Deliverable 5.4

Assessment of the role of different management and climate scenarios on CA-based crop yields and water use efficiency using simulation models

Author/s: (ARVALIS); participants: UdL, CSIC, INRA, CREA, ENSA, INRAT.

Approved by all Principal Investigators: Francesca Degan (ARVALIS) Carlos Cantero-Martínez, UdL; Jorge Álvaro-Fuentes (CSIC); Michele Rinaldi (CREA); Mathieu Marguerie (ARVALIS); Clementine Bourgois (ARVALIS), Mohamed Annabi (INRAT); Rachid Moussadek (INRA); Mourad Latati (ENSA)

Approved by Leader of Work Package (WP5): Carlos Cantero-Martínez (UdL)

Approved by Project Coordination: Michele Rinaldi (CREA)

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Executive summary

This document presents results from an experimental field network in the Mediterranean basin and the assessment of water and nitrogen efficiency in conservation agricultural cropping systems, focusing mainly on durum wheat performances, supported by the European projet CAMA.

The aim of the trials was the quantification of the improvement of crop–soil–water conditions in Southern Europe and Northern Africa in the conservation agricultural systems. In this context, understanding and assessing water and nitrogen efficiency in the framework of conservation agriculture emerge as vital pursuits for sustainable and efficient agricultural practices.

This paper aims to delve into the intricate dynamics of water and nitrogen efficiency assessment within the framework of conservation agriculture, drawing upon relevant scientific literature to illuminate key insights and potential avenues for further research.

The nexus between nitrogen use efficiency and water use efficiency in conservation agriculture holds significant implications for sustainable and resource-efficient farming practices. Efficient nutrient and water management strategies are pivotal for optimizing crop productivity while minimizing environmental impact.

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1. Introduction

1.1. Scope of the document and objectives

This document presents results from an experimental field network in the Mediterranean basin and the assessment of water and nitrogen efficiency in conservation agricultural cropping systems, focusing mainly on durum wheat performances, supported by the European projet CAMA (Rinaldi et al., 2022). The aim of the trials was the quantification of the improvement of crop–soil–water conditions in Southern Europe and Northern Africa in the conservation agricultural systems. Moreover, it provides information on the challenges of fertilisation and water management in different environments of the Mediterranean basin. In this context, understanding and assessing water and nitrogen efficiency in the realm of conservation agriculture emerge as vital pursuits for sustainable and efficient agricultural practices. This paper aims to delve into the intricate dynamics of water and nitrogen efficiency assessment within the framework of conservation agriculture, drawing upon relevant scientific literature to illuminate key insights and potential avenues for further research.

1.2. Notations, abbreviations and acronyms

CA	Conservation Agriculture
CAMA	Conservation Agriculture in the Mediterranean Area
CAP	Common Agricultural Policy
CDERP	Communication, dissemination and exploitation of results plan
EC	European Commission
IPR	Intellectual Property Rights
PMT	Project Management Team
RD&I	Research, Development and Innovation
RIA	Research and Innovation Action
TRL	Technological Readiness Level
WP	Work Package
WT	Work Task
NUE	Nitrogen Use Efficiency
WUE	Water Use Efficency
CHN	Carbon, Water and Nitrogen model
AAC or AUC	Area Under the Curve
MET	Maximum evapotranspiration
AET	Actual evapotranspiration
FHLAI_AAC_PreEp	Water stress index LAI pre-Flowering
FNbio_AAC_PreEp	Nitrogen stress index Biomasse pre-Flowering
FSbio_AAC_PreEp	Stress index Biomasse pre-Flowering
FCbio_AAC_PreEp	Colimitation factor pre-Flowering
CumDif_etm_etr_PreEp	sum MET-AET (mm) pre-Flowering
Rap_etr_etm_AAC_PreEp	Stress pre-flow (AET/MET) pre-Flowering

1.3. Background

Conservation agriculture, built upon the principles of minimal soil disturbance, crop residue retention, and strategic crop rotations, not only enhances soil health but also plays a pivotal role in optimizing nutrient and water management for crops like winter wheat . The practice of leaving crop residues on the soil surface in conservation agriculture is not only associated with an increase in soil carbon content but also contributes to improved nutrient and water retention and availability. The organic matter provided by crop residues serves as a valuable source of nutrients, fostering a nutrient-rich soil environment.

The critical importance of water and nitrogen (N) availability in global crop growth is emphasized by the need for increased resource use efficiency to meet growing food demands. Efficient management of water and N is essential for closing yield gaps in major cereal crops, supporting sustainable agriculture production, especially in Mediterranean basin, facing water restrictions. In the context of wheat cultivation, effective fertilization, particularly nitrogen management, is crucial for maximizing ressource efficiency. Agriculture stands as the primary consumer, accounting for approximately 75–80% of the available freshwater resources. In the current scenario, a significant proportion of water utilized for crop cultivation is sourced from rainfed soil moisture, with non-irrigated agriculture contributing to about 60% of production in developing countries. Projections by the Food and Agriculture Organization (FAO) indicate an anticipated surge of approximately 14% in agricultural water withdrawals by the year 2030 to meet the escalating global demand for food. Plant growth is intricately linked to water transpiration, with crop water deficit leading to yield reductions. Crop water deficit leads to yield and biomass reductions, while optimal nitrogen status enhances crop tolerance to drought and improves water use efficiency (WUE) in semiarid environments (Siahpoosh & Dehghanian, 2012; Xue et al., 2006).

Conservation agriculture provides a favourable platform for precise nutrient application, minimizing nutrient losses and enhancing nutrient use efficiency. Research studies, such as those conducted by Smith & Chalk, 2020 and Brown et al. (2020), have highlighted the positive impact of conservation agriculture on nitrogen utilization by winter wheat, showcasing increased nutrient uptake and reduced nitrogen leaching compared to traditional tillage systems.

The co-limitation of N and water availability underscores the necessity to optimize both resources simultaneously for maximum plant growth (Quemada & Gabriel, 2016). At the cropping system level, most N losses are influenced by water, necessitating careful management strategies (Bijay-Singh & Craswell, 2021; Follett & Hatfield, 2001). The relevance of agriculture to environmental concerns, such as N losses and emissions, is at the centre of European political strategies (Green Deal, Farm to Fork). Water and N use efficiency can be quantified on various scales, from leaf to field, with NUE and WUE defined and subdivided based on different components. Simultaneous enhancement of water and N use efficiency is a strategic approach to maximize productivity while addressing environmental challenges (Sadras, 2004).

Enhancing the productivity of rainfed agriculture becomes imperative, and this can be achieved through strategic interventions such as reduction of runoff and evaporation coupled with an augmentation of water infiltration and retention, and optimization of water use and efficiency. Particularly in semiarid rainfed conditions, the adoption of Conservation Agriculture (CA) systems, which involve the retention of crop residues on the soil surface, has demonstrated a substantial increase in soil water storage. Notably, this effect is more pronounced in regions characterized by higher aridity levels. The implementation of inversion tillage, especially in soils prone to crust formation, is discouraged under such conditions, as it can adversely impact infiltration, diminish water storage capacity, and consequently lead to diminished crop yields. A crucial component of conservation agriculture is mulching, which exerts a considerable influence on soil evaporation, transpiration, crop yield, and water and nitrogen use efficiency. Mulching practices have been shown to reduce evaporation by 23 and 45 mm in winter wheat and maize fields, respectively, compared to non-mulched counterparts. Furthermore, the residue cover in conservation agriculture systems acts as a natural mulch, helping to regulate soil temperature and moisture content, which is particularly advantageous for durum wheat during the critical growth stages. This mulching effect, combined with efficient nitrogen management practices, not only supports optimal durum wheat growth but also contributes to the overall sustainability of agricultural systems. The integration of conservation agriculture principles, tailored nutrient management, and strategic fertilization practices underscores a holistic approach towards achieving both productivity and environmental sustainability in durum wheat cultivation.

2. Metodology

Analytical approach

In this paper we use both field experimental network and simulations with the CHN crop model. Moreover, to assess the model results, the Diagchamp method (Rinaldi et al., 2022) was used to quantify other the yield limiting factors, not considered by the crop model, and allowing to build the yield boundary function. Results were integrated into a comprehensive analysis, unfolding in four distinct steps. In Step 1, the efficacy of the CHN crop simulation model in predicting yield and its responsiveness to water and nitrogen inputs. Moving to Step 2, a cluster of water and nitrogen stress kinetics were gathered to describe stress patterns according with environments and treatments. In Step 3, the potential and actual biomasses at the flowering stage are correlated with indicators of nitrogen and water stress. Step 4 delved into the connection between the degree of co-limitation and deviations observed between actual yield and the boundary function.

Data description

On-farm research networks (OFRNs) offer a valuable platform for assessing the effectiveness of management strategies within the real-conditions of farmer and within the context of specific cropping systems, incorporating the inherent variability present in these systems (Johnston et al., 2003). The CAMA project OFRN allows to replicate on-farm experiments across diverse locations in the Mediterranean basin and three growing seasons (2021, 2022, 2023). The statistical inference regarding treatment effects is progressively broadened over both time and space (Moore & Dixon, 2015). The CAMA OFRN have two levels of replication, the strips within a trial, and the trials representing different environments and characterizing between-trial variability across the specific region of Mediterranean basin. The four main factors studied are soil tillage, nitrogen fertilisation management, irrigation and presence of legume crops (as previous crop or as intercrop or as associated crop).

We partitioned the dataset into two distinct groups: data originating from the field trials of WP3 and data stemming from WP5. The trials within WP3, a constituent of Work Package 3, encompass one or more experimental strips implemented with diverse Conservation Agriculture methodologies. These methodologies are classified into two categories based on the presence or absence of irrigation (R1 = rainfed, R2 = irrigated field) and the presence or absence of legumes, which includes previous crops, catch crops, or associated crops (L0 = absence of legume crop, L1 = presence of legume crop).

Conversely, the trials within Work Package 5, conducted in Algeria, entail multifactorial experiments investigating the impacts of nitrogen fertilization (D1 = lowest, D2 = medium, D3 = highest nitrogen doses), in conjunction with the presence or absence of legumes, specifically chickpeas (C0 = absence, C2 = presence), in association with durum wheat. To facilitate a comparative analysis between the two datasets, we standardized the coding for the presence or absence of associated legumes in WP5 to align with the codification utilized in WP3. Additionally, in both datasets, No Tillage is represented as T1, while Conventional Tillage is denoted as T2 (Figs. 1 and 2).

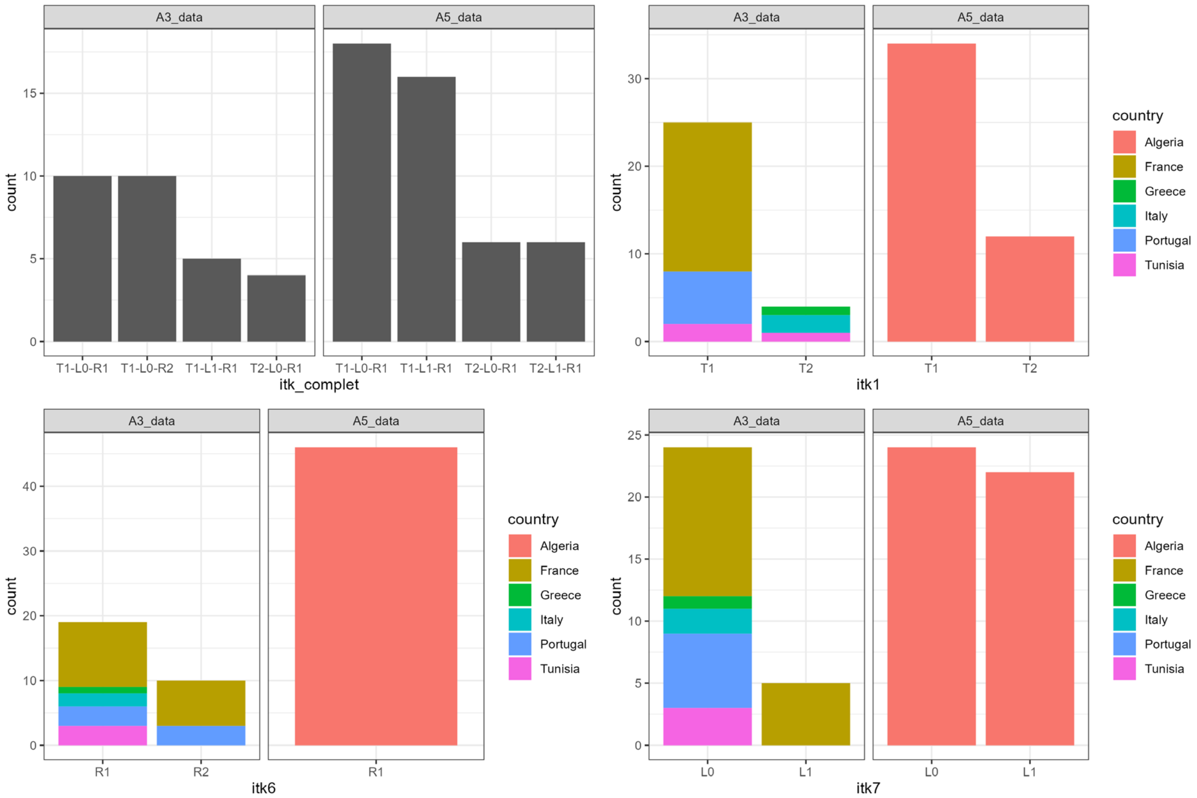


FIGURE 1 THE FOUR FIGURES REPRESENT THE NUMBER OF TRIALS BASED ON THE FACTORS STUDIED AND BY COUNTRY: T1 = NO OR MINIMUM TILLAGE, T2=CONVENTIONAL TILLAGE, L0 = ABSENCE OF LEGUME CROP, L1 = PRESENCE OF LEGUME CROP, R1 = RAINFED, R2 = IRRIGATED FIELD.

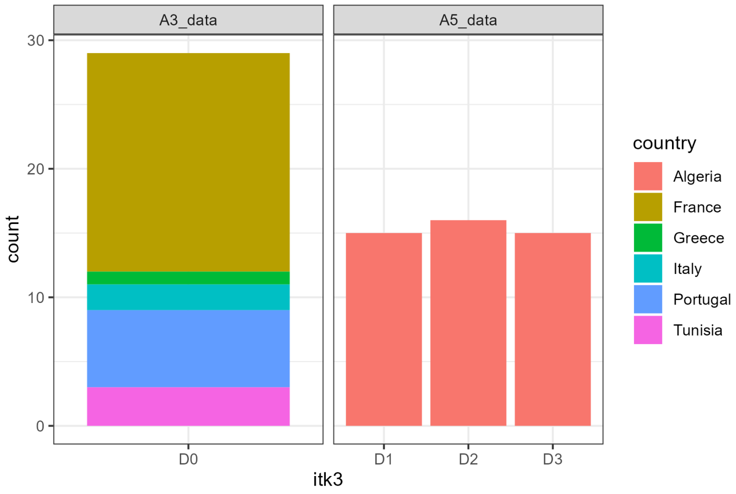


FIGURE 2 THE NUMBER OF TRIALS BASED ON THE FACTORS STUDIED AND BY COUNTRY. D0 = NO STUDIED FACTOR, D1 = LOWEST, D2 = MEDIUM, D3 = HIGHEST NITROGEN DOSES.

For each field, the following elements of the technical itinerary and environmental characterization are noticed for the three growing seasons of the project (2021, 2022 and 2023) (Fig. 3).

Type	Theme	Indicator (*used for modelization)
Technical itinerary	**Previous crop type***	**Legume / No legume**
	Type of tillage before crop*	**DS/MT/CT**
	Irrigation*	**Number of irrigation on the studied crop**
	Crop*	**Bread Wheat or Durum Wheat**
	Variety*	**Genotype used**
	Sowing date of the crop and sowing density*	**Sowing density in grains/m²**
	Water inputs (irrigation and rain)*	**mm**
	Nitrogen Inputs and type of fertilizer*	**Kg N/ha or kg**
	Crop protection	**Type and dose of herbicides, fungicides and insecticides**
Environmental data	**Soil analysis**	**SOM, texture, depth**
	Soil nitrogen content at BBCH 31	**Kg N/ha**
	Soil moisture art BBCH 31	**Soil water contents (%)**
	Weather data	**Daily rainfall, minimum and maximum temperature, daily radiation, wind speed**

FIGURE 3: TECHNICAL ITINERARIES AND ENVIRONMENTAL DATA COLLECTED BY FAMER'S FIELD.

CHN crop model

The Crop Hydro-Nitrogen (CHN) model (Fig. 4), developed by ARVALIS - Institut du végétal, operates as a mechanistic crop model designed primarily for real-time decision support during the agricultural season. To facilitate CHN use, well-defined parameters in the three compartments are essential. The model employs three modules for calculations and equations, corresponding to carbon (C), water (H), and nitrogen (N) fluxes. CHN assesses water, nitrogen, and carbon fluxes within the soil-plant-atmosphere continuum daily, considering each 1cm layer of soil. Comprising three main compartments—soil, plant, and atmosphere—the model is intricately connected to databases administered by ARVALIS. The soil compartment interfaces with a comprehensive soil database housing approximately 500 records, providing detailed descriptions of various soil horizons. These records are categorized based on characteristics such as limestone content, stoniness, soil texture, depth, and hydromorphy. Pedotransfer functions integrated into the database estimate additional soil characteristics. The atmosphere compartment links to a weather database containing daily data from over 700 weather stations across France, spanning more than 25 years.

Utilizing the Monteith principle for the plant compartment (Monteih et al., 1977), CHN models foliar growth and biomass production in response to intercepted solar radiation. Root growth is also modeled, contributing to estimates of available nitrogen and water. Stresses related to hydric and nitrogenous availability impact foliar and biomass growth, incorporating response functions inspired by Sinclair's work (Sinclair, 1986). Crop development is simulated using ARVALIS phenological models connected to a variety database comprising over 400 maize, 350 bread wheat, and 50 durum wheat varieties, updated annually.

The carbon fluxes module incorporates the AMG model (Andriulo et al., 1999), allowing for the simulation of long-term organic carbon stock evolution in the soil. For nitrogen fluxes, CHN utilizes a nitrogen balance derived from standard formalisms, Comifer references, bibliography (Mary et al., 1999, Justes et al., 2009), and ARVALIS research. CHN manages nitrogen forms daily, considering potential inputs and losses: organic nitrogen, urea, ammoniac and nitrate. Each day, CHN updates each step of the nitrogen balance calculation by taking into account potential inputs and losses from the soil compartment: soil supplies (humus mineralization, crop residues mineralization, catch crop residues mineralization, organic waste products mineralization, and mineralization due to ploughing up grassland), mineral fertilizer inputs, atmospheric nitrogen inputs, symbiotic nitrogen inputs, eventual nitrogen inputs in irrigation water, nitrogen losses by run-off, by leaching, by volatilization, nitrogen organization, and finally nitrogen uptakes by the plant.

The water fluxes module employs a water balance model distinguishing topsoil evaporation and plant transpiration. Inspired by Lecoeur's work (Lecoeur, 2000, Lecoeur et al., 2004) and other models like PILOTE, the model calculates daily in a sequence that includes estimating plant transpiration, evaluating effective rain, simulating evaporation and transpiration, and determining soil moisture levels and water stocks.

The CHN crop model demonstrates precision in estimating biomass at the flowering stage. However, the accuracy of yield and its components' estimations is comparatively lower. In this study, we focus on estimating stress indicators during the pre-flowering period.

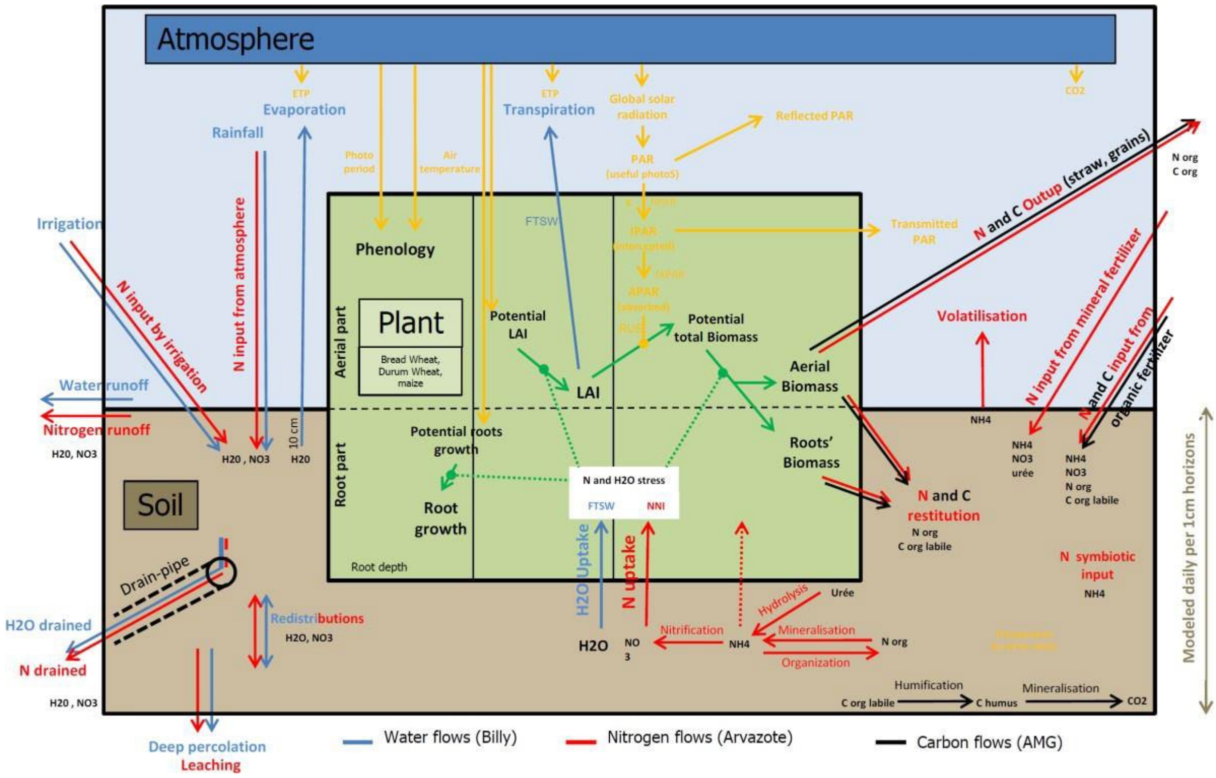


FIGURE 4 SYNOPTIC OF CHN CROP MODEL.

Agronomic field data measurements

CHN simulations are resetting by fields measurements on:

- Crop stages.
- Soil nitrogen residues and moisture at BBCH 31.
- Biomass and nitrogen absorbed at flowering.

-

Satellite and field-based data assimilation in CHN model

Utilizing the Kalman smoothing and filtering technique with a dynamic regression model, we establish a continuous framework by dynamically regressing a series of known variance point observations, as outlined in the *Working with Dynamic Crop Models*, 2014, pages 332-334.

Data analysis

Software

All statistical analyses were performed with R software version 4.1.2 (R Come Team 2021). The required packages are mentioned in the following paragraphs.

Clustering analysis

Hierarchical cluster analysis on a set of dissimilarities and methods for analyzing was implemented with the package cluster and the function pam. This algorithms produces a partitioning (clustering) of the data into k clusters “around medoids”, a more robust version of K-mean (Kaufman & Rousseeuw, 1990; Reynolds et al., 2006; Schubert & Rousseeuw, 2019; Siahpoosh & Dehghanian, 2012)

Indicators of NUE and WUE

The indicators used to characterize water and nitrogen use efficiency are resumed in the Table 1.

Theme	Indicator	Explanations
Nitrogen stress	**NNI**	**Nitrogen Nutrition Index at flowering**
	Nitrogen stress index biomass	**Nitrogen stress index biomass calculated by CHN for each day of crop growing from 0 (maximal water stress level) to 1 (no water stress)**
	FNbio_AAC_PreEp	**Area Under the Curve (AUC) of Nitrogen stress index Biomasse pre-Flowering**
	NUE_biomasse	**Nitrogen use efficiency for the biomass at flowering (tDM/kgN)**
Water stress	**MET**	**Maximum evapotranspiration (mm)**
	AET	**Actual evapotranspiration (mm)**
	CumDif_etm_etr_PreEp	**sum MET-AET (mm) pre-Flowering**
	Stress pre-flow (AET/MET) pre-Flowering	**AET/MET**
	Water stress index biomass	**Water stress index biomass calculated by CHN for each day of crop growing from 0 (maximal water stress level) to 1 (no water stress)**
	FHLAI_AAC_PreEp	**Area Under the Curve (AUC) of Water stress index LAI pre-Flowering**
	WUE_biomasse	**Water use efficiency for the biomass at flowering (tDM/mm)**
Global stress indices	**FSbio_AAC_PreEp**	**Area Under the Curve (AUC) of Stress index Biomasse pre-Flowering**
	FCbio_AAC_PreEp	**Area Under the Curve (AUC) of CWN Colimitation factor pre-Flowering**
	Rap_etr_etm_AAC_PreEp	**Area Under the Curve (AUC) of water Stress (AET/MET) pre-Flowering**

TABLE 1 DATA COLLECTED TO COMPUTE NITROGEN AND WATER USE EFFICENCY.

The degree of co-limitation (CWN) was quantified as a function of model-derived nitrogen stress index (NSI) and water stress index (WSI), on biomass or on LAI,, expressed as

$$CWN = 1 - |NSI - WSI|.$$

Stress indices range from zero (indicating no stress) to 1 (representing maximum stress), with CWN approaching 1 when both nitrogen and water resources exert constraints of similar magnitude on crop growth. This analytical approach encompasses different steps, amalgamating a modified version of Casanova et al.'s method (Casanova et al., 2002) to construct boundary functions for estimating attainable yield, along with the methodology introduced by Calviño and co-workers (P. A. Calviño & Sadras, 1999; P. Calviño & Sadras, 2002) and by Sadras (Sadras, 2004) to identify factors contributing to the gap between actual and attainable yield.

The colimitation of nitrogen and water availability can also be computed by the relationship between nitrogen use efficiency and water input, or water use efficiency (Quemada and Gabriel, 2016 - Figure 5).

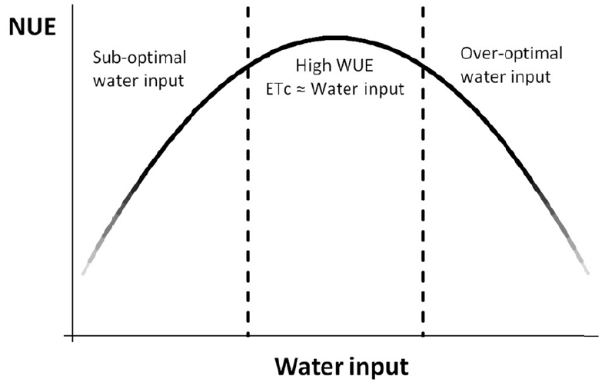


FIGURE 5 SCHEMATIC REPRESENTATION OF WATER INPUT AND NITROGEN USE EFFICIENCY (QUEMADA & GABRIEL, 2016)

Assessment of the temporal dynamic of proximal sensing variables

All the stress index kinetic analyses were performed on the stress index variables values in each trial. To integrate the variables across time, we chose an approach using a calculation of the area under the curve (AUC) for each temporal dynamic, by using the R function 'auc' (package MESS) with the spline function option from the first to the last date of simulations. We were able to process AUC for all variables in all trials. By doing that, we obtain single integrated values, representative of the evolution of the stress indicator across time.

Correlations calculations

Pearson correlations between measured variables were performed with R ggplot2/GGally packages graphical function 'ggpairs'.

Variance analysis

To assess the effect of the treatments on output variables (abiomass at flowering, INN at flowering and difference between potential and actual biomass at flowering) and AUC of stress index variables (Water stress index LAI, Nitrogen stress index Biomass, Stress index Biomass, Colimitation factor, sum MET-AET (mm), Stress pre-flow (AET/MET)), a variance analysis (ANOVA type III) has been carried out with a mixed model using the Restricted Maximum Likelihood (REML) procedure (Rpackages emmeans, lmerTest, car, nlme, stats, lme4, pbkrtest) on the data per treatments and replicate across both trials, differentiating fixed and random effects with interactions. All p-values are provided in the Results section. An effect is considered as significant for a p-value below 0.1. The model used is provided in equation 1.

[Equation 1] $$Y_{ij} = m + treat_j + |country_j \times year_i| + \varepsilon_{ij}$$

Where: Y_{ij} = Variable Y measured in trial i, for treatement j, μ = general mean of variable Y, treat t_j = effect of treatement j, $trial_i$ = effect of trial I, ε_{ij} = prediction error of Y_{ij} measured in trial I and for tratement j, inside | | = random effect, x = interaction.

3. Results

3.1. Step 1: Performance indicators of CHN crop model simulations

The assessment of crop model simulation performance (Figure 6 and Figure 7) reveals two primary findings: firstly, the CHN crop model simulation exhibits an error margin of approximately 4.6 t MS/ha for biomass and 80 kg N/ha for absorbed nitrogen in aerial biomass. Secondly, minimal to no enhancement in performance is achieved through the application of the assimilation method, specifically the Kalman smoothing and filtering technique. Nonetheless, our analysis underscores the significance of assimilating observed data into the CHN model framework. Notably, our examination focuses exclusively on trials incorporating measurements, whether derived from field-based observations or satellite imagery.

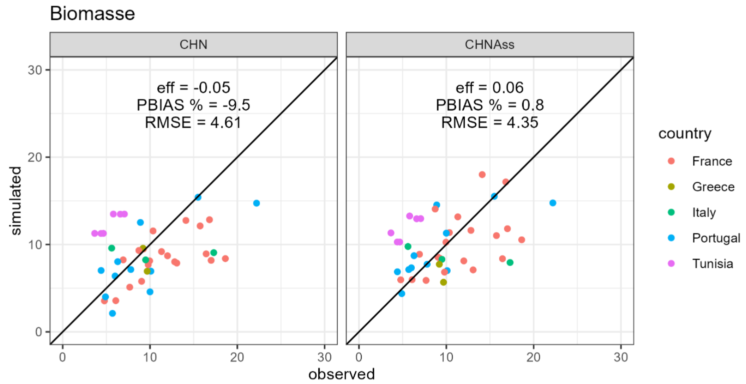


FIGURE 6 BIOMASS SIMULATION PERFORMANCES OF CHN MODEL WITH AND WITHOUT SATELLITE IMAGINERY DATA ASSIMILATION WITH KALMANN METHOD (WP3 DATASET).

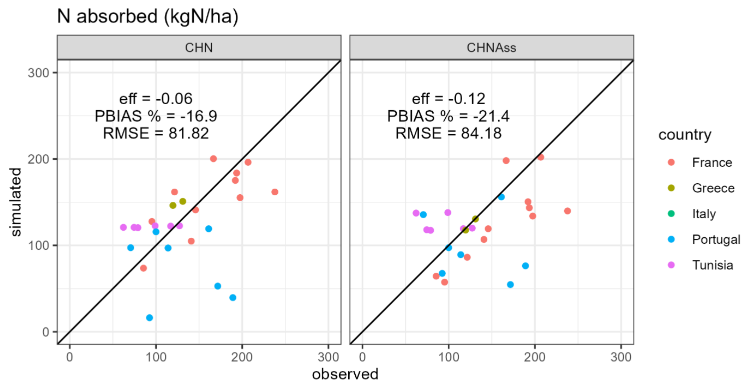


FIGURE 7 NITROGEN ABSORBED SIMULATION PERFORMANCES OF CHN MODEL WITH AND WITHOUT SATELLITE IMAGINERY DATA ASSIMILATON WITH KALMANN METHOD (WP3 DATASET).

The evaluation of crop model performance in the WP5 trials (referenced in Figure 8 and Figure 9, right) unveils that the CHN crop model constrains biomass production in the environments of Northern Africa. Specifically, the simulation conducted by the CHN crop model displays a discrepancy of approximately 14.85 t MS/ha concerning biomass, and 210 kg N/ha regarding absorbed nitrogen in aerial biomass, when devoid of the integration of field observed data.

Moreover, advancements in model accuracy are achieved through the utilization of assimilation techniques, particularly the Kalman smoothing and filtering method, particularly when integrating field observations rather than satellite imagery. This refinement results in a reduction of errors to 0.9 t MS/ha for biomass and 3.87 kg N/ha for absorbed nitrogen in aerial biomass (Figure 8 and Figure 9, right).

Nevertheless, our analysis underscores the paramount importance of integrating observed data into the CHN model framework, which is primarily derived from field-based observations.

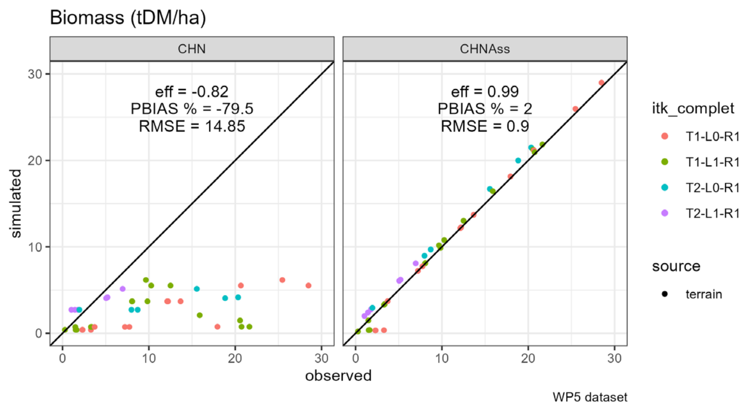


FIGURE 8 BIOMASS SIMULATION PERFORMANCES OF CHN MODEL WITH AND WITHOUT SATELLITE IMAGINERY DATA ASSIMILATION WITH KALMANN METHOD (WP5 DATASET, ALGERIA).

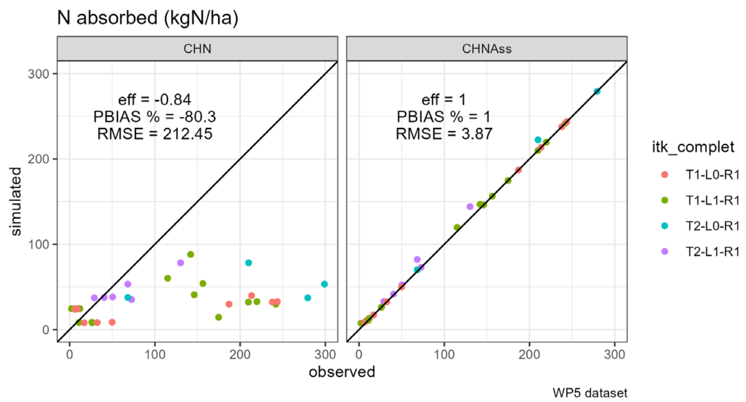


FIGURE 9 NITROGEN ABSORBED SIMULATION PERFORMANCES OF CHN MODEL WITH AND WITHOUT SATELLITE IMAGINERY DATA ASSIMILATON WITH KALMANN METHOD (WP5 DATASET, ALGERIA).

3.2. Step 2: Stress pattern dynamics

Dynamic analysis of stress patterns facilitates the classification of trials based on daily water and nitrogen stresses. The daily indicators of water and nitrogen stress are centered around the date of heading and are averaged over 100-day windows to facilitate inter-trial comparisons. Clustering is conducted subsequent to calculating Euclidean distances between trials. An alternative clustering approach involves utilizing the 'pam()' function within the 'cluster{}' package. The optimal number of clusters for each stress index is determined by maximizing the 'Average Silhouette Width' variable. These clusters are sequentially labeled according to increasing stress levels, denoted as N1, ..., Nn, and W1, ..., Wn, where 'n' represents the number of clusters. Factorial clustering is then executed by amalgamating classifications from the two stress indices. The outcomes are visually presented (Figure 10 and Figure 11), revealing a diverse array of stress patterns encompassing both nitrogen and water indicators. Some trials exhibit susceptibility to water or nitrogen stress prior to flowering, while others manifest it post-flowering. To elucidate the impact of studied factors, such as legume crop type, rainfed or irrigated conditions, and nitrogen levels, we present in the subsequent table the correlation between stress pattern groups and these factors. We can use the Chi-square test of independence to determine if there is a statistically significant relationship between two categorical variables (Table 1).

In relation to the WP3 datasets, the table illustrates noteworthy statistical relationships among tillage practices, legume crop types, and the distinction between rainfed and irrigated conditions concerning water stress indices and combined nitrogen and water index categories. The analysis suggests a particularly robust correlation, notably with the presence of legume crops and the combined effect of legume crops with rainfed or irrigated conditions. However, no discernible statistical correlation emerged between these factors and nitrogen stress indicators. Remarkably, the nitrogen stress pattern within the WP3 dataset appears unaffected by any of the investigated factors.

Additionally, concerning the WP5 dataset, statistically significant correlations are observed with tillage practices and the presence of legume crops. Unexpectedly, no statistically significant correlation is identified with the total amount of nitrogen ('D' factor). This observation may be elucidated by a more pronounced influence of site characteristics and annual variations on nitrogen stress dynamics, or the presence or absence of associated legume crops, rather than the total nitrogen content, which is typically applied once during the growing cycle (absence of nitrogen-splitting strategies in the WP5 trials).

Stress dynamic for each trial are in the 5Annexe agroclimatic indicators and patterns.

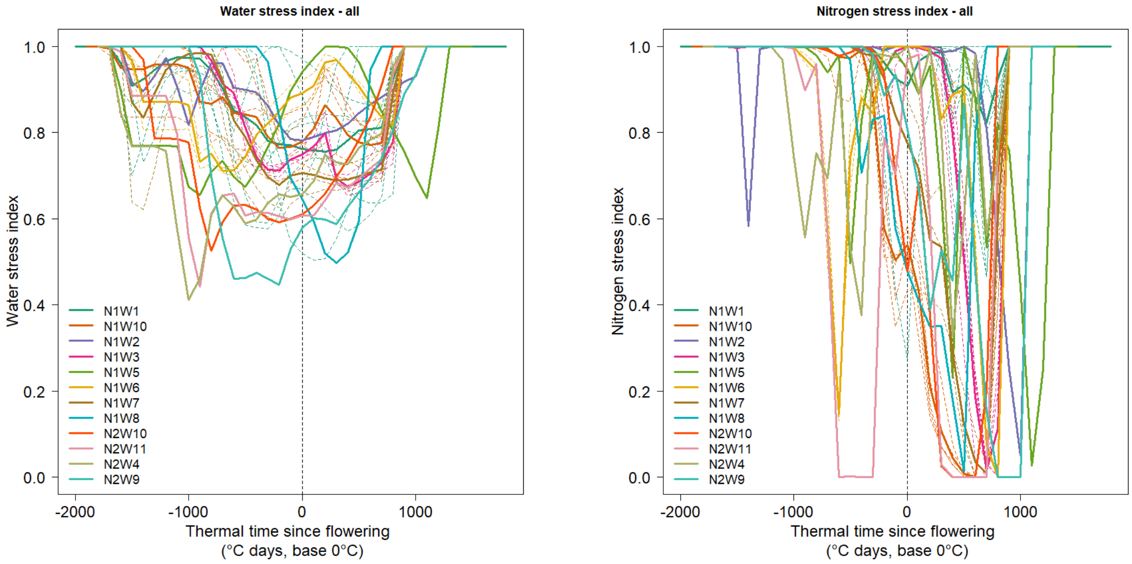


FIGURE 4 STRESS PATTERN DYNAMICS FOR WP3 DATASET.

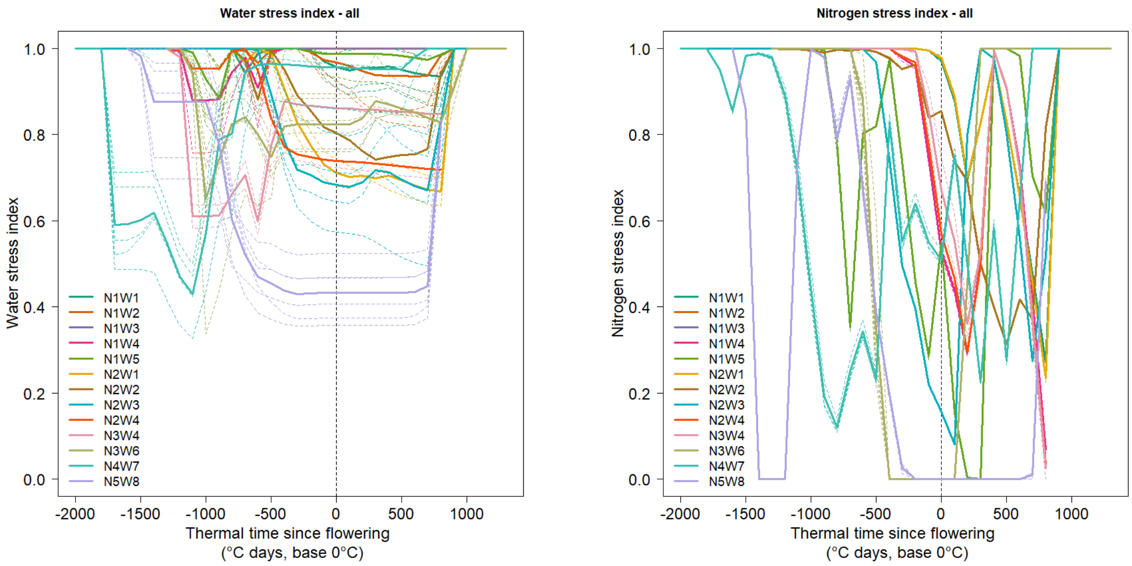


FIGURE 5 STRESS PATTERN DYNAMICS FOR WP5 DATASET.

group	var	itk_name	p_value	p_name
WP3	stressN	L-R	0.44766312	NS
WP3	stressN	T-L-R	0.28739497	NS
WP3	stressN	T	0.93561892	NS
WP3	stressN	R	1	NS
WP3	stressN	L	0.7868696	NS
WP3	stressW	L-R	0.00266845	***
WP3	stressW	T-L-R	0.00769572	***
WP3	stressW	T	0.13267068	NS
WP3	stressW	R	0.02328035	**
WP3	stressW	L	0.01017213	**
WP3	class	L-R	0.00088202	***
WP3	class	T-L-R	0.00338467	***
WP3	class	T	0.18326121	NS
WP3	class	R	0.03660831	**
WP3	class	L	0.00226996	***
WP5	stressN	L-D	0.90832789	NS
WP5	stressN	T-L-D	0.71950397	NS
WP5	stressN	T	0.00199481	***
WP5	stressN	D	0.94774648	NS
WP5	stressN	L	0.12541339	NS
WP5	stressW	L-D	1	NS
WP5	stressW	T-L-R	0.00113604	***
WP5	stressW	T-L-D	0.99520376	NS
WP5	stressW	T	8.74E-08	***
WP5	stressW	D	0.99999983	NS
WP5	stressW	L	0.99988374	NS
WP5	class	L-R	0.58680899	NS
WP5	class	L-D	0.99891425	NS
WP5	class	T-L-R	0.00015546	***
WP5	class	T-L-D	0.78449604	NS
WP5	class	T	6.94E-06	***
WP5	class	D	0.9955158	NS
WP5	class	L	0.58680899	NS

Table 2 Chi-square test of independence. Where stressN is the nitrogen stress index, StressW the water stress index, L = legume crop, R = rainfed/irrigation, T = tillage, D = nitrogen dose.

3.3. Step 3: Impact of stress on actual biomass

Additional constraining variables manifest in the WP3 and WP5 trials, hindering the attainment of potential biomass. Notably, the investigation into the presence or absence of legumes and the occurrence or non-occurrence of rainfall demonstrate statistically significant impact with the presence of crop legume (Figure 13). These limitations are expounded upon in the 3.4 deliverable of this project, particularly concerning weed management. Nitrogen and water stresses are discussed in the following paragraph.

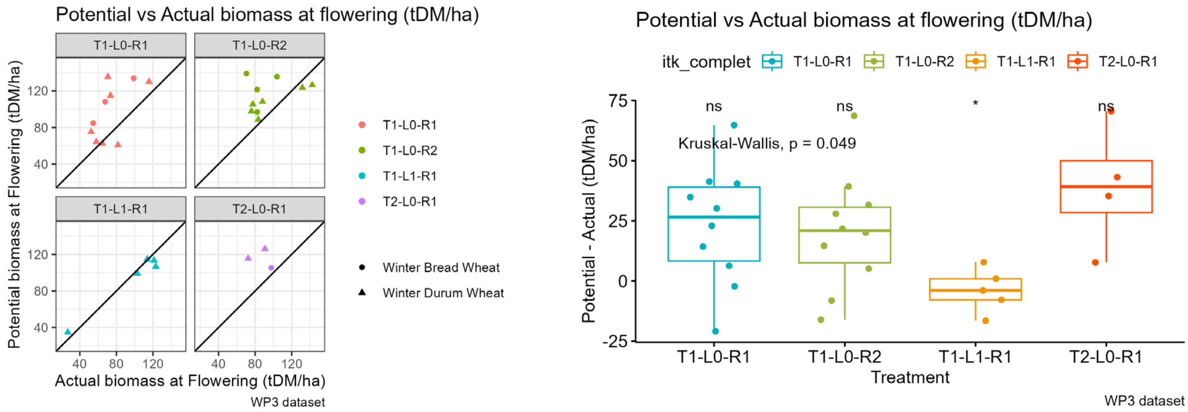


FIGURE 6 POTENTIAL VS ACTUAL BIOMASS AT FLOWERING (TDM/HA) FOR WP3 DATASET.

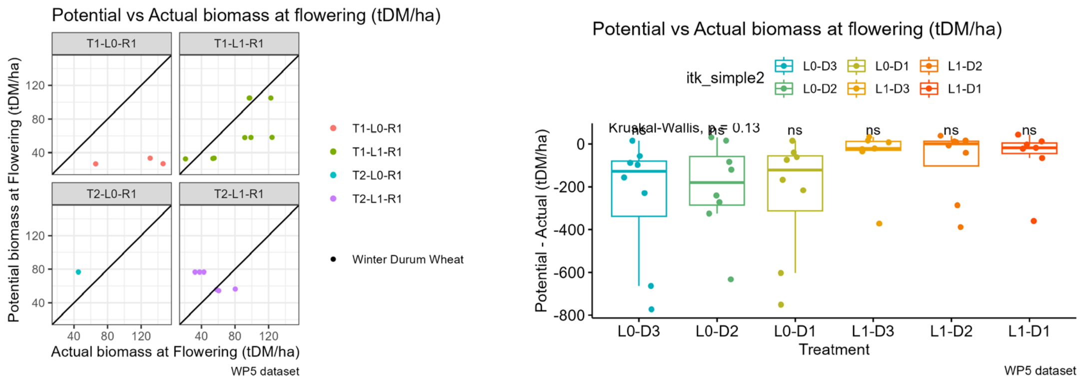


FIGURE 7 POTENTIAL VS ACTUAL BIOMASS AT FLOWERING (TDM/HA) FOR WP5 DATASET.

3.4. Step 4: co-limitation of water and nitrogen stresses

3.4.1. Correlations between biomass variables and stress indicators

In the WP3 dataset, the analysis of correlation between biomass at flowering and stress indices reveals an intriguing pattern where the colimitation index demonstrates a stronger correlation with nitrogen stress, as illustrated in Figure 14. Surprisingly, the colimitation index doesn't seem to correlate with the presence or absence of legume crop treatment. However, it's crucial to acknowledge that the dataset size for legume crop presence is relatively small, underscoring the need for additional data to confirm this observation. Noteworthy irrigation is the treatment with the most significant impact on the colimitation and water stress index, which is the presence or absence of irrigation (R1 = rainfed, R2 = presence of irrigation). Within the WP3 dataset, the deltas between potential and actual biomass exhibit a robust correlation with various stress indicators. Particularly prominent are the Area Under the Curve (AUC) pre-flowering, associated with water stress on the Leaf Area Index (LAI), nitrogen stress on biomass, comprehensive stress indicators, and colimitation indicators. However, this correlation diminishes in the presence of crop legumes. Interestingly, the most substantial and statistically significant correlations emerge when both legume crops and irrigation are absent.

