

Spectral entropy as a mean to quantify water stress history for natural vegetation and irrigated agriculture in a water-stressed tropical environment

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Abstract

Spectral entropy (Hs) is an index which can be used to measure the structural complexity of time series data. When a time series is made up of one periodic function, the Hs value becomes smaller, while Hs becomes larger when a time series is composed of several periodic functions. We hypothesized that this characteristic of the Hs could be used to quantify the water stress history of vegetation. For the ideal condition for which sufficient water is supplied to an agricultural crop or natural vegetation, there should be a single distinct phenological cycle represented in a vegetation index time series (e.g., NDVI and EVI). However, time series data for a vegetation area that repeatedly experiences water stress may include several fluctuations that can be observed in addition to the predominant phenological cycle. This is because the process of experiencing water stress and recovering from it generates small fluctuations in phenological characteristics. Consequently, the value of Hs increases when vegetation experiences several water shortages. Therefore, the Hs could be used as an indicator for water stress history. To test this hypothesis, we analyzed Moderate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) data for a natural area in comparison to a nearby sugarcane area in seasonally-dry western Costa Rica. In this presentation, we will illustrate the use of spectral entropy to evaluate the vegetative responses of natural vegetation (dry tropical forest) and sugarcane under three different irrigation techniques (center pivot irrigation, drip irrigation and flood irrigation). Through this comparative analysis, the utility of Hs as an indicator will be tested. Furthermore, crop response to the different irrigation methods will be discussed in terms of Hs, NDVI and yield.

