

Mixing apple cultivars as part of a systems approach to manage apple scab (*Venturia inaequalis*)

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Abstract

Apple scab (Venturia inaequalis) is the most important fungal disease in apple production in Northwest Europe, requiring high fungicide inputs in both organic and conventional orchards. In this study, we evaluated a mixed orchard approach as part of a systems strategy to reduce disease pressure. In 2023, a 1 hectare trial was established on a biodynamic farm in the Netherlands to compare a monoculture of 'Elstar' with two cultivar mixture designs (row-by-row and tree-by-tree) comprising 'Elstar', 'Natyra', 'Santana', 'Boskoop', and 'Topaz'. The three treatments (monoculture, row-by-row, and tree-by-tree mixtures) were arranged in a randomized complete block design with eight replicates. Cultivar mixtures are expected to disrupt secondary scab infections by limiting conidial spread, while winter sanitation practices target primary inoculum reduction. Trapping for apple sawfly (Hoplocampa testudinea) and apple blossom weevil (Anthonomus pomorum), combined with sugar dispensers to attract ants (Lasius niger) away from aphid colonies (Dysaphis plantaginea), are integrated to manage aphid and weevil pests, enhancing overall orchard resilience.

Keywords: cultivar mixtures; apple scab; organic orchard management

Introduction

Among all pests and diseases affecting apple production in Northwest Europe, apple scab (*Venturia inaequalis*) is the most significant fungal pathogen, demanding the highest fungicide input and the greatest number of applications in both organic and conventional systems. Reducing reliance on fungicides necessitates a stacked set of measures within a systems approach to control the disease. One potential component of such an approach is the use of mixed apple cultivars. Integrating genetically diverse cultivars within the same orchard block can disrupt the spatial spread of the pathogen, thereby reducing overall disease pressure. This strategy combines host resistance with ecological interactions, enhancing orchard resilience while lowering fungicide dependence (Steward *et al.*, 2023).

Cultivar mixtures typically include combinations of scab-susceptible and scab-resistant varieties, arranged either in alternating rows or on a tree-by-tree basis. Resistant cultivars serve as both physical and epidemiological barriers, impeding the dispersal of inoculum and decreasing the likelihood of successful infection cycles (Didelot *et al.*, 2007, 2010; Parisi *et al.*, 2013). Furthermore, lower fungicide input in such systems supports beneficial arthropods and microbial communities, contributing to a richer, potentially more balanced orchard ecosystem.

The disease cycle of *V. inaequalis* involves two spore types: wind-dispersed ascospores and rain-splashed conidia. Ascospores initiate primary infections in spring from overwintered leaf litter, while conidia drive secondary infections during summer. Cultivar mixing is particularly effective against this latter phase, as the presence of neighbouring trees of different cultivars limits conidial spread and infection success due to cultivar-specific resistance. However, since secondary infections depend on the initial inoculum load,

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orchard sanitation remains essential. Practices that promote leaf decomposition and reduce ascospore production during autumn and winter complement cultivar mixing, together forming an integrated, ecologically based strategy for long-term control of apple scab in organic production systems.

The aim of this experiment is to investigate, under commercial orchard conditions, the effect of mixing apple cultivars on the development of apple scab. Cultivar mixing is integrated with other measures to form a complete systems approach, with the ultimate goal of reducing reliance on fungicides. This system also provides an opportunity to assess the impact of cultivar mixtures on other pests and diseases.

Materials and Methods

Orchard design

In May 2023, a 1 ha apple orchard was established under replant conditions on biodynamic farm *De Muyehof* in Nieuwerkerk, southwestern Netherlands. The experiment had three levels of cultivar mixing: a monoculture of 'Elstar', a row-by-row mixture, and a tree-by-tree mixture. The mixed plots contained five apple cultivars: 'Elstar', 'Natyra', 'Santana', 'Boskoop', and 'Topaz'. The cultivars 'Natyra', 'Santana', and 'Topaz' possess *Vf*-based scab resistance, while 'Boskoop' is considered robust and 'Elstar' moderately susceptible to apple scab. All five cultivars are also grown elsewhere on the farm.

The three treatments were arranged in a randomized complete block design with eight replicates, yielding 24 plots in total. Each plot consisted of five rows of 13 trees, planted at a spacing of 3.25 × 1.25 m. Every sixth row served as a buffer, planted with 'Concorde' pear trees. To the east lies a mature 'Elstar' orchard with a known history of apple scab. The prevailing wind direction in the region is (south-)west.

The alleyways were sown with a grass–clover mixture, and in spring 2024, every second alley was enriched with narrow flower strips in the middle of the alley to provide nectar and pollen for pollinators and natural enemies. Clover was maintained in the remaining alleys to support soil health and nitrogen fixation.

