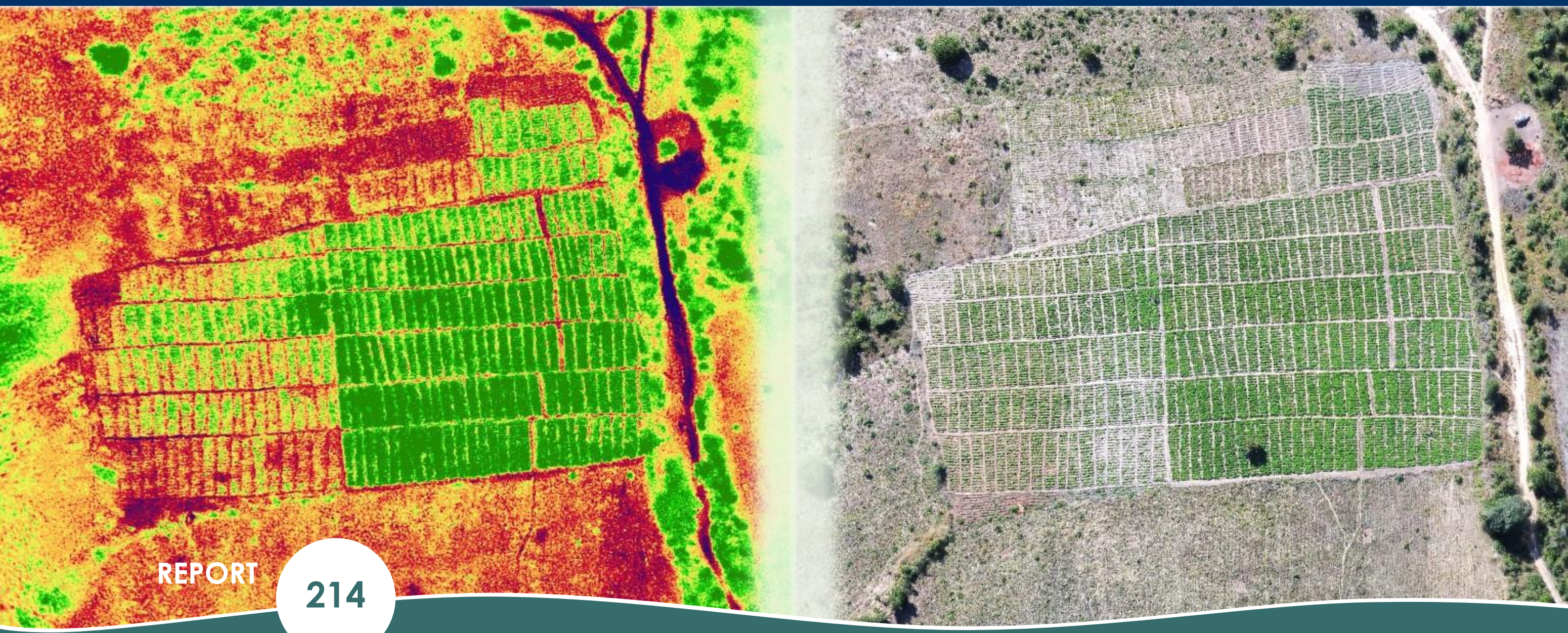
Analysis of the Agricultural Crop Productivity Using Flying Sensors

Technical report - Horticultural season 2020



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CLIENT NCBA Clusa

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Title page image caption
Flying sensor image from Manica project location with colored vegetation status map (left) and visual aerial image (right)

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Summary

The PROMAC II project is an ongoing project of NCBA Clusa introducing conservation farming practices to various locations in the Manica, Tete, and Zambezia provinces in Mozambique, with the objective to increase agricultural productivity. This project incorporates flying sensor (drone) activities in the PROMAC II project as a Monitoring and Evaluation (M&E) indicator of the practices and as an innovative technology for providing technical staff with spatial information on crop development. Flying sensor imagery can provide data at regular intervals with high spatial resolution and an additional camera for vegetation stress detection. This information is used to analyze the productivity of selected areas.

Project locations in the Manica province are monitored using flying sensor imagery during the horticultural season (2020). The crop types cultivated at these locations are black beans (Preto), common beans (Vulgaris), cabbage, onions, tomatoes, and maize. Flying sensor imagery is acquired at regular (monthly) intervals. Further imagery processing is conducted to achieve maps of the vegetation status and canopy cover.

The approach for calculating agricultural productivity is based on light use efficiency models that required three components for calculation: photosynthetically active radiation (PAR), fraction of absorbed PAR (FAPAR), and the crop specific light use efficiency. The FAPAR is computed using the canopy cover values from the flying sensor images and applying a linear interpolation to achieve daily values throughout the season.

Results are provided on the crop development during the growing season for vegetation status and canopy cover. These are found on the online data portal (https://www.futurewater.nl/ncbaclusaportal/). Canopy cover maps for the project locations are made for flights performed in June and July. A comparison of the canopy cover is made between PROMAC (conservation agricultural farming) fields, and non-PROMAC (conventional agricultural farming) fields. This comparison found that canopy cover was higher for PROMAC fields in June, whilst non-PROMAC fields were similar or slightly higher in July. This could be the result of different peak moments in the crop development. Overall, the canopy cover comparison concluded that values were higher for PROMAC fields.

The assessment of agricultural productivity is presented with maps of canopy cover and fresh marketable crop yield. These indicate average values of yield from each field, and the spatial variability between fields. The latter provides a good assessment of the effectiveness of locally adopted interventions and the impact on production. For cabbage and tomato the values were found to be close to typical values found in literature. Yield values for onion were found to be slightly lower than typical yield values. For both beans and maize the values were lower, however for maize the reasoning was that the planting period was later thus not a full crop cycle was monitored by the flying sensors. Typical yield values used in this analysis were based on references representing yields of the same or similar seed varieties planted in Mozambique or similar regions. In comparison with the yield values measured in the field, the assessment gave overall higher values for most crop types.

In conclusion, this report provides a method for assessing the agricultural productivity with flying sensor data and using this information as an M&E tool to report on productivity increases. Additionally, the spatial variation achieved by presenting the yield data in maps, gives decision-makers relevant information to improve their production for next seasons.

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1 Introduction

1.1 Project description

The PROMAC II project is an ongoing project of NCBA Clusa introducing conservation farming practices to various locations in the Manica, Tete, and Zambezia provinces in Mozambique, with the objective to increase agricultural productivity. This project incorporates flying sensor (drone) activities in the PROMAC II project as a Monitoring and Evaluation (M&E) indicator of the practices and as an innovative technology for providing technical staff with spatial information on crop development. Flying sensor imagery can provide data at regular intervals with high spatial resolution and an additional camera for vegetation stress detection. This information is used to analyze the productivity of selected areas. A report on the agricultural productivity assessment of the rainy season (2019-2020) was provided half-way the project[1].

1.2 Relevance

The interventions and conservation agricultural practices introduced by the project have the objective to increase agricultural productivity in the area and provide a better food security situation for the population. The effectiveness of these interventions can be measured by monitoring the crop yield from the fields. This is conventionally done by making yield reports at the end of the season and monitoring the amount of marketable produce. In this report a methodology is presented by using flying sensor technology. This gives additional insight in the spatial variability of crop yields. Additionally, fields that have adopted interventions can be compared with fields that use traditional practices. This gives insight in the impact of the interventions on the productivity.

1.3 Season overview

The horticultural season in Mozambique typically starts in April or May and continues till August or September. The crop growing cycle of horticultural crops is shorter than of the rainy season crops. Farmers also vary in their choice of planting date, which can occur as early as March or as late as July. Several farmers make use of (supplemental) irrigation during this season to limit the impact of water stress on crops. Precipitation is usually minimal during this season. This season was the second growing season that NCBA Clusa staff applied the flying sensor activities and have worked mostly independently with some supervision.

1.4 Reading guide

This technical report provides the analysis of the agricultural productivity for locations monitored with flying sensors during the horticultural season (2020). The next chapter (chapter 2) will elaborate on the methodology used for this analysis. Chapter 3 expands on the results for crop development by presenting the results of the flying sensors at different moments during the crop growing season. Chapter 4 provides the results on agricultural productivity. Lastly, chapter 5 provides the concluding key messages from this analysis and points of recommendation.

[1] Van Opstal, J.D., J. Beard, M. de Klerk. 2020. Analysis of the Agricultural Crop Productivity Using Flying Sensors – Technical report Rainy Season 2019-2020. FutureWater Report 203.

2 Methodology

2.1 Project locations

Flying sensor activities were conducted from an operators unit located in Manica and Zambezia province. For the Manica province, flights were scheduled over five selected project locations to monitor the crop development and agricultural productivity during the growing season. The five locations are indicated on the map below in Figure 1. At these locations various horticultural crops were grown and interventions introduced by the project to promote conservation agriculture, such as ripper for land preparation, high-yield seed varieties. These locations were selected by NCBA Clusa staff based on the criteria that they should be representative for PROMAC activities. Additionally, it is beneficial that a cluster of fields are located within a flight to ensure efficient data collection. The field boundaries and field data are compiled and presented in Annex 1 to 3 for the locations Corenzi, Laquimo, and Tawanda.

