Electrical Grid-Supportive Agri PV

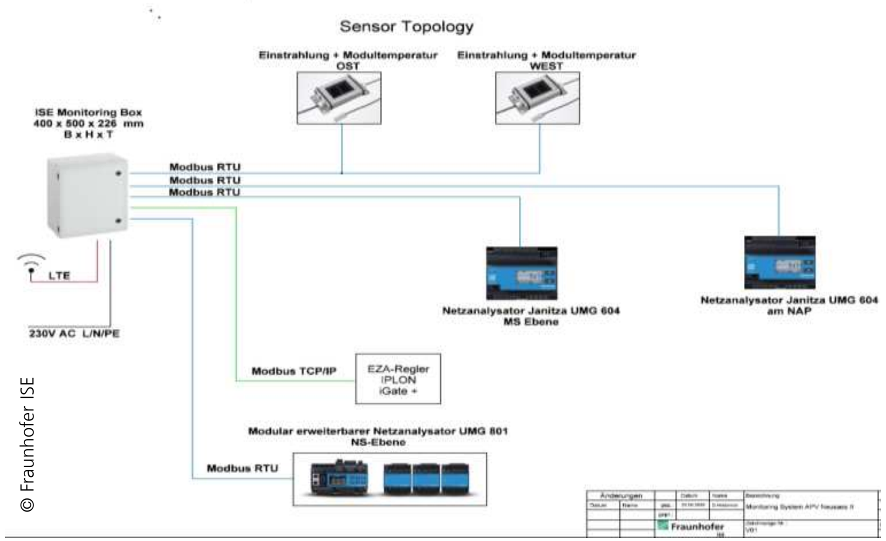
Combined Fixed South PV and Vertical East-West AV System

- Model Region Agrivoltaics BW: Applied pilot installations and technologies
- Evaluation of grid-supportive effect of combined conventional South and bifacial vertical East-West PV plants
- South facing fixed 3.15MWp plant with restricted grid connection capacity of 3.2 MW
- Shared grid connection with 2.97 MW_p of vertical E-W bifacial PV plant

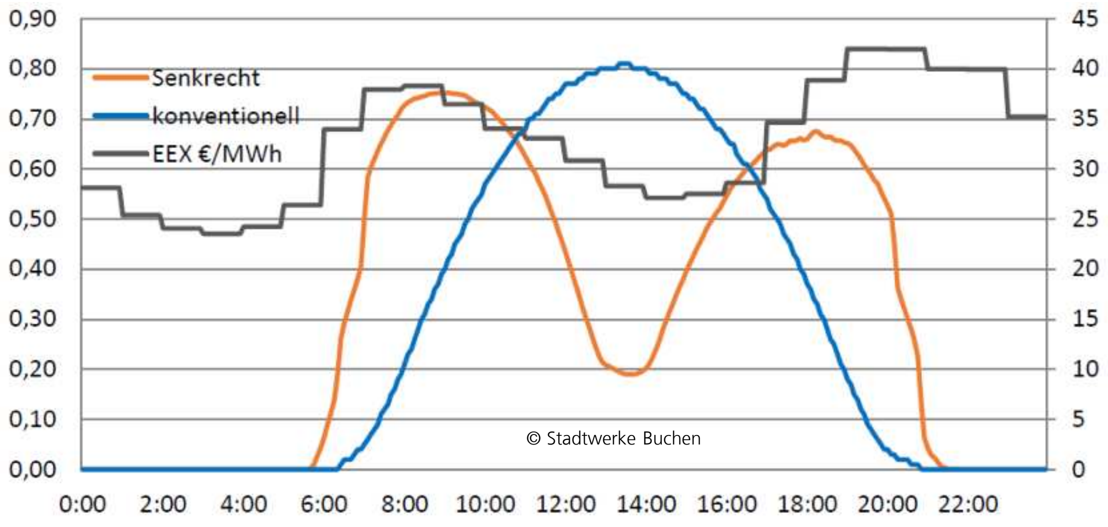
Electrical Grid-Supportive Agri PV

Combined Fixed South PV and Vertical East-West APV System

Modellregion Agri-PV BW



Sensor equipment of AV system



Combined production incl. example of market price

- Network analysators for medium level voltage before and after grid connection point
- combined medium voltage level switch gear with separate measurement equipment
- Possibility of deeper analysis of grid interactions like frequency / reactive power

- Demand oriented and grid-supportive power generation in the morning and evening hours.
- Possibly higher market prices of up to 10%
- Efficient use of existing infrastructure avoiding high investments for grid expansion measures
- Faster deployment of renewable energy power plants

Fraunhofer ISE

Model Region Agrivoltaics Baden-Württemberg

Protecting Apple Orchards with a Day-Ahead Tracker Control Strategy

Maddalena Bruno [1], Bilal Abdul-Qayyoom Khalid [1], Greta Ott [2], Elgin Hense [2], Tamara Bretzel [1], Oliver Hörnle [1] , Leonhard Gfüllner [1], and Matthew Berwind [1]

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2 Landwirtschaftliches Technologiezentrum (LTZ), Augustenberg 1, 76227 Karlsruhe, Germany

SCAN TO LEARN MORE

1. Introduction

- **Agrivoltaic systems** provide an innovative solution to land-use conflicts that often arise between agriculture and energy production.
- **Horizontal single-axis tracking (HSAT) agrivoltaic system** enable effective management of light distribution between solar panels and the underlying crops through innovative control algorithms [1].
- This work presents the tracking strategy methodology implemented at the Nussbach facility, located in Western Germany, as part of the Model Region Agrivoltaics BW project [2]

2. Methodology

The methodology is structured in several parts:

- **Tracking Optimization:** Analyzes five statistically representative days per month using historical data to account for weather variability obtaining the optimized tracking profiles.
- **Day-Ahead Control**: Utilizes next-day weather forecasts to align operational strategies with irradiation profiles, ensuring optimal light exposure.
- **Day-Ahead Adaptive Strategy:** Incorporates sensor data to fine-tune the tracking strategy based on the health status of the crops.

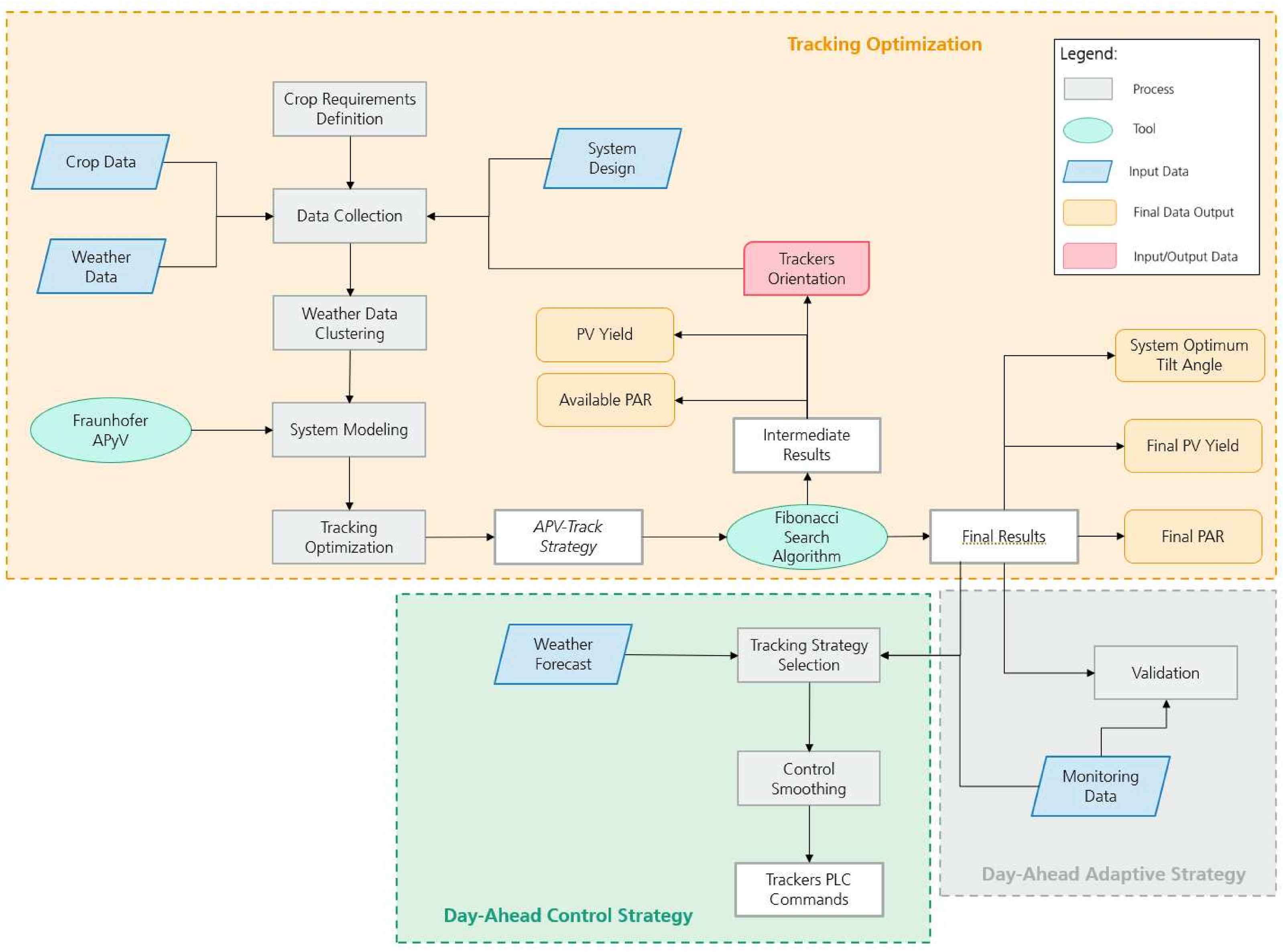

Figure 1: Methodology Flowchart

- **Forecast data:** In a first step, day-ahead control strategies are utilized. Corrective actions during the day are not possible based on updated forecasts, however, day-ahead sensor-based protective measures are enabled. The strategy therefore relies on the weather forecast from the previous night that inherently shows increasing uncertainty over the course of a day.
- **Validation:** Temporally dependent differences between simulated and measured data are crucial to be evaluated. Thus, sensors data are also used to validate the simulation results. The location and type of sensors used is illustrated in *Figure 2*.

