Water Productivity Analysis: Rainfed Season 2021-2022

APSAN-Vale project

REPORT 238

CLIENT Agência de Desenvolvimento do Vale Zambeze (ADVZ)

AUTHORS
Lisa Verschuren
Tijmen Schults
Martijn de Klerk
Jonna van Opstal

DATE September 2022

Water Productivity Analysis: Rainfed Season 2021-2022

APSAN-Vale project

FutureWater Report 238

Client
Agência de Desenvolvimento do Vale Zambeze (ADVZ)

Authors
Lisa Verschuren – Hydrologist (l.verschuren@futurewater.nl)
Tijmen Schults – Hydrologist (t.schults@futurewater.nl)
Martijn de Klerk – Flying Sensor Expert, Project Manager (m.deklerk@futurewater.nl)
Jonna van Opstal – Senior Water Productivity Expert (j.vanopstal@futurewater.nl)

APSAN-Vale project partners
Resilience B.V.
HUB
ThirdEye Limitada

Date
September 2022

ADDRESS
FutureWater B.V.
Costerweg 1V
6702 AA Wageningen
The Netherlands

FutureWater

TELEPHONE +31 317 460 050
WEBSITE www.futurewater.eu

Preface

The APSAN-Vale project aims to increase climate resilient agricultural productivity and food security, with a specific objective to increase the water productivity and profitability of smallholder farmers in Mozambique. The project prioritises small (family sector) farmers to increase food and nutritional security, and will demonstrate the best combinations of adoption strategies and technological packages. The impact of the adopted strategies or technological packages is assessed on the farming plot level, sub-basin, as well as basin level. The main role of FutureWater is monitoring water productivity in the target areas (both spatial and seasonal/annual variation) using remote sensing data from Flying Sensors (drones), satellite imagery, and WaPOR data portal in combination with a water productivity simulation model and field observations. This report shows the water productivity analysis for the 2021-2022 rainfed season (November 2021 – May 2022) in three different locations in Mozambique. This analysis is crucial to evaluate the impact of field interventions on water productivity.

Summary

Farmers are seeking best practices that can achieve higher crop yields, thus profits and food security. With limited resources such as water, the increase in production needs to be considered per unit of water consumed, which is expressed in the term 'Water Productivity'. Water productivity can be used as a performance indicator to monitor changes in an agricultural area (at plot, farm, or irrigation system level). If interventions are implemented, water productivity can indicate if the intervention had a positive or negative impact on the use of water or if it remained unchanged. This report provides an assessment of the water productivity during the rainfed growing season of 2021 – 2022 (December to April) for the APSAN-Vale project areas.

Various methods were used to provide a reliable assessment of the water productivity, such as using the data available from the field, flying sensor imagery, and open-access remote sensing datasets from WaPOR and Sentinel 2. The satellite remote sensing data was used supplemental to flying sensor imagery to capture more frequently the crop development and fill in the gaps between the monthly intervals of the flying sensor imagery intervals. The supplemental data provided by Sentinel 2 imagery is useful for a better determination of the crop curve.

At field scale the crop-specific water productivity is calculated using flying sensor (drone) and satellite imagery, and AquaCrop model simulations. The flying sensors used are equipped with a near-infrared camera for detection of the vegetation status. These images are processed and translated to canopy cover values. Ultimately, the images of the flying sensors were combined with the Sentinel 2 imagery, to determine the maximum canopy cover. In AquaCrop the field data and maximum canopy cover from flying sensors and Sentinel 2 are used to simulate the farming practices for each field, to determine yield and water productivity. At sub-basin and basin scale the biomass water productivity is calculated using data from FAO's water productivity data portal WaPOR (http://wapor.apps.fao.org).

During the 2021-2022 rainfed season a total of 168 flying sensor flights were performed over 32 farm fields, covering a total of 460 ha. In the end, for the water productivity analysis, data from 23 farmers was used: 9 in Báruè, 6 in Moatize, and 8 in Nhamatanda. The results of the flying sensor imagery acquired throughout the season are presented in printed field maps and shared through our online portal. Over the past year, substantial efforts were made to disseminate the maps made by ThirdEye's AgPilots (or flying sensor operators) for a larger public online, through the APSAN-Vale Flying Sensor portal. The portal can be accessed through https://futurewater.eu/apsanvaleportal/.

The field scale water productivity presented results for 23 farmers which were monitored throughout the rainfed season as part of the APSAN-Vale project. The water productivity was calculated only for maize, as maize is a typical rainfed crop. Maize water productivity was found to range from 0.70 to 0.87 kg/m3 kg/m3 in Báruè, 0.60 to 0.76 kg/m3 in Moatize, 0.51-0.74 kg/m3 in Nhamatanda. After normalization for climatic conditions, the increase in overall crop specific water productivity was found to be +95% in Báruè, +87% in Moatize, and +95% in Nhamatanda, resulting in an average +92% increase in comparison with the baseline values. This is a +24% increase compared to the previous rainfed season report (2020-2021) and achieves the set target for 2021-2022 of +25% as stated in the project logframe.

Furthermore, the water productivity was calculated at sub-basin scale, which is representative for the community of farmers adopting practices being demonstrated and promoted by the selected PPCs (Pequenos Produtores Comercial, small commercial farmers). An area of 300 ha around each selected PPC is determined to be representative for the area of the sub-basin (or community). At sub-basin scale the water productivity analysis makes use of the WaPOR data portal and calculates the biomass water productivity. The highest water productivity values were found in Báruè; here the highest values are observed in Báruè I of 1.79 kg/m3. The biomass water productivity was found to range from 1.60 to 1.79

kg/m3 in Báruè, 0.88 to 1.06 kg/m3 in Moatize, and 0.88 to 1.18 kg/m3 in Nhamatanda. The relative change of water productivity compared to the baseline values is +30%, +40% and +48% for Báruè, Moatize, and Nhamatanda, respectively. The overall increase in water productivity estimated at the sub-basin (community) level is +39%.

At basin scale the catchment delineation from each district was used as the boundary of the basin. The water productivity was determined using the WaPOR data portal providing values on biomass water productivity. These values are compared with the baseline assessment and determined that an increase of water productivity was achieved of +30%, +20%, and +11% for Báruè, Moatize, and Nhamatanda respectively. The average increase in biomass water productivity was +20% for all districts together.

Content

List of Tables

List of Figures

1 Introduction

1.1 APSAN-Vale project description

The APSAN-Vale project started at the end of 2018 and is a 4.5-year project with the objective to: 'Pilot innovations to increase the water productivity (WP) and Food Security for Climate Resilient smallholder agriculture in the Zambezi valley of Mozambique'. Water productivity is used as an indicator to quantify the impact of innovations on smallholder agriculture. These innovations can be technical packages (interventions and training), and the adoption of lessons learned through farmer-to-farmer communication. Information on water productivity needs to incorporate both temporal and spatial aspects. The temporal changes in water productivity indicate if an intervention increased water productivity. The spatial patterns in water productivity indicate if the knowledge is being adopted in the region and increased the overall water productivity of the locality, and district. Project activities take place in three districts namely: Báruè, Moatize, and Nhamatanda. Within each district, various localities are selected for piloting innovations. The location of the districts and current project activities are shown in Figure 1.

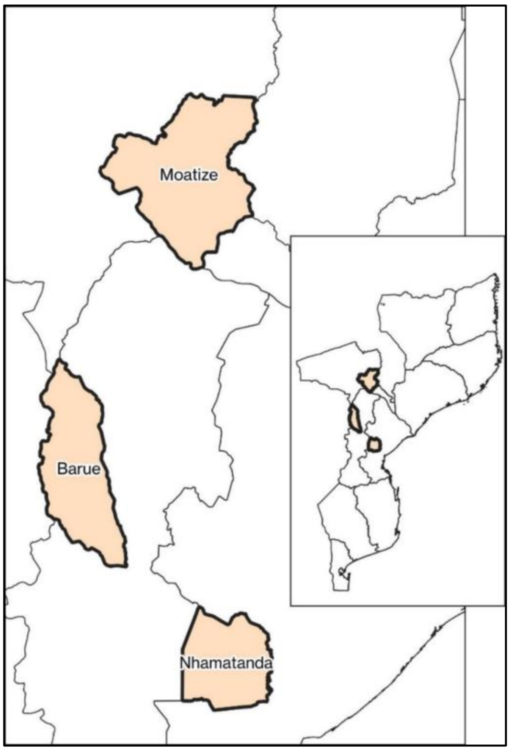


Figure 1. Location districts of APSAN-Vale project activities

1.2 Relevance of analysing water productivity

In order to meet the future needs of food and fibre production, developing and developed countries need to focus more on efficient and sustainable use of land and water (Bastiaanssen and Steduto, 2017)[1]. Farmers have been able to gain profit by increasing agricultural production per unit of land. However, it is key to include the water consumption component in agricultural production. This would allow for improving agricultural production per unit of water consumed.

Water productivity can be used as a performance indicator to monitor changes in an agricultural area (at plot, farm, or irrigation system level). If interventions are implemented, water productivity can indicate if the intervention had a positive or negative impact on the use of water or remained unchanged. In addition, spatial information on water productivity can indicate areas that have higher performance (early adopters) and whether practices are taken over by other farmers.

1.3 Logframe indicators

Within the APSAN-Vale project, several logframe indicators were formulated. The indicators linked with the water productivity assessment are listed in Table 1. Some indicators require the calculation of crop-specific water productivity (1.2 and 1.3), whilst other indicators use biomass water productivity (1.4). The water productivity is calculated at field, sub-basin, and basin scales, thus providing the required maps at different spatial scales. The annual targets for the water productivity outcomes are percentages of

[1] Bastiaanssen, W. G. M. and Steduto, P.: The water productivity score (WPS) at global and regional level: Methodology and first results from remote sensing measurements of wheat, rice and maize, Sci. Total Environ., 575, 595–611, doi:10.1016/j.scitotenv.2016.09.032, 2017.

increase compared to the baseline assessment (Van Opstal and Kaune, 2020)2 and are indicated in Table 1 as cumulative values, whereas the output maps are the annual total for each year.

Table 1. Logframe indicators related to water productivity.

	#	Indicator	Baseline	Target 2019	Target 2020	Target 2021
Goal	0.3	Increased water productivity	0%	7.5%	15%	25%
Outcome	1.2	Water footprint for selected crops	0%	7.5%	15%	25%
	1.3	Water productivity for maize	0%	7.5%	15%	25%
	1.4	Biomass water productivity	0%	7.5%	15%	25%
Outputs	1.1.1	# of field-level maps	0	30	60	60
	1.1.2	# of sub-basin level maps	0	10	20	20
	1.1.3	# of basin level maps	0	6	12	12

1.4 Season overview

The rainfed growing season started at the end of November 2021 and ended in May 2022. The sole crop that was analysed during this season was maize, as this was the only crop that was cultivated by the farmers this season. Harvest occurs throughout the season at different times depending on the growing length of the crops, local climate conditions, and management strategies. The flying sensor activities occurred with flights taken once every 3-4 weeks with the total number of flights, flight area, and farmers monitored, presented in Table 2. In the end, for the water productivity analysis, data from 23 farmers was used.

Table 2. Overview of the number of flights made and farmers monitored during this season

	Báruè	Moatize	Nhamatanda	Total
Flights taken	64	61	42	167
Farmers monitored	10	7	8	25
Area covered	200 ha	140 ha	160 ha	500 ha
Farmers monitored for WP	9	6	8	23

1.5 Project locations

1.5.1 Fields

For each district, several small commercial farmers (Pequenos Produtores Comercial or PPCs) were selected for the project to implement numerous innovative practices (boas practicas) for boosting water productivity. Most of the selected PPCs were monitored with flying sensor flights. In Báruè, Moatize, and Nhamatanda, nine, six, and eight PPCs respectively were monitored for the water productivity analysis. The locations of the PPCs monitored during the irrigation season are visualised in Figure 2.

[2] Van Opstal, J.D., A. Kaune. 2020. Water Productivity Technical Report - Baseline assessment for APSAN-Vale project. FutureWater Report 195

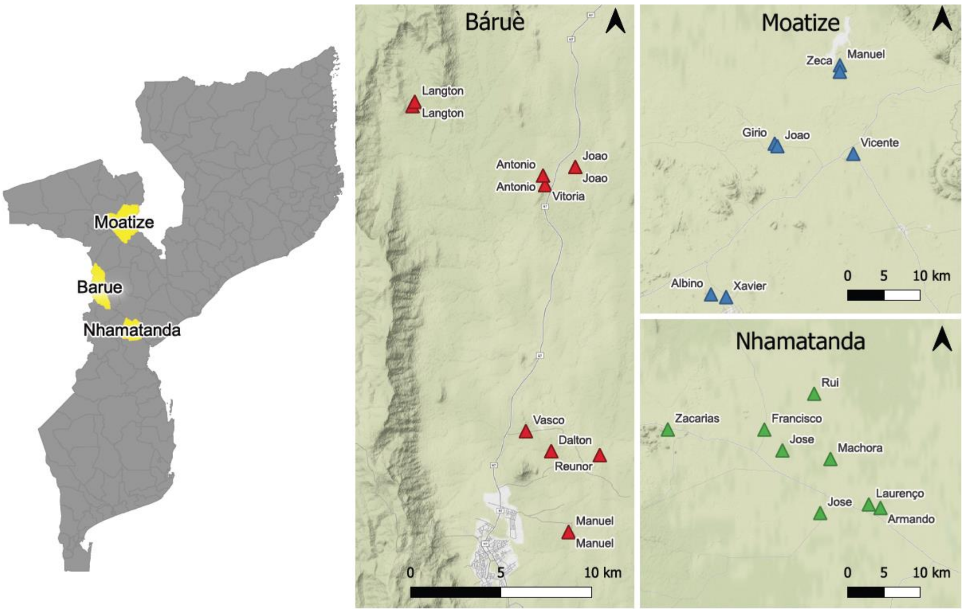


Figure 2. Location of selected PPCs monitored with flying sensor flights during the 2021-2022 rainfed season

1.5.2 Sub-basins

The sub-basin scale is the spatial scale between the field scale of the PPCs and the basin scale as described in Section 2.1.3. For the analysis of the sub-basin level water productivity, a representative size is selected of local communities surrounding the PPCs. The objective of the APSAN-Vale project is to increase the water productivity of several communities through knowledge exchange of the interventions being implemented. It is expected that communities surrounding the PPCs will adopt certain best practices. Therefore, the increase in water productivity is best monitored at a scale that captures the change in the communities. The sub-basin or community area is selected using a buffer of approximately 300 ha radius surrounding the selected PPCs. The locations of these communities are presented in Figures 3, 4, and, 5 for Báruè, Moatize, and Nhamatanda, respectively. Each has selected 3 to 4 clusters at the location of the PPCs.

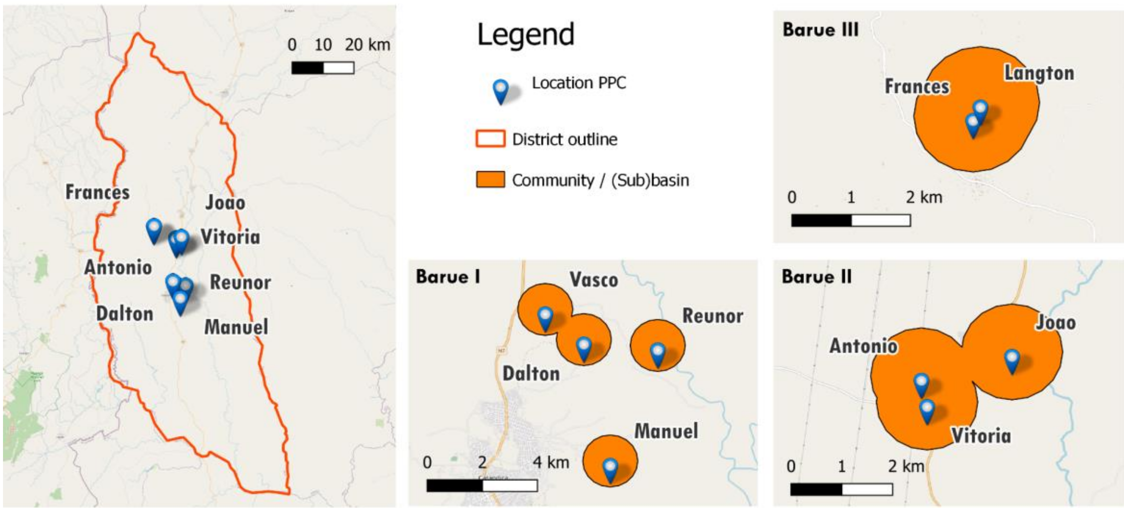


Figure 3. Location and boundaries of sub-basin areas in Báruè

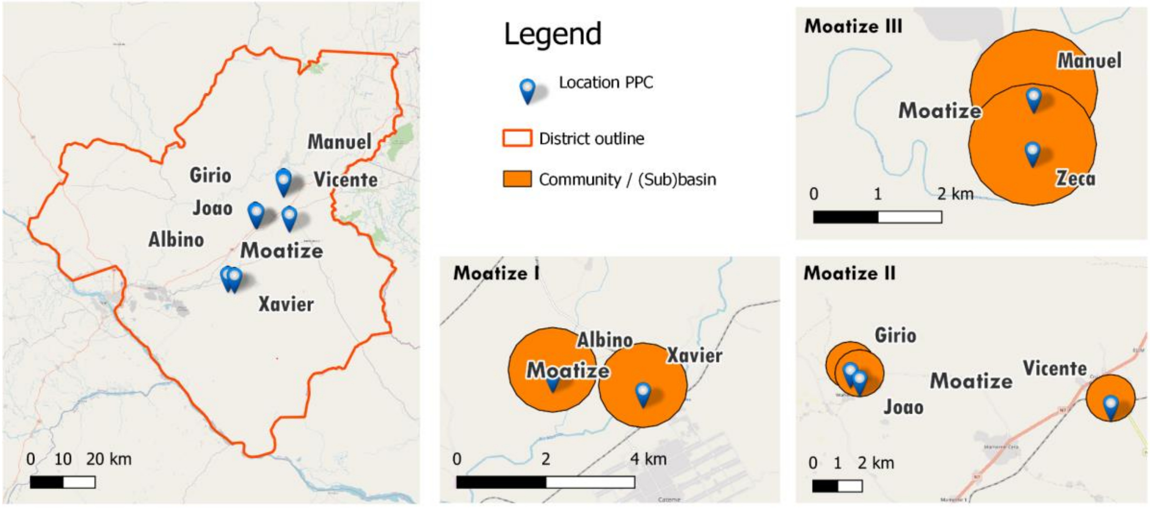


Figure 4. Location and boundaries of sub-basin areas in Moatize

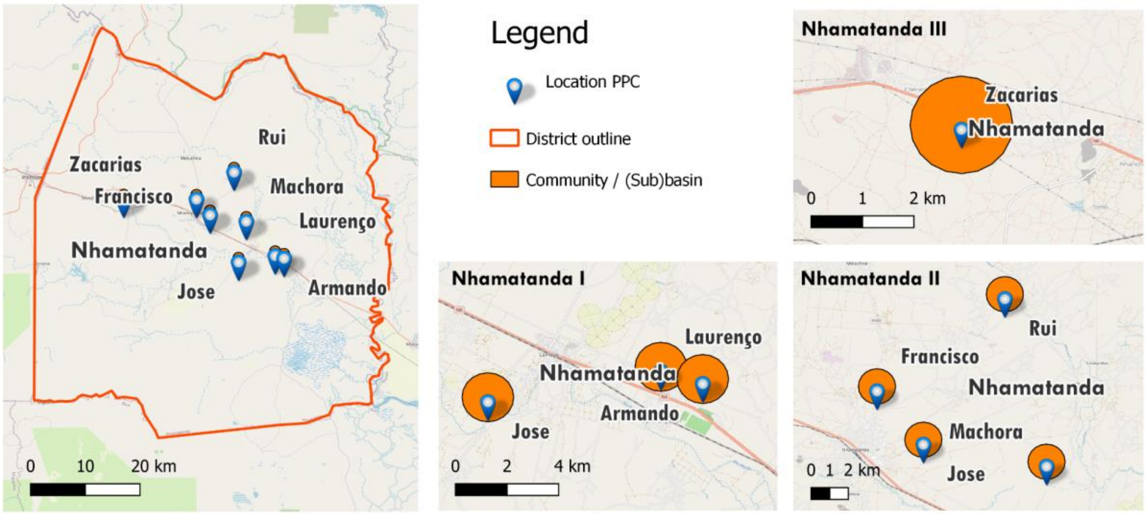


Figure 5. Location and boundaries of sub-basin areas in Nhamatanda

1.5.3 Basins

The basin delineation was performed using a Digital Elevation Model (DEM) at 30m resolution provided by the Shuttle Radar Topography Mission (SRTM) of NASA, and QGIS tools. Details on the steps involved can be reviewed in the manual (Kwast and Menke, 2019)[3]. The outflow points for the basins are determined by evaluating the location of the project activities in the fields, as were determined at the start of the project[4]. The sub-basins are representative of the localities of the project, whereas the basins represent the larger picture of the upstream area. The delineations and locations of project activities are shown in the maps in Figure 6. Measurements of water flow were conducted by project partners at strategic locations in the streams to quantify water abstractions for irrigation.

[3] van der Kwast, H. & Menke, K., QGIS for Hydrological Applications - Recipes for Catchment Hydrology and Water Management, Locate Press, 2019.
[4] Van Opstal, J.D., A. Kaune. 2020. Water Productivity Technical Report - Baseline assessment for APSAN-Vale project. FutureWater Report 195.

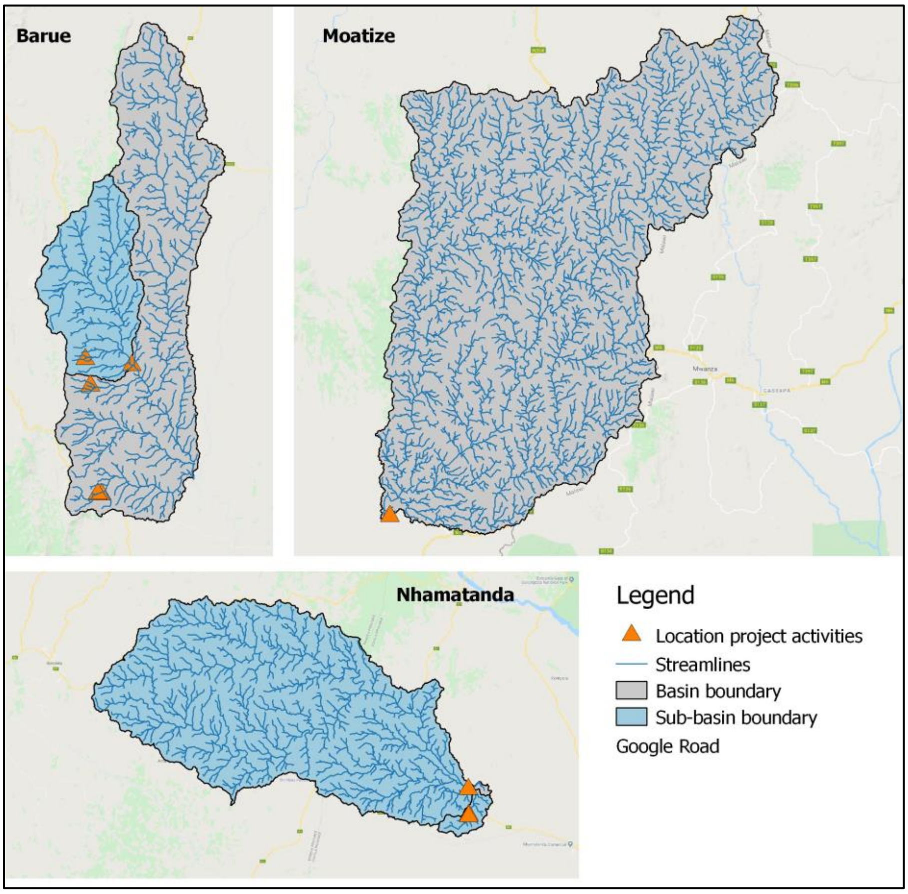


Figure 6. Delineation of basins and streamlines for Báruè, Moatize, and Nhamatanda

1.6 Reading guide

This technical report provides the results of the water productivity analysis at field, sub-basin, and basin scale using Flying Sensor Imagery, crop modeling, and FAO's WaPOR database. The next chapter (chapter 2) elaborates on the methodology used for conducting the water productivity analysis. Chapter 3 provides an analysis of the meteorological conditions during the growing season and compares it with past years. Chapters 4, 5, and 6 provide the results of the water productivity analysis at the field, sub-basin, and basin scale respectively. Chapter 7 assesses the water productivity results and compares them with the baseline assessment values. Chapter 8 provides the summarizing and concluding remarks.