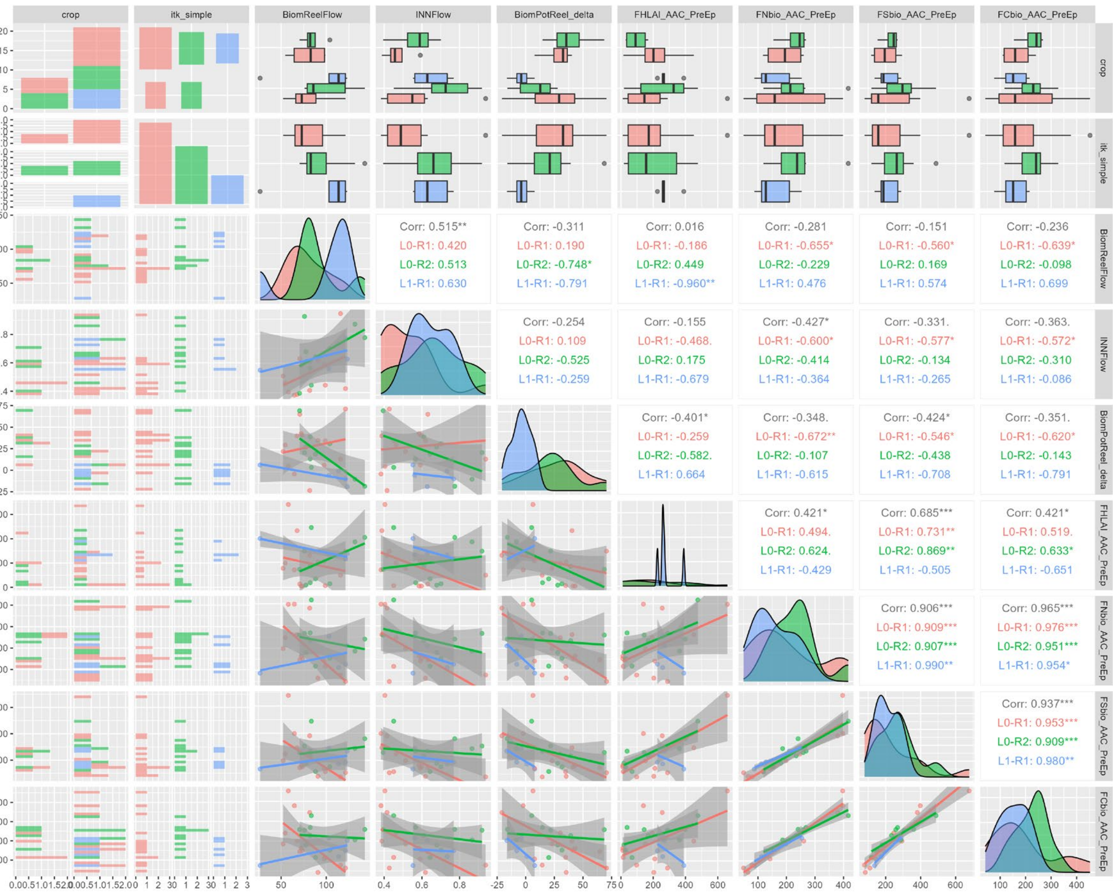


FIGURE 8 BIOMASSES AND INN CORRELATION WITH STRESS INDEXES (WP3 DATASET).

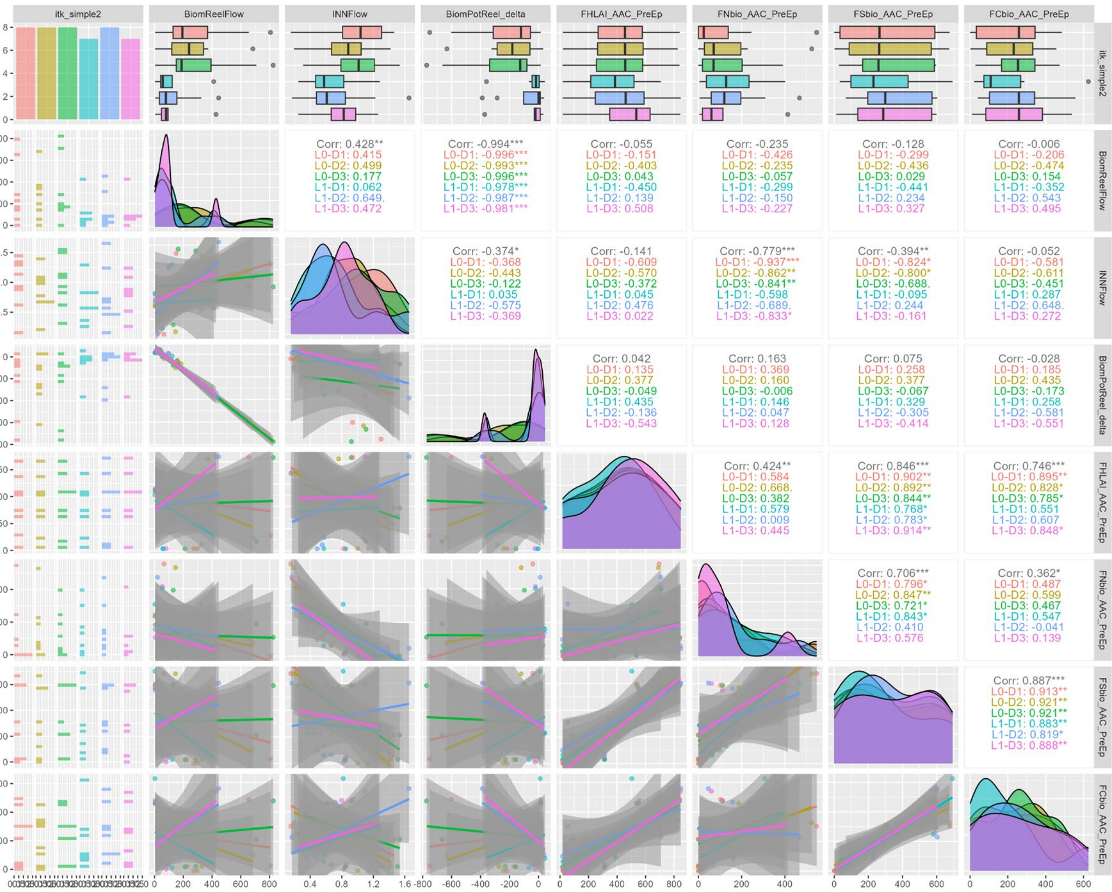


FIGURE 9 BIOMASSES AND INN CORRELATION WITH STRESS INDEXES FOR LEGUME CROP AND NITROGEN DOSE (WP5 DATASET).

In the WP5 dataset, the deltas between potential and actual biomass demonstrate any correlations with nitrogen and water stress indicators, yet not with the colimitation indicator. This suggests that within this dataset, there isn't a discernible impact on biomass due to the colimitation of water and nitrogen stresses. However, the colimitation indicator does exhibit a correlation with the water stress index. Moreover, the combination of two factors—specifically, the presence or absence of legume crops and nitrogen doses—reveals correlations with nitrogen stress indicators.

3.4.2. Variance analysis

Variance analysis elucidates the treatment effects across multiple trials and variables. In the WP3 trials, significant statistical effects of both legume crop presence and irrigation are observed, particularly evident in variables such as QNFlow, INNFLow, AUC of Nitrogen stress, and colimitation. Notably, the presence of legume crops and irrigation demonstrates a robust statistical influence on Water Use Efficiency (WUE) for biomass production. Conversely, in the WP5 dataset, minimal correlation with nitrogen dose is observed, except for the Nitrogen Use Efficiency (NUE) indicators, which are derived directly from total nitrogen amounts. The presence of legume crops significantly impacts variables such as Actual Biomass, QN, INN, NUE, and WUE biomass at flowering. However, the effect of tillage practice could not be adequately tested due to the limited number of trials in Conventional tillage. The presence of legume crops in combination with higher nitrogen doses (D3-L1) leads to increased water stress. It is plausible that the presence of another crop alongside wheat, along with the higher biomass produced by wheat due to increased nitrogen supply, cannot be sustained under rainfed conditions without irrigation.

variable	units	L0-R1	L1-R1	L0-R2
BiomReelFlow	tDM/ha	79.98	97.57	93.79
QNFlow	kgN/ha	95.04	134.08	140.71
INNFlow		0.54	0.69	0.73
FHLAI_AAC_PreEp		186.22	215.92	157.73
FNbio_AAC_PreEp		188.13	88.40	170.96
FSbio_AAC_PreEp		214.14	126.39	200.18
FCbio_AAC_PreEp		178.25	78.33	160.35
CumDif_etm_etr_PreEp	mm	22.40	41.16	25.62
NUE_Biom	tDM/kgN	0.96	0.89	0.65
WUE_Biom	tDM/mm	0.36	0.60	0.25

TABLE 3 WP3 DATASET: MEAN RESULTS.

variable	Legume crop	Irrigation	Legume crop	Irrigation
BiomReelFlow	50.60	49.40	NS	NS
QNFlow	31.44	68.56	*	**
INNFlow	28.79	71.21	*	***
FHLAI_AAC_PreEp	39.99	60.01	NS	NS
FNbio_AAC_PreEp	95.47	4.53	*	NS
FSbio_AAC_PreEp	96.05	3.95	NS	NS
FCbio_AAC_PreEp	95.12	4.88	*	NS
CumDif_etm_etr_PreEp	95.43	4.57	NS	NS
NUE_Biom	2.64	97.36	NS	*
WUE_Biom	73.91	26.09	***	***

TABLE 4 WP3 DATASET: CONTRIBUTION TO TOTAL VARIANCE (%) AND SIGNIFICANCE OF EACH TESTED EFFECT FOR FIXED EFFECTS.

variable	year:country	Residual	year:country	Residual
BiomReelFlow	0.00	100.00	***	***
QNFlow	48.69	51.31	***	***
INNFlow	63.04	36.96	NS	NS
FHLAI_AAC_PreEp	22.14	77.86	***	***
FNbio_AAC_PreEp	44.80	55.20	***	***
FSbio_AAC_PreEp	28.03	71.97	***	***
FCbio_AAC_PreEp	44.86	55.14	***	***
CumDif_etm_etr_PreEp	30.65	69.35	***	***
NUE_Biom	30.24	69.76	NS	NS
WUE_Biom	67.98	32.02	NS	NS

TABLE 5 WP3 DATASET: CONTRIBUTION TO TOTAL VARIANCE (%) AND SIGNIFICANCE OF EACH TESTED EFFECT FOR RANDOM EFFECTS.

variable	units	D1-L0	D2-L0	D3-L0	D1-L1	D2-L1	D3-L1
BiomReelFlow	tDM/ha	293.2	258.4	311.6	158.7	136.6	163.5
QNFlow	kgN/ha	306.3	252.6	309.2	146.1	165.8	175.2
INNFlow		1.0	0.9	1.0	0.7	0.7	0.8
FHLAI_AAC_PreEp		431.3	428.1	426.5	427.6	426.1	433.6
FNbio_AAC_PreEp		118.0	139.9	123.1	151.2	161.5	106.8
FSbio_AAC_PreEp		306.6	309.6	320.1	326.3	345.3	307.6
FCbio_AAC_PreEp		228.9	216.3	251.7	239.2	260.2	236.5
CumDif_etm_etr_PreEp	mm	52.8	52.2	54.1	53.6	54.0	56.3
NUE_Biom	tDM/kgN	10.0	4.6	5.7	5.4	2.3	3.6
WUE_Biom	tDM/mm	1.2	1.1	1.3	0.7	0.6	0.7

TABLE 6 WP5 DATASET: MEAN RESULTS.

variable	Nitrogen Dose	Legume crop	interaction	Nitrogen Dose	Legume crop	interaction
BiomReelFlow	5.96	93.44	0.60	NS	***	NS
QNFlow	4.13	90.58	5.29	NS	***	NS
INNFlow	15.82	74.55	9.63	NS	**	NS
FHLAI_AAC_PreEp	23.19	0.69	76.12	NS	NS	NS
FNbio_AAC_PreEp	58.91	11.20	29.89	NS	NS	NS
FSbio_AAC_PreEp	18.89	27.17	53.93	NS	NS	NS
FCbio_AAC_PreEp	7.95	20.14	71.91	NS	NS	NS
CumDif_etm_etr_PreEp	56.09	38.84	5.07	NS	NS	NS
NUE_Biom	55.50	38.97	5.53	**	**	NS
WUE_Biom	5.85	93.44	0.71	NS	***	NS

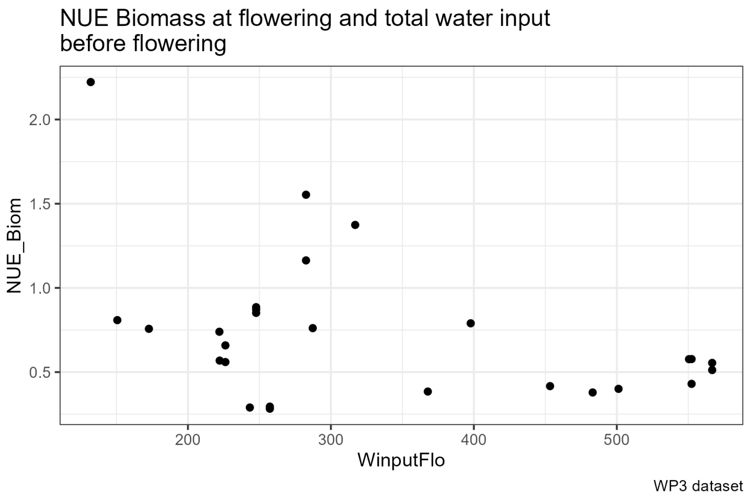
TABLE 7 WP5 DATASET: CONTRIBUTION TO TOTAL VARIANCE (%) AND SIGNIFICANCE OF EACH TESTED EFFECT FOR FIXED EFFECTS.

variable	Year :site	Residual	Year :site	Residual
BiomReelFlow	85.8	14.2	***	***
QNFlow	63.5	36.5	***	***
INNFlow	45.3	54.7	NS	NS
FHLAI_AAC_PreEp	99.8	0.2	***	***
FNbio_AAC_PreEp	82.7	17.3	***	***
FSbio_AAC_PreEp	96.7	3.3	***	***
FCbio_AAC_PreEp	90.2	9.8	***	***
CumDif_etm_etr_PreEp	97.7	2.3	***	***
NUE_Biom	65.8	34.2	***	***
WUE_Biom	83.9	16.1	NS	NS

TABLE 8 WP5 DATASET: CONTRIBUTION TO TOTAL VARIANCE (%) AND SIGNIFICANCE OF EACH TESTED EFFECT FOR RANDOM EFFECTS.

3.4.3. water input and nitrogen use efficiency

Plotting Nitrogen Use Efficiency (NUE) for biomass at flowering against water input at flowering does not clearly represent patterns or correlations between these two phenomena. It appears that water input alone may not fully explain NUE variations. Additional factors, such as the presence of legume crops, likely contribute to further understanding the relationships.



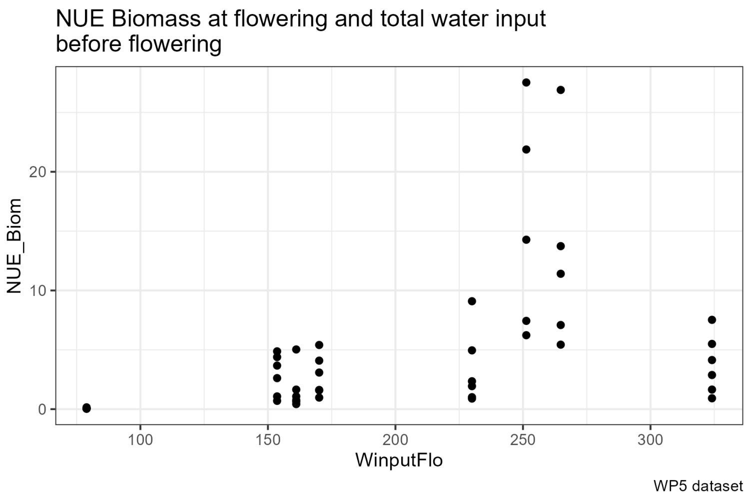


TABLE 9: NUE FOR THE BIMASS AT FLOWERING RELATED TO THE TOTAL AMOUNT (RAIN AND IRRIGATIONS).

4. General Conclusions

On the crop model results

In the WP3 data set, without satellite assimilation, there is a notable discrepancy in the prediction of biomass and nitrogen absorbed, attributed to various factors such as the presence of limiting factors, nitrogen residues from previous crops, and the quality of available data regarding previous crop information (Figure 6 and Figure 7). The incorporation of LAI and Chlorophyll assimilation did not significantly enhance precision in the predictions, suggesting potential limitations in the accuracy of satellite-derived data. This lack of precision raises questions regarding the reliability of satellite data, prompting an examination of factors influencing data accuracy. It is essential to investigate the frequency of LAI and chlorophyll assimilation to determine if the interval between data updates impacts the model's predictive capability. Additionally, considering the size of the plots under analysis could shed light on potential discrepancies, as larger plots might introduce more variability into the analysis compared to smaller plots.

Given that the CHN crop model simulates biomass at flowering but not yield, the conclusions drawn from water and nitrogen stress assessments are reliable from sowing to flowering. However, it is important to note that several nitrogen and water stresses may occur after flowering, as indicated by the results of the stress pattern analysis.

On nitrogen use efficiency and water use efficiency in conservation agriculture

The results obtained from the models applied in Work Packages 3 and 5 reveal a discernible influence of colimitation by both nitrogen and water in conservation agriculture trials conducted within the Mediterranean region. The presence or absence of a legume crop appears to mitigate nitrogen stress under specific circumstances, particularly in instances where water inputs are not restrictive and maintain levels above a certain threshold. Notably, the presence of a legume crop exerts a significant impact on biomass at flowering, especially within the WP5 datasets. Moreover, the presence of a legume crop demonstrates statistically significant effects only when the total amount of applied nitrogen is deemed inefficient, thereby generating nitrogen stress, with the Normalized Nitrogen Index (NNI) at flowering falling below 0.9. The determination of optimal nitrogen dosage and application timing poses a critical challenge in these contexts, where patterns of nitrogen and water stress can exhibit substantial variability in response to climatic hazards. Water stress manifests its influence when the higher biomass resulting from elevated nitrogen doses and the presence of associated legume crops produce a potential biomass that exceeds precipitation levels without supplementary irrigation. Furthermore, irrigation exerts a pronounced impact on the total amount of nitrogen absorbed by the plant at flowering, as well as nitrogen and water use efficiency, underscoring a stronger influence of water stress relative to nitrogen stress within the WP3 dataset.

The nexus between nitrogen use efficiency and water use efficiency in conservation agriculture holds significant implications for sustainable and resource-efficient farming practices. Efficient nutrient and water management strategies are pivotal for optimizing crop productivity while minimizing environmental impact. There are several interconnected approaches that can be employed to enhance both nitrogen and water use efficiency concurrently:

Precision Agriculture Technologies: Integration of precision agriculture technologies, such as sensor-based irrigation and nutrient application systems, allows for real-time monitoring of soil moisture and nutrient levels. This enables farmers to apply nitrogen and water precisely where and when they are needed, minimizing wastage and optimizing resource utilization .

Cover Cropping and Crop Rotation: Implementing cover cropping and crop rotation practices in conservation agriculture contributes to improved soil structure and nutrient cycling. This, in turn, enhances the availability of nitrogen and water to crops, promoting greater NUE and WUE.

Innovative Irrigation Techniques: Adoption of efficient irrigation techniques, such as drip or micro-irrigation systems, not only conserves water but also facilitates controlled and targeted application of nutrients. This ensures that nitrogen is delivered directly to the root zone, enhancing NUE and reducing the risk of nutrient leaching .

Enhanced Soil Organic Matter: Practices that increase soil organic matter, such as the incorporation of crop residues into the soil, positively influence water retention and nutrient availability. This promotes a conducive environment for root development and nutrient uptake, ultimately improving both NUE and WUE .

Utilization of Nitrogen-Fixing Crops: Intercropping or rotating with nitrogen-fixing crops can contribute to the biological fixation of nitrogen, reducing the reliance on synthetic fertilizers. This not only improves NUE but also positively impacts water dynamics in the soil.

Adoption of Conservation Tillage: Conservation tillage practices, including minimal tillage or no-till methods, help in retaining soil moisture and organic matter. This, in turn, enhances the efficiency of both nitrogen and water utilization by creating a more favorable environment for nutrient uptake and reducing water evaporation.

Integrated Nutrient and Water Management Plans: Developing comprehensive nutrient and water management plans tailored to specific agroecosystems is crucial. This involves considering soil characteristics, climate conditions, and crop requirements to optimize the synergistic effects of nitrogen and water use in conservation agriculture.

By exploring and implementing these integrated approaches, conservation agriculture can achieve a harmonized enhancement of nitrogen and water use efficiency, contributing to sustainable agricultural practices with positive economic and environmental outcomes. These strategies not only promote resource conservation but also align with the broader goals of achieving food security and mitigating the environmental impact of agricultural activities.

References

Bijay-Singh, & Craswell, E. (2021). Fertilizers and nitrate pollution of surface and ground water: An increasingly pervasive global problem. *SN Applied Sciences*, *3*(4), 518. https://doi.org/10.1007/s42452-021-04521-8

Calviño, P. A., & Sadras, V. O. (1999). Interannual variation in soybean yield: Interaction among rainfall, soil depth and crop management. *Field Crops Research*, *63*(3), 237–246. https://doi.org/10.1016/S0378-4290(99)00040-4

Calviño, P., & Sadras, V. (2002). On-farm assessment of constraints to wheat yield in the south-eastern Pampas. *Field Crops Research*, *74*(1), 1–11. https://doi.org/10.1016/S0378-4290(01)00193-9

Casanova, D., Goudriaan, J., Forner, M. M. C., & Withagen, J. C. M. (2002). Rice yield prediction from yield components and limiting factors. *European Journal of Agronomy*, *17*(1), 41–61. https://doi.org/10.1016/S1161-0301(01)00137-X

Follett, R. F., & Hatfield, J. L. (2001). Nitrogen in the Environment: Sources, Problems, and Management. *The Scientific World JOURNAL*, *1*, 920–926. https://doi.org/10.1100/tsw.2001.269

Johnston, L. J., Renteria, A., & Hannon, M. R. (2003). Improving validity of on-farm research. *Journal of Swine Health and Production*, *11*(5), 240–246.

Kaufman, L., & Rousseeuw, P. J. (1990). *Finding Groups in Data: An Introduction to Cluster Analysis* (1st ed.). Wiley. https://doi.org/10.1002/9780470316801

Moore, K. J., & Dixon, P. M. (2015). Analysis of Combined Experiments Revisited. *Agronomy Journal*, *107*(2), 763–771. https://doi.org/10.2134/agronj13.0485

Quemada, M., & Gabriel, J. L. (2016). Approaches for increasing nitrogen and water use efficiency simultaneously. *Global Food Security*, *9*, 29–35. https://doi.org/10.1016/j.gfs.2016.05.004

Reynolds, A. P., Richards, G., De La Iglesia, B., & Rayward-Smith, V. J. (2006). Clustering Rules: A Comparison of Partitioning and Hierarchical Clustering Algorithms. *Journal of Mathematical Modelling and Algorithms*, *5*(4), 475–504. https://doi.org/10.1007/s10852-005-9022-1

Rinaldi, M., Almeida, A. S., Álvaro Fuentes, J., Annabi, M., Annicchiarico, P., Castellini, M., Cantero Martinez, C., Cruz, M. G., D'Alessandro, G., Gitsopoulos, T., Marandola, D., Marguerie, M., Lamouchi, S., Latati, M., Lopez Francos, A., Moussadek, R., & Pecetti, L. (2022). Open Questions and Research Needs in the Adoption of Conservation Agriculture in the Mediterranean Area. *Agronomy*, *12*(5), 1112. https://doi.org/10.3390/agronomy12051112

Sadras, V. O. (2004). Yield and water-use efficiency of water- and nitrogen-stressed wheat crops increase with degree of co-limitation. *European Journal of Agronomy*, *21*(4), 455–464. https://doi.org/10.1016/j.eja.2004.07.007

Schubert, E., & Rousseeuw, P. J. (2019). Faster k-Medoids Clustering: Improving the PAM, CLARA, and CLARANS Algorithms. In G. Amato, C. Gennaro, V. Oria, & M. Radovanović (Eds.), *Similarity Search and Applications* (Vol. 11807, pp. 171–187). Springer International Publishing. https://doi.org/10.1007/978-3-030-32047-8_16

Siahpoosh, M. R., & Dehghanian, E. (2012). Water Use Efficiency, Transpiration Efficiency, and Uptake Efficiency of Wheat during Drought. *Agronomy Journal*, *104*(5), 1238–1243. https://doi.org/10.2134/agronj2011.0320

Smith, C. J., & Chalk, P. M. (2020). The role of 15N in tracing N dynamics in agro-ecosystems under alternative systems of tillage management: A review. *Soil and Tillage Research*, *197*, 104496. https://doi.org/10.1016/j.still.2019.104496

Working with Dynamic Crop Models. (2014). Elsevier. https://doi.org/10.1016/C2011-0-06987-9

Xue, Q., Zhu, Z., Musick, J. T., Stewart, B. A., & Dusek, D. A. (2006). Physiological mechanisms contributing to the increased water-use efficiency in winter wheat under deficit irrigation. *Journal of Plant Physiology*, *163*(2), 154–164. https://doi.org/10.1016/j.jplph.2005.04.026

5. Annex Trial list

nb	Trial name	crop	Treatments	comment_itk1Wsol	comment_itk2Asso	comment_itk3Nitrogen	comment_itk4covercrop	comment_itk5previouscrop	comment_itk6irrig
1	Algeria-S1Oued_2021	Winter Durum Wheat	T1-F1-D1-C0-P0-R1	T1 = No Tillage	F1 = Winter Durum Wheat	D1 =30 kg N/ha	C0 = no cover crop	P0 = no effect of previous crop	R1 = Rainfed
2	Algeria-S1Oued_2021	Winter Durum Wheat	T1-F1-D2-C0-P0-R1	T1 = No Tillage	F1 = Winter Durum Wheat	D2 =60 kg N/ha	C0 = no cover crop	P0 = no effect of previous crop	R1 = Rainfed
3	Algeria-S1Oued_2021	Winter Durum Wheat	T1-F1-D3-C0-P0-R1	T1 = No Tillage	F1 = Winter Durum Wheat	D3 =100 kg N/ha	C0 = no cover crop	P0 = no effect of previous crop	R1 = Rainfed
4	Algeria-S1Oued_2021	Winter Durum Wheat	T1-F2-D1-C2-P0-R1	T1 = No Tillage	F2 = Winter Durum Wheat and chickpea	D1 =30 kg N/ha	C2 = associated	P0 = no effect of previous crop	R1 = Rainfed
5	Algeria-S1Oued_2021	Winter Durum Wheat	T1-F2-D2-C2-P0-R1	T1 = No Tillage	F2 = Winter Durum Wheat and chickpea	D2 =60 kg N/ha	C2 = associated	P0 = no effect of previous crop	R1 = Rainfed
6	Algeria-S1Oued_2021	Winter Durum Wheat	T1-F2-D3-C2-P0-R1	T1 = No Tillage	F2 = Winter Durum Wheat and chickpea	D3 =100 kg N/ha	C2 = associated	P0 = no effect of previous crop	R1 = Rainfed
7	Algeria-S1Oued_2022	Winter Durum Wheat	T1-F1-D1-C0-P0-R1	T1 = No Tillage	F1 = Winter Durum Wheat	D1 =30 kg N/ha	C0 = no cover crop	P0 = no effect of previous crop	R1 = Rainfed
8	Algeria-S1Oued_2022	Winter Durum Wheat	T1-F1-D2-C0-P0-R1	T1 = No Tillage	F1 = Winter Durum Wheat	D2 =60 kg N/ha	C0 = no cover crop	P0 = no effect of previous crop	R1 = Rainfed
9	Algeria-S1Oued_2022	Winter Durum Wheat	T1-F1-D3-C0-P0-R1	T1 = No Tillage	F1 = Winter Durum Wheat	D3 =100 kg N/ha	C0 = no cover crop	P0 = no effect of previous crop	R1 = Rainfed
10	Algeria-S1Oued_2022	Winter Durum Wheat	T1-F2-D1-C2-P0-R1	T1 = No Tillage	F2 = Winter Durum Wheat and chickpea	D1 =30 kg N/ha	C2 = associated	P0 = no effect of previous crop	R1 = Rainfed
11	Algeria-S1Oued_2022	Winter Durum Wheat	T1-F2-D2-C2-P0-R1	T1 = No Tillage	F2 = Winter Durum Wheat and chickpea	D2 =60 kg N/ha	C2 = associated	P0 = no effect of previous crop	R1 = Rainfed
12	Algeria-S1Oued_2022	Winter Durum Wheat	T1-F2-D3-C2-P0-R1	T1 = No Tillage	F2 = Winter Durum Wheat and chickpea	D3 =100 kg N/ha	C2 = associated	P0 = no effect of previous crop	R1 = Rainfed
13	Algeria-S1Oued_2023	Winter Durum Wheat	T1-F1-D1-C0-P0-R1	T1 = No Tillage	F1 = Winter Durum Wheat	D1 =30 kg N/ha	C0 = no cover crop	P0 = no effect of previous crop	R1 = Rainfed
14	Algeria-S1Oued_2023	Winter Durum Wheat	T1-F1-D2-C0-P0-R1	T1 = No Tillage	F1 = Winter Durum Wheat	D2 =60 kg N/ha	C0 = no cover crop	P0 = no effect of previous crop	R1 = Rainfed
15	Algeria-S1Oued_2023	Winter Durum Wheat	T1-F1-D3-C0-P0-R1	T1 = No Tillage	F1 = Winter Durum Wheat	D3 =100 kg N/ha	C0 = no cover crop	P0 = no effect of previous crop	R1 = Rainfed
16	Algeria-S1Oued_2023	Winter Durum Wheat	T1-F2-D1-C2-P0-R1	T1 = No Tillage	F2 = Winter Durum Wheat and chickpea	D1 =30 kg N/ha	C2 = associated	P0 = no effect of previous crop	R1 = Rainfed
17	Algeria-	Winter Durum Wheat	T1-F2-D2-C2-P0-R1	T1 = No Tillage	F2 = Winter Durum Wheat and	D2 =60 kg N/ha	C2 = associated	P0 = no effect of	R1 = Rainfed

	S1Oued_2023				chickpea			previous crop	
18	Algeria-S1Oued_2023	Winter Durum Wheat	T1-F2-D3-C2-P0-R1	T1 = No Tillage	F2 = Winter Durum Wheat and chickpea	D3 =100 kg N/ha	C2 = associated	P0 = no effect of previous crop	R1 = Rainfed
19	Algeria-S2Mezloug_2021	Winter Durum Wheat	T1-F1-D1-C0-P0-R1	T1 = No Tillage	F1 = Winter Durum Wheat	D1 =30 kg N/ha	C0 = no cover crop	P0 = no effect of previous crop	R1 = Rainfed
20	Algeria-S2Mezloug_2021	Winter Durum Wheat	T1-F1-D2-C0-P0-R1	T1 = No Tillage	F1 = Winter Durum Wheat	D2 =60 kg N/ha	C0 = no cover crop	P0 = no effect of previous crop	R1 = Rainfed
21	Algeria-S2Mezloug_2021	Winter Durum Wheat	T1-F1-D3-C0-P0-R1	T1 = No Tillage	F1 = Winter Durum Wheat	D3 =100 kg N/ha	C0 = no cover crop	P0 = no effect of previous crop	R1 = Rainfed
22	Algeria-S2Mezloug_2021	Winter Durum Wheat	T1-F2-D1-C2-P0-R1	T1 = No Tillage	F2 = Winter Durum Wheat and chickpea	D1 =30 kg N/ha	C2 = associated	P0 = no effect of previous crop	R1 = Rainfed
23	Algeria-S2Mezloug_2021	Winter Durum Wheat	T1-F2-D2-C2-P0-R1	T1 = No Tillage	F2 = Winter Durum Wheat and chickpea	D2 =60 kg N/ha	C2 = associated	P0 = no effect of previous crop	R1 = Rainfed
24	Algeria-S2Mezloug_2021	Winter Durum Wheat	T1-F2-D3-C2-P0-R1	T1 = No Tillage	F2 = Winter Durum Wheat and chickpea	D3 =100 kg N/ha	C2 = associated	P0 = no effect of previous crop	R1 = Rainfed
25	Algeria-S2Mezloug_2022	Winter Durum Wheat	T1-F1-D1-C0-P0-R1	T1 = No Tillage	F1 = Winter Durum Wheat	D1 =30 kg N/ha	C0 = no cover crop	P0 = no effect of previous crop	R1 = Rainfed
26	Algeria-S2Mezloug_2022	Winter Durum Wheat	T1-F1-D2-C0-P0-R1	T1 = No Tillage	F1 = Winter Durum Wheat	D2 =60 kg N/ha	C0 = no cover crop	P0 = no effect of previous crop	R1 = Rainfed
27	Algeria-S2Mezloug_2022	Winter Durum Wheat	T1-F1-D3-C0-P0-R1	T1 = No Tillage	F1 = Winter Durum Wheat	D3 =100 kg N/ha	C0 = no cover crop	P0 = no effect of previous crop	R1 = Rainfed
28	Algeria-S2Mezloug_2022	Winter Durum Wheat	T1-F2-D1-C2-P0-R1	T1 = No Tillage	F2 = Winter Durum Wheat and chickpea	D1 =30 kg N/ha	C2 = associated	P0 = no effect of previous crop	R1 = Rainfed
29	Algeria-S2Mezloug_2022	Winter Durum Wheat	T1-F2-D2-C2-P0-R1	T1 = No Tillage	F2 = Winter Durum Wheat and chickpea	D2 =60 kg N/ha	C2 = associated	P0 = no effect of previous crop	R1 = Rainfed
30	Algeria-S2Mezloug_202	Winter Durum Wheat	T1-F2-D3-C2-P0-R1	T1 = No Tillage	F2 = Winter Durum Wheat and chickpea	D3 =100 kg N/ha	C2 = associated	P0 = no effect of previous crop	R1 = Rainfed

	2								
31	Algeria-S2Mezloug_2023	Winter Durum Wheat	T1-F1-D1-C0-P0-R1	T1 = No Tillage	F1 = Winter Durum Wheat	D1 =30 kg N/ha	C0 = no cover crop	P0 = no effect of previous crop	R1 = Rainfed
32	Algeria-S2Mezloug_2023	Winter Durum Wheat	T1-F1-D2-C0-P0-R1	T1 = No Tillage	F1 = Winter Durum Wheat	D2 =60 kg N/ha	C0 = no cover crop	P0 = no effect of previous crop	R1 = Rainfed
33	Algeria-S2Mezloug_2023	Winter Durum Wheat	T1-F1-D3-C0-P0-R1	T1 = No Tillage	F1 = Winter Durum Wheat	D3 =100 kg N/ha	C0 = no cover crop	P0 = no effect of previous crop	R1 = Rainfed
34	Algeria-S2Mezloug_2023	Winter Durum Wheat	T1-F2-D1-C2-P0-R1	T1 = No Tillage	F2 = Winter Durum Wheat and chickpea	D1 =30 kg N/ha	C2 = associated	P0 = no effect of previous crop	R1 = Rainfed
35	Algeria-S2Mezloug_2023	Winter Durum Wheat	T1-F2-D2-C2-P0-R1	T1 = No Tillage	F2 = Winter Durum Wheat and chickpea	D2 =60 kg N/ha	C2 = associated	P0 = no effect of previous crop	R1 = Rainfed
36	Algeria-S2Mezloug_2023	Winter Durum Wheat	T1-F2-D3-C2-P0-R1	T1 = No Tillage	F2 = Winter Durum Wheat and chickpea	D3 =100 kg N/ha	C2 = associated	P0 = no effect of previous crop	R1 = Rainfed
37	Algeria-S3Baida_2021	Winter Durum Wheat	T2-F1-D1-C0-P0-R1	T2 = Conventional Tillage	F1 = Winter Durum Wheat	D1 =30 kg N/ha	C0 = no cover crop	P0 = no effect of previous crop	R1 = Rainfed
38	Algeria-S3Baida_2021	Winter Durum Wheat	T2-F1-D2-C0-P0-R1	T2 = Conventional Tillage	F1 = Winter Durum Wheat	D2 =60 kg N/ha	C0 = no cover crop	P0 = no effect of previous crop	R1 = Rainfed
39	Algeria-S3Baida_2021	Winter Durum Wheat	T2-F1-D3-C0-P0-R1	T2 = Conventional Tillage	F1 = Winter Durum Wheat	D3 =100 kg N/ha	C0 = no cover crop	P0 = no effect of previous crop	R1 = Rainfed
40	Algeria-S3Baida_2021	Winter Durum Wheat	T2-F2-D1-C2-P0-R1	T2 = Conventional Tillage	F2 = Winter Durum Wheat and chickpea	D1 =30 kg N/ha	C2 = associated	P0 = no effect of previous crop	R1 = Rainfed
41	Algeria-S3Baida_2021	Winter Durum Wheat	T2-F2-D2-C2-P0-R1	T2 = Conventional Tillage	F2 = Winter Durum Wheat and chickpea	D2 =60 kg N/ha	C2 = associated	P0 = no effect of previous crop	R1 = Rainfed
42	Algeria-S3Baida_2021	Winter Durum Wheat	T2-F2-D3-C2-P0-R1	T2 = Conventional Tillage	F2 = Winter Durum Wheat and chickpea	D3 =100 kg N/ha	C2 = associated	P0 = no effect of previous crop	R1 = Rainfed
43	Algeria-S3Baida_2022	Winter Durum Wheat	T2-F1-D1-C0-P0-R1	T2 = Conventional Tillage	F1 = Winter Durum Wheat	D1 =30 kg N/ha	C0 = no cover crop	P0 = no effect of previous crop	R1 = Rainfed
44	Algeria-S3Baida_2022	Winter Durum Wheat	T2-F1-D2-C0-P0-R1	T2 = Conventional Tillage	F1 = Winter Durum Wheat	D2 =60 kg N/ha	C0 = no cover crop	P0 = no effect of previous crop	R1 = Rainfed
45	Algeria-S3Baida_2022	Winter Durum Wheat	T2-F1-D3-C0-P0-R1	T2 = Conventional Tillage	F1 = Winter Durum Wheat	D3 =100 kg N/ha	C0 = no cover crop	P0 = no effect of previous crop	R1 = Rainfed
46	Algeria-	Winter Durum Wheat	T2-F2-D1-C2-P0-R1	T2 = Conventional	F2 = Winter Durum Wheat and	D1 =30 kg N/ha	C2 = associated	P0 = no effect of	R1 = Rainfed

	S3Baida_2022			Tillage	chickpea			previous crop	
47	Algeria-S3Baida_2022	Winter Durum Wheat	T2-F2-D2-C2-P0-R1	T2 = Conventional Tillage	F2 = Winter Durum Wheat and chickpea	D2 =60 kg N/ha	C2 = associated	P0 = no effect of previous crop	R1 = Rainfed
48	Algeria-S3Baida_2022	Winter Durum Wheat	T2-F2-D3-C2-P0-R1	T2 = Conventional Tillage	F2 = Winter Durum Wheat and chickpea	D3 =100 kg N/ha	C2 = associated	P0 = no effect of previous crop	R1 = Rainfed
49	France-OraB10_2021	Winter Durum Wheat	T1-F1-D0-C0-P2-R1	T1 = No Tillage	F1 = Winter Durum Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P2 = leg	R1 = Rainfed
50	France-OraB11_2021	Winter Durum Wheat	T1-F6-D0-C1-P2-R1	T1 = No Tillage	F6 = Durum wheat and alfalfa - destroyed	D0 = no Nitrogen treatement	C1 = destroyed	P2 = leg	R1 = Rainfed
51	France-OraB12_2021	Winter Durum Wheat	T1-F7-D0-C1-P2-R1	T1 = No Tillage	F7 = Winter Winter Durum Wheat and sainfoin destroyed	D0 = no Nitrogen treatement	C1 = destroyed	P2 = leg	R1 = Rainfed
52	France-OraB21_2022	Winter Durum Wheat	T1-F8-D0-C1-P1-R1	T1 = No Tillage	F8 = Winter Winter Durum Wheat and oat destroyed	D0 = no Nitrogen treatement	C1 = destroyed	P1 = no leg	R1 = Rainfed
53	France-OraB23_2022	Winter Durum Wheat	T1-F1-D0-C0-P1-R1	T1 = No Tillage	F1 = Winter Durum Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P1 = no leg	R1 = Rainfed
54	France-OraB25_2022	Winter Bread Wheat	T1-F3-D0-C0-P1-R1	T1 = No Tillage	F3 = Winter bread Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P1 = no leg	R1 = Rainfed
55	France-OraB6_2021	Winter Durum Wheat	T1-F5.1-D0-C1-P2-R1	T1 = No Tillage	F5.1 = Winter Durum Wheat and sorghum and oats	D0 = no Nitrogen treatement	C1 = destroyed	P2 = leg	R1 = Rainfed
56	France-OraB7_2021	Winter Durum Wheat	T1-F5.2-D0-C1-P2-R1	T1 = No Tillage	F5.2 = Winter Durum Wheat and sorghum v1	D0 = no Nitrogen treatement	C1 = destroyed	P2 = leg	R1 = Rainfed
57	France-OraB8_2021	Winter Durum Wheat	T1-F5.3-D0-C1-P2-R1	T1 = No Tillage	F5.3 = Winter Durum Wheat and sorghum v1	D0 = no Nitrogen treatement	C1 = destroyed	P2 = leg	R1 = Rainfed
58	France-OraB9_2021	Winter Durum Wheat	T1-F5.4-D0-C1-P2-R1	T1 = No Tillage	F5.4 = Winter Durum Wheat and sorghum v1	D0 = no Nitrogen treatement	C1 = destroyed	P2 = leg	R1 = Rainfed
59	France-Oral1-I2_2022	Winter Bread Wheat	T1-F3-D0-C0-P2-R2	T1 = No Tillage	F3 = Winter bread Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P2 = leg	R2 = Irrigation
60	France-Oral3-I4_2022	Winter Durum Wheat	T1-F1-D0-C0-P2-R2	T1 = No Tillage	F1 = Winter Durum Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P2 = leg	R2 = Irrigation
61	Frison-Col_2022	Winter Durum Wheat	T1-F1-D0-C0-P1-R2	T1 = No Tillage	F1 = Winter Durum Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P1 = no leg	R2 = Irrigation
62	Frison-Dab_2021	Winter Durum Wheat	T1-F1-D0-C0-P1-R2	T1 = No Tillage	F1 = Winter Durum Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P1 = no leg	R2 = Irrigation
63	Frison-Mai_2022	Winter Durum Wheat	T1-F1-D0-C0-P1-R2	T1 = No Tillage	F1 = Winter Durum Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P1 = no leg	R2 = Irrigation
64	Frison-Man_2021	Winter Durum Wheat	T1-F1-D0-C0-P1-R2	T1 = No Tillage	F1 = Winter Durum Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P1 = no leg	R2 = Irrigation
65	Gassier_2022	Winter Durum Wheat	T2-F1-D0-C0-P1-R2	T2 = Conventional	F1 = Winter Durum Wheat	D0 = no Nitrogen	C0 = no cover	P1 = no leg	R2 =

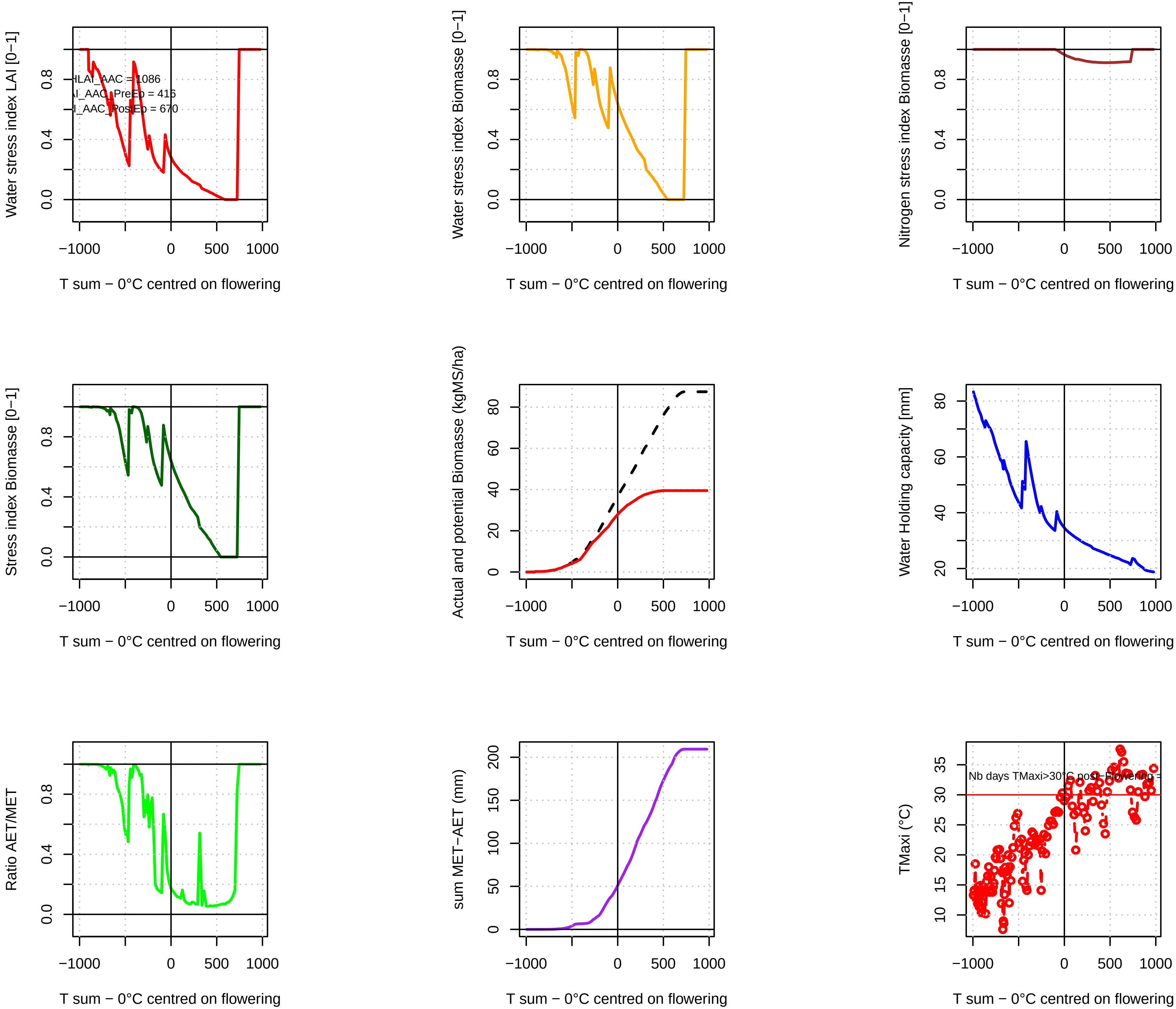
				Tillage		treatement	crop		Irrigation
66	Greece-Drim_2021	Winter Bread Wheat	T2-F3-D0-C0-P1-R1	T2 = Conventional Tillage	F3 = Winter bread Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P1 = no leg	R1 = Rainfed
67	Greece-Drim_2022	Winter Durum Wheat	T2-F1-D0-C0-P1-R1	T2 = Conventional Tillage	F1 = Winter Durum Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P1 = no leg	R1 = Rainfed
68	Greece-Thes_2021	Winter Bread Wheat	T2-F3-D0-C0-P1-R1	T2 = Conventional Tillage	F3 = Winter bread Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P1 = no leg	R1 = Rainfed
69	Italy-Sfinge_2022	Winter Durum Wheat	T2-F1-D0-C0-P1-R1	T2 = Conventional Tillage	F1 = Winter Durum Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P1 = no leg	R1 = Rainfed
70	Italy-Sfinge1_2021	Winter Durum Wheat	T2-F1-D0-C0-P1-R1	T2 = Conventional Tillage	F1 = Winter Durum Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P1 = no leg	R1 = Rainfed
71	Italy-Sfinge2_2021	Winter Durum Wheat	T2-F1-D0-C0-P1-R1	T2 = Conventional Tillage	F1 = Winter Durum Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P1 = no leg	R1 = Rainfed
72	Joubert_2022	Winter Durum Wheat	T1-F1-D0-C0-P2-R2	T1 = No Tillage	F1 = Winter Durum Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P2 = leg	R2 = Irrigation
73	Jourdan_2021	Winter Durum Wheat	T1-F4-D0-C2-P2-R1	T1 = No Tillage	F4 = Durum wheat and alfalfa associated	D0 = no Nitrogen treatement	C2 = associated	P2 = leg	R1 = Rainfed
74	Jourdan-Luz_2022	Winter Durum Wheat	T1-F4-D0-C2-P1-R1	T1 = No Tillage	F4 = Durum wheat and alfalfa associated	D0 = no Nitrogen treatement	C2 = associated	P1 = no leg	R1 = Rainfed
75	Jourdan-SF_2022	Winter Durum Wheat	T1-F5-D0-C1-P1-R1	T1 = No Tillage	F5 = Winter Durum Wheat and sorghum	D0 = no Nitrogen treatement	C1 = destroyed	P1 = no leg	R1 = Rainfed
76	Moullet-Lab_2021	Winter Durum Wheat	T2-F1-D0-C0-P2-R1	T2 = Conventional Tillage	F1 = Winter Durum Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P2 = leg	R1 = Rainfed
77	Moullet-Luz_2021	Winter Durum Wheat	T1-F4-D0-C2-P2-R1	T1 = No Tillage	F4 = Durum wheat and alfalfa associated	D0 = no Nitrogen treatement	C2 = associated	P2 = leg	R1 = Rainfed
78	Moullet-Luz_2022	Winter Durum Wheat	T1-F4-D0-C2-P2-R1	T1 = No Tillage	F4 = Durum wheat and alfalfa associated	D0 = no Nitrogen treatement	C2 = associated	P2 = leg	R1 = Rainfed
79	Moullet-Tou_2021	Winter Durum Wheat	T1-F1-D0-C0-P1-R1	T1 = No Tillage	F1 = Winter Durum Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P1 = no leg	R1 = Rainfed
80	Moullet-Tou_2022	Winter Durum Wheat	T1-F1-D0-C0-P1-R1	T1 = No Tillage	F1 = Winter Durum Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P1 = no leg	R1 = Rainfed
81	Portugal-Comenda_2022	Winter Durum Wheat	T1-F1-D0-C0-P1-R1	T1 = No Tillage	F1 = Winter Durum Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P1 = no leg	R1 = Rainfed
82	Portugal-Melinho_2021	Winter Bread Wheat	T1-F3-D0-C0-P1-R2	T1 = No Tillage	F3 = Winter bread Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P1 = no leg	R2 = Irrigation
83	Portugal-Murtaes_2021	Winter Bread Wheat	T1-F3-D0-C0-P1-R1	T1 = No Tillage	F3 = Winter bread Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P1 = no leg	R1 = Rainfed
84	Portugal-	Winter Bread Wheat	T1-F3-D0-C0-P1-R1	T1 = No Tillage	F3 = Winter bread Wheat	D0 = no Nitrogen	C0 = no cover	P1 = no leg	R1 = Rainfed

