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Microclimate and biomass dynamics of peat grassland under photovoltaic modules

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Abstract

To mitigate climate change effects, measures that reduce the emission of greenhouse gases from the use of fossil energy or from carbon mineralisation in drained peatland are discussed. The use of photovoltaic (PV) systems on peat with grassland combines CO_2 reduction and provides income for farmers. Little is known about how microclimate affects biomass and quality. We conducted an experiment at a peatland site with existing grassland in North Germany, where a photovoltaic system was installed in 2021. Measurements were taken over two growing seasons in 2023 and 2024 across three distinct sections: (i) adjacent grassland not affected by PV modules as a control, (ii) directly under the PV modules, and (iii) in the aisle between PV module blocks. Eight TOMST sensors per section continuously recorded soil moisture and surface temperature. Grass samples were collected in a three-cut system to assess herbage biomass production and nutritive value. Our results indicate slightly reduced biomass under PV modules, with higher crude protein and lower water-soluble carbohydrates. The study contributes to the understanding of the combined use of PV and grassland.

Keywords: herbage, microclimate, peat, photovoltaic, sensors

Introduction

There is growing interest in the use of photovoltaic (PV) systems on agricultural land as a means of combining renewable energy production with continued forage cultivation. (Weselek *et al.*, 2019). The PV modules and the technical design of the PV system can influence microclimatic conditions, which in turn may affect the quantity and quality of biomass (Zinken *et al.*, 2024). This study examines a PV system installed on peatland to analyse surface temperature, biomass yield, crude protein, and water-soluble carbohydrates across three treatments: free grassland, under modules, and in the aisle between modules.

Materials and methods

This investigation took place at the 'Solarpark Lottorf' in Schleswig-Holstein, Germany. The PV modules used in the park feature a single-axis tracking system, measure 2 m in length, and have an edge height ranging from 640 mm up to 2170 mm above ground level. Rows are spaced 4 metres apart. Starting in April 2023, a total of 24 TMS-4 sensors (TOMST, Prague, Czech Republic) were used to continuously monitor soil moisture and temperature. A single sensor measured values across three vertical zones relative to the soil surface: 6 cm below, 2 cm above, and 15 cm above ground. The treatment areas were studied: (i) a free grassland area without PV coverage, (ii) an area directly under the modules, and (iii) the aisle between the module blocks. Each treatment was represented by a transect measuring 4 m×10 m, along which sensors were placed approximately one metre apart. In the 'under' transect, sensors were placed in a strategic arrangement beneath two adjacent rows of modules, located at their

Table 1. Annual mean surface temperature (°C) for the five positions in the two areas across the two sampling years

	Surface temperature (°C)				
	left_edge	under	right_edge	between	free
2023					
Aisle	15.57	15.49	15.58	15.42	15.9
Module	14.53	14.56	14.71	14.81	15.9
2024					
Aisle	14.6	14.6	14.84	14.77	14.86
Module	14.06	14.01	14.11	14.24	14.86

lateral edges, directly under the modules and between the modules. Data logging was performed at 15-minute intervals, covering two entire growing seasons (2023 and 2024). Biomass sampling followed a three-cut regime, with harvests conducted on 27 May (both years), 26 July (2023)/6 August (2024), and 28 September (2023)/7 October (2024). Samples were taken from a 30 cm×60 cm area located east of each sensor within every transect, resulting in 24 grass samples per sampling event. After drying, the grass samples were analysed by Near-Infrared Spectroscopy (NIRS) to determine, among others, crude protein (CP) and water-soluble carbohydrates (WSC). Groups of four sampling points from the free area were averaged and used as the corresponding fifth position for the other two areas. Annual yields were summed for each year, and CP and WSC are given as weighted means. EMMs for DM, CP, and WSC were obtained from linear models with year, area, and position as fixed effects; mean surface temperature is shown descriptively.