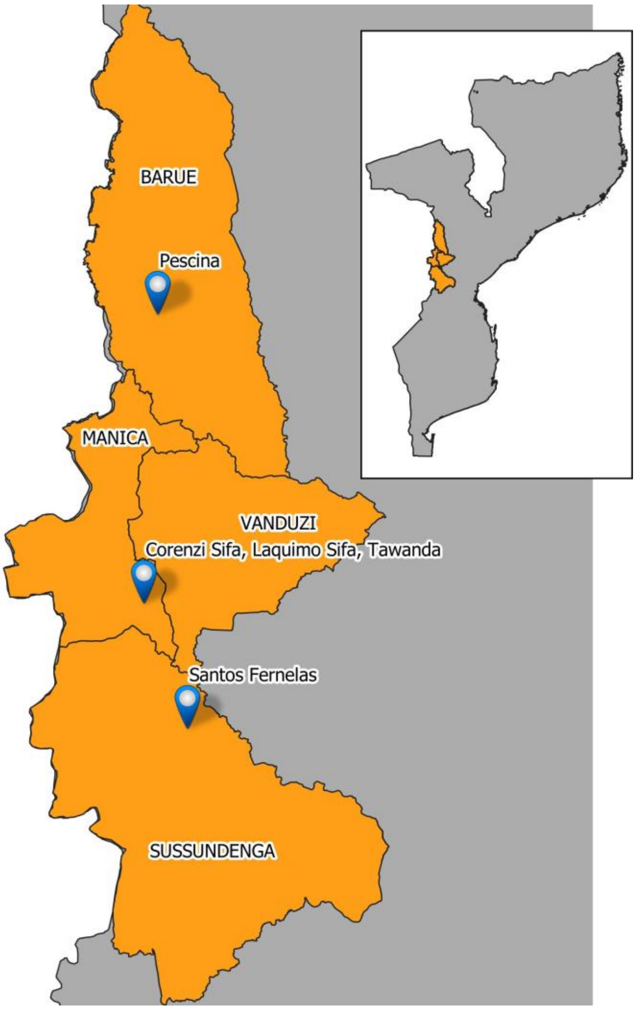


Figure 1 Five locations of flying sensor activities in Manica province (Barue, Sussendenga, Vanduzi. and Manica districts)

2.2 Flying Sensor Imagery

2.2.1 Flying sensor equipment

Figure 2 Photo of the Flying Sensor in action

The Flying Sensor equipment used consists of a DJI Mavic Pro drone with visual camera, with an additionally attached MAPIR[2] camera to detect vegetation status. Figure 2 shows a photo of the Flying Sensor used including both cameras. One camera makes RGB (red-green-blue) images, similar to visual images as seen with the human eye. The second MAPIR camera measures the Near Infrared wavelength, which is not visible to the human eye. The near infrared (NIR) wavelength has a good response to the conditions of the vegetation. Figure 3 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 small holder agriculture.

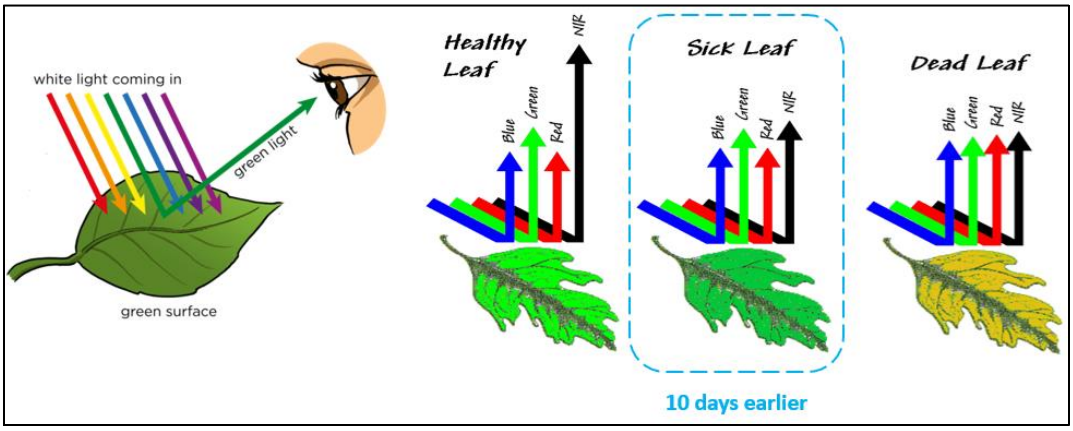


Figure 3 Illustration explaining the response of near infrared (NIR) wavelength to vegetation status

2.2.2 Imagery acquisition

Flying sensor images were acquired throughout the growing season. Table 1 provides an overview of the flights performed during the horticultural season for the five project locations. For two locations three flights were performed representing the overall growing season, namely for Corenzi and Laquimo Sifa. For Tawanda two flights were performed, and for Pescina and Santos one flight was conducted. For the latter two, the flight was conducted as crop status flights. They capture a moment during the season and

[2] For more information visit https://www.mapir.camera/

is not representative for the crop development. Therefore, these two locations are not included in the detailed agricultural productivity analysis, which requires flights throughout the growing season to estimate the crop development. Annex 1 to 3 presents the field data of the locations and indicates that several crops were planted during the period of the flights. Some fields were planted (and harvested) before the first flight and are omitted from further analysis.
The total area monitored by flying sensors was 90 ha. with the locations Laquimo Sifa and Tawanda being the largest.

Table 1 Overview of flights and area during the Horticultural Season of 2020

	Corenzi Sifa	Laquimo Sifa	Tawanda	Pescina	Santos Fernelas
May	29th May	29th May			
June	23rd June	16th June	16th June	9th June	
July	29th July	29th July	29th July		1st July
Total Area	16 ha.	23 ha.	25 ha.	6 ha.	20 ha.

2.2.3 Imagery processing

The imagery acquired by the Flying Sensors undergoes further processing. Firstly, the single images for each flight are stitched together to form an ortho mosaic. These are then georeferenced so it can be used in further geospatial analysis. These steps are performed using software packages: Agisoft Metashape[3], and QGIS[4] (geospatial software).

2.3 Canopy Cover

The canopy cover 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). Full vegetation cover will result in a canopy cover of 100%. Canopy cover is a good indication of the crop development during the growing season. When seeds have been planted and the field mainly consists of bare soil, the canopy cover is 0%. With the development of the crop the canopy cover will increase to a peak. Full cover is achieved with optimal planting densities and favorable conditions of soil moisture, fertilization, and disease control.

The canopy cover is calculated using the Near Infrared (NIR) band, which is most sensitive to the status of the vegetation. The calculation is performed using R coding and implementing the K-Means package[5]. Pixels in the images are classified into bare soil or vegetation. A grid of 1x1 meter (=1 m^2) is overlaid over a crop field. The number of vegetation pixels (of 0.05x0.05 meter = 0.0025 m^2) is counted to determine the percentage of the grid that is covered by vegetation, thus the canopy cover. An example of this calculation in shown in Figure 4.

[3] For more information visit https://www.agisoft.com/
[4] For more information visit https://www.qgis.org/
[5] For more information visit https://uc-r.github.io/kmeans_clustering

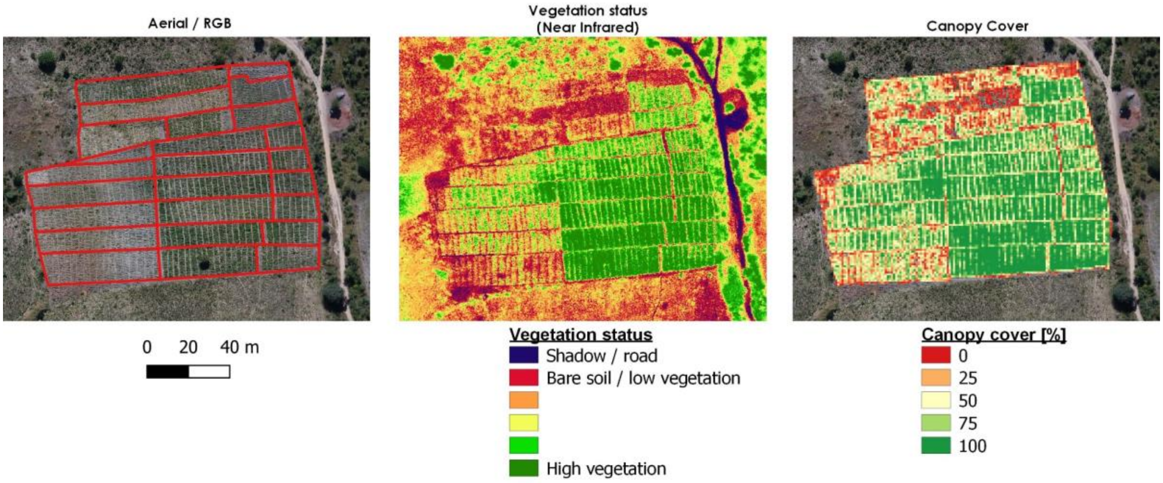


Figure 4 Flying sensor results for RGB (left), vegetation status (middle), and canopy cover (right) for a field in Corenzi