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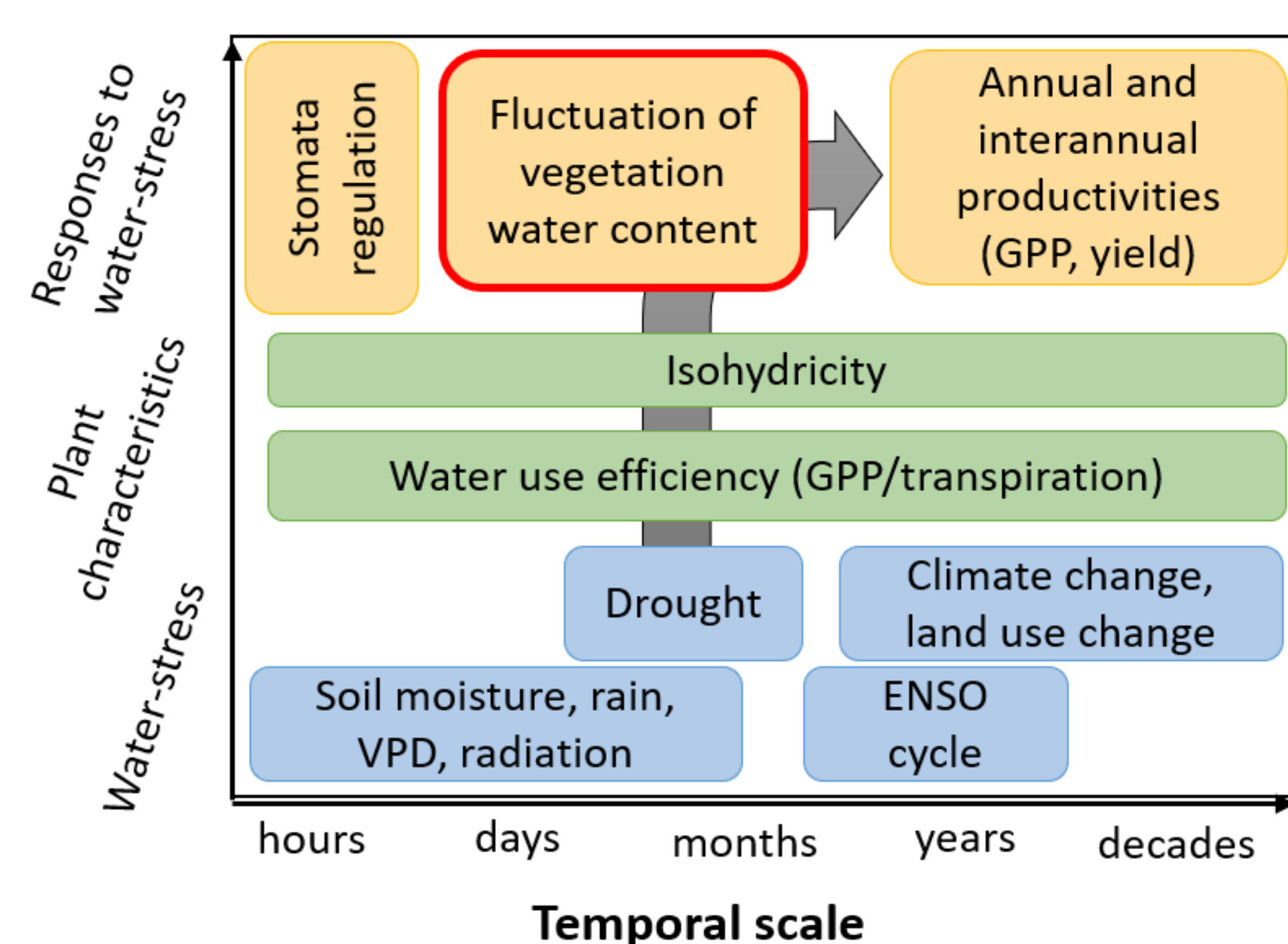
