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Occurrence of Orb-Weaving Spiders and Web Construction on the Braces in Agrivoltaics Structures

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Abstract

Agrivoltaics—the integration of solar photovoltaic systems with agriculture—is a growing trend worldwide. Although studies have clarified the effects of photovoltaic panels above farmland on microclimate and crops, their impact on the organisms within farmland remains poorly documented. Assessing the influence of agrivoltaic installations on organisms within farmland is crucial, as biodiversity and beneficial arthropods that prey on pests can positively affect crop yields. This study assessed the effects of agrivoltaic structures on orb-weaving spiders, which are beneficial arthropods, in Chiba City, Chiba Prefecture, Japan. Over four investigations conducted from June to September 2023, we discovered that the vertical distribution of orb-weaving spiders was concentrated in the structural braces within the photovoltaic panel framework. In terms of horizontal distribution, spiders were most prevalent in areas adjacent to forests, where prey insects were relatively abundant. These findings suggest that agrivoltaic structures, which are typically absent on farmland, can serve as scaffolding for orb-weaving spiders and that the location of web construction within agricultural fields depends on prey availability.

Discipline: Agricultural Environment
Additional key words: agroecosystem, artificial structure, beneficial arthropod, insect pest, photovoltaic panel

Introduction

Agrivoltaics—the installation of solar photovoltaic systems above farmland while conducting agricultural activities—has garnered global interest as an innovative approach to mitigating greenhouse gas emissions (Chalgynbayeva et al. 2023, Widmer et al. 2024). Although solar photovoltaics play an important role in providing renewable energy and thus helping to reduce emissions, the very rapid spread of solar photovoltaics sometimes causes land overdevelopment issues. In Japan, however, farmland is abundant and sometimes not well managed. Agrivoltaics has the potential to solve those problems through the dual use of farmland for crop and energy production, such that additional land development is not required. Furthermore, energy production on farmland provides farmers with an additional source of income, allowing for agricultural production to be sustained even on poor-quality farmland (MAFF 2024, Tsuchiya et al. 2024). Thus, the expansion of agrivoltaics in Japan may improve the nation’s food and energy security. The adoption of agrivoltaics is on the rise worldwide, but there is limited research available on the effects of agrivoltaic structures on the agricultural environment. Previous studies have demonstrated that photovoltaic panels positioned above farmland impact microclimatic factors such as shading, air temperature, and humidity (Tsuchiya et al. 2025); this in turn affects

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plant growth and crop yields (Homma et al. 2016, Marrou et al. 2013, Weselek et al. 2021). These microclimatic factors may also have repercussions on the organisms inhabiting areas within and around farmland. To our knowledge, the only study that describes this phenomenon suggests that the increase in humidity due to panel installation caused an increase in lace bugs (Othman et al. 2019).

There is a need for more research on the ecological impact of agrivoltaics, particularly with regard to biodiversity within and around the farmland. The impact of combining solar photovoltaics with agriculture has been documented in the United Kingdom (Solar Energy UK 2023) and the United States (Graham et al. 2021). However, most such studies have focused on photovoltaic installation in lands adjacent to farmland, leaving a knowledge gap regarding installations above farmland. A U.S. study indicated that partial shading by solar panels around agricultural fields increased floral abundance because of various microclimatic changes, potentially benefiting flower-visiting insects (Graham et al. 2021). Other studies, however, have reported on the negative effects of these systems, such as bird collision fatalities with solar panels near farmland (Ho 2016, Kosciuch et al. 2020). In the context of agrivoltaics, Othman et al. (2019) found that panels and support poles can localize soil moisture content, potentially elevating the risk of increasing pest populations. Likewise, the Shizuoka Agricultural Experiment Station in Japan reported a higher incidence of insect infestation on shade-tolerant kiwifruit (*Actinidia deliciosa*), a crop well-suited to agricultural photovoltaics, when cultivated under photovoltaic panels (Shizuoka Prefecture 2020). These findings collectively highlight the growing understanding that the concurrent use of photovoltaic power generation and agriculture can have discernible impacts on the organisms within farmland. It is also well established that biological communities within and around agricultural fields can substantially affect crop yields. For instance, Michalko et al. (2019) reported that an abundance of spiders positively influenced crop yields by aiding in pest suppression. However, the effects of organisms on crop yields have yet to receive significant attention in the context of agrivoltaics. This lack of information may be attributed to the fact that the shading caused by photovoltaic panels can substantially impact crops, making it challenging to assess the concurrent effects of the agroecosystem on agricultural outcomes.

