allows for frequent application of a range of alternative substances. These include carbonates, mineral clays, plant-derived

oils and extracts, beneficial microbes, and similar products. Such methods are central to “zero-residue” fruit production systems (Rozman *et al.*, 2013).

Inorganic alternatives to synthetic fungicides – such as copper-based products, lime sulphur, and wettable sulphur – have also been investigated (Jamar *et al.*, 2008). Bicarbonate salts are another widely studied option for scab control (Ilhan *et al.*, 2006; Tamm *et al.*, 2006). These inorganic fungicides typically act through multi-site contact mechanisms and are generally regarded as posing no risk of developing fungicide resistance (Fungicide Resistance Action Committee, 2024).

The study aimed to determine whether inorganic products could replace synthetic fungicides in the second half of the growing season without reducing apple yield or quality, and to investigate how different orchard systems respond to these management strategies.

## Materials and Methods

The investigation on apple scab control strategies influenced by orchard systems was conducted at the Institute of Horticulture (LatHort) in a mature orchard located at Lat: 56.6092713, Lon: 23.3064627. The apple trees were planted in 2009. During two seasons (2024 – 2025), the investigation on the influence of factors observed on the very scab susceptible cultivar ‘Ligol’ (Uselis, 2006; Valiūškaitė *et al.*, 2017) on dwarf rootstock B.396. Each treatment of the experiment has three replications.

The trial covers the following treatments (Table 1):

- synthetic fungicides (SyFu) on manually pruned slender-spindle canopy trees (density 1666 trees per ha);
- synthetic fungicidal treatments applied during the first stage of scab infection only (Control) for the mechanically pruned (in summer) apple trees of vertical axis canopy (planting density 2500 trees per ha), and
- synthetic fungicides combined with inorganic substances during the secondary period (SyInFu) scab infection period (mechanically pruned, vertical axis, 2500 trees per ha).

Soil characteristics at the trial site for cultivar ‘Ligol’: Haplic Luvisol (Hypereutric), sandy loam with  $\text{pH}_{\text{KCl}}$  6.4 – 6.5, organic matter 3.2 – 3.5 %, plant-available phosphorus ( $\text{P}_2\text{O}_5$ ) and potassium ( $\text{K}_2\text{O}$ ) were 77 – 106  $\text{mg}\cdot\text{kg}^{-1}$   $\text{P}_2\text{O}_5$  and 170 – 183  $\text{mg}\cdot\text{kg}^{-1}$   $\text{K}_2\text{O}$ , respectively, and Mg: 279 – 383  $\text{mg}\cdot\text{kg}^{-1}$ , Ca: 1045 – 1235  $\text{mg}\cdot\text{kg}^{-1}$  (Egner-Riehm method (DL method)), boron (B) content in air-dried sample: 0.9 – 1.1  $\text{mg}\cdot\text{kg}^{-1}$ , copper (Cu): 6.2 – 7.2  $\text{mg}\cdot\text{kg}^{-1}$ , manganese (Mn): 104 – 130  $\text{mg}\cdot\text{kg}^{-1}$  and zinc (Zn): 2.0 – 2.6  $\text{mg}\cdot\text{kg}^{-1}$ . Cu, Mn and Zn content in the air-

Table 1

Apple scab management treatments in the trial

Type of substance and orchard management	Apple scab management strategies		
	Synthetic fungicides primary & secondary (SyFu)	Synthetic fungicides primary only (Control)	Synthetic fungicides primary & inorganic secondary (SyInFu)
Synthetic	captan, cyprodinil, dodine, difenoconazole, mefentrifluconazole, dithianon		
Inorganic	copper (II) hydroxide*	copper (II) hydroxide*	copper (II) hydroxide*, sulphur potassium bicarbonate, lime sulphur
Number of applications	six applications of synthetic fungicides in 2024, and eight in 2025.	three applications of synthetic fungicides in 2024, and five in 2025.	three applications of synthetic fungicides and three inorganic fungicides in 2024, and five and three, respectively, in 2025.
Orchard systems	density: 1666 trees per ha; canopy: slender spindle	density: 2500 trees per ha; canopy: vertical axis (mechanically pruned)	

\*copper (II) hydroxide was used for the first application

dried sample expressed as respective element content in 0.05 M EDTA-Na<sub>2</sub> solution.