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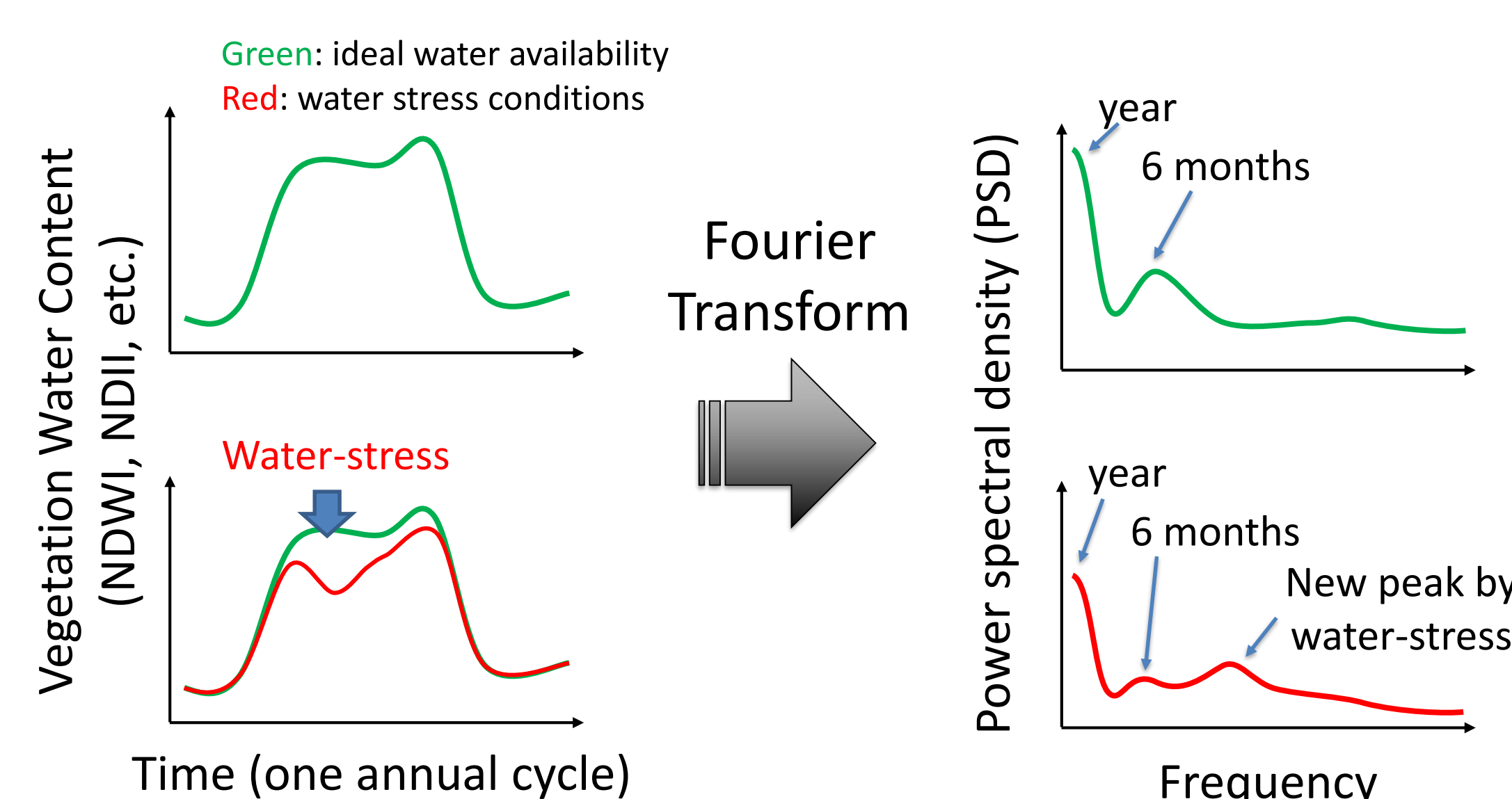
Introduction