	Murtaes_2022					treatement	crop		
85	Portugal-Romeiras_2021	Winter Bread Wheat	T1-F3-D0-C0-P1-R2	T1 = No Tillage	F3 = Winter bread Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P1 = no leg	R2 = Irrigation
86	Portugal-TorreFigueiras_2021	Winter Bread Wheat	T1-F3-D0-C0-P1-R2	T1 = No Tillage	F3 = Winter bread Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P1 = no leg	R2 = Irrigation
87	Portugal-TorreFigueiras_2022	Winter Bread Wheat	T1-F3-D0-C0-P1-R2	T1 = No Tillage	F3 = Winter bread Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P1 = no leg	R2 = Irrigation
88	Rouit_2022	Winter Durum Wheat	T2-F1-D0-C0-P1-R2	T2 = Conventional Tillage	F1 = Winter Durum Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P1 = no leg	R2 = Irrigation
89	Spain-1_2021	Winter Bread Wheat	T1-F3-D0-C0-P1-R1	T1 = No Tillage	F3 = Winter bread Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P1 = no leg	R1 = Rainfed
90	Tunisia-SC_2021	Winter Durum Wheat	T2-F1-D0-C0-P1-R1	T2 = Conventional Tillage	F1 = Winter Durum Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P1 = no leg	R1 = Rainfed
91	Tunisia-SD_2021	Winter Durum Wheat	T1-F1-D0-C0-P1-R1	T1 = No Tillage	F1 = Winter Durum Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P1 = no leg	R1 = Rainfed
92	Tunisia-TCS_2021	Winter Durum Wheat	T1-F1-D0-C0-P1-R1	T1 = No Tillage	F1 = Winter Durum Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P1 = no leg	R1 = Rainfed
93	Vadon-Luz_2022	Winter Durum Wheat	T1-F4-D0-C2-P2-R1	T1 = No Tillage	F4 = Durum wheat and alfalfa associated	D0 = no Nitrogen treatement	C2 = associated	P2 = leg	R1 = Rainfed
94	Vadon-SF_2022	Winter Durum Wheat	T1-F5-D0-C1-P1-R1	T1 = No Tillage	F5 = Winter Durum Wheat and sorghum	D0 = no Nitrogen treatement	C1 = destroyed	P1 = no leg	R1 = Rainfed
95	Vernet - cama_2021	Winter Durum Wheat	T1-F1-D0-C0-P2-R1	T1 = No Tillage	F1 = Winter Durum Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P2 = leg	R1 = Rainfed
96	Vernet-Arb_2022	Winter Durum Wheat	T1-F1-D0-C0-P2-R2	T1 = No Tillage	F1 = Winter Durum Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P2 = leg	R2 = Irrigation
97	Vernet-DW_2021	Winter Durum Wheat	T2-F1-D0-C0-P2-R2	T2 = Conventional Tillage	F1 = Winter Durum Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P2 = leg	R2 = Irrigation
98	Vernet-Irr_2022	Winter Durum Wheat	T1-F1-D0-C0-P2-R2	T1 = No Tillage	F1 = Winter Durum Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P2 = leg	R2 = Irrigation
99	Vernet-Sec_2022	Winter Durum Wheat	T1-F1-D0-C0-P2-R1	T1 = No Tillage	F1 = Winter Durum Wheat	D0 = no Nitrogen treatement	C0 = no cover crop	P2 = leg	R1 = Rainfed

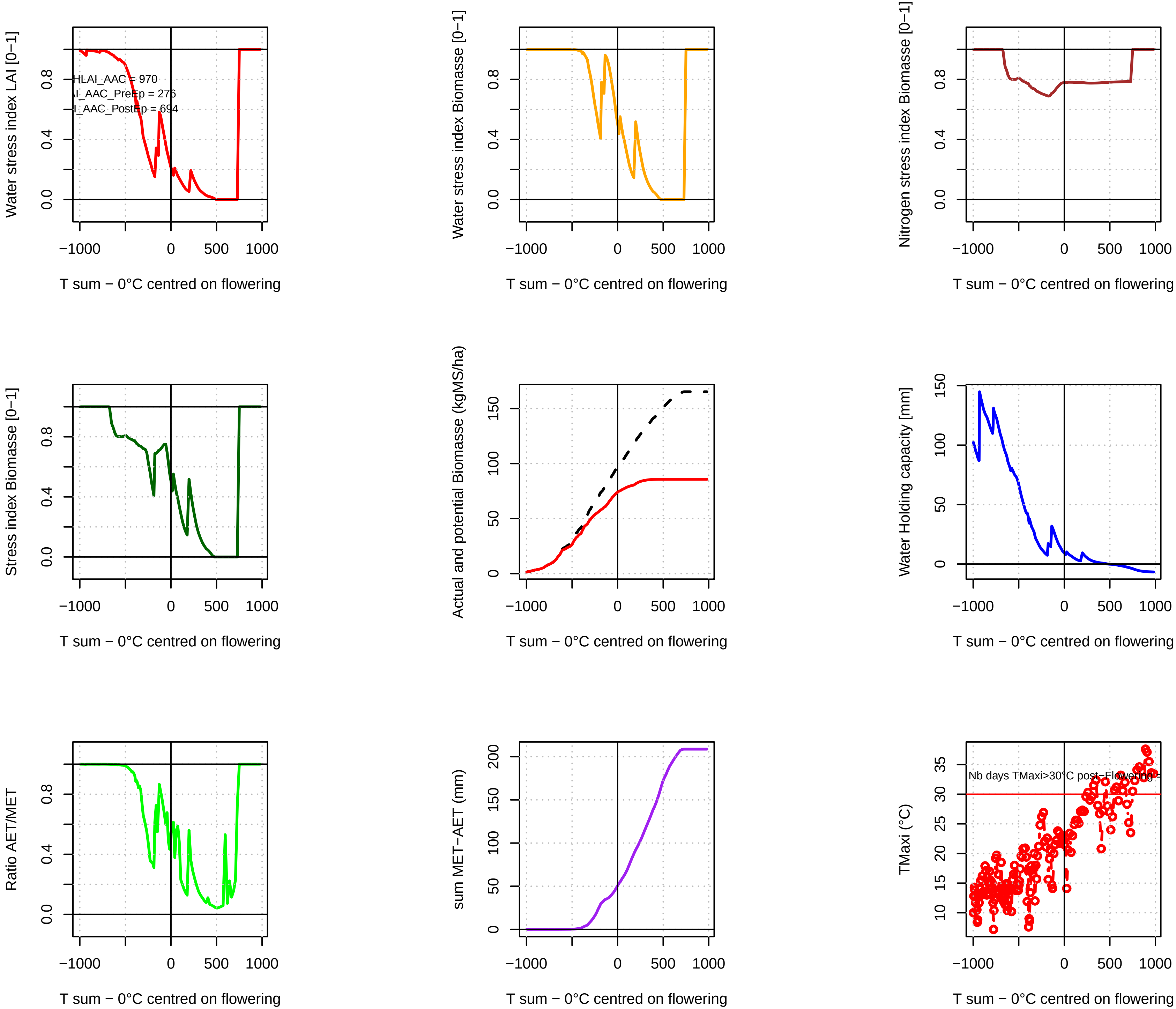
6. Annexe agroclimatic indicators and patterns

(Agroclim_all.pdf)

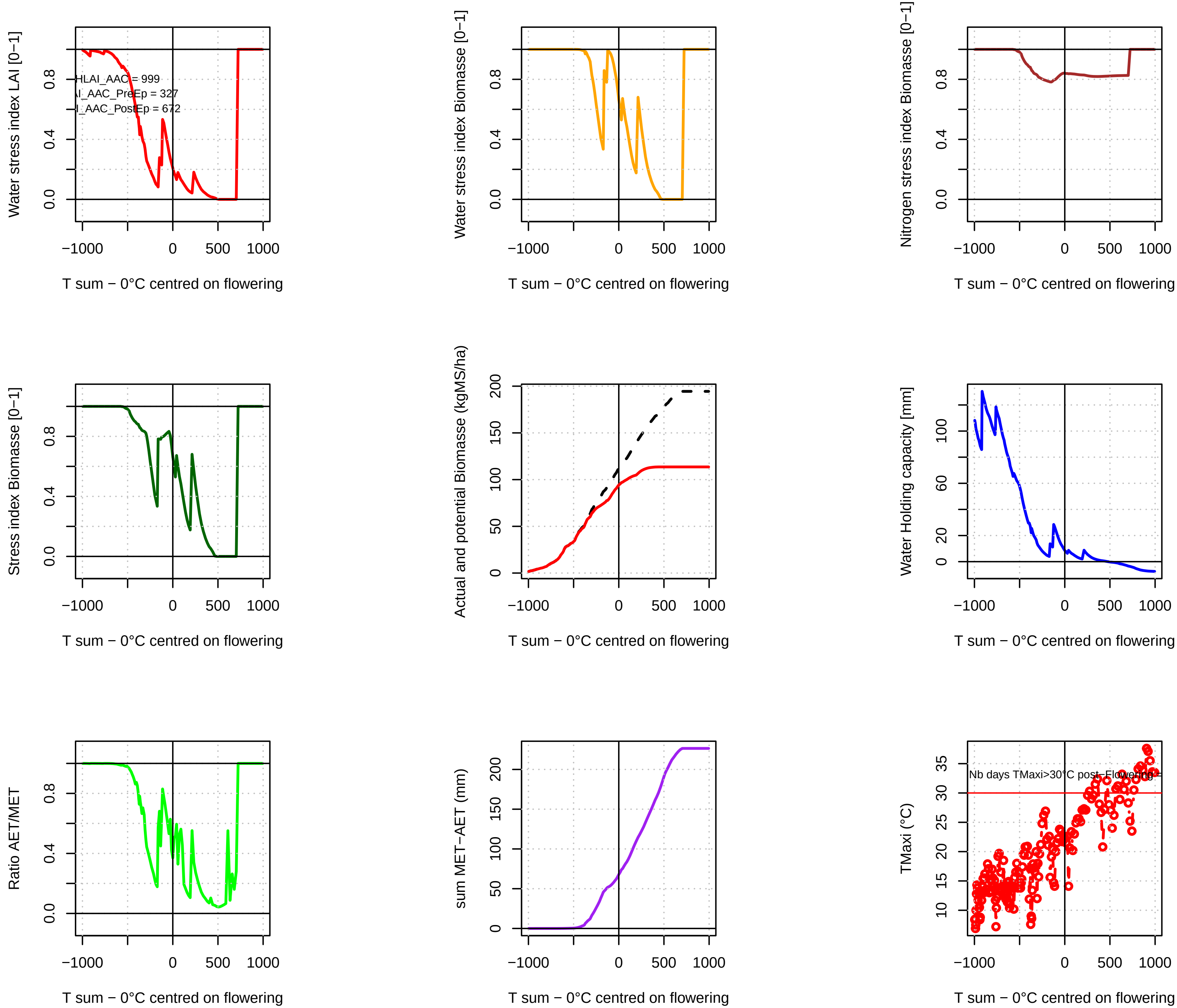
France−OraB21_2022_T1−F8−D0−C1−P1−R1



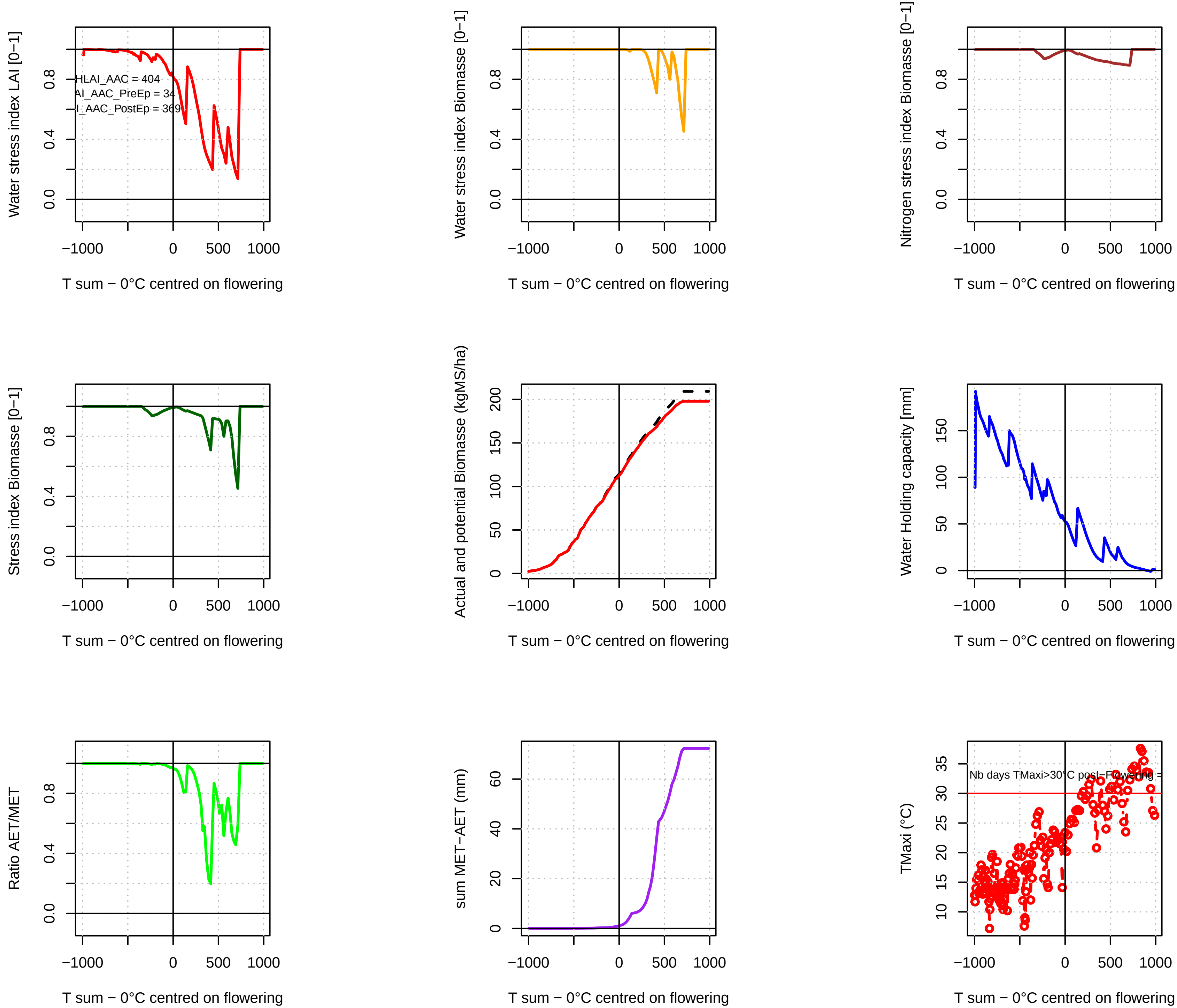
France−OraB23_2022_T1−F1−D0−C0−P1−R1



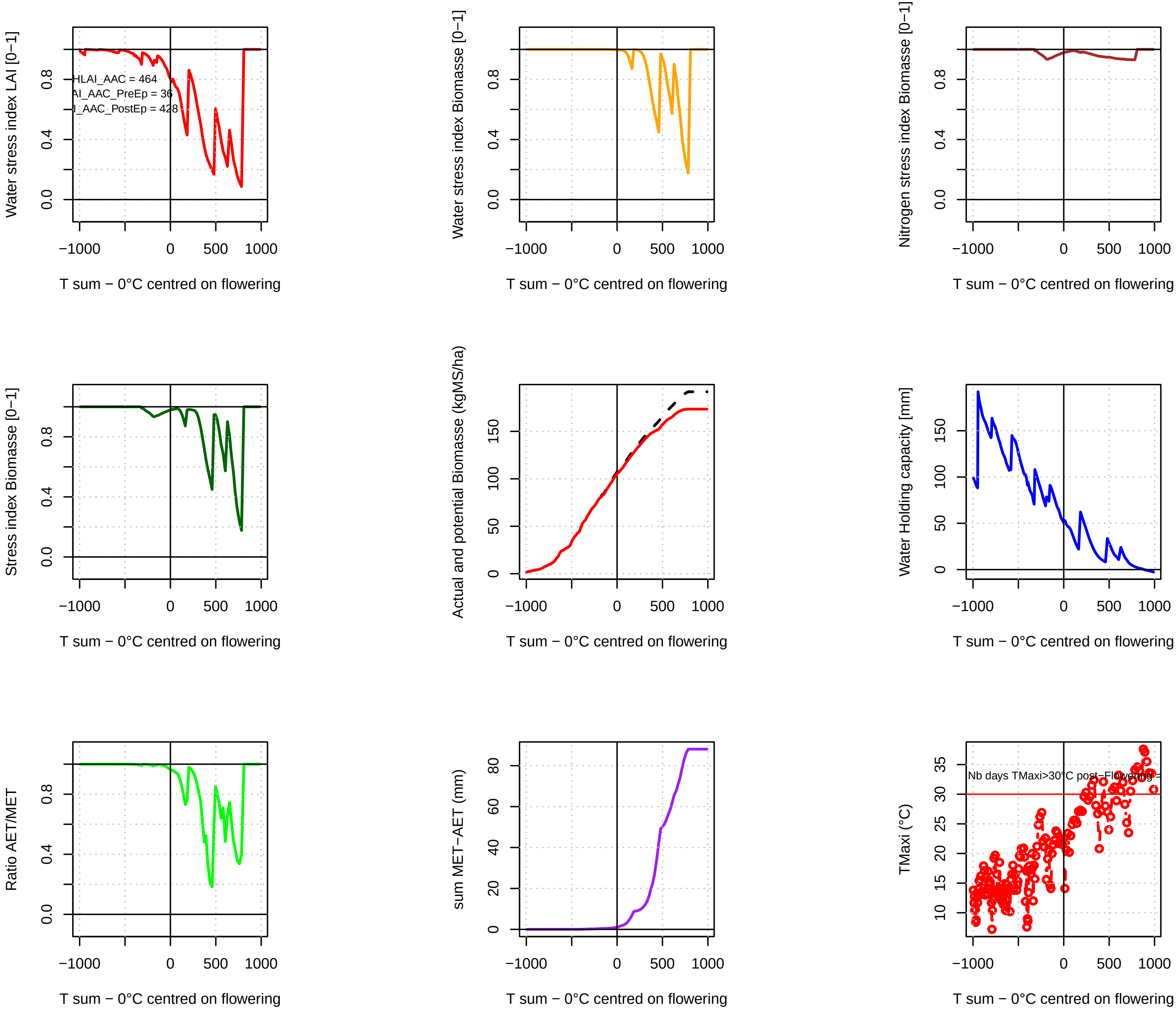
France−OraB25_2022_T1−F3−D0−C0−P1−R1

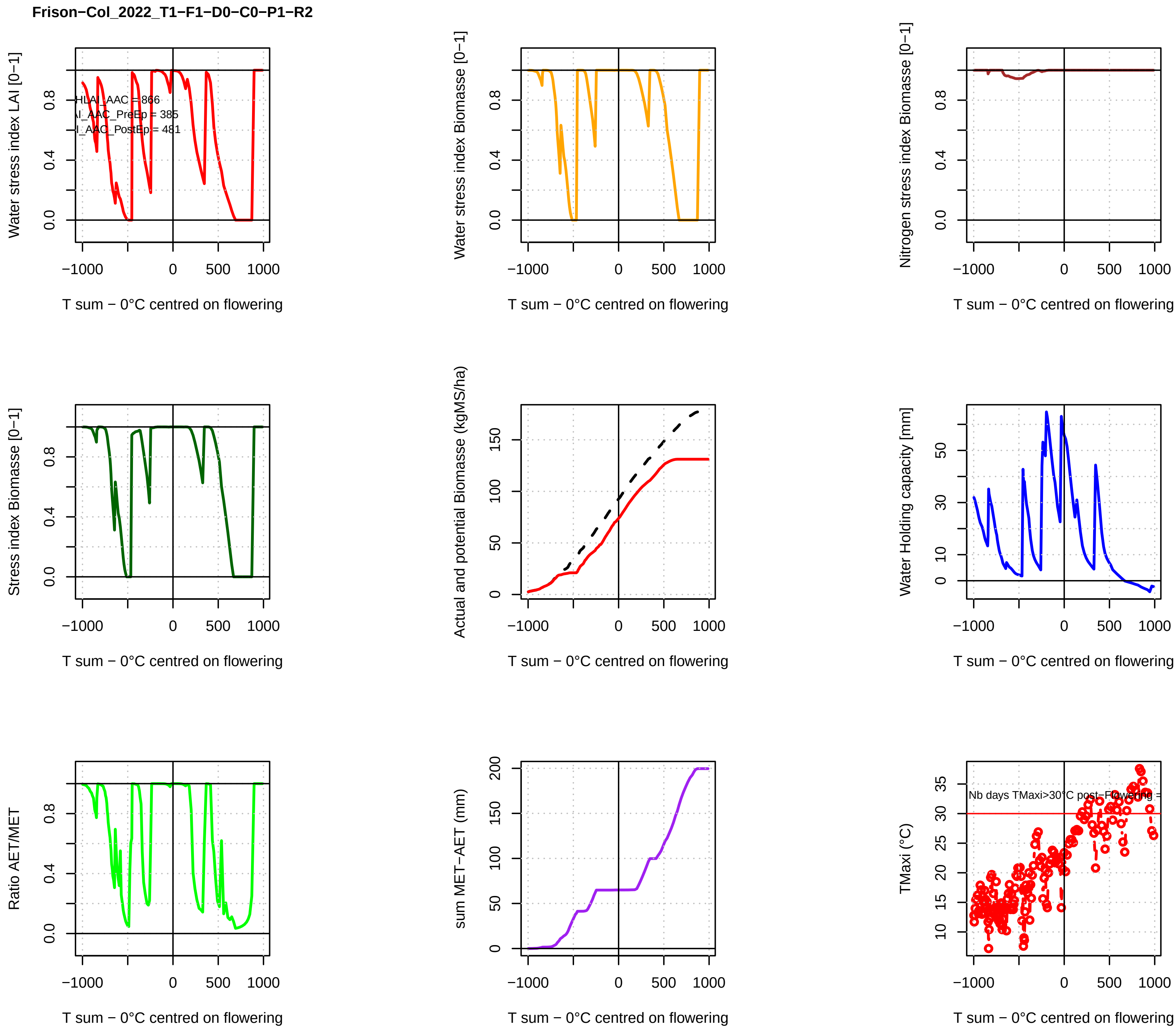


France−Oral1−I2_2022_T1−F3−D0−C0−P2−R2

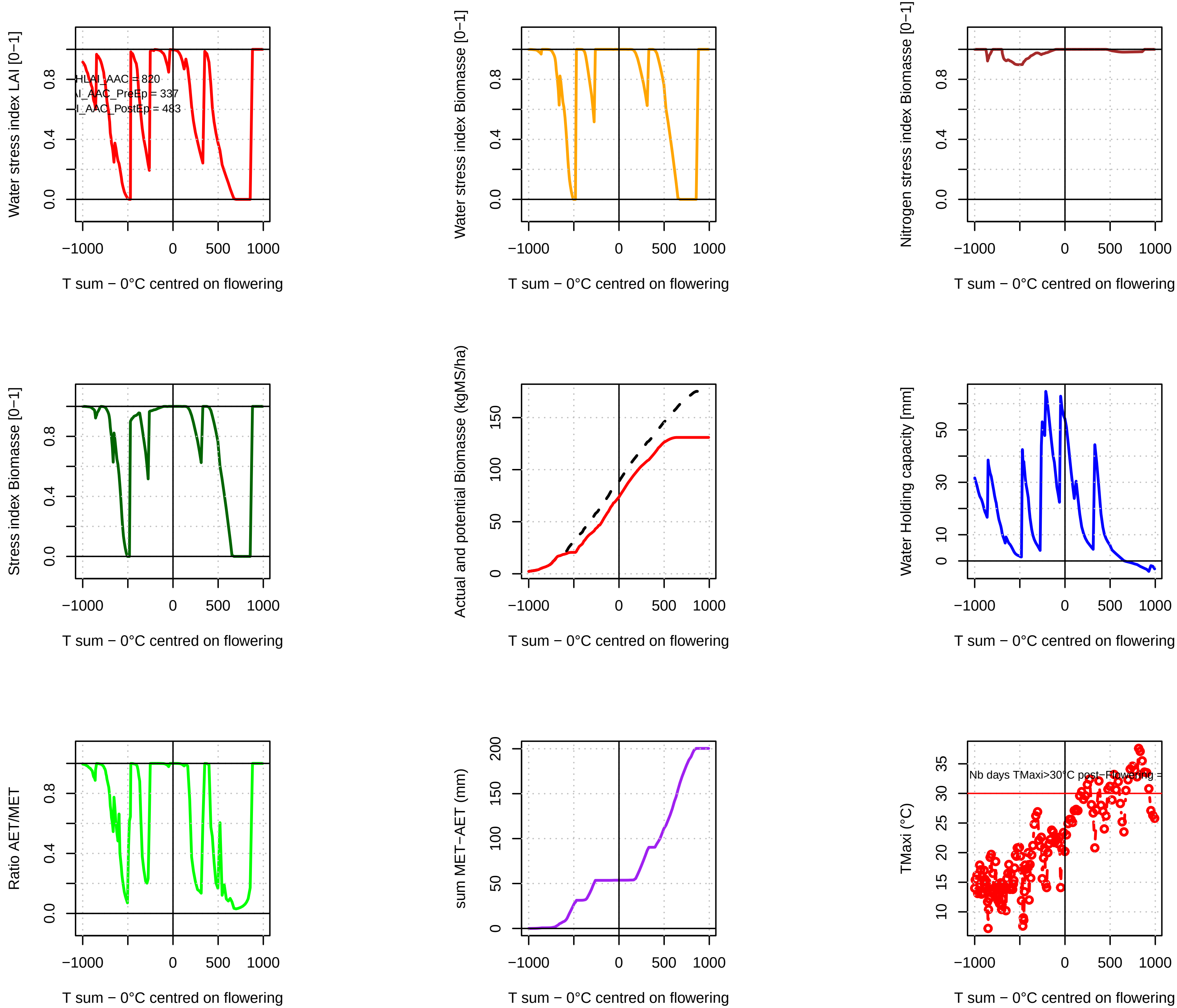


France−Oral3−I4_2022_T1−F1−D0−C0−P2−R2

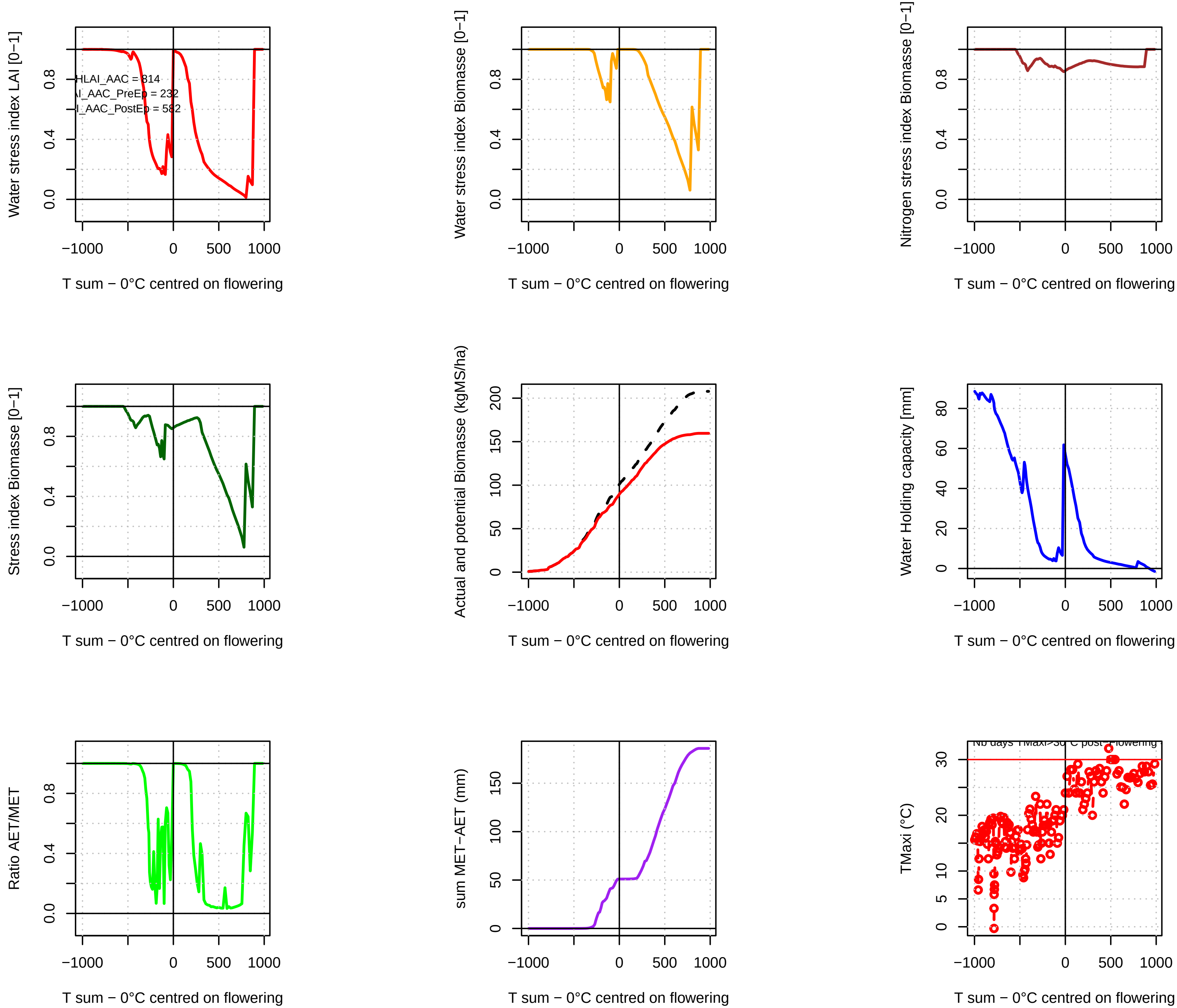



Frison−Col_2022_T1−F1−D0−C0−P1−R2
Water stress index LAI [0−1]
HLAI_AAC = 866
I_AAC_PreEp = 385
I_AAC_PostEp = 481
Water stress index Biomasse [0−1]
Nitrogen stress index Biomasse [0−1]
Stress index Biomasse [0−1]
Actual and potential Biomasse (kgMS/ha)
Water Holding capacity [mm]
Ratio AET/MET
sum MET−AET (mm)
TMaxi (°C)
Nb days TMaxi>30°C post−Flowering =
T sum − 0°C centred on flowering
−1000
0
500
1000

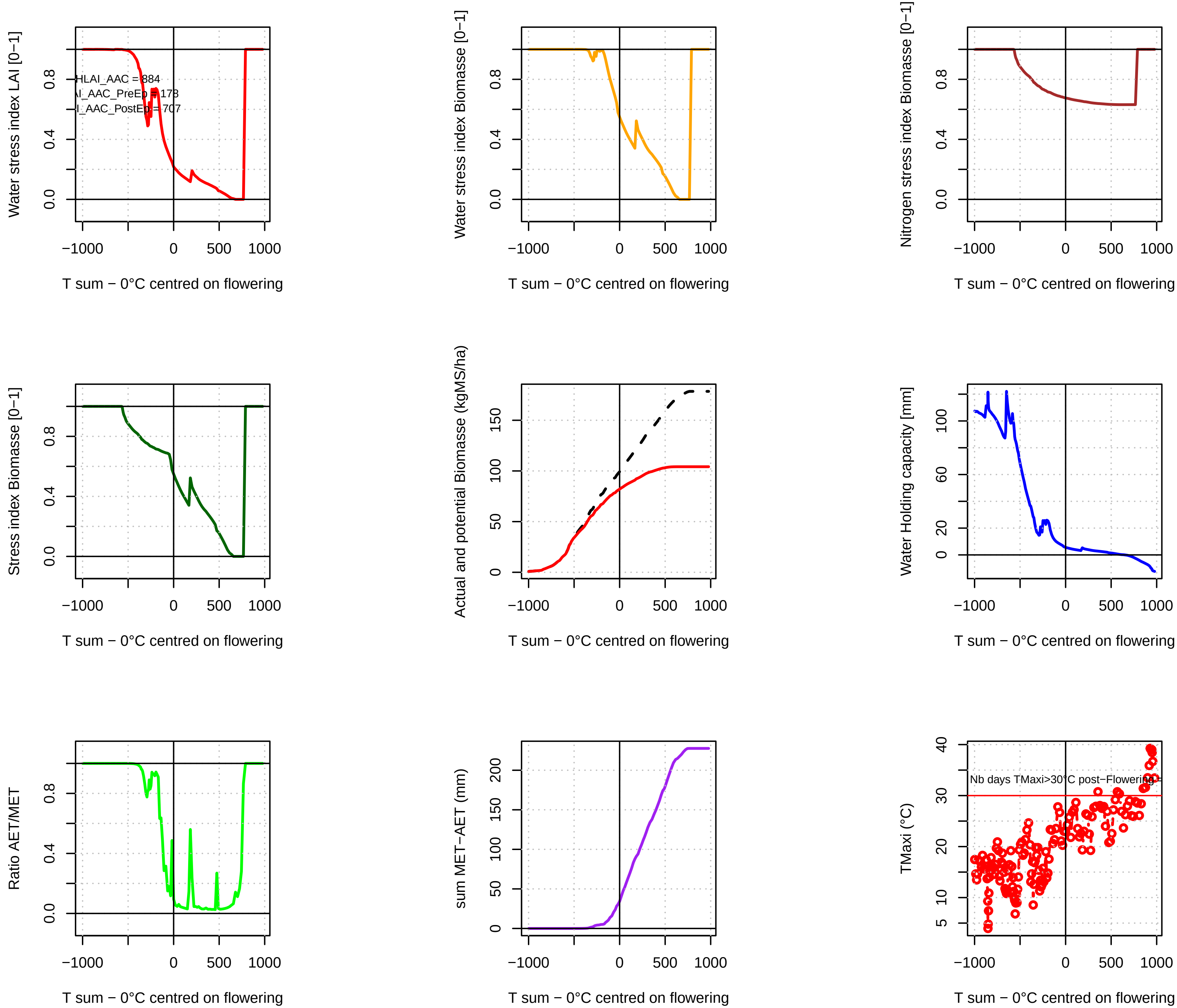
Frison−Mai_2022_T1−F1−D0−C0−P1−R2



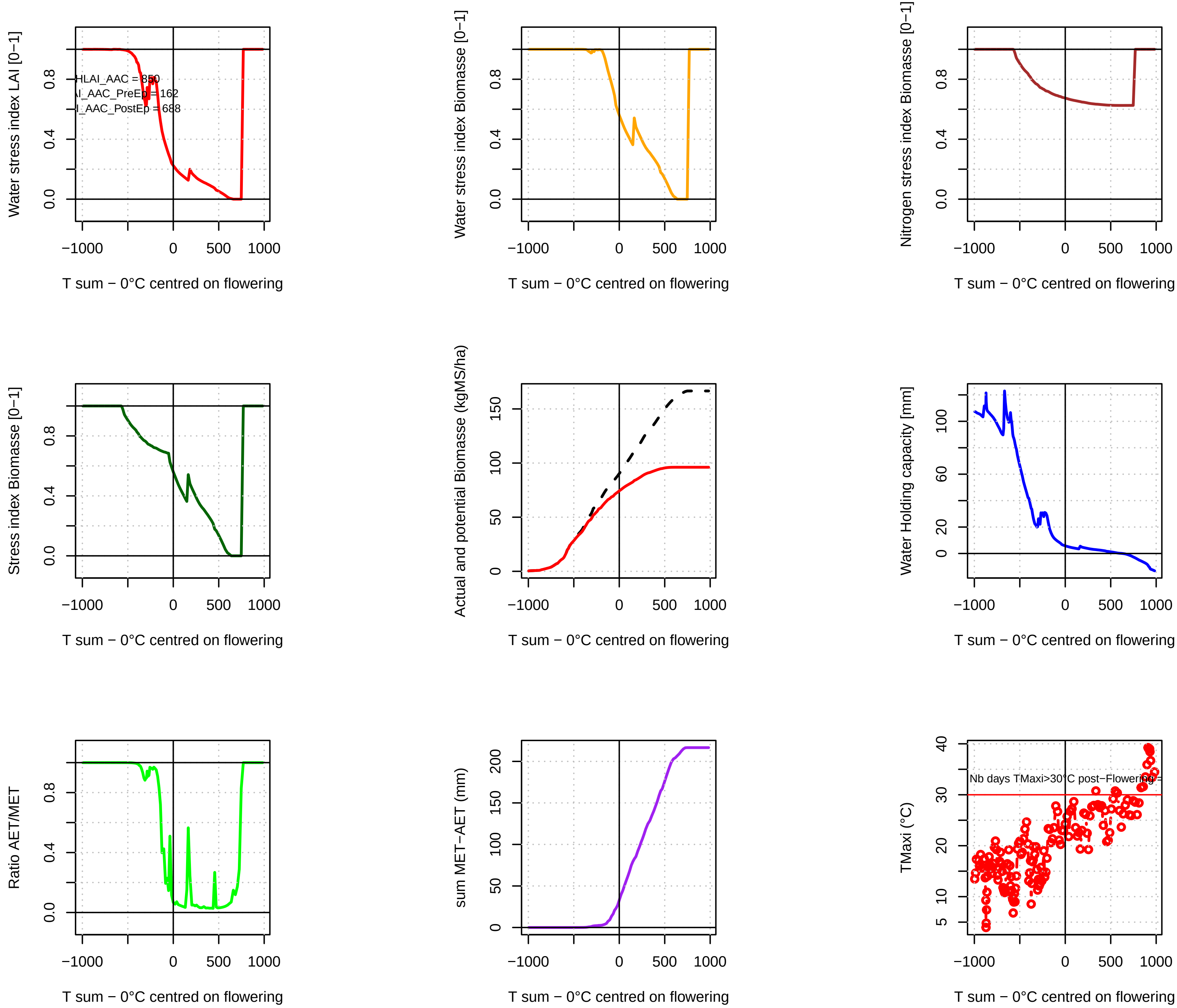
Greece−Thes_2021_T2−F3−D0−C0−P1−R1

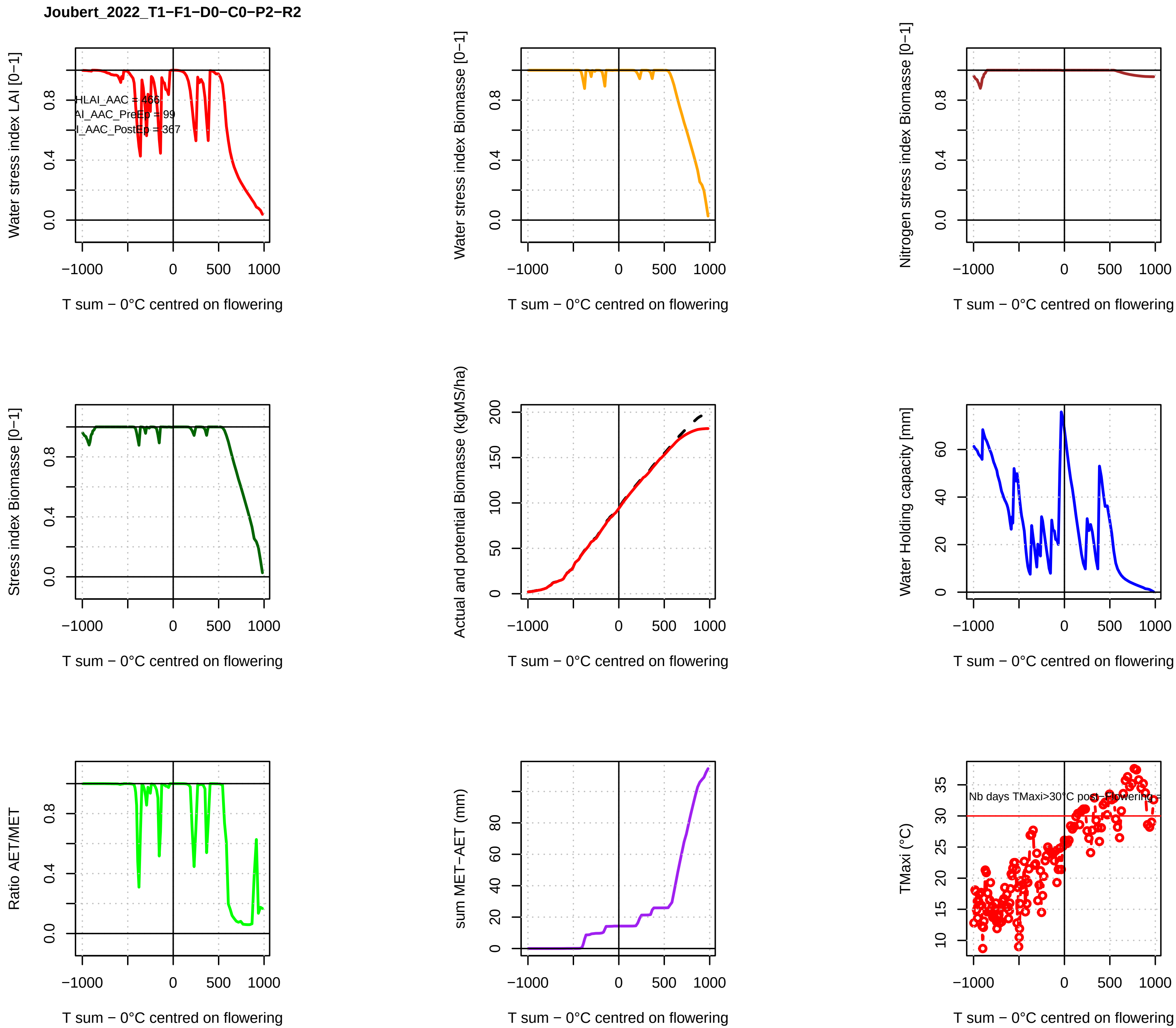


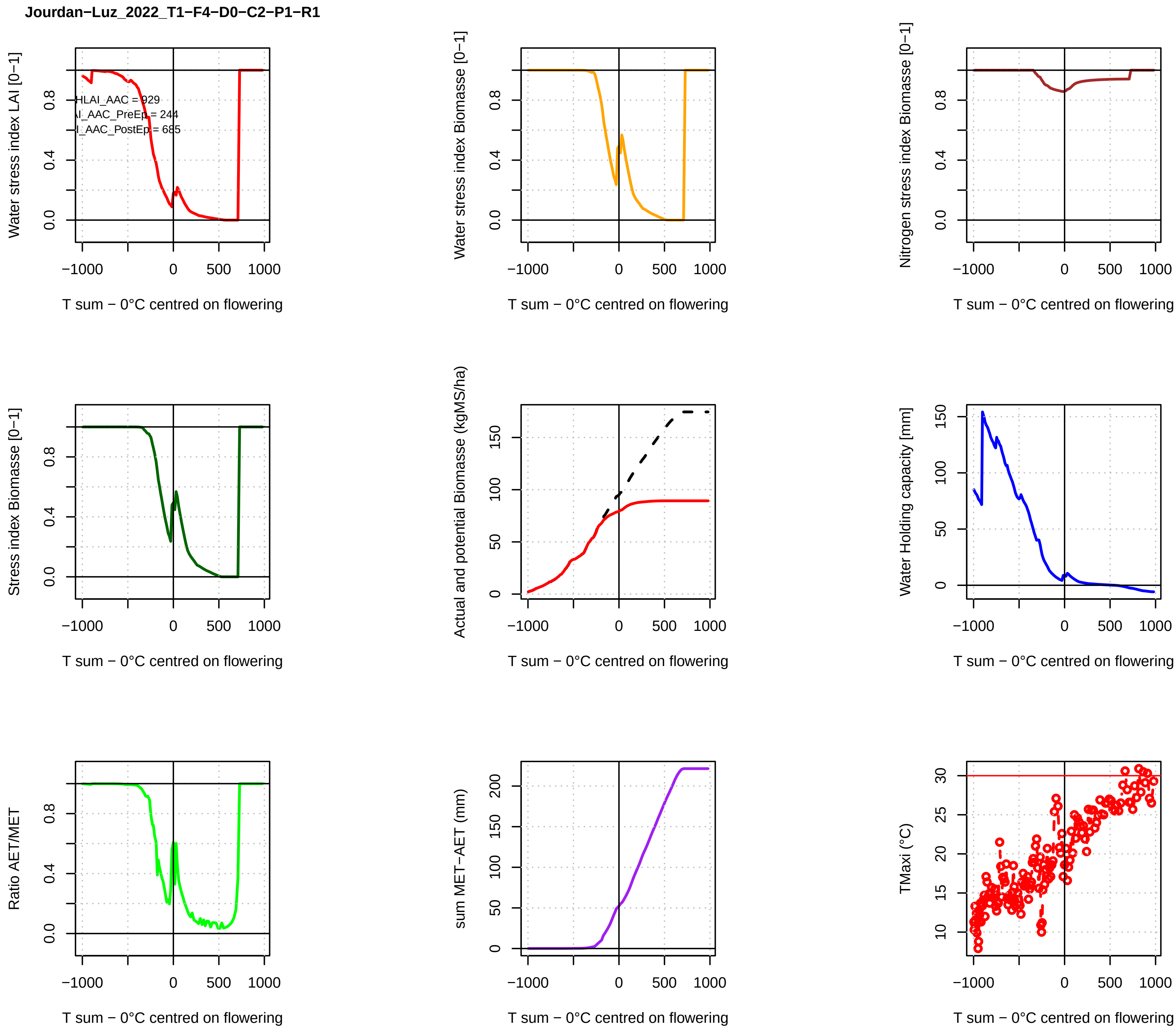
Italy−Sfinge1_2021_T2−F1−D0−C0−P1−R1



Italy−Sfinge2_2021_T2−F1−D0−C0−P1−R1

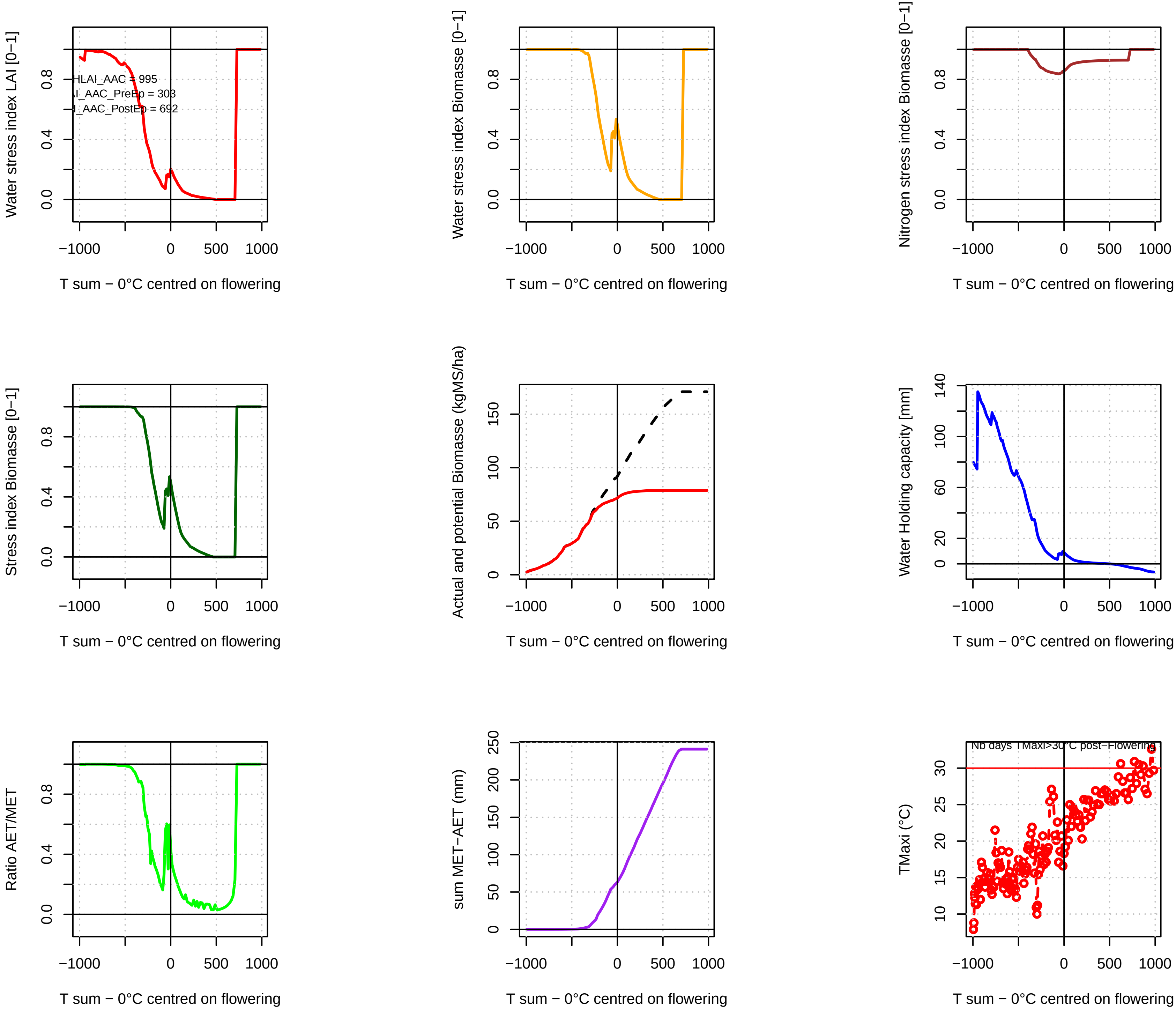



Joubert_2022_T1−F1−D0−C0−P2−R2
Water stress index LAI [0−1]
HLAI_AAC = 466
AI_AAC_PreEp = 99
I_AAC_PostEp = 367
Water stress index Biomasse [0−1]
Nitrogen stress index Biomasse [0−1]
Stress index Biomasse [0−1]
Actual and potential Biomasse (kgMS/ha)
Water Holding capacity [mm]
Ratio AET/MET
sum MET−AET (mm)
TMaxi (°C)
Nb days TMaxi>30°C post−Flowering =
T sum − 0°C centred on flowering
−1000
0
500
1000

