Analysis of the Agricultural Crop Productivity Using Flying Sensors

Technical report - Rainy season 2019 - 2020

REPORT 203

CLIENT NCBA Clusa

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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 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.

Five locations in the Manica province are monitored using flying sensor imagery during the rainy season (2019-2020). The crop types cultivated at these locations are soybean, maize, and beans. 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/). The assessment of agricultural productivity is presented with maps of 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.

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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 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.

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 rainy season in Mozambique typically starts in December and continues till end April. During these months heavy rain events occur providing an average of 700 - 800 mm seasonal precipitation (as recorded in Manica province). In exceptional years the precipitation can be up to 1100 mm or in dry years only 500 mm. This year (2019-2020) the rainy season is categorized as an average rainfall year as recorded in Manica province with CHIRPS[1] satellite based data. Locally, several heavy rainfall events led to the flooding of areas and project locations. This resulted in inaccessible roads and crop losses.
This season was the first growing season that NCBA Clusa staff applied the flying sensor activities after having received all required trainings the months before.

1.4 Reading guide

This technical report provides the analysis of the agricultural productivity for locations monitored with flying sensors during the rainy season (2019-2020). 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] https://chc.ucsb.edu/data/chirps

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, regular 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 crops were grown and interventions introduced by the project. An overview is provided in Table 1, including interventions for reducing erosion through grass strips and interventions to reduce soil evaporation through mulching or zero / minimum tillage. Lastly, ripper is a technique to enhance infiltration by having a shallow ploughing. All interventions are categorized as conservation agricultural practices and are being promoted by the project as interventions to increase agricultural production.

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

Table 1 Overview locations of flying sensor activities including crop types and interventions

Locations:	Augusto Charles	Bandula	Engles - Vanduzi	Maximino	Muzongo
Crop types	Maize, Soybean	Beans, Maize, Sesame	Soybean, Maize	Maize, Soybean, Sesame	Maize
Interventions:					
Mulching	✓	✓	✓	✓	✓
Zero / Min tillage	✓	✓	✓	✓	✓
Ripper	✓	✓	✓	✓	✓
Grass strips		✓			

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.

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

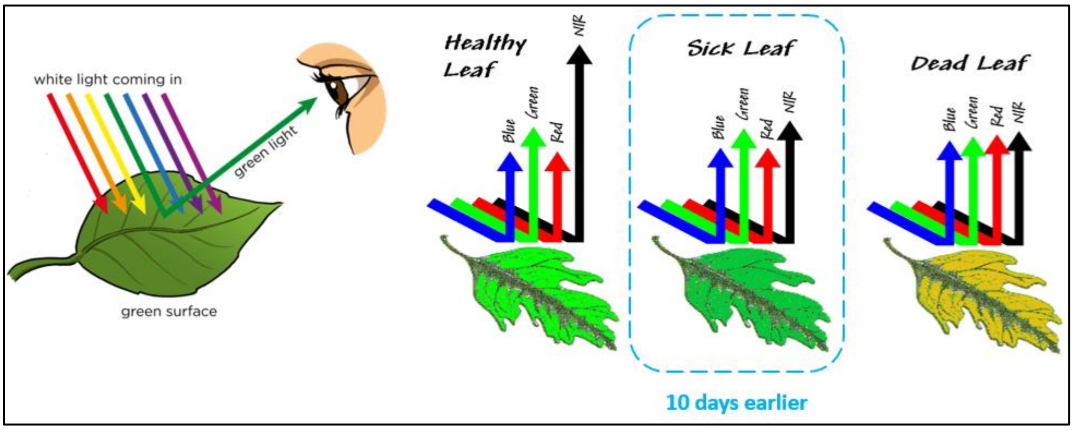


Figure 3 Illustration explaining the response of near infrared (NIR) wavelength to vegetation status

2.2.2 Imagery acquisition

Flying sensor images were acquired at regular intervals throughout the growing season. Table 2 provides an overview of the flights performed during the rainy season for the five project locations. For most locations a total of three to four flights were performed at monthly intervals. Muzungo had two flights performed because it was added at a later moment in the flying sensor activities. Table 1 shows that most crops were planted end of November to early January. Halfway the growing season the Maximino location had flood damage due to heavy rain events. The roads were inaccessible and a flight could not be made. Also some fields had damage to crops and another planting was required.
The total area monitored by flying sensors was 174 ha. with the locations Engles (Vanduzi) and Maximino being the largest.