2 Methodology

2.1 Approach

2.1.1 Water productivity concept

Water productivity consists of two components: production (either as crop yield or biomass) and water consumed. Water consumption occurs through evapotranspiration which is the sum of plant transpiration through the stomata in the leaves, and evaporation that occurs from the soil surface and intercepted water by the leaves (Squire, 2004)[5]. Within this project, the use of evapotranspiration (versus irrigation application) was selected, because it represents the component of the water balance that cannot be reused by downstream users in a river basin context. Return flows from agricultural areas (through runoff or subsurface flow) are available for re-use in the downstream areas if the quality of the water is sufficient. As such, water productivity can be expressed as:

$$Biomass\ water\ productivity\ [kg/m^3]\ = \frac{Biomass\ production\ [kg]}{Evapotranspiration\ [m^3]}$$

$$Crop\ specific\ water\ productivity\ [kg/m^3]\ = \frac{Crop\ harvestable\ yield\ [kg]}{Seasonal\ evapotranspiration\ [m^3]}$$

This water productivity assessment contains two approaches to measuring water productivity, at different scales:

1. Field scale water productivity: At the field scale, the most detailed information is available regarding crop type, planting and harvesting dates, and management strategies. At this scale, crop-specific water productivity was calculated for the selected crops at the three different districts using crop simulation modeling in combination with flying sensors and satellite imagery (Section 2.1.2).
2. Sub-basin and basin scale water productivity: At sub-basin and basin scales limited information is available on the spatial distribution of the crop types. At this scale biomass water productivity was calculated using data from WaPOR, FAO's Open Access Portal with water productivity data (Section 2.1.3).

2.1.2 Field scale water productivity

The crop-specific water productivity at field scale is determined by crop modelling using field observations and data retrieved from flying sensors and satellite imagery. Figure 7 displays the workflow for performing the crop-specific water productivity analysis. The water productivity is calculated with FAO's AquaCrop model. Field data for setting up the AquaCrop simulations are taken from the weather station and field notebooks. Flying sensors capture images at regular intervals to calculate the canopy cover. This dataset is supplemented with satellite (Sentinel 2) imagery for a higher frequency of data (at lower spatial resolution). This information is integrated with the AquaCrop model to calibrate the model and calculate water productivity. The advantage of combining remote sensing observations from flying sensors, satellite data, and simulation modeling, is that spatial insight is gained in the diversity of farm management practices. Thus, for each field, the most fitting AquaCrop simulation run is selected to be representative of that field. In the next sections, the various steps are elaborated on.

---

[5] Squire, G. L.: Water Productivity in Agriculture: Limits and Opportunities for Improvement. Edited by J. W. Kijne, R. Barker, D. Molden. Wallingford, UK: CABI Publishing (2003), pp. 352, ISBN 0-85199-669-8, Exp. Agric., 40(3), 395–395, doi:10.1017/S0014479704372054, 2004.

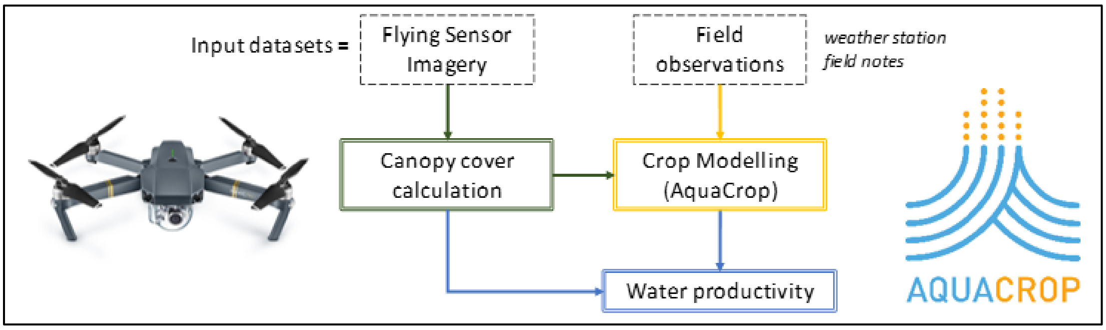


Figure 7. Workflow for calculation of crop-specific water productivity analysis

WaPOR is FAO's water productivity data portal (https://wapor.apps.fao.org) containing information on evapotranspiration, biomass production, land cover, and many other layers. Information at the basin scale was extracted by deriving a catchment delineation for the selected districts. This was performed using a DEM (digital elevation model). The catchment delineation is shown in Figure 6 for the selected areas.

2.1.3 Sub-basin and basin scale water productivity

The land cover layer in WaPOR was used to determine the location of croplands in the basins. The procedure for this analysis follows the guidance provided by the WaterPIP project (Water Productivity in Practice) and the workflow is schematically presented in Figure 8. In Section 2.7 the WaPOR datasets used for this analysis are described in more detail. At the sub-basin scale, similar layers are used for extracting information regarding water productivity.

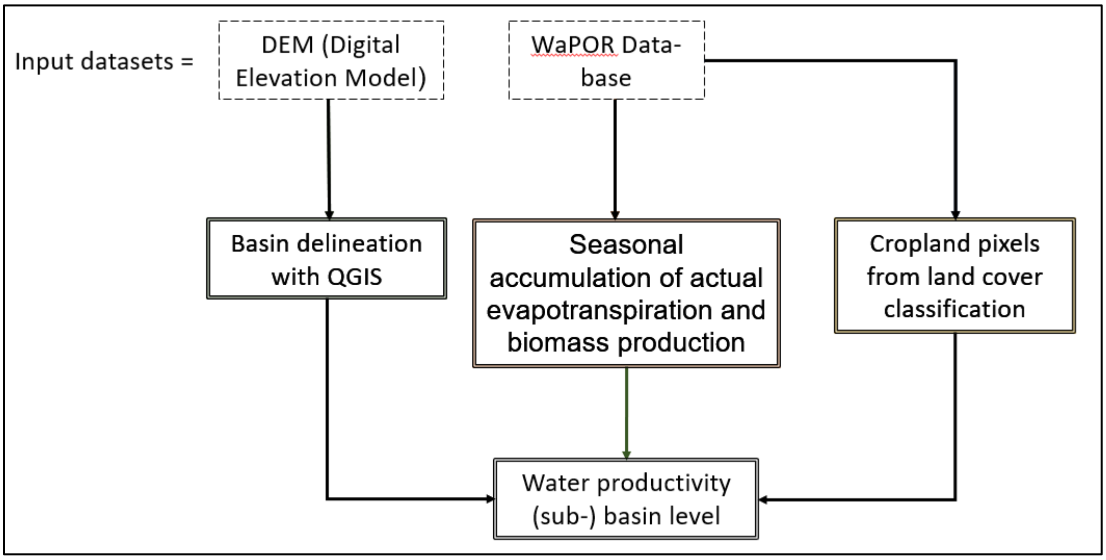


Figure 8. Workflow for biomass water productivity analysis

2.1.4 Overview of methodology

The flowchart provides an overview of the different steps that were taken during this project (Figure 9). The following sub-sections will be dedicated to explaining each step.

Figure 9. Flowchart representing the project methodology

2.2 Step 1: Acquiring flying sensor imagery

2.2.1 Flying sensor equipment

Figure 10. The APSAN-Vale flying sensor in action

The flying sensor equipment used in APSAN-Vale is a Mavic Pro drone and an additional camera to detect vegetation status. Figure 10 shows a photo of the Flying Sensor used including both cameras. One camera makes RGB (red-green-blue) images, similar to visual images seen with the human eye. The second camera measures the near-infrared (NIR) wavelength, which is not visible to the human eye. The near-infrared wavelength has a good response to the conditions of the vegetation. Figure 11 gives an illustration of the response to stressed conditions of a leaf. If the leaf is in optimal health the NIR wavelength has a high response. If the leaf is under stressed or sick conditions the NIR wavelength has a lower response. This is already measured by the NIR wavelength before it is visible to the human eye.

Another advantage of using the Flying Sensors in this project is the flexibility for imagery capture and the high spatial resolution of the acquired imagery. The flying sensors can make flights when required at the desired intervals. For this project, the frequency of imagery acquisition was aimed at once every 3 weeks, which best captures the crop development stages. This interval was sometimes longer due to weather conditions or logistics. The spatial resolution of the imagery is 4-8 cm, providing sufficient detail to capture the spatial variation of smallholder agriculture.

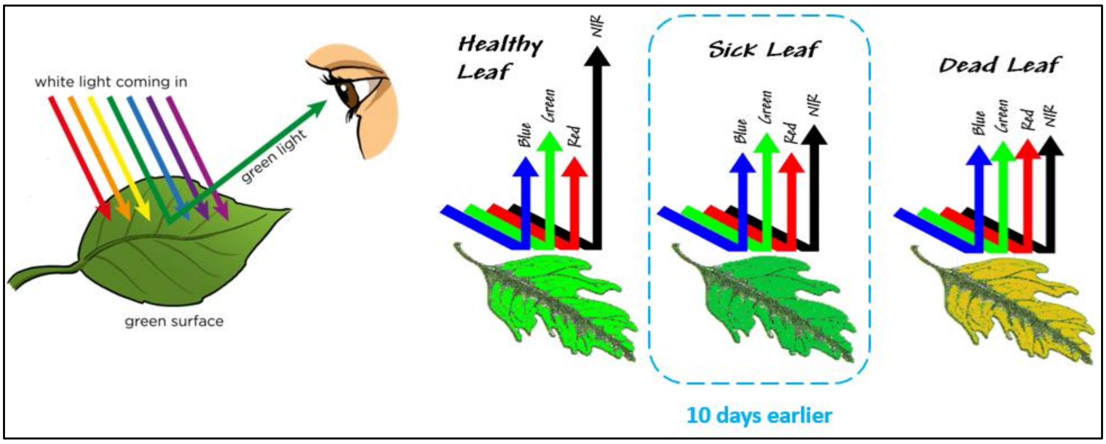


Figure 11. Illustration explaining the response of near-infrared (NIR) wavelength to vegetation status

2.2.2 Flying sensor imagery acquisition

Flying sensor images were acquired at regular intervals throughout the growing season. In Table 3 an overview is provided of the number of flights performed and on which date (sometimes spread over 2 or 3 days). The total number of flights for Báruè, Moatize, and Nhamatanda, were 64, 61, and 42, respectively. The total area monitored with the flying sensors was 180 ha, 120 ha, and 160 ha for Báruè, Moatize, and Nhamatanda, respectively.

Table 3. Overview of flights and area during the rainfed season of 2021-2022

	Báruè	Moatize	Nhamatanda
December		15-12-2021 17-12-2021	
January	20-01-2022 21-01-2022	13-01-2022 14-01-2022	18-01-2022 20-01-2022
February	10-02-2022 11-02-2022	01-02-2022 02-02-2022 05-02-2022	08-02-2022 09-02-2022
March	18-03-2022	08-03-2022 10-03-2022 11-03-2022 29-03-2022 30-03-2022	15-03-2022 22-03-2022
April	05-04-2022 07-04-2022 08-04-2022		06-04-2022
Flights taken	64	61	42
Area covered	180 ha	120 ha	160 ha

2.3 Step 2: Enriching data with Sentinel 2 imagery

Sentinel 2 is an open-access satellite platform providing imagery every 3 to 5 days at a spatial resolution of 10x10m. This resolution is sufficient for capturing the crop development of agricultural fields but too coarse for determining detailed within-field spatial variations. These within-field spatial variations can be monitored with flying sensor imagery at a higher resolution. Sentinel 2 data is used supplemental to the flying sensor imagery to capture more frequently the crop development and fill in the gaps between the 3-to-5-week intervals of the flying sensor imagery intervals (as indicated in Table 3).

The Sentinel 2 imagery is first processed to cloud-free imagery through the quality bands provided with the imagery dataset. The NDVI is calculated and used to determine the fraction of vegetational cover by determining the NDVI for bare soil and fully vegetative cover fields. The fraction of vegetational cover is similar to the canopy cover derived from the flying sensor imagery. Processing of the Sentinel 2 imagery was conducted using the cloud computing of Google Earth Engine (https://earthengine.google.com/).

2.4 Step 3: Processing to canopy cover maps

The imagery acquired by the Flying Sensors was post-processed. At first, the single images for each flight were stitched together to form an ortho mosaic. These were then georeferenced so they could be used in further geospatial analysis. These steps were performed using software packages: Agisoft Metashape, and QGIS (geospatial software).

The next processing steps were required to achieve a time series of canopy cover maps. The flying sensor images were processed using R coding, also making the process more efficient. The NIR band of the image was used to determine the vegetation pixels of each image using the 'kmeans' R package for automatic imagery classification. Manually the user determines which class is appointed as vegetation. This information is then used to calculate the canopy cover, which is an indication of the vegetation cover over a surface in percentage and is in the same category as other vegetation indices commonly used in remote sensing e.g. Leaf Area Index (LAI) or Normalized Difference Vegetation Index (NDVI). Canopy cover ranges from 0 to 100%. Full vegetation cover will result in a canopy cover of 100%. A grid of 1x1 meter (=1 m2) is overlaid over a crop field. The number of vegetation pixels (of 0.05x0.05 meter = 0.0025 m2) is counted to determine the percentage of the grid that is covered by vegetation, thus the canopy cover. This information is used in combination with crop modeling to determine the crop yield, and water productivity.

2.5 Step 4: Crop growth modelling

2.5.1 AquaCrop

The AquaCrop model was selected for simulating crop growth and water consumption, which is based on FAO principles as reported in FAO Irrigation and Drainage Papers #56 and #66. It simulates both crop development and the water balance, resulting in crop water productivity results.

Several crop growth models have been developed to simulate crop yield and water productivity. The model selection depends on the application scale and the ability to constrain model parameter uncertainty. AquaCrop is a widely used crop model developed by FAO, which simulates the yield response to water using physically-based parameters. It has been used in climate change impact studies in various parts of the world (Hunink et al., 2014[6]; Hunink and Droogers, 2010[7], 2011[8]). In addition, AquaCrop has been applied to predict water productivity and crop yield based on flying sensor

[6] Hunink, J. E., Droogers, P. and Tran-mai, K.: Past and Future Trends in Crop Production and Food Demand and Supply in the Lower Mekong Basin., 2014.
[7] Hunink, J. E. and Droogers, P.: Climate Change Impact Assessment on Crop Production in Albania. World Bank Study on Reducing Vulnerability to Climate Change in Europe and Central Asia (ECA) Agricultural Systems, FutureWater Report 105., 2010.
[8] Hunink, J. E. and Droogers, P.: Climate Change Impact Assessment on Crop Production in Uzbekistan. World Bank Study on Reducing Vulnerability to Climate Change in Europe and Central Asia (ECA) Agricultural Systems, FutureWater Report 106., 2011

information (den Besten et al., 2017[9], van Opstal, 2019[10]) and to assess irrigation scheduling scenarios (Goosheh et al., 2018[11]). It is especially recommended for small-scale farm-level applications. In addition, it is an open-source model which is freely available for application. Hence, the appropriate model for APSAN-Vale purposes.

FAO has pre-established model parameters to simulate the canopy cover, actual crop transpiration and soil evaporation, biomass, and crop yield for a growth period from sowing to harvest (Figure 12). In this work, selected model parameters were tuned based on observations. Tuned model parameters included plant density, length of the growth period, increase in canopy cover, decrease in canopy cover, harvest index, fertility stress, and cover of weeds.

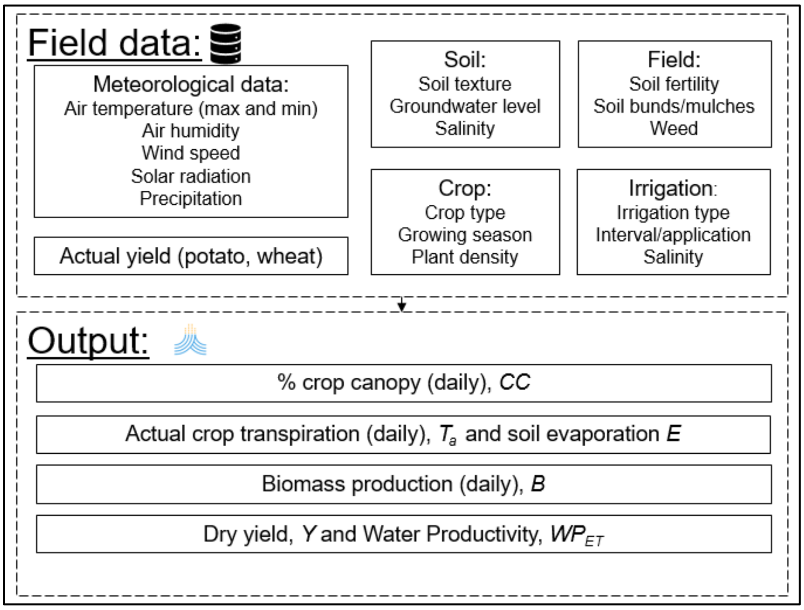


Figure 12. Field data and output simulations of the AquaCrop model

2.5.2 Input data

<u>Weather</u>

Weather data was required as input for the AquaCrop model. This data was derived from a variety of sources. Weather stations from the Trans-African Hydro-Meteorological Observatory (TAHMO) were installed at each district office to represent the weather conditions in the area. These stations were installed in early 2019 and provide meteorological observations until the end of the rainfed season. Occasionally malfunctions occur in the TAHMO equipment. During these periods the weather data was supplemented with open-access remote sensing weather data available such as precipitation data from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) database or the WaPOR database for reference evapotranspiration. Additionally, long-term average weather data was acquired from the Global Land Data Assimilation System (GLDAS) data products. This is explained in the baseline assessment report (FutureWater Report 195)[12].

[9] den Besten, N., Simons, G. and Hunink, J.: Water Productivity assessment using Flying Sensors and Crop Modeling. Pilot study for Maize in Mozambique, 2017.
[10] Van Opstal, J.D.. 2019. APSAN-Vale Water Productivity Rainfed season 2018/2019. FutureWater Report.
[11] Goosheh, M., Pazira, E., Gholami, A., Andarzian, B. and Panahpour, E.: Improving Irrigation Scheduling of Wheat to Increase Water Productivity in Shallow Groundwater Conditions Using Aquacrop, Irrig. Drain., 0(0), doi:10.1002/ird.2288, 2018.
[12] Van Opstal, J.D., A. Kaune. 2020. Water Productivity Technical Report - Baseline assessment for APSAN-Vale project. FutureWater Report 195.

Field data

The next step for the AquaCrop simulations was to collect basic crop information from the selected sites (Báruè, Moatize, and Nhamatanda). Basic information about planting dates, plant density, total growth length (length of the crop cycle), and crop yield are key to obtaining reliable AquaCrop simulations. Several of these parameters are specific for each field. Therefore, the notes taken in the fieldbook of the PPCs were copied and linked to specific fields (indicated with polygons or shape files) to make the simulation tailored to the situation of the PPC. In Annex 1 the input data on management decisions can be found.
In the AquaCrop model, several crop parameters must be used to simulate crop-specific canopy cover, transpiration, biomass, and yield during the growing season to finally determine water productivity. Crop-specific parameters were obtained from the original crop files available in the AquaCrop model. Crop files in Growing Degree Days mode (°C days) were used. The Growing Degree Days accounts for the effects of temperature regimes on crop phenology.

Specific crop model parameters must be tuned to obtain accurate crop yields. In Table 4 the calibrated crop model parameters per crop are shown. These parameters include the Harvest Index, HI (%), Increase in Canopy Cover, CGC (-), Decrease in Canopy Cover, CDC (-), and the length of specific growing stages (e.g. sowing to emergence, sowing to maximum rooting depth, etc). HI is a known parameter to convert biomass into crop yield. CGC is a measure of the intrinsic ability of the canopy to expand. After the canopy begins to senesce, the canopy cover is reduced progressively by applying an empirical canopy decline coefficient (CDC). HI, CGS and CDC vary depending on the crop variety and seed quality. The length of specific crop growth stages is determined by the received Growing Degree Days (°C days). The length of the growing stages was tuned based on the collected information on the length of the crop cycle (from planting to harvest in Annex 1).

Table 4. Calibrated parameters for maize in Báruè, Moatize, and Nhamatanda

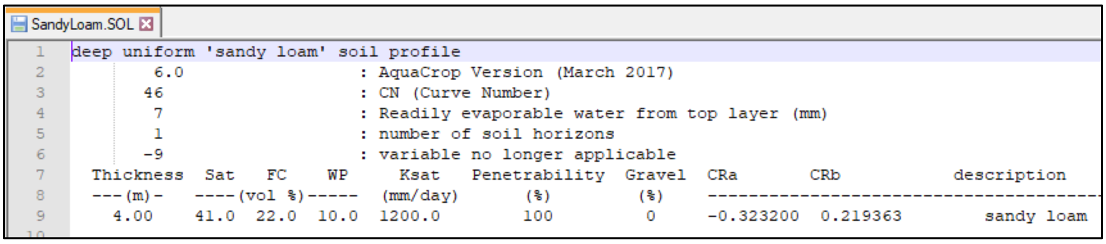
Parameter	Maize
HI (%)	75
CGC (-)	0.011-0.016
CDC (-)	0.0014-0.002
From sowing to emergence (°C days)	310
From sowing to maximum rooting depth (°C days)	1672
From sowing to start senescence (°C days)	1525
From sowing to maturity (length of crop cycle) (°C days)	1977
From sowing to flowering (°C days)	852
Length of the flowering stage (°C days)	279

Soil and field management information

According to the collected field information the soil texture of each site was determined. The hydraulic properties of the soil are correlated with the soil texture. The AquaCrop model includes pre-established hydraulic properties such as Field Capacity (FC) and Wilting Point (WP) for each soil texture. Field Capacity and Wilting Point values are key to determining the soil water storage capacity and determining the water stress thresholds. In Table 5 the soil textures obtained for each site are shown. The soil type for Báruè was updated in the past season, due to acquired new field data. In Figure 13, an example of FC and WP values (FC=22%, WP=10%) used in the AquaCrop model is shown for sandy loam.