In 2024, the apple trees with vertical axes canopy transformation began transitioning to a mechanically pruned orchard (using the “Orizzonti Orchard Pruner – Fruit”, the trees were pruned at the end of the dormant period in spring and in mid-August only); the process continued in 2025 with manual pruning of trees at the dormant period and summer mechanical pruning.

During the primary scab infection period, synthetic fungicides with active substances captan, cyprodinil, dodine, difenoconazole, mefentrifluconazole and dithianon were used (Table 1). For the first fungicide application, copper (II) hydroxide (an inorganic fungicide) was used in all treatments. During the secondary scab infection period, in the SyInFu treatment, inorganic substances containing sulphur, potassium bicarbonate and lime sulphur were used. In the treatment, SyFu applied six synthetic fungicides in 2024 and eight in 2025. The control had three applications of synthetic fungicides in 2024 and five in 2025. In the SyInFu treatment, there were three applications of synthetic fungicides and three of inorganic fungicides in 2024, and five and three, respectively, in 2025.

In the field trial, RIMpro was used to determine the optimal timing for applying the inorganic substances and synthetic fungicides during both the primary and secondary apple scab infection periods. The model's calculations were based on weather data collected from a Davis Vantage Pro2 meteorological station (Davis Instruments, Hayward, USA) installed at the

trial location. For simulation purposes, the green tip stage (BBCH 53) was used as the biofix – the starting point for modelling primary infection risk – in both 2024 and 2025. Additionally, RIMpro includes a model that simulates fungicide applications, estimating both fungicide coverage and degradation over time. The reduction in fungicide effectiveness is modelled based on factors such as rain-induced wash-off and dilution due to leaf expansion.

The meteorological conditions in both seasons of investigation differ. In both years, the beginning of the primary scab infection was fixed by 1 April (biofix). Average air temperature was 7.7 and 8.1 °C, and the sum of precipitation was 26.2 and 47.6 mm in April of 2024 and 2025, respectively. In May, the average air temperature was 15.0 and 10.0 °C, and the sum of precipitation was 17.8 and 115.4 mm, respectively. At the end of the primary scab infection (in June), the average air temperature was 17.8 and 15.4 °C, and the sum of precipitation was 21.6 and 80.8 mm, respectively. Information obtained for the 2024 season for the secondary scab infection: in July, the average air temperature was 19.6 °C, and the sum of precipitation was 140 mm; in August, the average air temperature was 18.7 °C, and the sum of precipitation was 22.0 mm. In July of 2025, the average air temperature was 19.5 °C, and the sum of precipitation was 165.4 mm.

To measure the incidence of apple scab on leaves and fruit, in the scab-susceptible cultivar 'Ligol', assessments were carried out on 25 terminal shoot leaves and 25 fruits per replicate (tree). Severity assessments of fruit were recorded two months before harvest by

visually estimating scab severity using a scale: 1, 2 and 3, where 1 point means no attack, 2 points: 1-3 spots per fruit, 3 points: >3 spots per fruit. Leaf and fruit incidence was determined as the percentage of leaves or fruits showing at least one visible scab lesion.

To estimate the influence of orchard systems, the yield per tree was obtained. Average fruit weight and yield per hectare were calculated, as well as the yield efficiency estimated per trunk cross-sectional area (TCSA) and canopy volume. The vegetative parameters of the trees (trunk diameter, canopy width and height) were measured and used to calculate related parameters. The trunk diameter was measured 20 cm above the graft union of the tree. The canopy width was measured in two directions – along and perpendicular to the tree row. To estimate the average fruit weight, a bucket containing 30 - 40 fruits per tree was collected, with the fruit taken from different locations within the canopy; the sample bucket was weighed, and the total weight was divided by the number of fruits in the bucket. The canopy volume estimated by the method adapted by I. Dimza (Rubauskis *et al.*, 2011), where the canopy width (of two directions), tree height, and the fulfilment of the canopy are taken into account. The index of biennial yielding was calculated by the relation of the two-season maximum and minimum yield difference to the cumulative value of yields (Skrivele *et al.*, 2000).

The data were analysed using a general linear model (GLM) in IBM SPSS Statistics 25, which included Analysis of Variance (ANOVA) and Pearson's correlation, a tool for data analysis in MS Excel.

## Results and Discussions

Meteorological conditions play a significant role in the fungicide-reduction strategy or in replacing synthetic fungicides with inorganic alternatives. The first season was comparable to a warm and dry one.