2.4 Agricultural productivity calculation

2.4.1 Approach

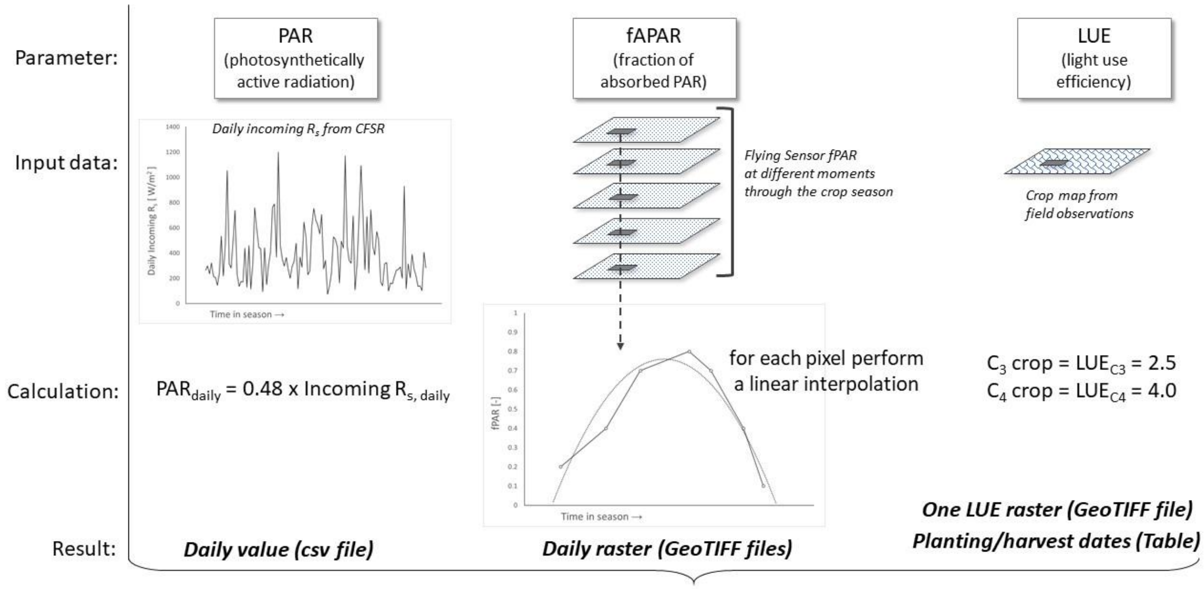
Figure 5 presents schematically the workflow for the calculation of agricultural productivity. This calculation is based on light use efficiency models as developed by plant physiologists and more recently adopted in remote sensing projects[6]. The workflow is composed of the calculation of three parameters: photosynthetically active radiation (PAR), fraction of absorbed PAR (FAPAR), and the light use efficiency. Each parameter is explained in the next sections, followed by the method for seasonal interpolation.

2.4.2 Photosynthetically active radiation (PAR)

The amount of solar radiation arriving at the surface is determined by the location on earth (latitude and longitude), the day of year, and the amount of cloud cover preventing radiation to pass through. Data products are available to estimate solar radiation using satellite remote sensing. In this report the CFSR (The National Centers for Environmental Prediction (NCEP) Climate Forecast System) dataset is downloaded for the five project locations[7]. The amount of solar radiation arriving at the surface that can be used for photosynthesis is called photosynthetically active radiation (PAR). This is approximately 48% of the total solar radiation arriving at the surface.

[6] Hilker, T., Coops, N. C., Wulder, M. A., Black, T. A., & Guy, R. D. (2008). The use of remote sensing in light use efficiency based models of gross primary production: A review of current status and future requirements. Science of the Total Environment, 404(2–3), 411–423. https://doi.org/10.1016/j.scitotenv.2007.11.007

[7] Saha, S., et al. 2011, updated daily. NCEP Climate Forecast System Version 2 (CFSv2) 6-hourly Products. Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory. https://doi.org/10.5065/D61C1TXF.



$$\text{Total Seasonal Biomass} = \sum_{d=1\,(planting)}^{d=?\,(harvest)} PAR_d \times fAPAR_d \times LUE$$

Figure 5 Schematic of workflow for biomass production analysis from flying sensor imagery

2.4.3 Fraction of absorbed PAR (FAPAR)

The conversion of PAR to biomass through photosynthesis depends on the amount of the radiation that is absorbed by the plant. At full vegetation cover the leaf surface is maximum and the radiation can be optimally absorbed. However, with limited vegetation cover or bare soil the amount of absorbed radiation is reduced. This amount of absorbed radiation is expressed by the fraction of absorbed PAR (FAPAR). In this study the FAPAR is related to the canopy cover, which represents the amount of full vegetation cover. A widely used equation to calculate FAPAR is developed by Hipps et al. (1983)[8]:

$$IPAR = 93.55 * (1.0 - \exp(-0.91 * LAI))$$

The leaf area index (LAI) is related to the canopy cover from the flying sensor imagery to calculate the FAPAR using the equation above. Note that the maximum FAPAR that can be achieved is 0.91 (91%). It is found that at high or full vegetative cover the FAPAR has an asymptotic relation and a 100% FAPAR is not achieved in field conditions.

Satellite remote sensing does not match the high spatial resolution of flying sensor imagery. Therefore, the FAPAR is approximated by using the NDVI (normalized difference vegetation index). The equation developed by Hatfield et al. (1984)[9] has been widely used:

$$f = -0.161 + 1.257\text{NDVI}$$

[8] L.E. Hipps, G. Asrar, E.T. Kanemasu, Assessing the interception of photosynthetically active radiation in winter wheat, Agricultural Meteorology, Volume 28, Issue 3, 1983, Pages 253-259, ISSN 0002-1571, https://doi.org/10.1016/0002-1571(83)90030-4.

[9] Hatfield, J.L., Asrar, G., Kanemasu, E.T., 1984. Intercepted photosynthetically active radiation estimated by spectral reflectance. Rem. Sens. Environ. 14, 65–75.

2.4.4 Light Use Efficiency (LUE)

The light use efficiency (LUE) determines the efficiency of the plant to convert the absorbed energy (radiation) into photosynthesis. This mechanism is different between C3 (majority of the crops) and C4 (maize, sugar cane) crops, with C4 crops having a higher LUE. Crop varieties also differ in the value of the LUE. In addition, environmental conditions can have a limiting influence on the LUE if water or nutrients stress limit the growth of the plant. The factors used for LUE in this project for the selected crop types (maize, tomato, beans, onions, and cabbage) are listed in Table 2. Other crop parameters are also listed, which are explained in the next section regarding the seasonal interpolation. Typical values for yield are found in references as listed in Table 2 and footnotes.

Table 2 Overview of crop specific parameters for the calculation of the productivity

	Light Use Efficiency	Fraction of above ground biomass production	Harvest Index	Moisture content	Typical yield [ton/ha]
Maize					
PAN-601	3.5	0.65	0.35	60%	3 to 5 [10]
Tomato					
Carijota China Rio Grande Roma	2.5	0.65	0.55	82%	12[11]
Beans (Feijao)					
Bonus (Vulgar) Bonde (Vulgar)	2.5	0.65	0.20	80%	2.5 – 3[12]
Preto	2.5	0.65	0.20	80%	
Onions					
Branca (white) Vermelha (red)	2.5	0.65	0.60	85%	18-20[13]
Wild cabbage (Couve)					
Trochuda China	2.5	0.65	0.65	82%	30[14]
Cabbage (Repolho)					
Tropicana	2.5	0.65	0.65	82%	30

[10] PANNAR Quality Seeds Botswana Farmer's Guide www.pannar.com
[11] FAO 66 Crop yield response to water 2012
[12] Kisetu Nassary, Eliakira & Baijukya, Frederick & Ndakidemi, Patrick. (2020). Assessing the Productivity of Common Bean in Intercrop with Maize across Agro-Ecological Zones of Smallholder Farms in the Northern Highlands of Tanzania. Agriculture. 10. 117. 10.3390/agriculture10040117.
[13] Gererufael, L.A., Abraham, N.T. & Reda, T.B. Growth and yield of onion (Allium cepa L.) as affected by farmyard manure and nitrogen fertilizer application in Tahtay Koraro District, Northwestern Zone of Tigray, Ethiopia. Vegetos 33, 617–627 (2020). https://doi.org/10.1007/s42535-020-00132-7
[14] https://www.kzndard.gov.za/images/Documents/Horticulture/Veg_prod/expected_yields.pdf

2.4.5 Seasonal interpolation

Figure 5 indicates that the biomass production is calculated at daily time steps and then summed for the growing period, namely from planting date to harvest date. The variable that changes daily is the FAPAR, which follows the crop development curve. Throughout the season the flying sensors capture the crop development at regular (monthly) intervals, which are used to approximate the crop development curve. Through linear interpolation the FAPAR values are calculated on the days lacking a flying sensor image. For this reason, it is of importance that the number and frequency of the flying sensor images are sufficient to provide a good result of the interpolation.

In Table 1 it was noted that for two locations, Pescina and Santos, one flight was conducted. Therefore, a seasonal interpolation is not calculated for these locations. For the other locations the number of images is two to three, which is sufficient depending on the planting and harvest dates of the crops. Supplemental data from satellite remote sensing could not be used for the seasonal interpolation due to the size of the fields, which are typically small during the horticultural season.

The total seasonal biomass production is calculated by summing the daily values from plant date to harvest date. The planting and harvest dates used at each location are reported in Annex 1, 2 and 3. This information is derived from field notes. From the total biomass production, the crop dry yield, also known as agricultural production, is calculated. Crop specific parameters for this calculation are reported in Table 2. Firstly, the amount of biomass production that exists above ground is calculated being 65% of the total biomass, 35% consists of roots below ground. Furthermore, the harvest index indicates the fraction of the above ground biomass that is harvested as a marketable product. Typical values from literature are used as reported in Table 2 for the main crop types.

