

## Mixed cultivar planting and biodiversity integration in an organic apple orchard: Early results from a Geneva rootstock field trial

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### Abstract

*Organic apple production is increasingly challenged by climate change, irregular precipitation, emerging pests, declining biodiversity and the need to reduce external inputs. Low-input orchard systems integrating adapted rootstocks, resistant cultivars and functional biodiversity may offer a way towards greater resilience.*

*To investigate this approach, a 1.3-ha experimental orchard was established in 2022 at the Heuchlingen Fruit Research Station (LVWO Weinsberg, Germany). The trial combines a mixed cultivar planting scheme of 30 modern apple cultivars with five Geneva rootstocks (G.11, G.41, G.214, G.969 and G.210) and a range of biodiversity-enhancing measures. Agronomic parameters were assessed during the establishment phase (2023–2025), including phenology, disease incidence, flowering intensity, crop load, yield, canopy volume and trunk diameter.*

*A significant cultivar × rootstock interaction was observed, indicating cultivar-specific responses to the tested rootstocks. Rootstock G.210 showed the highest vegetative vigour, while the remaining Geneva rootstocks exhibited comparable early performance without clear inferiority. Disease incidence remained low across years. Biodiversity measures were rapidly established, with nesting structures occupied from the second year onward.*

*These early results demonstrate the feasibility of integrating Geneva rootstocks, mixed cultivar plantings and functional biodiversity within a low-input organic apple orchard system and provide a basis for long-term evaluation.*

**Keywords:** cultivars, rootstocks, Geneva, biodiversity, mixed orchard

### Introduction

Organic fruit production increasingly requires systematic and integrative approaches that consider orchard systems as dynamic agroecosystems rather than as collections of individual management measures. In organic apple production, sustainable plant protection is ideally conceptualised as a pyramidal system, in which adapted rootstocks, disease-tolerant cultivars, genetic diversity, and the integration of functional biodiversity and ecosystem services form the foundation, while direct plant protection measures represent the final and minimal level of intervention.

In recent years, however, economic and practical constraints in commercial fruit production have increasingly challenged this system-oriented approach. As a result, cultivar and rootstock selection in organic orchards has partly converged with that of integrated production systems. Consequently, the rootstock M9 remains the commercial standard in organic apple production due to its high agronomic performance. Under extensive management conditions and reduced weed control—both typical of organic systems—this rootstock can exhibit reduced yield performance and fruit quality (Atay et al. 2017), highlighting limitations of conventional orchard designs under low-input conditions.

The Geneva apple rootstock breeding program in the United States has developed several alternatives that may better support system-oriented and low-input production strategies (e.g. Robinson 2021). Rootstock G.11, for example, has demonstrated performance

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comparable or superior to M9 in organic orchards across multiple international trials (e.g. Hoeller & Guerra 2017). Additional Geneva rootstocks are currently under evaluation in Europe. Compared with M9, these rootstocks generally exhibit greater vigour and have been reported to show tolerance to replant disease, frost, drought stress, woolly apple aphid (*Eriosoma lanigerum* Hausm.), fire blight (*Erwinia amylovora* [Burrill] Winslow et al.), and crown rot (*Phytophthora* spp. De Bary). Moreover, increased competitiveness against weeds, improved water uptake under dry conditions, and sufficient anchorage without permanent support structures have been suggested. Collectively, these traits may allow for reduced intervention in the tree strip and facilitate the integration of biodiversity-enhancing measures within orchard systems.

In combination with disease-tolerant cultivars, mixed planting schemes, and the deliberate use of functional biodiversity, Geneva rootstocks may therefore enable a new type of organic apple orchard system (e.g. Cahenzli et al. 2018; Stewart et al. 2023; Wurm 2025). Such systems aim to reduce external inputs, including machinery use and plant protection measures, while increasing resilience to climatic variability. However, empirical evidence on the performance of these combined approaches under practical orchard conditions remains limited, particularly in long-term trials.

To address this gap, a “Next-Generation Organic Apple Orchard” was established as a long-term field experiment integrating multiple components of modern organic apple production. As the trial is ongoing, the present study does not aim to draw definitive conclusions on long-term performance. Instead, its objectives are to (i) describe the experimental design and methodological framework, (ii) present the integrated agronomic and biodiversity-based approach, and (iii) report first experiences and early observations regarding rootstock performance and the establishment of biodiversity measures.