Understanding plant physiological responses to water-stress is crucial for both natural vegetation and crops due to the increasing frequency of drought under climate change. To understand the impacts of water variability on vegetation, most previous research has tried to identify water-stress at from hours to decades [1], plant physiological characteristics [2], and the consequent variabilities of productivity [3]. However, changes in vegetative water content has not received as much attention. In this context, this research tries to address:

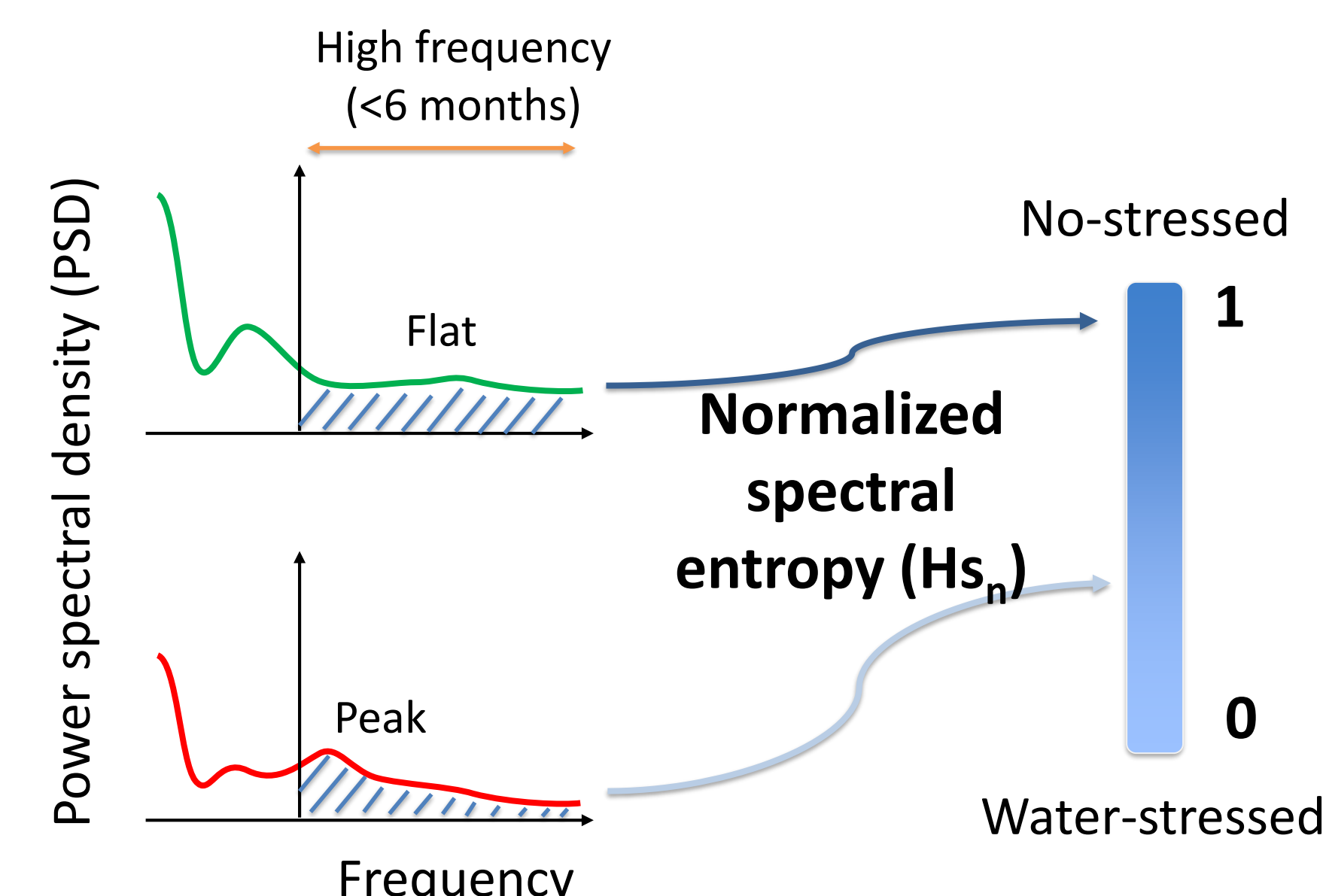
- Can **Spectral entropy (H_{sn})** be useful to identify fluctuations in vegetative water content using remote sensing data?



Theoretical background:



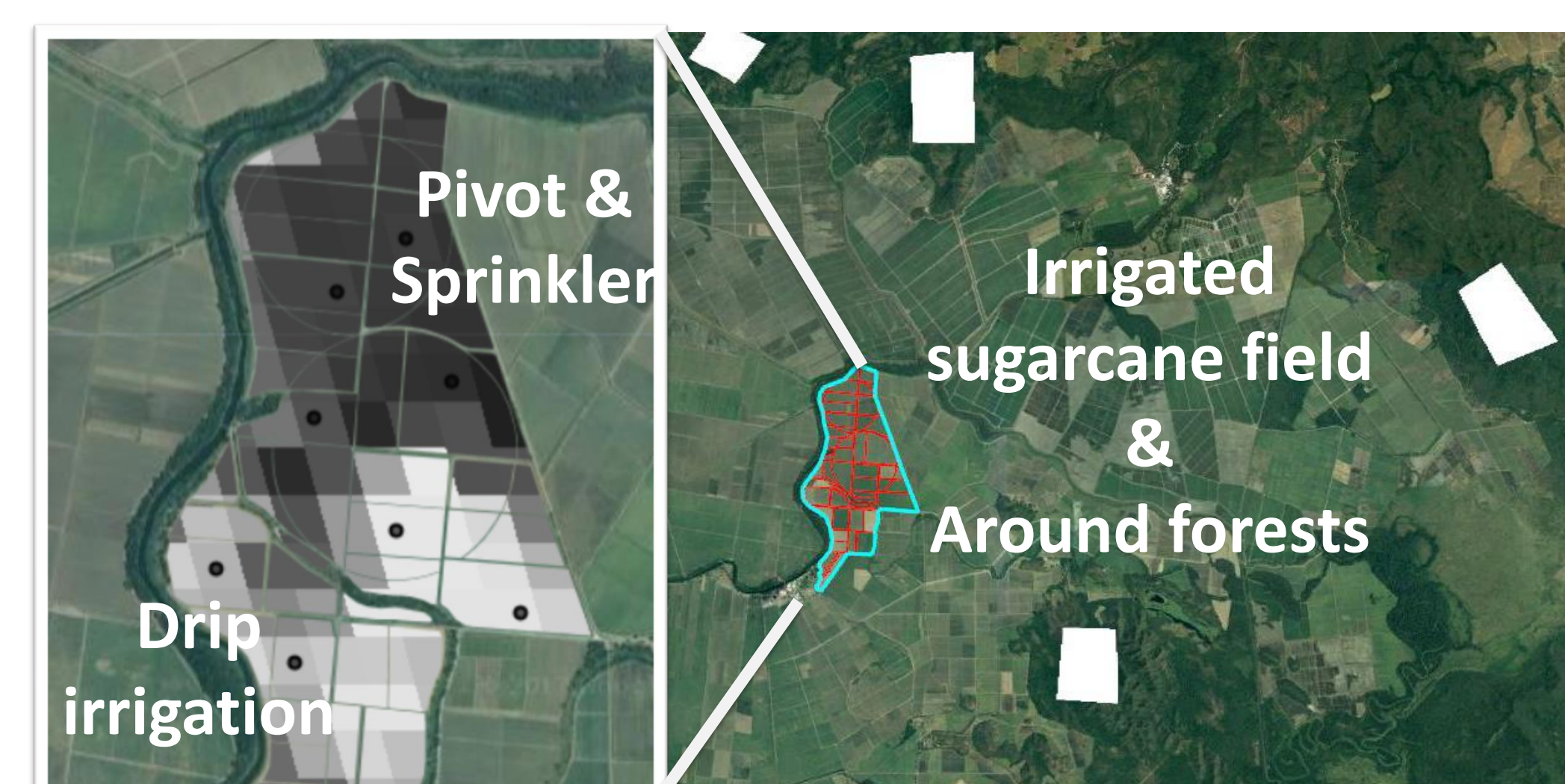
Dominant peaks in power spectral density (PSD) are at yearly and half-yearly frequencies due to phenological cycle. However, water-stress can generate high frequency peaks ([4] and above).



Normalized spectral entropy (H_{sn}) is an index which can be used to measure the structural complexity of time series. H_{sn} is high (i.e. close to 1) when the PSD distribution is flat, while H_{sn} is low when there are dominant peaks [5]. Computation of H_{sn} only using high frequencies (e.g. time scales less than seasonal) makes it possible to estimate the water-stress for each year.

Study site & Dataset

- Sugarcane fields and nearby forests in Costa Rica.
- Distinct wet & dry seasons, irrigation in dry only
- Analysis period: 2013 – 2016 (4 years)



Dataset (retrieved from Google Earth Engine [6])

- Precipitation: CHIRPS (ver. 2.0) [7]
- NDVI = $(R850 - R680)/(R850 + R680)$
- NDII = $(R850 - R1650)/(R850 + R1650)$ [8]