Table 2 also indicates the typical yield values of the different crop varieties as reported in literature. Several hybrid varieties are introduced through the PROMAC project, thereby increasing yield and also having shorter growing lengths. These values are used for calibration of the crop parameters, both the light use efficiency, harvest index and the moisture content. This was performed in one location (Tawanda) because this location had fields with all crop types. The same values for these parameters (light use efficiency, moisture content and harvest index) were used for the analysis of yield in the other locations with the same crop types and seed varieties. Values for moisture content were higher for beans and maize, than are typical for those crops, indicating that further calibration may be necessary with local conditions.

The typical yield values are taken from publicly available reports, papers, and seed production websites. Values were selected that are representative for local conditions, with a preference for values from Mozambique or surrounding countries. These typical yield values can be further expanded by adding field reports from the project fields to enhance the calibration.

2.5 Monitoring project impact

The PROMAC project introduced several interventions relating to conservation agriculture. The flying sensor data and the agricultural productivity analysis provide insight in the spatial variation of the crop yields achieved for each field. For the monitoring and evaluation of the project, an analysis on the change in agricultural productivity caused by the introduction of the interventions is required. For each location the flying sensor flight were performed in such a way that surrounding fields were also included in the images. These fields were not part of the PROMAC project and had conventional (traditional) farming practices. These surrounding fields were added to the analysis for all locations with sufficient flights (Corenzi, Laquimo, and Tawanda). Additional information on the location of the fields are indicated in Annex 1, 2, and 3. Unfortunately, the specific crop types and planting and harvest dates were not listed for the majority of the surrounding fields. From the flying sensor images this information was also not clearly distinguishable, unlike in the rainy season when the maize fields are more distinct.

The comparison of the PROMAC and non-PROMAC fields is performed by comparing the canopy cover images at two different dates during the season. This is a good indication of the productivity as well, because it is an input for the biomass production of the crops. The actual crop yields were not simulated due to the limited field availability of data for the non-PROMAC fields, which would make the comparison not well scientifically substantiated.

3 Seasonal crop development

3.1 Flying Sensor Imagery results

Flying sensor images were captured throughout the growing season at regular intervals. The flight dates for the five selected locations are indicated in Table 1. For each flight the result was an aerial (RGB) image and a vegetation status image provided by the near-infrared camera. As an example, for the location of Corenzi these images are shown in Figure 6 at three flight dates in May, June and July.

The smaller fields and block system are typical for the horticultural season. There is a clear contrast between the fields with bare soil and the full vegetation cover. It is also noticeable that by the end of July most of the field was harvested with the exception of the west side of the field (in the images: left), which was planted later. Annex 1 indicates that the fields in the East were planted in April and therefore are already visible in May. They were harvested by end July, which is explains the bare soil in the July image. The fields in the West were planted end of May and are therefore not visible yet in the May image. They were harvested by half August.

The vegetation status images are derived using the NIR band and show a good indication of the spatial variation in vegetation status. In the RGB images this is not always pronounced, however in the vegetation status images the various blocks show contrast. The comparison between RGB and vegetation status images (using the NIR camera) indicates the added value of using a NIR camera for monitoring vegetation, as it captures the vegetation status better.

Figure 6a Crop development for Corenzi location for three flight dates with RGB (top) and vegetation status (bottom)

Figure 6b Crop development for Corenzi location for three flight dates with canopy cover (in %)

The vegetation status images are then used for calculating the canopy cover which is shown in Figure 6b with green being full cover (100%). This is the aggregation of the high resolution (4 cm) pixels of NIR camera into 1x1m pixels. The trend for vegetation development is similar to that observed in the vegetation status images. All visual, vegetation status and canopy cover maps, which were captured throughout the horticultural season are also available through the online data portal (https://www.futurewater.nl/ncbaclusaportal/). Here the crop development can also nicely be seen.

3.2 Canopy cover assessment

The canopy cover is calculated for all the images acquired and are used to compare PROMAC fields with surrounding non-PROMAC fields. The location of these fields is presented in Figure 7 with the yellow fields being the PROMAC fields promoting conservation agriculture. The red fields are the non-PROMAC fields with conventional farming.

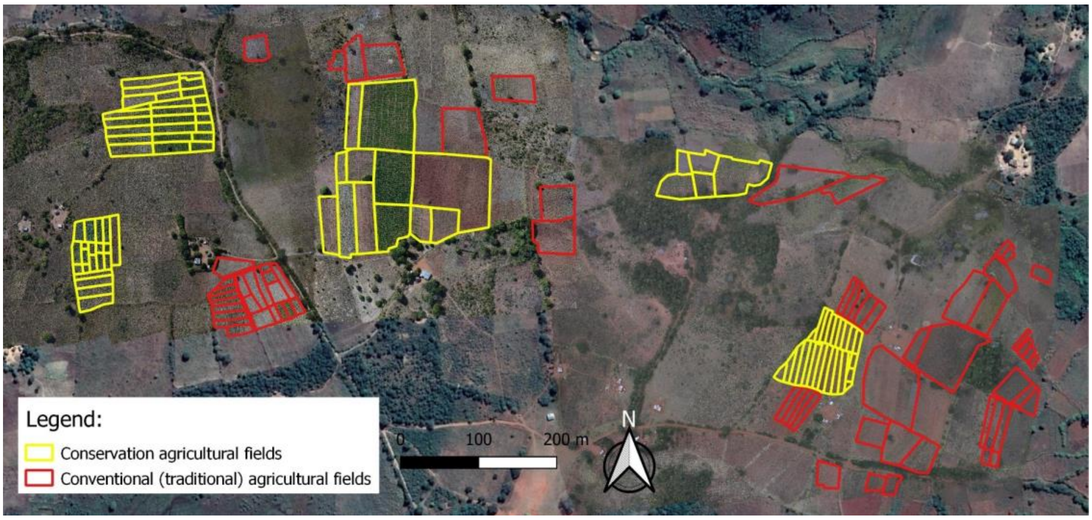


Figure 7 Location of conservation and conventional (traditional) agricultural fields for Corenzi (West), Laquimo (Center), and Twanda (East) locations

In Figure 8, 9, and 10, the canopy cover of Corenzi, Laquimo, and Tawanda respectively is displayed for the flights performed in June and July. It shows that some fields have full canopy cover and others have already been harvested or are yet in an early phase of crop development.

Figure 8 Canopy cover for Corenzi for June and July flights

Figure 9 Canopy cover for Laquimo for June and July flights

Figure 10 Canopy cover for Tawanda for June and July flights

A comparison is made of the average canopy cover values between the PROMAC (conservation farming) and non-PROMAC (conventional farming) fields. Both the average and the different percentiles is displayed in Table 3 to indicate the statistical distribution. The 50th percentile indicates that 50 percent of the pixels have a value of the 50th percentile or lower. Thus the 90th percentile indicates the top 10 percent of highest canopy cover values.

The results of June show that the PROMAC (conservation agricultural) fields in comparison with the non-PROMAC (conventional agriculture) clearly has a higher canopy cover from the 25th percentile onwards. The majority of the fields are statistically higher than the non-PROMAC fields with conventional farming practices. The numbers of July show that both conservation and conventional farming fields have a similar canopy cover, with conventional farming being slightly higher. However, these higher canopy cover values are still lower than the values for PROMAC (conservation agriculture) fields in June.

An explanation for this contrast observed in July is that the peak of crop development occurred earlier for conservation agriculture (PROMAC fields) than for conventional agriculture (non-PROMAC), assuming the planting dates are similar. If this is the case, then the canopy cover values in June are representative for peak crop development in the case of conservation (PROMAC) fields, whereas for the conventional (non-PROMAC) fields the peak crop development is in July. Comparing the two median values, represented by the 50th percentile, the conventional agriculture (in July) is on average 66.3%, which is substantially lower than conservation agriculture (in June), which is on average 79.5%

Table 3 Statistical distribution of canopy cover [%] for June and July images for PROMAC (conservation agricultural fields) and non-PROMAC (conventional agricultural fields).

	June		July	
	Conservation Agriculture (PROMAC)	Conventional Agriculture (non-PROMAC)	Conservation Agriculture (PROMAC)	Conventional Agriculture (non-PROMAC)
10th Percentile	22.5%	33.0%	24.8%	36.7%
25th Percentile	48.7%	44.5%	41.5%	47.5%
50th Percentile	79.5%	63.4%	56.8%	66.3%
75th Percentile	86.4%	80.5%	77.5%	79.8%
90th Percentile	88.4%	84.6%	85.9%	86.5%

4 Agricultural productivity

4.1 Mapping agricultural productivity

The agricultural productivity is assessed for the various main crop types at the Corenzi, Laquimo, and Tawanda locations. The main crop types are onion (cebola), cabbage (couve or repolho), common beans (feijão vulgar), black beans (feijão preto), maize (milho) and tomato (tomate). The location of fields with these crop types are shown in Figure 11 with beans, cabbage, and tomato having the majority of the fields.