Table 5. Soil texture in each site

Site	Soil texture
Báruè	Sandy Clay Loam
Moatize	Sandy Loam
Nhamatanda	Sandy Clay



```
SandyLoam.SOL
deep uniform 'sandy loam' soil profile
        6.0                   : AquaCrop Version (March 2017)
       46                     : CN (Curve Number)
        7                     : Readily evaporable water from top layer (mm)
        1                     : number of soil horizons
       -9                     : variable no longer applicable
  Thickness  Sat   FC    WP     Ksat   Penetrability  Gravel  CRa       CRb           description
  ---(m)-   ----(vol %)-----  (mm/day)      (%)         (%)    -----------------------------------
    4.00    41.0  22.0  10.0  1200.0        100          0     -0.323200  0.219363        sandy loam
```

Figure 13. Soil characteristics in Moatize as used in AquaCrop

2.6 Step 5: Calibrating crop development to obtain water productivity

The AquaCrop model was calibrated using the flying sensor and Sentinel 2 data. This was done by determining the maximum canopy cover using a fitted curved trendline. The average canopy cover values were taken and plotted over the course of the growing season. The canopy cover follows a positive curvilinear trend representing the crop development until full cover. The flying sensors monitored the canopy cover throughout the growing season and thus captured parts of the canopy curve at frequent intervals. This data was supplemented with additional data points from Sentinel 2. A similar curvilinear trend of crop development was also simulated in AquaCrop. For the calibration process, the combined maximum canopy cover from the flying sensors and Sentinel 2 data were compared with the AquaCrop simulated canopy cover. The output of AquaCrop was iteratively calibrated until similar results were found between the measured and simulated maximum canopy cover.

The AquaCrop model was set up using the modules and input data as listed in the previous sections. The calibrated parameters were mainly farm management variables that are sensitive in AquaCrop and could not be accurately measured in the field. The parameters selected for calibration were plant density, fertilizer stress, and maximum allowable soil water depletion (for irrigation events). After running the simulations with various parameter combinations the top simulations were selected displaying limited error with the canopy cover as observed from the flying sensor images. From the selected AquaCrop runs the calculated water productivity, evaporation, transpiration, and dry yield were averaged.

2.7 Step 6: Calculating sub-basin and basin water productivity

The FAO WaPOR database contains several datasets derived from satellite remote sensing and is available through the open access data portal: https://wapor.apps.fao.org. The layers used from WaPOR are actual evapotranspiration and interception (AETI), net primary production (NPP) and land cover (LCC). This paragraph describes the data layers used from the FAO WaPOR database and explains how they were used to calculate the water productivity values. The data layers were downloaded for the three basins in Mozambique (figure 6) and aggregated to find seasonal values for the rainfed season of 2021-2022: November 2021 to May 2021. Furthermore, the data layers were also downloaded for the sub-basins (figure 3, 4 and 5) for the rainfed season of 2021-2022.

2.7.1 Actual evapotranspiration and interception

The actual evapotranspiration from WaPOR is calculated using a surface energy balance algorithm based on the equations of the ETLook model[13]. It uses a satellite platform with both multi-spectral and thermal imagery acquisition. In addition, meteorological data from remote sensing data products were used as input. The energy balance components are calculated with the specified algorithm: net radiation, soil heat flux, and sensible heat flux. The latent heat flux is calculated as residual to the energy balance and represents the evapotranspiration (ET) component of the energy balance.

[13] Bastiaanssen et al. (2012)

The WaPOR actual ET dataset used in this report is from Level II (100 meters spatial resolution) and is available monthly. Every image between planting date and harvesting date is summed, which retrieves the seasonal sum for the actual evapotranspiration and interception.

2.7.2 Biomass production

Biomass production was calculated using the monthly net primary production (NPP) data layer from WaPOR. The NPP data was calculated in WaPOR using a light use efficiency model[14]. This model determines the amount of photosynthetic radiation that arrives at a surface and the amount that is absorbed by vegetation depending on the amount of vegetational cover and (non-)stress conditions. This indicates the result of the photosynthesis process in NPP or dry matter biomass production. The biomass production from WaPOR was summed for the rainfed season. From the seasonal summed biomass and seasonal summed actual evapotranspiration and interception, the water productivity for the 2021-2022 rainfed season was calculated.

2.7.3 Supplemental layers

In addition, reference evapotranspiration (ET) is also provided by the WaPOR data portal at 20 km. resolution and at daily time steps. A time series of this dataset is used as the required weather input data to the crop modelling.
Lastly, the land cover map in WaPOR is used to identify the pixels containing croplands. This is used to calculate the biomass water productivity for croplands, thus excluding the pixels of natural vegetation and urban areas.

2.8 Step 7: Normalizing for annual weather conditions

For the baseline assessment[15] meteorological data from a period of 17 years was used for the field scale analysis (2001 – 2017). For the basin scale analysis, this was 10 years of data (2009 – 2018). The period for the basin scale analysis was shorter due to the data availability of WaPOR. Both periods are deemed sufficient for capturing the inter-annual variability in weather conditions with both dry and wet years existing within a time frame of 10 years. The statistical results from this baseline analysis will therefore be representative of the variety of weather conditions.

In further analysis of this project, water productivity values are normalized for weather conditions to determine if changes in water productivity are a result of weather conditions or the impact of the project innovations. The normalization of water productivity values was calculated by using the equation below using 2021 as an example year and using reference evapotranspiration (ET_0) as representative of the annual weather conditions. This equation and methodology were described by Bastiaanssen and Steduto (2016)[16], as a method for comparing water productivity between years and regions with different climatic conditions.

$$WP_{norm,2019}\ [kg/m^3]\ = \frac{WP_{2021}\ \left[\frac{kg}{m^3}\right] \times ET_{0,average\ 2001-2018}\ [mm]}{ET_{0,2021}\ [mm]}$$

[14] Hilker et al. (2008) and several other publications
[15] Van Opstal, J.D., A. Kaune. 2020. Water Productivity Technical Report - Baseline assessment for APSAN-Vale project. FutureWater Report 195.
[16] Bastiaanssen, W. G. M., & Steduto, P. (2016). The water productivity score (WPS) at global and regional level: Methodology and first results from remote sensing measurements of wheat, rice and maize. Science of The Total Environment, 575, 595–611. https://doi.org/10.1016/j.scitotenv.2016.09.032

2.9 Step 8: Seasonal water productivity assessment

The final step was the seasonal water productivity assessment. In this step the water productivity results of the field, sub-basin, and basin scale were combined and compared to the baseline assessment and previous seasons. Assessment of the water productivity was performed at three levels. At first, the change in water productivity due to specific interventions in the field of the PPCs was assessed. This level is considered the local scale of changing water productivity. Secondly, the change in water productivity of the surrounding communities was assessed. This will be influenced by neighbouring PPEs and communities adopting the interventions. This level is considered as the increase in the overall water productivity of the region or sub-basin scale. Lastly, the basin level analysis was used to monitor the water productivity on a larger scale as it is expected that the impact of the project is directly measured at the basin scale due to the expanse of the area.

The average results of this season were compared to the 75th percentile[17] values of the baseline as presented in FutureWater Report 195[18]. This provided the average water productivity between 2001 and 2017. This assessment is the baseline of the water productivity for the project locations, without any interventions placed by APSAN-Vale activities. An assumption was made that the PPCs in the baseline had a commercial objective and achieved relatively higher productivity in comparison to the average of all farmers. Therefore, the baseline value used for the comparison is the 75th percentile, indicating that the baseline values were higher than the actual.

[17] This is a measure used in statistics indicating the value below which a given percentage of observations in a group of observations falls. In this case, 25% of the observations are found above the 75th percentile.
[18] Van Opstal, J.D., A. Kaune. 2020. Water Productivity Technical Report - Baseline assessment for APSAN-Vale project. FutureWater Report 195.

3 Seasonal weather results

3.1 Reference evapotranspiration

Meteorological data were collected from weather stations of TAHMO. The observations were used to compute daily reference evapotranspiration (ET) for the different districts throughout the rainfed season of 2021-2022. The time series of daily reference ET shows similar seasonal patterns for the three different districts (Figure 14). The daily reference ET for all districts varied between 2 and 7 mm/day. In the first few months, the fluctuations in daily reference ET are relatively large. The fluctuations decrease steadily throughout the rainfed period up until a rather homogenous reference ET was found at the end of the rainfed season. The calculated reference ET for Báruè was found to be overestimated in the first 15 days. WaPOR data was used to fill the overestimated values. Similarly, gaps were filled with the WaPOR reference ET product for individual days where the TAHMO stations did not record wind speed observations.

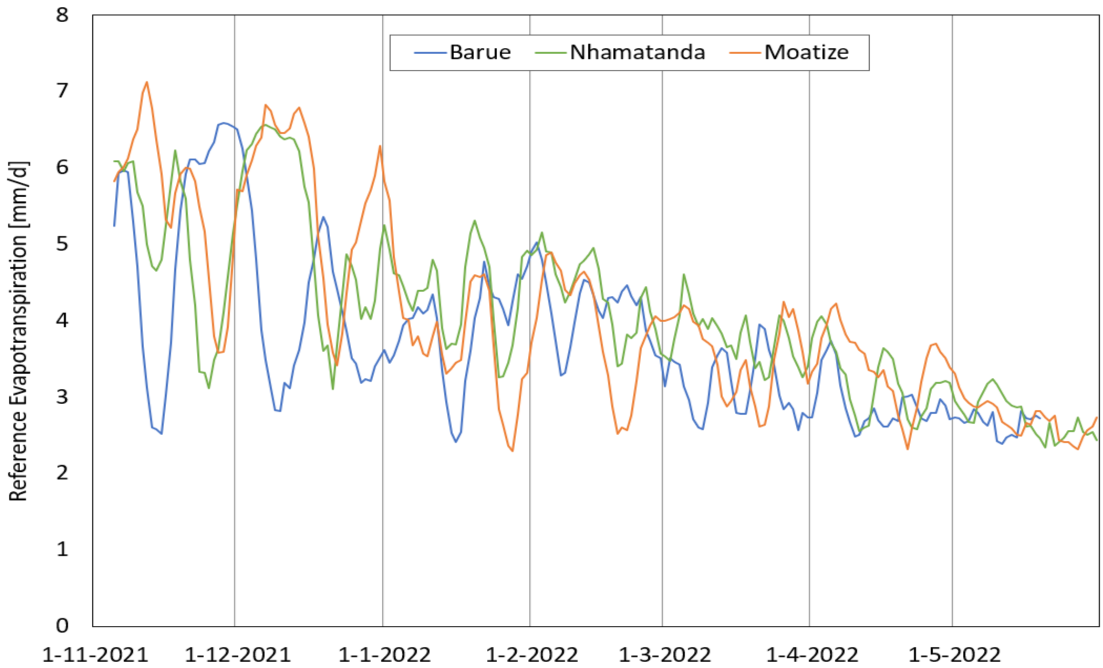


Figure 14. Five-day moving average reference evapotranspiration for Moatize and Nhamatanda during the 2021 irrigation season from TAHMO stations and supplemented WaPOR data for Moatize and Báruè.

The weather conditions of the rainfed season of 2021-2022 were compared to the historical dataset (2001-2018) as used in the baseline assessment. The historical dataset contains a multitude of dry and wet years and therefore is a good representation of the general weather conditions in the designated districts. The monthly reference ET during the 2021-2022 rainfed season was found to deviate from the average conditions (Figure 15). In December 2021, the monthly reference ET in all districts was significantly higher than in the historical dataset. The differences were largest in the Moatize district, where a difference of 41 mm was recorded. For the remaining part of the rainfed season, monthly reference ET was found to be lower than average. The total seasonal reference ET is presented in Table 6. It shows the 2021 season and the long-term average for the rainfed season. The presented values are used in the normalization of the water productivity results as described in Section 2.88 of this document.

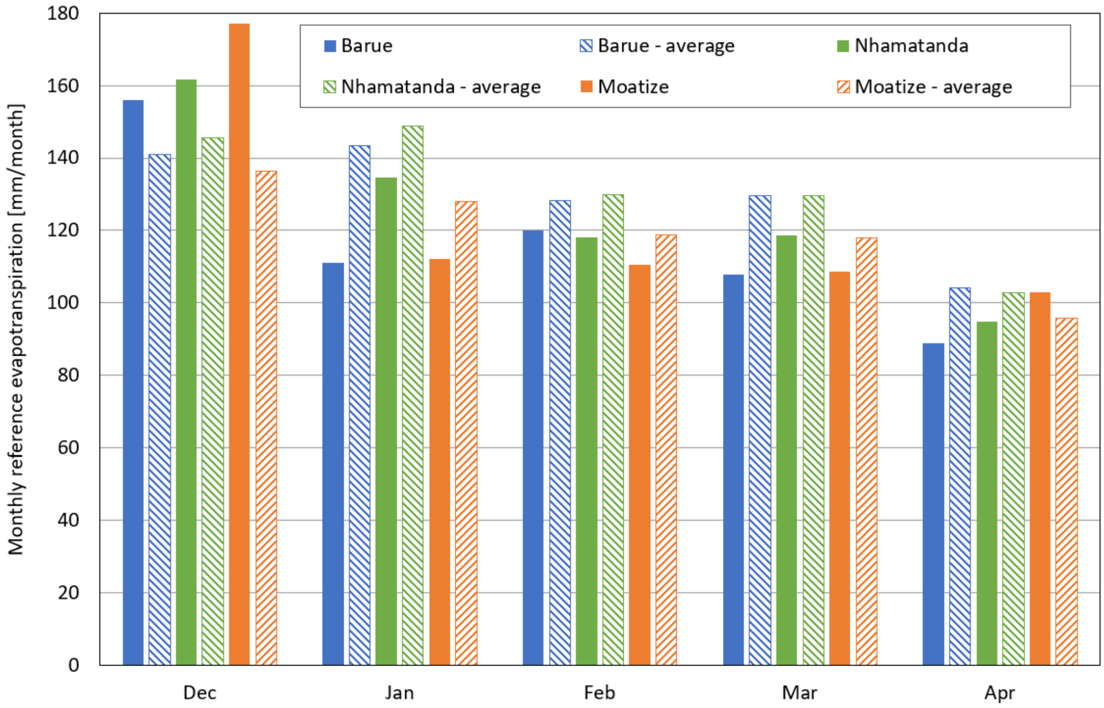


Figure 15. Comparison of monthly reference evapotranspiration during the rainfed season of 2021-2022 with the long-term average (2009-2018) calculated from TAHMO weather stations and WaPOR data.

Table 6. Seasonal total reference evapotranspiration for Báruè, Moatize, and Nhamatanda during the rainfed season of 2021-2022 (November to May) and long-term average (2001-2018) irrigation season

Reference ET [mm]	Báruè	Moatize	Nhamatanda
2021 irrigation season	537	587	569
2001-2018 long-term average	605	619	580

3.2 Precipitation

The rainfed season is characterized by heavy and erratic rainfall events. During the rainfed season of 2021-2022, malfunctions occurred at the station of Báruè, therefore satellite data from CHIRPS (as provided through the WaPOR portal) was used to fill the gaps. Figure 16 shows the daily precipitation for the season and shows that rainfall occurred irregularly and with some heavy rainfall events. Especially in April 2022, Báruè receives some large rainfall events. Few rainfall events occurred in the Nhamatanda district.

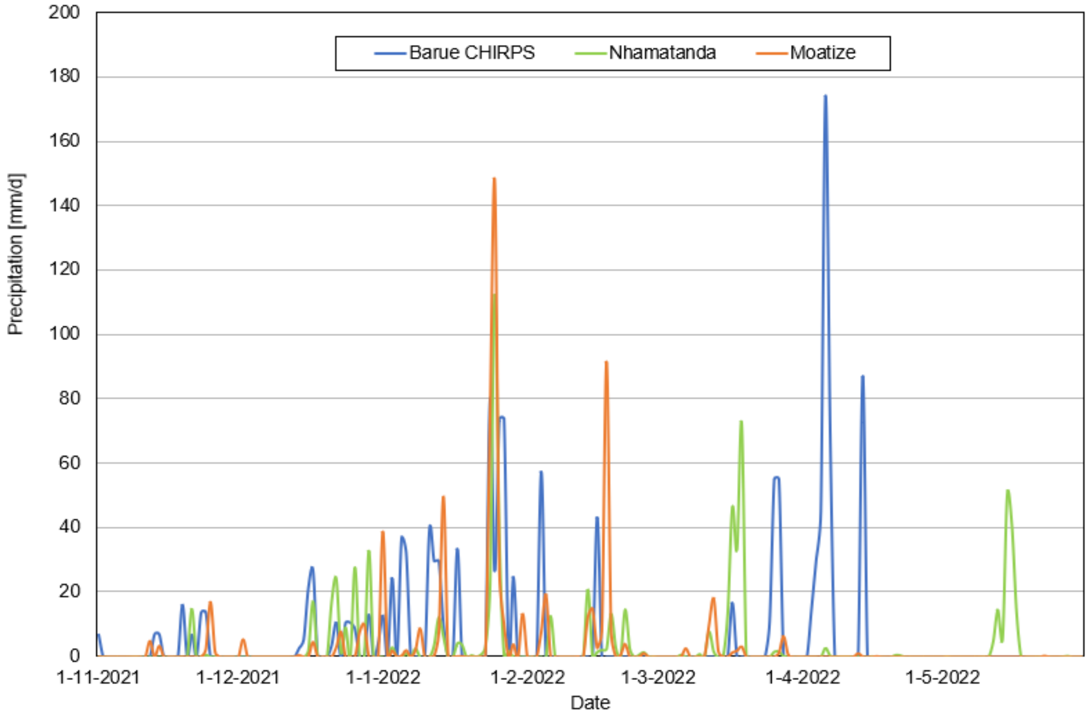


Figure 16. Daily precipitation for the rainfed season of 2021-2022 from TAHMO and CHIRPS

The total monthly precipitation shows that December 2021 was a dry month compared to the long-term average (Figure 17). January 2022 was wet for Báruè and Nhamatanda but not for Moatize. February and March were a bit drier than average for all districts. April was very wet for Báruè but not for the other districts. The seasonal precipitation for the three districts shows that for the whole season Báruè was significantly wetter (432 mm) than the long-term average (Table 7). Moatize and Nhamatanda were 43 and 139 mm drier respectively.

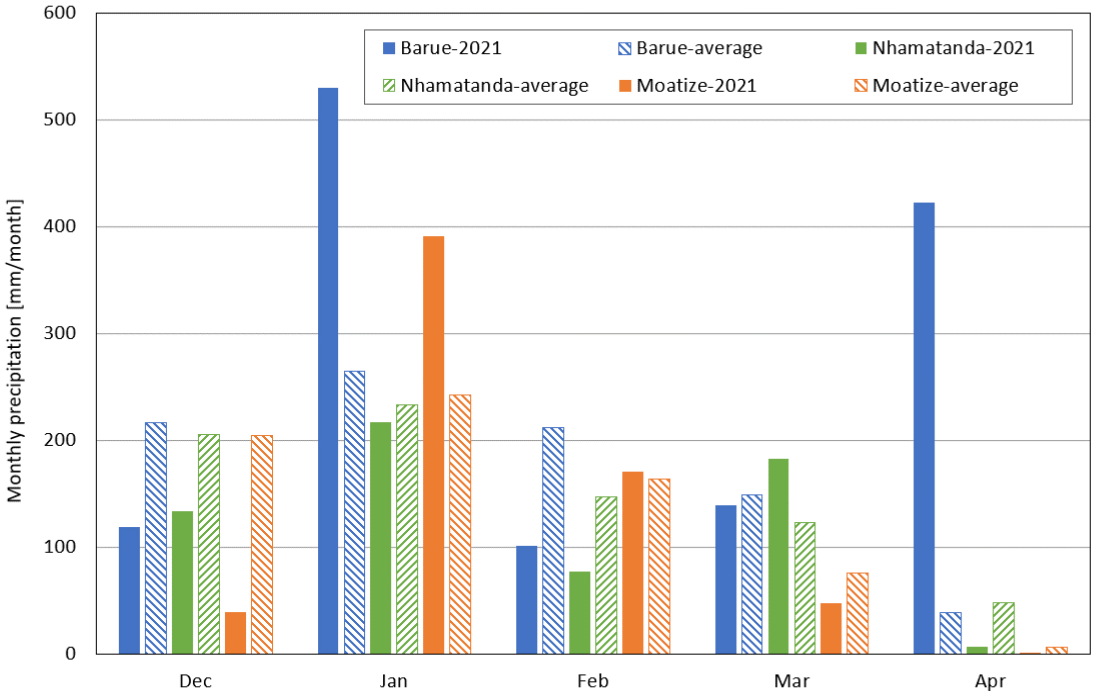


Figure 17. Comparison of the monthly average precipitation during the rainfed season of 2021-2022 with the long-term average (2001-2018) derived from the CHIRPS dataset.

Table 7. Seasonal precipitation for Báruè, Moatize, and Nhamatanda during the rainfed season of 2021-2022 and long-term average (2001-2018) rainfed-season

Precipitation [mm]	Báruè	Moatize	Nhamatanda
Rainfed season 2021-2022	1312	616	650
2001-2018 long-term average rainfed	879	755	692

4 Field scale water productivity results

This chapter presents the results of the field scale water productivity assessment. AquaCrop model simulations were performed to present the crop development and farm management of each PPC monitored throughout the rainfed season of 2021-2022. The management decisions and other input data are presented in Annex 1 for each farmer. For Báruè, Moatize, and Nhamatanda the results of the water productivity are presented in Tables 8, 9, and 10, respectively. In the result tables, the water productivity is normalized for the weather conditions using the reference ET from Table 6 (Chapter 3), and methodology as described in section 2.8 of this document.

4.1 Báruè

The canopy curve of PPC Antonio is visualised in Figure 18 and depicts the growing cycle of the crop. The blue dots indicate average fractions of vegetation cover for different moments in the growing season. The fitted curvilinear trendline between the blue dots indicates the canopy curve. The maximum value of the curve was found to be 0.39, indicating a maximum canopy cover of 39% measured in the growing season. The 0.39 fraction of canopy cover is used to calibrate the AquaCrop model and determine the field-specific water productivity. The canopy curves from the other PPCs of Báruè are included in Annex 2.

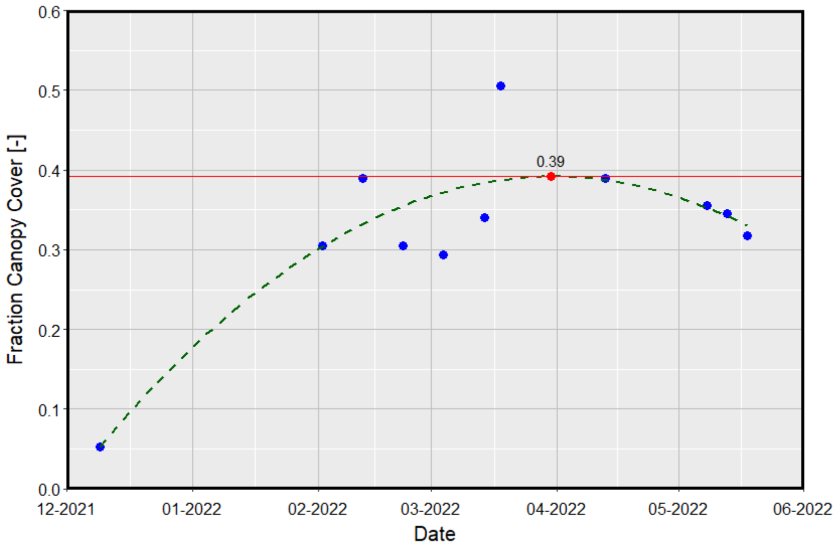


Figure 18. Fitted canopy curve for PPC Antonio with a maximum fraction canopy cover of 0.39

The results of the field scale water productivity analysis for the Báruè farmers are presented in Table 8. The water productivity values, normalized for the local climatic conditions (section 2.8), were found to vary between 0.7 and 0.87 kg/m^3, indicating an increase in water productivity for all farmers compared to the rainfed season baseline values. The average normalized water productivity is 0.8 kg/m^3. The percentual increase in water productivity compared to the baseline varies between +72% and +112%. Farmer Reunor showed slightly differing water productivity values for the three analysed fields, resulting from local conditions, planting date, or planting density. The dry crop yield was found to vary between 1.59 and 2.12 ton/ha. The average increase in water productivity compared to the baseline for all participating farmers in Báruè is +95%.