## **Material and Methods**

### ***Agronomy***

A selection of Geneva apple rootstocks (G.11, G.41, G.214, G.969 and G.210) was evaluated in combination with modern apple cultivars. Cultivars were selected for suitability in commercial organic fruit production while maximising genetic and resistance diversity, with particular emphasis on advanced breeding clones developed at LVWO Weinsberg. In total, 30 cultivars (five early-season, ten autumn and 15 storage cultivars) were selected in cooperation with the Foerdergemeinschaft Oekologischer Obstbau e.V. and the advisory board of LVWO Weinsberg. Most cultivars had previously been tested under elevated disease pressure or evaluated in earlier projects, and consumer acceptance was considered based on sensory assessments.

Trees were grafted in the nursery of the Heuchlingen Fruit Research Station and planted on 15 November 2022 on a former apple orchard site. The site is characterised by a mean annual temperature of 10.5 °C, approximately 700 mm annual precipitation, and fertile loess loam soils with soil quality ratings exceeding 70–80 points.

The experiment was established as a long-term, multifactorial field trial with a mixed cultivar planting scheme. Trees were arranged in blocks defined by harvest period. Due to the block-wise layout and mixed planting design, individual trees were not considered independent experimental units. Observations were recorded at the individual-tree level but aggregated at the block level for statistical analysis using block-level means or medians. Only trees planted in early 2023 that developed normally with the intended cultivar–rootstock combination were included in the evaluations; incomplete or unbalanced combinations were excluded.

Rootstock effects were explored using linear mixed-effects models to assess cultivar × rootstock interactions, with cultivar and rootstock as fixed effects and block as a random effect. Given the unbalanced design and the limited number of complete blocks, statistical inference was interpreted conservatively and supported by effect sizes, relative rankings and consistency of responses across cultivars and blocks. All analyses were conducted in R, and results should be interpreted as early establishment patterns rather than definitive long-term performance outcomes.

Trees were assessed in 2023–2025 for trunk diameter, flowering time, flowering intensity, crop load, incidence of apple scab (*Venturia inaequalis* (Cooke) G. Winter) and powdery mildew (*Podosphaera leucotricha* (Ellis et. Everh.) Salm.), yield performance and fruit quality. Canopy volume and rootstock sucker formation were additionally evaluated in 2025. All assessments followed the guidelines of the German working group for fruit-growing performance tests (AK OL 2003).

In all years, a reduced plant protection strategy was applied. Disease management focused primarily on the control of apple scab during the primary infection period. A maximum of one azadirachtin-based treatment per year was applied, and no copper-containing products were used.

Wild cherries							
Row	Rootstock	Cultivars					Row
1	G 11						1
2	G 41						2
3	G 214	Cultivar 1	Cultivar 2	Cultivar 3	Cultivar 4	Cultivar 5	3
4	G 969						4
5	G 210						5
6	G 11						6
7	G 41						7
8	G 214	Cultivar 6	Cultivar 7	Cultivar 8	Cultivar 9	Cultivar 10	8
9	G 969						9
10	G 210						10
11	G 11						11
12	G 41						12
13	G 214	Cultivar 11	Cultivar 12	Cultivar 13	Cultivar 14	Cultivar 15	13
14	G 969						14
15	G 210						15
16	G 11						16
17	G 41						17
18	G 214	Cultivar 16	Cultivar 17	Cultivar 18	Cultivar 19	Cultivar 20	18
19	G 969						19
20	G 210						20
21	Biodiversity row						21
22	G 11						22
23	G 41						23
24	G 214	Cultivar 21	Cultivar 22	Cultivar 23	Cultivar 24	Cultivar 25	24
25	G 969						25
26	G 210						26
27	G 11						27
28	G 41						28
29	G 214	Cultivar 26	Cultivar 27	Cultivar 28	Cultivar 29	Cultivar 30	29
30	G 969						30
31	G 210						31
32		Wild bee and butterfly meadow, seeded 05/2023					32
33		Wild bee and butterfly meadow, seeded 05/2023					33
Walnut alley							

**Resistance genes**

- No resistance
- Rvi5+Rvi6
- Rvi6
- Rvi10
- Rvi6+10
- Polygenic resistance

Figure 1: Planting scheme and resistance genes represented in the experimental orchard. Rows 1–5 contain early-ripening cultivars, rows 6–15 autumn-ripening cultivars, and rows 16–30 storage cultivars.