In 2024, April was characterised by an average air temperature 1.1 °C above the climatic norm (6.1 °C), and 9.6 mm less precipitation compared to the climatic norm in Latvia (35.8 mm (Latvian Environment, Geology and Meteorology Centre, 2025)). May recorded 3.6 °C higher average temperature and 32.6 mm less precipitation, while June had 2.6 °C higher average air temperature and 48.5 mm less precipitation (Figure 1). The primary scab infection led to nine slight-, five medium-, and one high-risk infection incidences. In total, during the primary scab infection season of 2024, RIMpro indicated infection risk values 15 times (Figure 2). During the secondary scab infection period, conditions were characterised by 1.8 °C higher average air temperature and an extreme amount of precipitation (64.3 mm or almost twice the climatic norm) in July 2024, and by 1.8 °C higher average air temperature and 56.6 mm less precipitation in August.

The second year of the study (2025) was characterised by cool and wet weather (Figures 1 and 3), creating favourable conditions for the development of both primary and secondary scab infections (Biggs & Stensvand, 2014). April was characterised by an average air temperature of 2.0 °C and 11.8 mm of precipitation above the climatic average in Latvia; vegetation began early. The month of May followed with 1.4 °C lower average air temperature (also spring frosts) and twice as much precipitation (65 mm more), June had an average air temperature pretty close to the climatic norm (0.2°C higher) and 10.7 mm more precipitation. Weather conditions led to nine slight, five medium, one high, and one extreme primary infection-risk incidents. In total, during the primary scab infection season of 2025, the decision support system RIMpro indicated infection risk values 16 times. The secondary apple scab development was enhanced by 1.7 °C higher average air temperature and an extreme amount of precipitation (89.7 mm above the climatic norm) in July 2025.

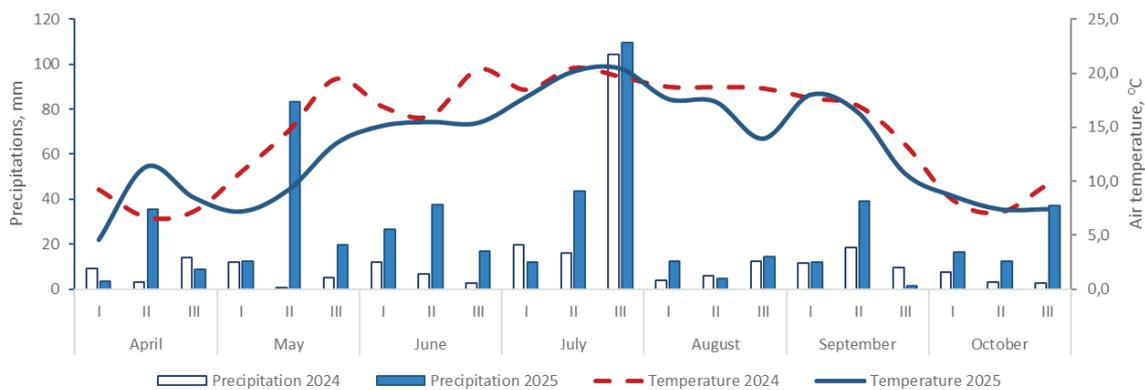


Figure 1. Precipitation and average air temperature in the decades during the period April – October, in 2024 and 2025.