As beneficial arthropods that prey on various insects, spiders can be broadly categorized into two groups: web-building spiders (such as orb-weaving spiders) and wandering spiders. In Japan, wandering spiders have been the focus of attention (Sasaba et al. 1970, Suenaga & Hamamura 2015). Still, web-building spiders are also attracting attention as natural enemies due to their high density in agricultural areas (Baba et al. 2018). Nevertheless, observations of orb-weaving spiders in rice paddy fields have demonstrated their beneficial impact on rice yield (Baba et al. 2018, Takada et al. 2012). Orb-weaving spiders have also been documented in cabbage fields (Suzuki & Okuma 1975), suggesting the potential presence of many orb-weaving spiders in crop fields.

The structural elements of photovoltaic panels, such as the trestles or support poles, might offer an ideal habitat for orb-weaving spiders. These structures serve as scaffolds for web building and are positioned at a height that does not impede human access. Additionally, it is known that more web builders tend to be found at the edge of the farmland than at the center (Gallé et al. 2019). The infrequent removal of webs by agricultural workers in these areas could provide favorable conditions for orb-weaving spiders. In this study, we investigated whether the number of webs differed between the edges and the interior of the agrivoltaic farmland. Furthermore, due to the absence of existing data on the prey organisms of spiders in agrivoltaic farmland, we examined the prey taxa to address this gap. To explore these questions, we assessed the effects of photovoltaic panel mounts on orb-weaving spiders within an agrivoltaic structure.

Materials and methods

1. Survey site

Our research was conducted at Okido Agri Energy Unit 1 (Okidocho, Midori Ward, Chiba City, Chiba Prefecture, Japan; Fig. 1), which is operated by Chiba Ecology Energy Inc. This location encompasses an area of approximately 1 ha, with the photovoltaic panels oriented to face south at an angle of approximately 48°, effectively positioning them in a southwest orientation. The site is equipped with 523 support poles, each featuring braces for reinforcement situated at a height of 2.93 m above the ground (Fig. 1). Furthermore, a total of 2,826 photovoltaic panels are installed, resting above the braces and positioned at a height of 3.97 m above the farmland. Crops cultivated from June to September 2023 included eggplants (*Solanum melongena*), sweet potatoes (*Ipomoea batatas*), taro (*Colocasia esculenta*), Jerusalem artichokes (*Helianthus tuberosus*), peanuts (*Arachis hypogaea*), figs (*Ficus carica*), and blueberries (*Vaccinium* sect. *Cyanococcus*). In certain sections, the land was left fallow. No pesticides were sprayed on the fields from January 2022 to September 2023. The

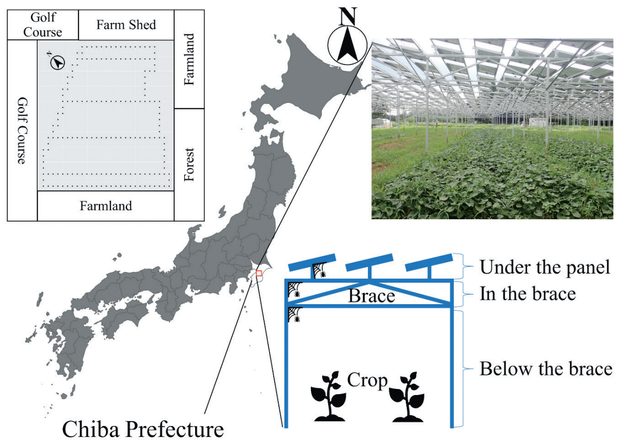

Fig. 1. Map showing the location of the survey site (Chiba Prefecture, Japan)

The dots and the surrounding text in the upper left show the horizontal distribution of the poles we surveyed and the surrounding environment, respectively. The photo shows photovoltaic panels above the field, and the diagram illustrates the three height categories of agrivoltaics structures we studied.

surrounding environment includes farmland, a golf course, and forested areas.

2. Data collection

We conducted observations and collected data at 178 predetermined support poles on four dates: 1 June, 12 July, 1 August, and 15 September 2023. The observation range of each pole was extended up to the midpoint between poles, ensuring there was no overlap with adjacent poles. The counting was specifically focused on orb-weaving webs located on the mounts and photovoltaic panels, irrespective of whether the web owner was present or absent. When a web owner was encountered, we identified the species. The height of the webs was categorized into three levels: under the photovoltaic panel (UP, 3.97 m-4.18 m), in the brace (IB, 2.93 m-3.97 m), and below the brace (BB, 0 m-2.93 m). During the July and August investigations, we also documented the prey insects ensnared in the orb-weaving webs. We identified prey taxa whose bodies were either partially or entirely caught in the webs; we did not attempt to identify small fragments of insect bodies.