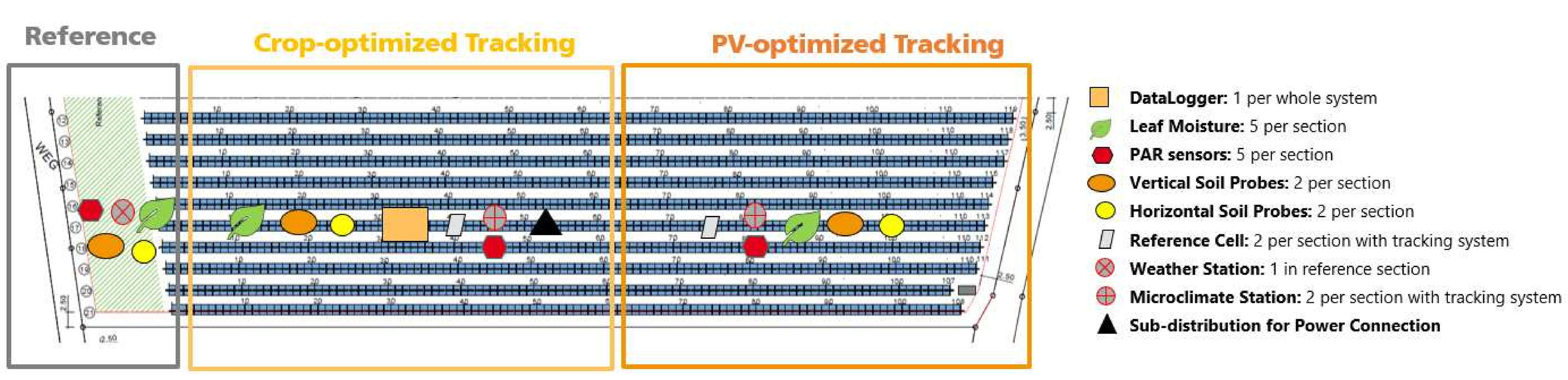

Figure 2: Overview of the Monitoring concept in Nussbach

3. Crop Requirements

- The definition of the crop requirements starts from **PAR reduction rates** reported in *Table 1*. These values are provided by **LTZ** [3], the agricultural partner of the Model Region project, and are empirically derived based on their long-term agronomical experience.
- Different thresholds are identified for the different phases of crop's development, based on the **phenological stage of the apple trees**. Particularly critical stages occur during the flowering and fruit colouring processes.

Month	Max PAR reduction [%]	Phase
March	40%	Budding/Sprouting
April	20-30%	Flowering sensitive to shading
May	20-30%	High importance of carbohydrate assimilation during flower formation
Juni	30-35%	Heat reduction for better fruit quality and sunburn protection
July until Mid-August	30-35%	Fruit ripening
Mid-August until September	20-30%	Fruit coloring

Table 1: Acceptable PAR reduction rates in the cropping season (© LTZ Augustenberg)

- Using a percentage threshold however is not ideal in optimization work. In fact, if the same threshold is applied to a sunny day or an overcast day, it leads to very different values of **DLI (Daily Light Integral)** for the plant.
- In this study, **absolute PAR targets in W/m²** are introduced. The targets are obtained by simulating the light received by the apple orchard using historical weather data from 1994 to 2014, and average weather conditions for each month.

Figure 3: 3D rendering (© Fraunhofer ISE) and picture (© Intech) of the pilot project in Nussbach

- This approach mitigates the impact of climate change and increasing GHI values, setting lower irradiation targets for the trees, thus ensuring that **power production is not excessively compromised.**

4. Results

- This study introduces an innovative approach by incorporating **crop shade sensitivity across various developmental stages** into the optimization process. As more data become available, the methodology can seamlessly adapt to consider variations in intraday shade sensitivity.
- Results indicate that **91% of the target irradiation for apples can be achieved** in the simulated year with tailored PV control, resulting in a moderate **20% reduction in electrical yield** [2].
- The field testing started in March and will continue until September. Expectations will be confirmed or refuted by field trial during the 2025 growing season currently ongoing.
- The results demonstrate **that efficient and sustainable dual land use** is achievable through the implementation of a well-managed agrivoltaic system.

[1] C. Toledo and A. Scognamiglio. "Agrivoltaic systems design and assessment: A critical review, and a descriptive model towards a sustainable landscape vision (three-dimensional agrivoltaic patterns)". In: Sustainability 13.12 (2021), p. 6871. DOI: https://doi.org/10.3390/su13126871

[2] Maddalena Bruno, Leonhard J. Gfüllner, and Matthew F. Berwind "Enhancing agrivoltaic synergies through optimized tracking strategies," *Journal of Photonics for Energy* 15(3), 032703 (27 January 2025) https://doi.org/10.1117/1.JPE.15.032703

[3] Landwirtschaftliches Technologiezentrum (LTZ) Augustenberg. https://ltz.landwirtschaft-bw.de/,Lde/Startseite

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Agrivoltaics on permanent grasslands

A subproject of the Model Region Agrivoltaics Baden-Württemberg

Nachtsheim J.[1], Obermeyer K.[2], Messner, J.[2], Weber J.[1]

[1] DHBW Ravensburg; [2] LAZBW Aulendorf

DHBW Duale Hochschule Baden-Württemberg Ravensburg

Project Information

- Duration: September 2023 to December 2026
- Cooperation Project of the Cooperative State University Baden-Württemberg (DHBW) and the Agricultural Center Aulendorf (LAZBW)
- Funded by the Ministry of Food, Rural Areas and Consumer Protection (MLR)

Objectives

- Investigation of the impact of PV-systems on:
  - Yield and quality of forage
  - Botanical composition and biodiversity
  - grassland management
  - Microclimate
- Knowledge transfer

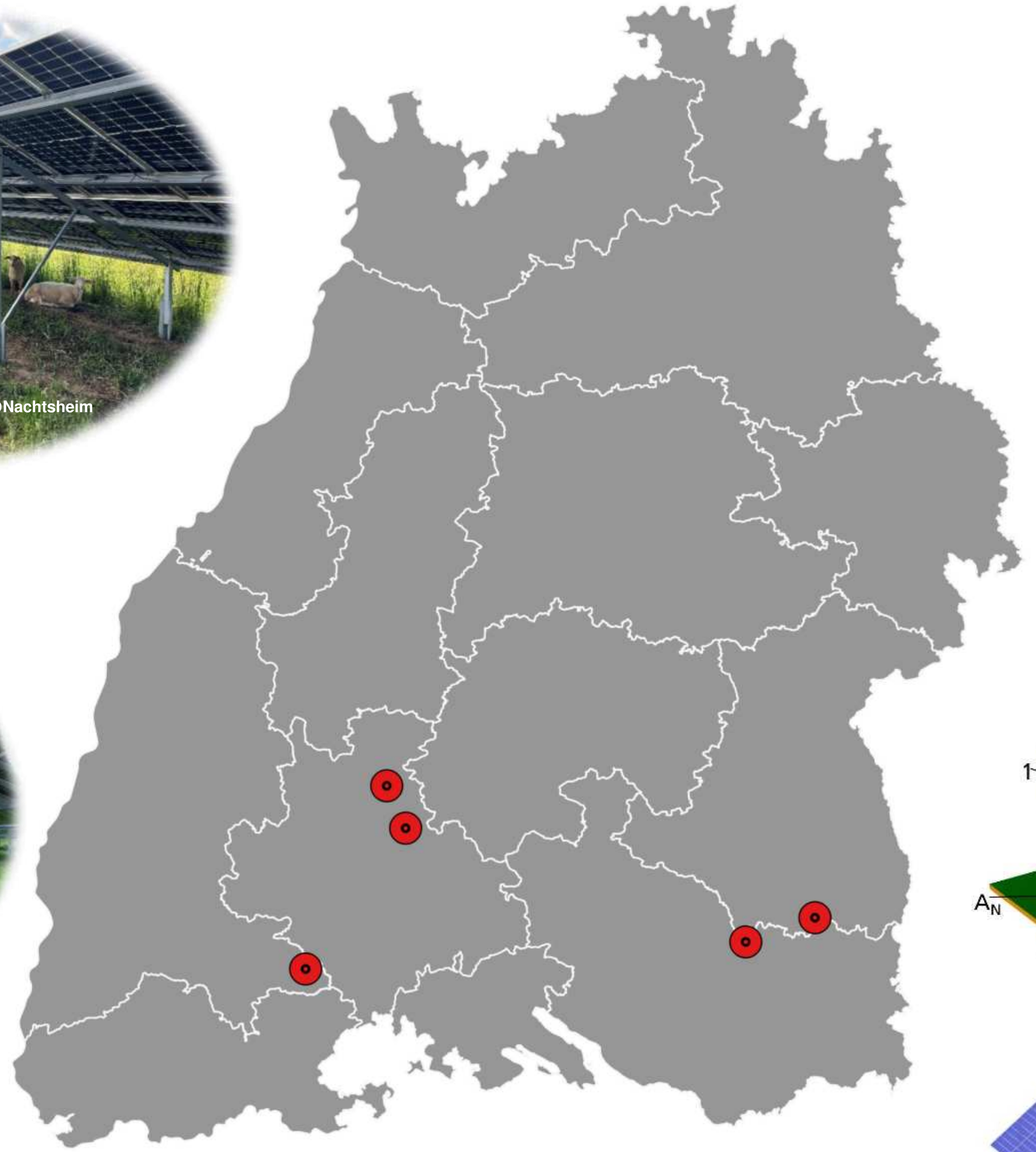

Fig. 1: Locations of the test plots in the south of Baden-Württemberg

Experimental Plots

- five different Locations (fig. 1):