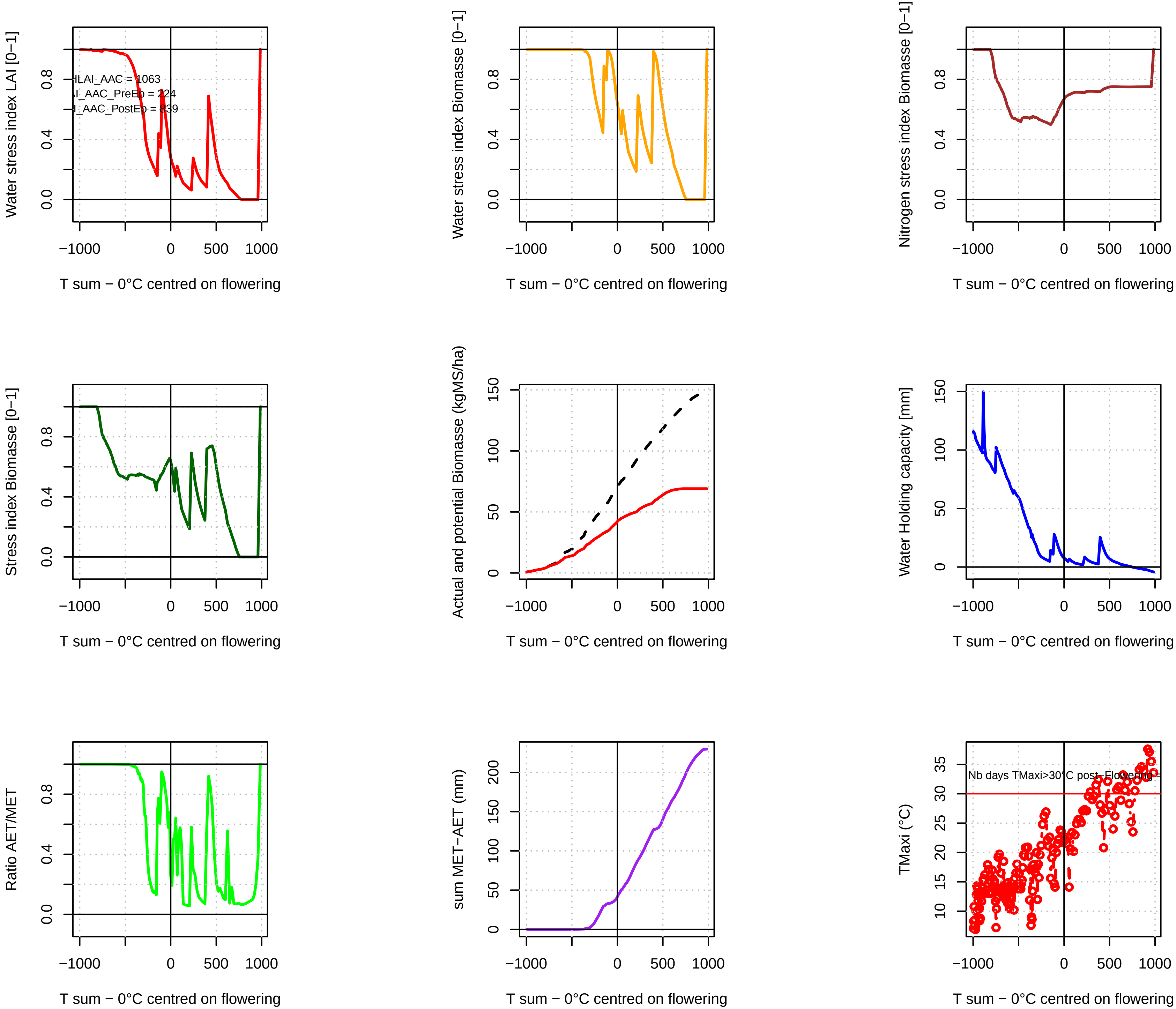


Jourdan−Luz_2022_T1−F4−D0−C2−P1−R1
Water stress index LAI [0−1]
HLAI_AAC = 929
I_AAC_PreEp = 244
I_AAC_PostEp = 685
Water stress index Biomasse [0−1]
Nitrogen stress index Biomasse [0−1]
Stress index Biomasse [0−1]
Actual and potential Biomasse (kgMS/ha)
Water Holding capacity [mm]
Ratio AET/MET
sum MET−AET (mm)
TMaxi (°C)
T sum − 0°C centred on flowering
0.0
0.4
0.8
0
50
100
150
200
10
15
20
25
30
−1000
500
1000

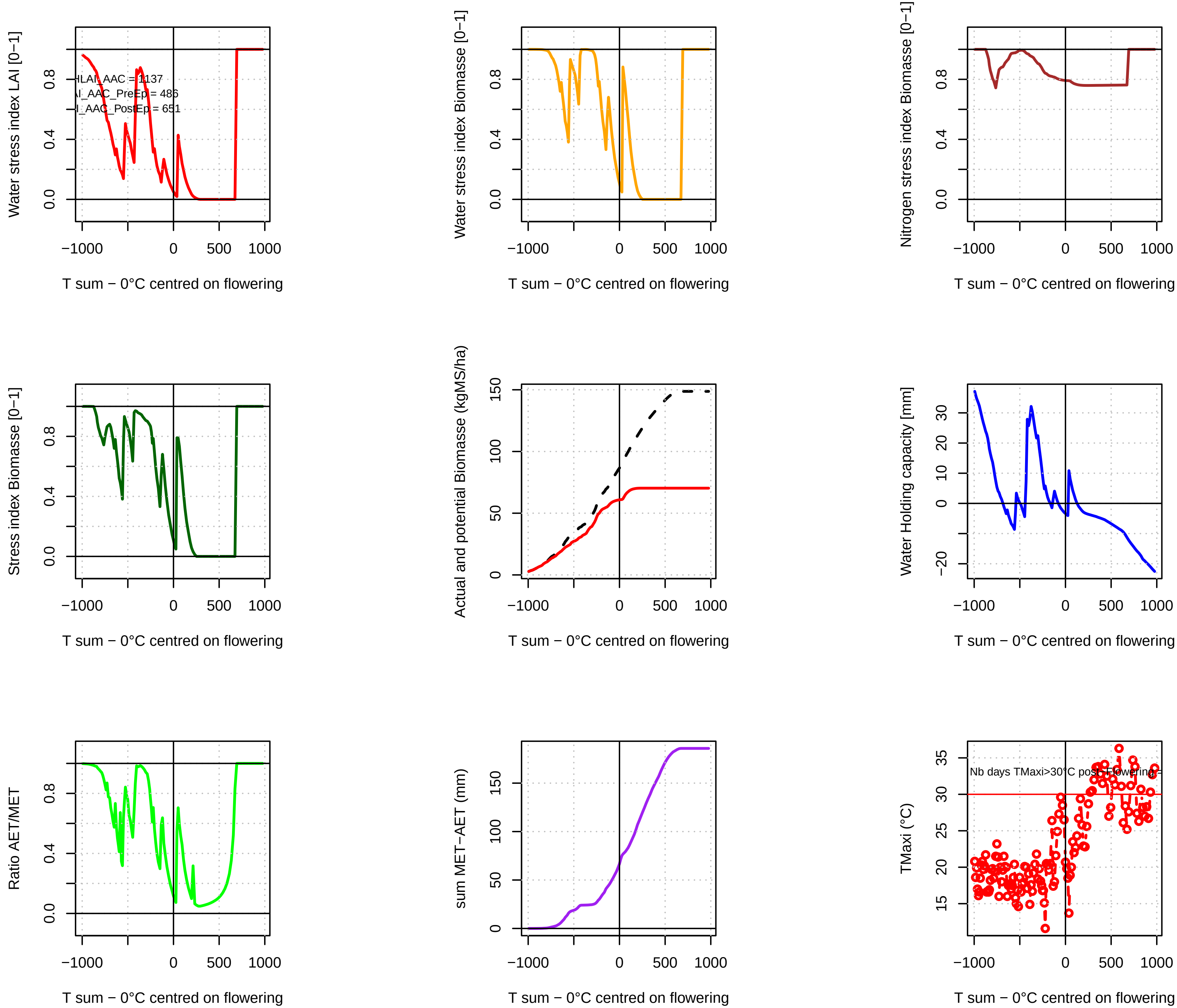
Jourdan−SF_2022_T1−F5−D0−C1−P1−R1



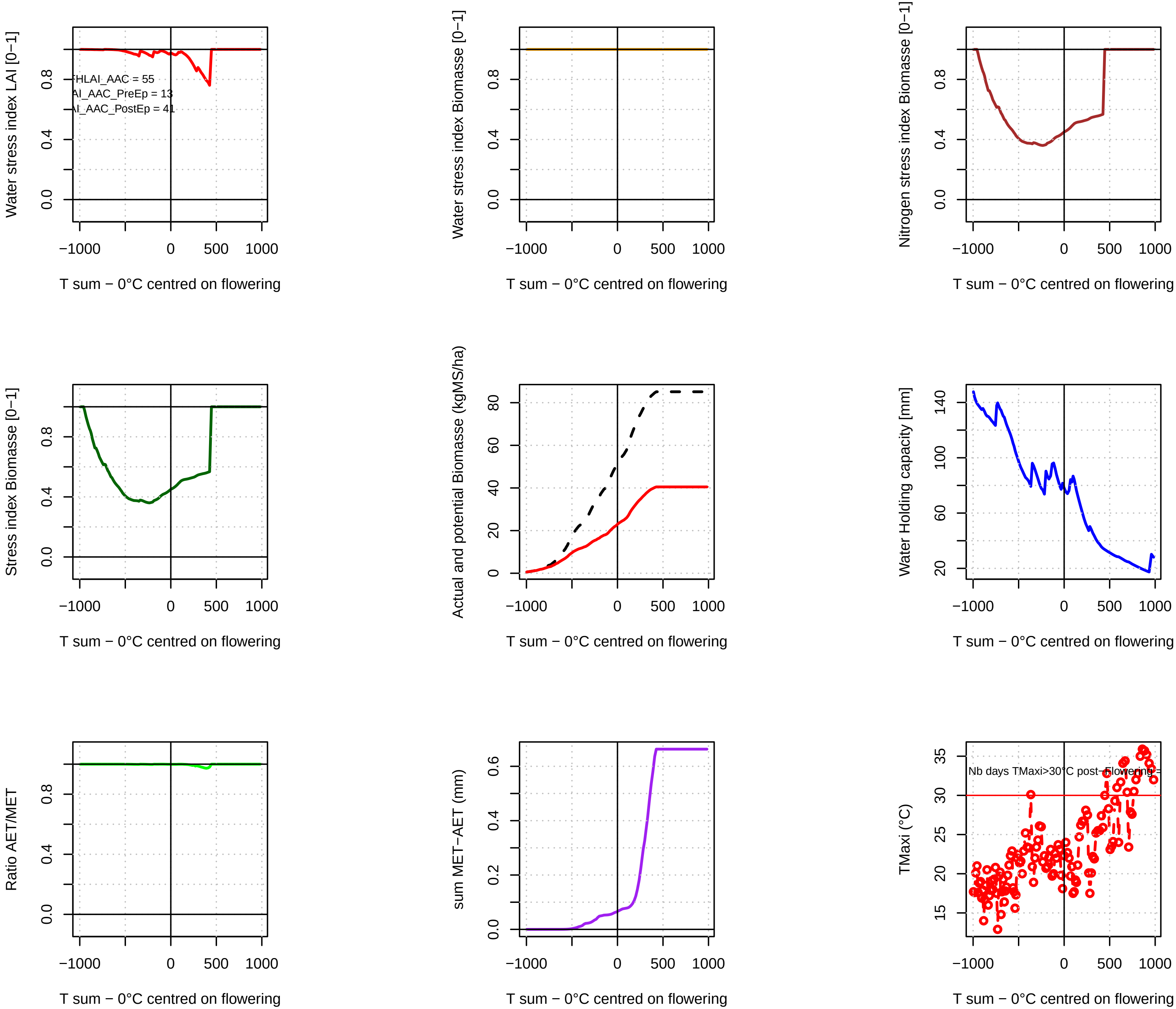
Moullet−Tou_2022_T1−F1−D0−C0−P1−R1



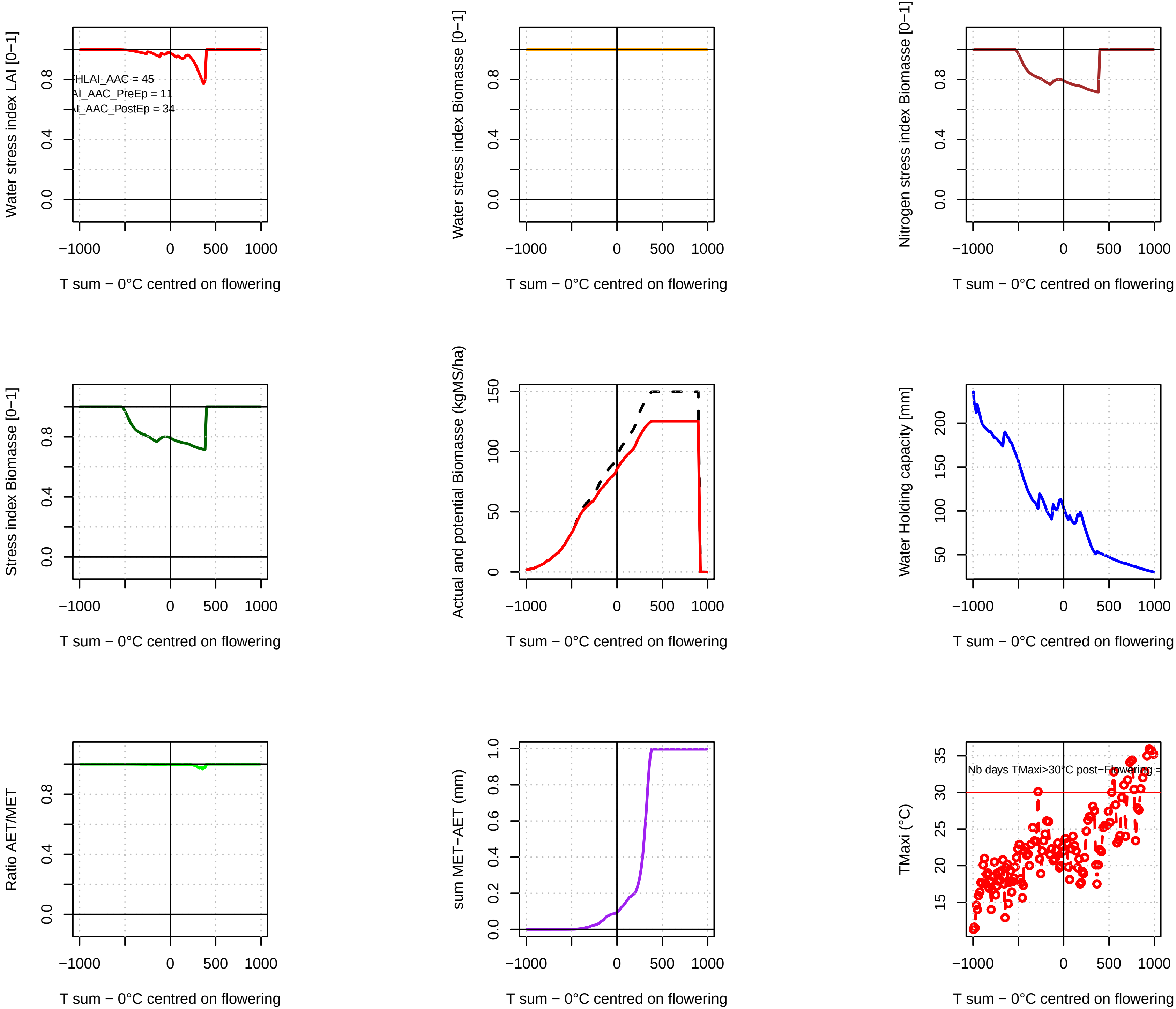
Portugal−Comenda_2022_T1−F1−D0−C0−P1−R1



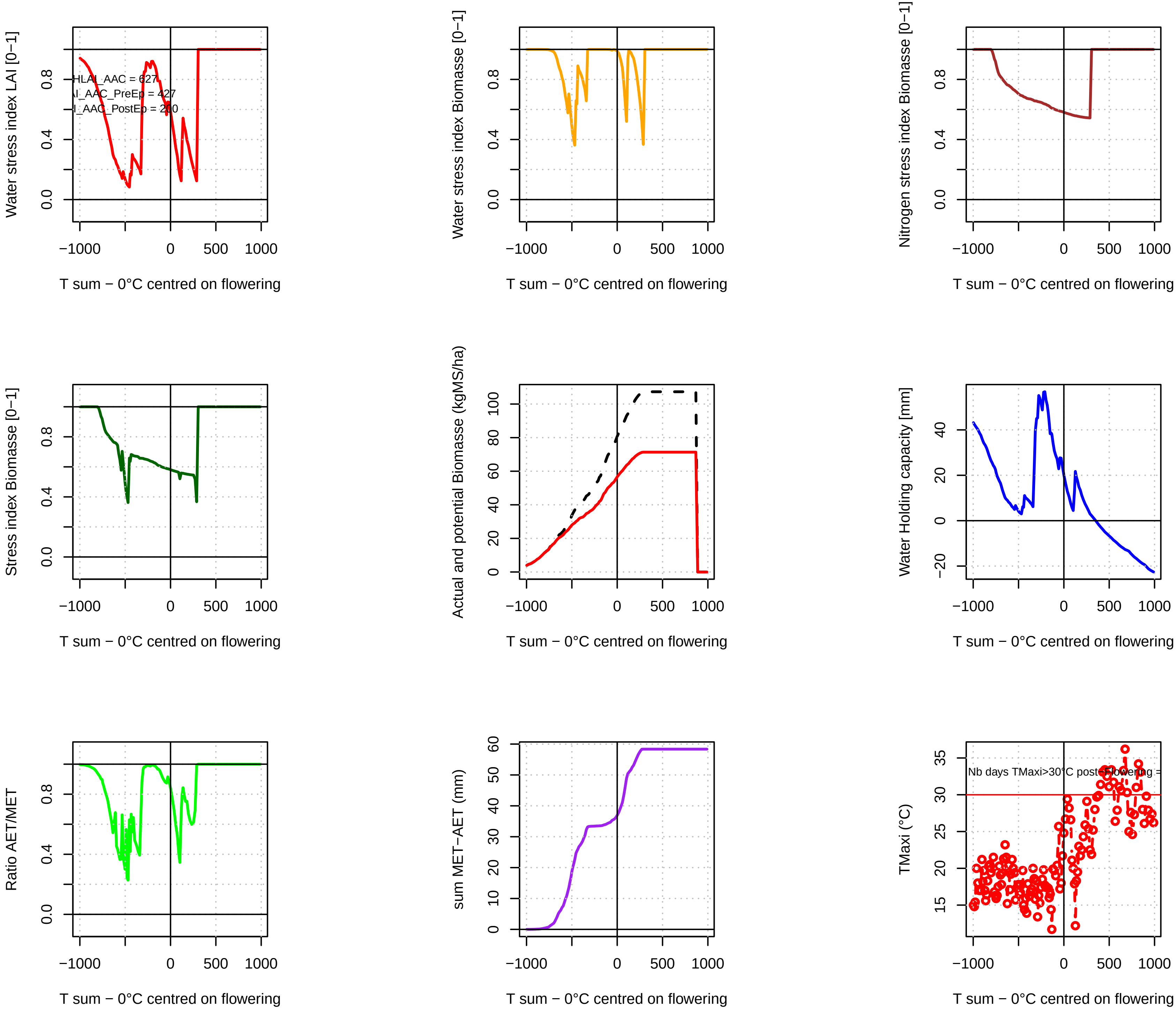
Portugal−Melinho_2021_T1−F3−D0−C0−P1−R2



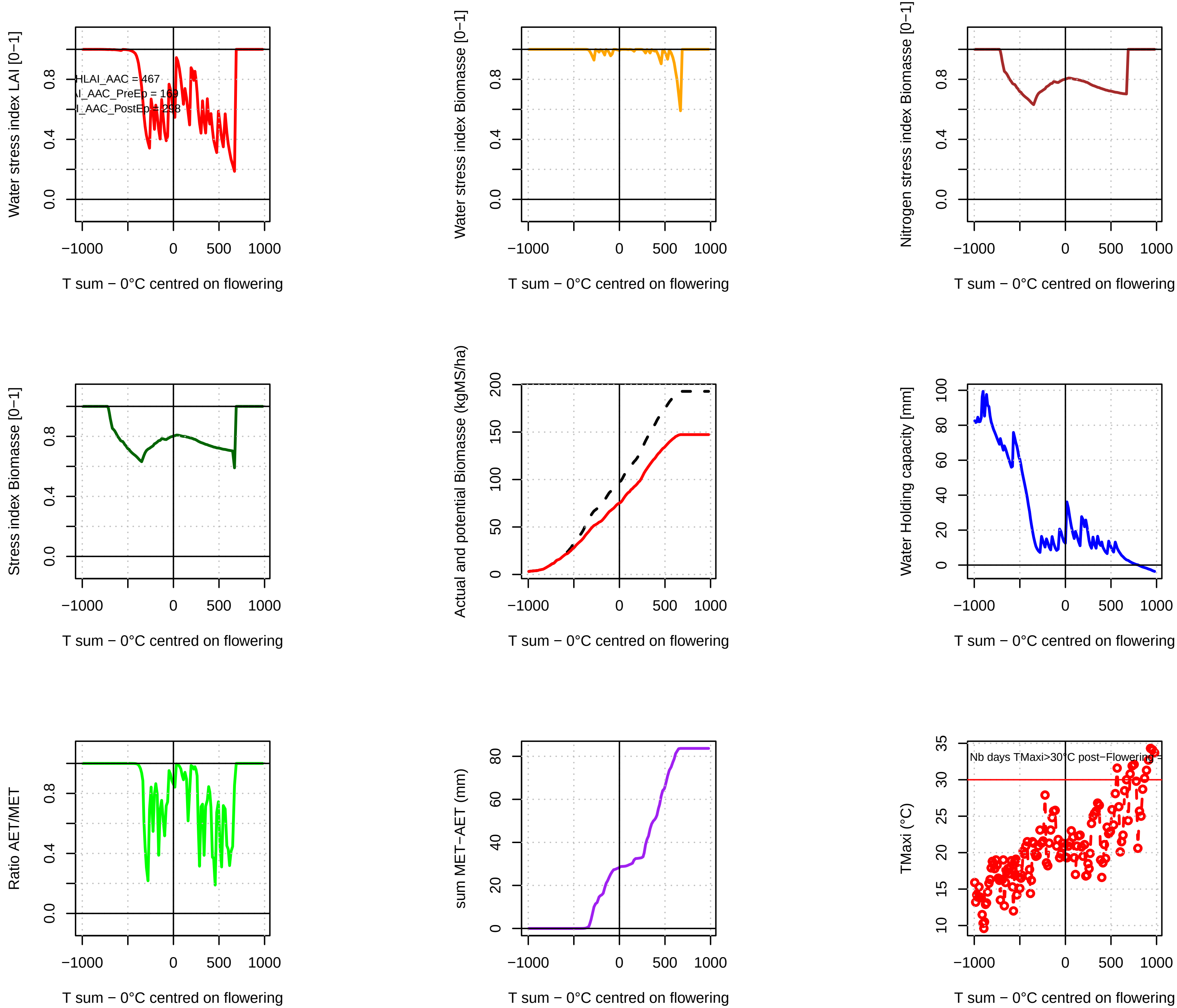
Portugal−Murtaes_2021_T1−F3−D0−C0−P1−R1



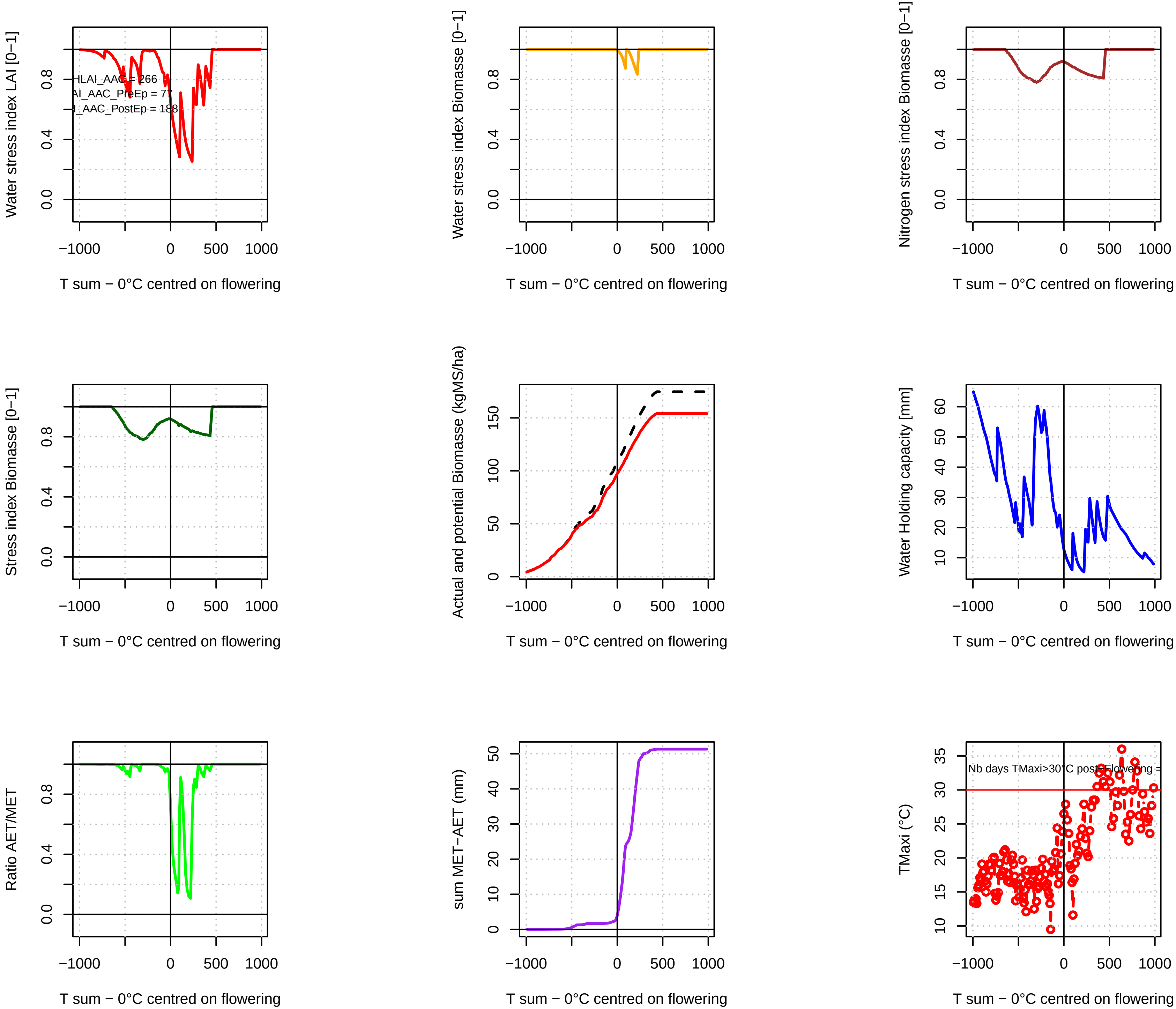
Portugal−Murtaes_2022_T1−F3−D0−C0−P1−R1

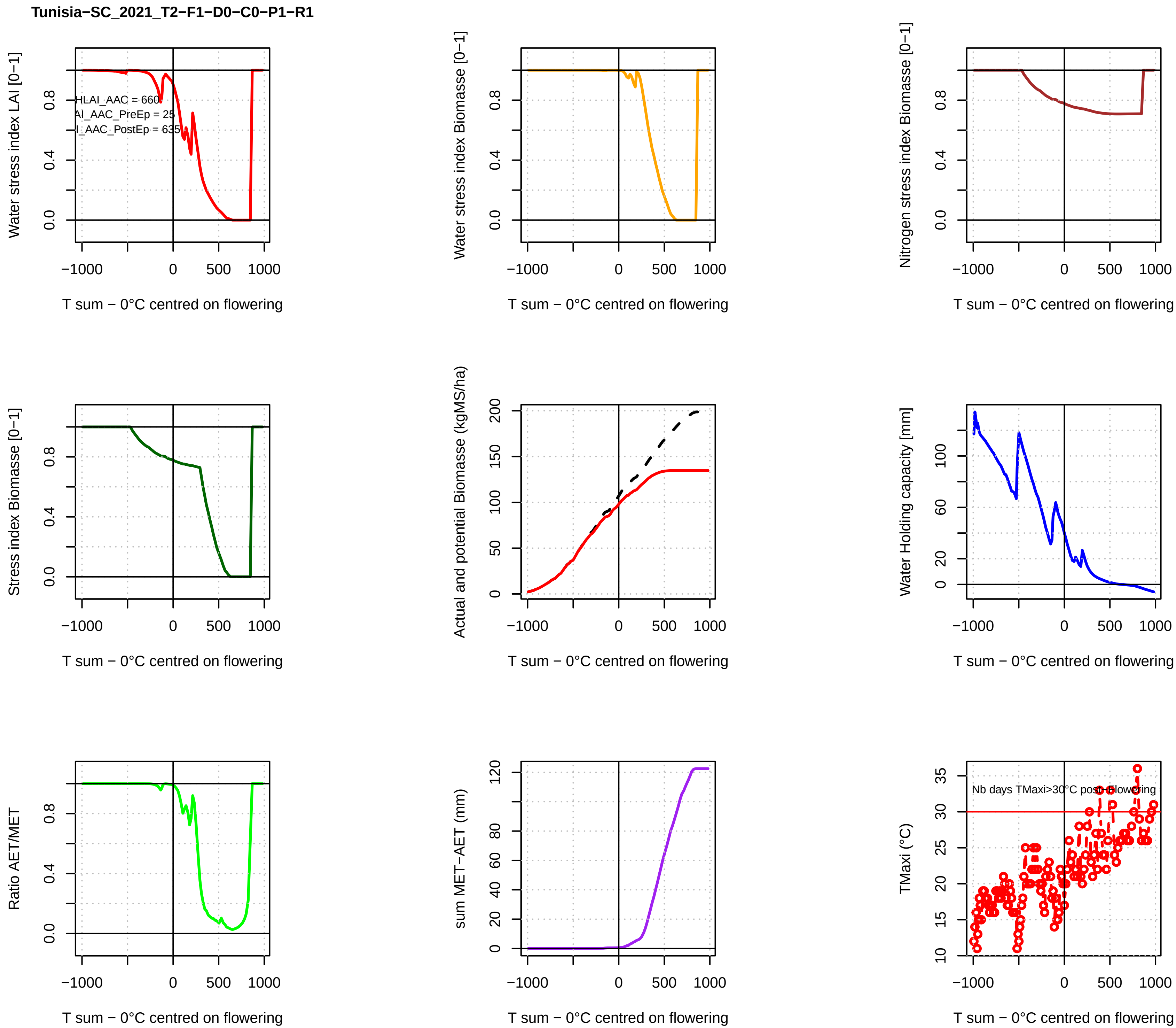


Portugal−TorreFigueiras_2021_T1−F3−D0−C0−P1−R2

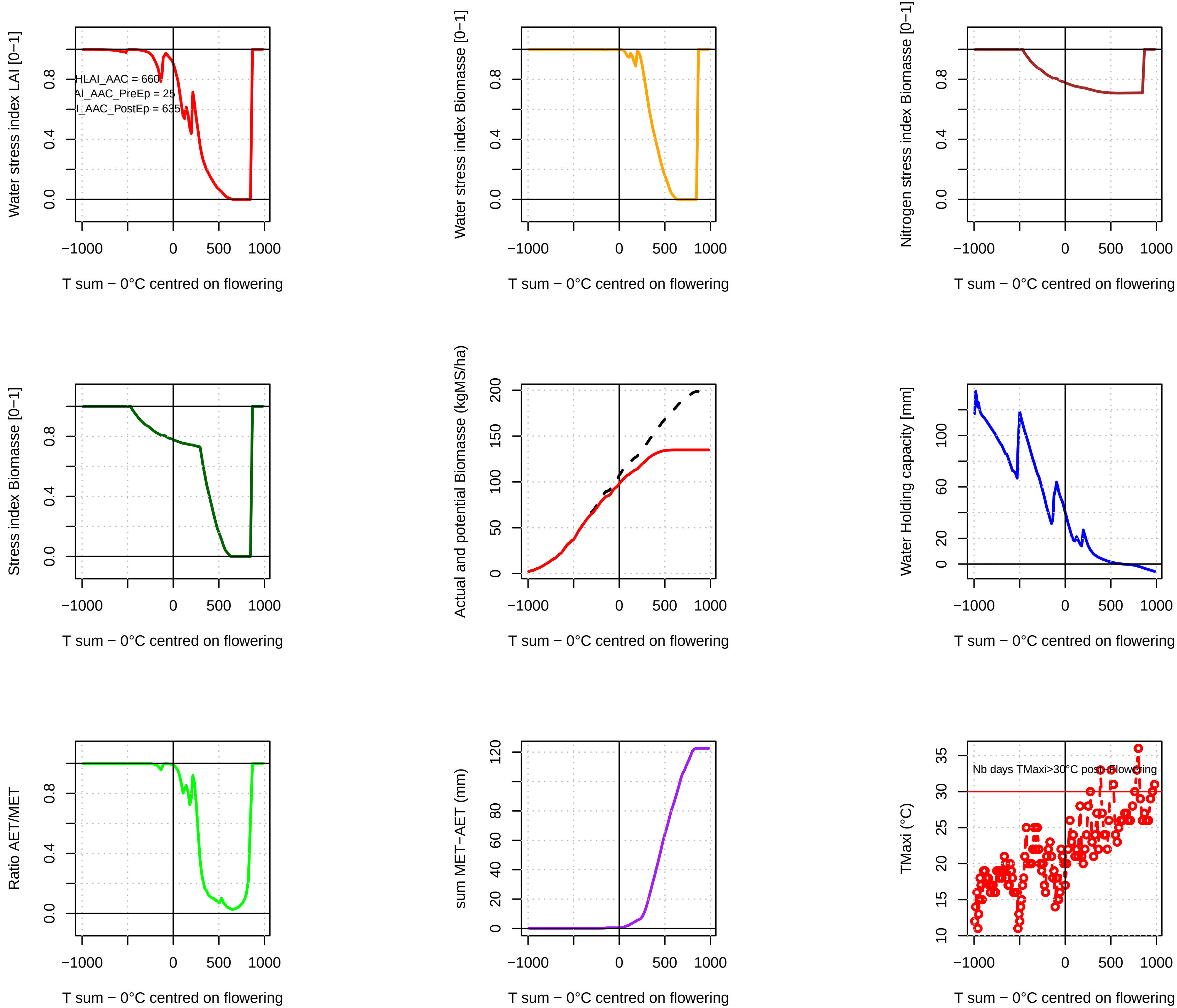


Portugal−TorreFigueiras_2022_T1−F3−D0−C0−P1−R2

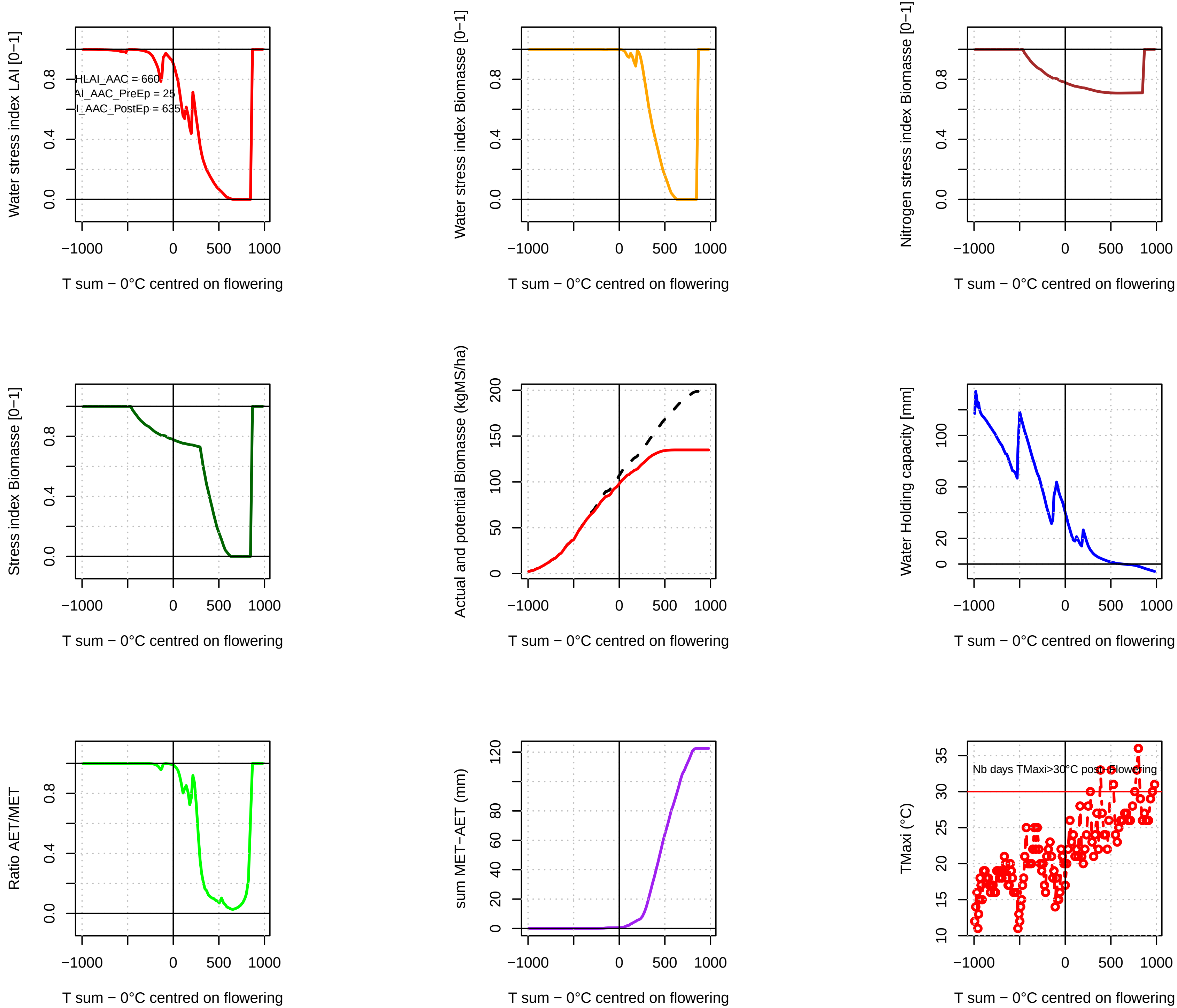



Tunisia−SC_2021_T2−F1−D0−C0−P1−R1
Water stress index LAI [0−1]
HLAI_AAC = 660
AI_AAC_PreEp = 25
I_AAC_PostEp = 635
Water stress index Biomasse [0−1]
Nitrogen stress index Biomasse [0−1]
Stress index Biomasse [0−1]
Actual and potential Biomasse (kgMS/ha)
Water Holding capacity [mm]
Ratio AET/MET
sum MET−AET (mm)
TMaxi (°C)
Nb days TMaxi>30°C post-flowering
T sum − 0°C centred on flowering