3. Statistical analysis

We utilized R 4.2.3 (R Core Team 2023), and the *rstatix*, *MASS*, and *nnet* packages for our statistical analysis. The support poles were categorized into two groups: at the periphery or the interior of the field. We employed Welch's *t*-test to compare the number of webs

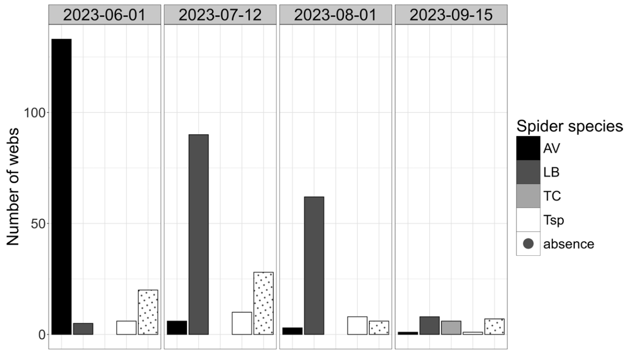

Fig. 2. The counted spider webs and web owner species

AV, LB, TC, and Tsp indicate *Araneus ventricosus*, *Leucauge blanda*, *Trichonephila clavata*, and *Tetragnatha* spp., respectively.

and the absence ratio of web owners between these two groups.

We employed a randomization test to assess potential bias in the horizontal distribution of spider webs. The randomization test involved generating random horizontal distributions from the number of spider webs observed in each survey as pseudo-data. Then, we calculated the centroid of the pseudo data for each iteration and performed this process 10,000 times. Next, we evaluated the bias in the observed horizontal distribution by comparing whether the centroid of the actual data fell within the 5% significance level of the pseudo-data distributions.

We performed a two-way ANOVA to assess the effects of web height and survey date on the total number of spider webs. As the ANOVA results showed that height affected the number of webs, we examined in detail what factors affected web height. We conducted an ordered logistic regression by using the *polr* function, with web height as the response variable and date, and absence ratio of web owners, spider species, and horizontal distribution in the field as explanatory variables.

Results

The orb-weaving spiders observed were classified into four species: *Araneus ventricosus*, *Leucauge blanda*, *Tetragnatha* spp., and *Trichonephila clavata*. The abundance of each species exhibited significant fluctuations across the survey dates, with *A. ventricosus* initially dominating and later yielding to *L. blanda* (Fig. 2). The number of spider webs and presence of the web owner gradually declined from 1 June to 15 September (Fig. 2). The lowest web owner absence rate was recorded on 15 September, at 30.4%. Examination of the horizontal distribution of spider webs revealed more webs at the periphery than in the interior of the field (t-test: $P < 0.01$). However, there was no significant difference in the percentage of absent web owners between the interior and the periphery (t-test: $P = 0.17$). Notably, the results of the randomization test indicated a statistically significant bias in the horizontal distribution, irrespective of the survey date (June: $P < 0.001$; July: $P < 0.001$; August: $P < 0.001$; September: $P < 0.05$; Fig. 3).

Throughout the four surveys, the effect of web height on the number of webs was statistically significant, whereas the survey date was not significant at the 0.05 level ($F3, 34 = 5.219$, $P = 0.011$). However, the P value for the survey date was 0.056, indicating a marginal trend that approached significance ($F3, 34 = 2.786$, $P = 0.056$). The highest number of webs was observed in the brace (Fig. 4). Ordered logistic regression revealed that four factors had a notable influence on the height of the webs: the southeast direction, the presence of *A. ventricosus* and *L. blanda*, and a survey date in July (Table 1). Effect-size measurements indicated that web construction increased in the southeast direction under the panel and in the brace, and only the presence of *T. clavata* had a positive effect on web construction below the brace (Table 1).

We observed six insect orders as prey items in the webs. Of them, Hemiptera, including aphids—an economically significant agricultural pest—comprised the majority, accounting for 65.31% of the total prey (Fig. 5). The second most abundant group of insect orders was Hymenoptera, with winged ants making up the majority. On average, each web captured approximately 1.8 prey organisms.