Table 2 Overview of flights and area during the Rainy Season of 2019 - 2020

Locations:	Augusto Charles	Bandula	Engles - Vanduzi	Maximino	Muzongo
Dec-2019				4th December	
Jan-2020		22nd January		22nd January	
Feb-2020	7th February	19th February	27th February	*flooded*	
Mar-2020	5th March	9th March	20th March	19th March	9th March
Apr-2020	15th April	8th April	8th April	15th April	8th April
Total Area	21 ha.	20 ha.	54 ha.	53 ha.	26 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 a 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

[3] For more information visit https://www.agisoft.com/
[4] For more information visit https://www.qgis.org/

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-Mmeans package. 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.

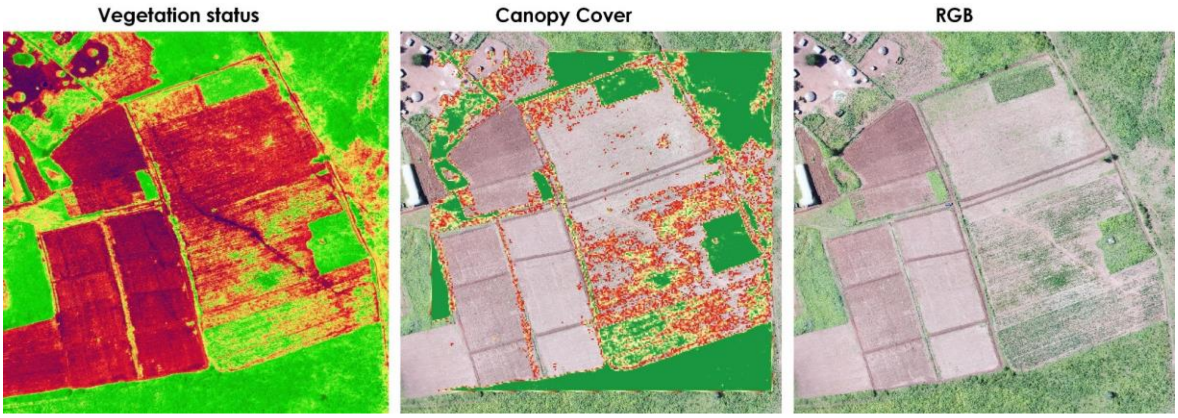


Figure 4 Flying sensor results for vegetation status (left), canopy cover (middle) and RGB (right)

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[5]. 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[6]. 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.

[5] 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

[6] 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.