Table 8. Results of AquaCrop water productivity, maximum Canopy Covers (CC), dry crop yield, and percent change of water productivity compared to baseline (75th percentile) for Báruè farmers

PPC code	Name	Crop type	Max. CC FS + S	Max. CC AquaCrop	Water productivity [kg/m^3]	Normalized water productivity [kg/m^3]	% Change with baseline	Dry crop yield [ton/h]
AP_BA_AM-01-01	Antonio	Maize	0.43	0.44	0.71	0.79	+92%	2.45
AP_BA_DC-01-01	Dalton	Maize	0.42	0.44	0.66	0.73	+78%	2.22
AP_BA_FL-01-01	Frances	Maize	0.43	0.44	0.66	0.73	+78%	2.25
AP_BA_JC-01-01	Joao	Maize	0.37	0.37	0.76	0.84	+105%	2.46
AP_BA_JC-01-02	Joao	Maize	0.37	0.37	0.76	0.84	+105%	2.46
AP_BA_LC-01-01	Langton	Maize	0.33	0.33	0.72	0.80	+95%	2.29
AP_BA_ML-01-01	Manuel	Maize	0.4	0.41	0.64	0.70	+72%	2.14
AP_BA_RF-01-01	Reunor	Maize	0.49	0.52	0.78	0.87	+112%	2.79
AP_BA_RF-01-02	Reunor	Maize	0.48	0.49	0.73	0.80	+96%	2.54
AP_BA_RF-01-03	Reunor	Maize	0.4	0.41	0.75	0.83	+102%	2.36
AP_BA_VB-01-01	Vasco	Maize	0.36	0.37	0.79	0.87	+112%	2.41
AP_BA_VB-01-02	Vasco	Maize	0.44	0.44	0.71	0.79	+93%	2.44
AP_BA_VT-01-01	Vitoria	Maize	0.36	0.37	0.74	0.82	+100%	2.38

The water productivity results are presented in field maps in Figure 19. For each PPC the water productivity values are visualised for the different fields. PPC Vasco and Joao show fields divided by a road. PPC Reunor has several fields. The water productivity values range from medium (yellow) to high (light to dark green).

Figure 19. Field water productivity maps of farmers in Báruè for the 2021-2022 rainfed season

4.2 Moatize

The canopy curve of field 2 of PPC Joao is visualised in Figure 20. The maximum value of the curve was found to be 0.41, indicating a maximum canopy cover of 41% measured in the growing season. The 0.41 fraction of canopy cover is used to calibrate the AquaCrop model and determine the field-specific water productivity. The canopy curves from the other PPCs of Moatize are included in Annex 2.

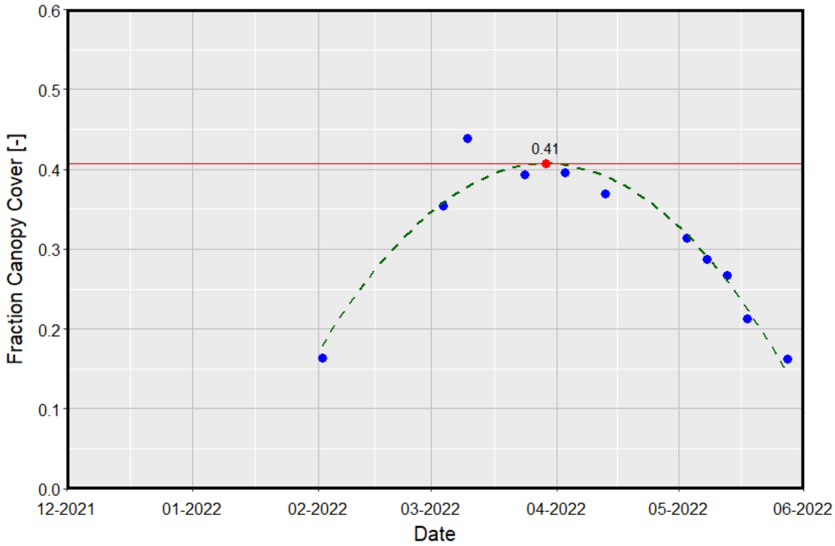


Figure 20. Fitted canopy curve for PPC Antonio with a maximum fraction canopy cover of 0.41

The results of the field scale water productivity analysis for the Moatize farmers are presented in Table 9. During the rainfed season of 2021-2022 maize was the sole crop that was cultivated. The water productivity values normalized for the local climatic conditions were found to vary between 0.59 and 0.74 kg/m^3, indicating an increase in water productivity for all farmers compared to the rainfed season baseline values. The average normalized water productivity was 0.69 kg/m^3. The percentual increase in water productivity compared to the baseline varies between +72% and +112%. Farmer Joao showed slightly differing water productivity values for the four analysed fields, resulting from either the local condition, planting date, or planting density. The dry crop yield was found to vary between 1.59 and 2.12 ton/ha. The average increase in water productivity compared to the baseline for all participating farmers in Báruè is +87%.

Table 9. Results of AquaCrop water productivity, maximum Canopy Covers (CC), dry crop yield, and percent change of water productivity compared to baseline (75th percentile) for Moatize farmers

PPC code	Name	Crop type	Max. CC FS + S	Max. CC AquaCrop	Water productivity [kg/m^3]	Normalized water productivity [kg/m^3]	% Change with baseline	Dry crop yield [ton/h]
MO-SA-MC-01-01	Manuel	Maize	0.43	0.44	0.76	0.74	+100%	2.12
MO-MA-JC-01-01	Joao	Maize	0.39	0.39	0.70	0.69	+86%	1.94
MO-MA-JC-01-02	Joao	Maize	0.41	0.41	0.73	0.71	+91%	2.01
MO-MA-JC-01-03	Joao	Maize	0.43	0.44	0.76	0.74	+100%	2.11
MO-MA-JC-01-04	Joao	Maize	0.38	0.39	0.69	0.67	+81%	1.88
MO-MA-GM-01-01	Girio	Maize	0.38	0.39	0.69	0.69	+85%	1.88
AP_BA_LC-01-01	Vicente	Maize	0.41	0.41	0.73	0.71	+91%	2.01
MO-CA-XT-01-01	Xavier	Maize	0.31	0.32	0.60	0.59	+58%	1.59

The water productivity field maps are presented in Figure 21. For each PPC the water productivity values are visualised for the different fields. Farmer Joao shows four different water productivity values for fields separated by roads. The water productivity values range from medium (yellow) to high (light to dark green).

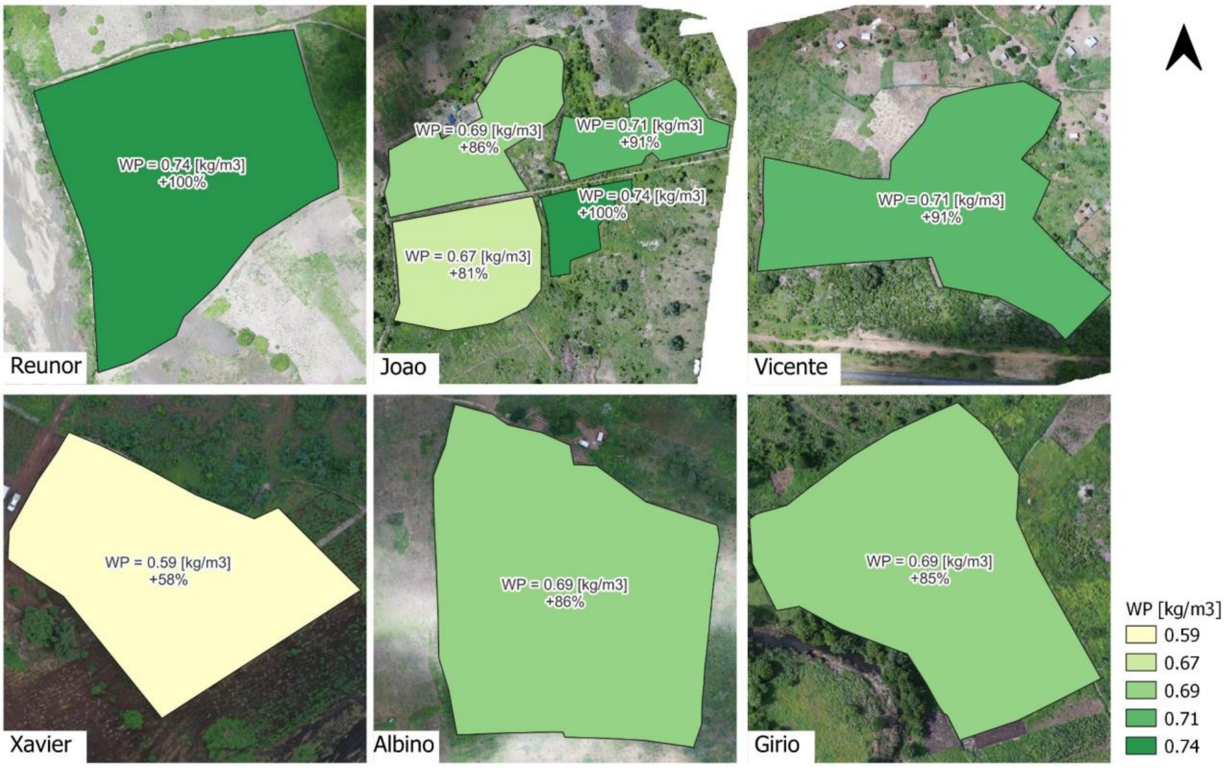


Figure 21. Field water productivity maps of farmers in Moatize for the 2021-2022 rainfed season

4.3 Nhamatanda

The canopy curve of PPC Jose 1 is visualised in Figure 22. The maximum value of the curve was found to be 0.39, indicating a maximum canopy cover of 39% measured in the growing season. The 0.39 fraction of canopy cover is used to calibrate the AquaCrop model and determine the field-specific water productivity. The canopy curves from the other PPCs of Báruè are included in Annex 2.

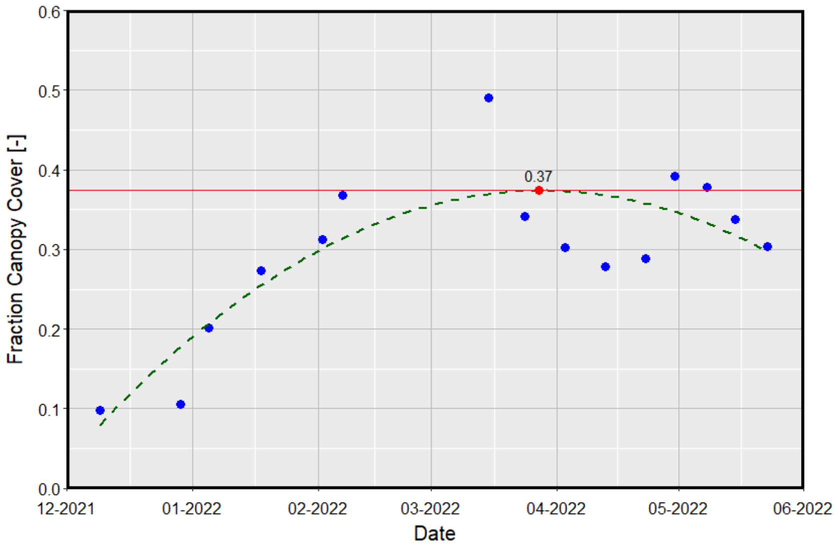


Figure 22. Fitted canopy curve for PPC Jose 1 with a maximum fraction of canopy cover of 0.37

The results of the field scale water productivity analysis for the Nhamatanda farmers are presented in Table 10. During the rainfed season of 2021-2022 maize was the sole crop that was cultivated. The water productivity values normalized for the local climatic conditions were found to vary between 0.53 and 0.78 kg/m3, indicating an increase in water productivity for all farmers compared to the rainfed season baseline values. The average normalized water productivity was 0.64 kg/m^3. The percentual increase in water productivity, compared to the baseline, varies between +62% and +136%. Farmer Lourenço showed slightly differing water productivity values for the two analysed fields, resulting from local conditions, planting date, or planting density. The dry crop yield was found to vary between 1.60 and 2.49 ton/ha. The average increase in water productivity is +95%.

Table 10. Results of AquaCrop water productivity, maximum Canopy Covers (CC), dry crop yield, and percent change of water productivity compared to baseline (75th percentile) for Nhamatanda farmers

PPC code	Name	Crop type	Max. CC FS + S	Max. CC AquaCrop	Water productivity [kg/m^3]	Normalized water productivity [kg/m^3]	% Change with baseline	Dry crop yield [ton/h]
NH-LM-JD-01-01	Jose 1	Maize	0.37	0.38	0.62	0.65	+97%	2.00
NH-LM-LL01-01	Lourenço	Maize	0.27	0.27	0.54	0.56	+70%	1.60
NH-LM-LL-01-02	Lourenço	Maize	0.24	0.26	0.53	0.55	+68%	1.85
NH-LA-AM-01-01	Armando	Maize	0.31	0.32	0.54	0.56	+71%	1.67
H-NS-RB-01-01	Rui	Maize	0.47	0.46	0.72	0.75	+127%	2.39
NH-MP-MN-01-01	Machoca	Maize	0.39	0.39	0.74	0.78	+136%	2.47
NH-NS-FA-01-01	Francisco	Maize	0.42	0.41	0.74	0.77	+135%	2.49
NH-NS-JM-01-01	Jose 2	Maize	0.36	0.36	0.51	0.53	+62%	1.66
NH-NC-ZF-01-01	Zacarias	Maize	0.37	0.37	0.61	0.63	+92%	2.01

The water productivity field maps are presented in Figure 23. For each PPC the water productivity values are visualised for the different fields. Farmer Lourenço shows two different water productivity values for separate fields. The water productivity values range from medium (yellow) to high (light to dark green).

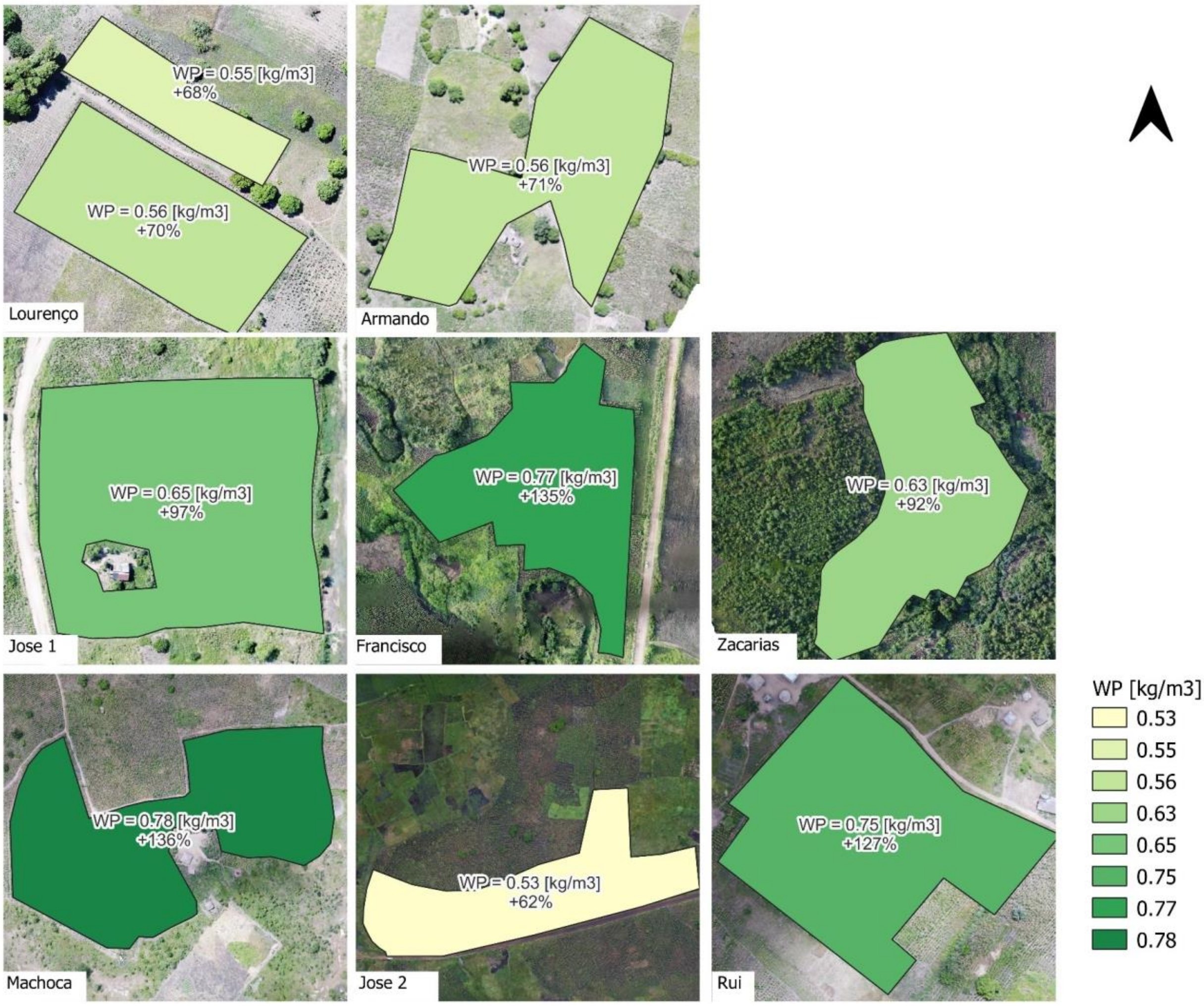


Figure 23. Field water productivity maps of farmers in Nhamatanda for the 2021-2022 rainfed season

5 Sub-basin scale water productivity results

The sub-basin scale is described as the level between the field scale of the selected PPCs and the basin scale delineated for each district. The sub-basin scale was determined to be a 300 ha radius around each selected PPC as described in section 2.1.3. of this document and presented in Figures 3, 4, and 5.

Data from the WaPOR portal was retrieved for the rainfed season for the months November 2021 to April 2022. The data products downloaded from WaPOR were Actual Evapotranspiration (in mm) and Net Primary Production, which was converted to Above Ground Biomass Production (in ton/ha). These data products were used to calculate the biomass water productivity for each sub-basin location.

Results are presented in Table 11 for each location. The highest water productivity values are consistently found in Báruè, due to the favourable climate in this region. Here the highest values are observed in Báruè I. The lowest values for water productivity are found in Moatize for the communities most downstream. The highest water productivity for Moatize is found in Moatize III, which is located upstream and closer to the mountains. For Nhamatanda the water productivity values are also highest the most upstream, but Nhamatanda III values are based on the 300 ha radius around only one farmer.

Table 11. Water productivity results of sub-basin analysis using WaPOR data portal

District	Sub-basin	Actual Evapo-transpiration [mm]	Biomass Production [ton/ha]	Biomass water productivity [kg/m^3]
Báruè	Báruè I	463	8	1.79
	Báruè II	431	7	1.60
	Báruè III	577	9	1.62
	Average	**490**	**8**	**1.67**
Moatize	Moatize I	466	4	0.88
	Moatize II	506	5	1.00
	Moatize III	535	6	1.06
	Average	**502**	**5**	**0.98**
Nhamatanda	Nhamatanda I	555	5	0.88
	Nhamatanda II	531	5	0.93
	Nhamatanda III	577	7	1.18
	Average	**554**	**6**	**1.00**

The maps of the sub-basin water productivity results are presented in Figures 24, 25, 26 for Báruè, Moatize, and Nhamatanda respectively.

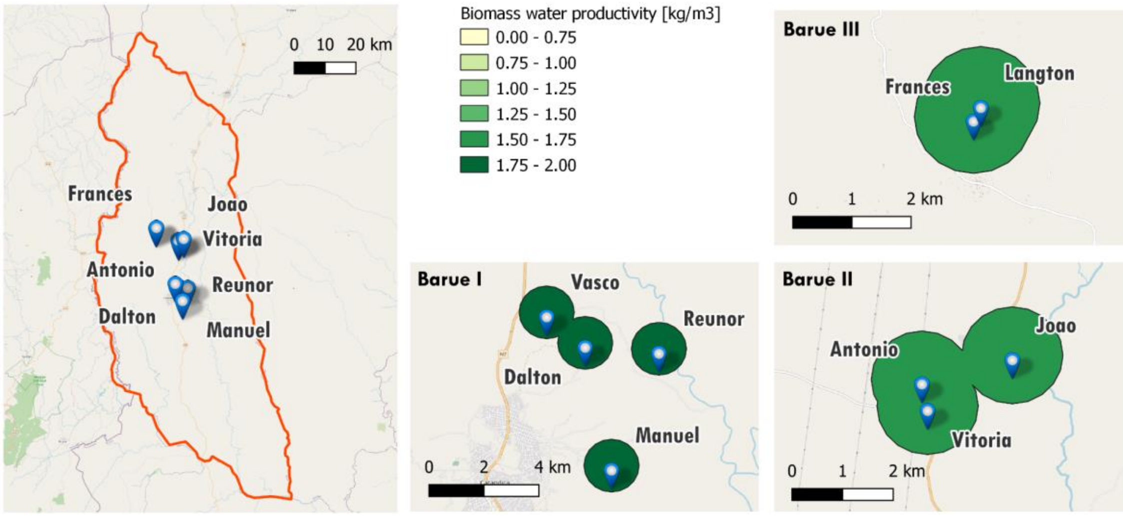


Figure 24. Biomass water productivity (kg/m³) for sub-basins in Báruè for the 2021-2022 rainfed season

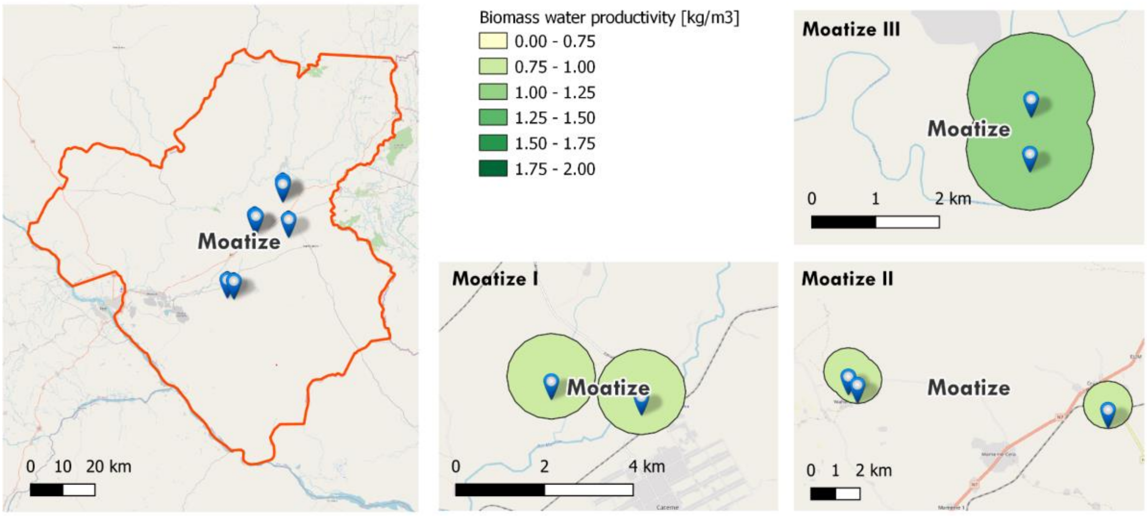


Figure 25. Biomass water productivity (kg/m³) for sub-basins in Moatize for the 2021-2022 rainfed season

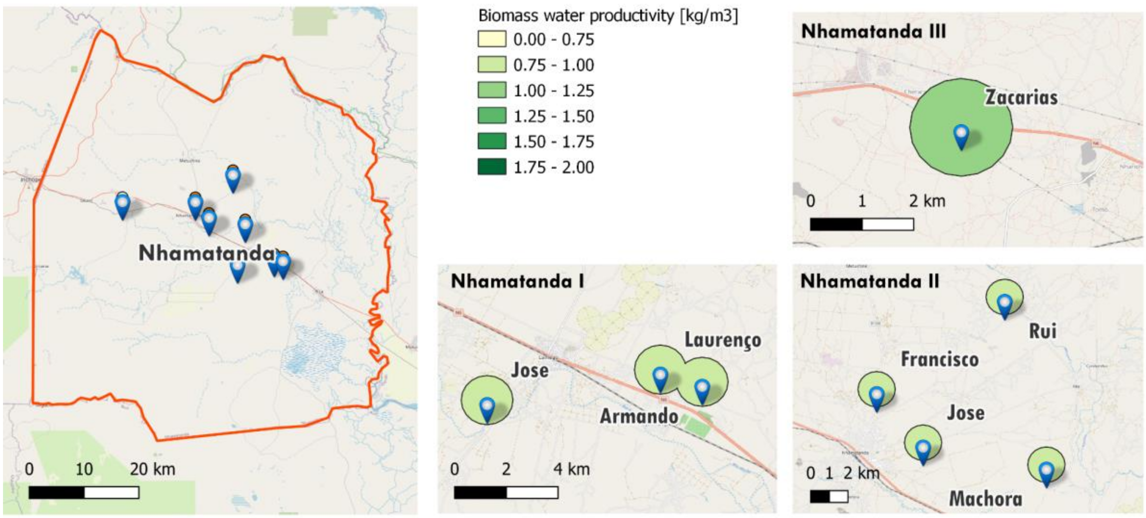


Figure 26. Biomass water productivity (kg/m³) for sub-basins in Moatize for the 2021-2022 rainfed season

6 Basin scale water productivity results

The basins were delineated for each district as shown in Figure 6 based on hydrological streamlines. These delineations were used with the WaPOR data portal to determine the biomass water productivity for each location. Table 12 provides an overview of the statistics found for actual evapotranspiration, biomass production, and water productivity for each basin, after masking out only the cropland pixels using the landcover layer provided in WaPOR. Báruè displays the highest biomass production of the area, followed by Moatize and Nhamatanda. The water productivity was also highest for Báruè, followed by Moatize, and lastly Nhamatanda.