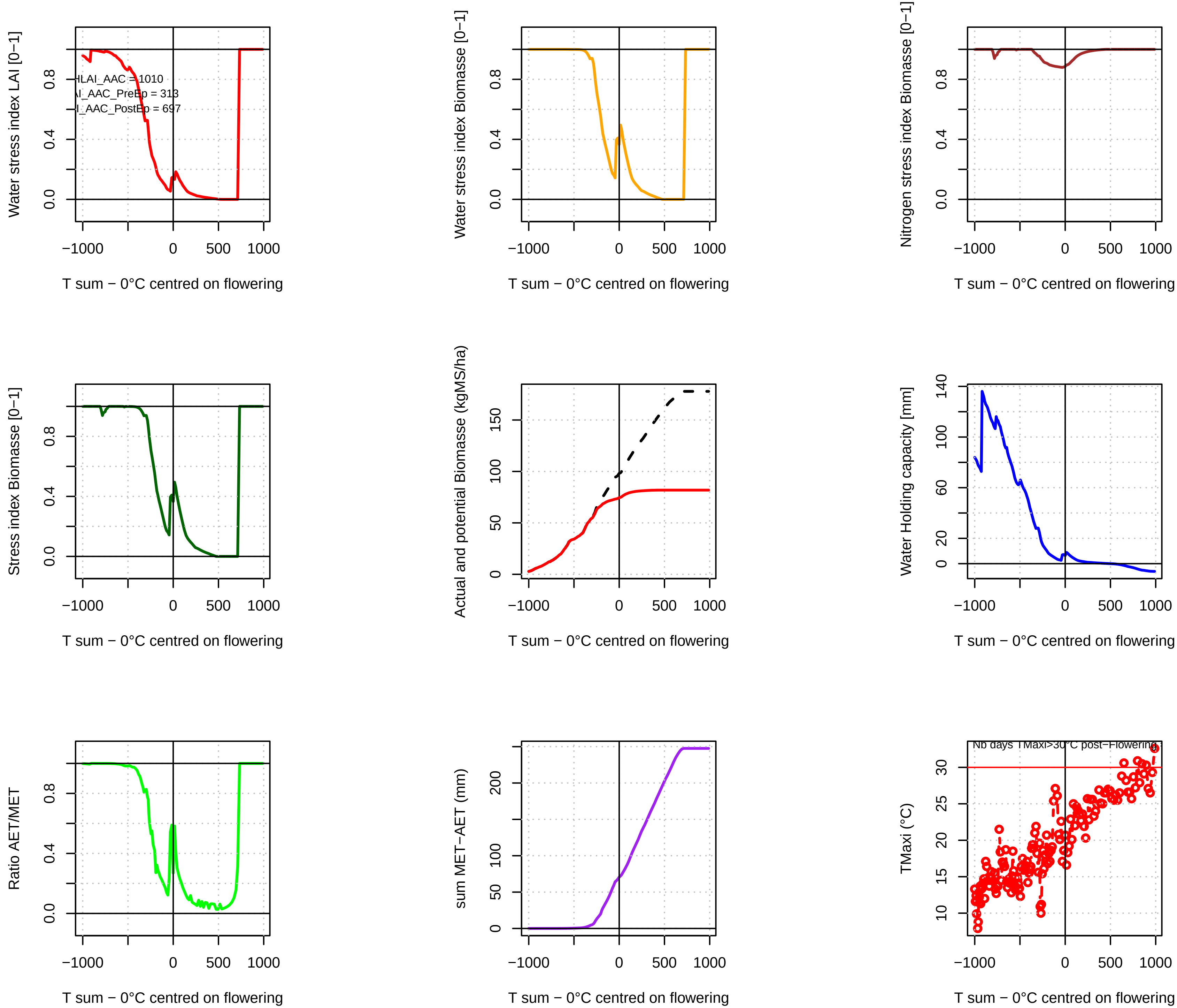
Tunisia−SD_2021_T1−F1−D0−C0−P1−R1

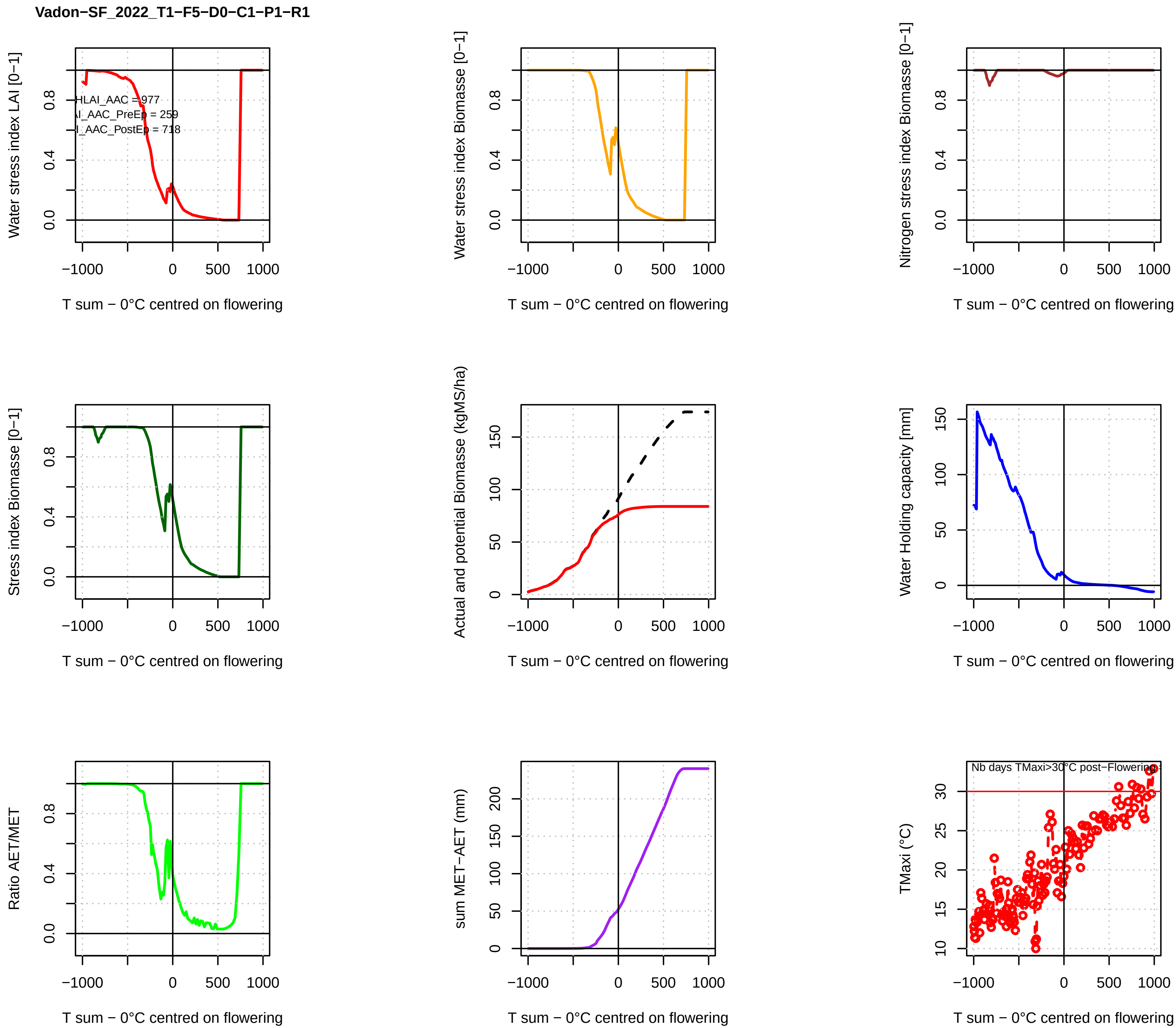


Tunisia−TCS_2021_T1−F1−D0−C0−P1−R1

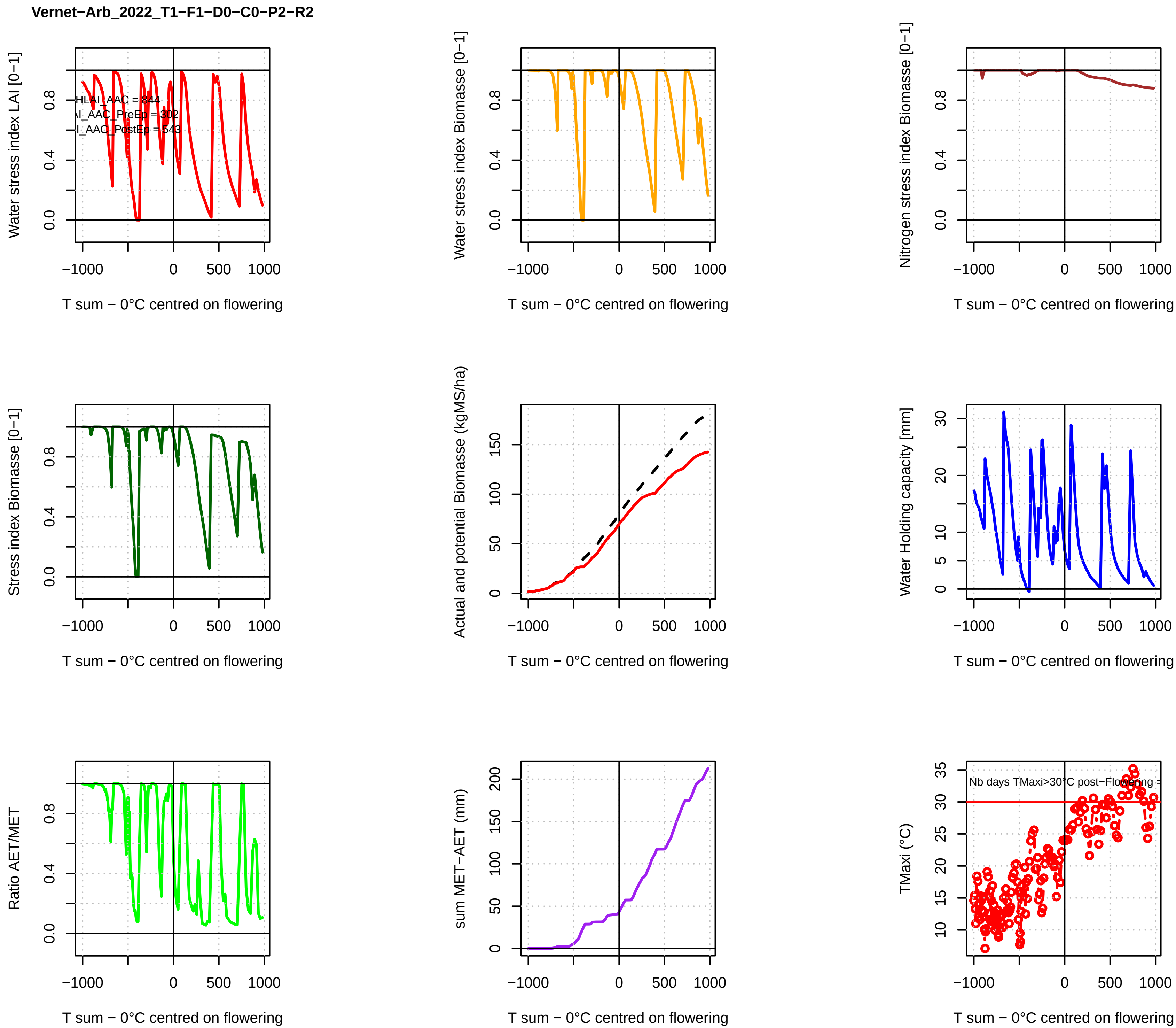


Vadon−Luz_2022_T1−F4−D0−C2−P2−R1

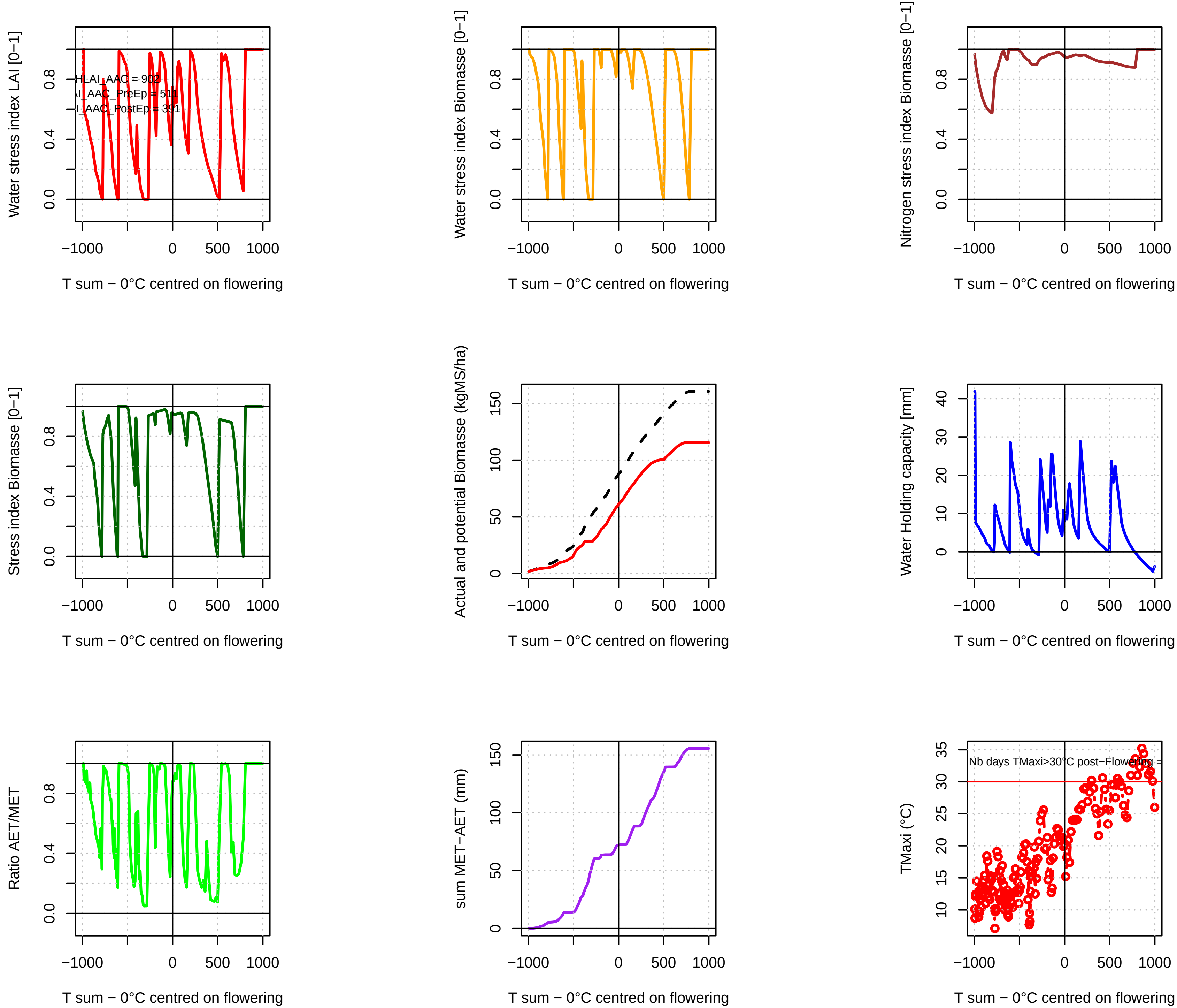


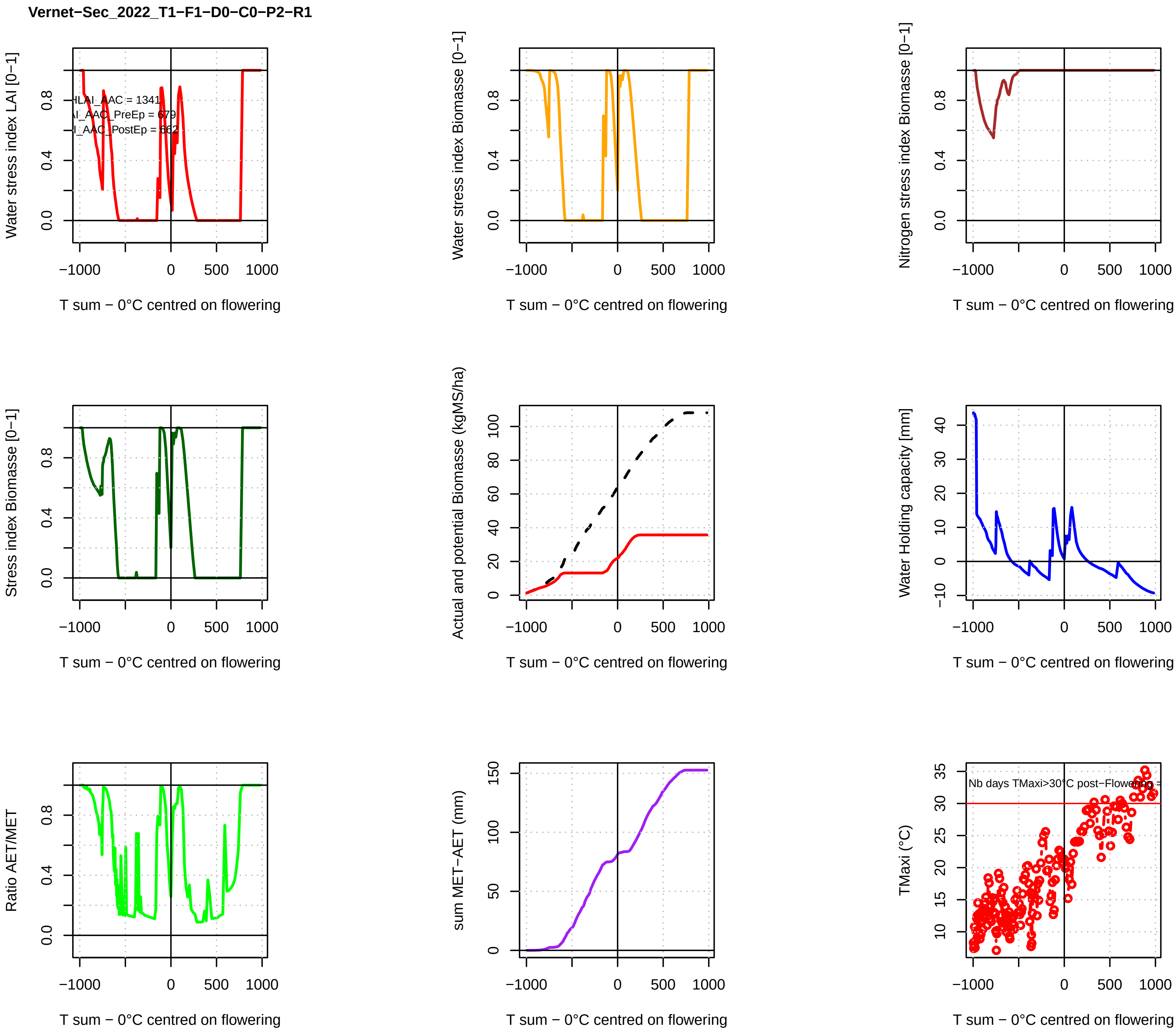


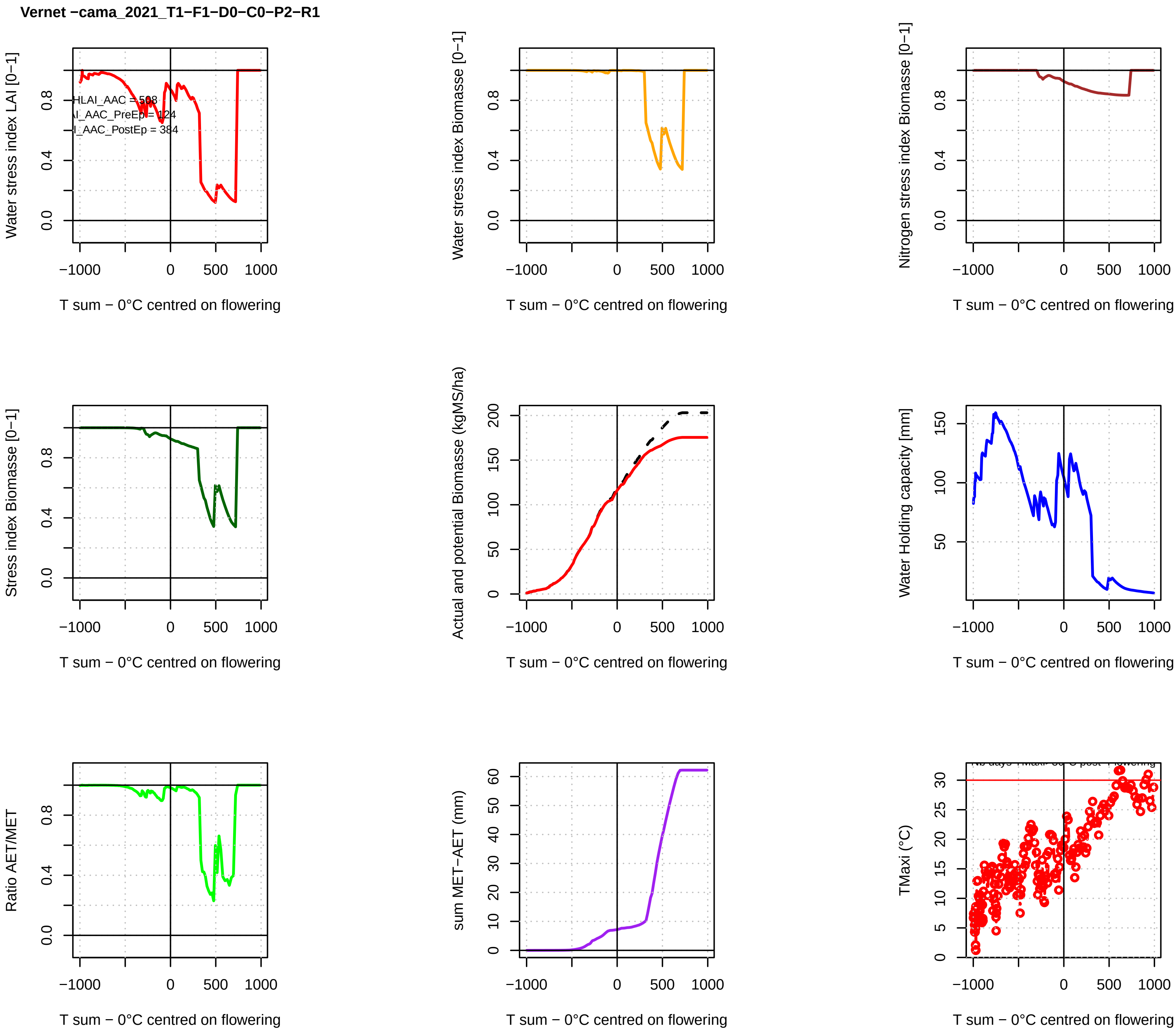
Vadon−SF_2022_T1−F5−D0−C1−P1−R1
Water stress index LAI [0−1]
HLAI_AAC = 977
I_AAC_PreEp = 259
I_AAC_PostEp = 718
Water stress index Biomasse [0−1]
Nitrogen stress index Biomasse [0−1]
Stress index Biomasse [0−1]
Actual and potential Biomasse (kgMS/ha)
Water Holding capacity [mm]
Ratio AET/MET
sum MET−AET (mm)
TMaxi (°C)
Nb days TMaxi>30°C post−Flowering
T sum − 0°C centred on flowering


Vernet−Arb_2022_T1−F1−D0−C0−P2−R2
Water stress index LAI [0−1]
HLAI_AAC = 844
AI_AAC_PreEp = 302
I_AAC_PostEp = 543
Water stress index Biomasse [0−1]
Nitrogen stress index Biomasse [0−1]
Stress index Biomasse [0−1]
Actual and potential Biomasse (kgMS/ha)
Water Holding capacity [mm]
Ratio AET/MET
sum MET−AET (mm)
TMaxi (°C)
Nb days TMaxi>30°C post−Flowering =
T sum − 0°C centred on flowering
−1000
0
500
1000

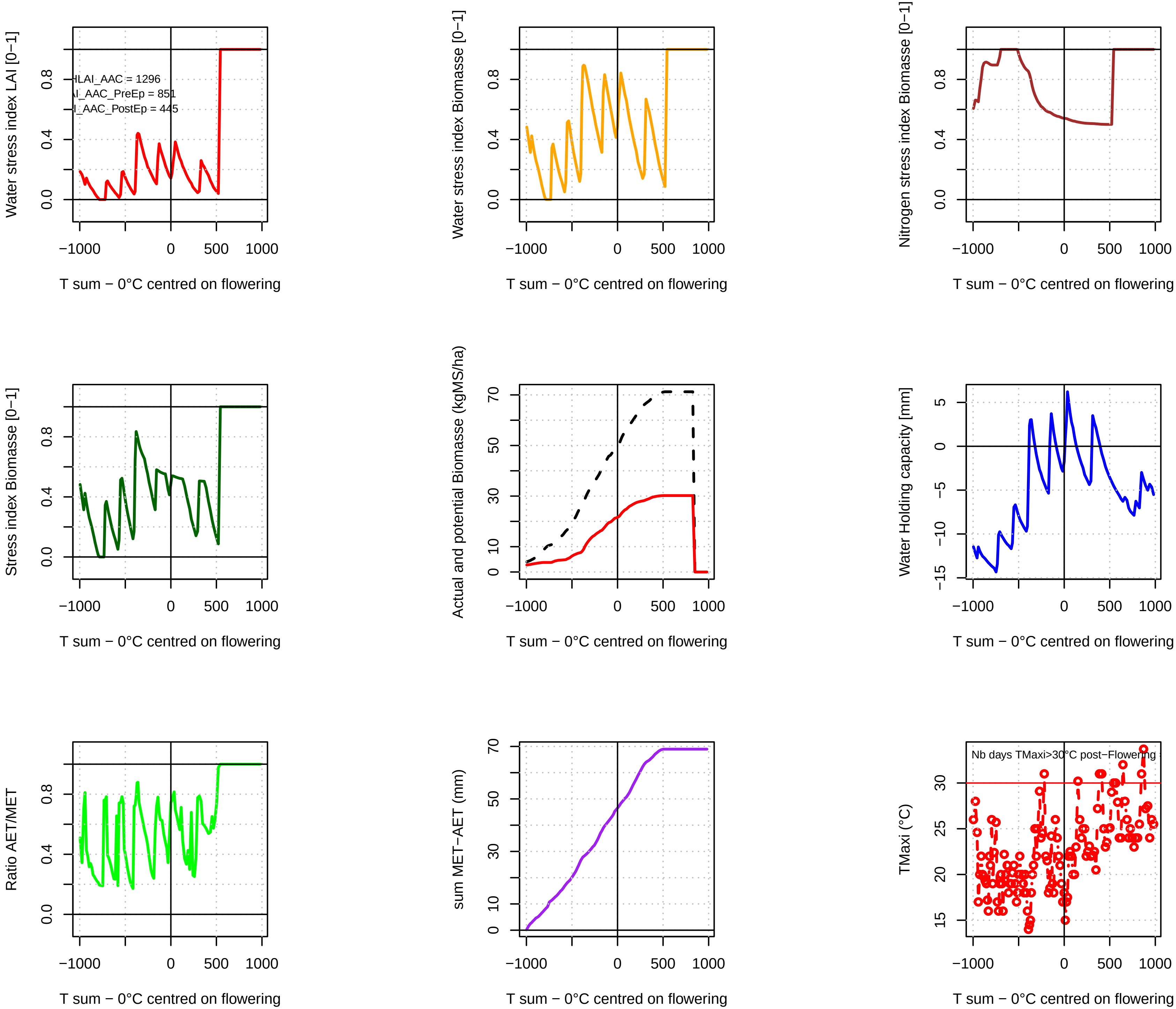
Vernet−Irr_2022_T1−F1−D0−C0−P2−R2



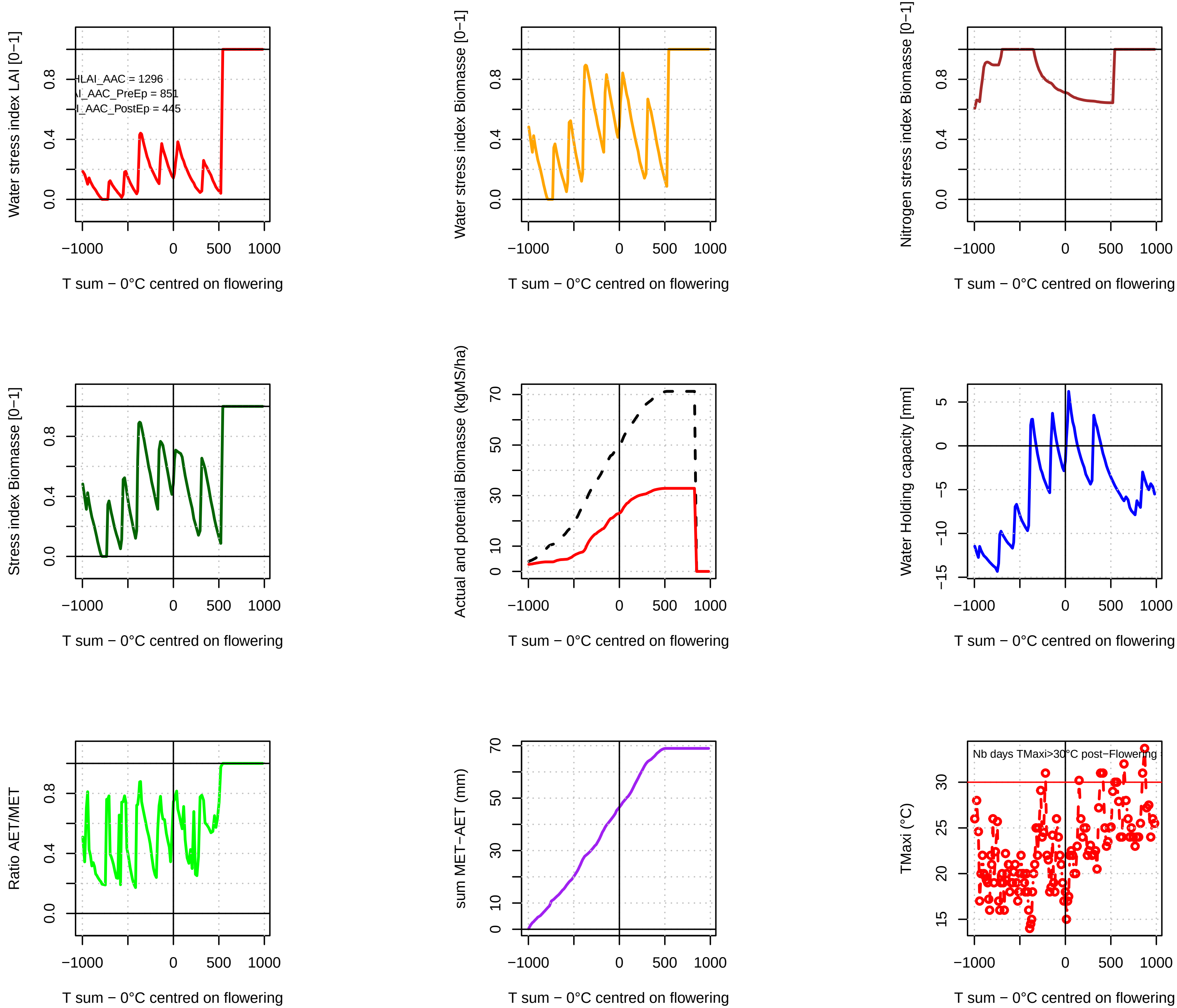

Vernet−Sec_2022_T1−F1−D0−C0−P2−R1
Water stress index LAI [0−1]
HLAI_AAC = 1341
I_AAC_PreEp = 679
I_AAC_PostEp = 662
Water stress index Biomasse [0−1]
Nitrogen stress index Biomasse [0−1]
Stress index Biomasse [0−1]
Actual and potential Biomasse (kgMS/ha)
Water Holding capacity [mm]
Ratio AET/MET
sum MET−AET (mm)
TMaxi (°C)
Nb days TMaxi>30°C post−Flowering =
T sum − 0°C centred on flowering


Vernet −cama_2021_T1−F1−D0−C0−P2−R1
Water stress index LAI [0−1]
HLAI_AAC = 508
Water stress index Biomasse [0−1]
Nitrogen stress index Biomasse [0−1]
Stress index Biomasse [0−1]
Actual and potential Biomasse (kgMS/ha)
Water Holding capacity [mm]
Ratio AET/MET
sum MET−AET (mm)
TMaxi (°C)
T sum − 0°C centred on flowering
−1000
0
500
1000

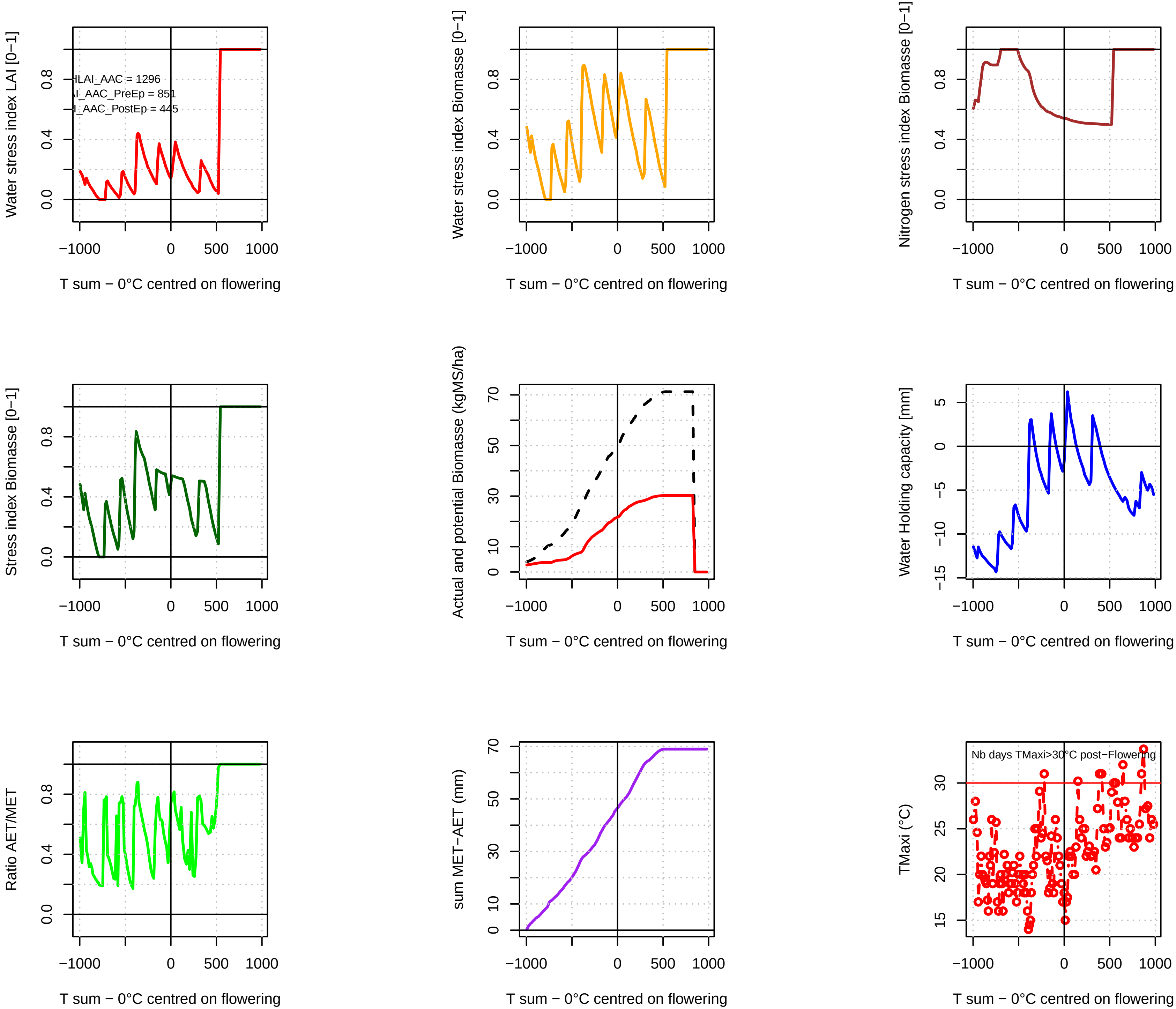
Algeria−S1Oued_2021_T1−F1−D1−C0−P0−R1



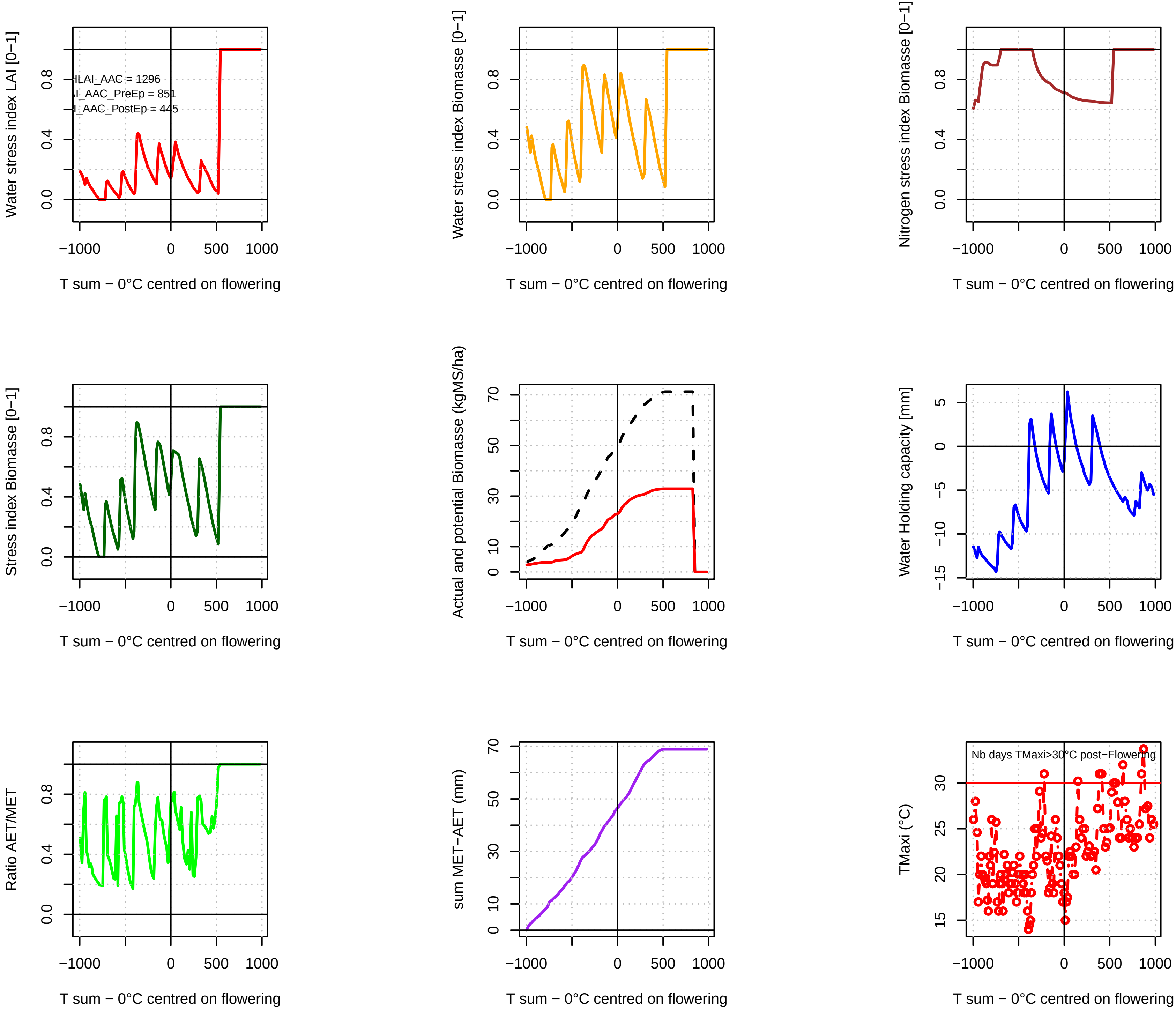
Algeria−S1Oued_2021_T1−F1−D2−C0−P0−R1

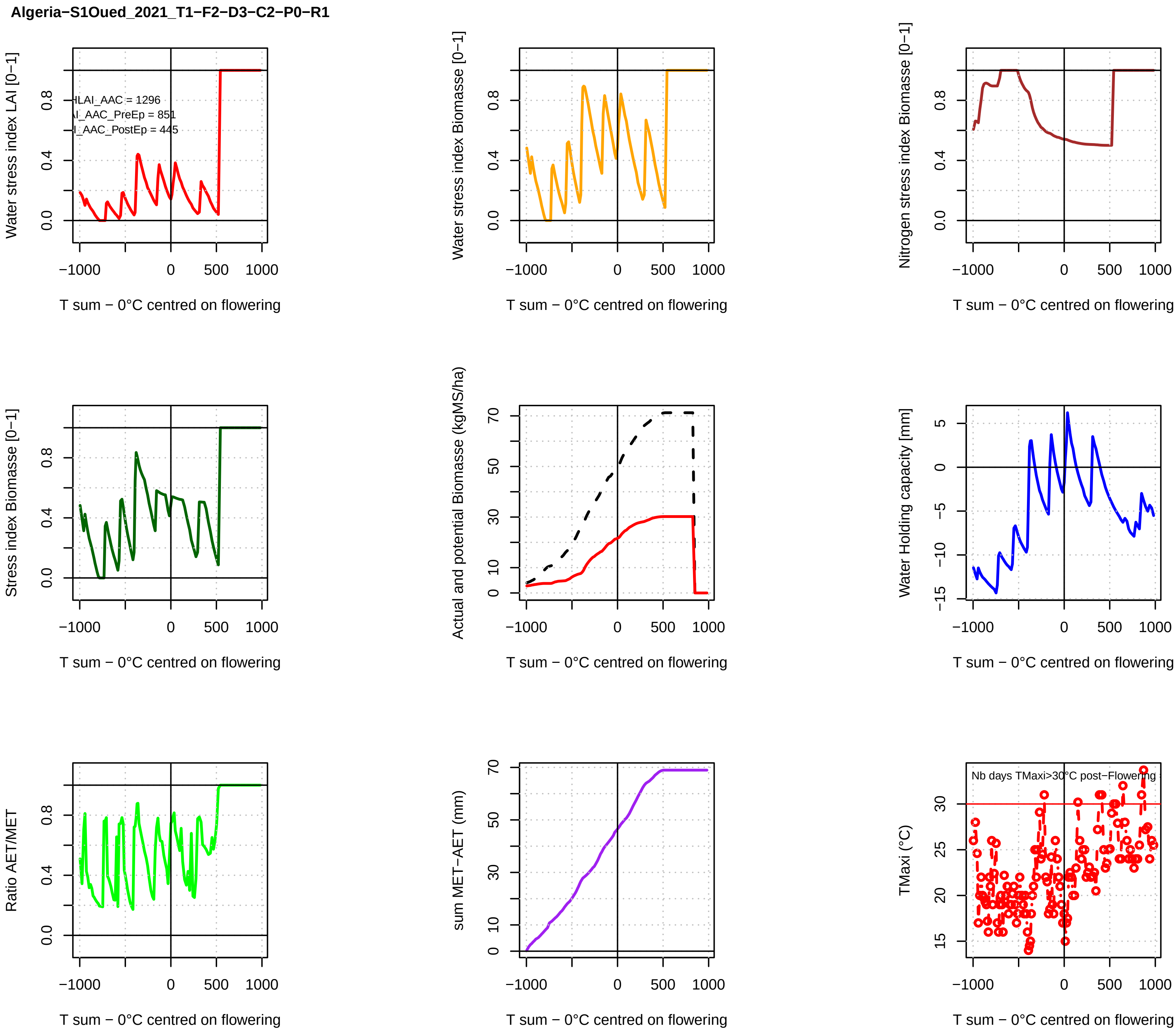


Algeria−S1Oued_2021_T1−F1−D3−C0−P0−R1

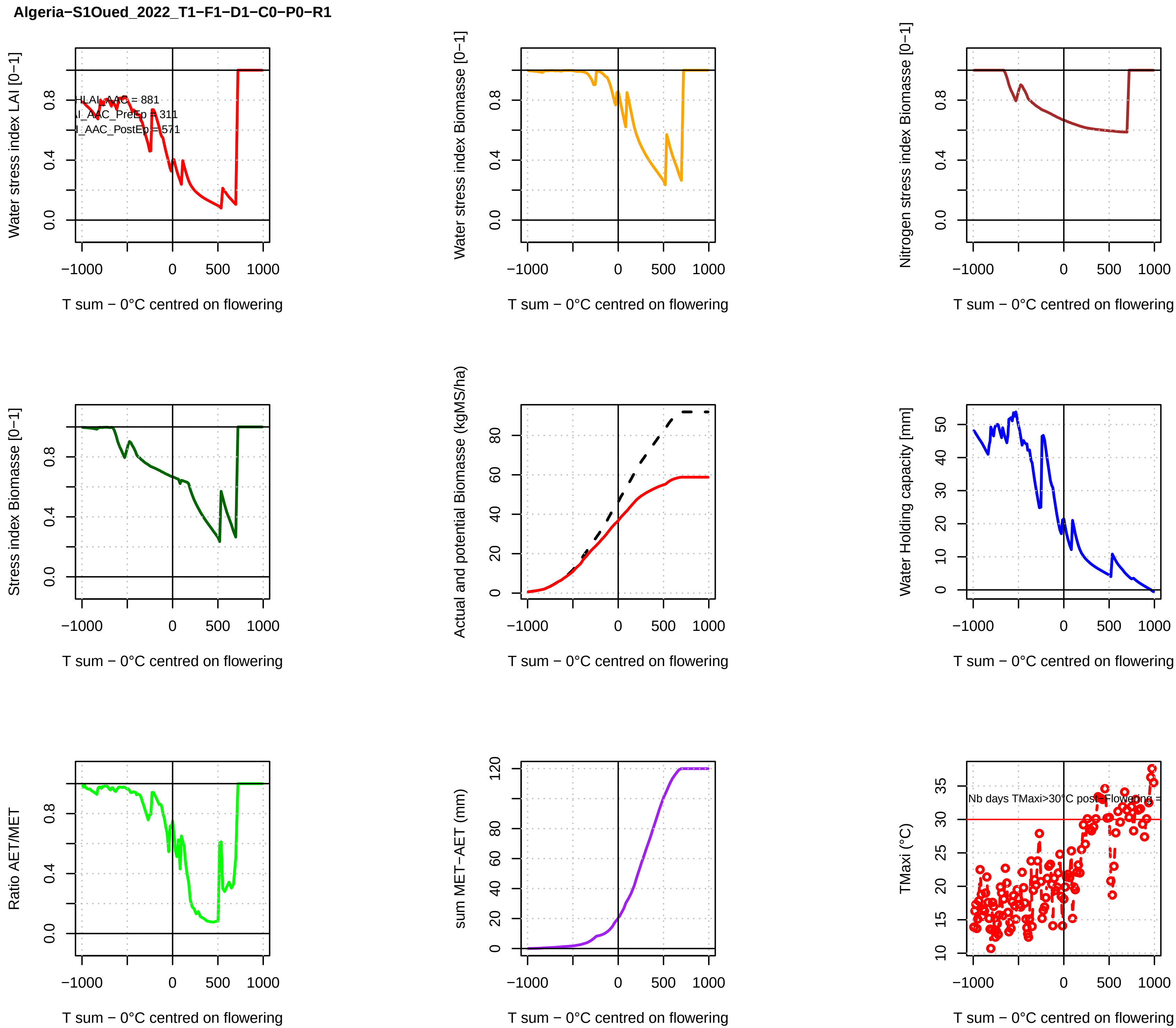


Algeria−S1Oued_2021_T1−F2−D2−C2−P0−R1

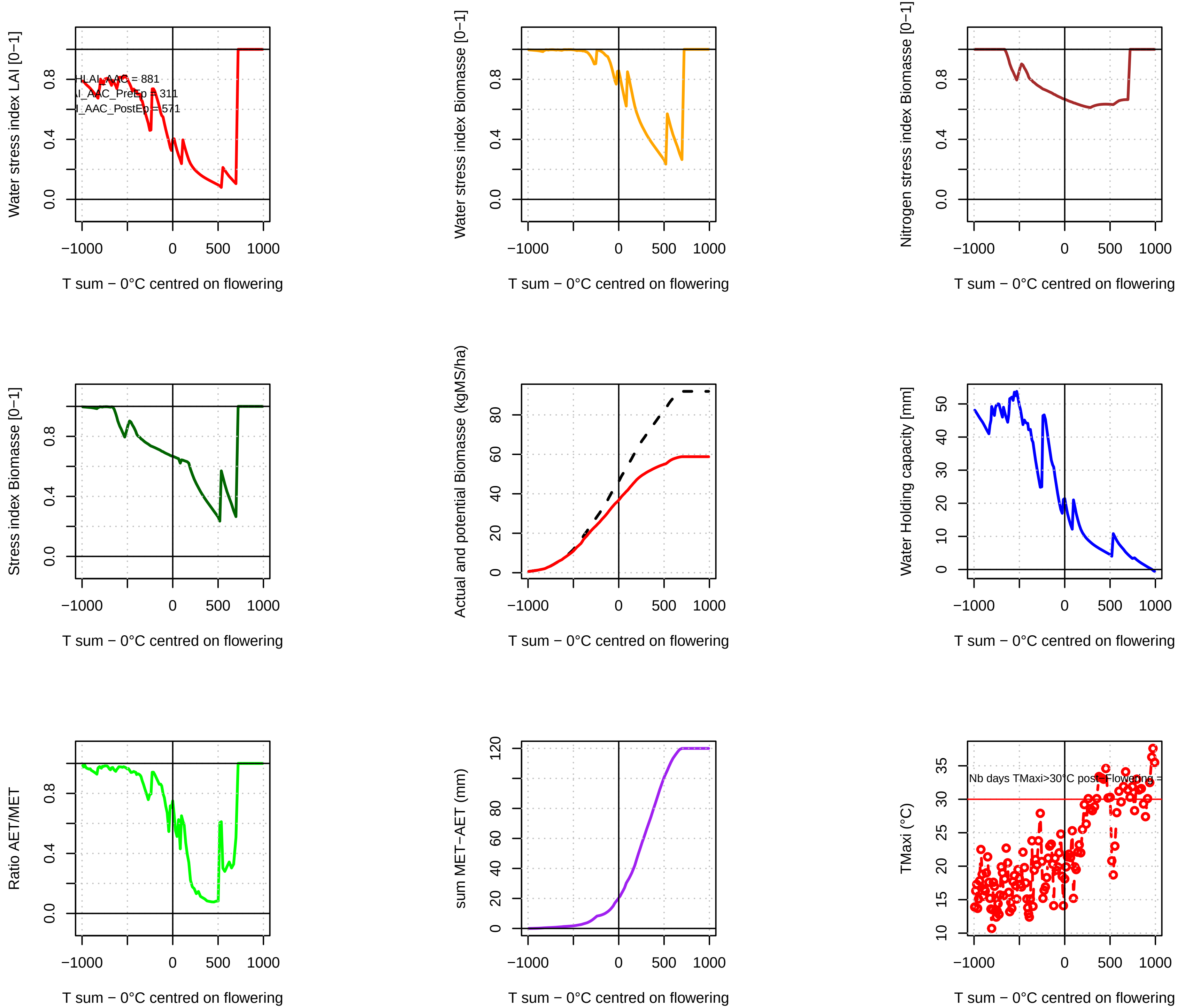




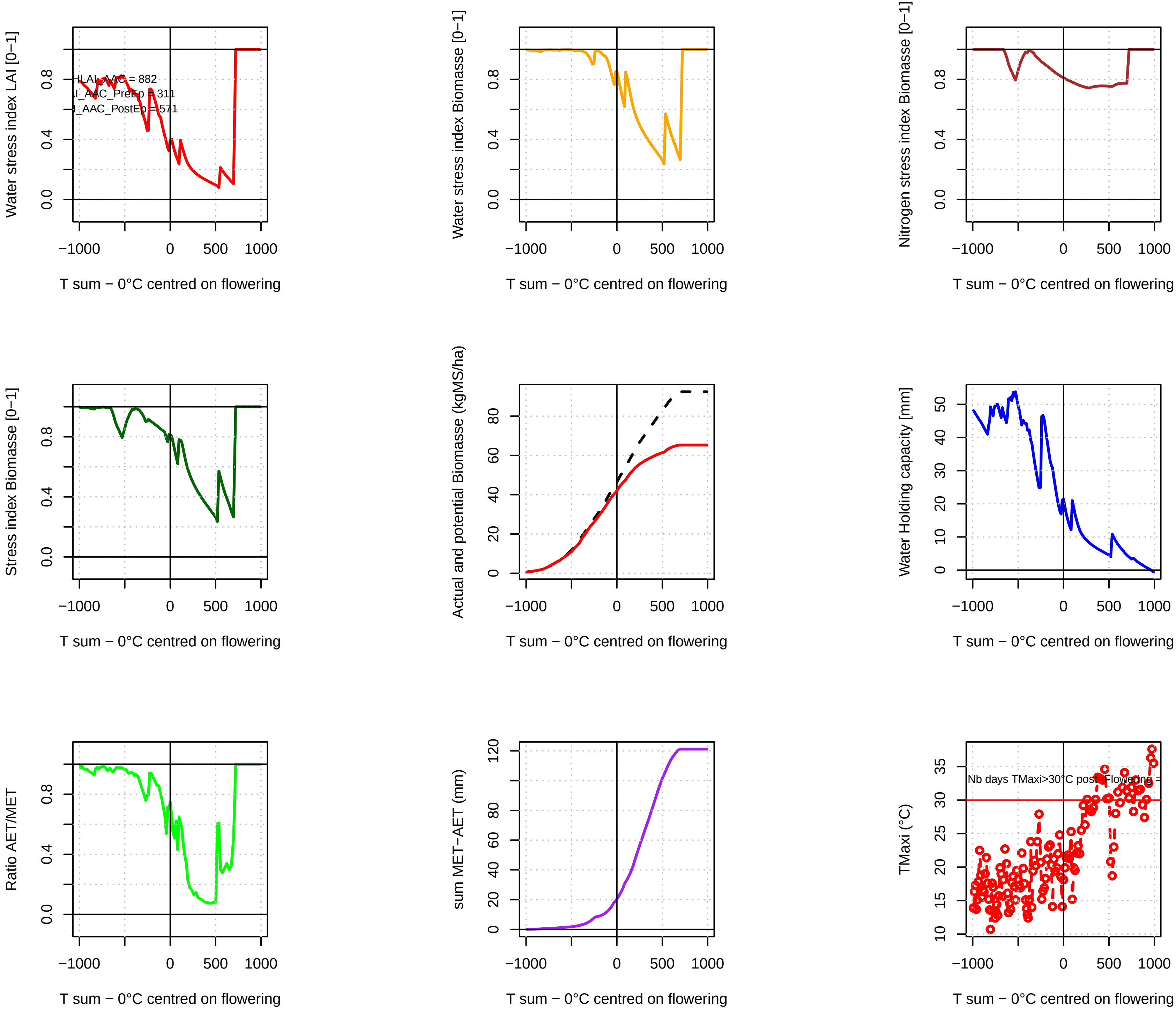
Algeria−S1Oued_2021_T1−F2−D3−C2−P0−R1
Water stress index LAI [0−1]
HLAI_AAC = 1296
AI_AAC_PreEp = 851
I_AAC_PostEp = 445
Water stress index Biomasse [0−1]
Nitrogen stress index Biomasse [0−1]
Stress index Biomasse [0−1]
Actual and potential Biomasse (kgMS/ha)
Water Holding capacity [mm]
Ratio AET/MET
sum MET−AET (mm)
TMaxi (°C)
Nb days TMaxi>30°C post−Flowering
T sum − 0°C centred on flowering