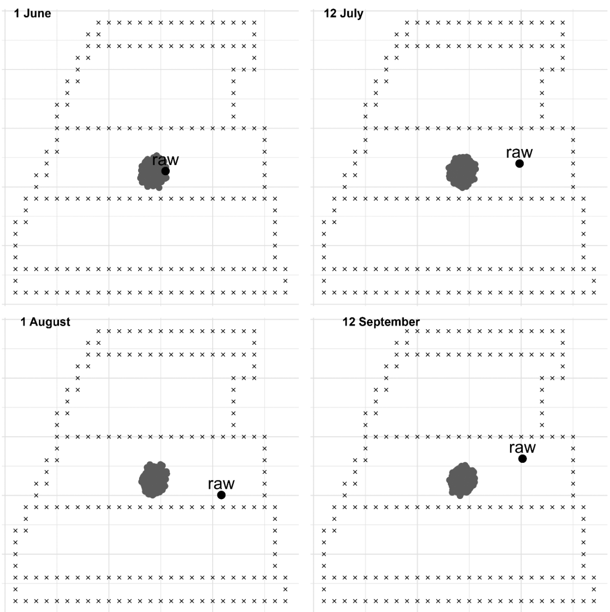

Fig. 3. Comparison between the centroids of raw (black dot) and pseudo data (grey blobs), each month
Cross marks indicate poles surveyed. The pseudo data were randomly created 10,000 times on the basis of the raw data.

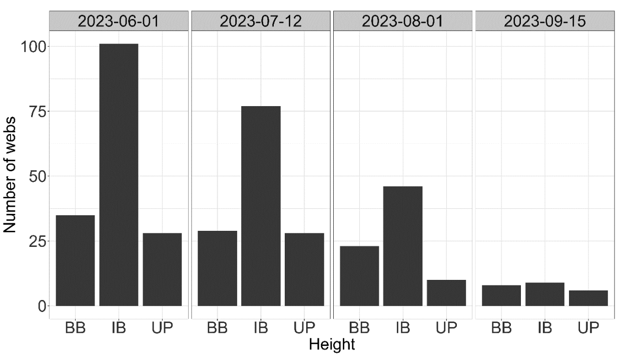

Fig. 4. Histogram of web height
UP, IB, and BB indicate under the photovoltaic panel (3.97 m-4.18 m), in the brace (2.93 m-3.97 m), and below the brace (0 m-2.93 m), respectively (see Fig. 1).

Discussion

In our surveys, we identified four groups of orb-weaving spiders in the agrivoltaic structure. Previous research conducted in Japan recorded *Araneus* sp., *Leucauge* sp., and *Tetragnatha* spp. at a cabbage field in the month of May (Suzuki & Okuma 1975). A comparison between our result in June and these results from the month of May implies that poles and photovoltaic panels

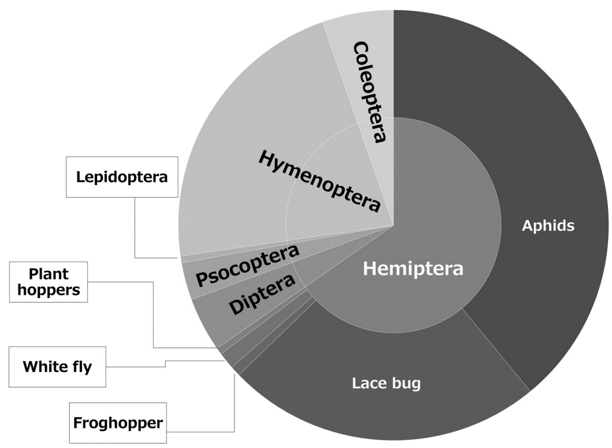

Fig. 5. Pie chart of the percentage of prey insect taxa captured in webs
The respective percentages are shown below. Hemiptera: 65.31% (Aphids: 39.00%, Lace bug: 23.72%, Froghopper: 0.01%, White fly: 0.01%, Plant hoppers: 0.01%), Diptera: 4.08%, Psocoptera: 2.81%, Lepidoptera: 0.01%, Hymenoptera: 21.94%, Coleoptera: 5.34%.