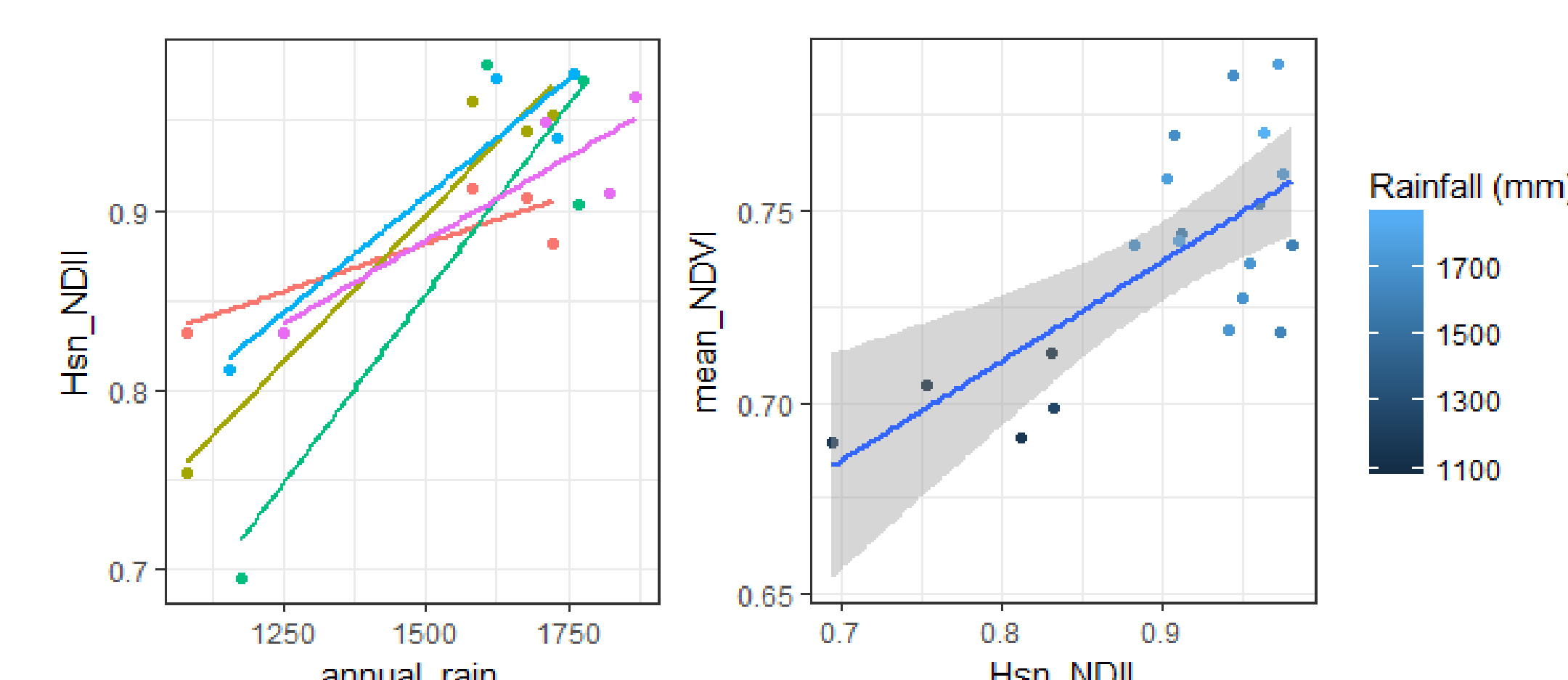
NDVI (for productivity) and NDII (for vegetation water content) are from MODIS Terra 16-day composites at 250 m resolution (MOD13Q1)

Pre-processing steps:

- Remove cloudy pixel, gapfilling & smoothing
- Remove planting years
- Adjust start day of growing season for each pixel based on sugarcane phenological cycle