Algeria−S1Oued_2022_T1−F1−D1−C0−P0−R1
Water stress index LAI [0−1]
HLAI_AAC = 881
I_AAC_PreEp = 311
I_AAC_PostEp = 571
Water stress index Biomasse [0−1]
Nitrogen stress index Biomasse [0−1]
Stress index Biomasse [0−1]
Actual and potential Biomasse (kgMS/ha)
Water Holding capacity [mm]
Ratio AET/MET
sum MET−AET (mm)
TMaxi (°C)
Nb days TMaxi>30°C post−Flowering =
T sum − 0°C centred on flowering
−1000
0
500
1000

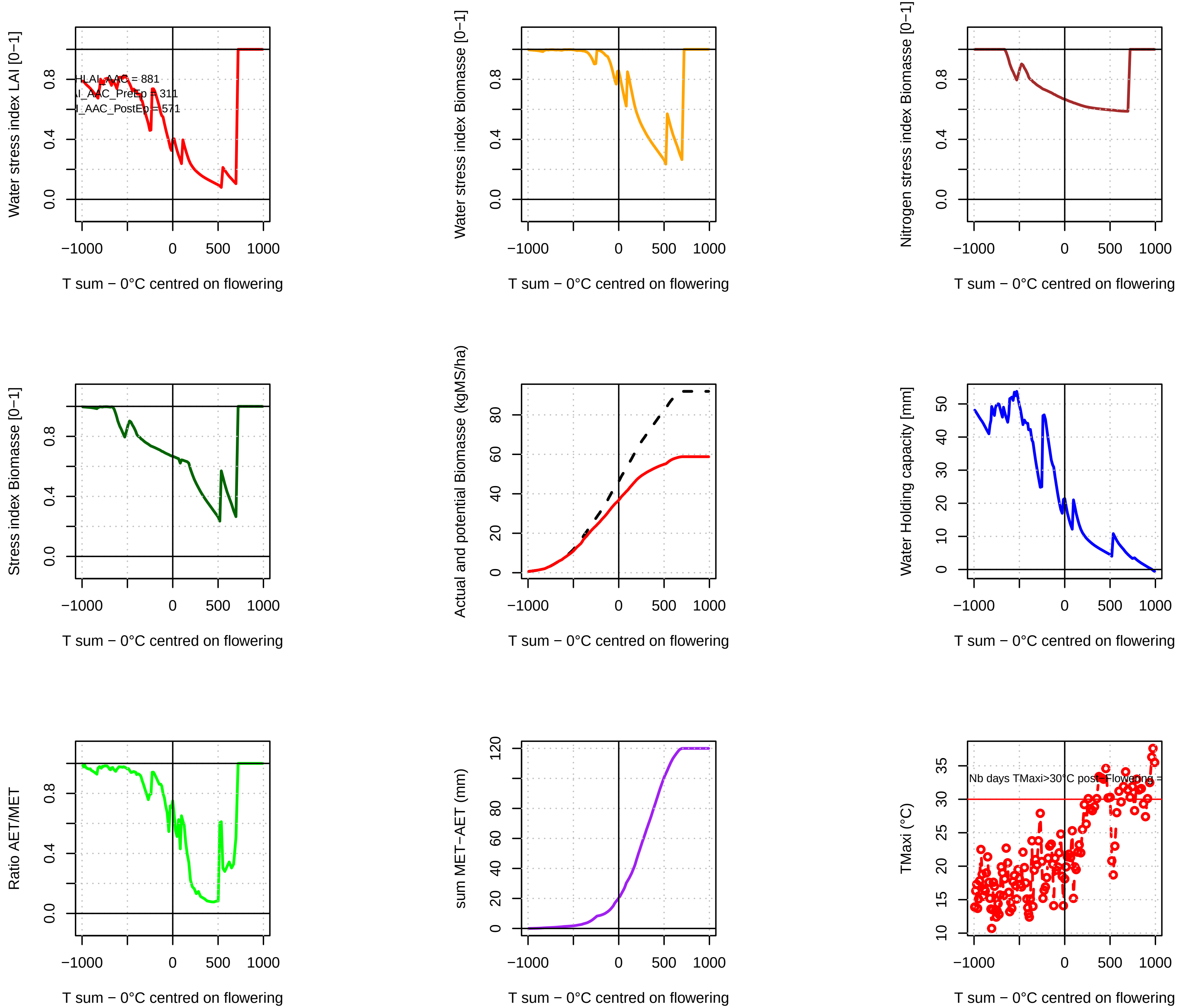
Algeria−S1Oued_2022_T1−F1−D2−C0−P0−R1



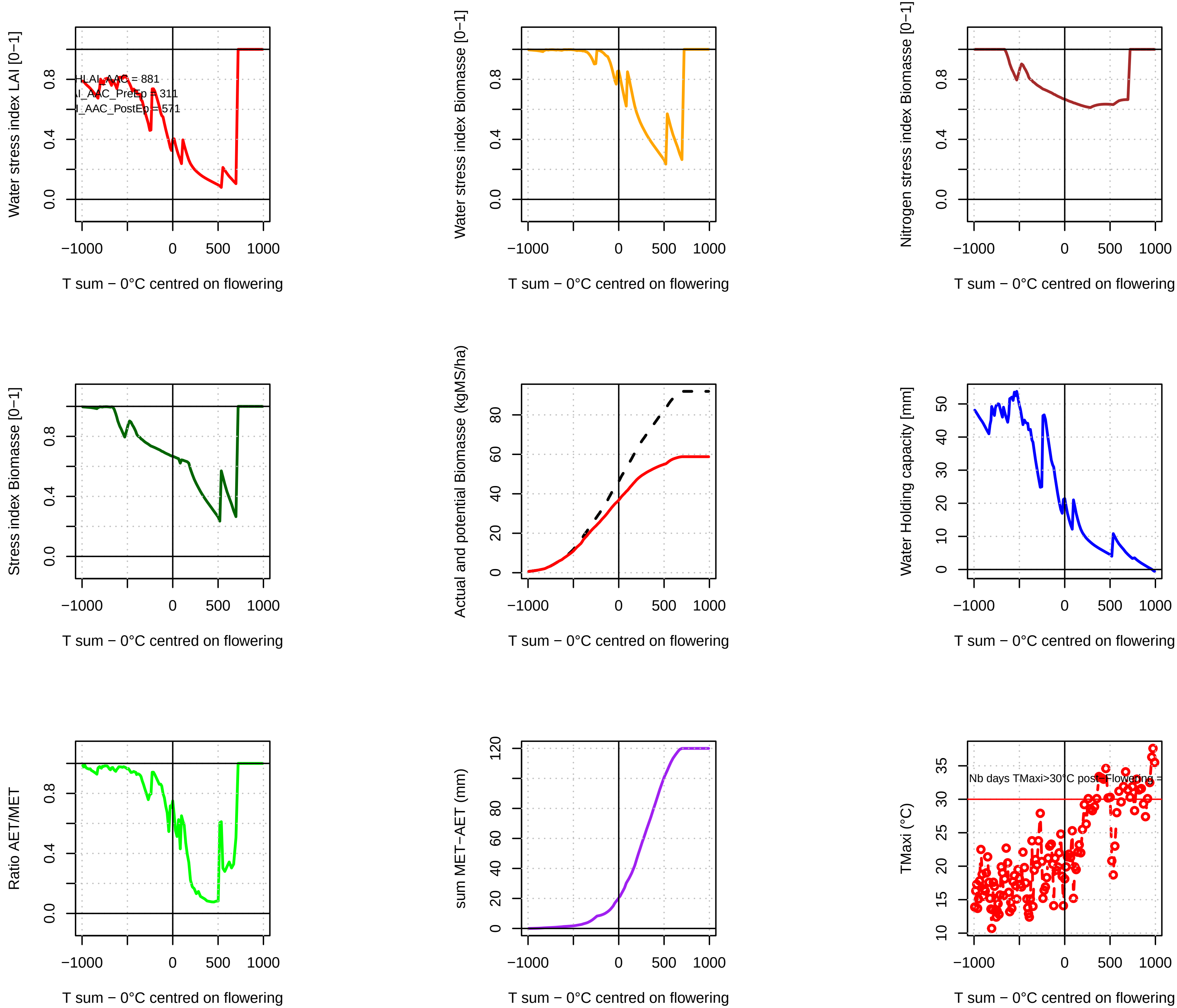
Algeria−S1Oued_2022_T1−F1−D3−C0−P0−R1

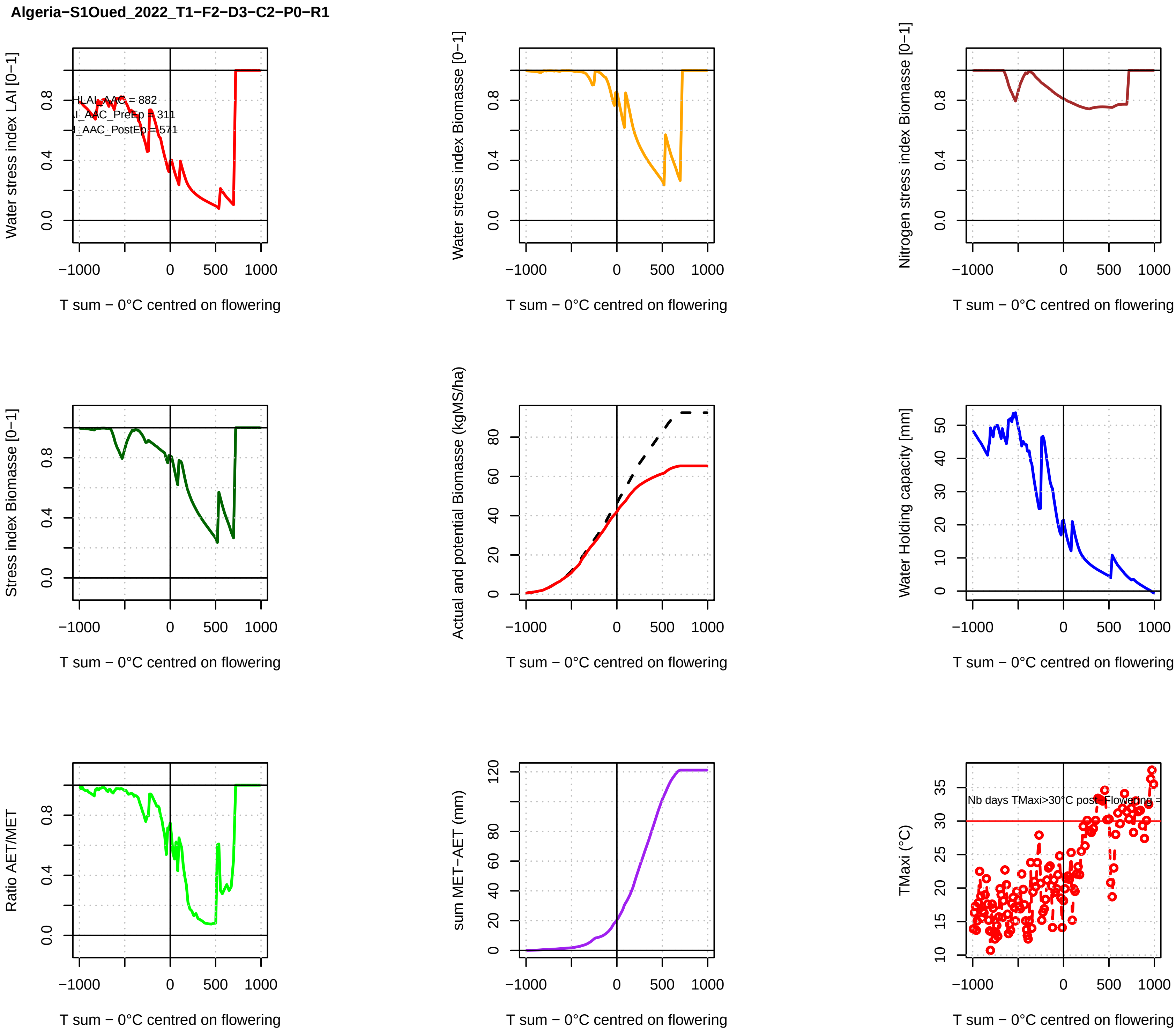


Algeria−S1Oued_2022_T1−F2−D1−C2−P0−R1

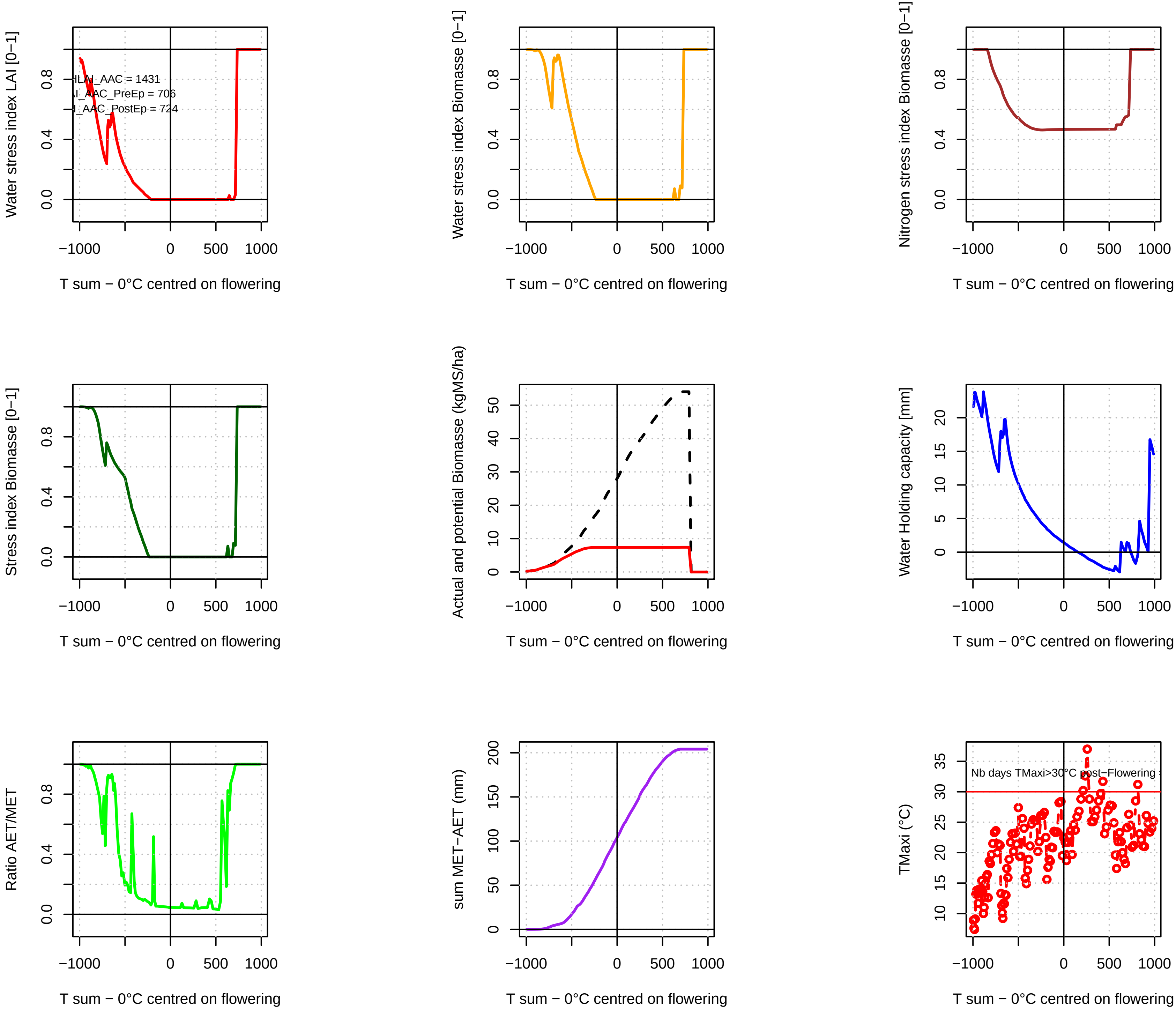


Algeria−S1Oued_2022_T1−F2−D2−C2−P0−R1

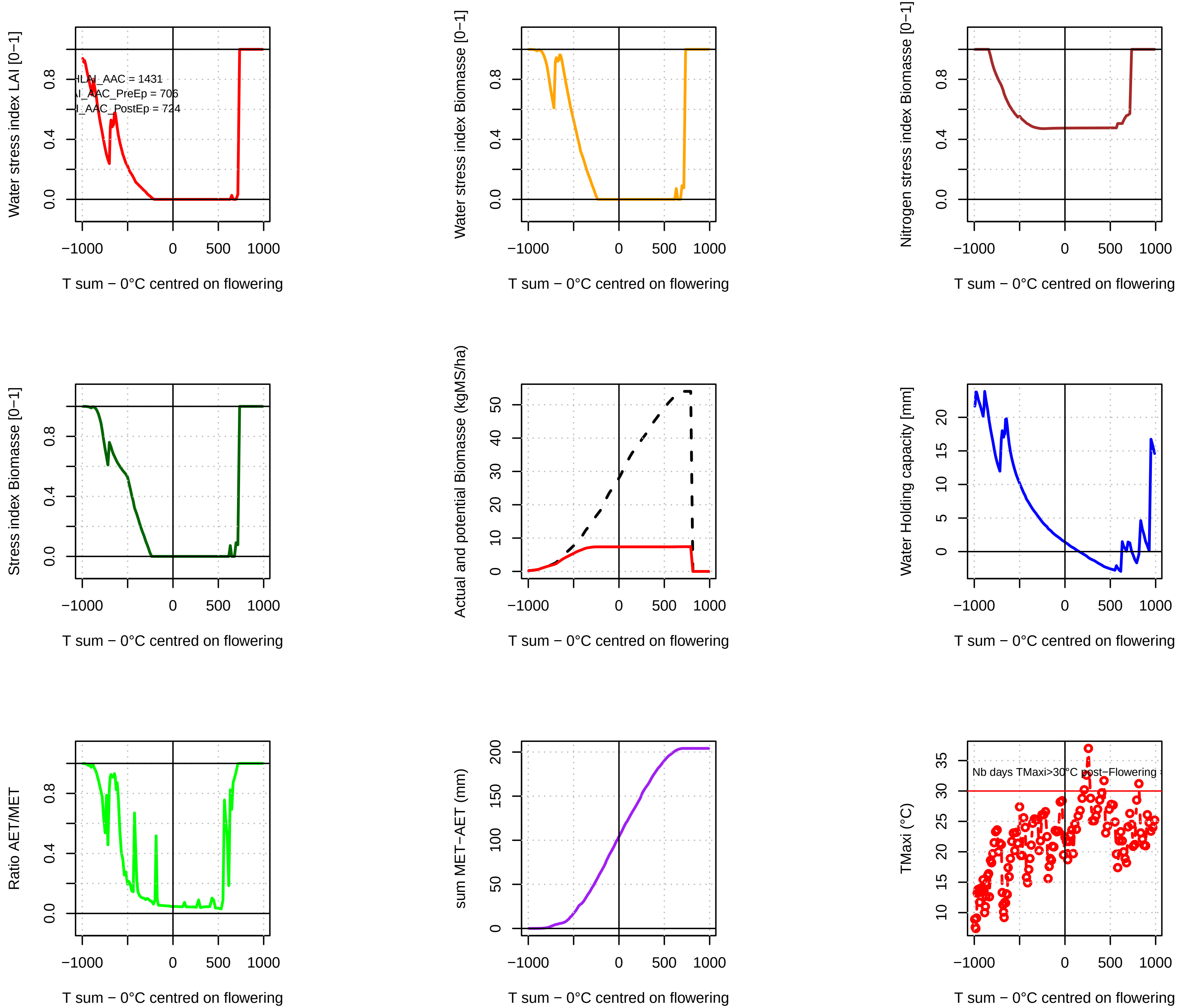



Algeria−S1Oued_2022_T1−F2−D3−C2−P0−R1
Water stress index LAI [0−1]
HLAI_AAC = 882
I_AAC_PreEp = 311
I_AAC_PostEp = 571
Water stress index Biomasse [0−1]
Nitrogen stress index Biomasse [0−1]
Stress index Biomasse [0−1]
Actual and potential Biomasse (kgMS/ha)
Water Holding capacity [mm]
Ratio AET/MET
sum MET−AET (mm)
TMaxi (°C)
Nb days TMaxi>30°C post−Flowering =
T sum − 0°C centred on flowering

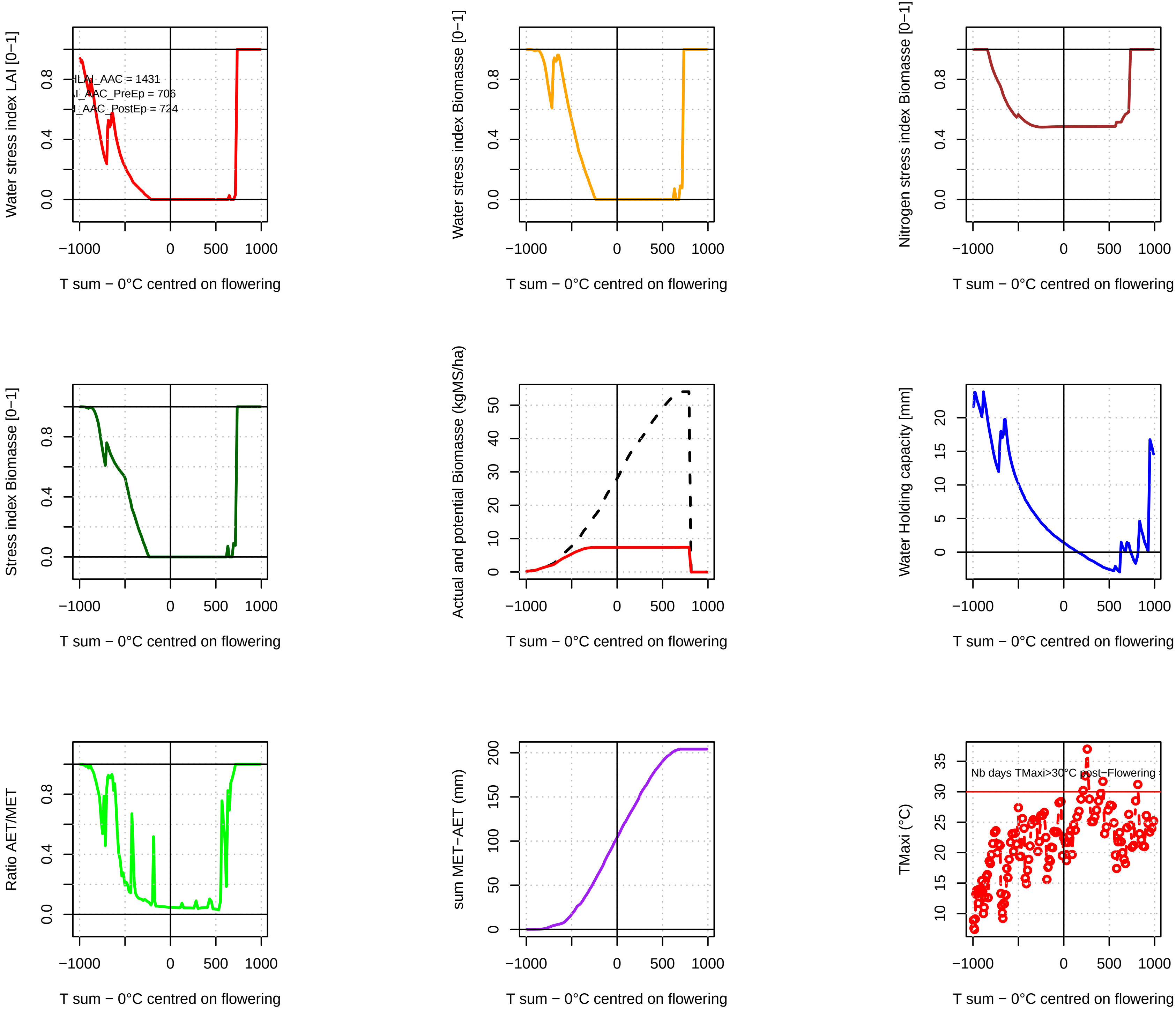
Algeria−S1Oued_2023_T1−F1−D1−C0−P0−R1



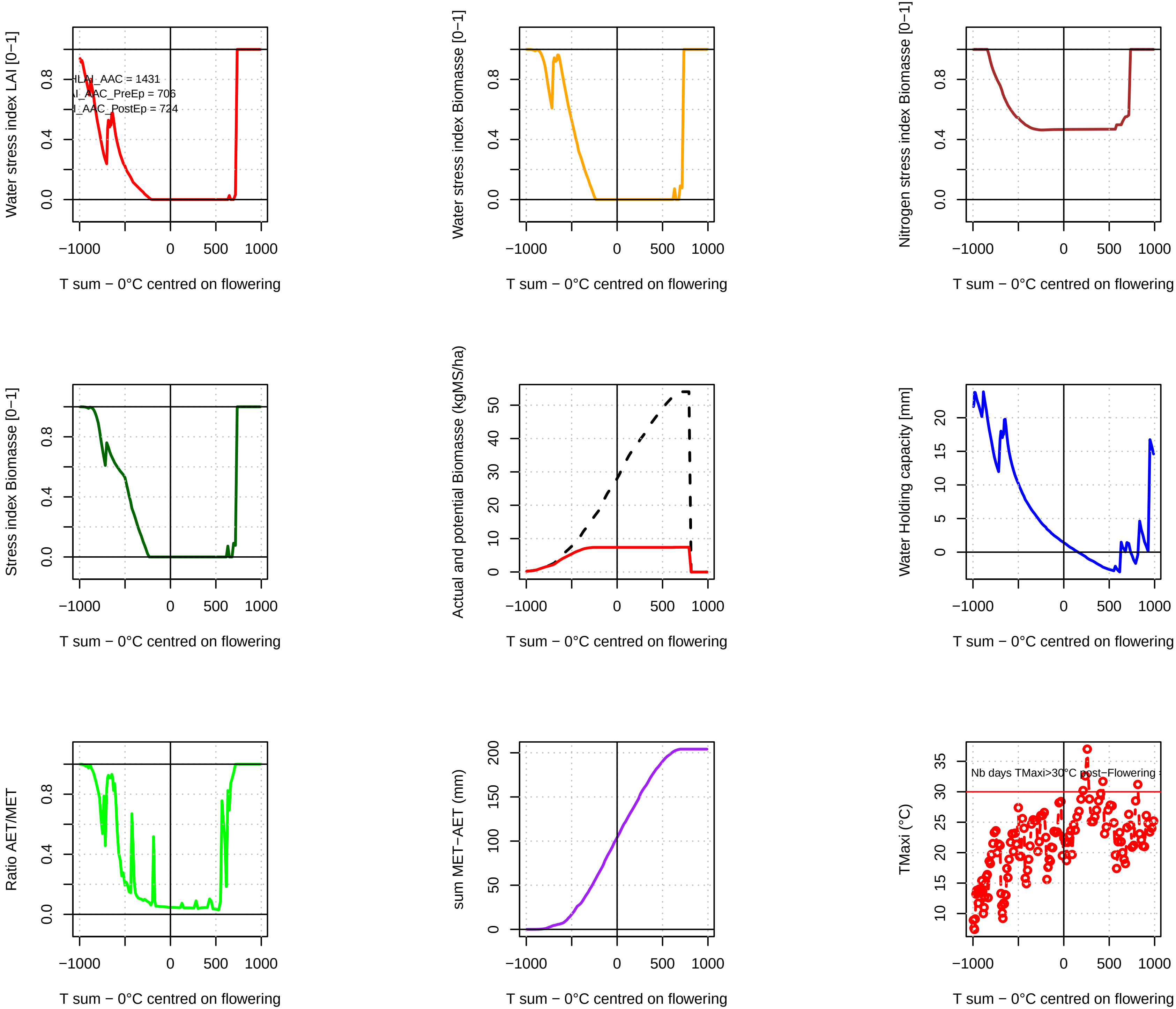
Algeria−S1Oued_2023_T1−F1−D2−C0−P0−R1



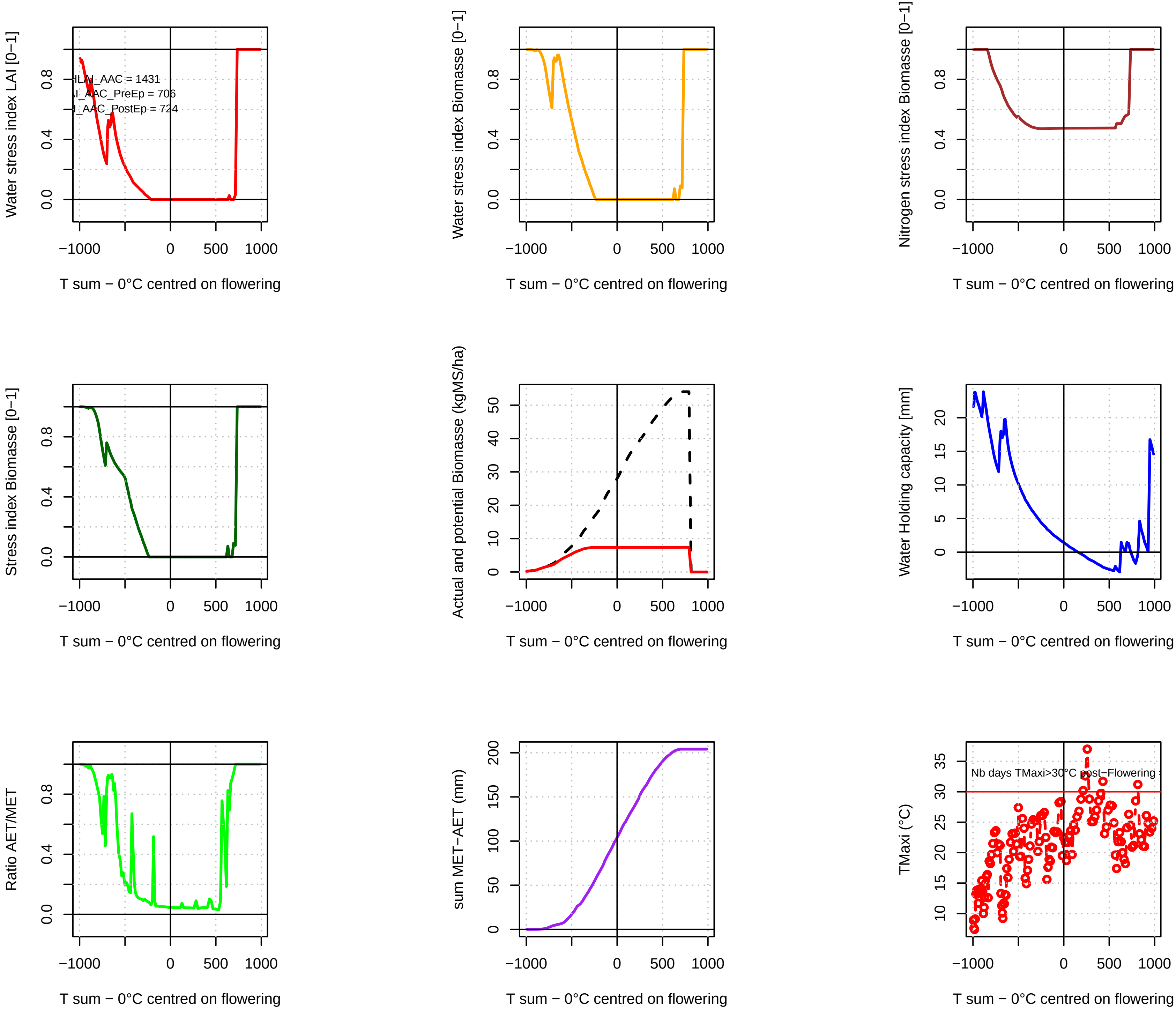
Algeria−S1Oued_2023_T1−F1−D3−C0−P0−R1



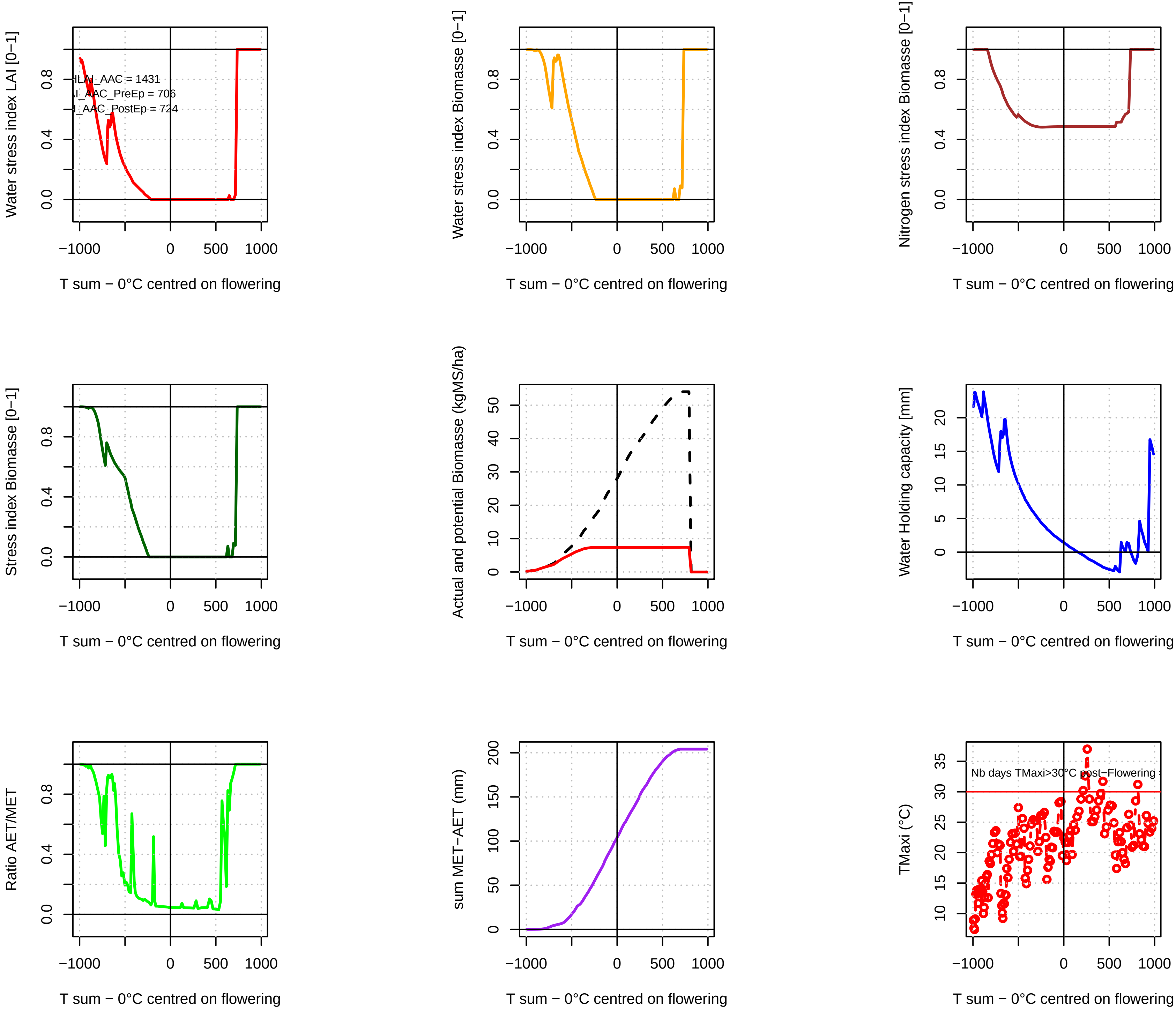
Algeria−S1Oued_2023_T1−F2−D1−C2−P0−R1



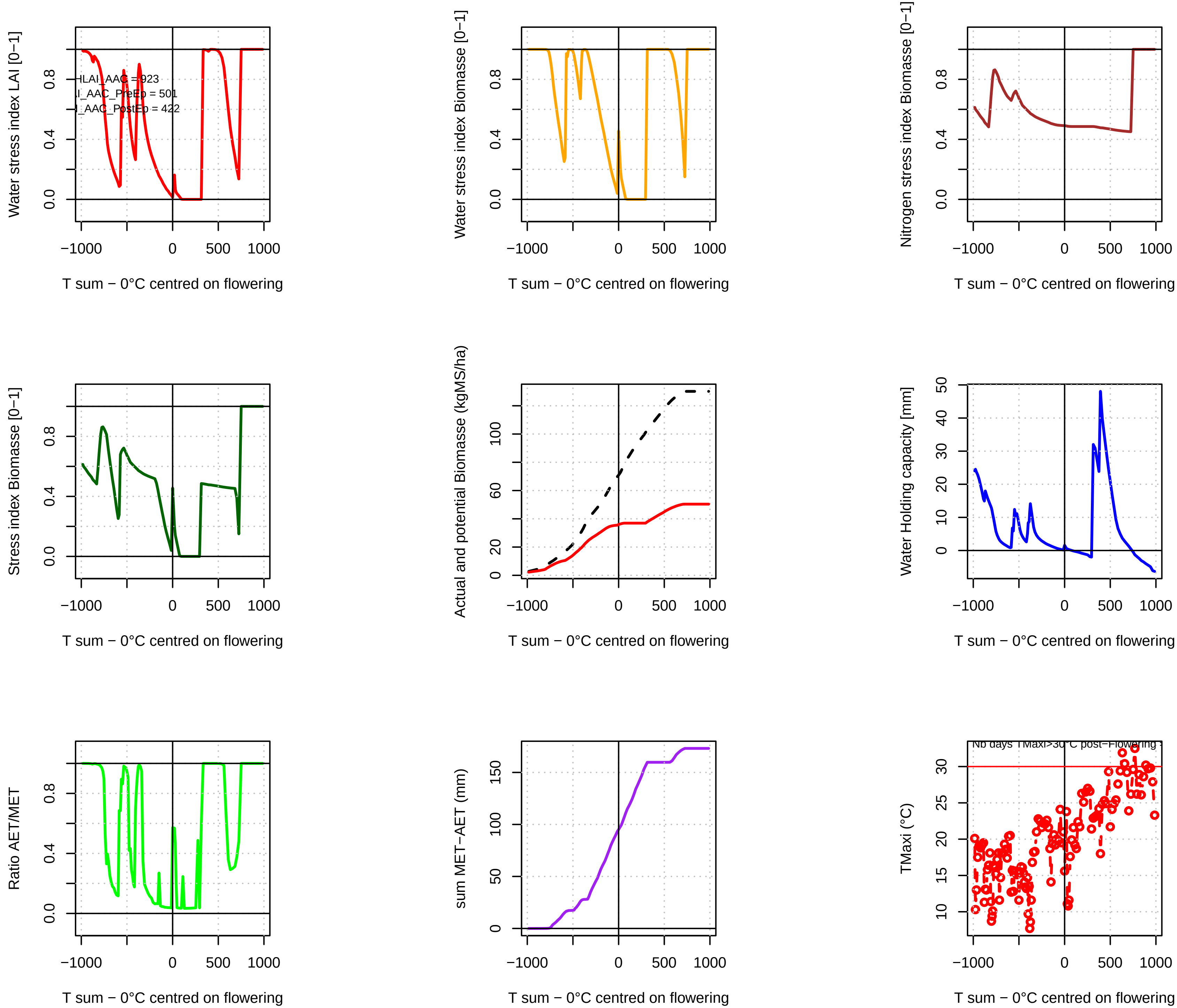
Algeria−S1Oued_2023_T1−F2−D2−C2−P0−R1



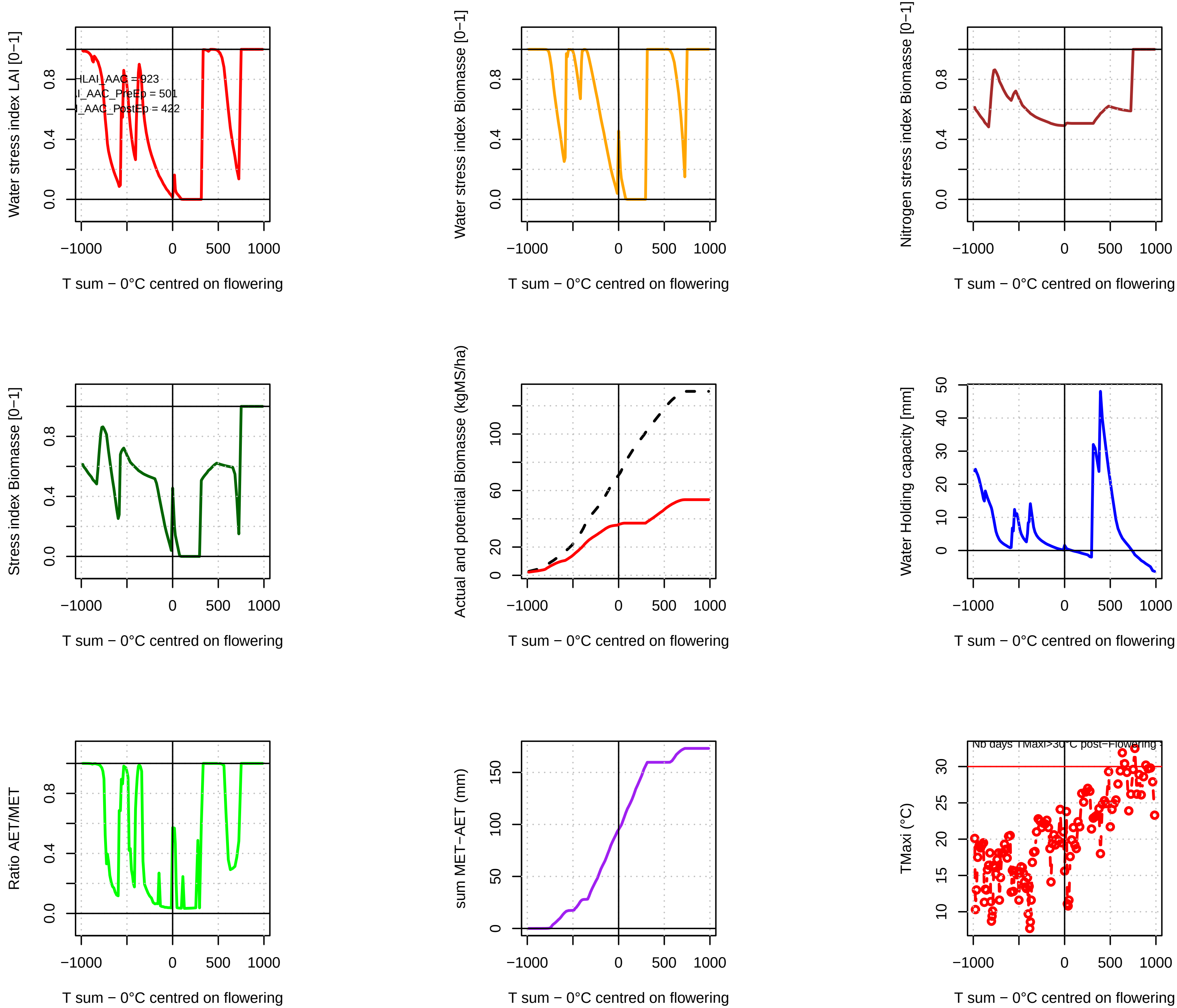
Algeria−S1Oued_2023_T1−F2−D3−C2−P0−R1



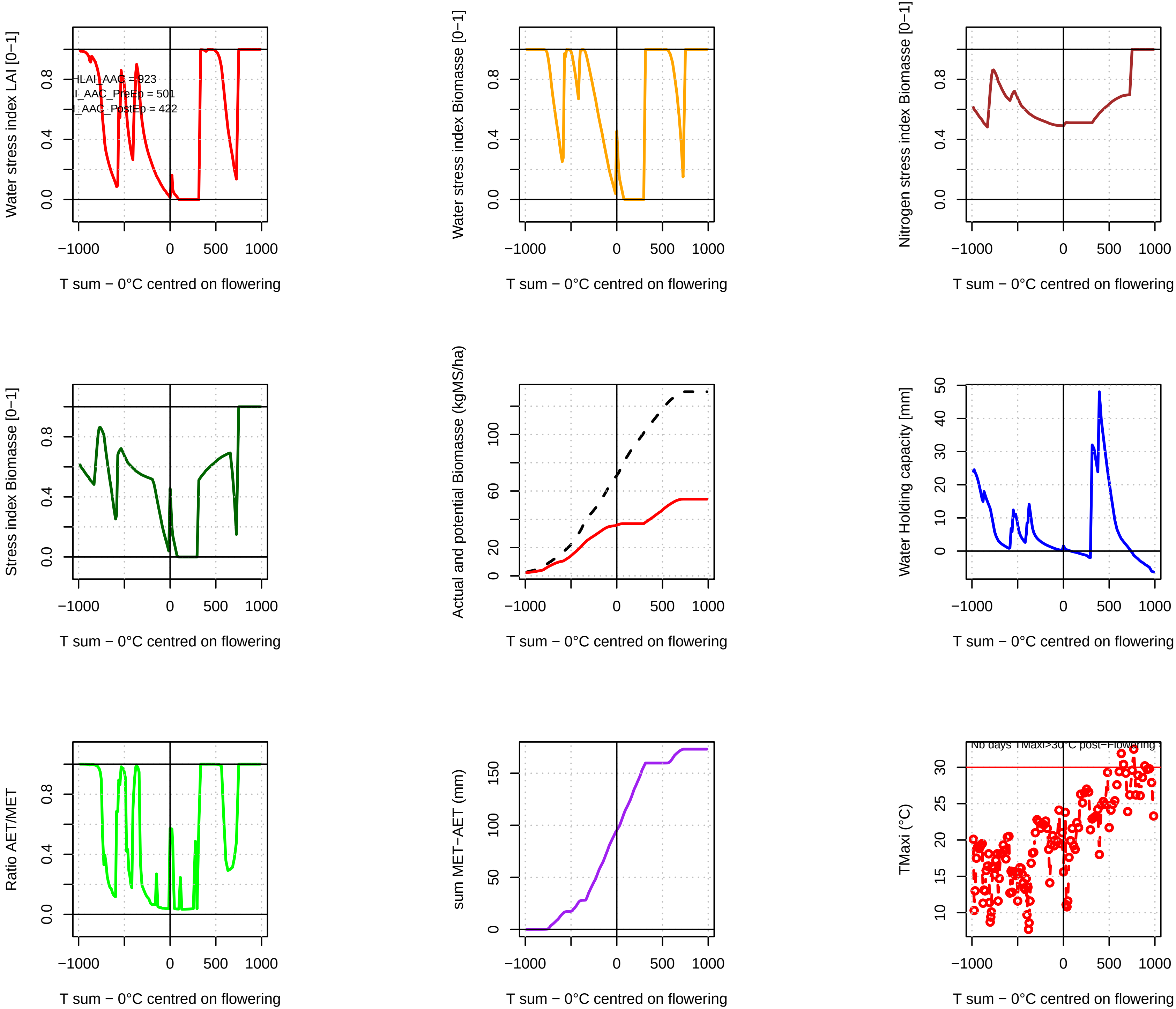
Algeria−S2Mezloug_2021_T1−F1−D1−C0−P0−R1