### Biodiversity

A range of biodiversity-enhancing measures compatible with commercial organic fruit production was implemented across the orchard. A total of eight bird nest boxes, following the recommendations of Epp (2020), and 11 wild bee nesting boxes were installed across the planting area. In each row, anchor plants were established at both ends, and a 50-cm-wide flowering strip was sown in the centre of each alley using diverse perennial mixtures; spring-flowering bulb species were added to provide early-season floral resources.

A dedicated biodiversity row was created by omitting one tree row and included structural elements such as brushwood and dead-wood piles, stone piles, a sand patch for ground-nesting bees, lacewing (*Chrysoperla carnea* Stephens) nesting boxes, and plantings of selected wild perennials and native shrubs. In addition, large “beacon trees” were planted to provide vertical habitat structures.

In 2024, earwigs (*Forficula Auricularia* L.) were promoted by installing downward-facing bamboo shelters on each tree. Earwig colonisation was quantified in selected rows (1–10 and 19–20). Apart from earwig counts, no quantitative assessment of insect communities associated with the biodiversity measures was conducted to date.

## Results

### Agronomical results

A linear mixed-effects model was used to assess whether rootstock performance differed between cultivars. The analysis revealed a significant interaction between rootstock and cultivar (likelihood-ratio test:  $\chi^2_{67} = 351.9$ ,  $p < 0.001$ ), indicating a cultivar-specific response to the tested rootstocks.

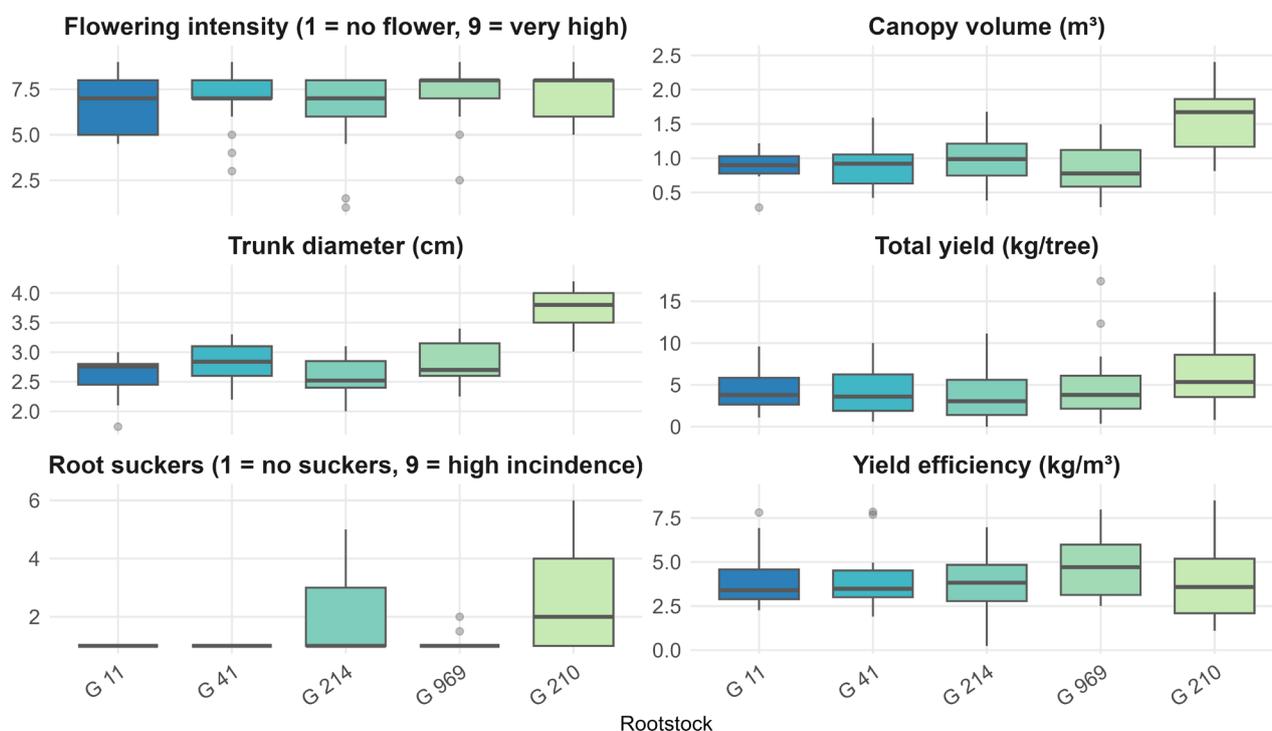


Figure 2: Results of the agronomic parameters measured in 2025. Trunk diameter was measured on 5 November 2025, rootstock suckers on 13 October 2025, and canopy volume on 17 September 2025.