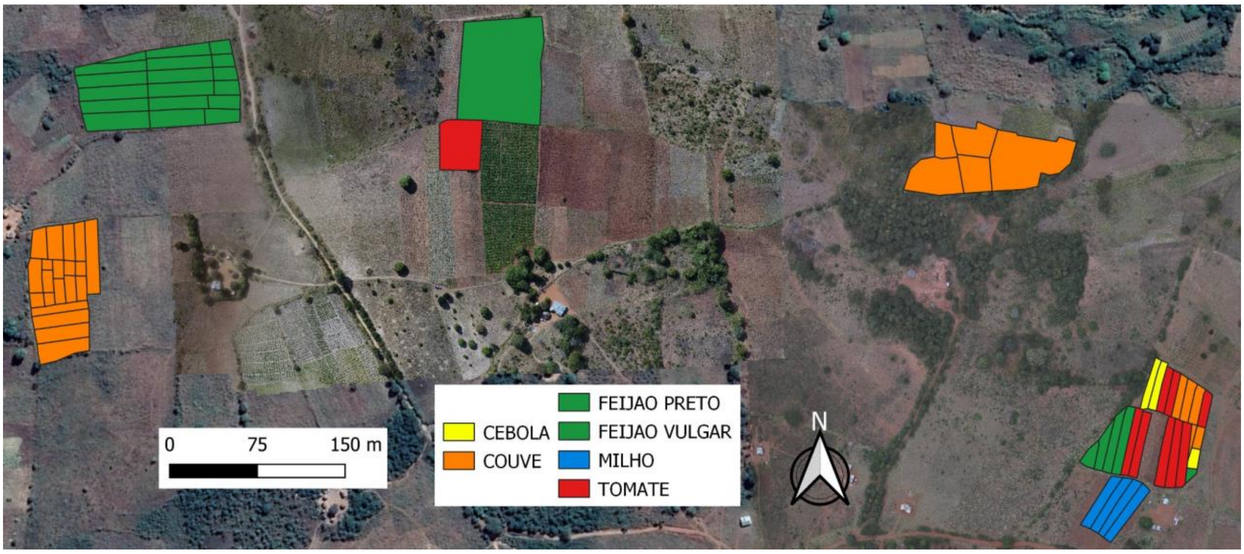


Figure 11 Map of crop types (above) for onions (cebola), cabbage (couve), common beans (feijão vulgar), black beans (feijão preto), maize (milho), and tomato (tomate) for the fields in Corenzi, Laquimo, and Tawanda.

The biomass production was calculated using a light use efficiency model and interpolating between the flights. Crop parameters are calibrated to local typical yield values as listed in Table. 2. Figure 12, 13, and 14 presents the results of the agricultural productivity as fresh (marketable) yield for the locations of Corenzi, Laquimo, and Tawanda. The values found for yield are higher than values measured in the field or reported locally. Likely the typical yield values reported in publications and online references have a higher range than are locally achieved in these project locations.

In Figure 12, 13, and 14 higher yields are associated with the cabbage fields, which usually have a higher fresh yield due to the moisture content and the higher harvest index. Between cabbage fields, some variability exists as shown in the Corenzi (in Figure 12: left) fields with fields having a slightly lower agricultural productivity (lighter green).

The smaller fields of Tawanda (in Figure 14: bottom right) display more variability and a diversity of crop types. Overall, the tomato and cabbage fields are performing well. Fields with beans show a lower productivity, which is expected as their typical yield is also lower.

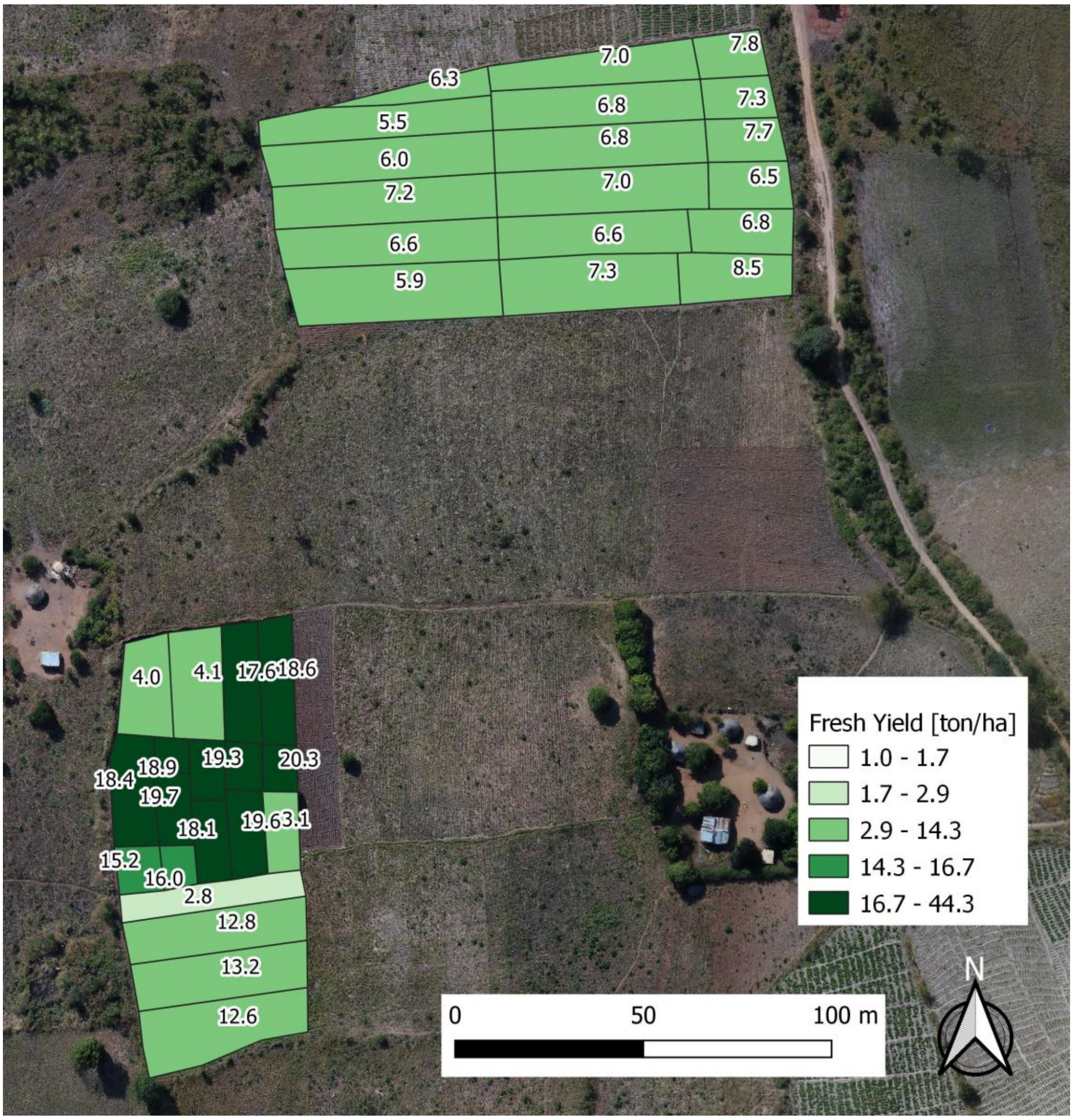


Figure 12 Agricultural productivity as fresh marketable yield (ton/ha) for Corenzi location

Figure 13 Agricultural productivity as fresh marketable yield (ton/ha) for Laquimo location