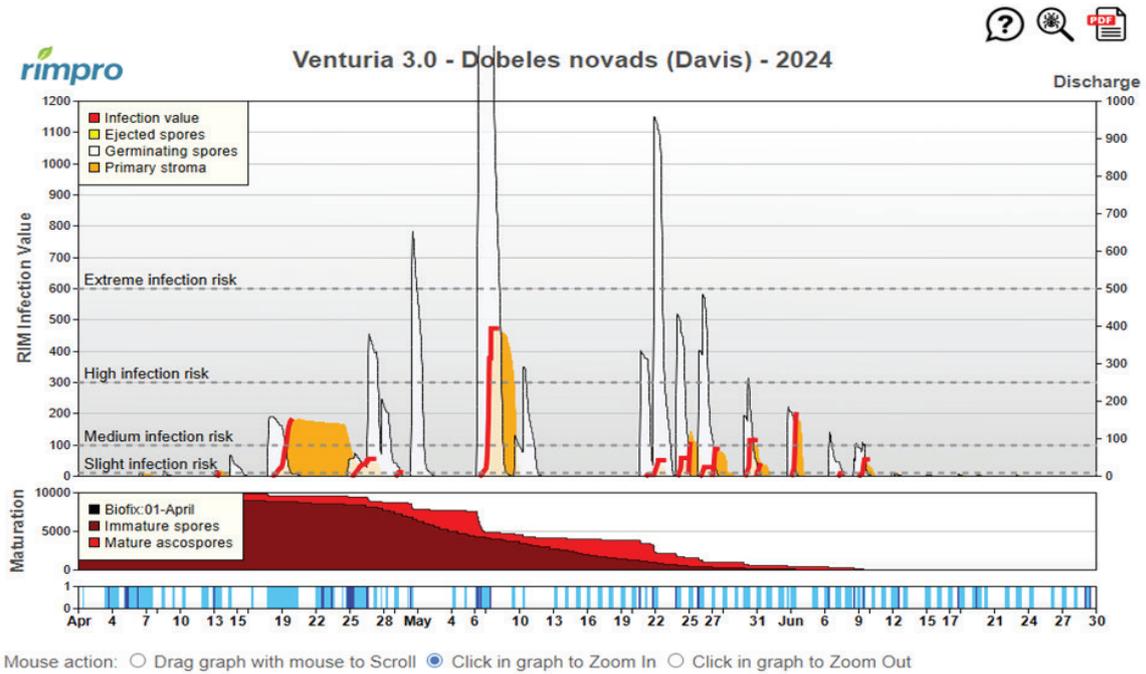


Figure 2. The prognosis of the primary scab-infection for the trial side of LatHort in 2024.

Figure used with permission of RIMpro B.V., the Netherlands.

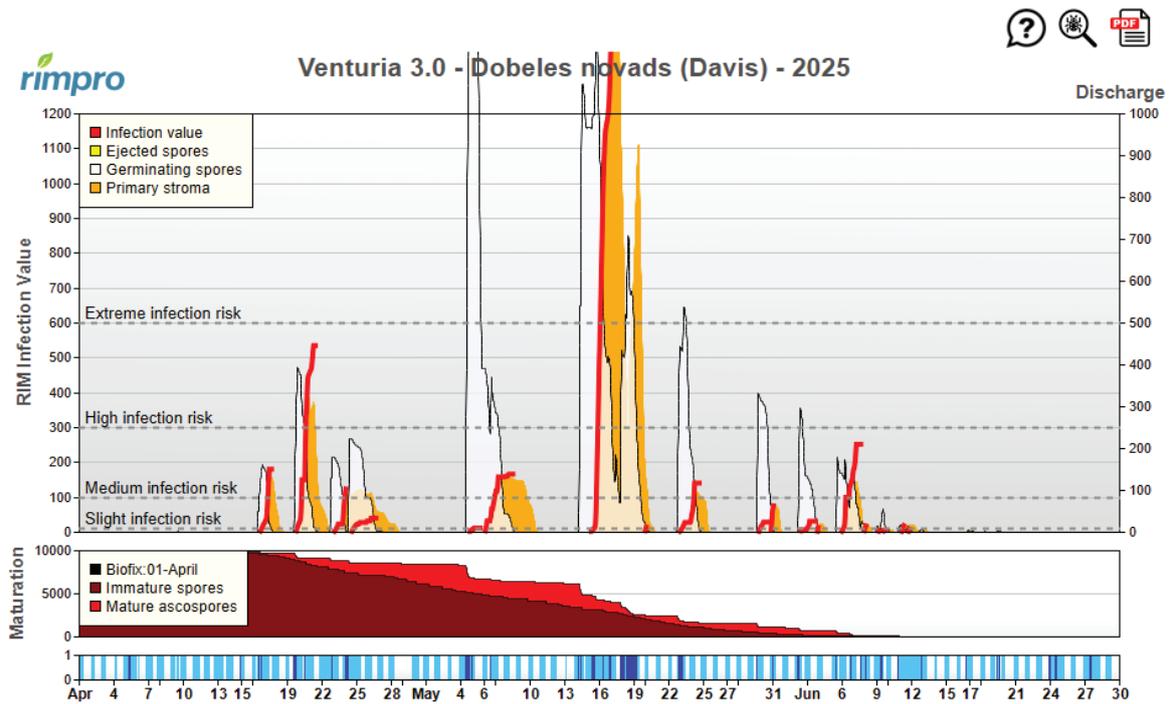


Figure 3. The prognosis of the primary scab-infection for the trial side of LatHort in 2025.