Table 12. Overview of statistics of actual evapotranspiration, biomass production, and water productivity for the basins of Báruè, Moatize and Nhamatanda

		Báruè	Moatize	Nhamatanda
Actual evapotranspiration [mm]	Average mean	475	482	566
	10th percentile	349	392	488
	90th percentile	602	576	659
Biomass production [ton/ha]	Average mean	8.1	7.3	6.5
	10th percentile	6.0	6.0	5.4
	90th percentile	10.1	8.7	7.9
Water productivity [kg/m^3]	Average mean	1.59	1.51	1.14
	10th percentile	1.44	1.35	1.06
	90th percentile	1.73	1.70	1.30

Figure 20 displays the water productivity maps of each basin. In Báruè, the water productivity downstream shows even distribution, but higher upstream a decrease in water productivity values can be seen. In Moatize the upstream area (north-east) displays higher water productivity values than downstream. These areas are also closer to the mountain range, which could influence the local weather conditions. The number of cropland pixels in Nhamatanda are limited, therefore less spatial variation can be observed, but is seems to be an even distribution.

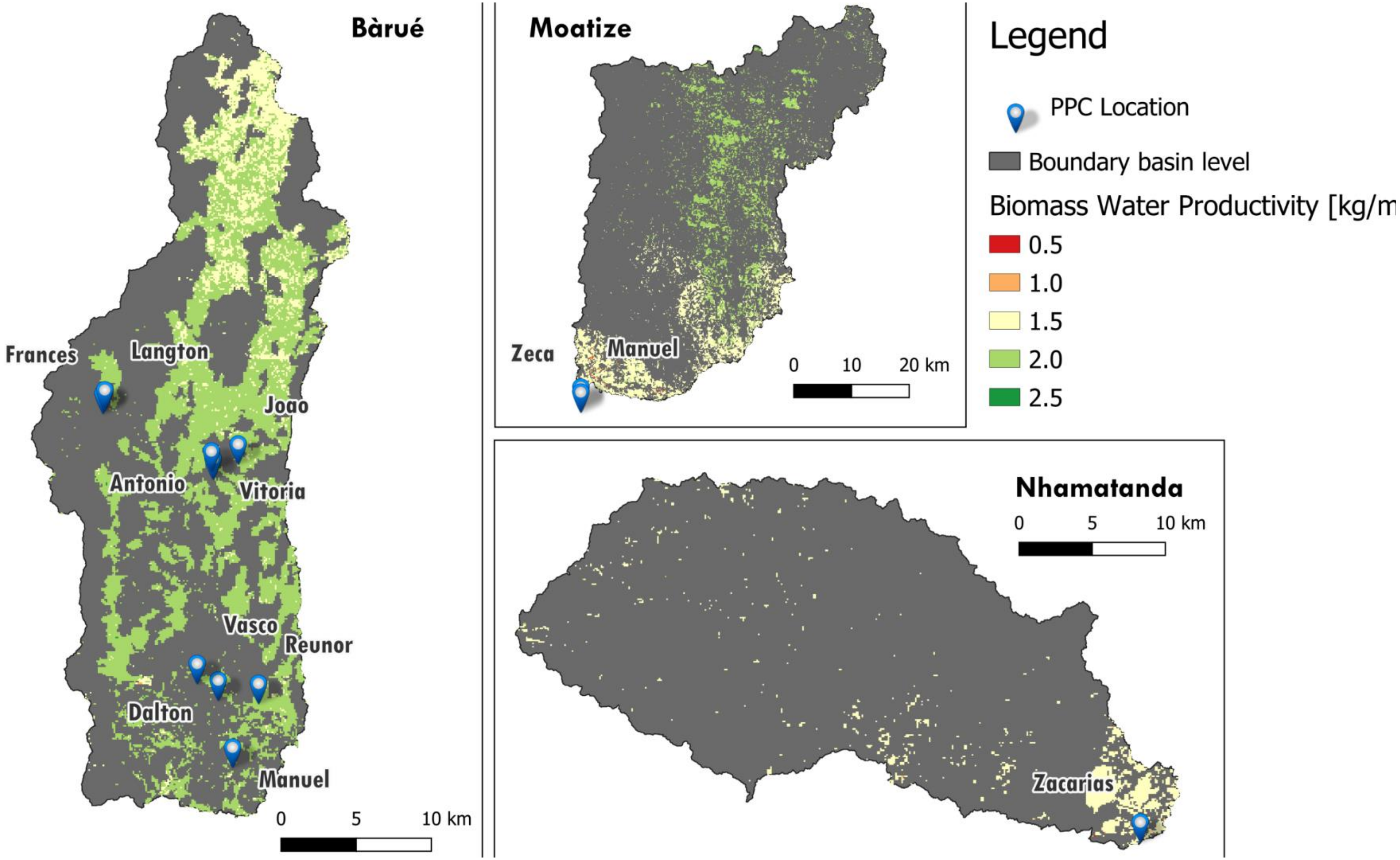


Figure 27. Seasonal biomass water productivity (kg/m^3) at basin scale for cropland pixels in Báruè, Moatize and Nhamatanda for the 2021 irrigation season

7 Seasonal water productivity assessment

The following sections elaborate on the change in water productivity on the different scales in comparison with the baseline; and the change in overall water productivity using the WaPOR database to assess for a larger area. Assessments make use of normalizing the water productivity for the seasonal weather conditions as explained in Section 2.8 of this report. Thus, changes in water productivity linked to the seasonal weather are minimised in the assessment. The water productivity assessment at the level of the PPC is presented followed by the overall water productivity assessment at the level of the sub-basins or communities and the basin level.

7.1 Field scale

Chapter 4 of this report presents the results of the field scale water productivity. An overview of this analysis is provided in Table 13 for each district indicating the overall change in water productivity. The values represent the normalized crop water productivity values. The overall increase is calculated by comparing the average (mean) of the normalized water productivity, with the 75th percentile[1] of the baseline. The assumption is that the PPCs are above-average farmers (in the top 25%) compared to the agricultural systems used in the baseline assessment, which is explained in Section 2.9. The overall average improvement in water productivity achieved at the field scale of the PPCs is +92%. The highest increase was observed in Báruè and the lowest in Moatize. Overall, the improvements in water productivity indicate a good achievement of the targets set in the logframe as presented in section 1.3 of this report. In comparison with the previous rainfed season (2020-2021)[2], which reported an average field scale water productivity increase of +68%, this rainfed season shows a notable change of improvements and a positive impact of farm management practices on the water productivity.

Table 13. Normalized maize water productivity (in kg/m^3) for the rainfed season of 2021-2022 compared to the baseline values

	Báruè	Moatize	Nhamatanda	Overall
Baseline water productivity				
Range	0.25 – 0.44	0.23 – 0.41	0.21 – 0.37	
75th Percentile	0.41	0.37	0.33	
Rainfed season 2021-2022 water productivity				
Range	0.70 – 0.87	0.60 – 0.76	0.51 – 0.74	
Average (mean)	0.80	0.69	0.64	
Relative change with baseline (%)	+95%	+87%	+95%	**+92%**

As this is the final rainfed season included in the APSAN-Vale project, this report contains an overall assessment of the change in water productivity throughout the four years the project lasted. These results are depicted in Figure 28 where values in the table indicate the water productivity of the corresponding rainfed season in that district. The values located at the top of the bars indicate the percentual change from the baseline.

All districts saw a positive change in water productivity throughout the years. The water productivity of Báruè and Nhamatanda both increased by +95%, while Moatize improved by +87%. The positive improvements in water productivity were not linear and in some cases the water productivity values were lower than the growing season before. This deviation is likely a result of different farm management practices or slightly changing analysis methods.

[1] This is a measure used in statistics indicating the value below which a given percentage of observations in a group of observations falls. In this case, 25% of the observations are found above the 75th percentile.
[2] Van Opstal, J.D., M. de Klerk, V. Hollander, J.E. Beard. 2021. Water Productivity Analysis: Rainfed Season 2020-2021. FutureWater Report 218.

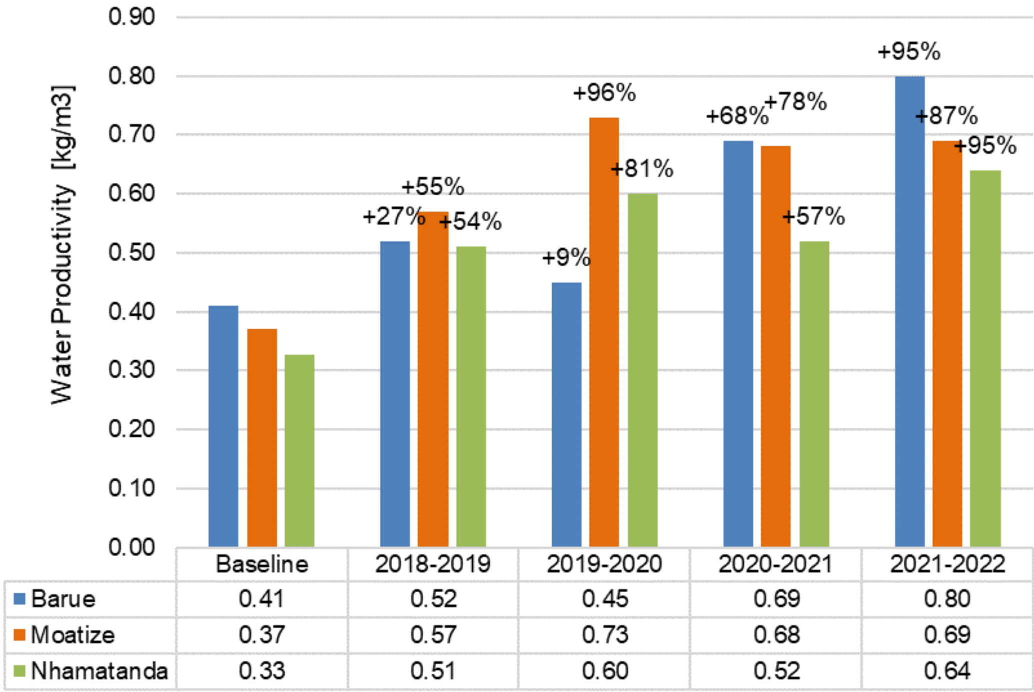


Figure 28. Overview of water productivity results for all assessments since the baseline.

7.2 Sub-basin scale

The sub-basin community scale water productivity was calculated using the 300 ha areas surrounding PPCs and the water productivity values as provided on the WaPOR data portal. The baseline values were not included for this spatial level in the baseline assessment report. For a baseline report the data from WaPOR and the average values for 2015 to 2018 for the rainfed season (November – May) were used.

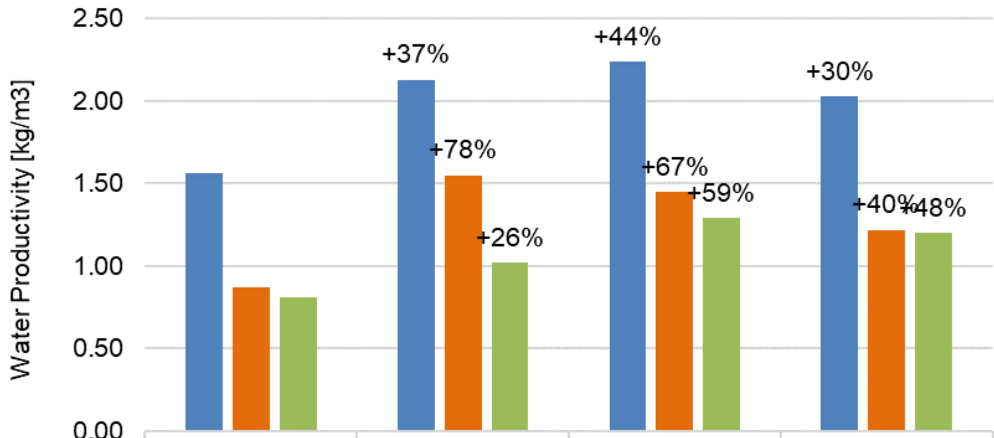
Table 14 presents the results of the baseline and comparison with the 2021-2022 rainfed season results. The overall increase of water productivity was observed to be +30% for Báruè, +40% for Moatize, and +48% for Nhamatanda. This indicates positive impact is achieved in the areas surrounding the PPCs and ultimately good practices are adopted to improve water productivity. The overall increase in water productivity is +40%, which is lower than the field scale water productivity due to the spatial scale being larger. It is assumed that the adoption of good agricultural practices is more dispersed at a large spatial scale.

Table 14. Biomass water productivity (kg/m^3) for the 2021-2022 rainfed season at sub-basin scale compared to the baseline of 2015-2020 as derived from the WaPOR data portal

	Báruè	Moatize	Nhamatanda	Overall
Baseline average 2015 – 2018	1.56	0.87	0.81	
Rainfed season 2021-2022	1.67	0.98	1.00	
Rainfed season 2021-2022 (normalized)	2.03	1.22	1.20	
Relative change with baseline (%)	+30%	+40%	+48%	**+40%**

For the sub-basins, an overall assessment of the change in water productivity through the project years was done as well. As the 2018-2019 rainfed season did not include a sub-basin analysis, only the last three years were included. These results are depicted in Figure 29 where values in the table indicate the water productivity of the corresponding rainfed season in that district. The values located at the top of the bars indicate the percentual change from the baseline.

All districts saw a positive change in water productivity throughout the years. The water productivity of Báruè increased by +30%, while Moatize improved by +40% and Nhamatanda improved by +48%. The positive improvements in water productivity were not linear and in some cases the water productivity values were lower than the growing season before. This deviation is likely a result of different farm management practices or slightly changing analysis methods. Furthermore, the Báruè results were mostly lower than Moatize and Nhamatanda, due to a higher initial water productivity in Báruè.



	Baseline	2019-2020	2020-2021	2021-2022
Barue	1.56	2.13	2.24	2.03
Moatize	0.87	1.55	1.45	1.22
Nhamatanda	0.81	1.02	1.29	1.20

Figure 29. Overview of the water productivity results for the sub basin scale

7.3 Basin scale

The assessment of water productivity at basin scale was performed using the WaPOR results from chapter 6. These indicate the water productivity values for cropland pixels at the selected basins of the project for the irrigation season. Table 15 presents the values of biomass water productivity after normalizing for the 2021 weather conditions and comparing with the baseline values. An average increase of biomass water productivity of +20% was perceived, ranging from +11% to +30% for the different districts. The previous irrigation season report (2020)[1] indicated an overall biomass water productivity increase of +16%, indicating that the 2021-2022 rainfed season had an even higher increase in water productivity at basin scale. This is a positive trend and requires further investigation to determine to what magnitude the increase is related to the field interventions and adoption by the community.

Table 15. Biomass water productivity (kg/m^3) for the 2021-2022 rainfed season at basin scale compared to the baseline

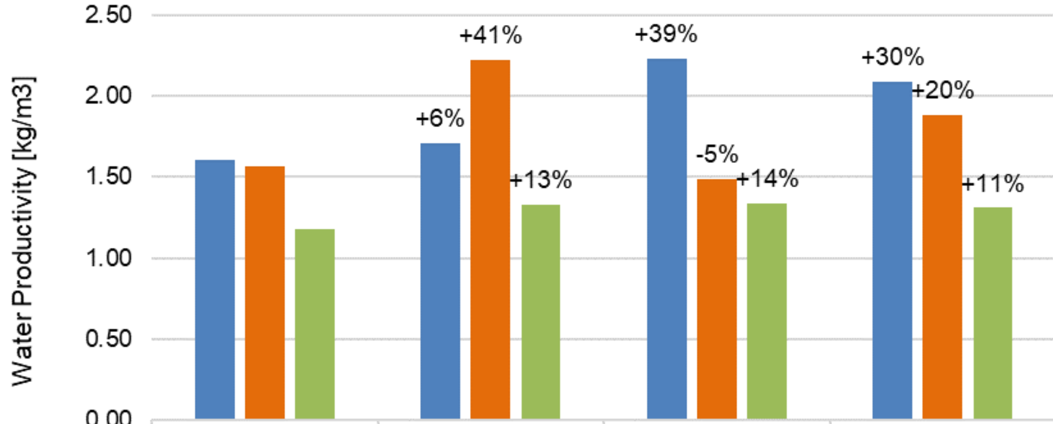
	Báruè	Moatize	Nhamatanda	Overall
Baseline average 2001-2018	1.61	1.57	1.18	
Rainfed season 2021-2022	1.59	1.51	1.14	
Rainfed season 2021-2022 (normalized)	2.09	1.88	1.31	
Relative change with baseline (%)	+30%	+20%	+11%	**+20%**

Lastly, an overall assessment for the change in water productivity was conducted for the basin analyses. These results are depicted in Figure 30 where values in the table indicate the water productivity of the

[1] Van Opstal, J.D., M. de Klerk, A. Kaune, C. Nolet, J.E. Beard. 2021. Water Productivity Analysis: Irrigation Season 2020. FutureWater Report 218.

corresponding rainfed season in that district. The values located at the top of the bars indicate the percentual change from the baseline.

All districts saw a positive change in water productivity throughout the years, but the Moatize basin saw a decrease of 5 percent in the 2020-2021 season. The water productivity of Báruè increased by +30%, Moatize improved by +20% and Nhamatanda increased by +11%. The positive improvements in water productivity were not linear and in some cases the water productivity values were lower than the growing season before. This deviation is likely a result of different farm management practices.



	Baseline	2019-2020	2020-2021	2021-2022
Barue	1.61	1.71	2.23	2.09
Moatize	1.57	2.22	1.49	1.88
Nhamatanda	1.18	1.33	1.34	1.31

Figure 30. Overview of the water productivity results for the basin

8 Concluding remarks

The water productivity results as presented in this report provide insight into the impact of the project activities both at the field, sub-basin (community), and basin scale. Various methods were used to provide a reliable assessment of the water productivity, using the data available from the field, flying sensor imagery, and open-access remote sensing datasets from WaPOR and Sentinel 2.

The field scale water productivity presented results for 23 farmers which were monitored throughout the rainfed season of 2021-2022 as part of the APSAN-Vale project. The water productivity was calculated for maize, the sole crop that was analysed during this growing season. The water productivity of maize production was found to range from 0.70 to 0.87 kg/m^3 in Báruè, 0.60 to 0.76 kg/m^3 in Moatize, and 0.51-0.74 kg/m^3 in Nhamatanda. After normalization for climatic conditions, the increase in overall crop-specific water productivity was found to be +95% in Báruè, +87% in Moatize, and +95% in Nhamatanda, resulting in an average +92% increase in comparison with the baseline values. This is a +24% increase compared to the previous rainfed season report (2020-2021) and achieves the set target for 2021-2022 of +25% as stated in the project logframe.

The results of the field water productivity give a good indication of trends in high and low water productivity. These results will be combined with the monitoring data from APSAN-Vale consortium partners indicating the adoption of practices of these farmers and the training sessions that were attended. In a follow-up report, a preliminary analysis will be provided on determining the impact of interventions on crop yield and water productivity.

Furthermore, the water productivity was calculated at the sub-basin scale, which is representative of the community of farmers adopting practices being demonstrated and promoted by the selected PPCs. An area of 300 ha around each selected PPC is determined to be representative of the area of the sub-basin (or community). At the sub-basin scale, the water productivity analysis makes use of the WaPOR data portal and calculates the biomass water productivity. The highest water productivity values were found in Báruè; here the highest values are observed in Báruè I at 1.79 kg/m^3. The biomass water productivity was found to range from 1.60 to 1.79 kg/m^3 in Báruè, 0.88 to 1.06 kg/m^3 in Moatize, and 0.88 to 1.18 kg/m^3 in Nhamatanda. The relative change of water productivity compared to the baseline values is +30%, +40% and +48% for Báruè, Moatize, and Nhamatanda, respectively. The overall increase in water productivity estimated at sub-basin (community) level is +39%.

At basin scale the catchment delineation from each district was used as the boundary of the basin. The water productivity was determined using the WaPOR data portal providing values on biomass water productivity. These values are compared with the baseline assessment and determined that an increase of water productivity was achieved of +30%, +20%, and +11% for Báruè, Moatize, and Nhamatanda respectively. The average increase in biomass water productivity was +20% for all districts together.