  0,15 – 11 ha area size

  0,1 – 4,3 MW installed PV capacity
- Management:
  - Intensive and extensive mowing frequency
  - Grazing (sheep, cattle)
- Bifacial vertically mounted modules, tracking systems and fixed south-facing modules

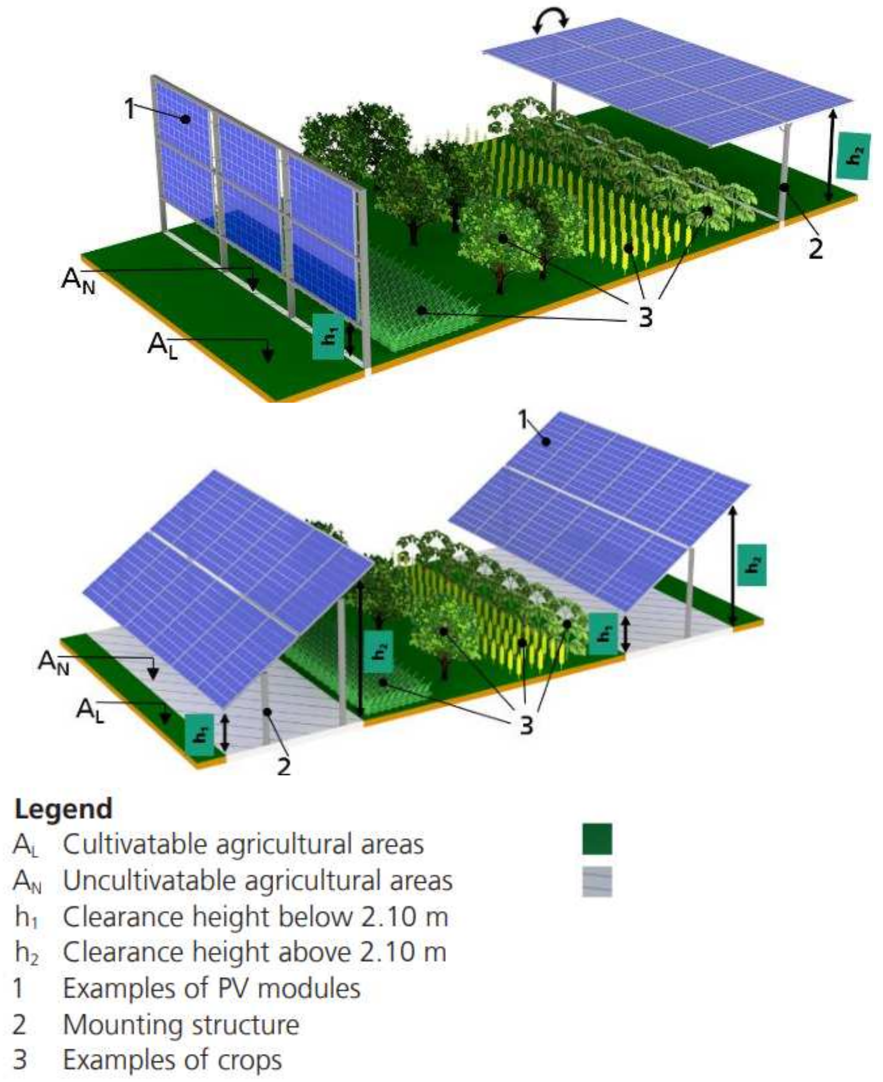

Fig. 2: llustration of Category 2 of DIN SPEC 91434 (Trommsdorff et al. 2024)

Materials and Methods

- Yield sampling inside and outside the PV-System
- Clover, grass and herb estimates and botanical recordings
- microclimate sensors under, between and outside the module rows (temperature, wind, humidity, PAR, soil moisture, soil temperature)
- animal observations under photovoltaic pasture systems

Baden-Württemberg Ministerium für Ernährung, Ländlichen Raum und Verbraucherschutz

Modellregion Agri-PV BW

LAZBW Landwirtschaftliches Zentrum Baden-Württemberg

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Baden-Wuerttemberg Cooperative State University (DHBW)

For more information, see:

References: Trommsdorff M, Gruber S, Keinath T, et al (2024) Agri-Photovoltaik:
Chance für Landwirtschaft und Energiewende - Ein Leitfaden für Deutschland. Stand Februar 2024. Hg. v. Fraunhofer ISE. Freiburg

Combination of Photovoltaics and free-range laying hens (Modellregion Agri-PV Baden-Württemberg)

Hochschule für Wirtschaft und Umwelt Nürtingen-Geislingen

Objectives

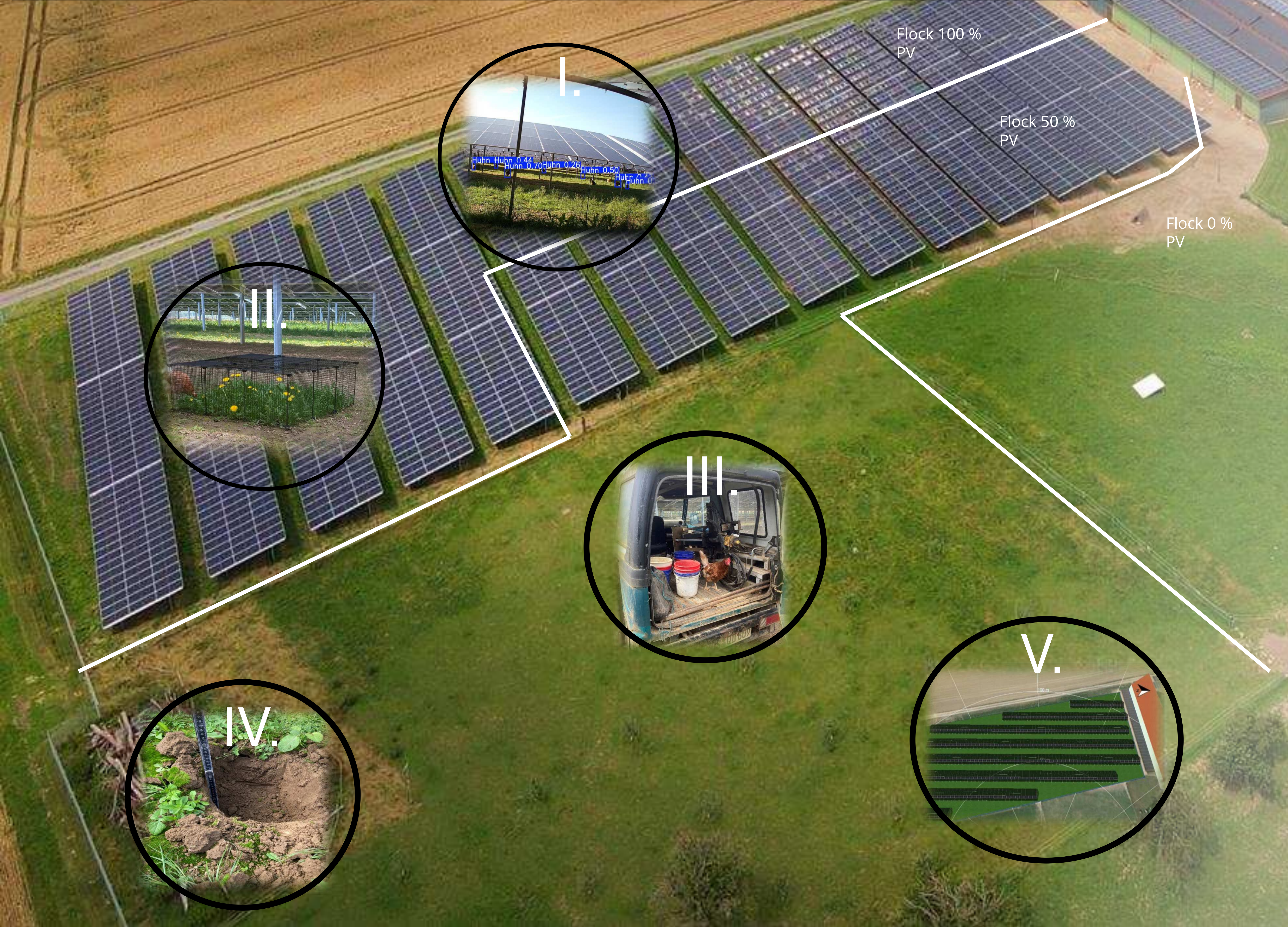
Numerous studies have shown that laying hens tend to prefer areas close to the barn (Zeltner & Hirt, 2003). This behavior often leads to overuse of the sward and elevated nutrient input, posing significant challenges for free-range systems (Elbe et al., 2006). This project investigates the integration of free-range poultry farming with photovoltaic (PV) systems on two farms. The study focuses on outdoor area utilization, nutrient deposition in the soil, impacts on vegetation, and economic considerations, with the aim of developing practical recommendations.

