Effects of agrivoltaic systems on flowering, yield and fruit quality in apple, pear and plum cultivation

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Abstract

Four different set-ups agrivoltaic systems (AV) combining solar electricity generation with apple, pear, and plum production were evaluated at two sites in southwest Germany. The experiment indicates reduced fruit set under AV conditions for apples and pears, while it was higher for plums. Colouring was delayed for apples and plums but less impaired for pears. These preliminary results illustrate the potential trade-offs between electricity generation and fruit productivity in temperate orchards, highlighting the need for long-term data to optimize light management and crop productivity in different AV setups.

Keywords: Agrivoltaics, Apple, Pear, Plum, Impacts

Introduction

Agrivoltaic systems (AV) enable dual use of fruit-growing land for both food and electricity production. Although several studies on AV have recently been published, general conclusions remain limited due to site-specific factors and heterogeneous system designs (Vaverkova et al., 2026). Hence, the suitability of AV for commercial fruit production remains uncertain as impacts vary considerably depending on the characteristics of the respective AV (Magarelli et al., 2024). To identify system configurations that enable high fruit as well as electricity yield, the Agricultural Technology Center Augustenberg conducts studies on multiple apple, pear, and plum cultivars as well as different types of solar modules. This enables comparative analysis of different AV.

Material and Methods

The experiments were conducted at two AV installations in Karlsruhe and Nußbach (Ortenau) in Baden-Wuerttemberg in Germany. At an organically cultivated site in Karlsruhe, six apple ('Swing® Xeleven', 'Bonita', 'Topaz', 'Natyra®', 'Freya®' and 'Rubelit') and two pear ('Conference' and 'Xenia®/Novembra®') cultivars planted in 2021 in one to six rows each were observed under three conditions. A control variant with no AV modules was compared to one treatment with semi-transparent fixed modules and one replication with fully shading tracking modules, which were tracked according to the sun's position to maximize electricity yield. At the conventionally cultivated Nußbach site, three apple ('Bonita', 'Topaz' and 'Boskoop') and three plum cultivars ('Moni®', 'Toptaste®' and 'Franzi®') are grown in two (apples) and one row (plums). The trees were planted in 2021. Two variants with fully shading tracked modules were compared to a control. Here, one treatment is tracked to generate maximal electricity yield and thus is analogous to the Karlsruhe site. In contrast, the tracking algorithm of the second variant is modified to increase light availability to the fruit trees. To monitor the influence of the shading on trees, flowers and fruits were counted on a sample of 16 to 20 (Nußbach) and 30 trees (Karlsruhe) for each cultivar and treatment, respectively. Additionally, ripeness and quality parameters of 30 fruits were assessed for each cultivar per variant. As normal distribution and homogeneity were not given, collected data were analysed using Kruskall-Wallis and Games-Howell tests.

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Results and Discussion

The number of apple flower clusters per tree varied strongly between years indicating high impacts of environmental conditions in the respective year as the average number varied more between 2024 and 2025 (up to ± 246) than within variants (up to ± 61 in 2024; up to ± 131 in 2025). Despite reduced flowers for most apple cultivars under AV conditions in 2025, fruit set was sufficient in that year. In 2025, mean of flowers (up to + 47%) and fruit set (up to + 31%) were higher for the plum variety 'Toptaste®' grown under AV conditions. In contrast, pears were impacted by the solar modules and showed reduced fruit set (up to - 58%). Further data are needed to validate those findings as they are in contrast with Reher et al. (2025) where no differences of AV on flowering and fruit set of pears were observed.

Apple While apple yield under AV conditions was higher in Nußbach in 2024 due to frost protection by the solar modules, it was reduced in 2025. Similarly, yield per tree was reduced (up to - 51%) under both types of AV modules in Karlsruhe in 2025 for most cultivars, while 'Freya®' yield was 21% higher under the tracked modules. It can be assumed that reduced yields are a consequence of shading. Similar results were observed by Juillion et al. (2024) for apple trees in France. However, more data are needed to validate these one-year findings. Especially different impact on yields of tracked and fixed modules is in focus for future research, as they were diverging between cultivars in 2025.

At both sites, colouration of apples under AV was delayed for 1–2 weeks. For most cultivars, soluble carbohydrates were slightly reduced also. Delayed ripening, indicated by reduced soluble carbohydrate contents, was as well observed for plums in 2025, but it was less pronounced in 2024. In contrast, the two pear cultivars grown at the Karlsruhe site showed reduced ('Xenia®/Novembra®') or no ('Conference') delay in ripening in 2025.

Management strategies could be tailored to AV with adapted tracking algorithms, crops, cultivars, and harvest dates. Further research is needed to evaluate whether these adaptations lead to high fruit quality and yield while enabling sufficient electricity generation.

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