Annex 1 – Overview of input data

Table 16. Field input data for Báruè

Year	Irrigation / rainfed	Region	ID plot	Name farmer	Lat	Lon	Soil texture (sandyloam, etc)	Stoniness (low, moderate, high)	Crop type (EN)	Crop type (PT)	Planting date	Harvest date (optional) Data de Colheita	Plant area [cm/cm]	Planting density [plant/m2]	Planting density [plant/ha]	Fertilizer use (low, moderate, optimal)	Mulching yes/no	Weed mgt (low, moderate, high)	Runoff mgt (yes/no)	Other relevant practices	Irrigation (yes/no)
c	rainfed	Baru	AP_BA_ACI-01-	Ananias Chicum	-18.018	33.240	sandy clay	low	soybean	soja	10-Feb-2021	11-jun	50x30	6.7	66666.7	optimal	no	Low	yes		no
2022	rainfed	Baru	AP_BA_AM-01-	Antonio Matavel	-17.860	33.203	sandy clay	low	maize	milho	5-Dec-2021	1-mei	90x70	1.6	15873.0	no	no	high	no		no
2022	rainfed	Baru	AP_BA_AM-01-	Antonio Matavel	-17.860	33.203	sandy clay	low	pigeon pea	feijao boer	12-Feb-2022	15-mei	90x70	1.6	15873.0	no	no	low	no		no
2022	rainfed	Baru	AP_BA_DC-01-0	Dalton Cassuad	-18.004	33.206	sandy clay	low		milho	28-Jan-2022	28-mei	90x70	1.6	15873.0	no	no	moderate	no		no
2022	rainfed	Baru	AP_BA_FL-01-0	Frances Lapson	-17.823	33.134	sandy clay	low	maize	milho	20-Jan-2022	4-jun	90x70	1.6	15873.0	no	no	moderate	no		no
2022	rainfed	Baru	AP_BA_JC-01-0	Joao Cebola	-17.855	33.219	sandy clay	low	maize	milho	1-Jan-2022	16-mei	90x70	1.6	15873.0	optimal	no	high	yes		no
2022	rainfed	Baru	AP_BA_JC-01-0	Joao Cebola	-17.855	33.219	sandy clay	low	maize	milho	1-Dec-2021	16-mei	90x70	1.6	15873.0	optimal	no	high	yes		no
2022	rainfed	Baru	AP_BA_JC-01-0	Joao Cebola	-17.855	33.219	sandy clay	low	soybean	soja	10-Jan-2022	N/A	50x30	6.7	66666.7	optimal	no	low	yes		no
2022	rainfed	Baru	AP_BA_LC-01-0	Langton Charles	-17.821	33.135	sandy clay	low	maize	milho	18-Dec-2021	1-apr	90x70	1.6	15873.0	no	no	low	no		no
2022	rainfed	Baru	AP_BA_ML-01-0	Manuel Lamione	-18.046	33.216	sandy clay	low	maize	milho	28-Dec-2021	12-mei	90x70	1.6	15873.0	no	no	moderate	no		no
2022	rainfed	Baru	AP_BA_RF-01-0	Reunor Finiasse	-18.006	33.232	sandy clay	low	maize	milho	17-Nov-2021	17-mrt	90x70	1.6	15873.0	no	no	moderate	yes		yes
2022	rainfed	Baru	AP_BA_RF-01-0	Reunor Finiasse	-18.006	33.232	sandy clay	low	maize	milho	17-Nov-2021	17-mrt	90x70	1.6	15873.0	no	no	moderate	yes		yes
2022	rainfed	Baru	AP_BA_RF-01-0	Reunor Finiasse	-18.006	33.232	sandy clay	low	maize	milho	10-Dec-2021	9-apr	90x70	1.6	15873.0	no	no	moderate	yes		yes
2022	rainfed	Baru	AP_BA_RF-01-0	Reunor Finiasse	-18.006	33.232	sandy clay	low	cabbage	repolho	17-Nov-2021		90x70	1.6	15873.0	no	no	moderate	yes		yes
2022	rainfed	Baru	AP_BA_RF-01-0	Reunor Finiasse	-18.006	33.232	sandy clay	low	tsunga	tsunga		N/A					no	moderate	yes		yes
2022	rainfed	Baru	AP_BA_RF-01-0	Reunor Finiasse	-18.006	33.232	sandy clay	low	pepper	pimenta	17-Nov-2021		90x70	1.6	15873.0	no	no	moderate	yes		yes
2022	rainfed	Baru	AP_BA_VB-01-0	Vasco Bonjesse	-17.994	33.193	sandy clay	low	maize	milho	4-Dec-2021	3-apr	90x70	1.6	15873.0	no	no	high	no		no
2022	rainfed	Baru	AP_BA_VB-01-0	Vasco Bonjesse	-17.994	33.193	sandy clay	low	maize	milho	4-Dec-2021	3-apr	90x70	1.6	15873.0	no	no	high	no		no
2022	rainfed	Baru	AP_BA_VB-01-0	Vasco Bonjesse	-17.994	33.193	sandy clay	low	pigeon pea	feijao	4-Feb-2022		90x70	1.6	15873.0	no	no	low	no		no
															0.0						
2022	rainfed	Baru	AP_BA_VT-01-0	Vitoria Tendai	-17.865	33.203	sandy clay	low	maize	milho	28-Dec-2021	12-mei	90x70	1.6	15873.0	no	no	low	no		no

FutureWater

Table 17. Field input data for Moatize

					Soil		Crop				Field mgt					
Year	Irrigation / rainfed	Region	ID plot	Name farmer	Soil texture (sandyloam, etc)	Stoniness (low, moderate, high)	Crop type (EN)	Crop type (PT)	Planting date	Harvest date (optional) Data de Colheita	Fertilizer use (low, moderate, optimal)	Mulching yes/no	Weed mgt (low, moderate, high)	Runoff mgt (yes/no)	Other relevant practices	Irrigation (yes/no)
2021-2022	Rainfed	Moatize	MO-SA-MC-01-01	Manuel Char	sandy cla	low	Maize	Milho	4-jan		Optimal	no	Low	no		no
2021-2022	Rainfed	Moatize	MO-SA-ZM-01-01	Zeca Marceli	sandy cla	low	Soybear	Soja	10-jan		Optimal	no	Low	no		no
2021-2022	Rainfed	Moatize	MO-MA-JC-01-01	Joao Cherene	sandy cla	Moderate	Maize	Milho	4-jan		optimal	no	Low	no		no
2021-2022	Rainfed	Moatize	MO-MA-GM-01-01	Girio Mussar	sandy cla	low	Maize	Milho	4-jan		Optimal	no	Low	no		no
2021-2022	Rainfed	Moatize	AP_BA_LC-01-01	Vicente Jurio	sandy cla	Moderate	Maize	Milho	4-jan		Optimal	no	Moderate	no		no
2021-2022	Rainfed	Moatize	MO-CA-XT-01-01	Xavier Toma	sandy cla	Low	Maize	Milho	4-jan		optimal	no	Low	no		no
2021-2022	Rainfed	Moatize	MO-CA-AB-01-01	Albino Banda	sandy cla	low	Maize	Milho	4-jan		optimal	no	Low	no		no

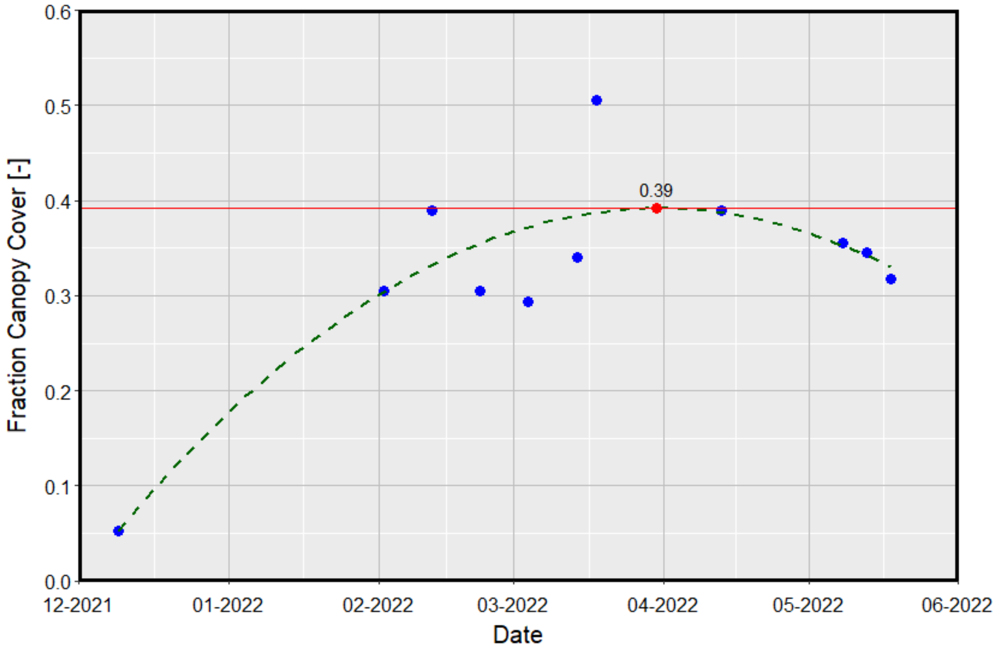
Table 18. Input field data for Nhamatanda

Year	Irrigation / rainfed	Region	ID plot	Name farmer	Soil texture (sandyloam, etc)	Stoniness (low, moderate, high)	Crop type (EN)	Crop type (PT)	Planting date	Harvest date (optional)	Planting density [plnts/m2]	Fertilizer use (low, moderate, optimal)	Mulching yes/no	Weed mgt (low, moderate, high)	Runoff mgt (yes/no)
2021-2022	Rainfed	Nhamatanda	NH-LM-JD	Jose Domingos	sandy clay	moderate	Maize	Milho	23.12.2022	25.04.2022	50x50	low	no	Moderate	no
2021-2022	Rainfed	Nhamatanda	NH-NM-LL	Lourenço Lampiao	sandy clay	moderate	Maize	Milho	16.12.2022	30.04.2022	80x50	low	no	Moderate	no
2021-2022	Rainfed	Nhamatanda	NH-LA-AM	Armando Malate	sandy clay	moderate	Maize	Milho	01.12.2022	17.04.2022	80x50	low	no	Moderate	no
2021-2022	Rainfed	Nhamatanda	NH-NS-RB	Rui Bassopa	sandy clay	moderate	Maize	Milho	20.12.2022	08.04.2022	80x50	low	no	Moderate	no
2021-2022	Rainfed	Nhamatanda	NH-MP-MP	Machoca Ntequenha	sandy clay	moderate	Maize	Milho	25.12.2022	17.04.2022	80x50	low	no	Moderate	no
2021-2022	Rainfed	Nhamatanda	NH-NS-JM	Jose Mamuel	sandy clay	moderate	Maize	Milho	15.12.2022	19.05.2022	80x50	low	no	Moderate	no
2021-2022	Rainfed	Nhamatanda	NH-NC-ZF	Zacarias Fulene	sandy clay	moderate	Maize	Milho	08.12.2022	15.04.2022	80x50	low	no	Moderate	no
2021-2022	Rainfed	Nhamatanda	Nh-NC-FA	Francisco Augusto	sandy clay	moderate	Maize	Milho	23.12.2022	26.24.2022	80x50	low	no	Moderate	no