Results and discussion

Across both the aisle and module areas, dry matter (DM) yields in 2023 were consistently higher than in 2024 (Fig. 1). The year effect was significant in the mixed model (p =0.003) and varied by sampling position, with some positions (e.g., right edge in the aisle area) showing larger reductions in 2024 than others. In the aisle area, the presence of rushes (*Juncus* spp.) may have influenced DM values. Mean surface temperatures (Table 1) were slightly higher in 2023 than in 2024. In both years, temperatures were marginally lower in the aisle area and lower under the modules compared to the free position, with left_edge and under showing the coolest values, followed by right_edge and between. This gradient corresponds to the changing shading pattern created by the module tracking system. Even in the aisle area, which is not directly beneath modules, reduced temperatures suggest partial shading from adjacent module rows. Crude protein concentrations were generally higher under the modules than in the aisle. Within the aisle area, the five positions yielded similar CP values, whereas under the modules, CP was markedly higher, especially at the left edge and directly beneath the modules. Reduced light availability could slow down plant development, consistent with Portner *et al.* (2023), who reported reduced biomass but higher CP under PV shading. The lower CP values in 2024 may partly reflect the slightly later sampling dates in that year. Differences in WSC concentrations were smaller and varied more among positions. In the aisle area, weighted mean WSC values of the four module positions were similar to values in the free position, whereas under the modules, in both years, WSC values were consistently lower than in the free (unshaded) positions. The lowest values occurred at the left edge and directly under the modules, with slightly higher values at the right edge and between positions. This pattern may be related to the PV module tracking system, which tilts westward during the day, reducing shading in the right-edge positions. WSC appeared less affected by the factor year than CP or DM. The mixed-model analysis (Year×Position×Area) confirmed significant main effects of year for DM and CP ($p < 0.05$) and a noticeable Year×Position interaction pattern for DM, suggesting that the

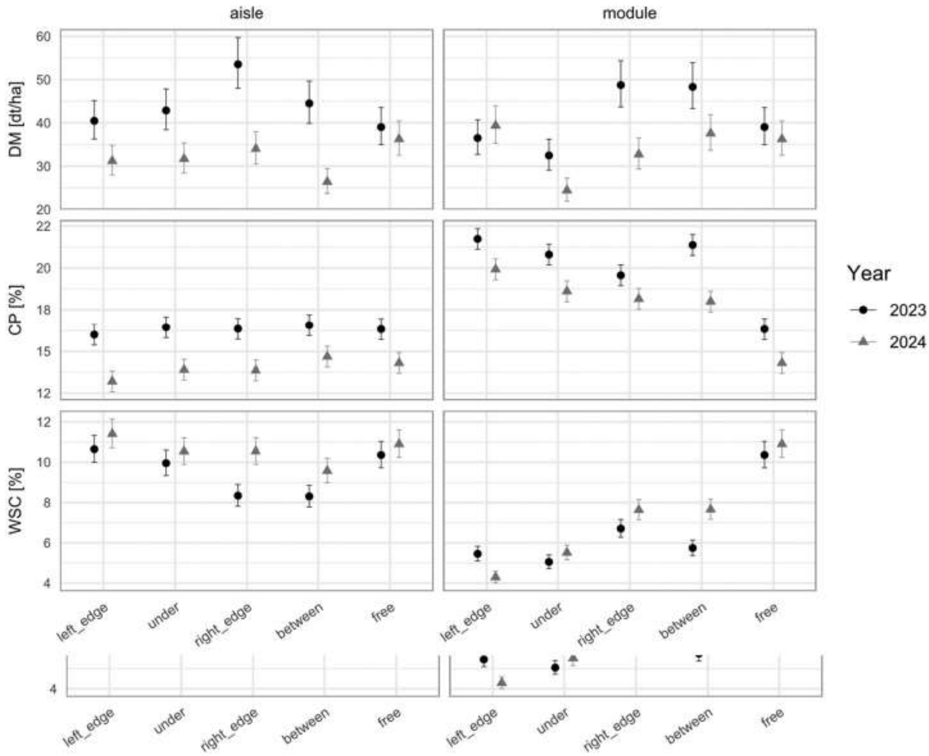

Figure 1. Estimated means of dry matter (DM), crude protein (CP)and water-soluble carbohydrates (WSC) by area (aisle and module) and position relative to PV modules across two years, based on linear models. Positions: left edge, under, right edge, between, free. Error bars indicate ±1 standard error for each group.

magnitude of interannual differences depended on sampling position. Overall, 2024 was characterised by reduced biomass and protein content, whereas carbohydrate concentrations were more stable.

Conclusion

Shading from PV modules altered both forage yield and quality, with biomass generally reduced under the modules but crude protein concentrations often higher, particularly in more shaded positions. Water-soluble carbohydrates were less affected and showed mainly position-specific variation. These patterns, consistent across two growing seasons, highlight the importance of microclimatic conditions created by PV arrays in shaping productivity and nutrient composition.

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