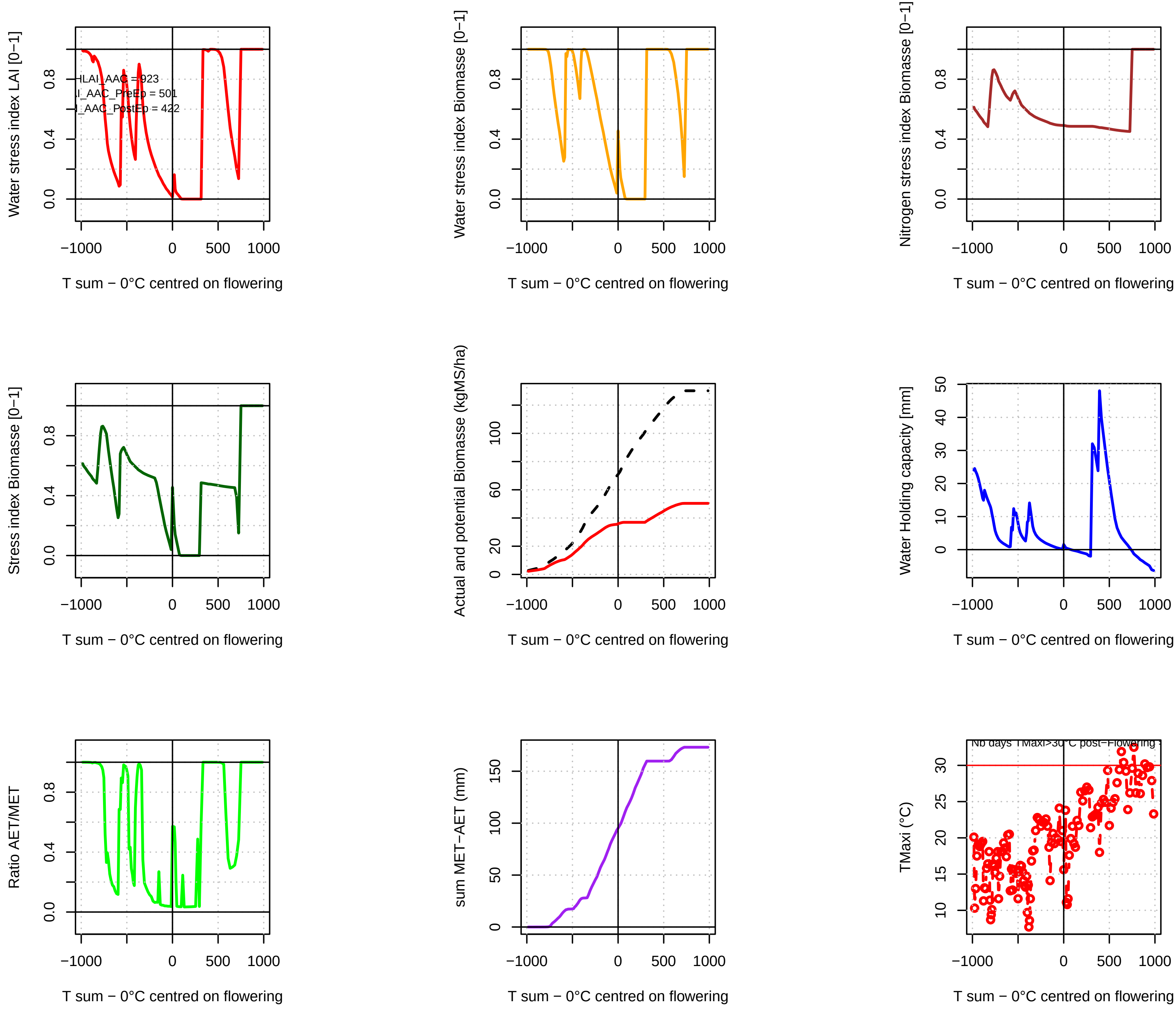
Algeria−S2Mezloug_2021_T1−F1−D2−C0−P0−R1



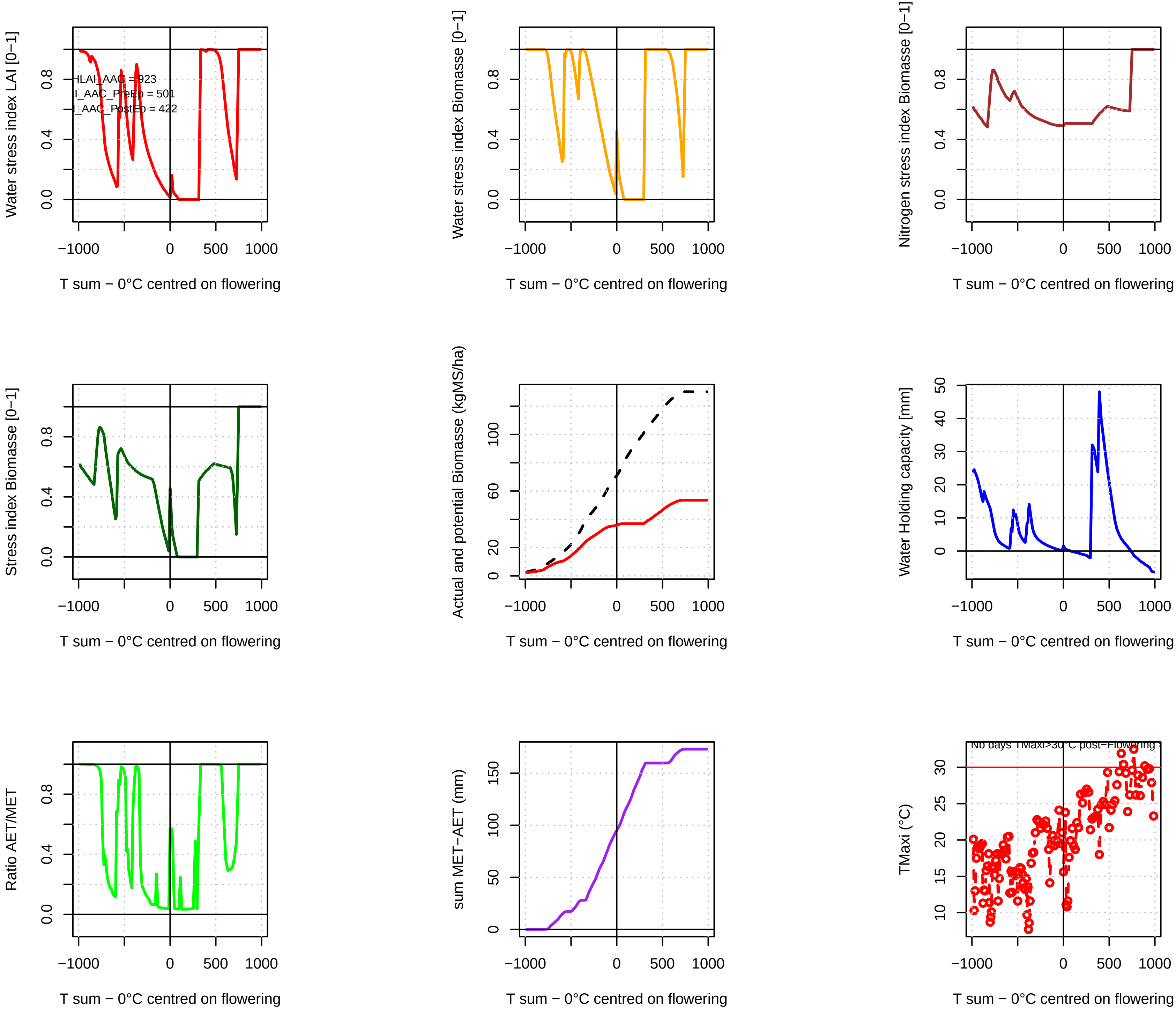
Algeria−S2Mezloug_2021_T1−F1−D3−C0−P0−R1



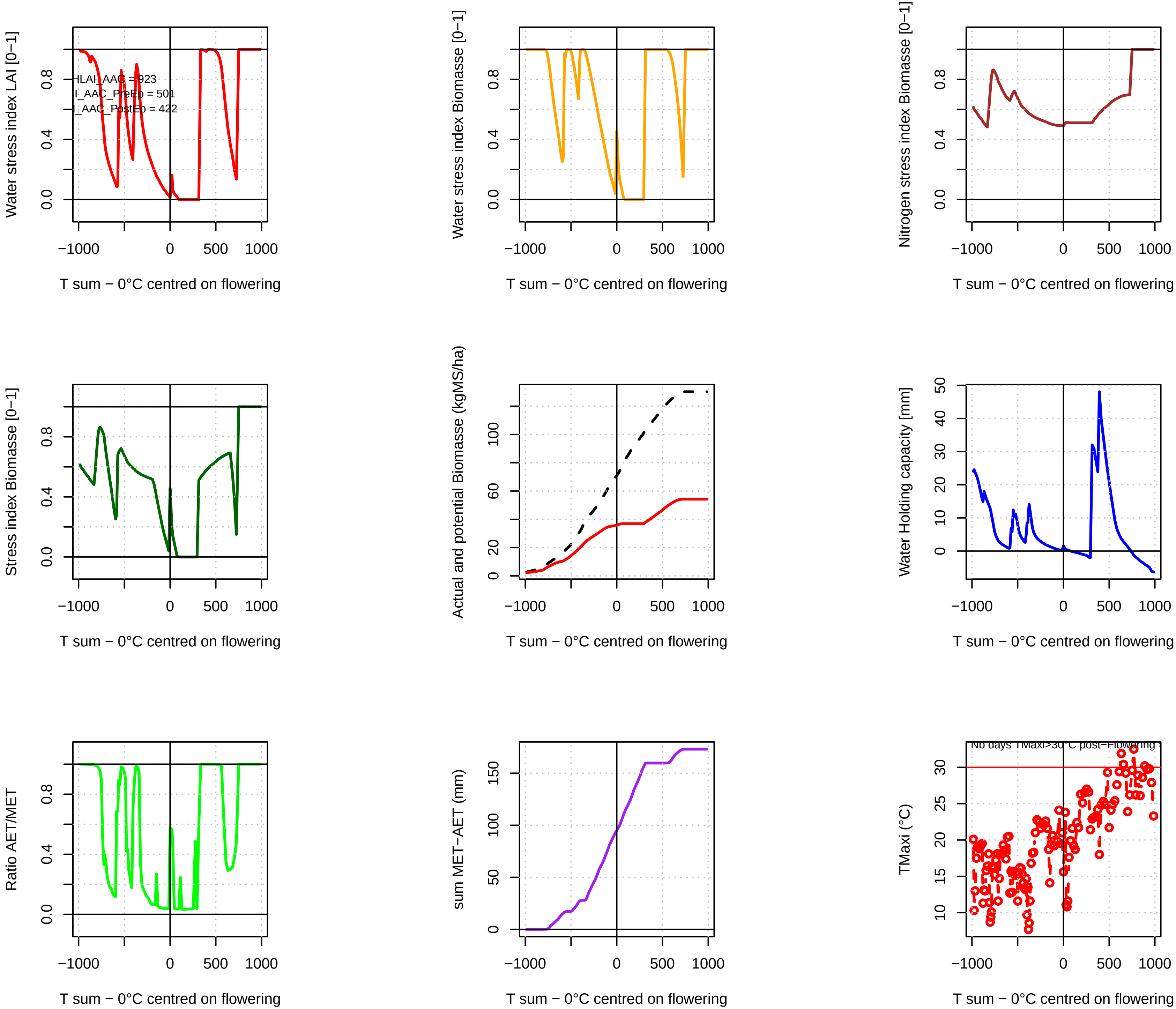
Algeria−S2Mezloug_2021_T1−F2−D1−C2−P0−R1



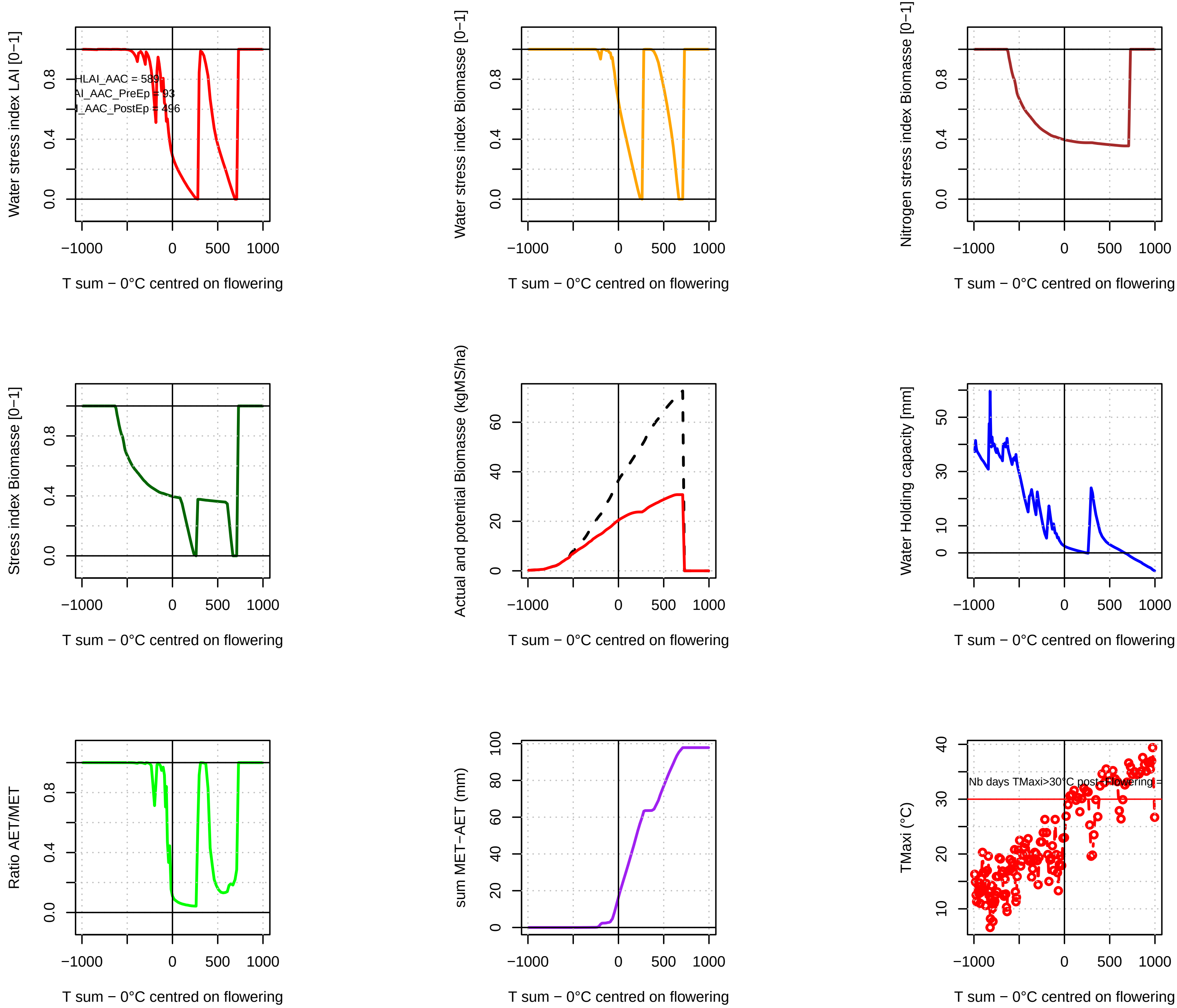
Algeria−S2Mezloug_2021_T1−F2−D2−C2−P0−R1



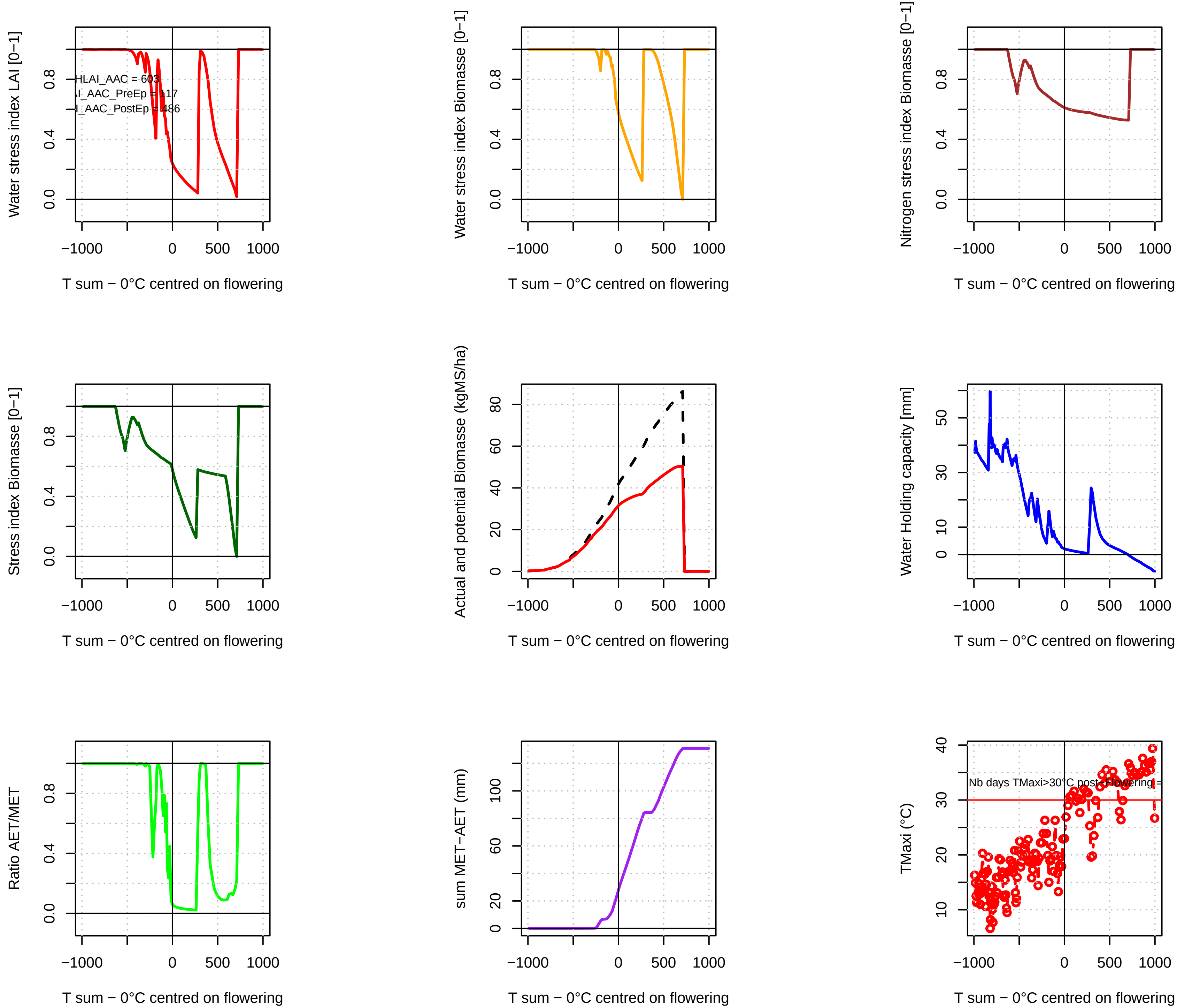
Algeria−S2Mezloug_2021_T1−F2−D3−C2−P0−R1



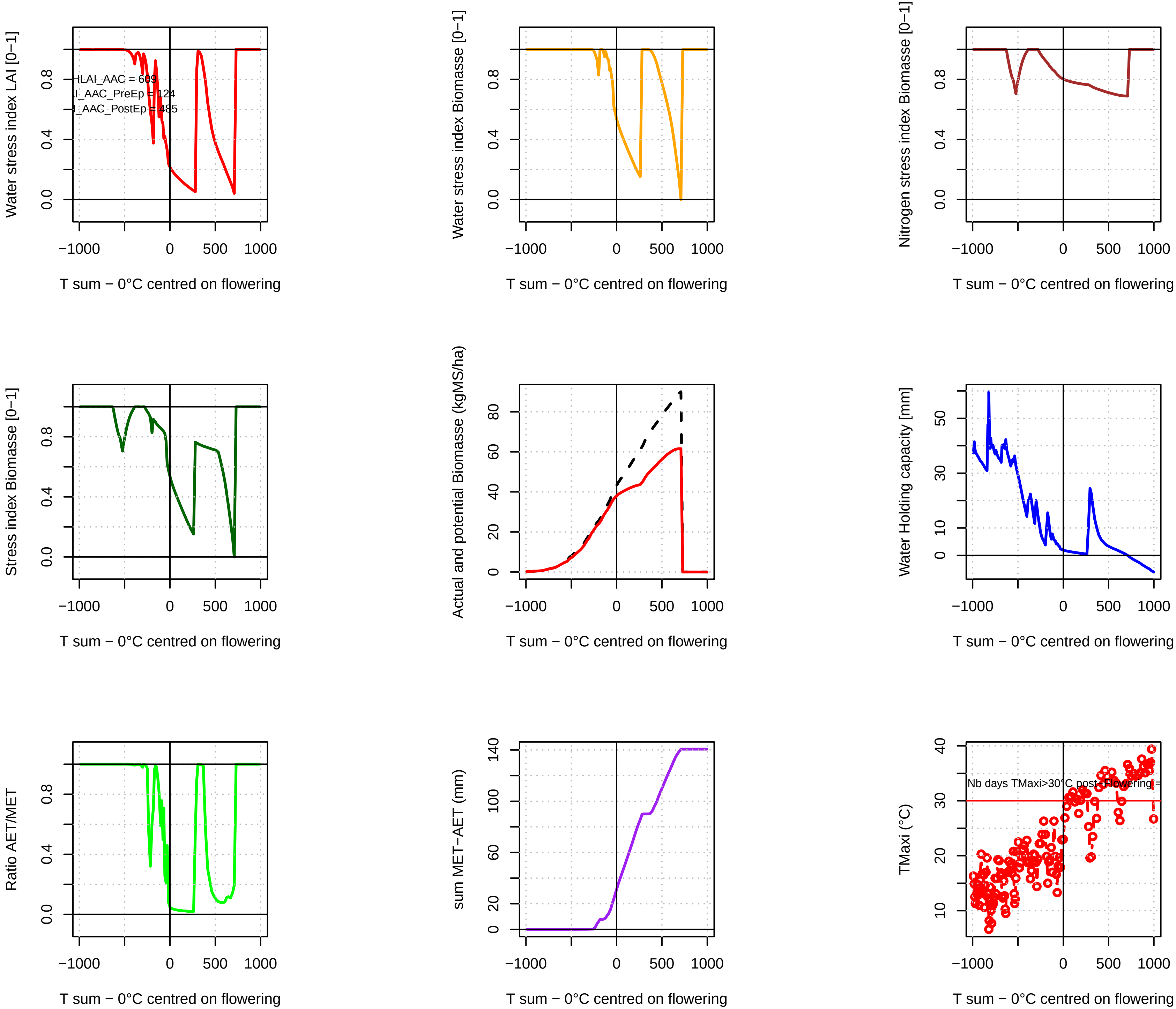
Algeria−S2Mezloug_2022_T1−F1−D1−C0−P0−R1



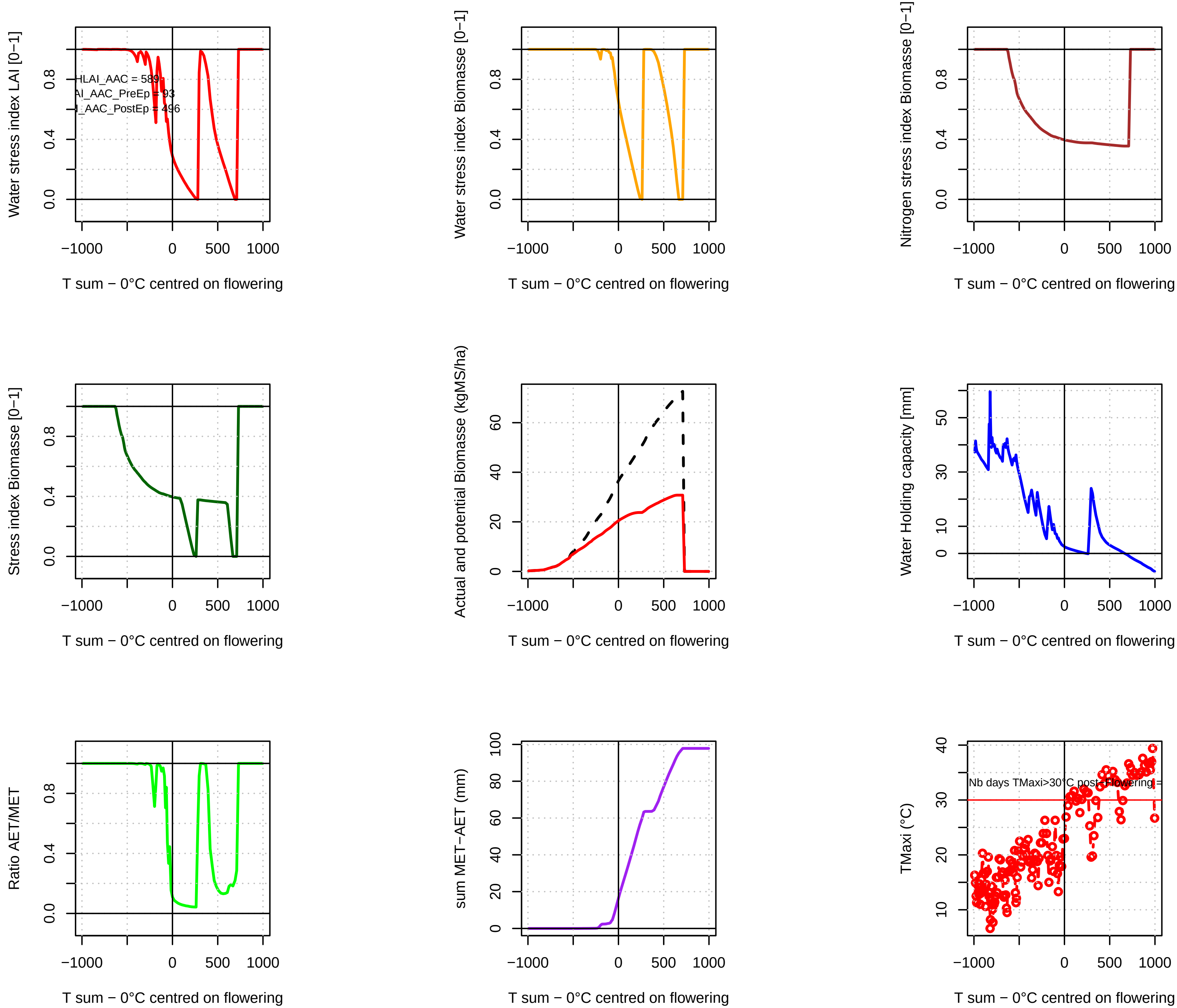
Algeria−S2Mezloug_2022_T1−F1−D2−C0−P0−R1



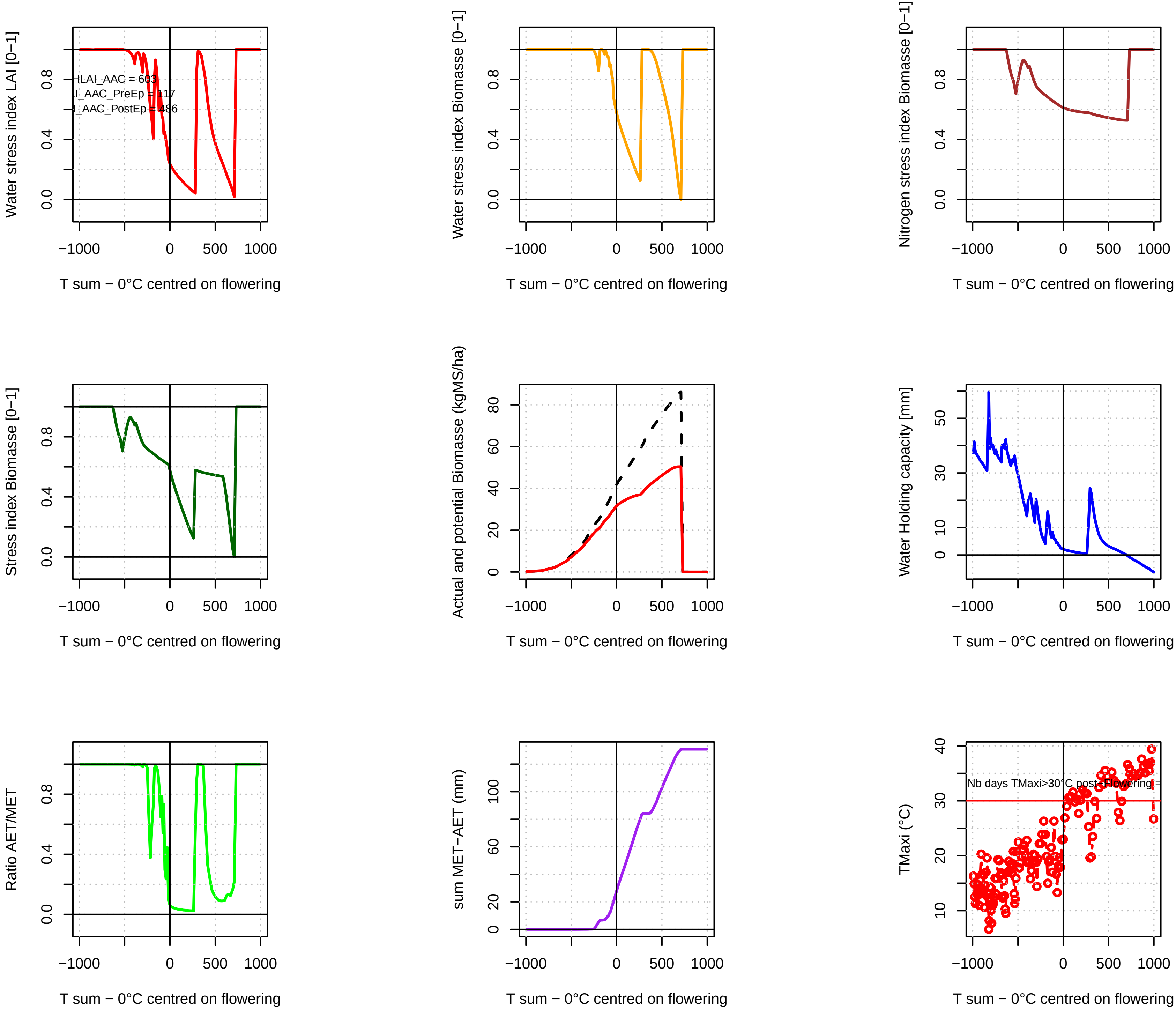
Algeria−S2Mezloug_2022_T1−F1−D3−C0−P0−R1



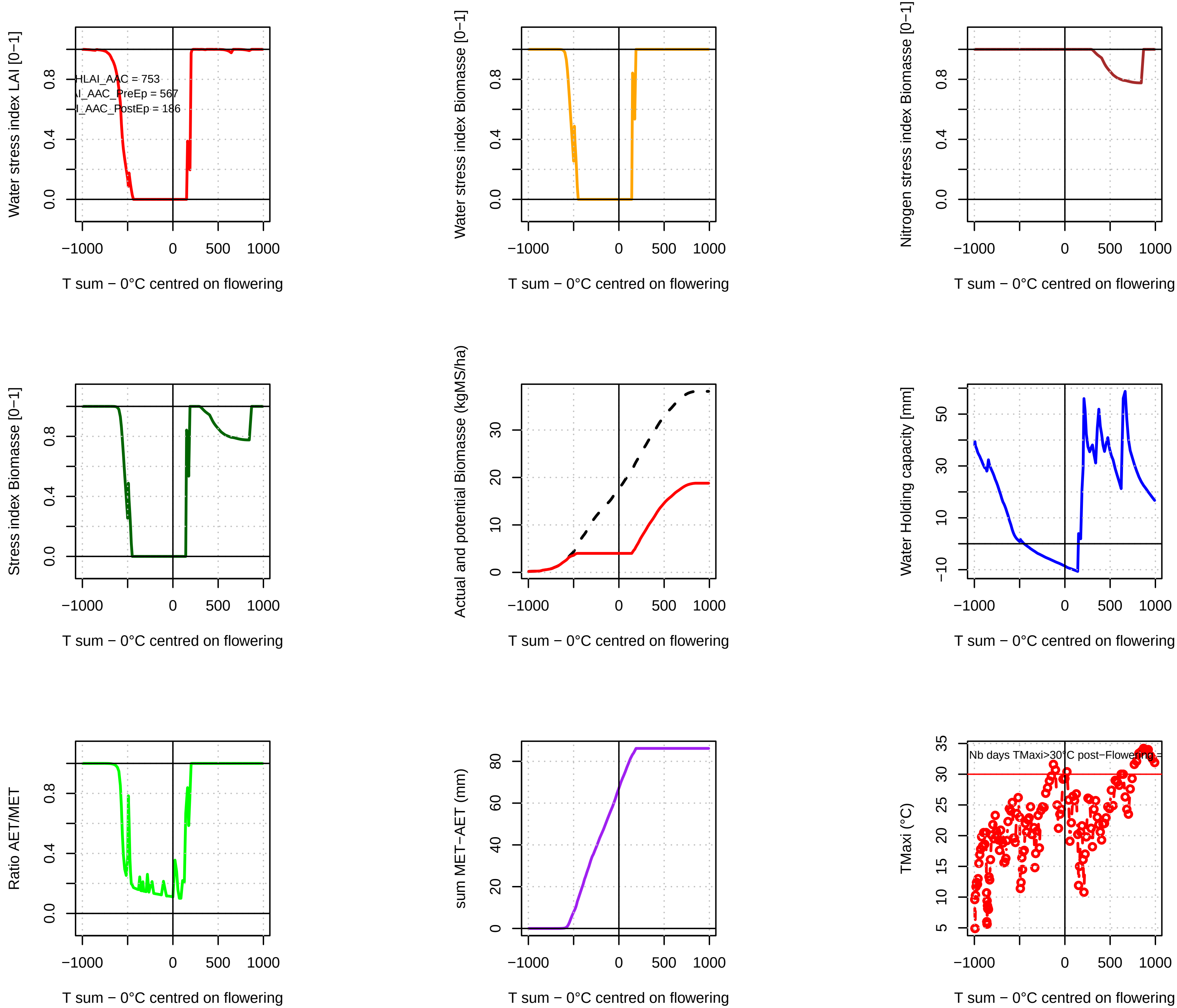
Algeria−S2Mezloug_2022_T1−F2−D1−C2−P0−R1



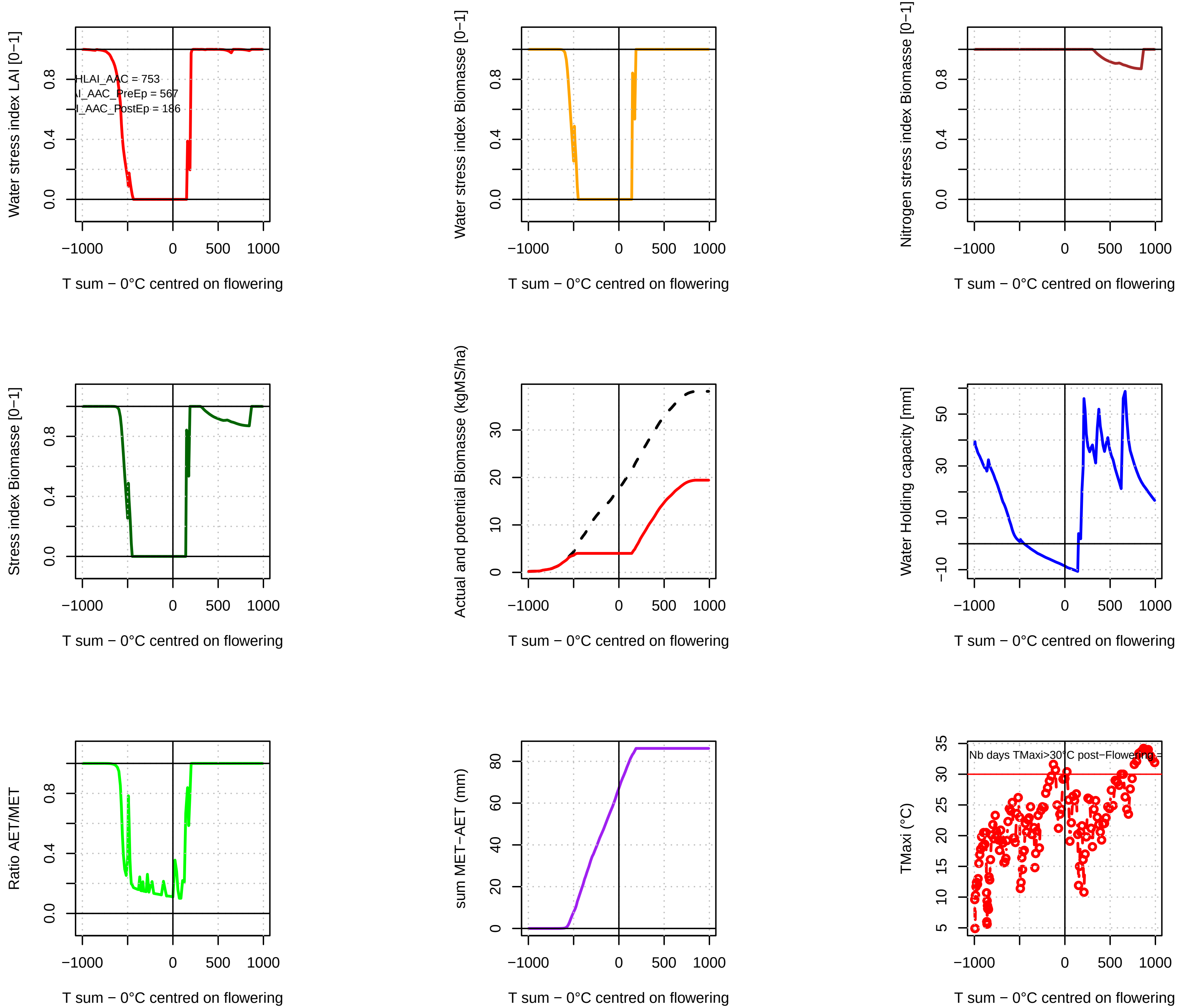
Algeria−S2Mezloug_2022_T1−F2−D2−C2−P0−R1



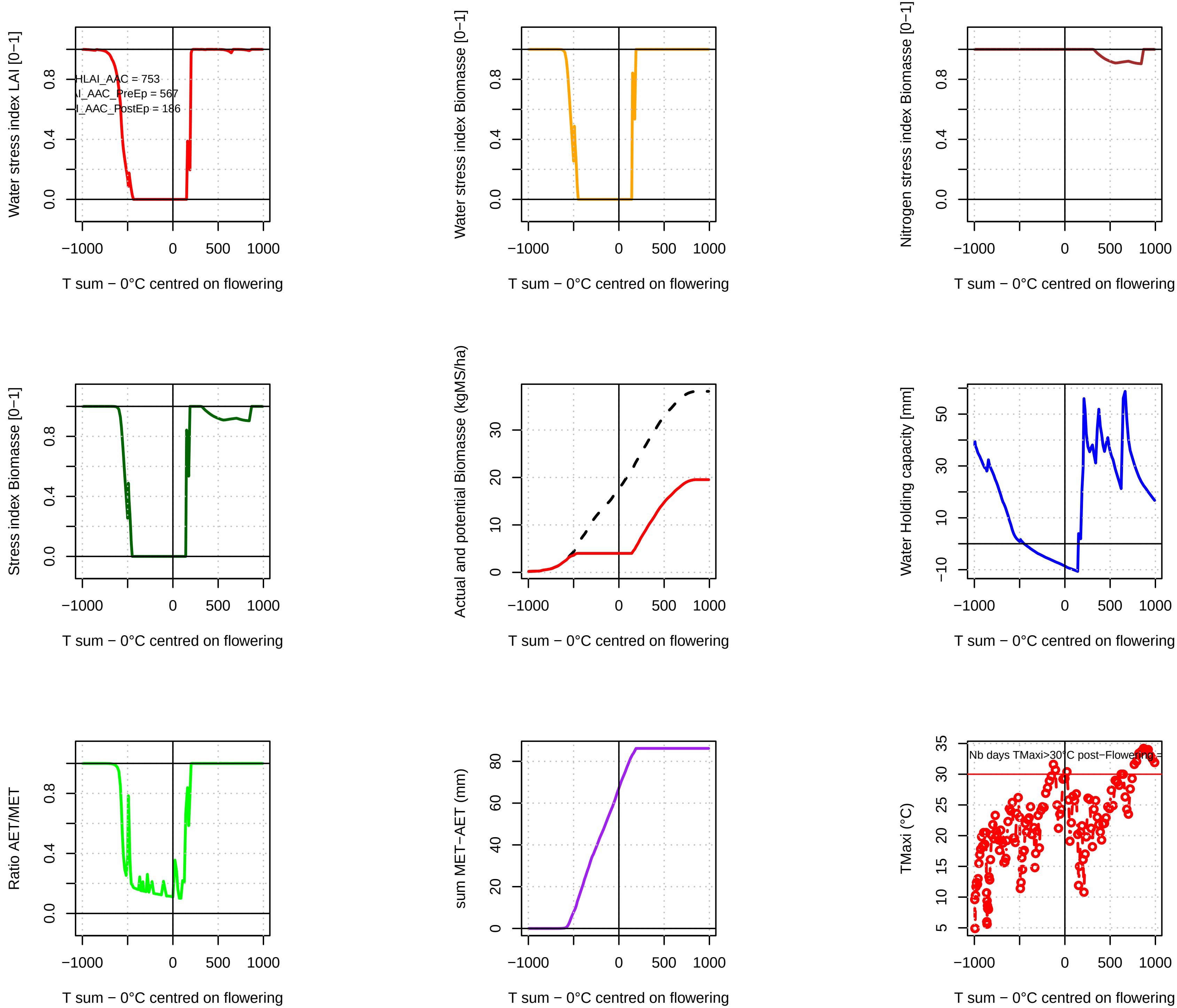
Algeria−S2Mezloug_2023_T1−F1−D1−C0−P0−R1



Algeria−S2Mezloug_2023_T1−F1−D2−C0−P0−R1



Algeria−S2Mezloug_2023_T1−F1−D3−C0−P0−R1



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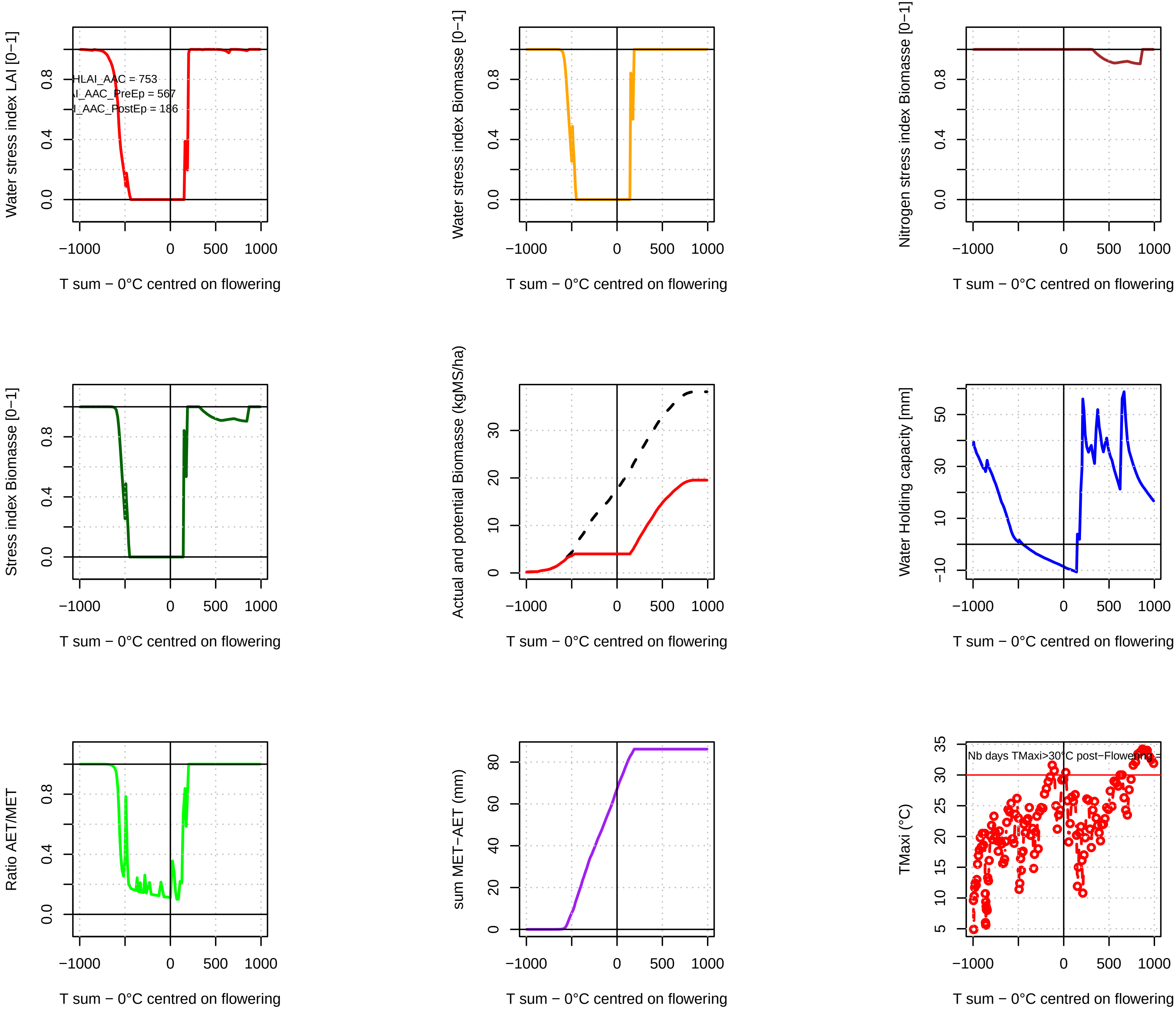