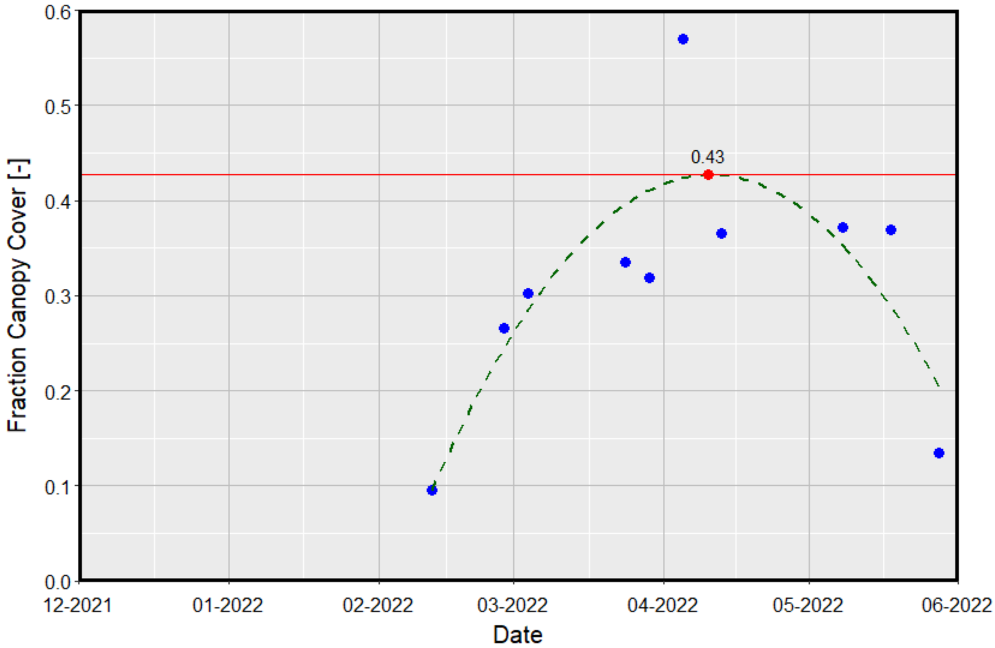
Annex 2 – Fitted canopy curves

<u>Báruè</u>

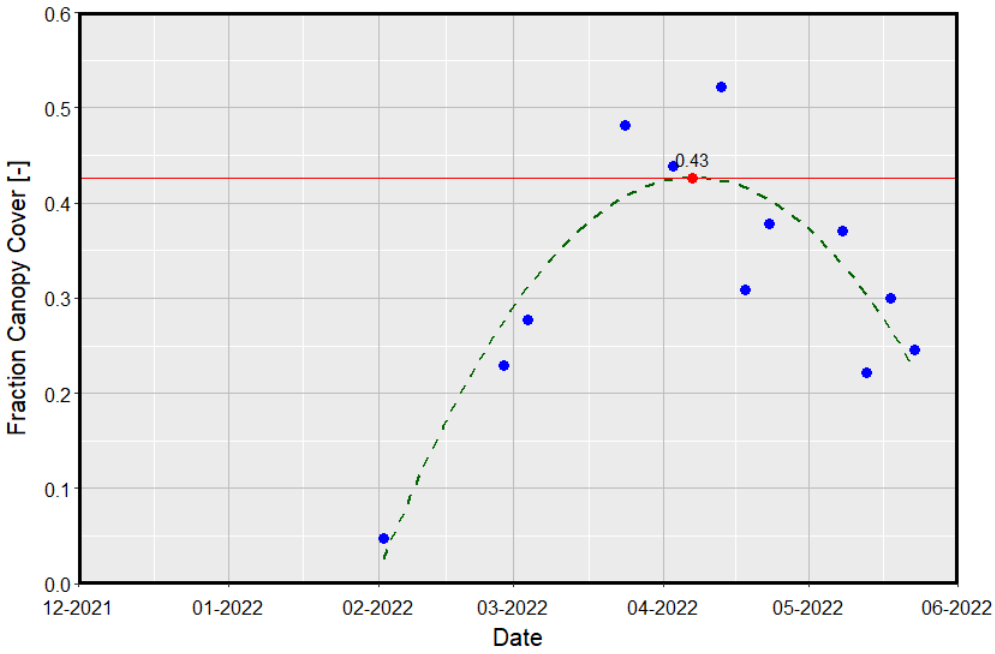
Antonio



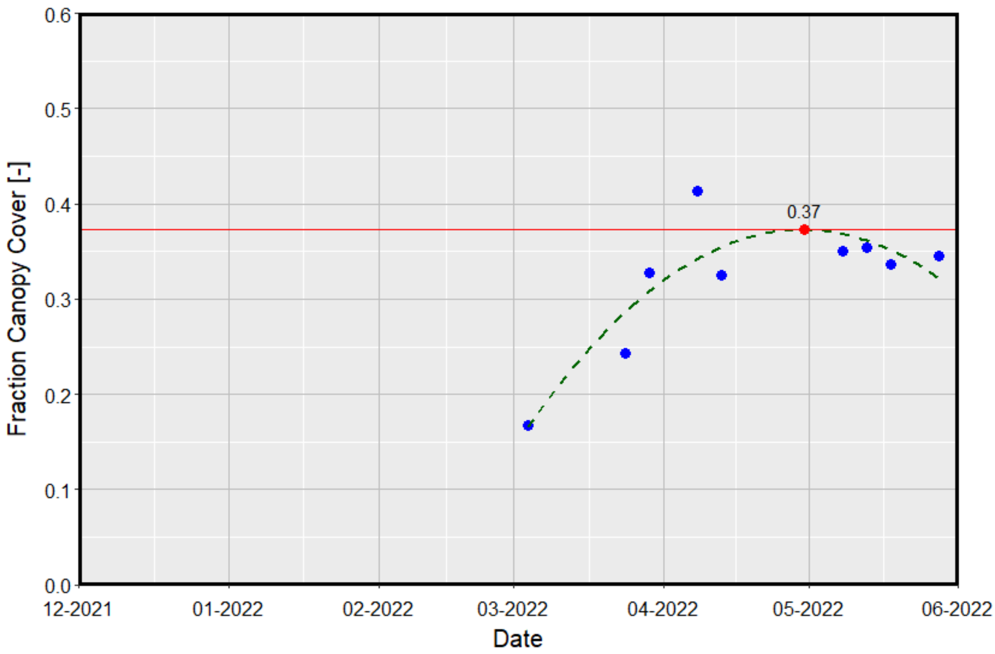
Dalton



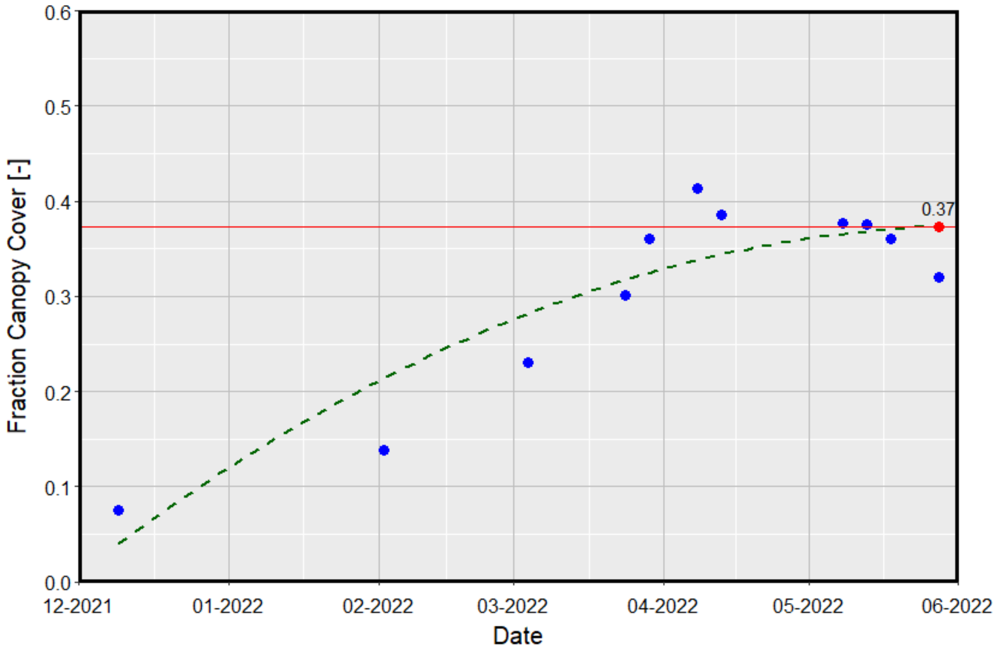
Frances



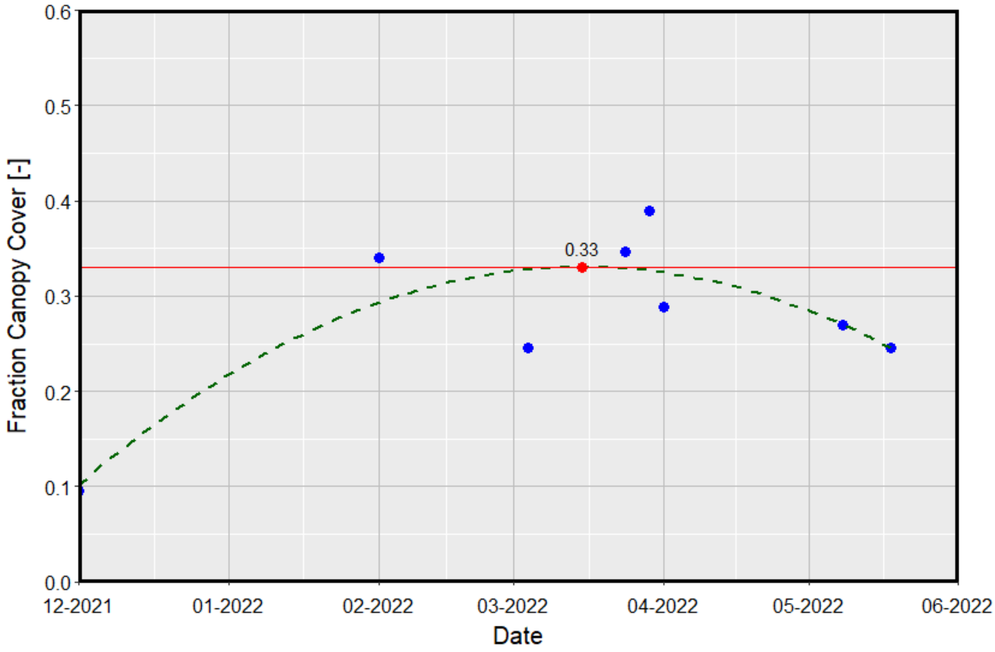
Joao 1



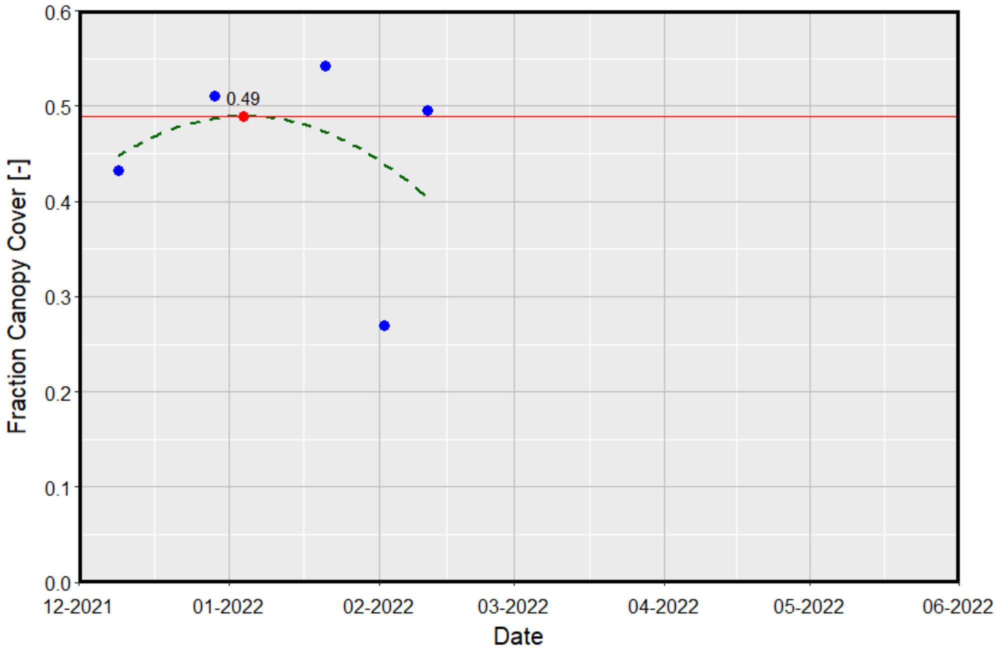
Joao 2



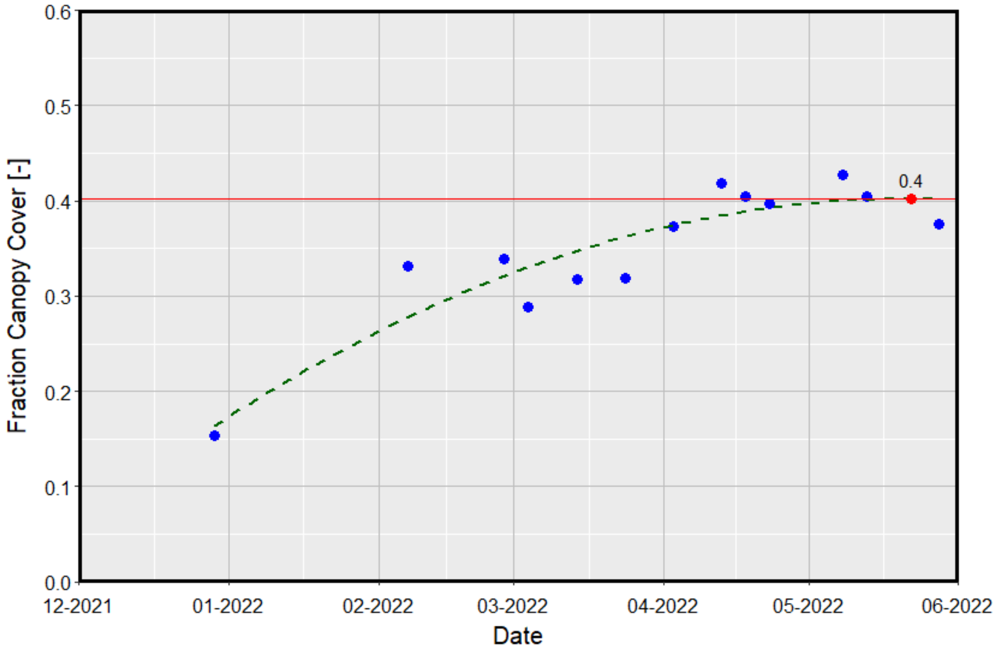
Langton



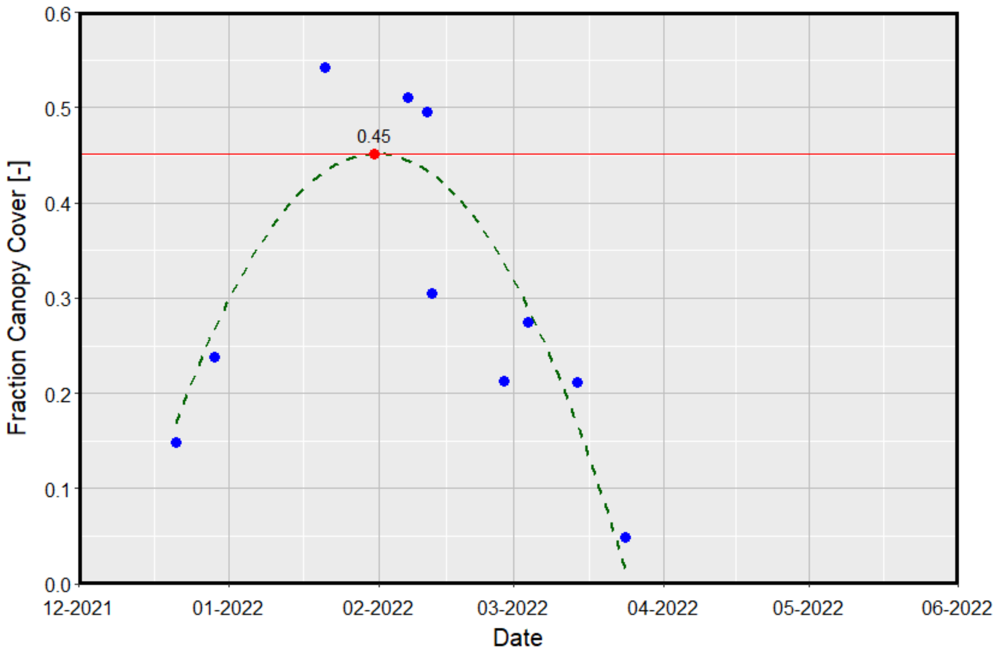
Manuel



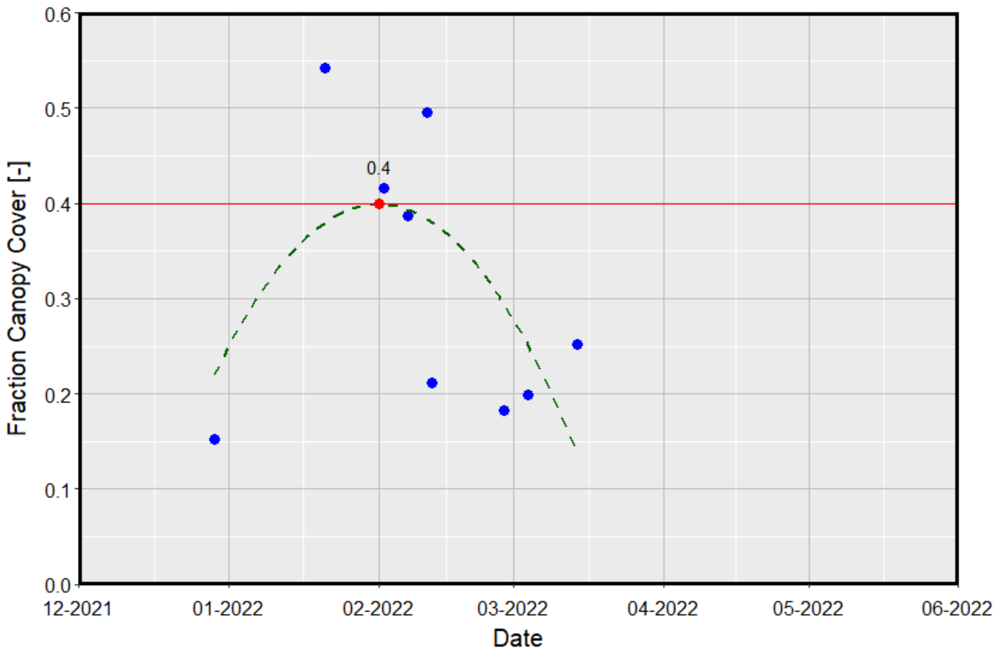
Reunor 1



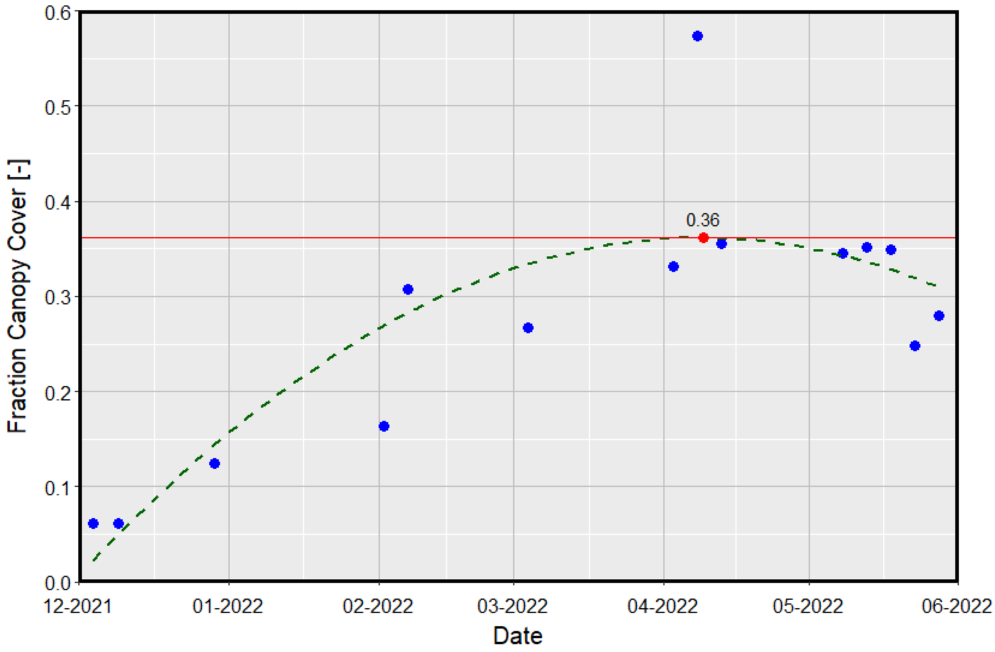
Reunor 2



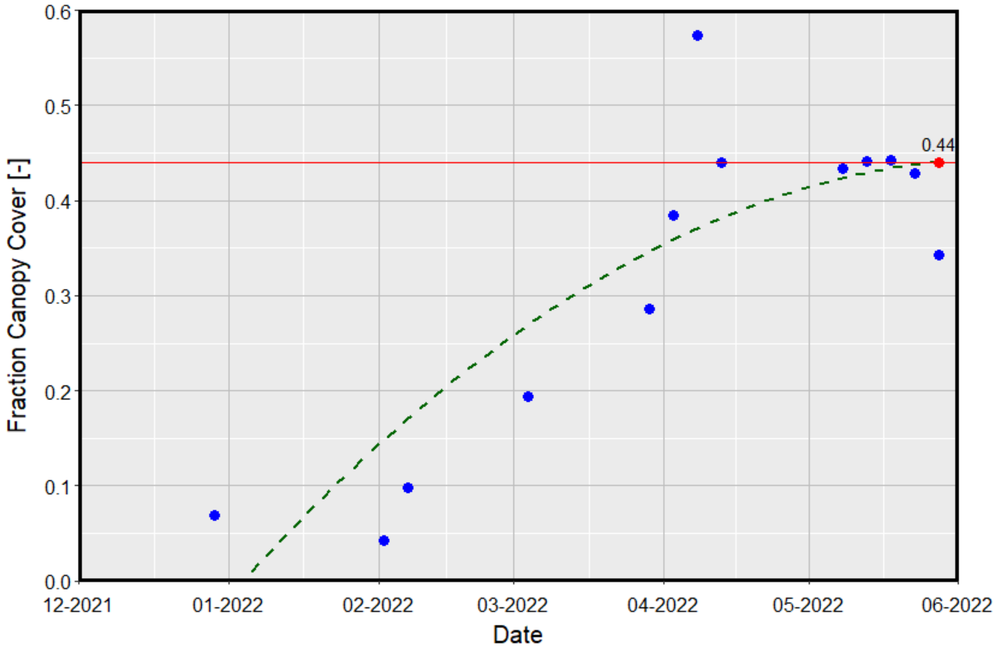
Reunor 3



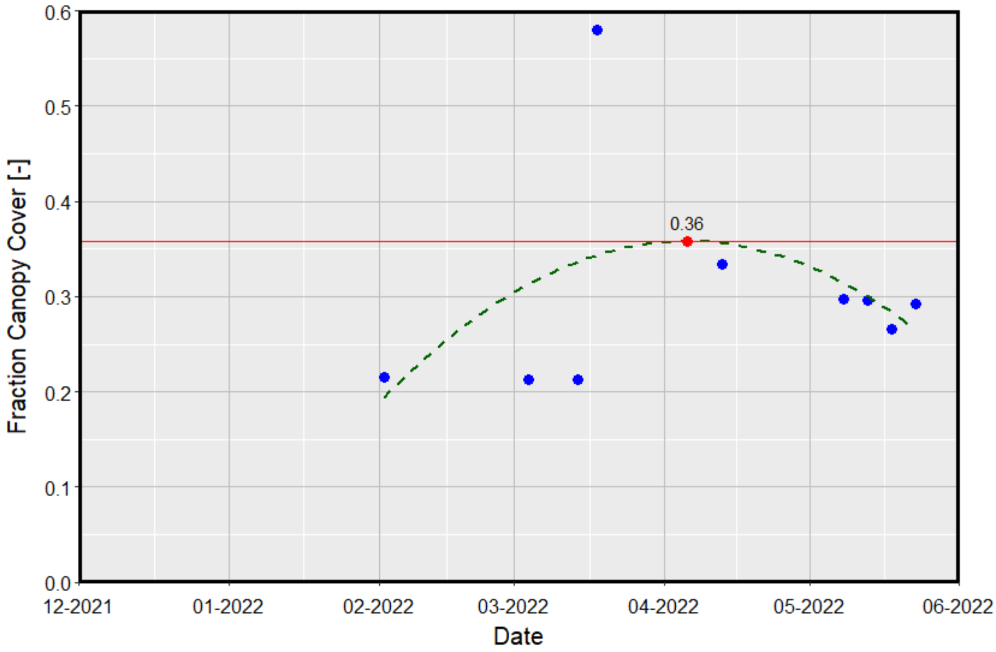
Vasco 1



Vasco 2

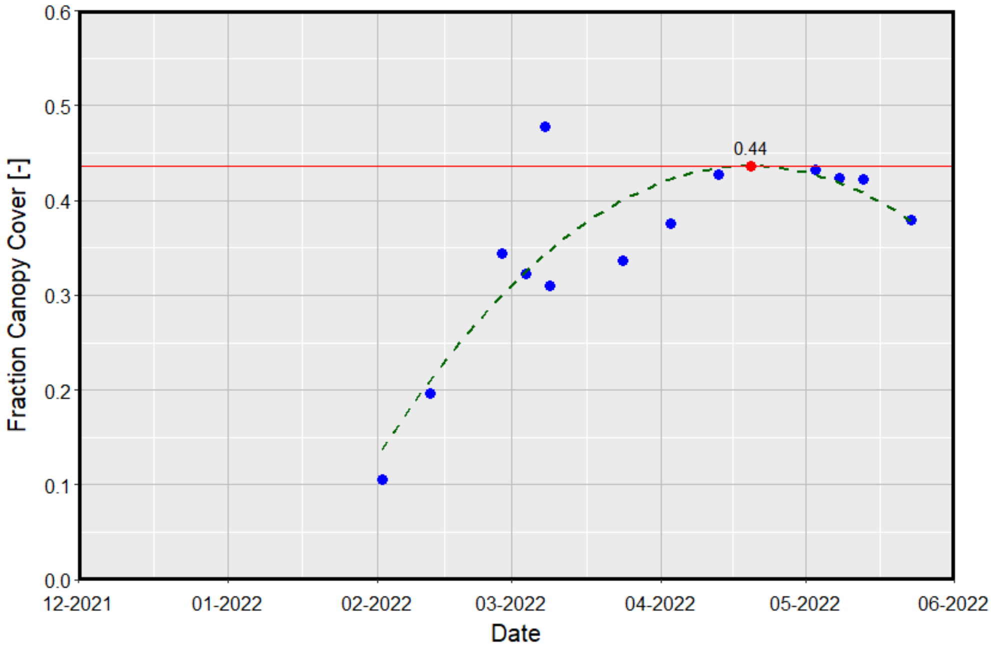


Vitoria

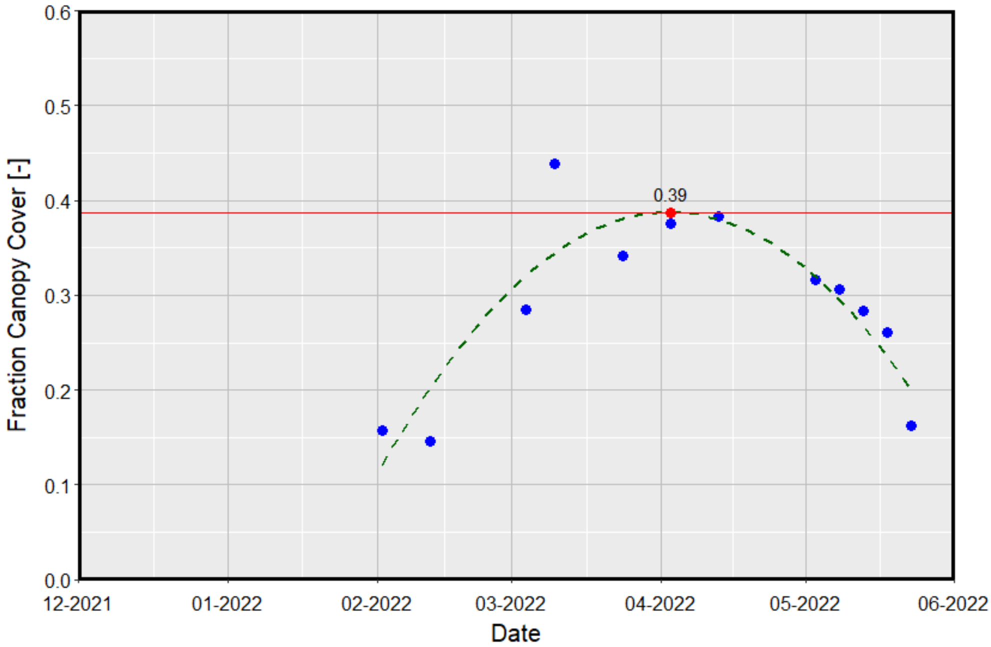


Moatize

Manuel

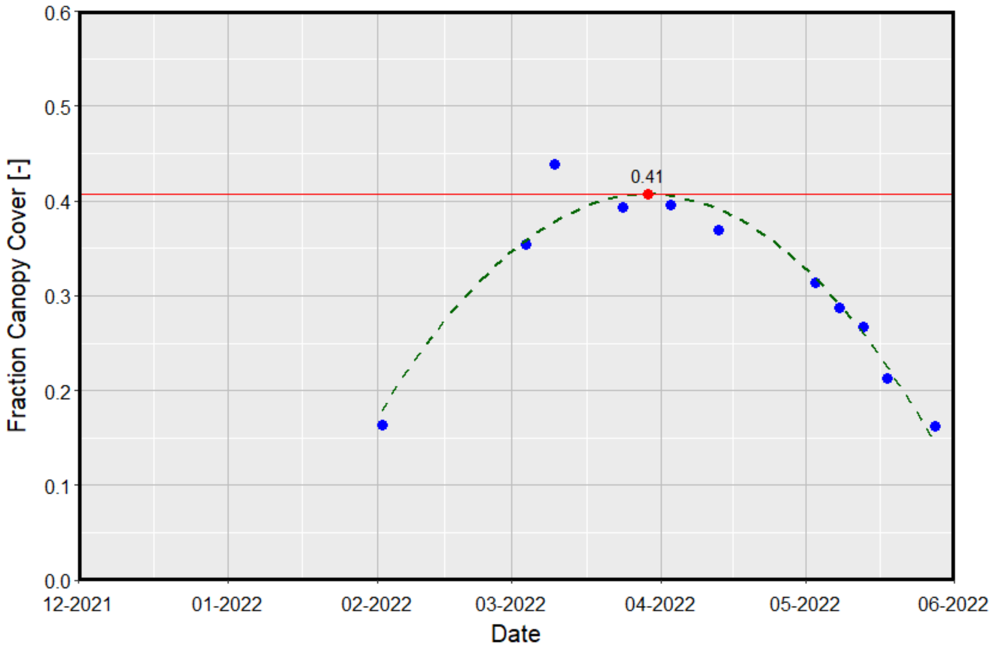


Joao 1



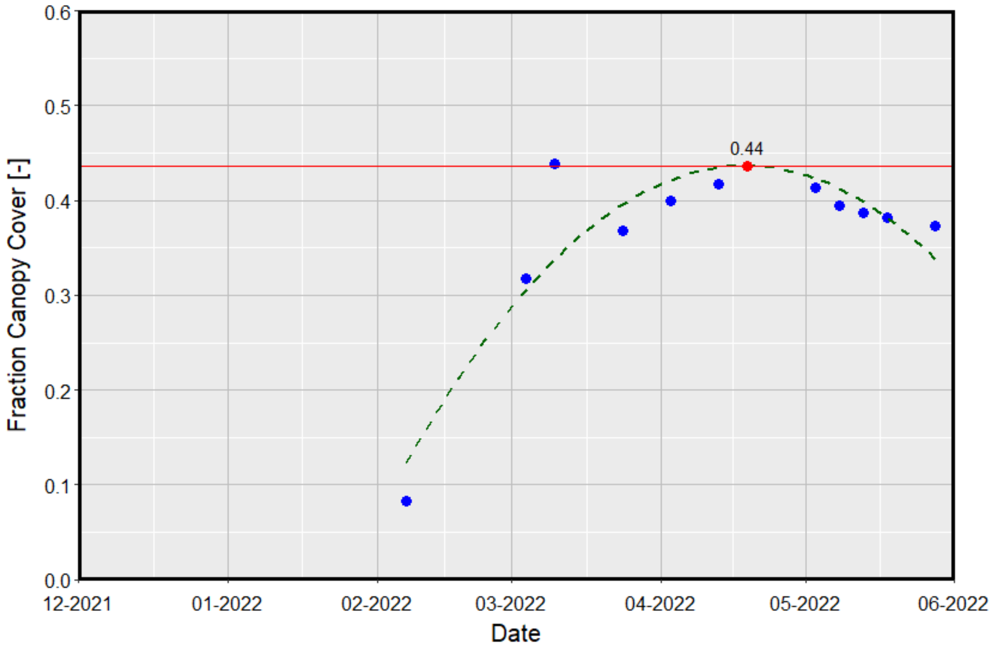
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Fraction Canopy Cover [-]
0.39
12-2021
01-2022
02-2022
03-2022
04-2022
05-2022
06-2022
Date

Joao 2

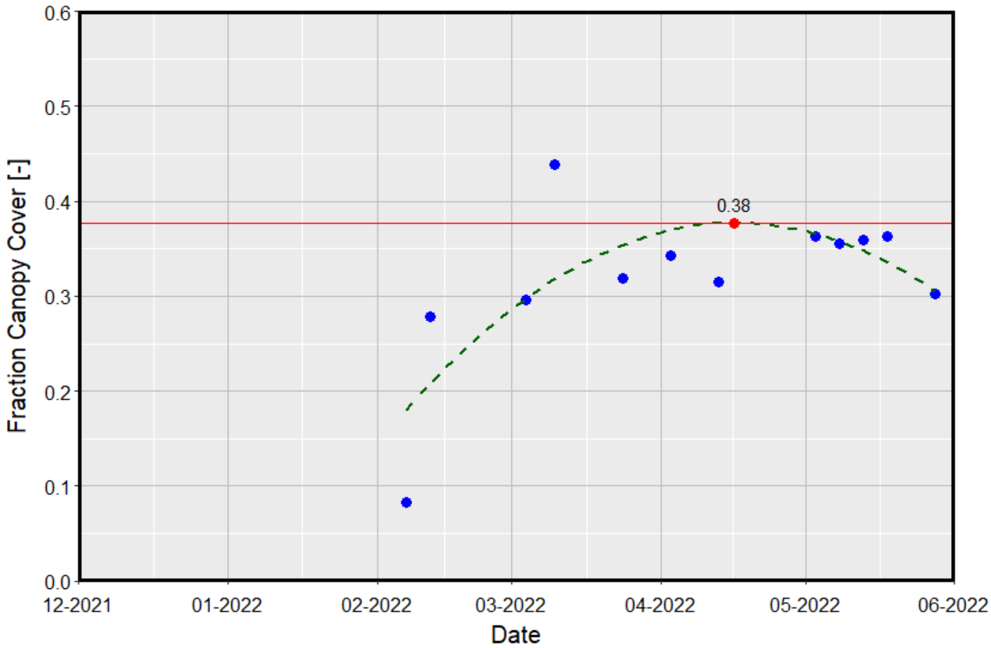


0.6
0.5
0.4
0.3
0.2
0.1
0.0
Fraction Canopy Cover [-]
0.41
12-2021
01-2022
02-2022
03-2022
04-2022
05-2022
06-2022
Date