Figure used with permission of RIMpro B.V., the Netherlands.

By obtaining data of apple scab-infected leaves of a very scab-susceptible cultivar 'Ligol' two months before the harvest, we observed statistically significant seasonal differences ( $p$ -value  $<0.01$ ). The treatment differences were observed in the season of 2024

( $p$ -value  $<0.01$ ). 70% of the scab infection incidences had apple tree leaves treated only with synthetic fungicides (SyFu). Comparable control and treatment with some inorganic substances (SyInFu) during the secondary scab infection period showed 96%

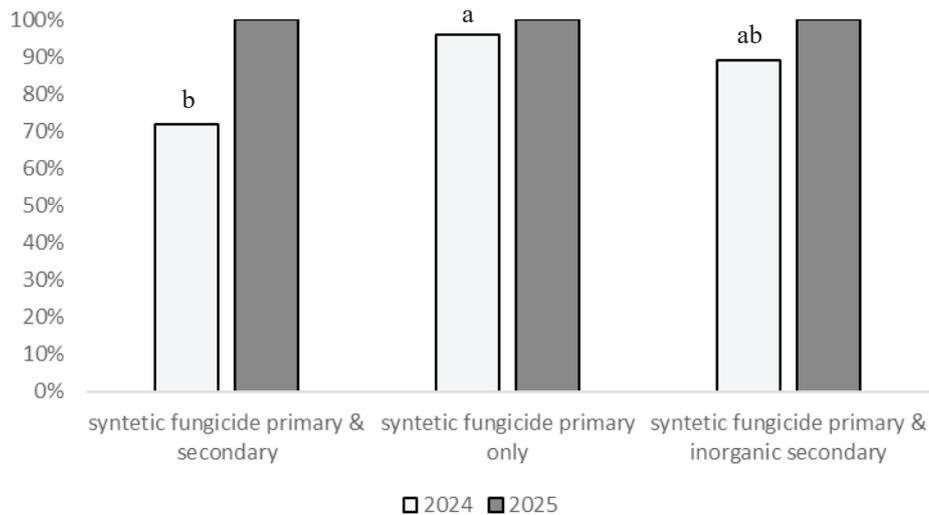


Figure 4. Apple scab-infected leaves of 'Ligol' in two seasons, two months before the harvest. *p*-value for treatment and season differences, interaction <0.01; letters mark statistically significant groups ( $LSD_{0.05}$ ).

and 89% of infected leaves, respectively (Figure 4). In the season of 2025, the apple leaves of 'Ligol' were 100% affected by scab.

The situation is different if the health of 'Ligol' fruit was determined. Estimating the proportion of undamaged, infected fruits – still marketable at a particular category, and damaged – fruits not suitable for storing and selling, the data varies significantly, influenced by factors (treatment variations, seasons, and interactions). Fruits were evaluated as suitable for selling (no categories of damaged fruits in all treatments) in 2024 (Figure 5). In 2025, the proportion of damaged fruit remained (7.5–15%), but

it was not statistically significantly different across the experimental treatments (*p*-value 0.70). The seasonal difference was noticeable and statistically significant (*p*-value 0.01).

Fruits infected with apple scab were found during both seasons. In this case, there are no statistically significant variations. However, the situations vary, as indicated by a statistically significant interaction between factors (treatments and season) (*p*-value 0.01). In 2024, significantly fewer infected fruits of the 'Ligol' cultivar with continuing fungicide application in the orchard during the secondary scab infection period by synthetic or inorganic fungicides