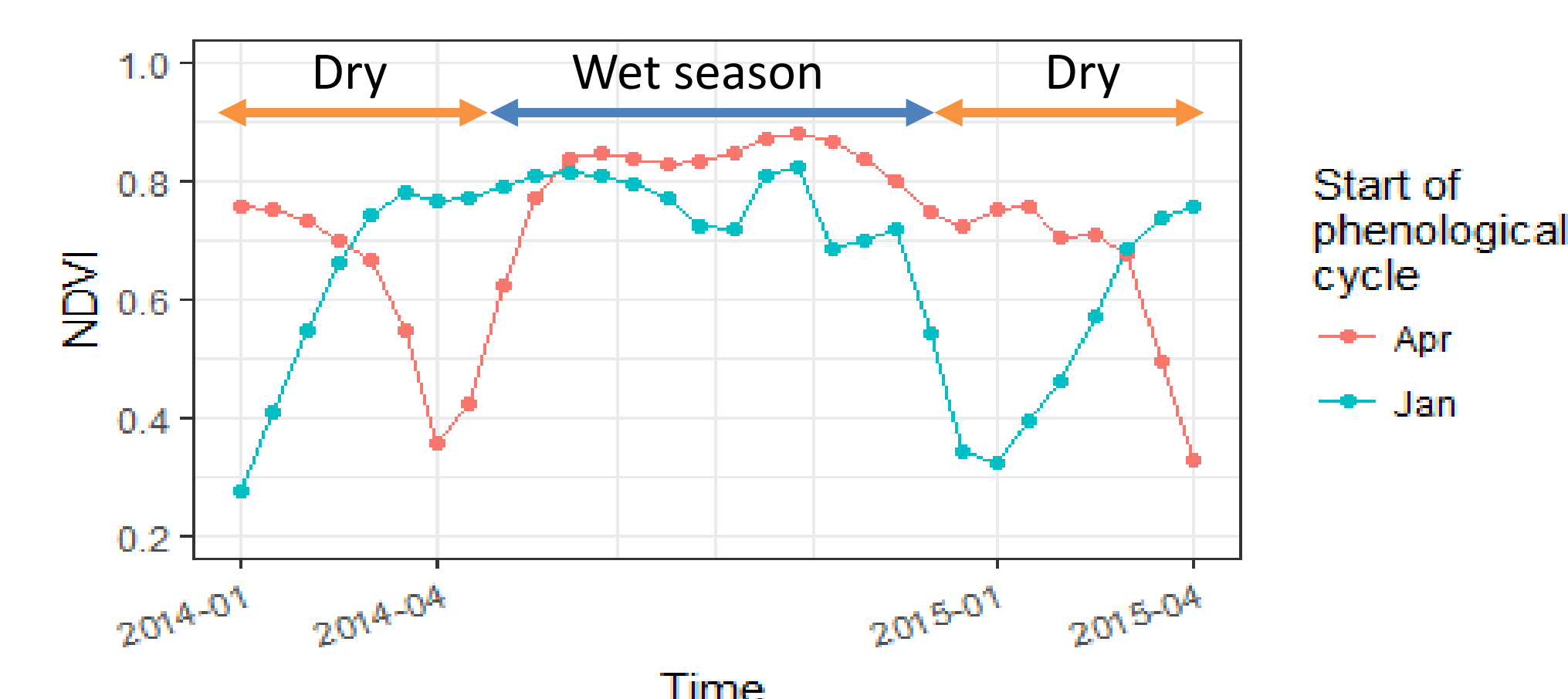
Result 1: Forests

- H_{sn} values for NDII were low in low-rainfall years (i.e., water-stressed years) for all forests. The lower left figure shows this relationship.
- The low H_{sn} for NDII are associated with low primary productivity (i.e., low mean NDVI value).