Methods

Farm 1: Barn orientation: E/W; PV orientation: S; 2.1 ha free range; 4 m² /laying hen; brown layer; study design: three flocks with 100 % PV, 50 % PV and 0 % PV.

Farm 2: Barn orientation: N/S; PV orientation: S; 2.3 ha free range; 4 m² /laying hen; white and brown layers; study design: two flocks with 100 % PV and 0 % PV.

Livstock	Soil	Vegetation	Economy
scan sampling method	phosphorus and nitrate analysis; volumetric soil moisture	dry matter yield; Göttingen estimation system	workreport; simulation software PV*Sol Premium



Preliminary results

I. Behavioral observation

Wildlife cameras document the number of hens within defined areas at different distances from the barn. A total of 14 cameras take a picture every hour. AI is used to count the hens in the images.

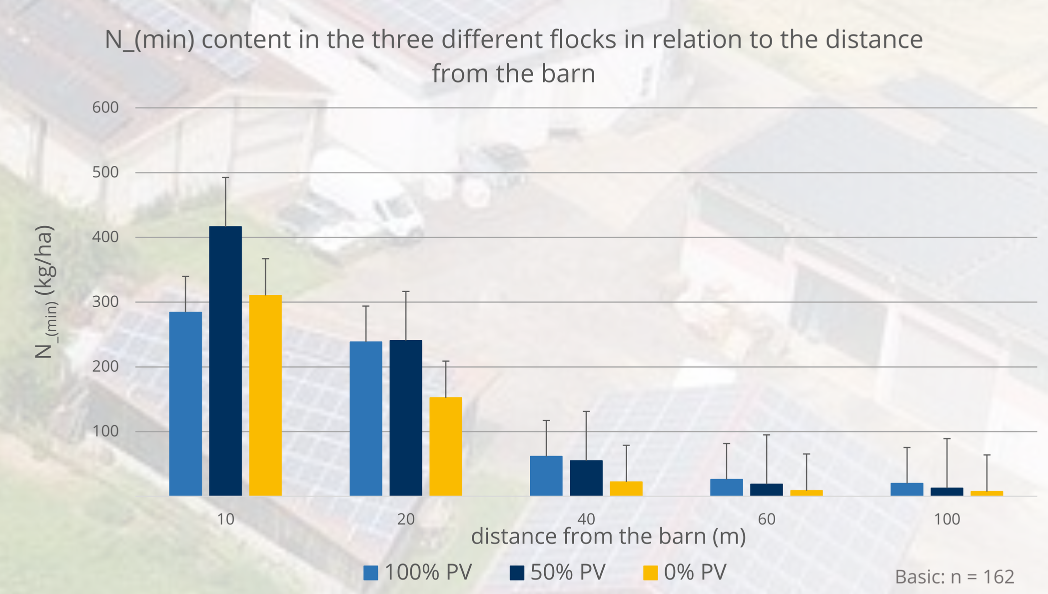
II. Vegetation analysis

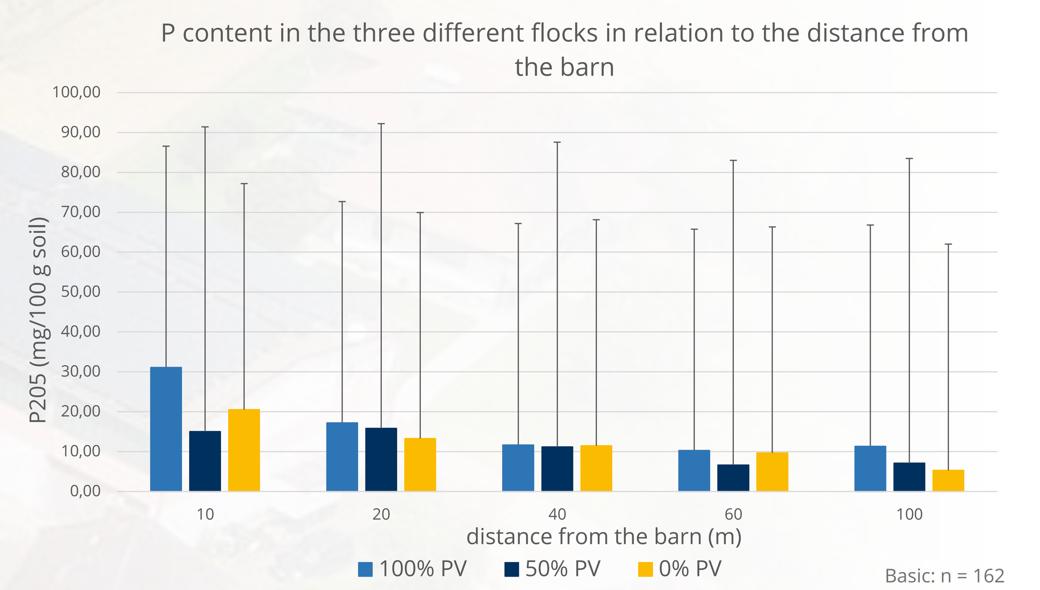
The soil cover, the plant species and the dry matter underneath the module tables and in the intermediate area is determined. The data from the 2024 evaluation is summarized in the table.

	Intermediate area	Underneath the module table
soil cover (%)	87	59
amount of plant species	6,3	3,1
dry matter (%)	17,9	12,2

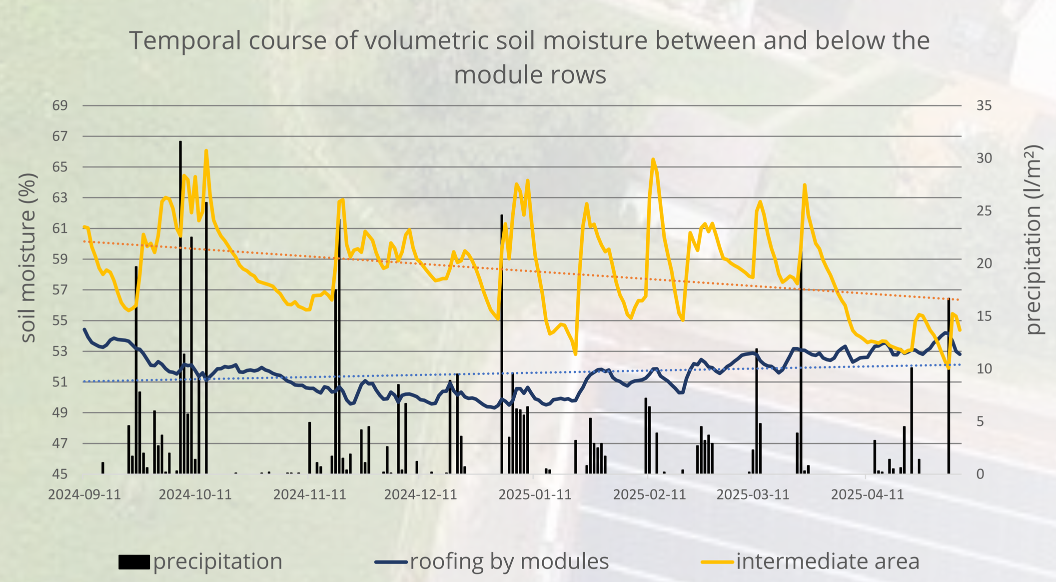
III. Soil analysis

The graphs illustrate the average N_(min) and P content of the three flocks in relation to their distance from the barn.

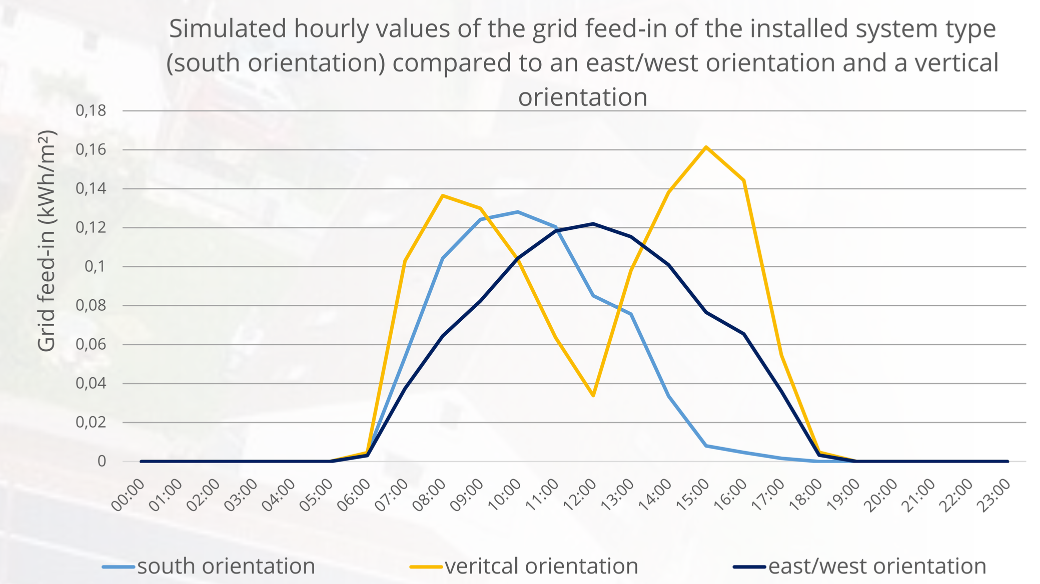




IV. Soil moisture analysis



V. Energy yield analysis



Future perspective

The empirical study enables the comparison of two PV systems with different orientation of the module rows. The results form the basis for practical advice on the design of PV systems on laying hen runs.