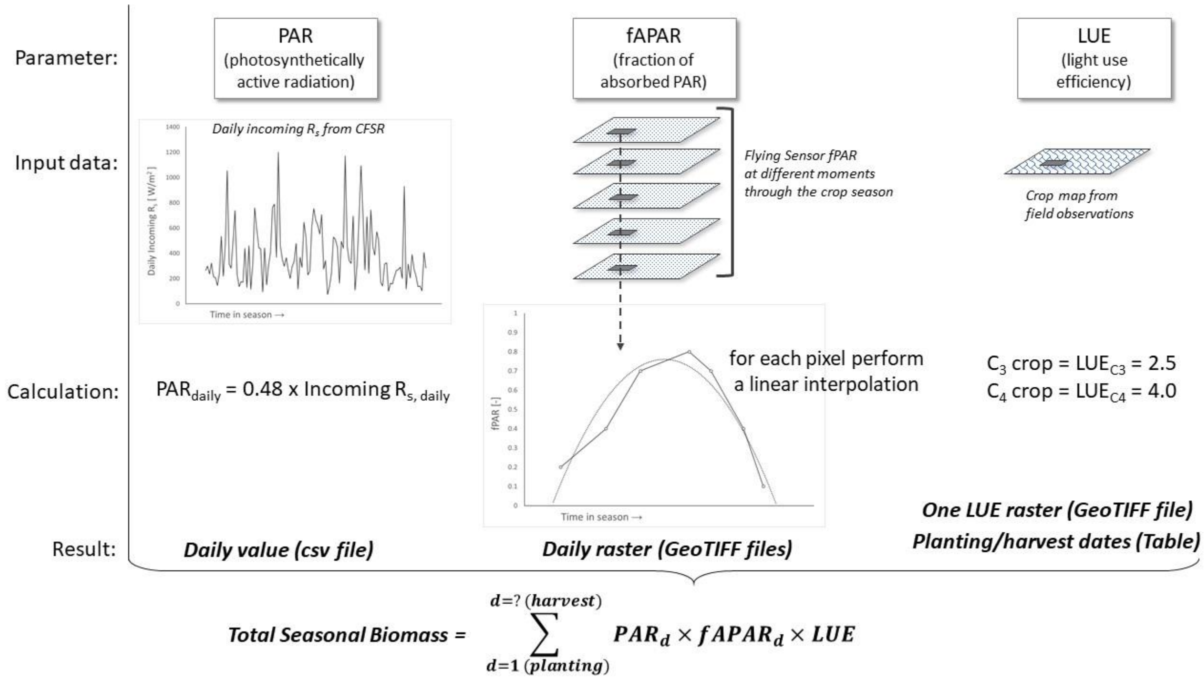


Figure 5 Schematic of workflow for biomass production analysis from flying sensor imagery

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 amout of full vegetation cover. A widely used equation to calculate FAPAR is developed by Hipps et al. (1983)[7]:

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

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)[8] has been widely used:

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

[7] 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.

[8] 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, soybean, and beans) are listed in Table 3. Other crop parameters are also listed, which are explained in the next section regarding the seasonal interpolation.

Table 3 Overview of crop specific parameters for the calculation of the productivity

	Light Use Efficiency	Fraction of above ground biomass production	Harvest Index	Yield potential [ton/ha]
Maize				
PAN-3M	3.5	0.65	0.3	3 to 5 [9]
PAN-2M	3.5	0.65	0.3	
ZM-523	3.5	0.65	0.3	
Local Maize	3.0	0.65	0.2	1 to 3 [10]
Soy				
SAFARI	1.8	0.65	0.2	
Beans				
IT-16	1.8	0.65	0.3	
Sesame				
LINDI	1.8	0.65	0.2	

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 2 it was noted that Maximino had the most flying sensor images, however due to the flooding the crop curve was abnormal. The crops were damaged due to the floods before reaching the peak and new plants were placed as replacement. This gave some variation in the interpolation of the Maximino dataset within the field with sections having different planting dates.

In Muzungo flights occurred only in the last two months of the growing period thus giving insufficient information of the development of the crop in the first part of the season. This can result in some discrepancies of the results.

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 Annexes 1 to 4, using information as noted in the field. From the total biomass production the crop dry yield or agricultural production is calculated. Crop specific parameters for this calculation is reported in Table 3. Firstly, the

[9] PANNAR Quality Seeds Botswana Farmer's Guide www.pannar.com
[10] FAOSTAT Mozambique and FAO Irrigation and Drainage Paper No.66

amount of biomass production that exists above ground is calculated being 65% of the total biomass, 35% exists as 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 3 for the three crop types.

Table 3 also indicates the yield potential 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 and the harvest index. This was performed in one location (Augusto Charles) and the parameters were then fixed for the analysis of yield in the other locations. The values for yield potential were found for maize crop varieties, therefore the other crop types were not calibrated. This can be further expanded in following analysis by adding field reports of the crop yields.

2.5 Monitoring project impact

The PROMAC project introduced several interventions relating to conservation agriculture as indicated in Table 1. The flying sensor data and the agricultural productivity analysis provides insight in the spatial variation of the crop yields achieved for each field. For the monitoring and evaluation of the project, information needs to be provided on the change in crop yield caused by the introduction of the interventions. For each location surrounding fields are added that were not included in the project and had local varieties and conventional (traditional) farming practices. These were analyzed in the locations Augusto Charles, Bandula, and Muzungo. Information on the location of the fields and the practices are indicated in Annexes 1, 2, and 3. Engles was not included in this analysis due to a lack of surrounding fields monitored by the flying sensors.

In the assessment the agricultural productivity is calculated for both PROMAC and non-PROMAC fields. A comparison is made in the different in average yields per crop type and variety (if relevant). The average crop yield per field was calculated by using only pixels that contained vegetation (>0.1 ton/ha), thereby omitting parts of the field that was fallow or had bare soil.

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 are indicated for the five selected locations in Table 2 of the previous chapter. For each flight the result was an aerial (RGB) image and a vegetation status image provided by the Near Infrared camera. For the location of Augusto Charles these images are shown in Figure 6 at three flight dates in February, March and April.