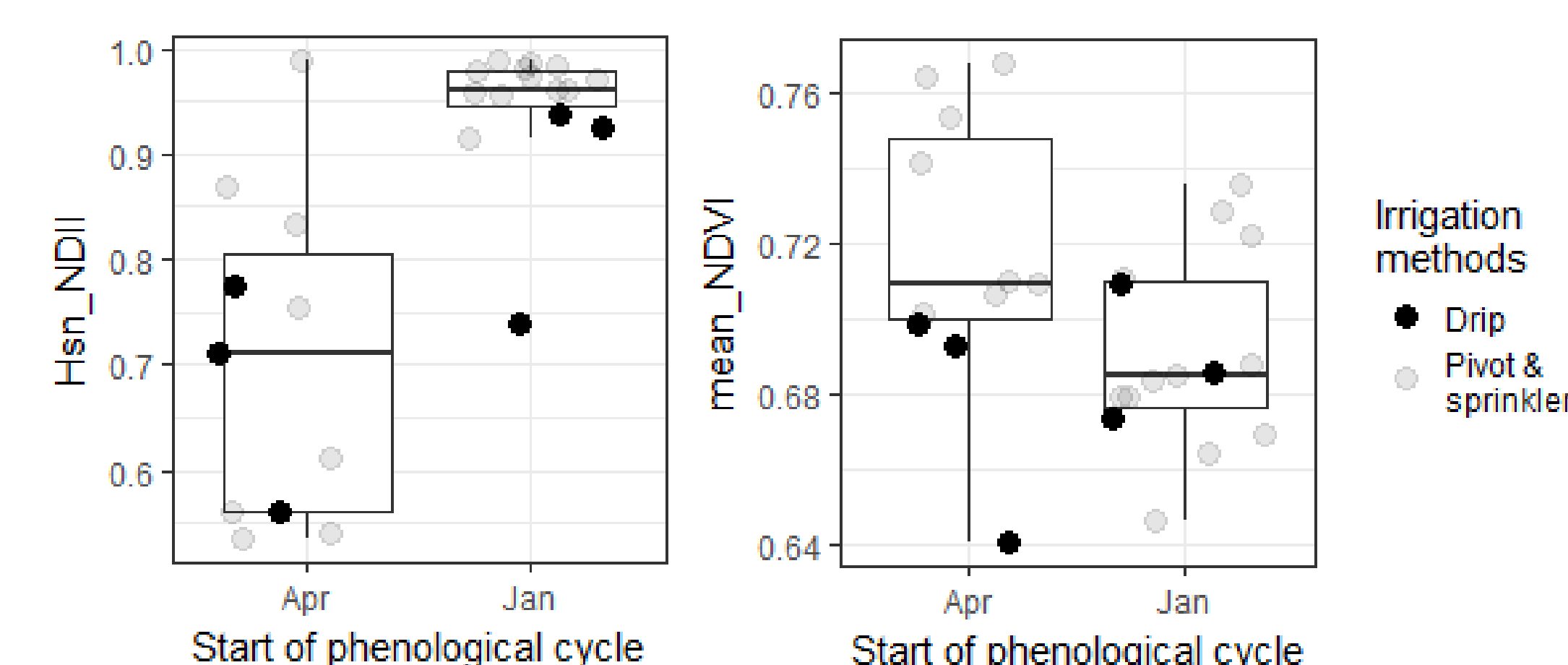


Result 2: irrigated agriculture

- The major factor controlling NDII H_{sn} was not rainfall but the *start day of the phenological cycle* at each plot.



- Stable water supply at the early growth phase from irrigation caused high NDII H_{sn} value for the a group of plots that showed a January onset of the phenological cycle. For plots showing an April onset of the phenological cycle, the rainfall dependency might cause large variability of NDII H_{sn} .
- Plots with a January onset rely heavily on irrigation for early growth due to limited rainfall, while plots with April onset use rainfall at early growth phase.



Discussion

1. H_{sn} vs. mean NDVI:

There is a significant positive relationship between H_{sn} and mean NDVI for the forests, but not for the sugarcane fields. In sugarcane plots, the high H_{sn} values did not necessarily correspond to higher productivity. This might be explained by physiological characteristics of sugarcane, which is rarely affected by early season water deficit [9], and the H_{sn} values at the sugarcane site are related to the early season irrigation. Because NDVI does not precisely represent productivity, yield data is needed for further analysis.

2. Drip irrigation vs. Pivot & Sprinkler irrigation:

Because of lack of data for the drip irrigation parcel (most parcels applying drip irrigation are too small for MODIS pixel), it is hard to compare. Nevertheless, the drip irrigation at the early growth phase gives some insights.

3. Differences in the onset timing of phenological cycles among plots requires further research.

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