Table 1. Factors that influenced web height according to ordered logistic regression

Coefficient	Estimate	S.E.	*t*-value	*P*
Poles SE[a]	0.033	0.015	2.177	**0.029**
Poles SW[a]	0.002	0.014	0.166	0.868
Araneus ventricosus[b]	1.026	0.323	3.177	**0.001**
Leucauge blanda[b]	1.659	0.367	4.525	**< 0.001**
Tetragnatha spp.[b]	0.340	0.314	1.081	0.280
Trichonephila clavata[b]	0.123	0.427	0.289	0.773
12 July[c]	0.715	0.282	−2.531	**0.011**
1 August[c]	0.205	0.207	0.992	0.321
15 September[c]	0.210	0.237	−0.887	0.375
Intercepts				
BB|IB[d]	0.047	0.395	−0.120	0.904
IB|UP[d]	2.803	0.419	6.698	**< 0.001**

[a] Poles SE and SW, each representing axes towards the southeast and southwest directions, respectively. The former indicates that larger numbers correspond to a more southeastward direction, while the latter shows that larger numbers correspond to a more southwestward direction.
[b] Spider species were based on unknown records.
[c] Survey dates were based on June 1.
[d] BB, IB, and UP represent that below the brace (0 m-2.93 m), in the brace (2.93 m-3.97 m), and under the photovoltaic panel (3.97 m-4.18 m), respectively (see Fig. 1).

above farmland have few impacts on spider fauna in Japan (Fig. 2). However, owing to the differences in survey site, season, and types of farm products among studies, there is a need for further research to clarify this issue. Dominant species changed markedly from June to July (Fig. 2), suggesting that *A. ventricosus* migrated into the surrounding forest and *L. blanda* then entered the ecological niche that was vacated by *A. ventricosus*. Similar to the results shown by Gallé et al. (2019), the frequent construction of webs at the field's periphery and the bias of the center of gravity oriented toward the southeast in all months (Fig. 3) imply that the area near the forest to the southeast may have a higher food capture potential (e.g., Uetz et al. 1982, Venner et al. 2000) and wind frequency (e.g., Hieber 1984) than the interior of the field.

Although the southeast direction and the presence of *A. ventricosus* and *L. blanda* influenced web height (Table 1), these factors likely reflected the number of spiders present. However, the influence of the survey date in July compared with June might be linked to the shift in dominant species, transitioning from *A. ventricosus* to *L. blanda* (Fig. 2). In fact, while *A. ventricosus* was observed to construct webs under the panels to some extent, *L. blanda* more frequently built webs in the braces, suggesting that these two species differed in preferred web-forming scaffolds or heights (cf., Muhammad et al. 2017). Among the three factors influencing the number of spiders, the height of web placement is the factor most likely to be influenced by human intervention (Gallé et al. 2019). Given the notably large spider abundance in the braces, the introduction of braces represents a potential strategy for enhancing orb-weaving spider populations in farmland.

Aphids, which constituted approximately half of the recorded hemipteran prey, are recognized as significant agricultural pests. Spider webs within this field captured aphids, consistent with previous studies (Gavish-Regev et al. 2009). The higher recorded abundance of aphids might be attributed to orb-weaving spiders at this site not actively feeding on aphids (Nyffeler 2009). Lace bugs—the second most prevalent among the hemipteran prey—are known to thrive in high humidity (Othman et al. 2019). In comparison with standard fields, future assessments of humidity levels and soil moisture distribution under the photovoltaic panels will help determine whether our observations are consistent across Japan. Although lace bugs are not considered significant pests in Japan, we must pay attention to their potential to become pests under photovoltaic panels.

Conclusion

Our surveys of orb-weaving spiders and their webs indicated that agrivoltaic structures and the environment surrounding the farmland influence the number of webs and web height. Specifically, we found lots of spider webs and insect prey in the braces near the forest. We consider that two factors explain these results: the ease of web construction and prey availability. In the spider webs, insects with the potential to be pests were also found, which could indicate that orb-weaving spiders have the potential to act as beneficial arthropods in agrivoltaic farmlands. However, this study did not provide evidence that these insects caused damage to crops within the field or that spiders directly preyed on pests, indicating the need to obtain data that suggests the relationship between spiders inhabiting agrivoltaic farmlands and pests.

More studies are required on the abundance of orb-weaving spiders in field areas. In our study, we were unable to account for the impact of agrivoltaic structures on this abundance. Nevertheless, spiders serve as native predators in the ecosystem, with the braces being identified as particularly suitable platforms for their web construction. Future studies should assess the role of spiders as natural predators by investigating their relationship with actual pest numbers and crop yields. It would likely be feasible to implement environmentally friendly farming practices that maximize the use of orb-weaving spiders through the strategic design of the agrivoltaic structure.

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