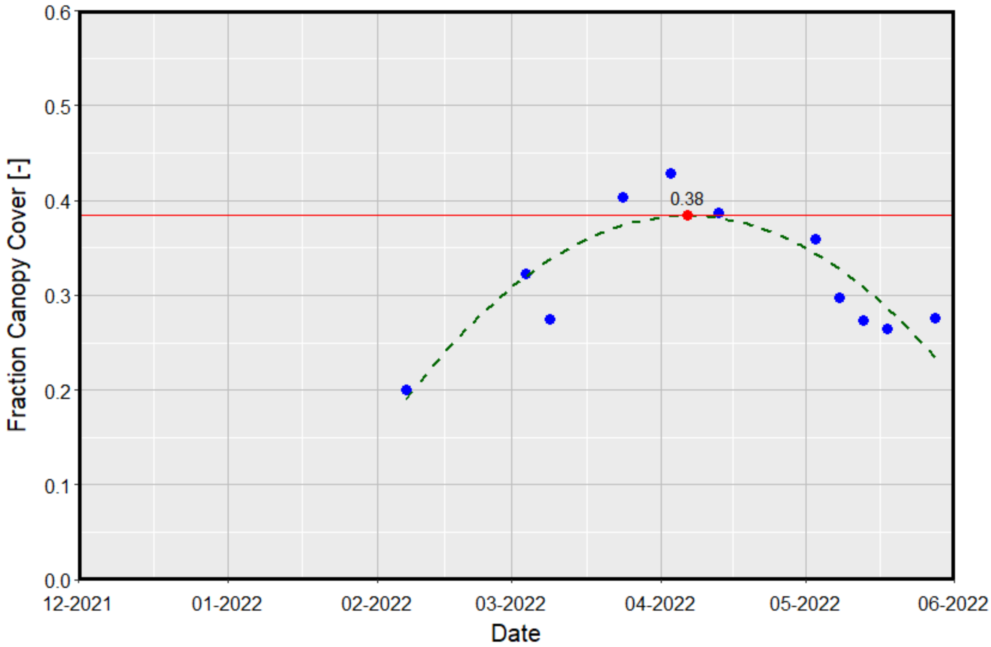
Joao 3


0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.44
Fraction Canopy Cover [-]
12-2021
01-2022
02-2022
03-2022
04-2022
05-2022
06-2022
Date

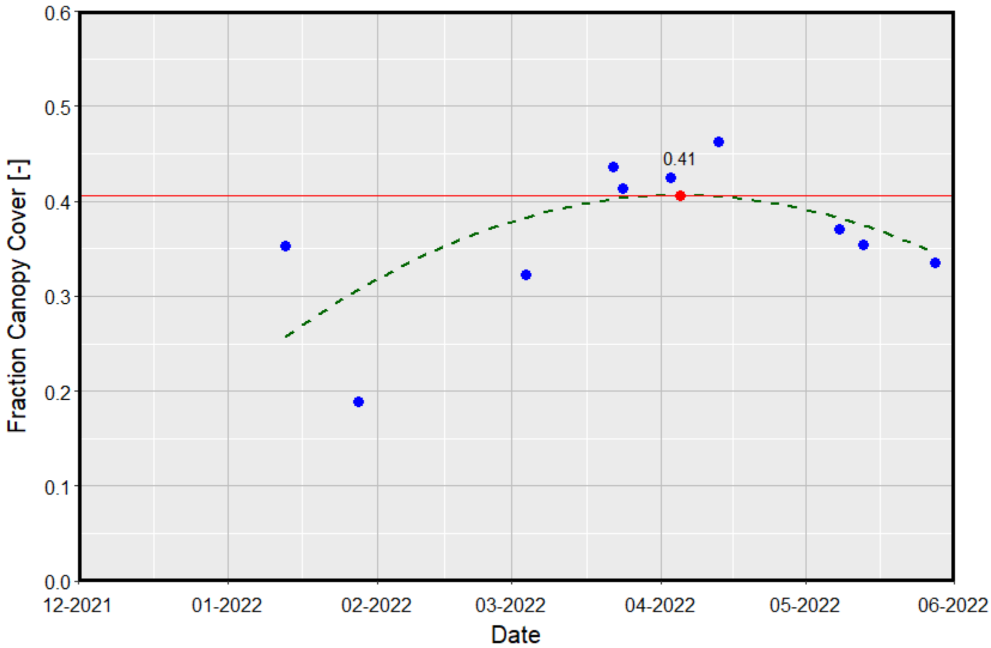
Joao 4


0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.38
Fraction Canopy Cover [-]
12-2021
01-2022
02-2022
03-2022
04-2022
05-2022
06-2022
Date

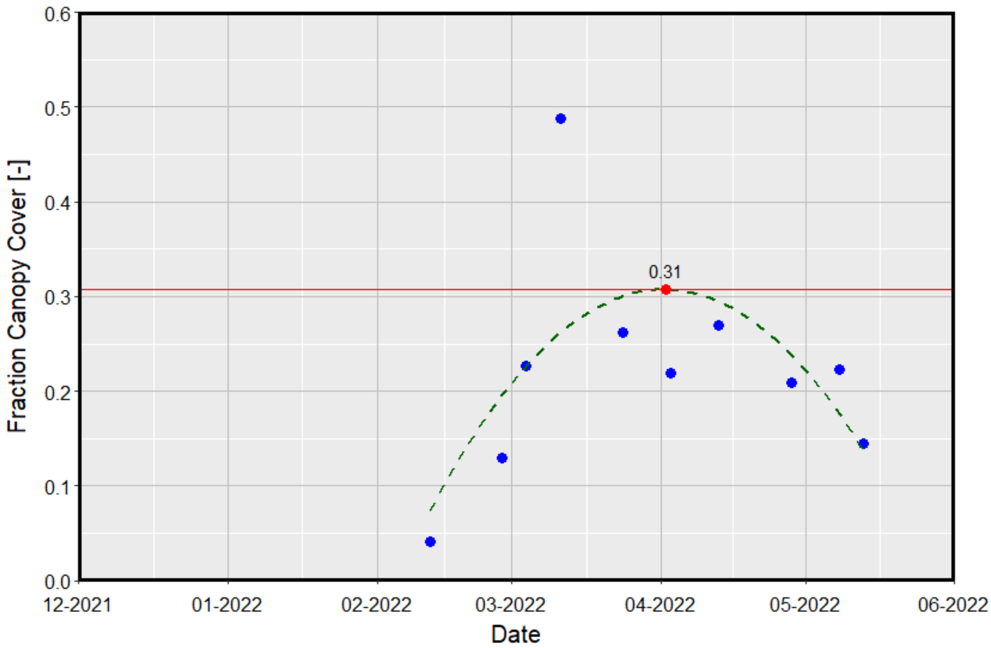
Girio



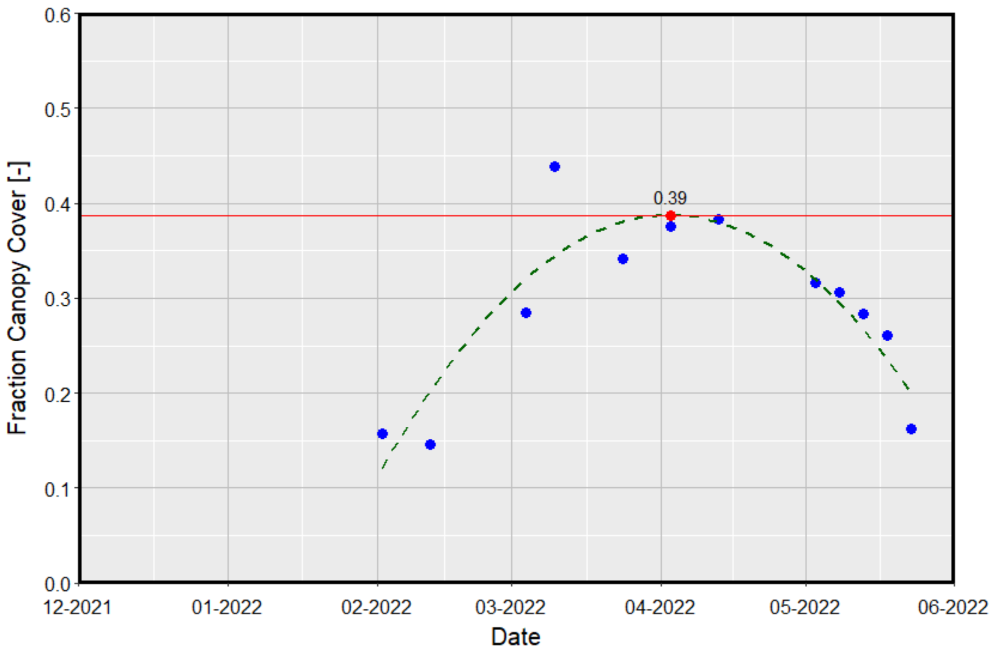
Vicente



Xavier

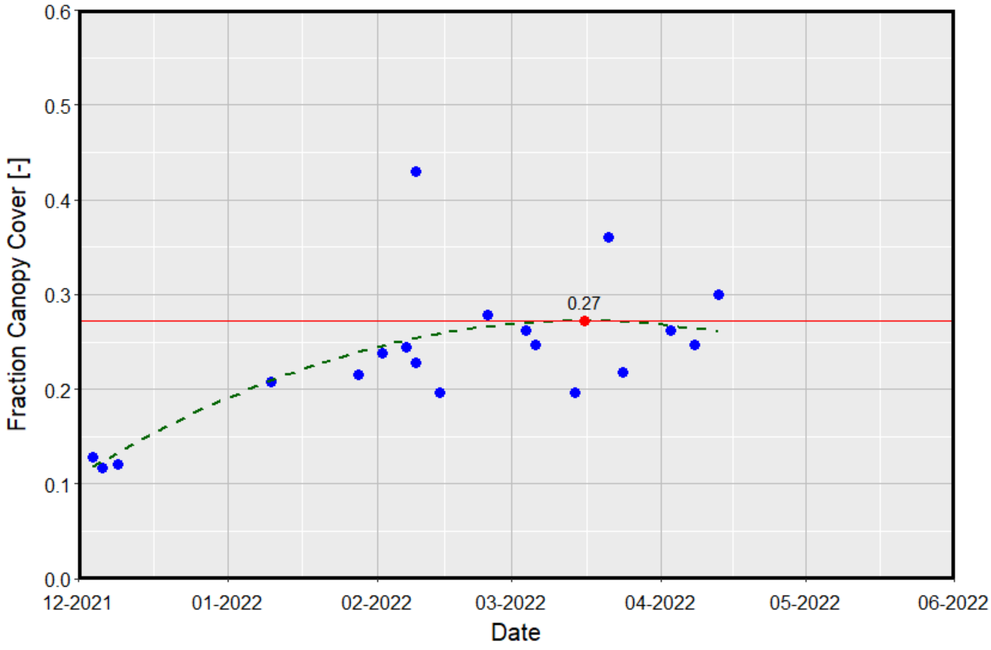


Albino

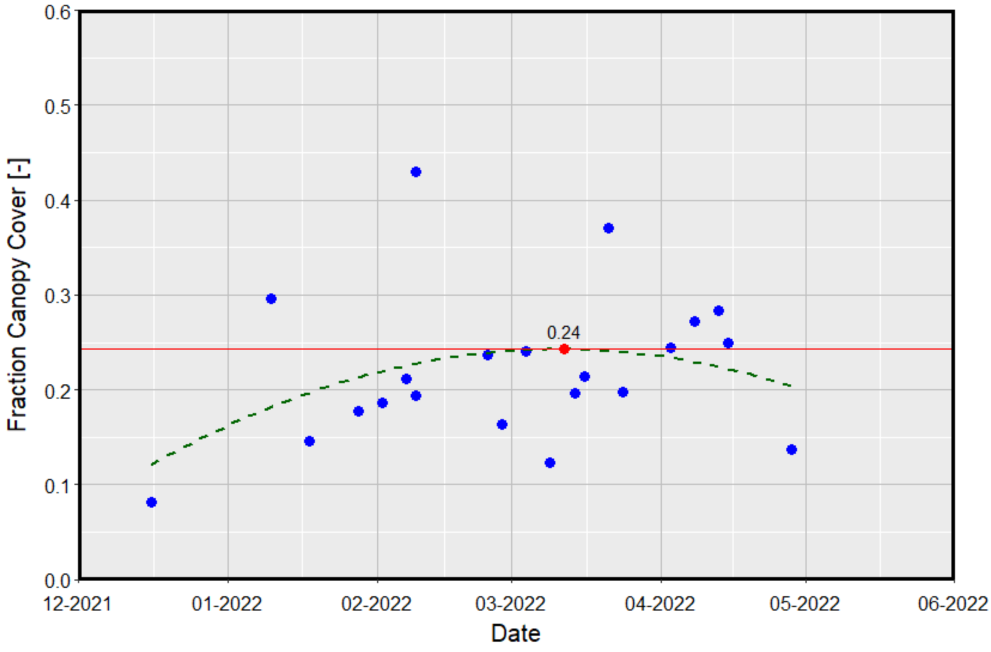


<u>**Nhamatanda**</u>

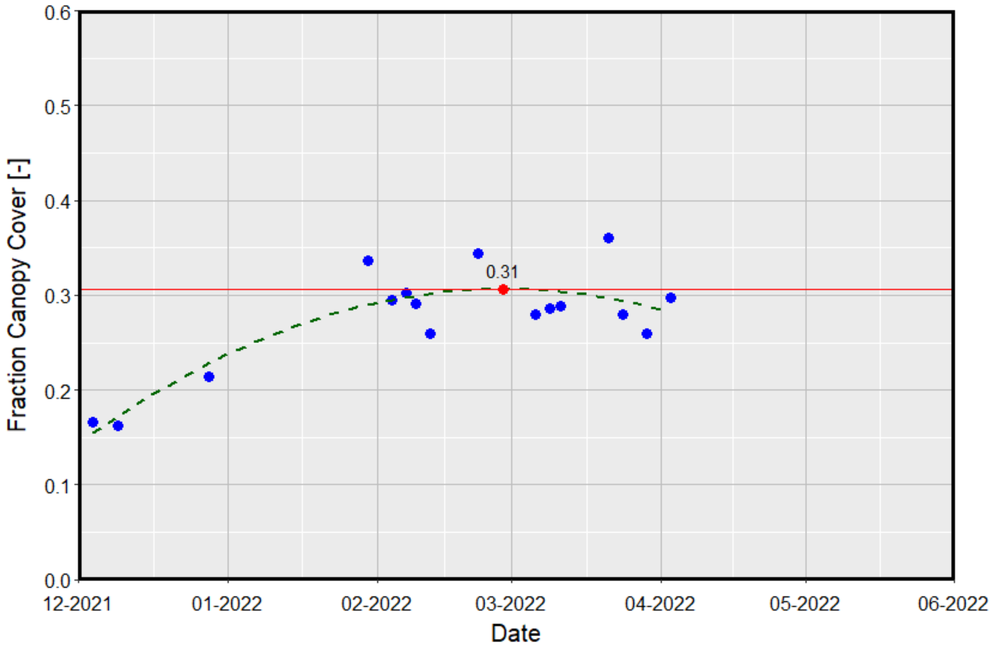
Lourenço 1



Lourenço 2

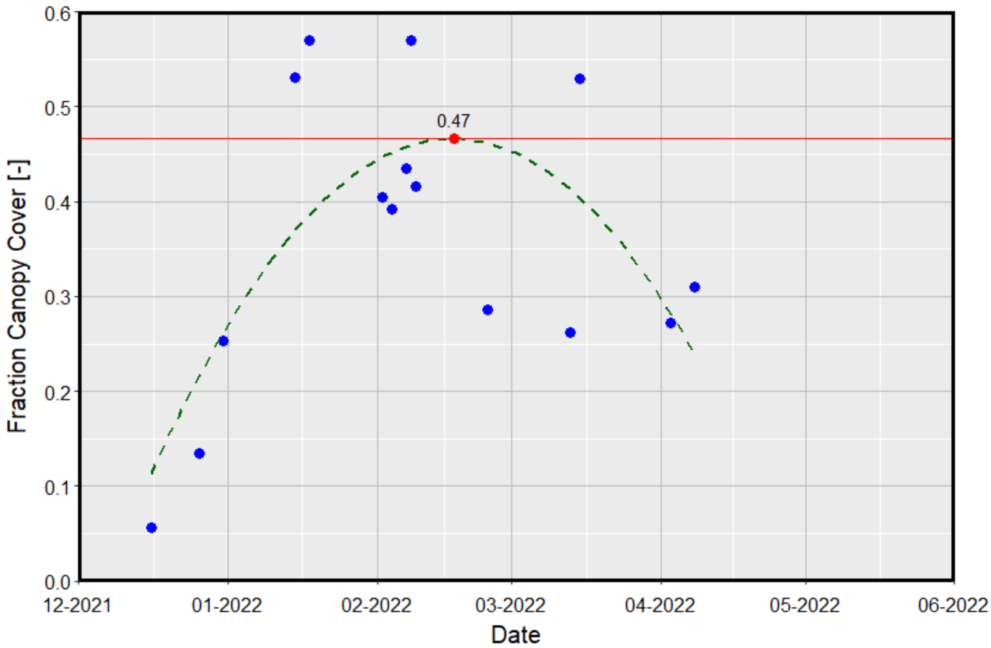


Armando



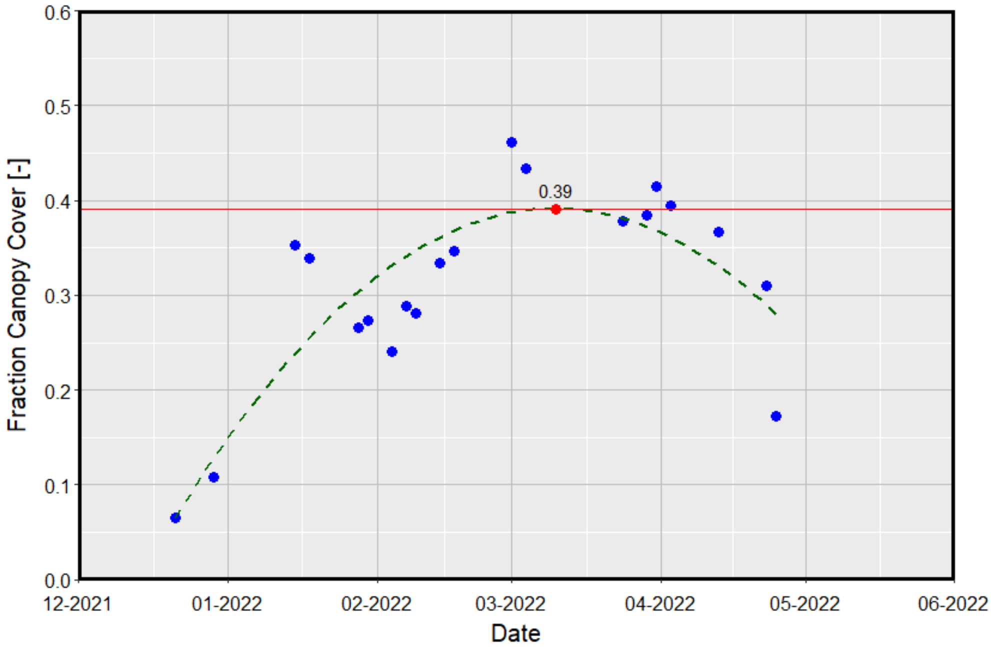
Fraction Canopy Cover [-]
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.31
12-2021
01-2022
02-2022
03-2022
04-2022
05-2022
06-2022
Date

Rui

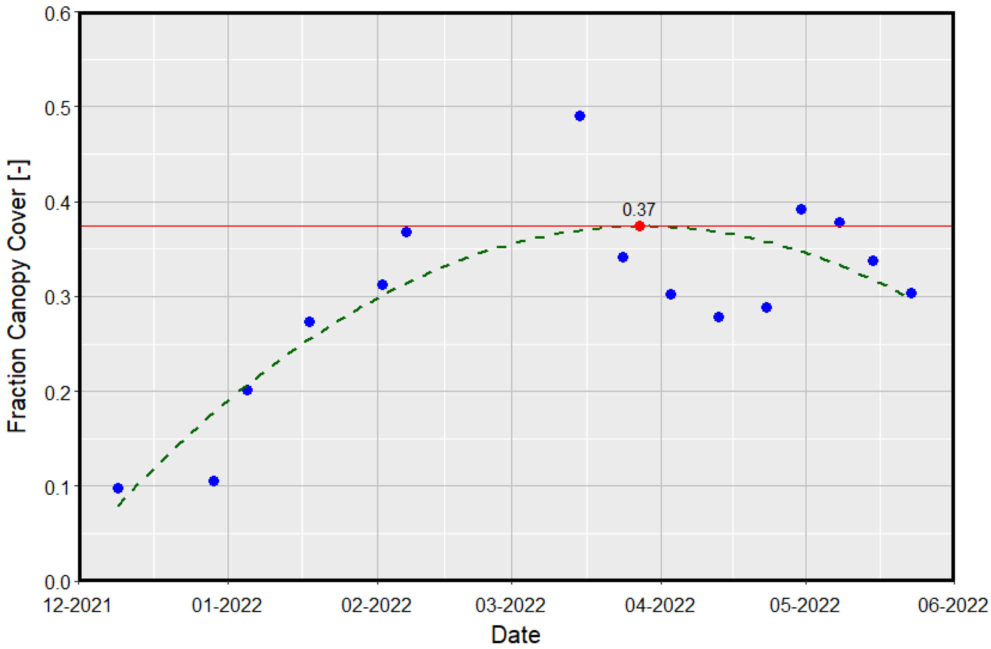


Fraction Canopy Cover [-]
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.47
12-2021
01-2022
02-2022
03-2022
04-2022
05-2022
06-2022
Date

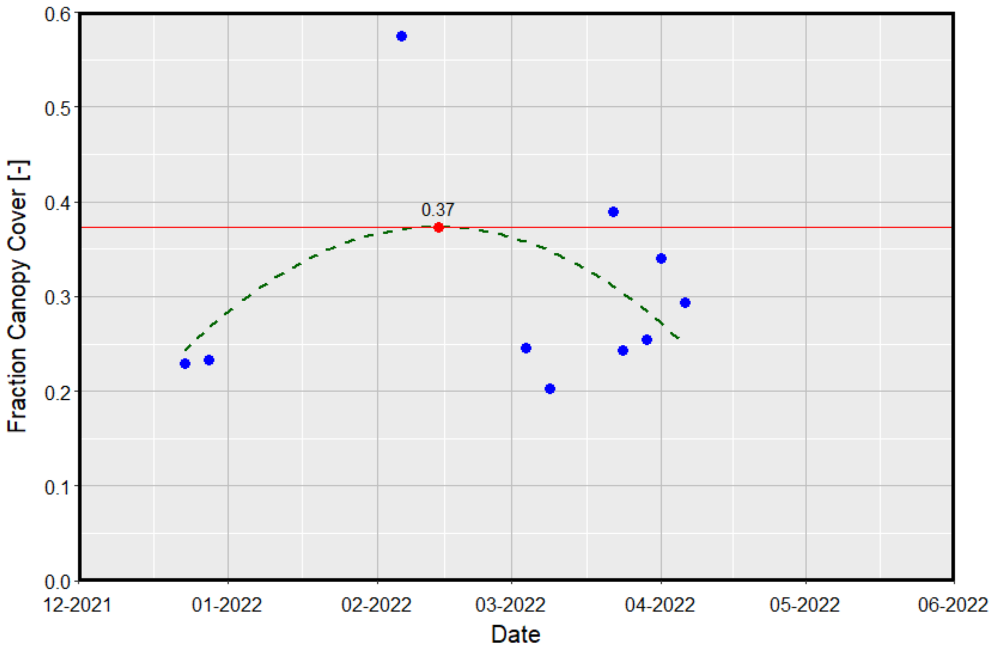
Machoca



Jose



Zacarias



Francisco