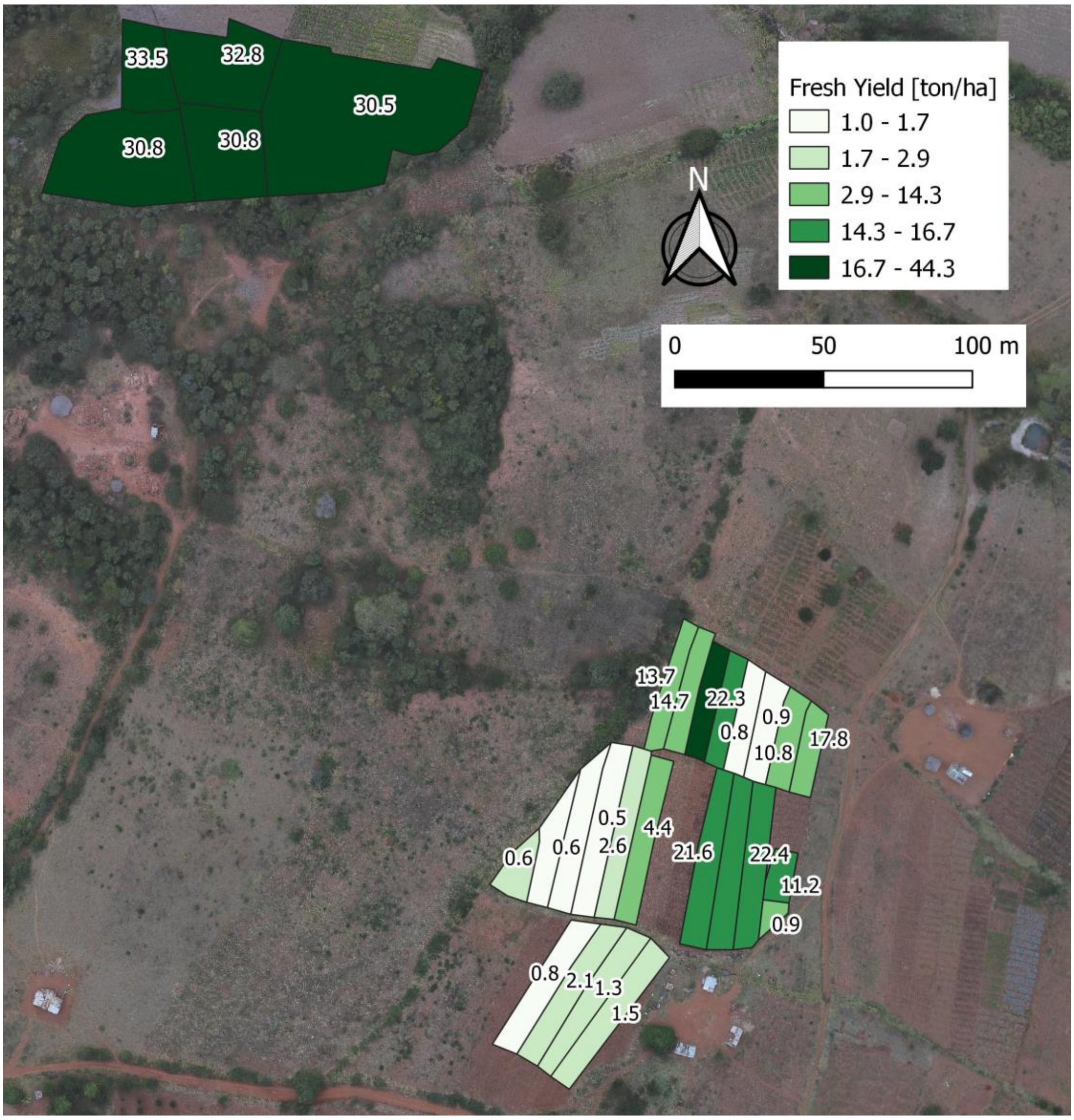


Figure 14 Agricultural productivity as fresh marketable yield (ton/ha) for Tawanda location

4.2 Overview and assessment of agricultural productivity

An overview of the results from the agricultural productivity assessment is provided in Table 4. The average fresh crop yield (in ton/ha) is presented for each location and each crop type.

Table 4 Overview of fresh crop yield results [ton/ha] for beans, cabbage, onion, maize, and tomato; including typical yield values from Table 2.

Fresh crop yield (ton/ha)	Corenzi	Laquimo	Tawanda	Typical yield (ton/ha)
Beans (common, Vulgaris)	3.4	3.3	0.9	2.5 - 3
Beans (black, Preto)			2.9	2.5 - 3
Cabbage	13.7		28.3	30
Onion			14.1	18 - 20
Maize			2.0	3 - 5
Tomato		13.6	12.5	12

In general, the yield values reported in Table 4 are higher than the yield measured in the field. The calibration was performed using typical values from literature and online publications, usually representative for Mozambique or regions with similar climatic and socio-economic conditions. References of the typical yield values are listed in section 2.4.4 in this report. These typical values are higher than field measurements performed in the project locations. Field measurements displayed some variability therefore it was opted in this analysis to use the typical yield values.

Tawanda had for all crop types some fields and was used mainly for calibrating the crop-specific parameters (Table 2). The yield found for common beans (Vulgaris) is low compared with to typical yield values found in reports. However, for black beans (Preto) the yield was comparable with typical yield values. The yield values found for cabbage and tomato all fall within the expected range. The yield values for onion are slightly lower than the typical yield values found in the reports. The yield for maize is significantly lower than expected, however Annex 3 shows that the maize was planted in June, therefore the full crop cycle was likely not represented by the flights used for this analysis.

Common beans (Vulgaris) for Corenzi and Laquimo display values close to typical values. The cabbage yield in Corenzi is lower than the potential and the values found in Tawanda. On the map in Figure 12 it is shown that the fields display more variation in cabbage yield, therefore the overall average is low. For tomato the yield in Laquimo is close to typical values found in literature.

From field observations it was also noted the existence of intercropping and the occurrence of weeds. These can partially influence the canopy cover values, giving slightly higher values due to some vegetation being represented by the intercropping or weeds. This could be adjusted with further detailed field observations and local yield reports. However, the major crop type will be dominant in the overall crop development curve, resulting in sufficient input for this agricultural productivity assessment.

5 Concluding remarks

This report presents the assessment of the agricultural productivity during the horticultural season (2020) for PROMAC project locations in the Manica province. These locations were monitored with flying sensors during the growing season. The total area that was monitored encompassed 90 ha. The flying sensors were equipped with an additional camera capturing the near-infrared radiation, which is more sensitive to vegetation. This imagery is used to compute canopy cover and monitor the crop development during the growing season. Additional information was acquired from the field on crop type, planting and harvest date.

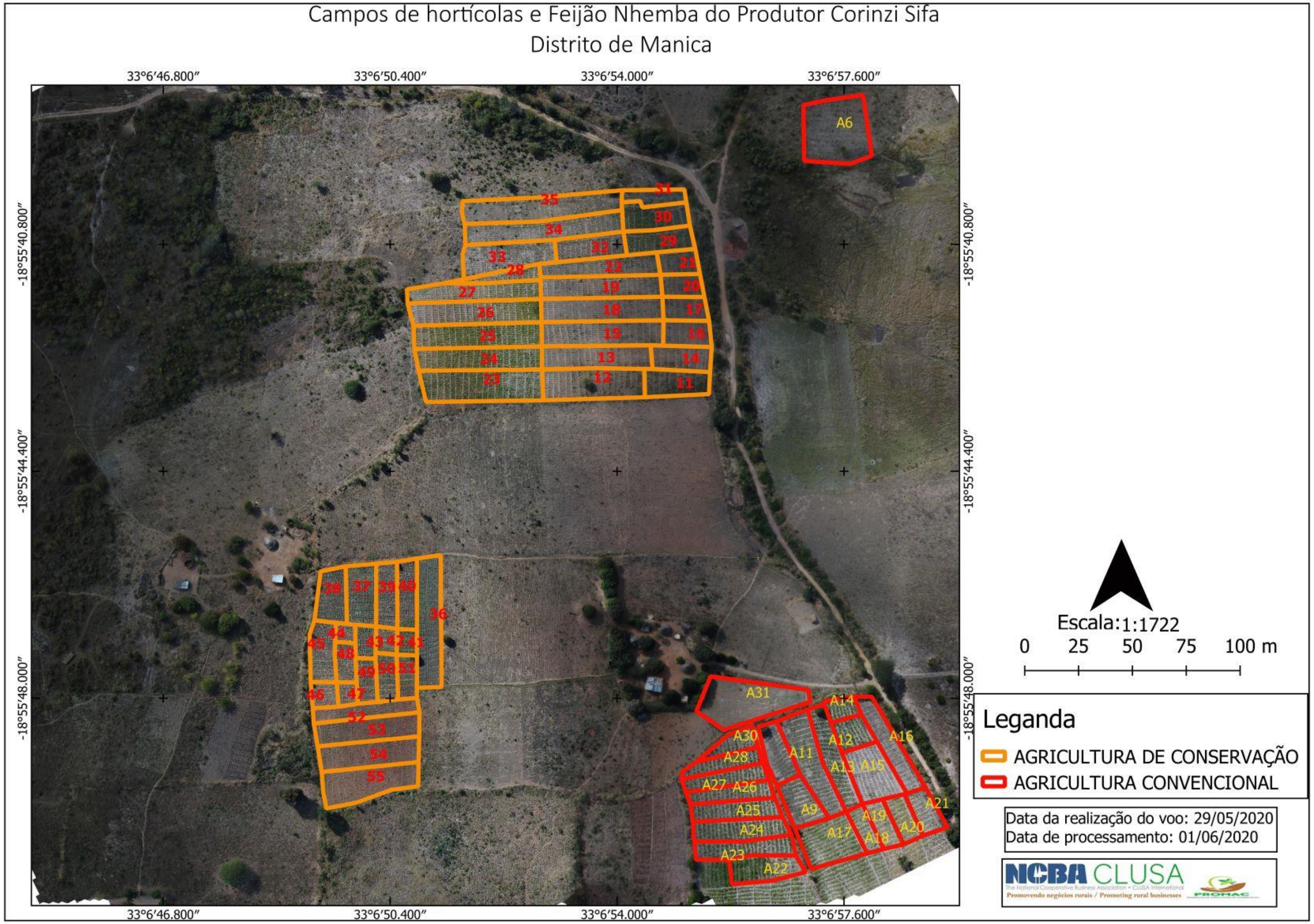
The approach of the light use efficiency models for calculating biomass production was applied. The fraction of absorbed PAR (FAPAR) was computed from the canopy cover values. A linear seasonal interpolation method was used to interpolate the FAPAR between the flight dates thus giving daily values following the crop growing curve. The results were computed to seasonal biomass production and crop yield, with the latter using crop specific parameters.

A comparison is made between the project fields where PROMAC is implementing several conservation agricultural practices, and surrounding fields where conventional farming practices are performed. For the three locations: Corenzi, Laquimo, and Tawanda, the comparison is made using the field notes of PROMAC and non-PROMAC fields, and the canopy cover images derived from flying sensors. The comparison showed that the canopy cover in June was significantly higher for the PROMAC fields with conservation agriculture than the fields with conventional farming techniques. In July this different was less pronounced, and the conventional fields displayed a slightly higher canopy cover. This likely reflects a difference in the timing of peak crop development.