The smaller fields on the left (West) are a good example of capturing the different stages in the crop development with full cover and bare soil after harvest. This development is even more pronounced in the vegetation status images showing green color for full cover and red to dark blue color for bare soil. The comparison between RGB and vegetation status images (using the NIR camera) indicates the added value of using a NIR for monitoring vegetation, as it captures the vegetation status better.

The NIR images are then used for calculating the canopy cover which is shown in the last row with green being full cover (100%). This is the aggregation of the high resolution (4 cm) pixels of the flying sensors into 1x1m pixels. The trend for vegetation development is similar to that observed in the vegetation status images. For the smaller fields on the left there is some variation perceived between fields in the amount of vegetation cover. In the two larger fields there is a distinction within the field likely due to different practices. The crop development of all images as captured throughout the rainy season are also available through the online data portal (https://www.futurewater.nl/ncbaclusaportal/).

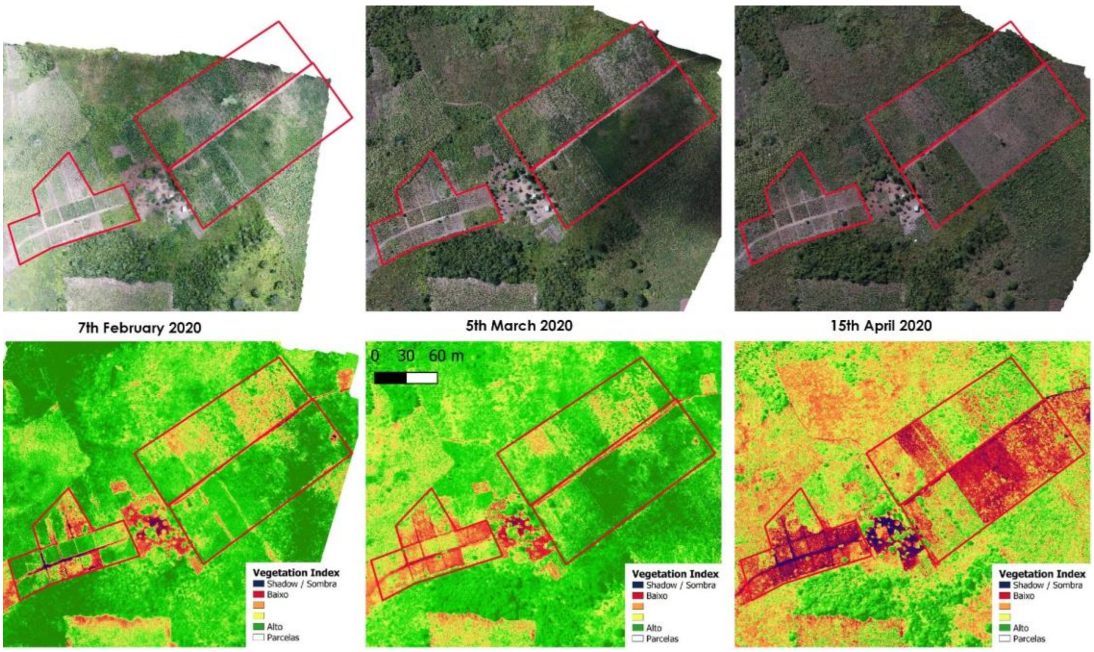


Figure 6a Crop development for Augusto Charles location for three flight dates with RGB (top) and vegetation status (bottom)

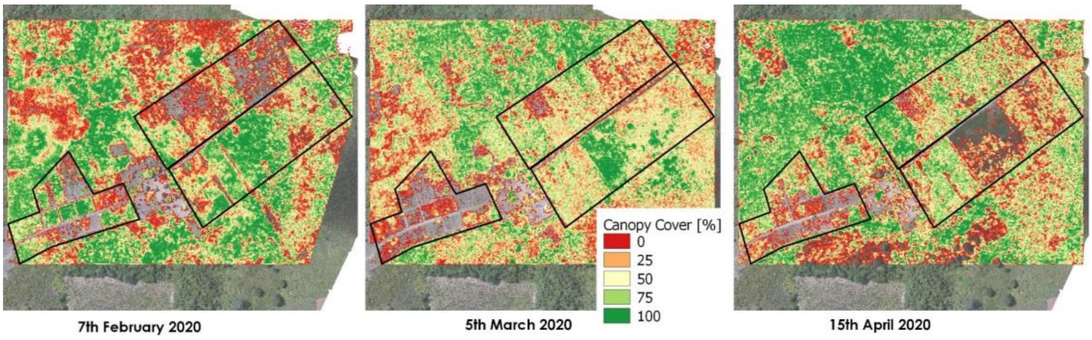


Figure 6b Crop development for Augusto Charles location for three flight dates with canopy cover (in %)