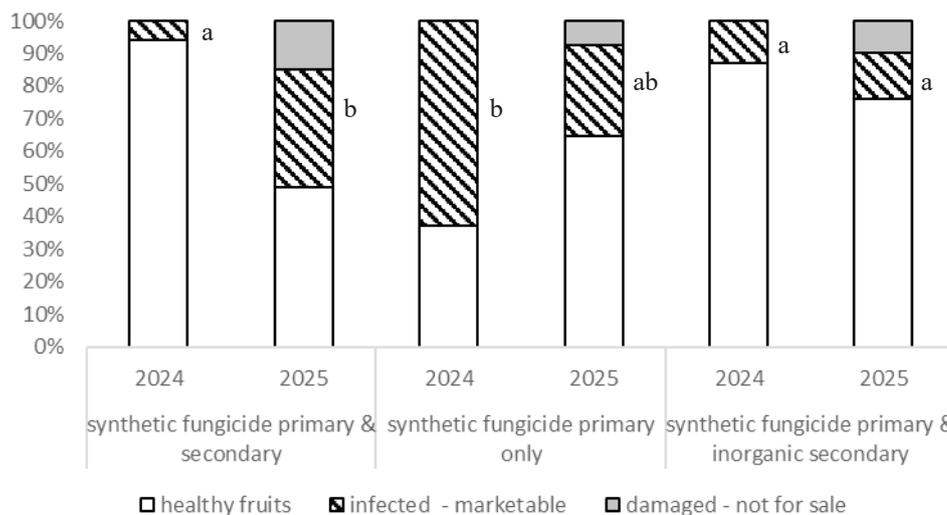


Figure 5. Proportion of marketable fruits of 'Ligol' (two months before the harvest) depending on plant protection and orchard management strategy.

*p*-value of treatments on the proportion of infected fruits <0.01, damaged 0.70; difference of seasons 0.86 and 0.01, and interactions of treatment and seasonal effect 0.01 and 0.70, respectively; letters mark statistically significant groups ( $LSD_{0.05}$ ).

were found (Figure 5). In the control treatment, where fungicides were applied only during the primary scab infection period, a high proportion of fruits (63%) were infected. Statistically significantly fewer infected fruits (p-value 0.01) had treatment variants with synthetic fungicides (6%) and inorganic fungicides (13%) during the secondary scab infection period. In 2025, the situation with scab-infected fruits was different, determined by the comparably cold and wet meteorological conditions (Figure 1). With a set of factors, including inorganic fungicides during the secondary scab infection period, the fruits were less infected (14%) and comparable to the previous season. Almost a third (28%) of fruits were infected if fungicides were applied during the primary scab infection period (Control) only. The situation with the SyFu application was slightly worse: the proportion of infected fruit was 36%. In this case, the difference of orchard systems – planting density and type of canopy – slender spindle with a wider canopy than mechanically pruned vertical axes, occurs.

Therefore, the importance of the orchard systems and the related management of apple trees becomes significant. Several studies (Holb, 2005; Majeed *et al.*, 2017) have highlighted the importance of improving sunlight penetration and airflow, and reducing humidity within the canopy – factors closely linked to tree and row spacing, canopy density, and canopy width. Therefore, the investigation in the mature orchard with the same background (Pole *et al.*, 2017; Rubauskis *et al.*, 2022) allows us to consider the influence of the orchard system. The dense part of the orchard with a vertical-axis canopy was transformed to enable mechanical pruning in 2024, when abundant production was expected. In 2024, the apple trees were mechanically pruned at the end of the dormancy period to achieve a narrow canopy (targeted canopy width ~0.8 m at its lower part). Other manipulations of the apple tree canopies in the spring of 2024 were not performed to avoid extensive growth. To maintain the narrow canopy, mechanical pruning was performed in the middle of August, cutting off new shoots that had generally developed at the ends of shortened branches. Continuing the transformation of apple trees, manual pruning was performed the following spring. The long shoots inside the canopy were cut off, the old branches were renewed, etc. In summer (mid-August 2025), the mechanical pruning was repeated, with a strategic goal to avoid excessive growth. The plan is to continue mechanical pruning in the summer, in the short term before the harvest, and to combine it with manual pruning in spring to maintain a narrow, transparent apple tree canopy hedge.

The yield of the orchard is the leading indicator of performance in the production of good-quality

apples. The abundant yield leads to biennial bearing in some cultivars (Rubauskis *et al.*, 2022). The analysis focused solely on yields in 2024 and 2025. In the case of 'Ligol', an off-year in yielding was particularly expected, as shown by the high index of biennial yielding (Table 2). On average, in 2024, the highest yield per hectare for 'Ligol' on B.396 was in a vertical axis orchard system reaching 75.6 t·ha<sup>-1</sup> (Table 2). The difference exceeded 21% compared with the orchard section, where trees were trained as slender spindles. The statistical significance of this orchard difference was greater than 90%. The correlation analysis indicated that the overall yield depended primarily on the number of fruits per tree ( $r = 0.84$ ) rather than on their average weight ( $r = 0.29$ ). In 2025, the yield was smaller, and no statistically significant difference was observed.