The productivity assessment shows the spatial variability in production between fields. Values for common beans (Vulgaris) ranged from 0.9 to 3.4 ton/ha. The value for black beans (Preto) was on average 2.9 ton/ha. The value for cabbage ranged from 13.7 to 28.3 ton/ha. The average yield for onion was 14.1 ton/ha. The average yield for maize was 2 ton/ha, which likely is not represented by a full crop cycle. The yield of tomato ranged from 12.5 to 13.6 ton/ha. Field measurements from the project locations indicated lower yields were achieved from these fields, however values were variable. Additional field reports specifically on yield per unit of area, could provide clarifications of the values and support the calibration of the crop parameters. However, with the results determined using this methodology the values determined for agricultural productivity are within the reasonable range found in references and seed companies.

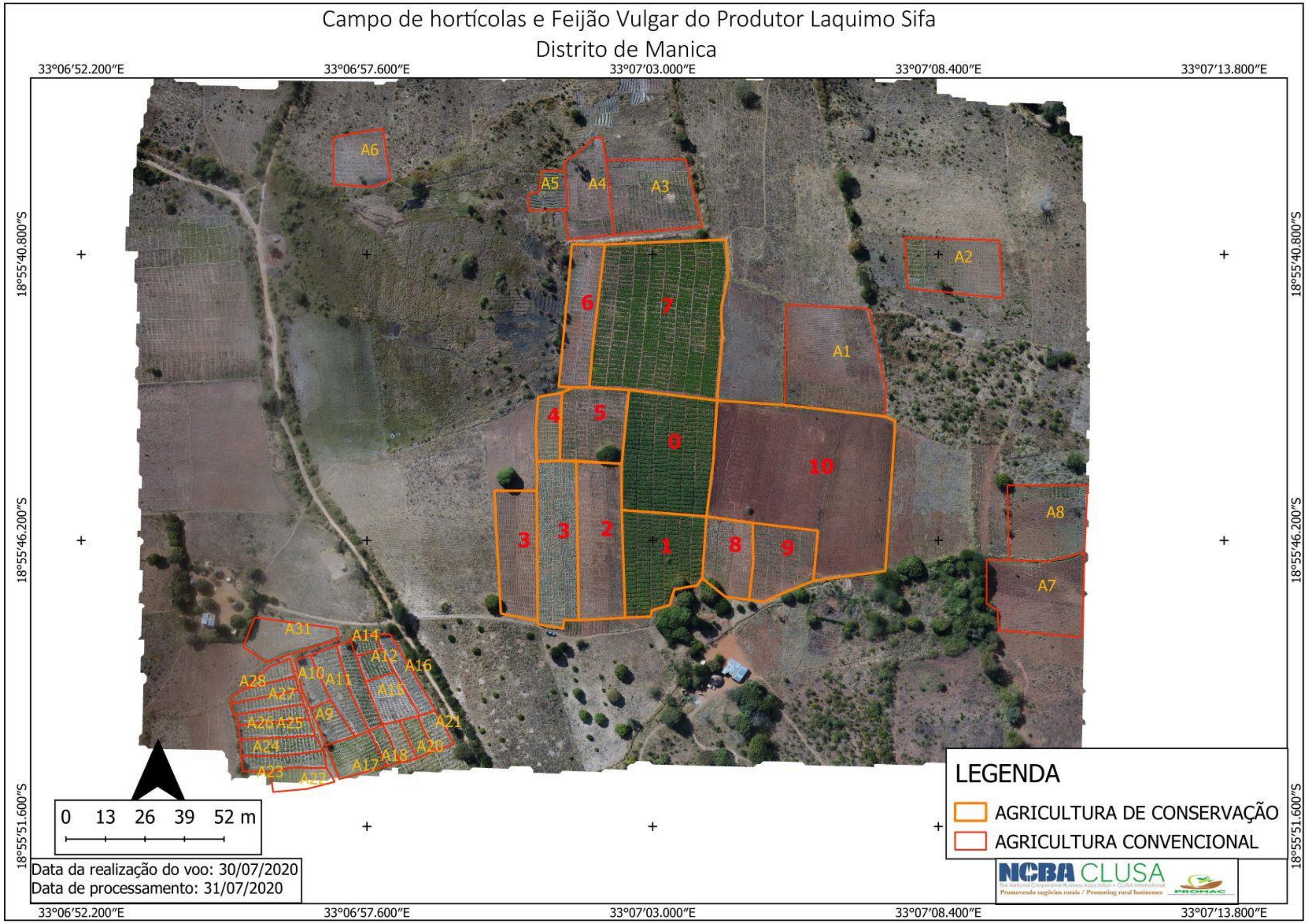
In conclusion, this report provides a method for assessing the agricultural productivity with flying sensor data and using this information as an M&E tool to report on productivity increases. Additionally, the spatial variation achieved by presenting the yield data in maps, gives decision-makers relevant information to improve their production for next seasons.

Annex 1 – Field Data Corenzi



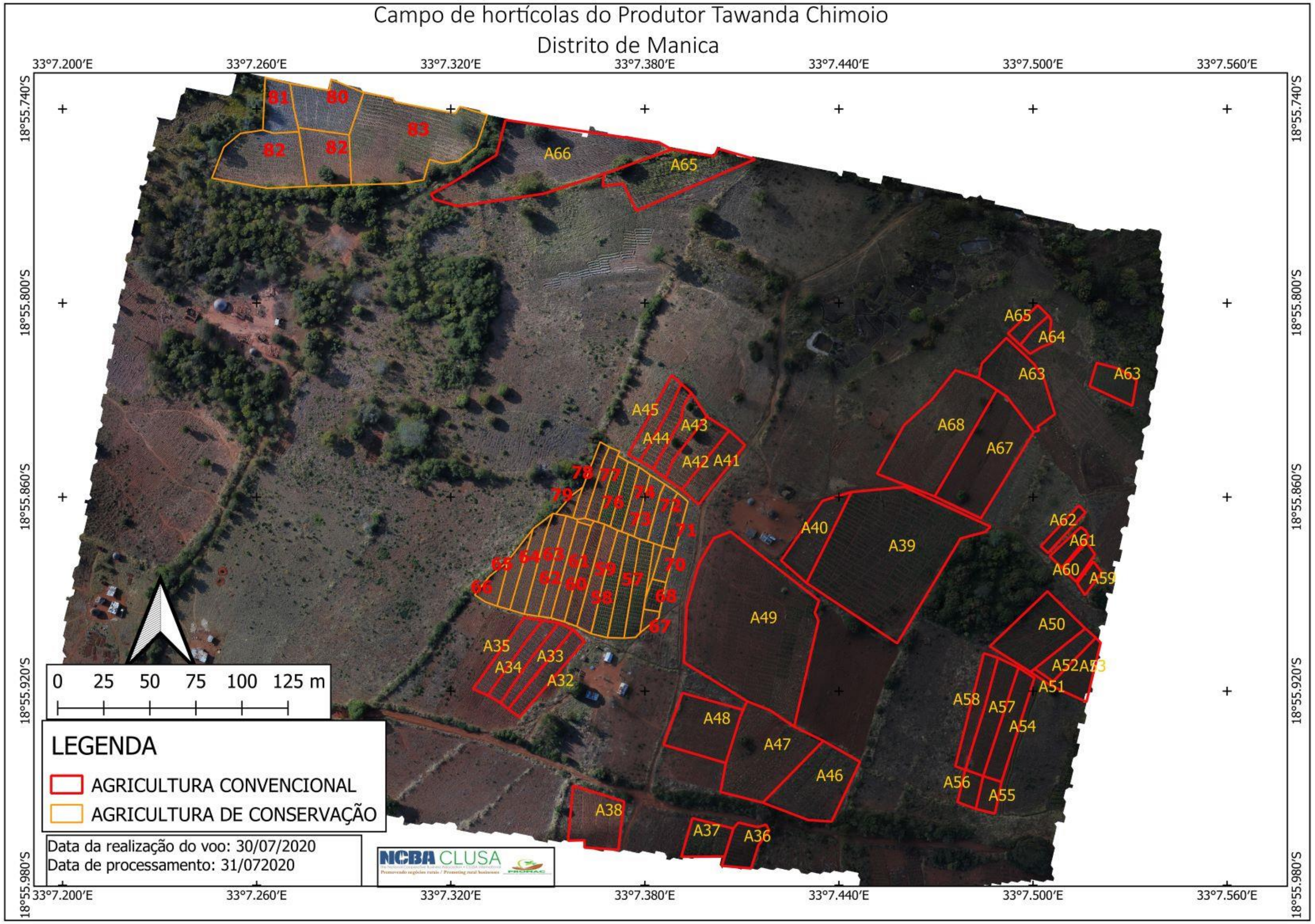
ID	PROMAC?	Cultura	PlantDate	HarvestDate	Practicas	Variedad
11	YES	FEIJAO VULGAR	15/04/2020	25/07/2020	AC	BONDE
12	YES	FEIJAO VULGAR	15/04/2020	25/07/2020	AC	BONDE
13	YES	FEIJAO VULGAR	15/04/2020	25/07/2020	AC	BONDE
14	YES	FEIJAO VULGAR	16/04/2020	25/07/2020	AC	BONDE
15	YES	FEIJAO VULGAR	16/04/2020	25/07/2020	AC	BONDE
16	YES	FEIJAO VULGAR	16/04/2020	27/07/2020	AC	BONDE
17	YES	FEIJAO VULGAR	16/04/2020	27/07/2020	AC	BONDE
18	YES	FEIJAO VULGAR	17/04/2020	27/07/2020	AC	BONDE
19	YES	FEIJAO VULGAR	17/04/2020	27/07/2020	AC	BONDE
20	YES	FEIJAO VULGAR	17/04/2020	27/07/2020	AC	BONDE
21	YES	FEIJAO VULGAR	17/04/2020	27/07/2020	AC	BONDE
22	YES	FEIJAO VULGAR	17/04/2020	27/07/2020	AC	BONDE
23	YES	FEIJAO VULGAR	02/05/2020	10/08/2020	AC	BONDE
24	YES	FEIJAO VULGAR	02/05/2020	10/08/2020	AC	BONDE
25	YES	FEIJAO VULGAR	02/05/2020	10/08/2020	AC	BONDE
26	YES	FEIJAO VULGAR	02/05/2020	11/08/2020	AC	BONDE
27	YES	FEIJAO VULGAR	02/05/2020	11/08/2020	AC	BONDE
28	YES	FEIJAO VULGAR	02/05/2020	11/08/2020	AC	BONDE
36	YES	COUVE	30/05/2020	19/06/2020	AC	TROCHUDA
37	YES	COUVE	26/05/2020	15/06/2020	AC	TROCHUDA
38	YES	COUVE	26/05/2020	15/06/2020	AC	TROCHUDA
39	YES	COUVE	03/05/2020	20/06/2020	AC	TROCHUDA
40	YES	COUVE	03/05/2020	20/06/2020	AC	TROCHUDA
41	YES	COUVE	03/05/2020	20/06/2020	AC	TROCHUDA
42	YES	COUVE	03/05/2020	20/06/2020	AC	TROCHUDA
43	YES	COUVE	03/05/2020	20/06/2020	AC	TROCHUDA
44	YES	COUVE	03/05/2020	20/06/2020	AC	TROCHUDA
45	YES	COUVE	03/05/2020	20/06/2020	AC	TROCHUDA
46	YES	COUVE	03/05/2020	20/06/2020	AC	TROCHUDA
47	YES	COUVE	03/05/2020	20/06/2020	AC	TROCHUDA
48	YES	COUVE	03/05/2020	20/06/2020	AC	TROCHUDA
49	YES	COUVE	05/05/2020	20/06/2020	AC	TROCHUDA
50	YES	COUVE	05/05/2020	20/06/2020	AC	TROCHUDA
51	YES	COUVE	05/06/2020	20/06/2020	AC	TROCHUDA
52	YES	COUVE	05/06/2020	20/06/2020	AC	TROCHUDA
53	YES	COUVE	05/05/2020	20/06/2020	AC	TROCHUDA
54	YES	COUVE	05/05/2020	20/06/2020	AC	TROCHUDA
55	YES	COUVE	05/05/2020	20/06/2020	AC	TROCHUDA