3.2 Seasonal interpolation results

For each canopy cover pixel (1 m resolution) the seasonal interpolation is applied to calculate the daily and total seasonal biomass production. The interpolation is applied to the FAPAR images that are achieved for each flight date. The result of the interpolation is demonstrated in Figure 7 for a crop pixel in the Engles-Vanduzi location. The left graph for FAPAR indicates a zero FAPAR at the time of planting and harvest because there is bare soil. At three flights the FAPAR was captured, namely at day of year 423, 445, and 464, which are the 27th February, 20th March, and 8th April, respectively. For the first two dates the crop is at peak vegetation cover and the FAPAR is approximately 0.9 (90%). For the last date the FAPAR decreased with the crop (maize) senescing and preparing for harvest.

The graph for daily biomass production during the season is presented in Figure 7 (on the right). The biomass production depends on the FAPAR and also the available PAR as measured daily with the weather data for solar radiation. The overall trend is similar to the crop curve of FAPAR, however some dips and peaks are perceived due to clear sky or cloudy conditions. The accumulation of daily biomass production is used to calculate the total seasonal biomass production and provide the agricultural productivity specific for each crop type, which is presented in the next chapter.

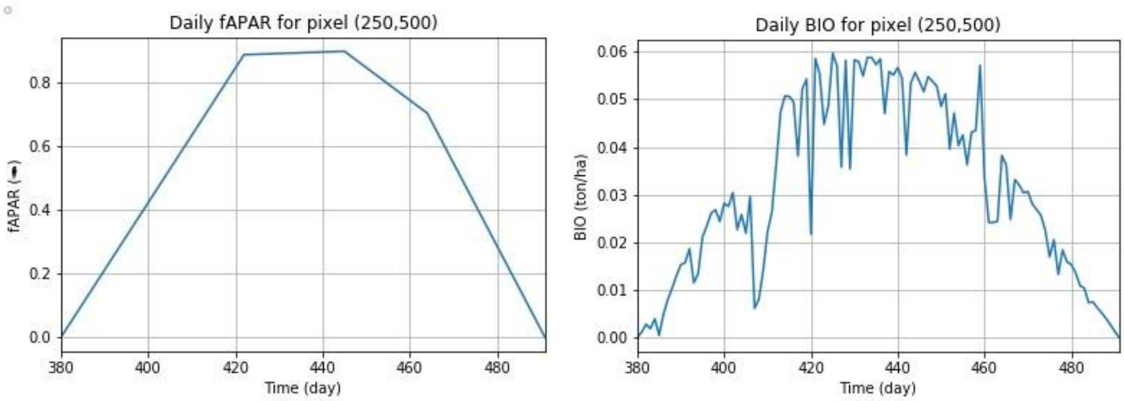


Figure 7 Seasonal interpolation results for a pixel in Engles-Vanduzi field with day of year as time (on the horizontal axis) and FAPAR as fraction (left) and daily biomass production [ton/ha] (right)

4 Agricultural productivity assessment

4.1 Crop yield results

4.1.1 Location: Augusto Charles

At the Augusto Charles location two crop types were grown, namely soybean and maize. These are indicated in different colors in Figure 8. The biomass production is calculated with a different light use efficiency for maize in comparison with soybean because maize is a C4 crop. Therefore, a higher biomass production is expected for maize fields. The result of the total seasonal biomass production as calculated from the seasonal interpolation, is used to calculate the crop yield for each pixel using the crop parameters in Table 3 for harvest index. The results for crop yield are presented in Figure 8 for the Augusto Charles location. The crop yield for the soybean field is 1.2 ton/ha and for maize fields it ranges from 0.7 to 8.4 ton/ha as indicated in Figure 8. A yield of 8.4 ton/ha seems high especially when looking at the yield potential even of the hybrid seed varieties, used in this field. However, most other fields showed reasonable values for yield. The fields with a high yield result should be evaluated with more field notes on the occurrence of weeds or intercropping, which may influence the canopy cover values of this field and thus the yield results. Overall, the values may require more calibration to field conditions, however the maps give an adequate representation of the spatial pattern between fields of similar crop type.

