Photosynthesis and growth of Spinach in APV systems

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Spinach is an important leafy vegetable that is eaten both fresh and processed into frozen foods. In Germany, 66 kt of spinach were produced in 2024 on an area of 3500 ha [1]. As spinach grows well in semi-shaded conditions[2] and it may be a good candidate for cultivation in APV systems. Due to its short life cycle and robust growth, spinach is also particularly suitable as a model species for investigating photosynthetic adaptations to shading and fluctuating light conditions and how they can help in understanding plant development.

We investigated the effect of solar panels on photosynthesis and growth of two spinach varieties:

(1) Grown in pots in a polytunnel equipped with organic photovoltaic (OPV) modules

(2) Field-grown in an APV system with conventional silicon PV modules

Materials & Methods

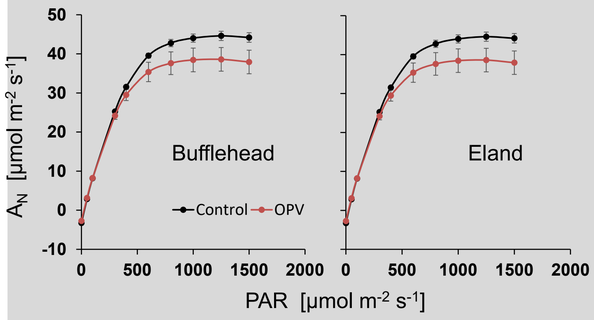
Spinach varieties
- „Bufflehead“ (fast growth)
- „Eland“ (slow growth)

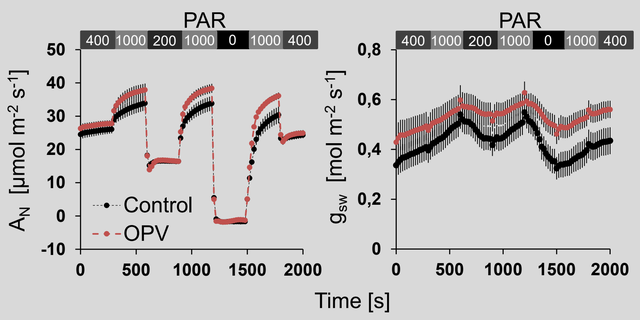
Photosynthesis measurements
- Leaf Gas exchange with LI-6800
- Light response curves of photosynthesis
- Reactions of photosynthesis to light fluctuations

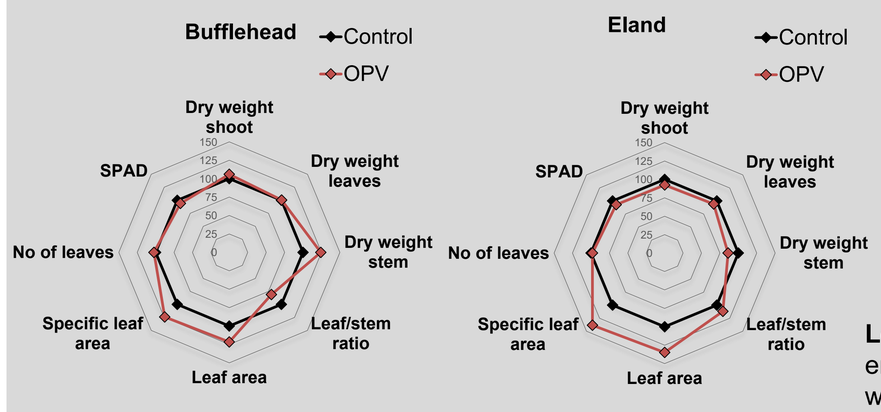
Sampling
- Shoot biomass, leaf area, specific leaf area (SLA) etc.
- Chlorophyll content (SPAD)

Polytunnel

- Summer cultivation (2024)
- Polytunnel with OPV modules
- Modules with 5% transparency (400-780 nm)
- „Zebra-design“ resulting in frequent time intervals of shading and sun
- 50% light reduction overall
- Control: Polytunnel without modules







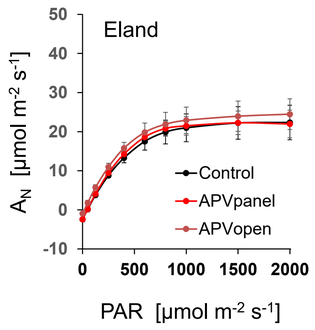
Top left: light response curves of photosynthesis (A_N) of different genotypes and treatments (n=3)

