Agrivoltaics Intermittent Shading: Defining Ecophysiological Responses and Yield Impact on Rice

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Our research is part of the ADELI project, a collaborative effort involving EDF Renewables, ADEME, Rem Tec, INRAe, and CIRAD, which explores agrivoltaics on irrigated rice-based systems (rice-legume rotation) in the Camargue, a delta region in South France. In a previous work [1], we presented our aim to focus on characterizing shade heterogeneity under panels and studying its impact on rice physiology, development, and production. Our current reflection stems from two observations. Firstly, simulations data of the radiative environment under the ADELI Agrivoltaic demonstrator reveal three levels of heterogeneity depending on the studied zone of 0,25m²: distinct patterns of daily shade (intra-day heterogeneity), different levels of shading over the cycle (seasonal heterogeneity), and varied dynamics depending on the location under the panels (spatial heterogeneity). Secondly, while a few studies have considered horizontal heterogeneity [2], [3] or vertical heterogeneity [4], in microclimatic studies or crop response, we note a scarcity of works addressing these aspects in the context of agrivoltaics. The presented work focuses on the study of intra-day heterogeneity, addressing several key questions: (i) Does useful genetic diversity exist among locally adapted cultivars regarding tolerance to the type of shading encountered under solar panels? (ii) How does the diurnal distribution of a given quantity of PAR (intermittent vs. constant shade) impact photosynthetic acclimation to shade, and consequently, growth and yield? Lastly, based on these considerations, (iii) how should microclimate, photosynthesis, and growth models be adapted to accurately predict crops in agrivoltaics?

To address these questions, we conducted an experiment under controlled conditions in a phytotron. We examined the responses of 15 rice varieties on various traits related to phenology, morphology, photosynthesis, and production—under conditions of constant or intermittent shade. Three treatments were defined:

- T0: optimal conditions (max PAR = 1200µmoles.m².s-1)
- T1: constant shade (40%, max PAR = 720µmoles.m-2.s-1)
- T2: intermittent shading mimicking conditions under panels (40%, PAR amplitude of 300 to 1200µmoles/m-².s-1 over the day).

The DLI (daily light integral) of T1 and T2 are identical (Fig. 1).

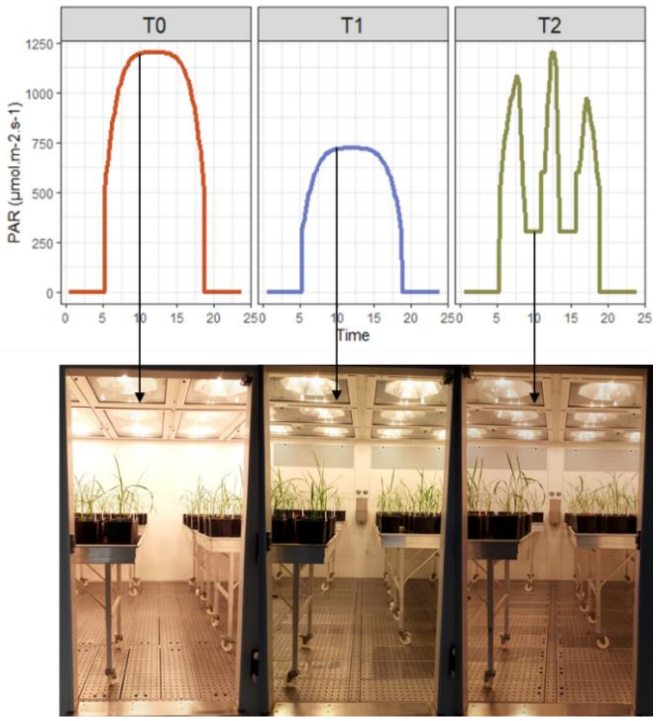

Fig. 1 : Daily light dynamics (PAR) in the three treatments and corresponding phytotron perspectives.

This trial exposed distinct responses in rice under intermittent shading conditions compared to constant shading ones. In our experiment, constant 40% shading had a significant impact on total biomass production and yield. In terms of morphological variables, our findings align with existing literature on the effects of shade. We observed the expected outcomes of larger and longer leaves; accompanied by a trade-off involving an increase in specific leaf area (SLA). Additionally, we noted an increase in stem height and a diminished tillering dynamic, resulting in an average reduction of 24.6% in the number of tillers. Ecophysiological parameters also exhibited an enhanced electron transport rate (ETR) at low light levels and diminished maximum ETR at high levels (higher alpha and reduced ETRm). When considering intermittent shading, it exerted a significant adverse effect on both vegetative biomass weight and yield. These impacts on yield can be attributed to effects on several morphological and ecophysiological parameters. In particular, shade intermittence results in intensified stem etiolation, thinner leaves without significant increase in area (increase of SLA), and the reduction in tillering (tiller number reduced by an average of 29.7%). Surprisingly, light intermittence has also a notable impact on measured ecophysiological parameters: both alpha and ETR results indicated that almost all varieties displayed lower adaptation to both low and high light levels. Significantly lower alpha than T1 and lower ETRm than T0 and even T1 suggested less efficient electron transport in both low and high light levels. This implies that high-light periods do not compensate for low-light ones, particularly in the light phase of photosynthesis.

Further studies are needed to determine what variables – such as nitrogen concentration, SLA, non-photochemical quenching (NPQ)… - can explain this change in electron transport capacity, and to what extent theses one parameters, together with a lower light interception surface, can explain this reduction in biomass and yield.

In conclusion, this study showed that shade intermittence distinctly impacted morphology, photosynthesis, and production of rice when compared to constant shading with an equivalent DLI. Notably, this impact remains consistent across the studied genotypes. Therefore, the observed intra-day shade heterogeneity warrants further in-depth exploration and underscores the necessity of its incorporation into modelling efforts within the context of agrivoltaics.

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