Characteristics	Farm 1	Farm 2
orientation towards the barn	lengthways	transverse
width of a module row [m]	6,8	4,4
row distance [m]	2,1	4,5
amount of drip edges	3	2
module type	bifacial	monofacial

Baden-Württemberg
MINISTERIUM FÜR ERNÄHRUNG, LÄNDLICHEN RAUM UND VERBRAUCHERSCHUTZ

Funded by the Ministry of Food, Rural Areas and Consumer Protection Baden-Württemberg (Ministerium für Ernährung, Ländlichen Raum und Verbraucherschutz Baden-Württemberg)

NGU Nürtingen-Geislingen University

Modellregion Agri-PV

Project trailer

Elbe, U., Roß, A., Steffens, G., Van den Weghe, H., & Winckler, C. (2005). Organic layer hen husbandry in large flocks: Specific use of outdoor runs and nutrient input. In J. Heß & G. Rahmann (Eds.), *Proceedings of the 8th Scientific Conference on Organic Agriculture* (pp. 307–310). Kassel: kassel university press GmbH.

Zeltner, E., & Hirt, H. (2003). Use of outdoor runs by different layer hybrids during rearing and laying period. In B. Freyer (Ed.), *Proceedings of the 7th Scientific Conference on Organic Agriculture* (pp. 257–260). Vienna: University of Natural Resources and Life Sciences, Institute of Organic Farming.

Agrivoltaic systems in apple cultivation at Kompetenzzentrum Obstbau Bodensee

Yield and selected external fruit quality parameters in 2023 and 2024

Bohr, A., Weißhaupt, S., Buchleither, S., Mayr, U.

Modellregion Agri-PV BW

KOB KOMPETENZZENTRUM OBSTBAU BODENSEE

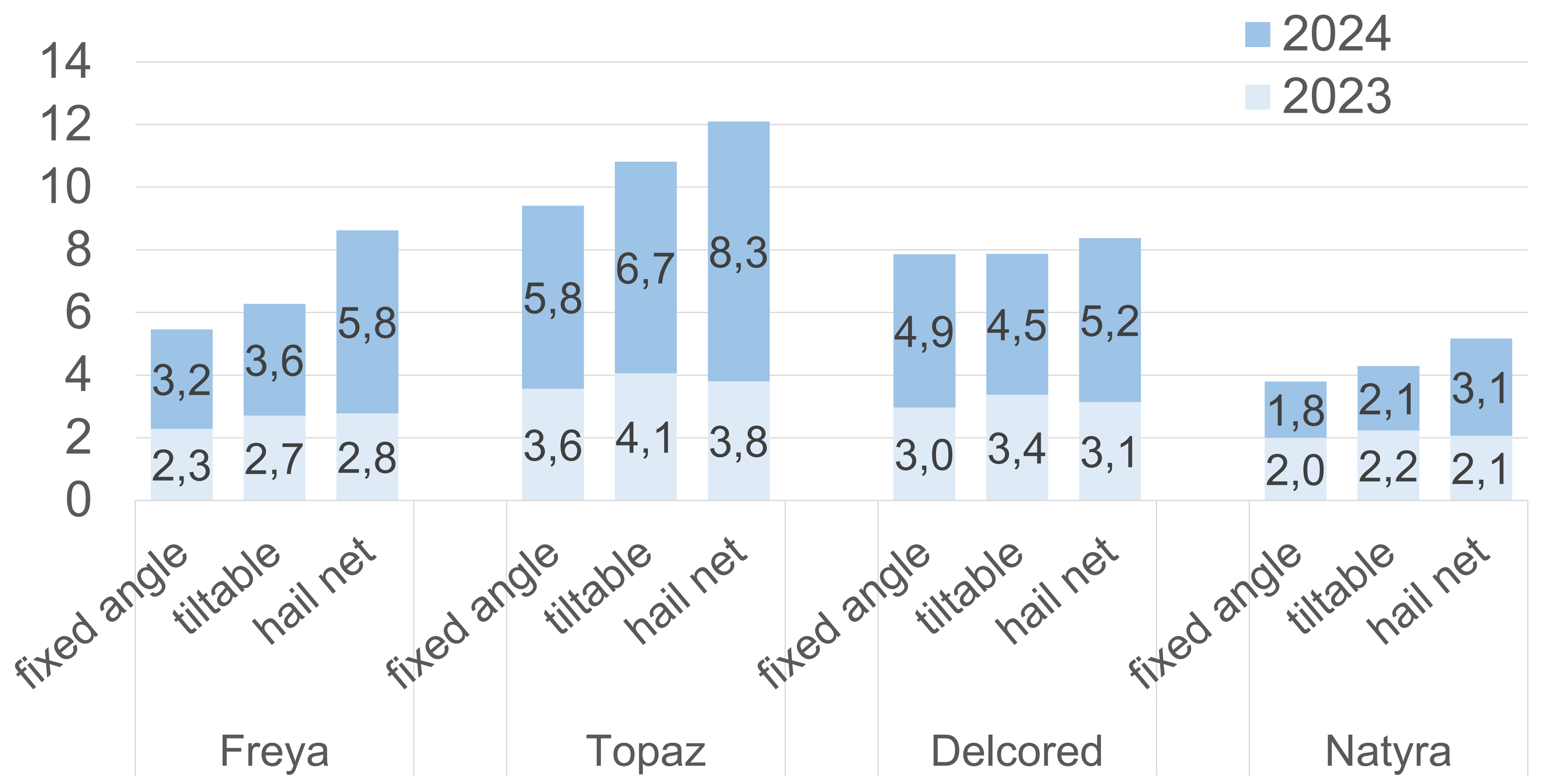
Agrivoltaics at KOB

Fixed angle system (10° East/West)

Tiltable system (East/West)

- Trial site is certified organic, planted in spring 2022 – trees are still young
- Comparison of four varieties tolerant to apple scab: Freya / Topaz / Delcored / Natyra
- Control Block covered by grey hail net

Yield per tree in kg 2023-2024



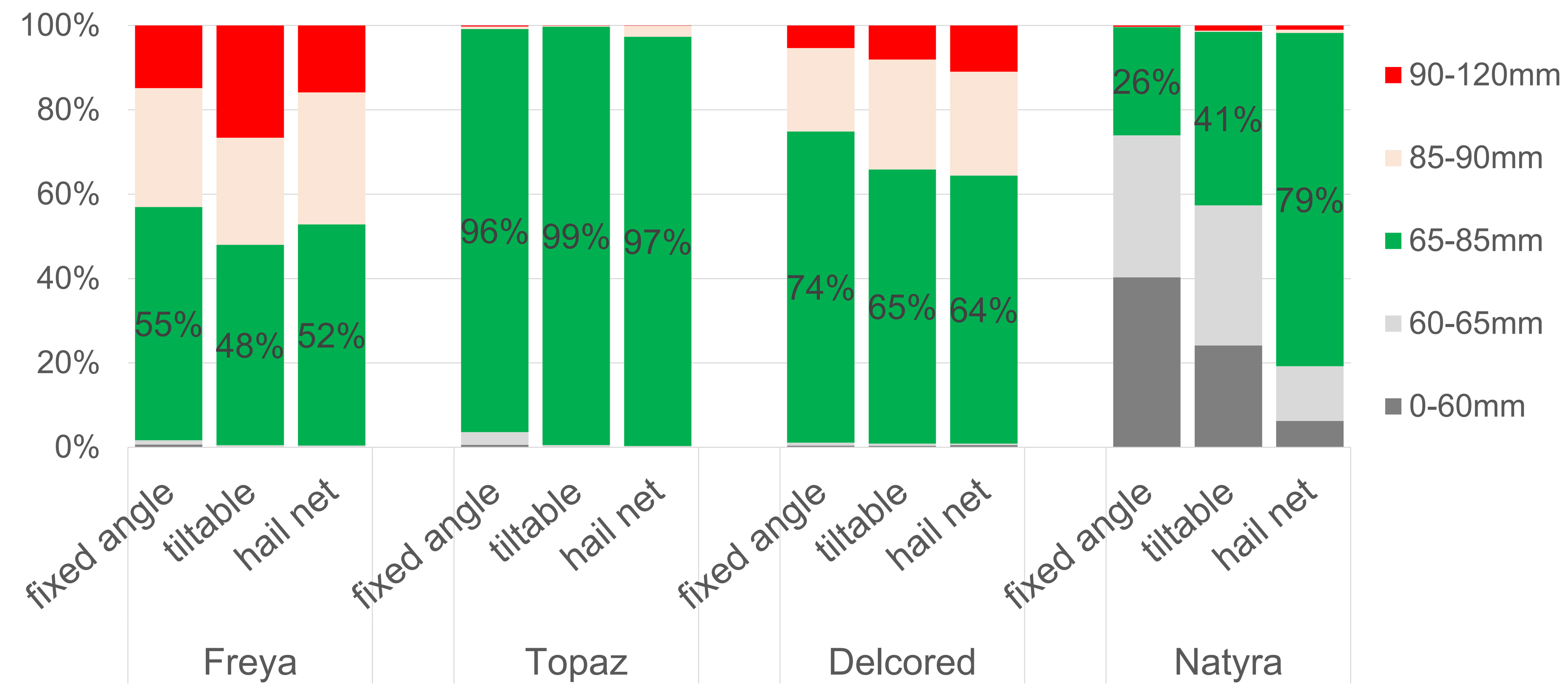
Average yield in kg/tree summed up from all pickings (one to three depending on year and variety), N = 80 trees (4 plots à 20 trees each). Data generated at KOB using an AWETA sorting machine.