Annex 2 – Field Data Laquimo Sifa



ID	PROMAC?	Cultura	PlantDate	HarvestDat	Practicas	Variedad
0	SIM	()BABYCORN	13/05/2020	21/08/2020	AGRICULTURA DE CONSERVACAO	PACIFIC
1	SIM	BABYCORN	21/05/2020	21/08/2020	AGRICULTURA DE CONSERVACAO	PACIFIC
2	SIM	COUVE	05/05/2020	15/05/2020	AGRICULTURA DE CONSERVACAO	TROCHUDA
3	SIM	REPOLHO	13/04/2020	19/05/2020	AGRICULTURA DE CONSERVACAO	TROPICANA
4	SIM	COUVE CHINA	13/04/2020	21/04/2020	AGRICULTURA DE CONSERVACAO	COUVE-CHINA
5	SIM	TOMATE	20/04/2020	27/06/2020	AGRICULTURA DE CONSERVACAO	ROMA-VF
6	SIM	FEIJAO VULGAR	03/03/2020	15/06/2020	AGRICULTURA DE CONSERVACAO	BONUS
7	SIM	FEIJAO VULGAR	06/05/2020	25/08/2020	AGRICULTURA DE CONSERVACAO	BONUS
8	SIM	COUVE-CHINA	04/03/2020	14/04/2020	AGRICULTURA DE CONSERVACAO	COUVE-CHINA
9	SIM	TOMATE	03/03/2020	14/04/2020	AGRICULTURA DE CONSERVACAO	ROMA-VF
A3	NÃO	FEIJAO VULGAR				
A4	NÃO	FEIJAO VULGAR				
A5	NÃO	TOMATE				

Annex 3 – Field Data Tawanda



ID	PROMAC?	Cultura	PlantDate	HarvestDat	Practicas	Variedad
56	SIM	TOMATE	06/01/2020	EM CAMPO	AGRICULTURA DE CONSERVACAO	CARIJOTA
57	SIM	TOMATE	01/06/2020	EM CAMPO	AGRICULTURA DE CONSERVACAO	CARIJOTA
58	SIM	TOMATE	02/06/2020	EM CAMPO	AGRICULTURA DE CONSERVACAO	CARIJOTA
59	SIM	PIRIPIRE	16/07/2020	EM CAMPO	AGRICULTURA DE CONSERVACAO	BANDAI
60	SIM	PIRIPIRE	17/07/2020	EM CAMPO	AGRICULTURA DE CONSERVACAO	BANDAI
61	SIM	TOMATE	20/07/2020	EM CAMPO	AGRICULTURA DE CONSERVACAO	CHINA
62	SIM	TOMATE	20/07/2020	EM CAMPO	AGRICULTURA DE CONSERVACAO	CHINA
63	SIM	FEIJAO VULGAR	20/07/2020	EM CAMPO	AGRICULTURA DE CONSERVACAO	BONUS
64	SIM	FEIJAO VULGAR	20/07/2020	EM CAMPO	AGRICULTURA DE CONSERVACAO	BONUS
65	SIM	FEIJAO VULGAR	20/07/2020	EM CAMPO	AGRICULTURA DE CONSERVACAO	BONUS
66	SIM	FEIJAO VULGAR	20/07/2020	EM CAMPO	AGRICULTURA DE CONSERVACAO	BONUS
67	SIM	FEIJAO PRETO	15/07/2020	EM CAMPO	AGRICULTURA DE CONSERVACAO	FEIJAO PRETO
68	SIM	CEBOLA	28/05/2020	17/08/2020	AGRICULTURA DE CONSERVACAO	BRANCA
69	SIM	COUVE	29/07/2020	17/08/2020	AGRICULTURA DE CONSERVACAO	TROCHUDA
70	SIM	COUVE	29/07/2020	17/08/2020	AGRICULTURA DE CONSERVACAO	TROCHUDA
71	SIM	TOMATE	10/06/2020	EM CAMPO	AGRICULTURA DE CONSERVACAO	CARIJOTA
72	SIM	COUVE	11/06/2020	31/07/2020	AGRICULTURA DE CONSERVACAO	TROCHUDA
73	SIM	COUVE	12/06/2020	01/07/2020	AGRICULTURA DE CONSERVACAO	TROCHUDA
74	SIM	COUVE	13/06/2020	01/07/2020	AGRICULTURA DE CONSERVACAO	TROCHUDA
75	SIM	TOMATE	28/05/2020	EM CAMPO	AGRICULTURA DE CONSERVACAO	RIO-GRANDE
76	SIM	TOMATE	28/05/2020	EM CAMPO	AGRICULTURA DE CONSERVACAO	RIO-GRANDE
77	SIM	CEBOLA E REPO	11/06/2020	EM CAMPO	AGRICULTURA DE CONSERVACAO	VERMELHA E COMPANHIA CHIMAQUETE
78	SIM	CEBOLA E FEIJA	11/06/2020	EM CAMPO	AGRICULTURA DE CONSERVACAO	VERMELHA E BORN
79	SIM	PIRIPIRE	16/07/2020	EM CAMPO	AGRICULTURA DE CONSERVACAO	BANDAI
80	SIM	COUVE	15/06/2020	EM CAMPO	AGRICULTURA DE CONSERVACAO	TROCHUDA
81	SIM	COUVE	15/06/2020	EM CAMPO	AGRICULTURA DE CONSERVACAO	TROCHUDA
82	SIM	COUVE	15/06/2020	EM CAMPO	AGRICULTURA DE CONSERVACAO	TROCHUDA
83	SIM	COUVE	15/06/2020	EM CAMPO	AGRICULTURA DE CONSERVACAO	TROCHUDA
A32	SIM	MILHO	12/06/2020	EM CAMPO	AGRICULTURA DE CONSERVACAO	PAN- 601
A33	SIM	MILHO	13/06/2020	EM CAMPO	AGRICULTURA DE CONSERVACAO	PAN- 601
A34	SIM	MILHO	14/06/2020	EM CAMPO	AGRICULTURA DE CONSERVACAO	PAN- 601
A35	SIM	MILHO	14/06/2020	EM CAMPO	AGRICULTURA DE CONSERVACAO	PAN- 601
A39	NAO	TOMANTE			AGRICULTURA DE CONSERVACAO	
A40	NAO	REPOLHO			AGRICULTURA DE CONSERVACAO	