As expected, the cumulative yield per tree over two seasons was higher for trees with larger canopies - slender spindles. The factor influence is statistically significant at the 90% level (Table 2). The advantages of a narrow tree row with mechanically pruned vertical-axis apple canopy look promising as well. The differences are less statistically significant; however, trees with a smaller canopy, by volume (data from 2024), with dense planting provide comparable or slightly larger average yields over two seasons during the mature production period of the orchard per unit area (Table 2).

There were no differences in fruit weight between the orchard systems (Table 2) in 2024, with an average size of approximately 175 g for both. Typically, a higher number of fruits per tree suppresses the fruit size and the average fruit weight; however, due to effective fruitlet thinning, this effect was apparently avoided. For the yield of 2025, there were no statistically significant differences between orchard systems; slightly larger fruits were found in apple trees with a slender spindle canopy for 'Ligol' (Table 2).

Due to canopy management in the respective orchard systems in 2024, canopy volume was inversely correlated with yield performance ( $r = -0.54$ ). The canopy of slender-spindle trees was 2.7 times larger than that of vertical-axis trees. In 2024, the yield efficiency per unit canopy volume was higher in the vertical-axis orchard, with the difference being statistically significant at p-value 0.05 (Table 2). On the other hand, there is no indication that tree growth was suppressed. Furthermore, at the same time, the yield efficiency relative to yield per tree based on trunk cross-sectional area showed almost no difference between the orchard systems. The data on the 2025 vegetative parameters have not been analysed yet due to the short time available.

Table 2

**Influence of orchard system on the main performance characteristics in 2024 and 2025**

Growth and production parameters	Canopy type of orchard system		p-value
	Slender spindle	Vertical axis	
2024			
Number of fruits per tree at harvest	206	173	0.18
Average fruit weight, g	175	175	0.89
Yield per tree, kg	35.7	30.2	0.24
Yield per ha, tonnes	59.5	75.6	0.08
Volume of canopy, m <sup>3</sup>	4.72	1.73	<0.01
Yield per canopy volume, kg m <sup>-3</sup>	9.46	19.41	<0.01
Yield efficiency (yield per unit of TCSA), kg cm <sup>-2</sup>	0.43	0.45	0.75
2025			
Number of fruits per tree at harvest	64	44	0.42
Average fruit weight, g	280	255	0.31
Yield per tree, kg	12.2	7.7	0.29
Yield per ha, tonnes	20.3	19.2	0.89
Cumulative yield (2024 – 2025), kg per tree	48.0	37.9	0.08
Average yield (2024 – 2025), t ha <sup>-1</sup>	40.0	47.4	0.15
Index of biennial yielding	0.76	0.84	0.26

The results support the recommendation to use inorganic fungicides during the secondary infection period in apple orchards. In our study with the cultivar 'Ligol', treatments incorporating inorganic fungicides significantly reduced the incidence of fruit infection by *Venturia inaequalis* (apple scab). Many inorganic formulations act by multi-site contact modes of action; they carry a lower risk of pathogen resistance development and often have a reduced environmental footprint compared to repeated single-site synthetic fungicides. For example, the recent research found that inorganic substances provide an effective complementary tool in scab management and help reduce reliance on synthetic fungicides (Rancāne *et al.*, 2024). Additionally, work from the Walloon Agricultural Research Centre on rain-fastness of lime sulphur and other inorganic fungicides also demonstrates the practical feasibility of these products under orchard conditions (Jamar *et al.*, 2018).

In light of these findings, orchard managers seeking effective and sustainable scab control should prioritise inorganic fungicide applications – especially during the secondary infection period – within an integrated disease-management programme. This approach not only delivers efficacy but also aligns well with environmental stewardship and resistance-management goals.

## Conclusions

Leaf and fruit scab incidence in 'Ligol' varied significantly between seasons and treatments, with the secondary infection periods being critical for disease control.

Combining synthetic fungicides in the primary infection period with inorganic substances during the secondary period reduced fruit infection while partially reducing chemical use.

Orchard system and canopy management influenced yield efficiency, with vertical-axis trees showing higher productivity per canopy volume.

Further investigations are necessary because seasonal weather strongly affected scab development, emphasising the need for flexible, integrated management that combines pruning, canopy management, and targeted fungicide application.

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