Top right: Dynamics of photosynthesis (A_N) and stomatal conductance (g_{sw}) of Eland plants under fluctuating light conditions (n=6)

Left: Morphological traits at the end of the experiment approx. 10 weeks after sowing (in %, n=15), data is presented relative to control of each variety

Field

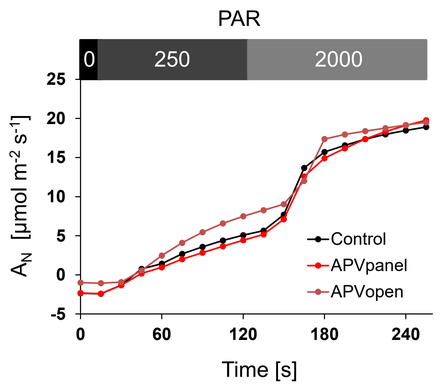
- Spring cultivation (2025)
- APV system with bifacial silicon PV modules in Bürgewald near Jülich
- Minimum height 2.5 m, 50% ground cover by modules
- APVpanel: area under panels rows, APVopen: area between rows
- Control: Neighboring field without PV modules

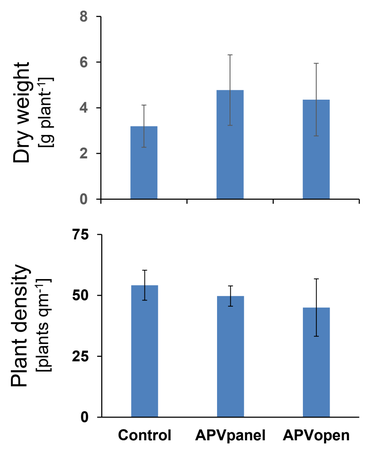


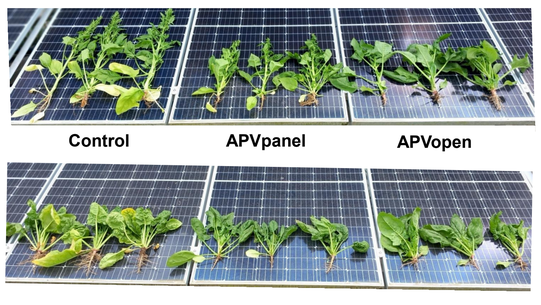
Left: light response curves of photosynthesis (A_N) of different treatments (n=8)

Right: Induction of photosynthesis (A_N) from darkness, transition from 0 to 250 to 2000 µmol m^{-2}s^{-1} (Eland, n=8)

Measurements per group on different dates, but at similar phenological stage (8-12 leaves)







Top: Variable phenology of varieties 10 weeks after sowing on May 29

Left: Dry biomass and plant density on acquisition dates of photosynthesis data (Control: May 7; APVpanel and APVopen: May 29, n=10)

Key findings

- Physiology adapted to conditions in APV systems by accelerating induction of photosynthesis upon transition from low light to high light (Polytunnel) or darkness to low light (Field)
- Light response curves showed higher photosynthetic capacity – but only for plants grown under OPV. Overall, photosynthesis rates in the field were only half as high as in Polytunnels
- Leaf biomass was surprisingly unaffected in Polytunnels, plants reacted by altering morphology and physiology and showed no delay in development, indicated by similar number of leaves
- In contrast, plant development was delayed in the field by approx. 3 weeks. Compared to Polytunnels, this may have been caused by reduced adaptability of spinach due to seasonal effects (spring vs. summer), different shading regimes or the growth systems (pot vs. field). This delay is critical for plant production, as the variable onset of bolting of Bufflehead complicates optimal timing of harvest.

References
[1] Statistisches Bundesamt: Betriebe, Anbauflächen, Erträge und Erntemengen von Gemüse. Available under www.destatis.de
[2] Yoneda, Y. *et al.* (2022). Control of Transmitted Solar Radiation Using Photoselective Covering Materials Improves Spinach (*Spinacia oleracea* L.) Yield during Summer. Japan Agricultural Research Quarterly, 6 (1), 67-75. https://doi.org/10.6090/jarq.56.67

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