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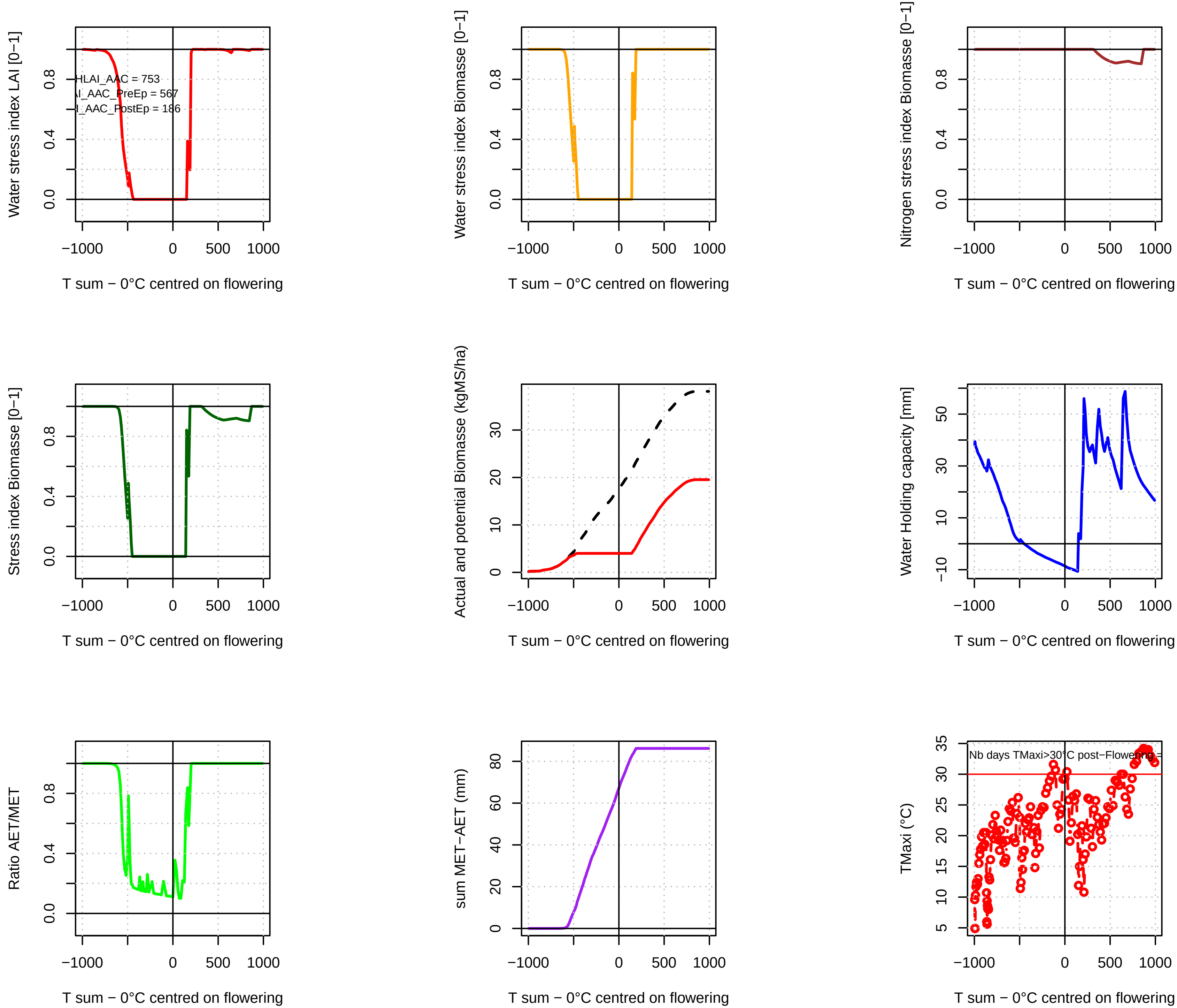
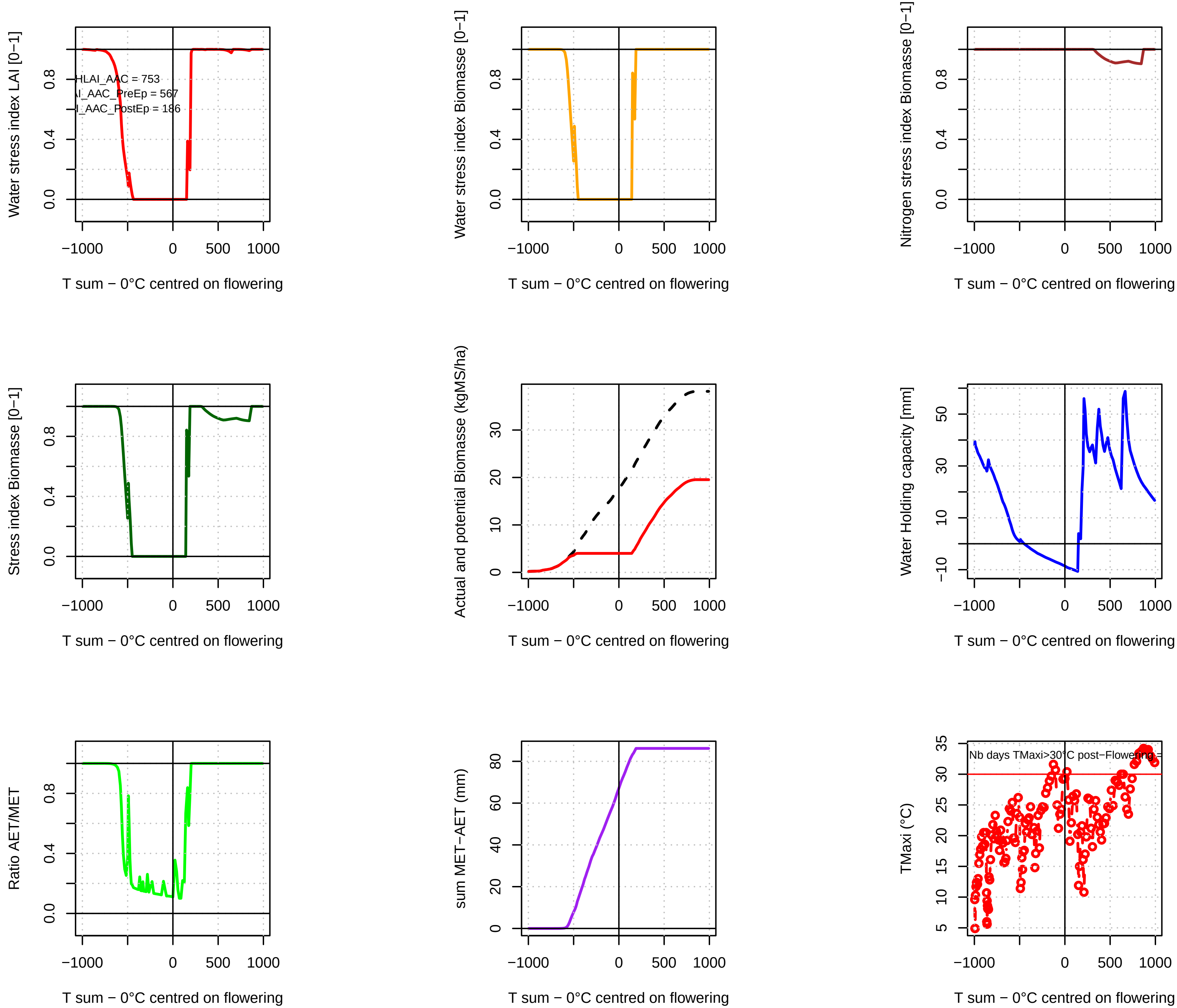
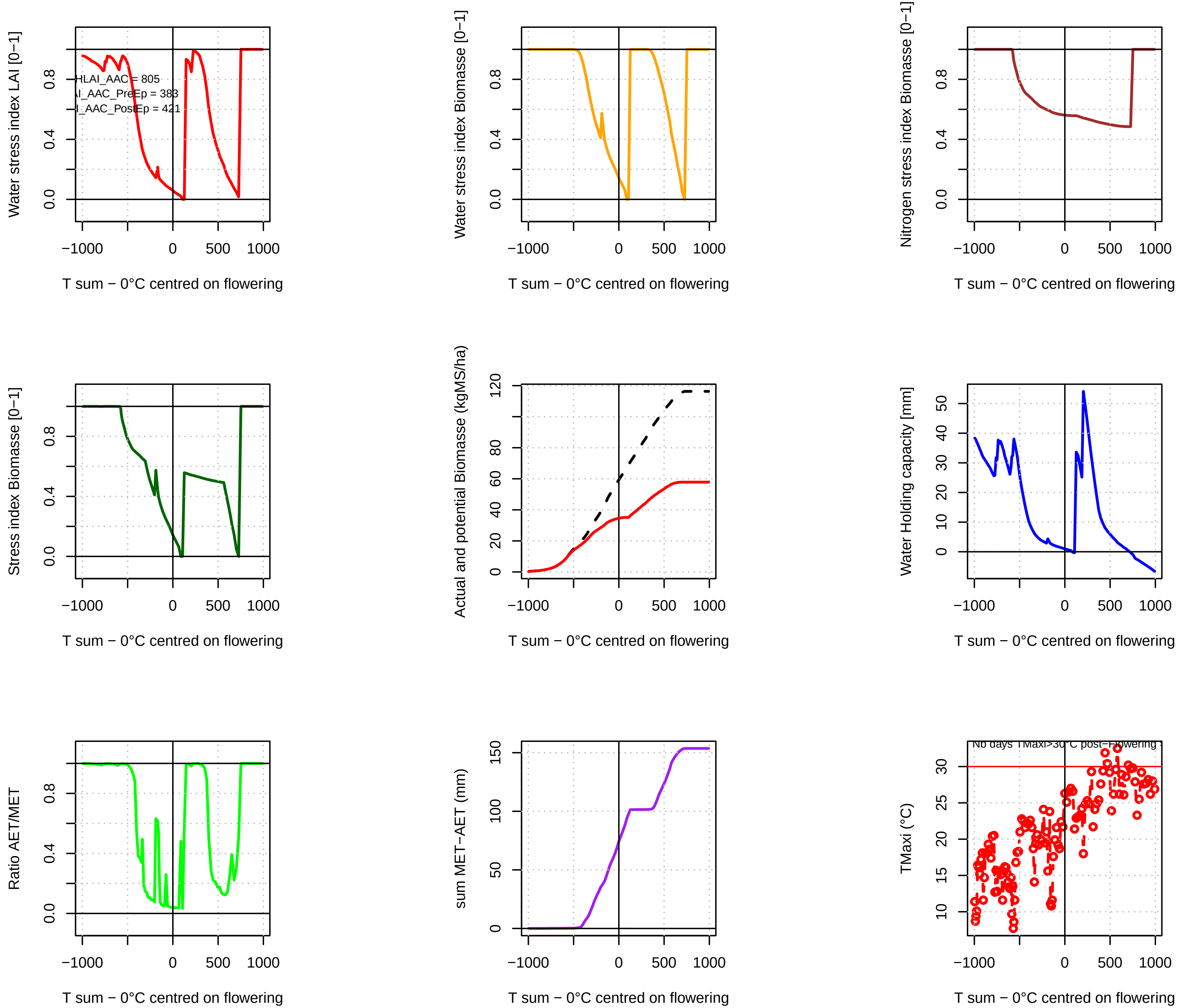
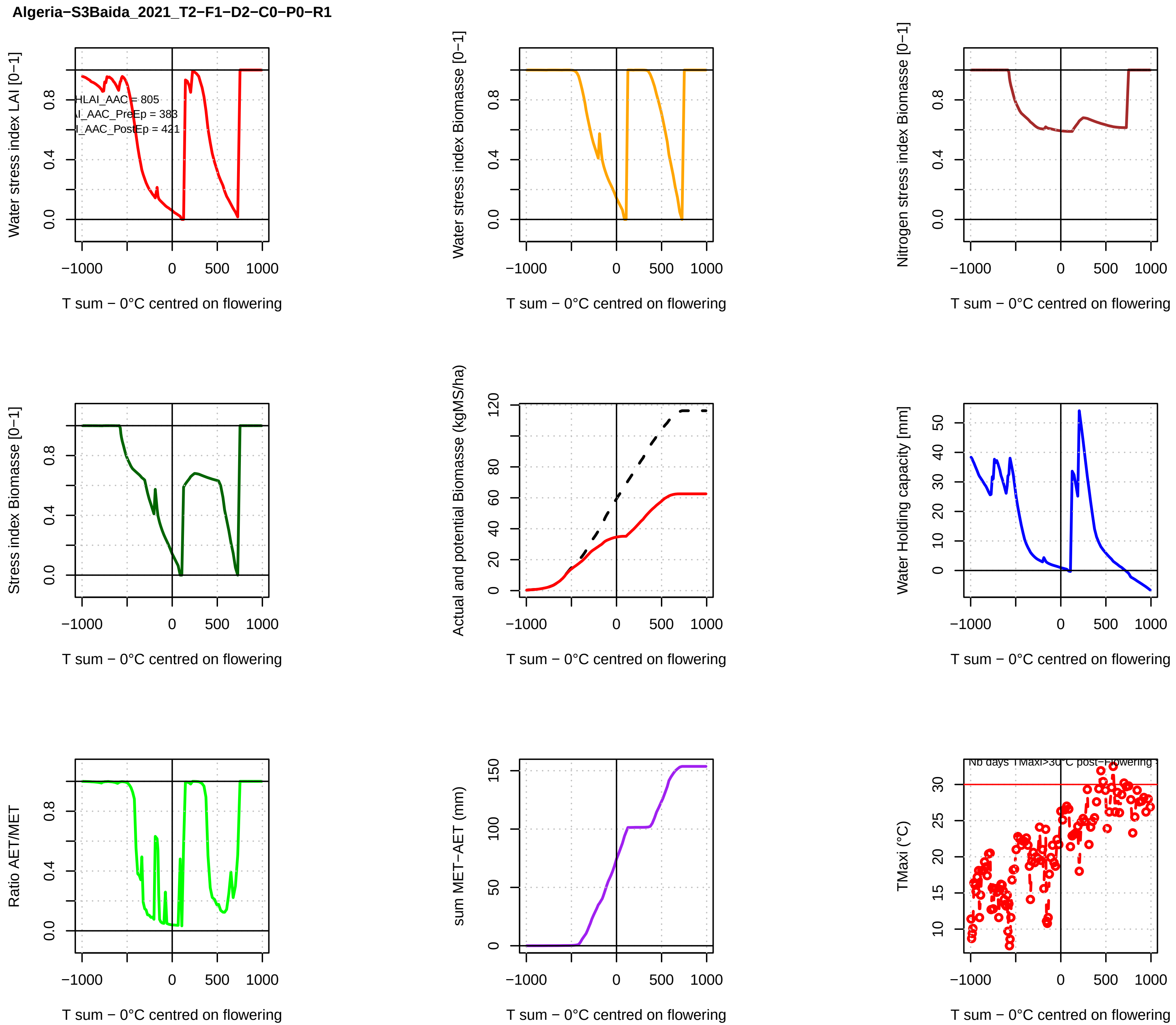


Algeria−S2Mezloug_2023_T1−F2−D3−C2−P0−R1

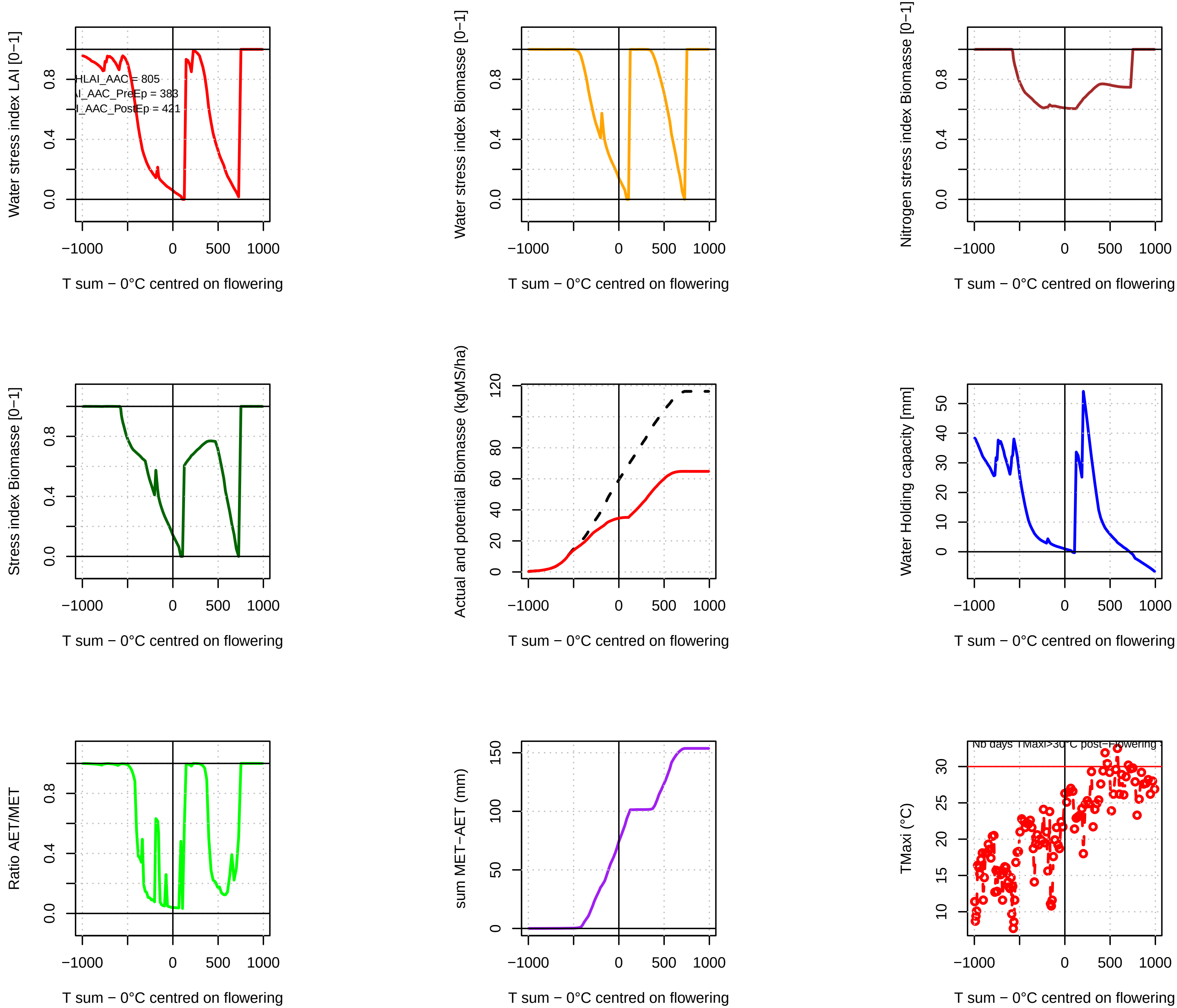


Algeria−S3Baida_2021_T2−F1−D1−C0−P0−R1

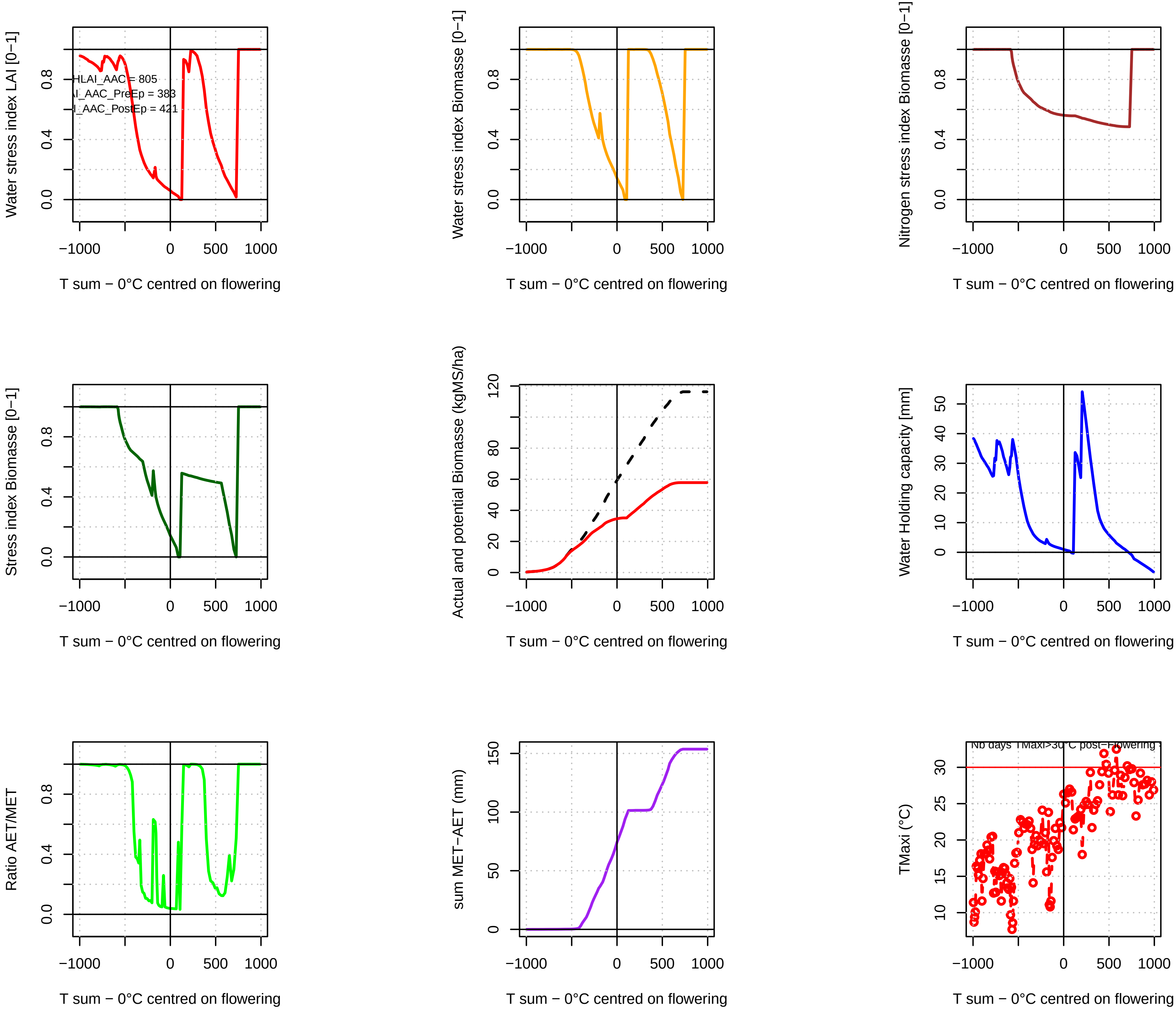



Algeria−S3Baida_2021_T2−F1−D2−C0−P0−R1
Water stress index LAI [0−1]
HLAI_AAC = 805
I_AAC_PreEp = 383
I_AAC_PostEp = 421
Water stress index Biomasse [0−1]
Nitrogen stress index Biomasse [0−1]
Stress index Biomasse [0−1]
Actual and potential Biomasse (kgMS/ha)
Water Holding capacity [mm]
Ratio AET/MET
sum MET−AET (mm)
TMaxi (°C)
Nb days TMaxi>30°C post−Flowering
T sum − 0°C centred on flowering
−1000
0
500
1000

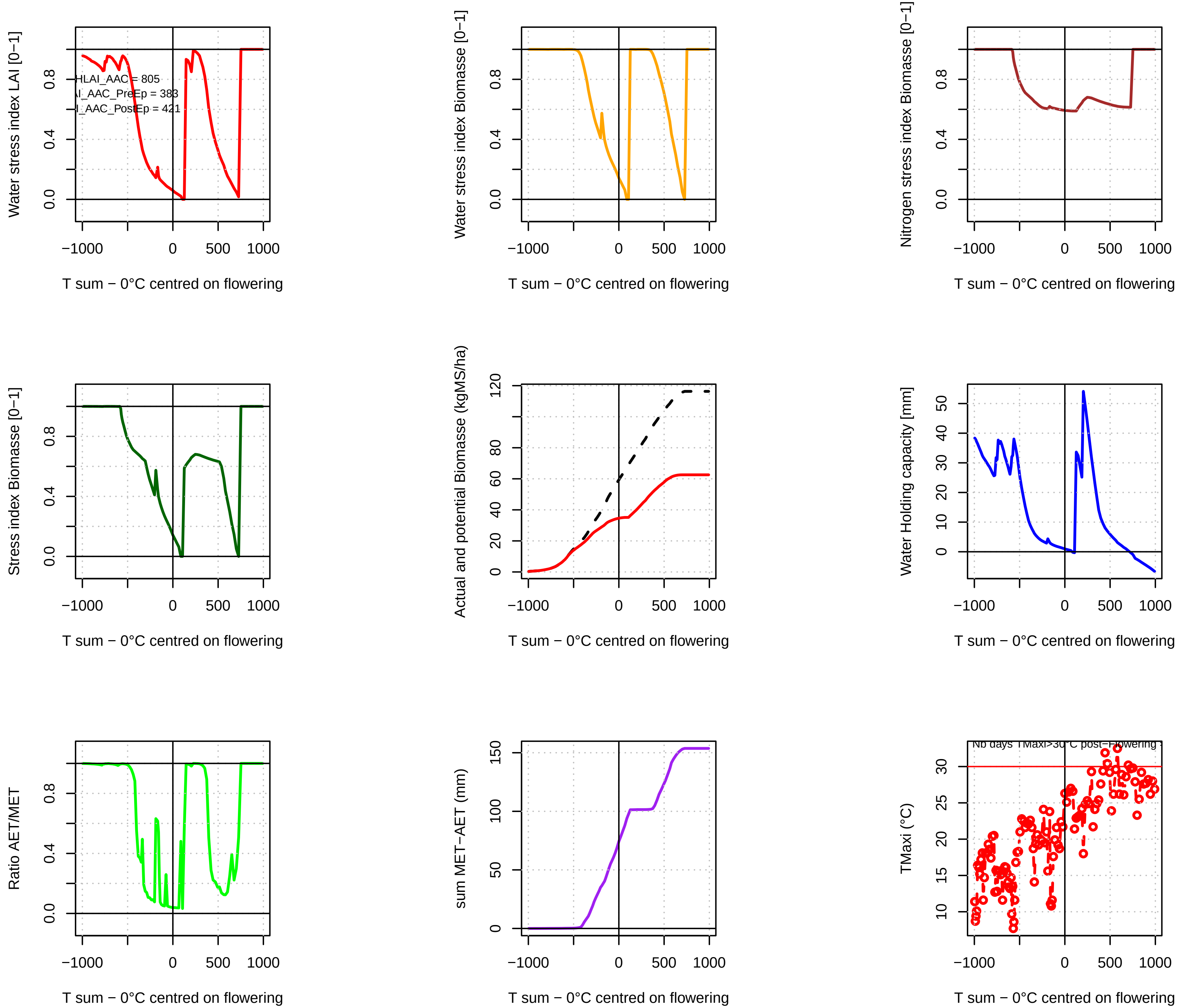
Algeria−S3Baida_2021_T2−F1−D3−C0−P0−R1

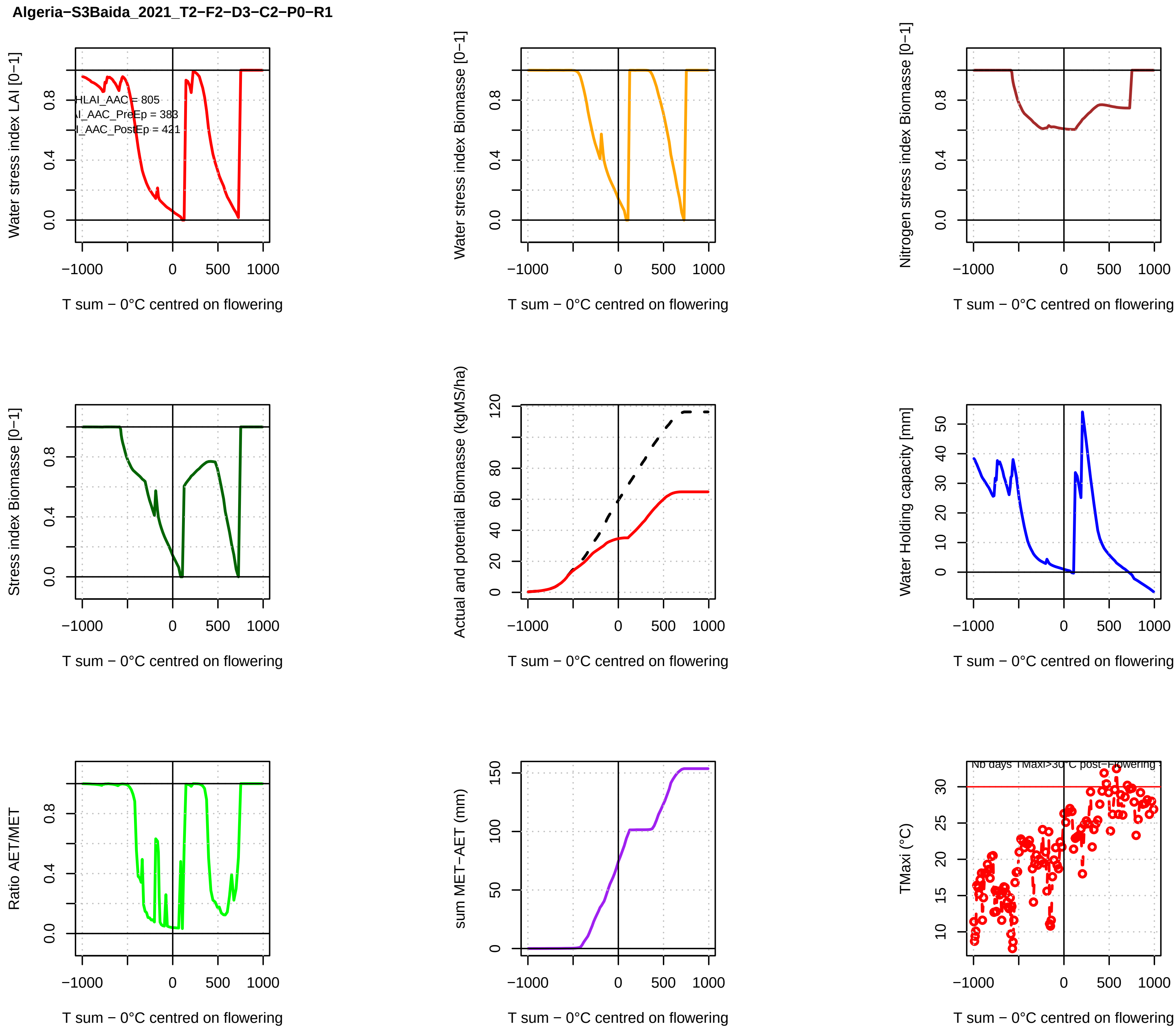


Algeria−S3Baida_2021_T2−F2−D1−C2−P0−R1

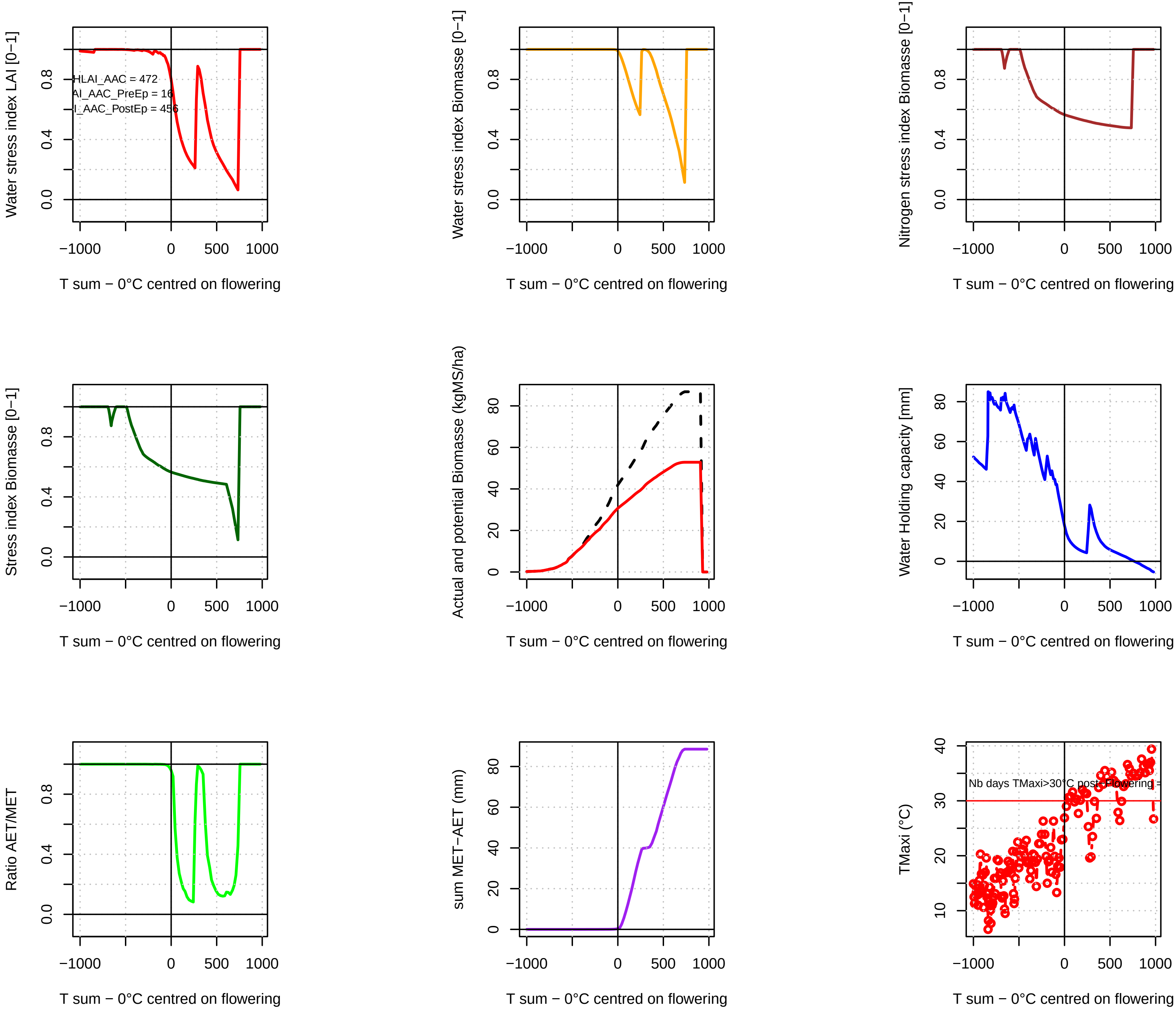


Algeria−S3Baida_2021_T2−F2−D2−C2−P0−R1

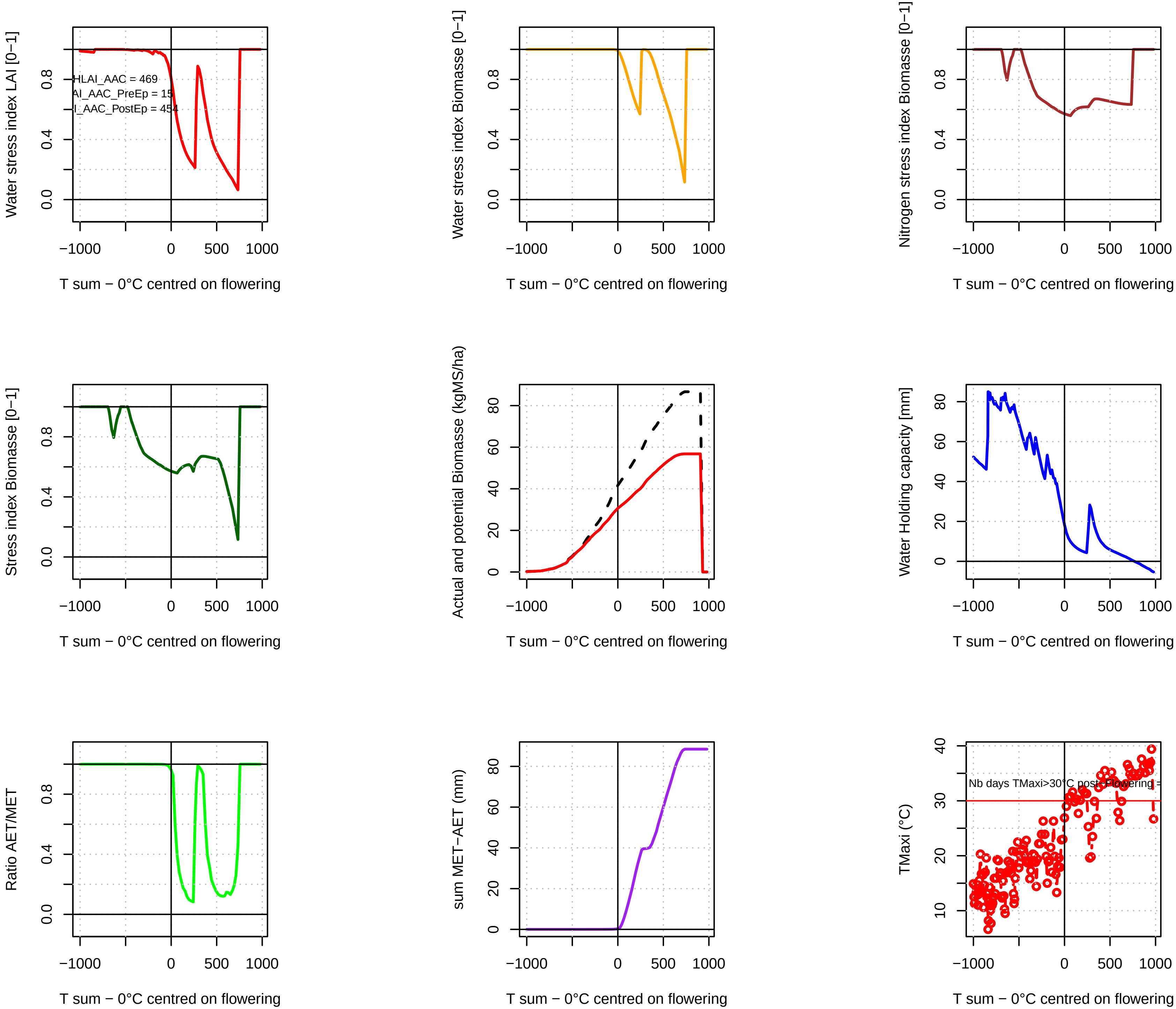



Algeria−S3Baida_2021_T2−F2−D3−C2−P0−R1
Water stress index LAI [0−1]
HLAI_AAC = 805
AI_AAC_PreEp = 383
I_AAC_PostEp = 421
Water stress index Biomasse [0−1]
Nitrogen stress index Biomasse [0−1]
Stress index Biomasse [0−1]
Actual and potential Biomasse (kgMS/ha)
Water Holding capacity [mm]
Ratio AET/MET
sum MET−AET (mm)
TMaxi (°C)
Nb days TMaxi>30°C post−Flowering
T sum − 0°C centred on flowering
−1000
0
500
1000

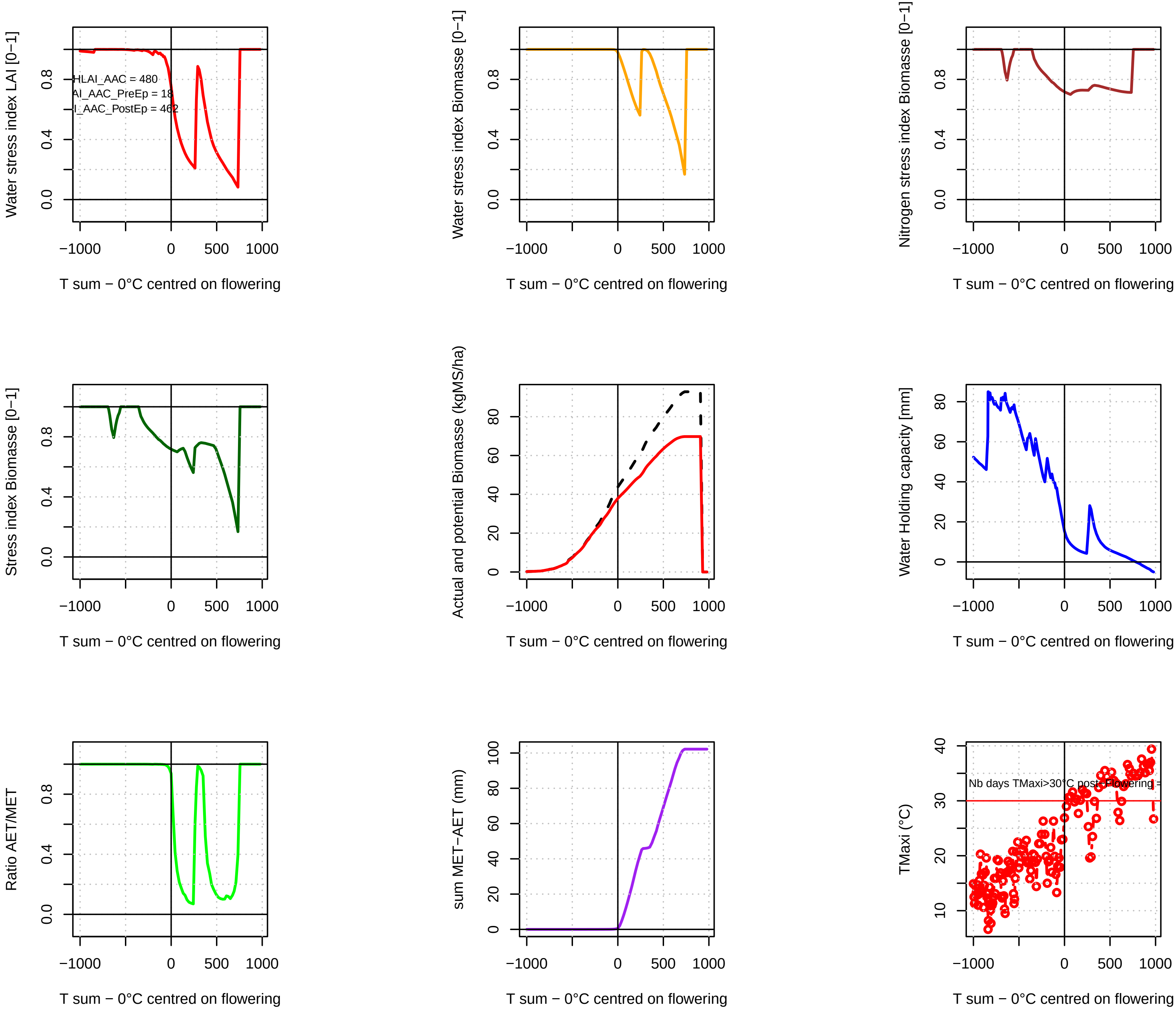
Algeria−S3Baida_2022_T2−F1−D1−C0−P0−R1



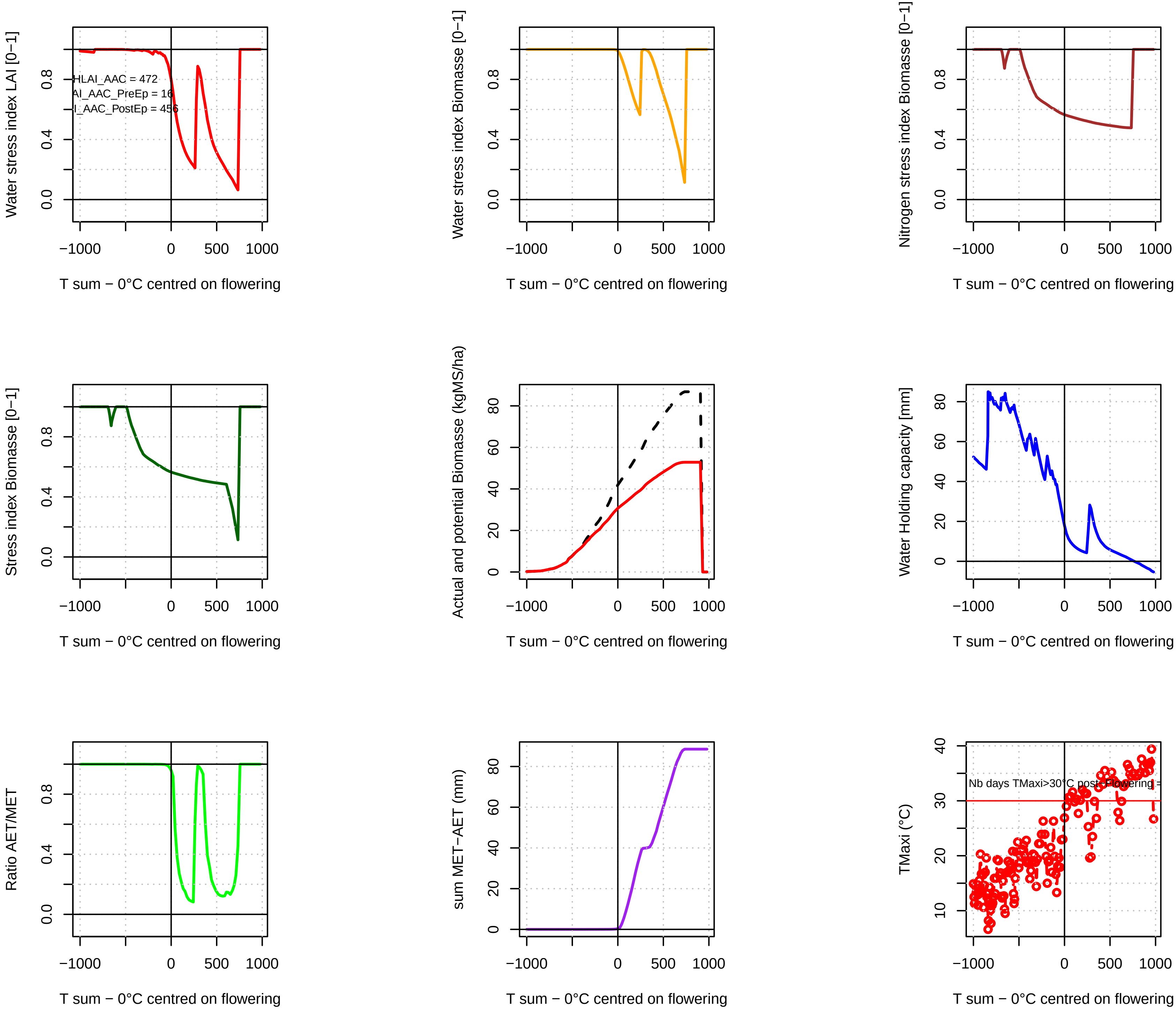
Algeria−S3Baida_2022_T2−F1−D2−C0−P0−R1



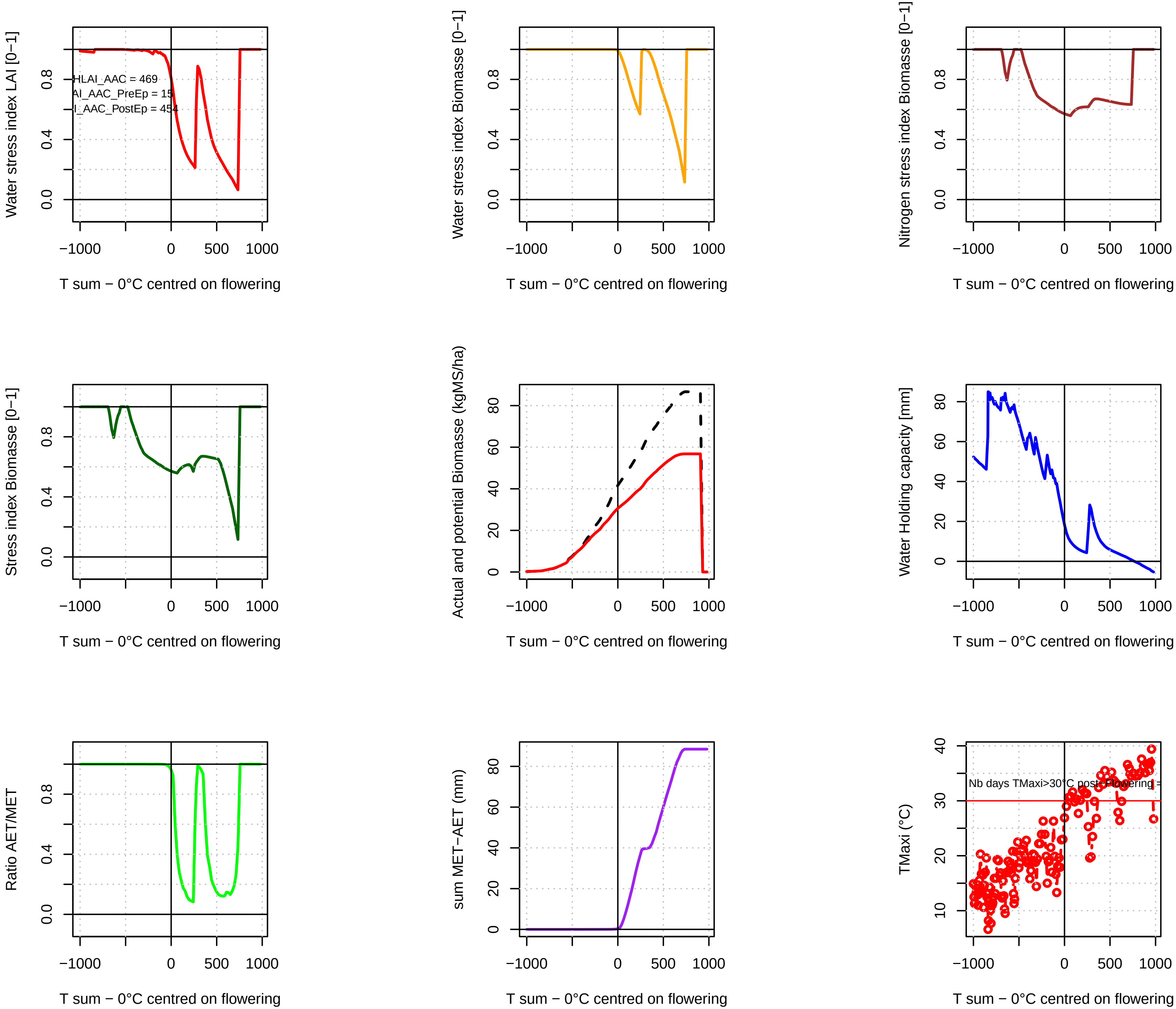
Algeria−S3Baida_2022_T2−F1−D3−C0−P0−R1



Algeria−S3Baida_2022_T2−F2−D1−C2−P0−R1



Algeria−S3Baida_2022_T2−F2−D2−C2−P0−R1



Algeria−S3Baida_2022_T2−F2−D3−C2−P0−R1