Conclusions 2023-2024

- so far highest cumulative yield under hail net with yield reduction varying with year and variety
- negative effect of agrivoltaics on both caliber size and fruit color
- clear differences between varieties, i.e. the choice of variety appears to be crucial regarding feasibility of agrivoltaics in apple cultivation
- trees are still young – more years of trial needed

Caliber size in 2024

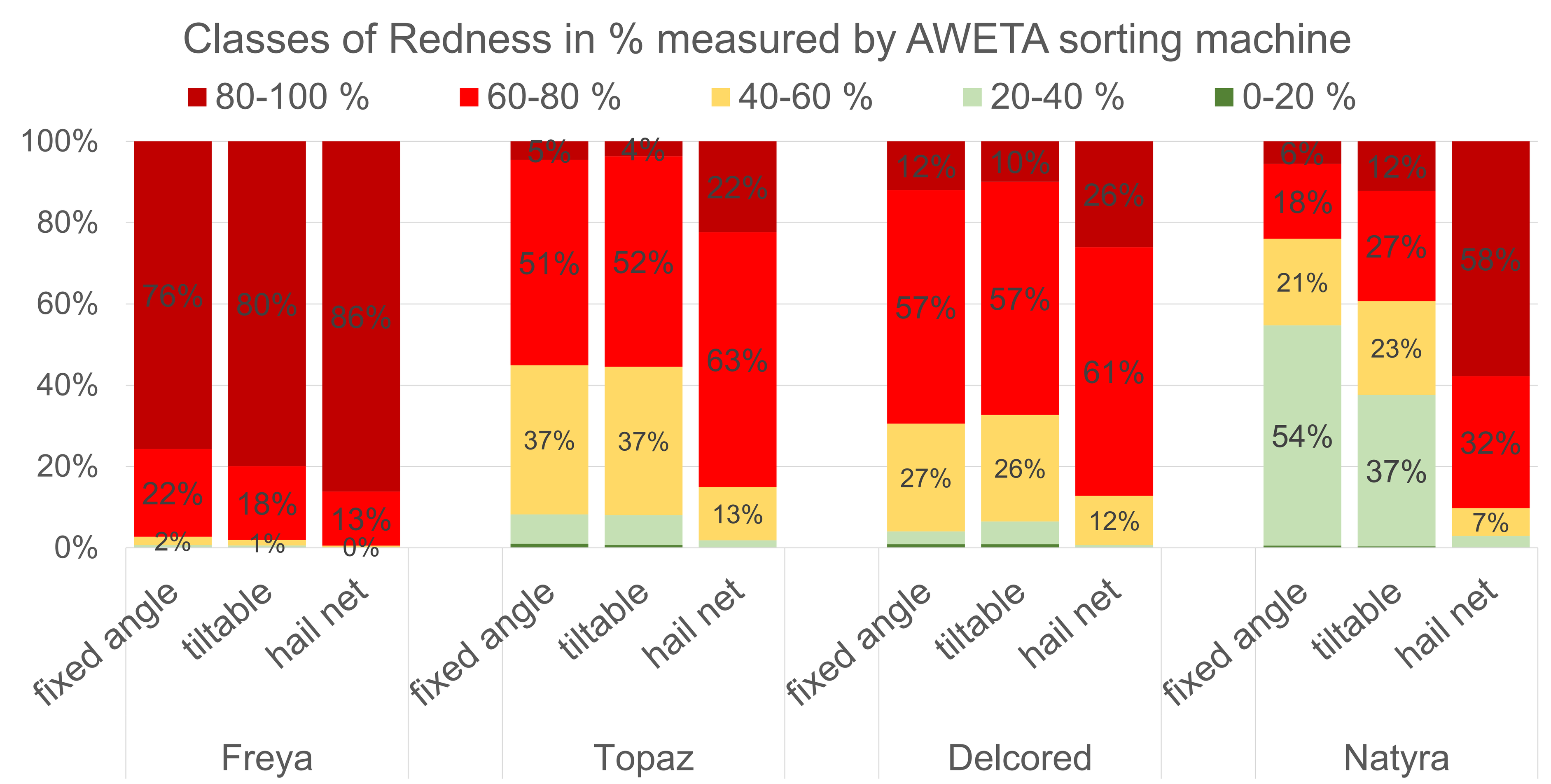
Desired caliber size of 65-85 mm displayed in green



Percentage of apples in caliber size classes based on sum of all pickings from N = 80 trees (4 plots à 20 trees each). Data generated at KOB using an AWETA sorting machine.

Fruit Color 2024

Classification of harvested fruit into classes of „Redness in %"



Percentage of apples in color classes measured by AWETA sorting machine using a camera system to detect redness of fruit surface. Sum of fruits from all pickings of N = 80 trees (4 plots à 20 trees each).

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Zur Modellregion KOB, Ravensburg

Zur Modellregion Obsthof Bernhard, Kressbronn

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Agrivoltaic systems in apple cultivation at Kompetenzzentrum Obstbau Bodensee

pome fruit diseases and arthropods

Weißhaupt, S., Bohr, A., Buchleither, S., Mayr, U.

KOB
KOMPETENZZENTRUM OBSTBAU BODENSEE

BACKGROUND

Agrivoltaics (AV) can be a chance for growers to combine growing apples in a protected environment with solar energy production. Expected benefits of apple cultivation under AV include protection against extreme weather (hail, sunburn) as well as positive effects on certain diseases (especially fungal diseases) due to the covering function of the solar panels. However, not only positive effects may occur. For example, reduced yield as well as a reduction in caliber were found in pear grown under semi—transparent panels in Belgium (Reher et al., 2025 [1]). Therefore, the impact of agrivoltaic cultivation on apple has to be analyzed in detail and concerning different parameters for each crop.

The test orchard at Bavendorf, Germany contains four different apple varieties (Freya, Topaz, Delcored, Natyra) planted in four replicates each. Per variety a total of 320 trees were planted in 2022. Two different AV systems (a fixed angle system and a tiltable system) are compared with control plots covered with grey hail net.

In addition to physiological tree parameters and yield a focus in the orchard is on evaluation of pome fruit diseases and arthropods. Among many other parameters, infestation with fungal storage diseases and wooly apple aphid was determined over a period of two years.

[1] Reher, T., Willockx, B., Schenk, A. *et al.* Agrivoltaic cultivation of pears under semi-transparent panels reduces yield consistently and maintains fruit quality in Belgium. *Agron. Sustain. Dev.* **45**, 25 (2025). https://doi.org/10.1007/s13593-025-01019-0

RESULTS – STORAGE ROTS

- Both agrivoltaic systems are able to reduce rot infestation after cold storage and shelf life
- Highest infestation mostly in hail net variants
- Topaz shows an increase in storage rot infestation over time

		% rot infestation after storage and shelf life			
		2023		2024	
		1st picking	2nd picking	1st picking	2nd picking
Freya	fixed angle	6.7	7.2	-	-
	tiltable	11.3	4.9	-	-
	hail net	**26.3**	**19.6**	-	-
Topaz	fixed angle	5.3	6.7	1.2	1.4
	tiltable	1.3	4.3	9.9	7.4
	hail net	**13.9**	-	**28.1**	**57.9**
Delcored	fixed angle	3.6	*	1.4	*
	tiltable	**8.5**	*	2.0	*
	hail net	6.2	*	**4.0**	*
Natyra	fixed angle	0.6	1.1	-	-
	tiltable	1.5	1.4	-	-
	hail net	**10.2**	**20.5**	-	-

\- no storage trial
* no 2nd picking

Storage rots on ‚Topaz' apples

Wooly aphid (*Eriosoma lanigerum*)

CONCLUSION

- Positive effect of covering function of AV on storage rots
- Negative effect of AV on wooly aphid infestation
- Clear differences between varieties

→ it is not sufficient to analyze AVs only with regard to apple cultivation, as the influence of the variety can also be very important

Modellregion Agri-PV BW

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MATERIAL & METHODS

Infestation with wooly aphid was evaluated in June 2023, May, June and July 2024 and in April 2025. It was recorded in 9 different infestation classes ranging from 0 = no infestation to 8 = very strong infestation. A severity score was calculated according to:

$$\text{severity index [\%]} = \frac{\sum_{i=0}^{i=8} (n_i \times i) \times 100}{\mathrm{N} \times 8}$$

i = infestation class
ni = number of fruits in class i
N = total numer of fruits

For evaluation of infestation with storage rots, about 150 fruit per variety and growing system were stored at 4°C for four to six months. After removal from cold storage and storage at room temperature for 10 days, storage rot incidence was determined for each variety and growing system.