Adverse weather conditions following establishment—heat and drought in summer 2023, followed by a wet winter and spring—affected early tree growth. Despite near 100% survival, growth performance varied among cultivars and remained below expectations in the first year, even with drip irrigation guided by soil sensors. Aphid infestations in 2023, particularly on 'Natyra' and 'Topaz', caused local damage despite targeted treatments.

Trapping techniques were applied to target apple sawfly (*Hoplocampa testudinea*) and apple blossom weevil (*Anthonomus pomorum*). Sugar dispensers were installed on every tenth tree in 2024 and on every fourth tree in half of the plots in 2025 to feed ants (*Lasius niger*) and divert them from aphid colonies, thereby enhancing biological control of rosy apple aphid (*Dysaphis plantaginea*) (Brouwer *et al.*, 2024; Kemp *et al.*, 2024).

Scab Management and Observations

In 2023, shortly after orchard establishment, two sulphur spray applications were carried out in mid-June and July to manage apple scab. Due to the warm and dry conditions following planting, additional potassium bicarbonate (VitiSan) treatments were applied against downy mildew. Leaf decomposition during the winter of 2023–2024 was satisfactory, aided by the limited amount of leaf litter.

In 2024, a preventive sulphur spray programme was implemented. VitiSan was applied both as a curative treatment and post-bloom against powdery mildew. Applications were made using a KWH three-row sprayer with 400 L of water per hectare. In the adjacent 'Elstar'

orchard at the east side, fallen leaves were collected in January 2025 to enhance decomposition and reduce overwintering scab inoculum; intensive preventative sprays were applied there due to high scab pressure.

Weather conditions influenced orchard development and disease dynamics. Spring 2023 was rainy, followed by a dry, early and warm summer and a wet August. The primary infection period in 2024 was characterized by prolonged wetness, creating favourable conditions for ascospore release and early scab development.

In 2025, an intensive spraying schedule and sanitary measures were implemented to reset the scab situation and make a fresh start to the trial. From 2026 onwards, the effects of the treatments will be reassessed.

Apple scab assessments were conducted in September 2023, May 2024, and August 2024. The first two assessments scored scab severity on a 0–3 scale, while the final assessment in 2024 recorded scab absence or presence (0–1). The percentage of infected ‘Elstar’ trees per plot was analysed using ANOVA or Kruskal–Wallis tests, depending on data distribution.

Results and discussion

In September 2023, statistically significant differences in scab incidence were observed among treatments ($p = 0.04$). Contrary to expectations, the tree-by-tree mixture exhibited the highest scab levels in ‘Elstar’ (81%), followed by the row-by-row mixture (79%) and the monoculture (72%). However, by May and August 2024, no significant treatment effects were detected (respectively 49–52% and 89% infected trees), indicating that cultivar mixing did not reduce scab incidence in ‘Elstar’. The high overall infection pressure in spring 2024 likely masked potential effects on secondary spread. Slightly higher scab incidence was visually observed near the adjacent older ‘Elstar’ orchard in 2023, possibly due to windborne inoculum, but this spatial trend was not evident in 2024. Only a few trees of the other varieties showed minor scab symptoms.

The unexpectedly high incidence of apple scab observed during both the establishment year (2023) and the subsequent growing season (2024) indicates that multiple interacting factors may have constrained the potential disease-suppressive effects of cultivar mixing. Despite the implementation of preventive sulphur-based spray programs and the inclusion of cultivars carrying *Vf*-based resistance, scab infection levels on ‘Elstar’ remained high across all treatments. This outcome suggests that external inoculum sources and environmental conditions exerted a dominant influence on disease development.

A plausible explanation for the high infection pressure is the proximity of the experimental orchard to a mature ‘Elstar’ block with a documented presence of scab infestation. Wind-dispersed ascospores from overwintered leaf litter in the adjacent orchards may have contributed substantially to early-season primary infections. Under such circumstances, the capacity of intra-orchard cultivar diversity to impede secondary spread would be limited, as primary inoculum was likely abundant and spatially uniform across treatments.

The warm and dry period following planting in 2023 may have had negatively affected tree establishment and vigour, while the wet spring of 2024 provided prolonged leaf wetness periods conducive to ascospore release and infection. Consequently, environmental factors likely overruled potential disease-mitigating effects of the mixed-planting design.

To refine the interpretation of these results, future research should include quantitative monitoring of ascospore release dynamics and dispersal, within-orchard conidial dispersal, and leaf litter decomposition rates. Integration of these data with infection risk models (e.g., RIMpro) and spatial analyses of disease incidence could help disentangle the contributions of external versus internal inoculum sources.

Further evaluation under reduced external inoculum pressure will be essential to determine the long-term efficacy of cultivar mixtures as a systems-based strategy for apple scab management in organic orchards. Complementary measures, such as enhanced sanitation, adjusted cultivar ratios, and optimized spray regimes, may strengthen the resilience of mixed-planting systems against scab epidemics.

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