With regard to canopy volume, rootstock G.210 showed significantly greater vigour than all other rootstocks. The rootstocks G.11, G.41, G.214 and G.969 varied in canopy volume depending on the cultivar–rootstock combination, but did not differ significantly from one another. Flowering intensity varied within and between cultivars in both 2024 and 2025, but did not differ significantly among rootstocks. Rootstock suckers were observed in 2025 only on G.210 and G.214; however, a statistically significant difference compared with the other rootstocks was found only for G.210, where sucker formation occurred at a relatively moderate level. Following a storm event in summer 2025, individual trees on rootstock

G.210 broke at the graft union. Only a small number of trees were affected; nevertheless, this aspect will be closely monitored in the coming years.

Apple scab symptoms were observed only to a very limited extent on the trees during the years 2023 to 2025, with the exception of the cultivar 'Elstar' in 2023, which showed a low infestation with apple leaf scab. Similarly, no notable symptoms of powdery mildew were observed.

### **Biodiversity results**

#### *Nest boxes, birds, and wild bees*

Bird nest boxes were occupied for breeding from the second year after installation onward. Occupancy rates reached 50% in 2024 and 37.5% in 2025. Wild bee nesting structures were also almost completely occupied from the second year of establishment.

Anchor plants developed well during the first three years after planting. In some cases, vigorous growth required additional pruning, particularly for wild rose species.

Initial sowing of flowering strips in May 2023 coincided with a prolonged hot and dry period, resulting in poor emergence. After re-sowing in September 2023, establishment was successful, and distinct flowering strips developed by spring 2024. By 2025, all flowering strips were fully established. Species-rich mixtures, such as the Veitshoechheim and Foeko mixtures, provided continuous flowering over extended periods, whereas other mixtures exhibited more limited flowering durations.

Tall-forb margins established at the orchard edges developed heterogeneously, with denser vegetation along the western border and sparser growth along the eastern border, likely due to shading and allelopathic effects from adjacent walnut trees.

#### *Biodiversity row*

The biodiversity row developed largely as intended. Structural elements and planted wild perennials established successfully and required minimal management. The sand strip for ground-nesting bees was rapidly colonised by weeds and required additional maintenance. Promotion of earwigs (*Forficula auricularia*) using bamboo shelters resulted in rapid establishment in 2025. A total of 81,499 earwigs were recorded across 600 bamboo tubes in the monitored rows, corresponding to an average of 135 individuals per occupied tube. Only 4.5% of the bamboo tubes remained unoccupied. In some cases, bamboo tubes were used by spiders or by the steel blue cricket hunter (*Chlorion aerarium* Patton).

No tree damage caused by voles or field mice was observed, although high rodent activity was noted, particularly within flowering strips. Three trees were lost due to infestation by leopard moth (*Zeuzera pyrina* L.).

### **Discussion**

While a significant cultivar–rootstock interaction was observed, its detailed interpretation is deferred to a future publication based on multi-year results from the ongoing long-term trial. Based on observations to date, G.969 cannot yet be confirmed to exhibit vigour comparable to that of G.210 in the present trial, as previously described by Fazio et al. (2018). A final assessment will only be possible after additional years of observation. Similarly, despite its high vigour and apparently good anchorage under current conditions, a support structure is still recommended for G.210 until further long-term data are available, particularly in light of the breakage of individual trees at the graft union following a storm event in summer 2025.

At present, it remains too early to draw robust conclusions regarding long-term tree vigour and yield efficiency of the individual cultivar–rootstock combinations. Additional years of

observation will be required to obtain meaningful and well-interpretable results. However, based on observations to date, flowering intensity and early yield performance suggest that all tested Geneva rootstocks exhibit a similarly satisfactory bearing behaviour, with no rootstock showing clearly inferior performance at this stage.

The experimental design lacks a comparison plot in which cultivars are planted in larger, non-mixed blocks; consequently, the effectiveness of genetic mixing for the regulation of diseases and pests can only be assessed to a limited extent. The multifactorial nature of the experiment further complicates the attribution of observed effects to individual biodiversity measures. In addition, the rootstock comparison does not include the M9 rootstock, meaning that comparisons with the traditional M9-based production system must be interpreted with caution.

Nevertheless, the trial is expected to generate more robust results in the near future, particularly with regard to identifying suitable cultivar–rootstock combinations for organic apple production. The experiment should therefore be regarded as a long-term research platform rather than a recommended orchard design.

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