RESULTS – WOOLY APHID

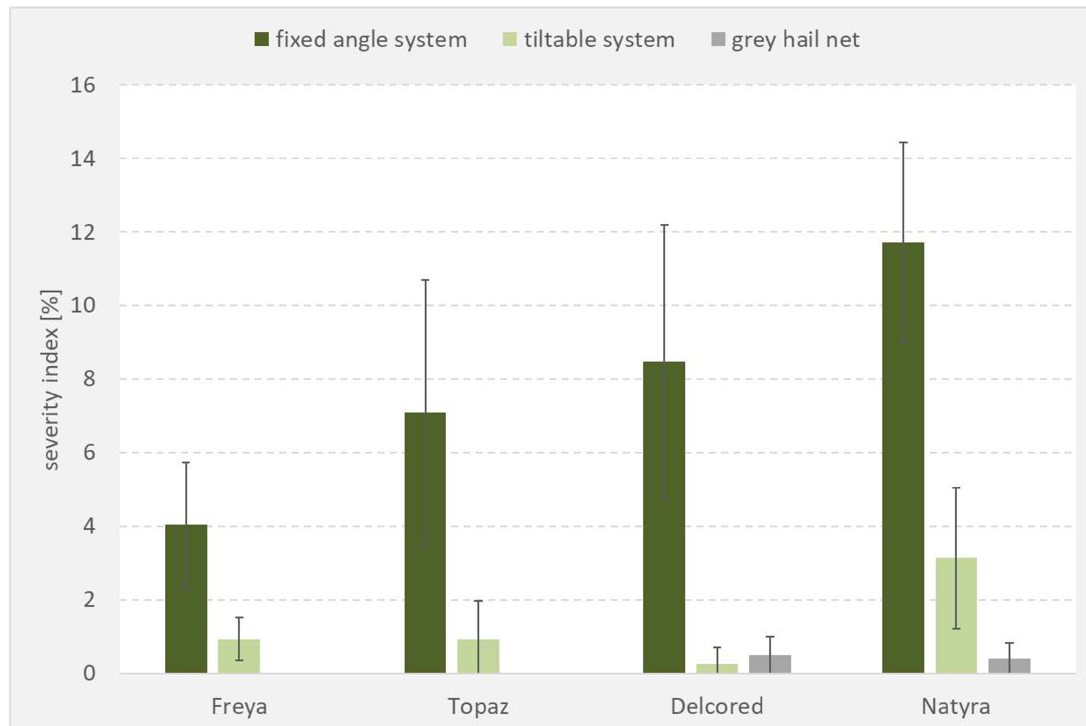

Figure 1: wooly aphid infestation of different varieties under different systems in April 2025

- Natyra shows the highest infestation with wooly aphid in April 2025
- Freya shows least infestation
- Overall more infestation under fixed angle system
- Lowest infestation mostly under grey hail net

- Over the years 2023-2025 increase in wooly aphid infestation by trend
- Highest infestation under fixed angle system for all observation dates

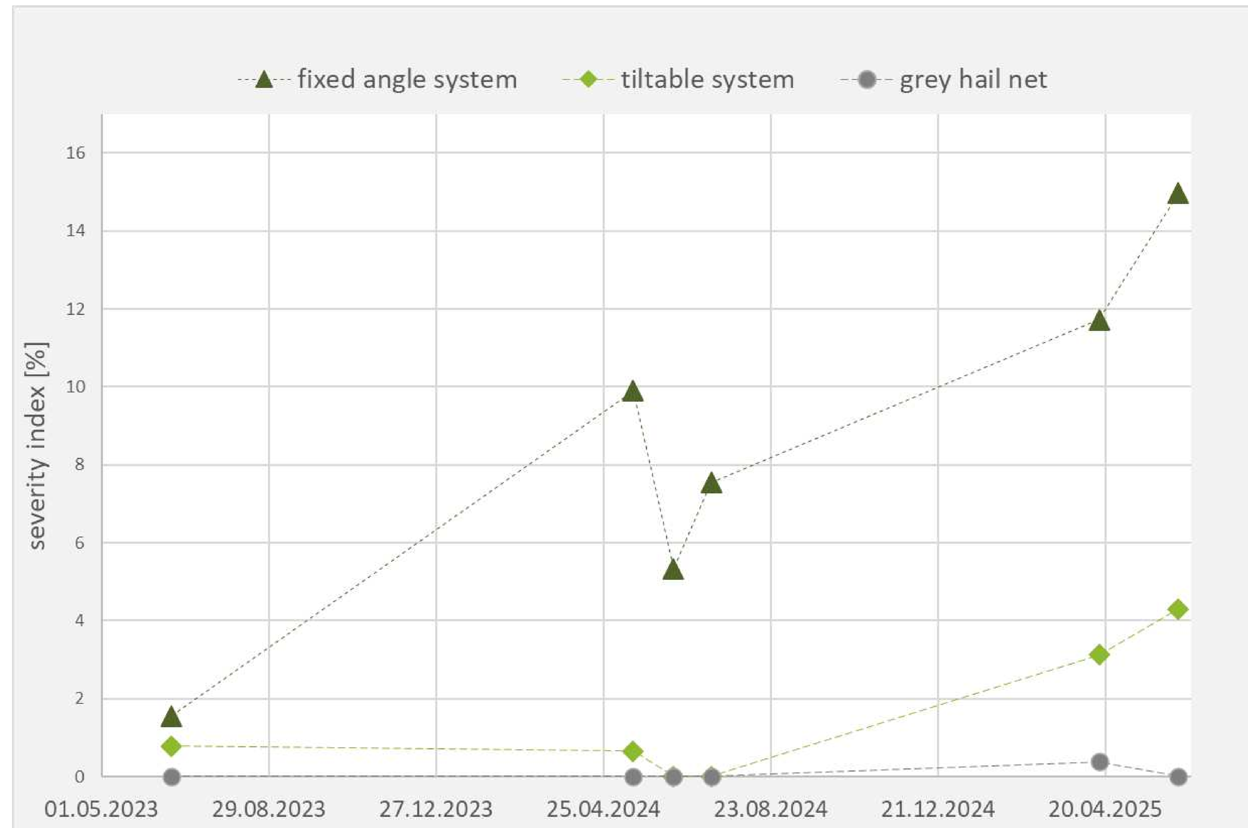

Figure 2: wooly aphid infestation in Natyra from June 2023 till April 2025

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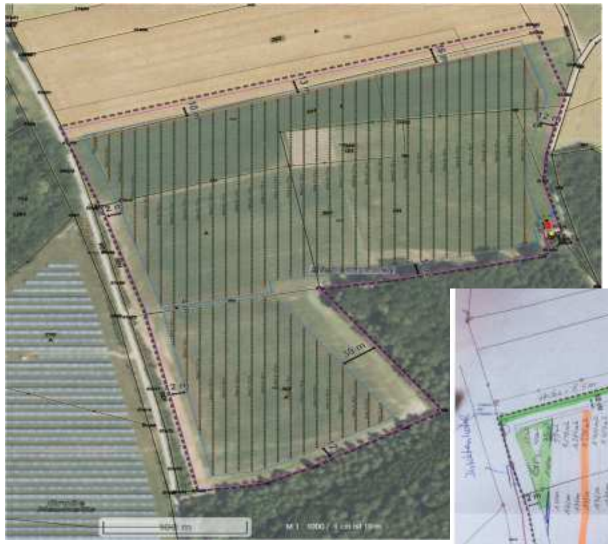
KOB, Ravensburg

Zur Modellregion
Obsthof Bernhard, Kressbronn

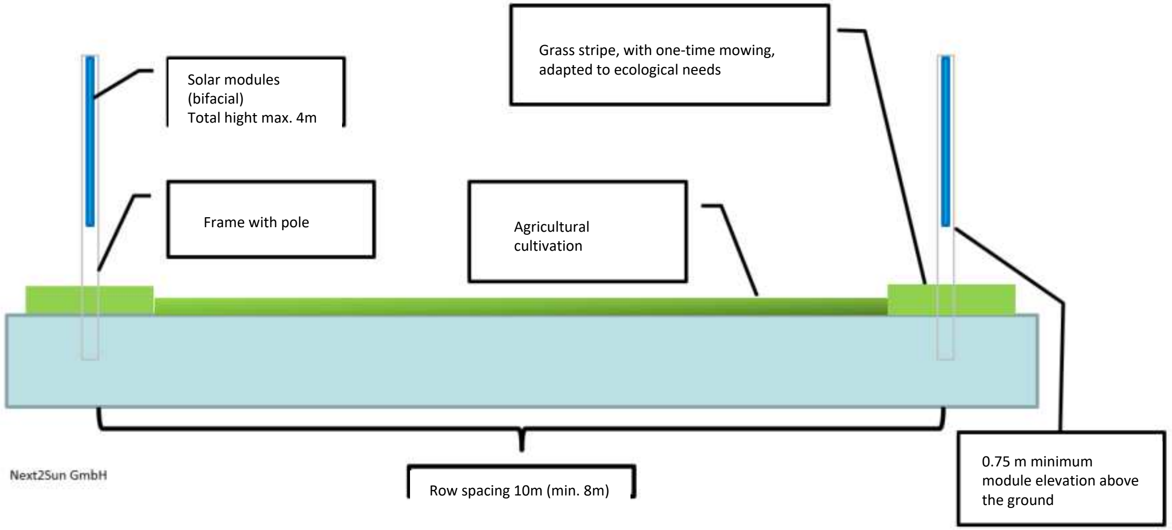
Agri - PV Neusaß II

Landsiedlung Baden-Württemberg GmbH

Construction plan:



The plant:



Modellregion Agri-PV BW

Agri - PV Neusaß II

LSBW
Landsiedlung Baden-Württemberg GmbH

Current state of implementation:

Biodiversity measurements surrounding the plant:


Dead wood heap


Pile of stones


Planting including trees


Waterhole


Skylark windows

Ornithological investigations previous to construction start (2022):

Found species

Falco tinnunculus
Certhia familiaris
Strix aluco
Phylloscopus sibilatrix
Regulus regulus
Troglodytes troglodytes
Phylloscopus collybita

Turdus merula
Motacilla alba
Fringilla montifringilla
Parus caeruleus
Fringilla coelebs
Dendrocopus major
Sylvia communis
Garrulus glandarius
Carduelis spinus
Alauda arvensis
Phylloscopus trochilus
Certhia brachydactyla
Sylvia borin
Emberiza citrinella
Picus viridis
Parus cristatus
Phoenicurus ochruros
Prunella modularis
Sitta europaea
Parus major
Corvus corax
Cuculus canorus
Buteo buteo
Turdus viscivorus
Dendrocopus medius
Sylvia atricapilla
Lanius collurio
Oriolus oriolus
Corvus corone
Columba palumbus
Erithacus rubecula
Milvus milvus
Motacilla flava
Aegithalos caudatus
Dryocopus martius
Turdus philomelos
Regulus ignicapilla
Sturnus vulgaris
Carduelis carduelis
Parus ater

Modellregion
Agri-PV BW

Model System Agrivoltaics and Cultivation of berries

Research questions

- Which species of berries can be cultivated?
- Do we need to change cultivation to have optimal yields?
- Which combination of AV and variety is economically useful?

Insights after one and a half years

- Beginn of harvest later in comparison to free range cultivation, how much later depends on species and variety
- Duration of flowering takes more time, so does harvesting
- Harvesting is more evenly spread, no real „peak“ with lots of ripe fruits
- Like in other protected cultivation mildew, aphids, mites, etc. are an issue
- Vegetative growth i.g. growth in length is stronger
- More testing is needed, especially which variety will cope with AV best
- Right now we are looking in strawberry, raspberry, blackberry, blueberry and red current

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LVWO WEINSBERG

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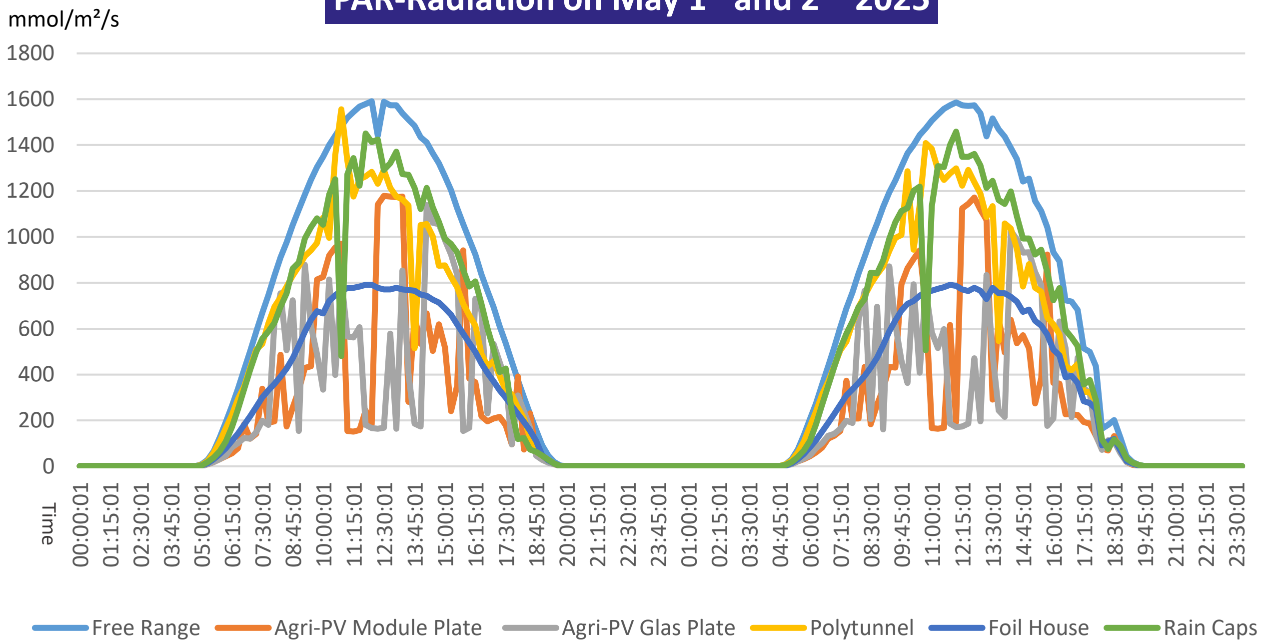
Modellregion Agri-PV BW

PAR-Radiation on May 1st and 2nd 2025



- PAR values measured so far indicate a light transmission of 40 – 50% compared to open field
- For Comparison: Rain Caps: 75%; Polytunnel: 70%; Foil House: ca. 50%

Temperature (Recorded from 27.03. – 28.05.)

	Free Range	Agrivoltaics	Rain Caps	Foil House	Polytunnel
Ø-Temperature (29.3. bis 29.05.)	12,8	12,98	14,12	17,2	16,26
Highest Value Free Range (2.05. 16:15)	29,59	29,054	29,2	31,306	30,1
Lowest Value Free Range (11.04. 6:00)	-0,544	0,121	-0,2	3,81	2,5

Suitability of Agri-Photovoltaics in Sweet Cherry Production

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Modellregion Agri-PV BW

Baden-Württemberg
Staatliche Lehr- und Versuchsanstalt für Wein- und Obstbau Weinsberg


Interior View


Top View

General Specifications

• Year of Construction:	2024		
• Location:	Bad Friedrichshall (Germany)		
• System Dimensions:	2.300 m²		
• System Hight :	4,10 m		
• Power Output:	225 kWp		
• Module Types:	A-Block:	77% Transparency	115 Wp
	B-Block:	49% Transparency	250 Wp
	C-Block:	10% Transparency	455 Wp

Research Questions

- Influence of the APV-System on yield and quality of current market varieties?
- Determination of the optimal transparency level of the modules compared to foil roofing?
- Occurrence of pests and plant diseases?
- Options to counteract the effects of potentially insufficient light availability?
- Influence of permanent roofing on soil processes?
- All experiments mirrored three times under
  1) low transparency
  2) high transparency
  3) standard foil roofing.


Front View

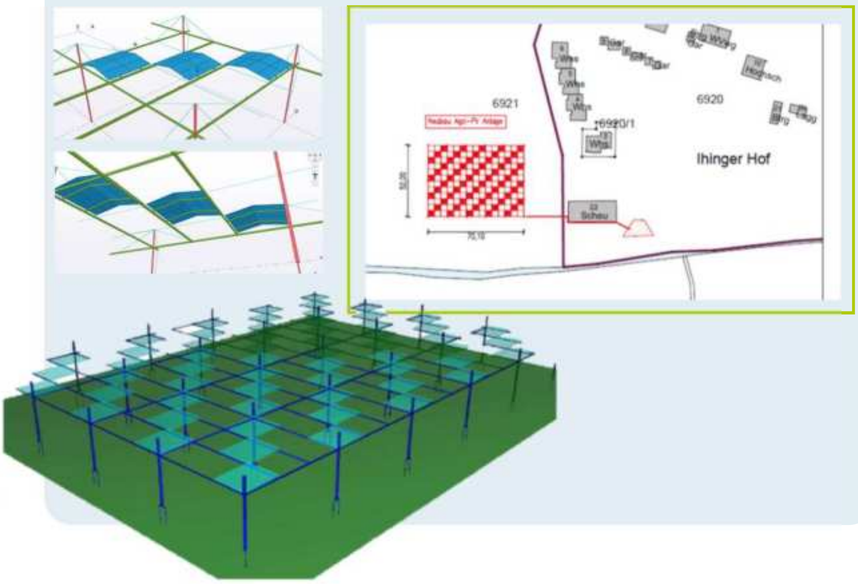
Elevated Agri-PV research facility for arable farming

a part of the 'Modellregion Agri-PV Baden-Württemberg'

FACTS ABOUT THE RESEARCH FACILITY

- Area: 0.36 ha
- Floor plan dimensions: 70 x 52 m
- Minimum clearance height: 5.5 m
- Anchoring via screw foundations
- Nominal output: 218 kWp
- Surface shading: 30 %
- Bifacial double glass modules
- Cultivation in plots (13 x 14 m each)
- Research focuses on both economically important and novel arable crops

LOCATION & DESIGN



AGRI-PV RESEARCH IN HOHENHEIM

Focus on researching the effects on:

- Yield quantity and quality of various crops under different weather conditions
- Plant physiology, especially the adaptation potential of plants
- Microclimate (especially water and light balance)
- Soil life and metabolism (carbon, nutrients, water)
- Local biodiversity
- Multifunctional use and provision of ecosystem services
- Agricultural and energy policy framework conditions and economic viability

More information:

https://agriphotovoltaik.uni-hohenheim.de/en

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