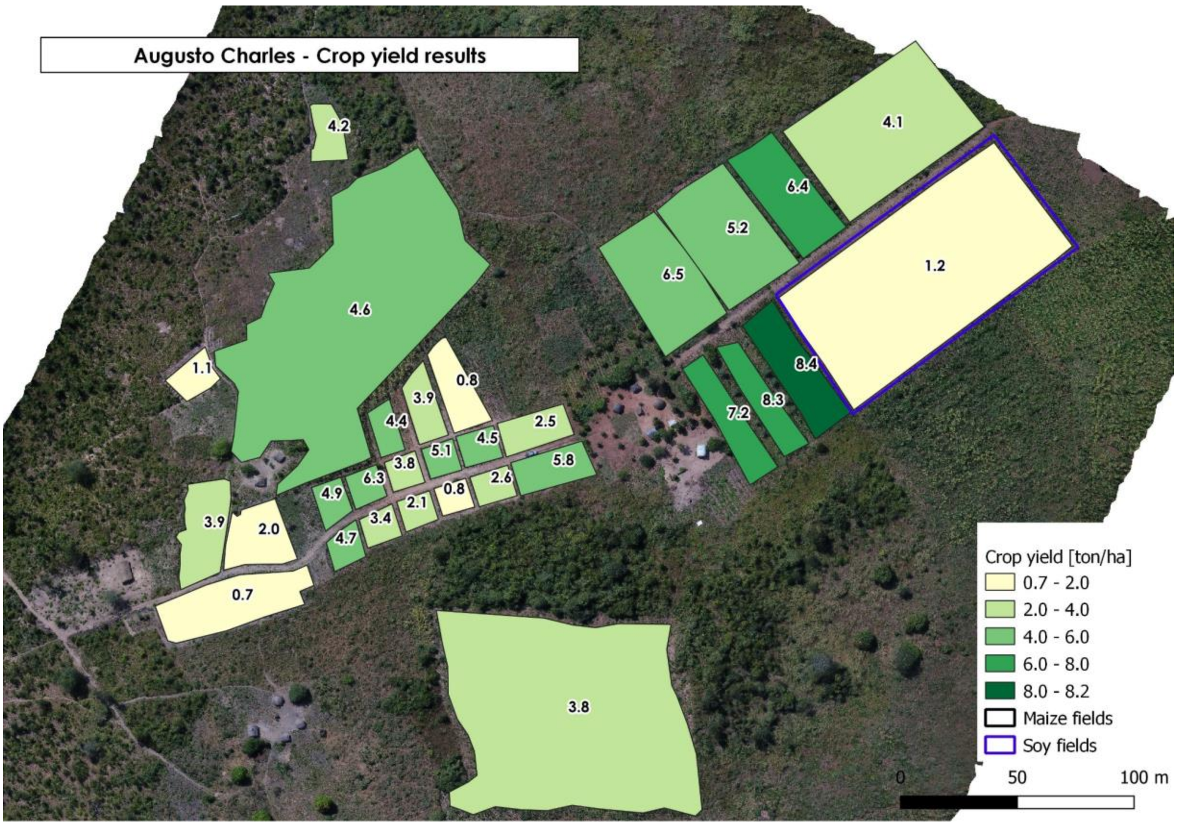


Figure 8 Agricultural productivity assessment for Augusto Charles for maize (milho) and soybean (soya)

4.1.2 Location: Bandula

The same analysis for crop yield was performed for the location Bandula. Results are presented in Figure 9 for the crop types: maize, soybean, sesame and beans. Yield results for maize fields ranged from 2.7 to 5.5 ton/ha. For soybean fields it ranged from 0.9 to 1.3 ton/ha. For sesame fields the range in yield was from 0.6 to 1.1 ton/ha and for beans it ranged from 1.1 to 1.6 ton/ha, as indicated in Figure 9. In comparison with Augusto Charles, the maize yield showed less variation between the lowest and highest yield reports.

Figure 9 Agricultural productivity assessment for Bandula for maize (milho), soybean (soya), sesame (gergelim) and beans (feijão)

4.1.3 Location Engles

The yield results for the fields at Engles are shown in Figure 10. For the maize field the yield was 4.7 ton/ha, which is similar to the range as observed in the Bandula location. The soybean fields show a range in yield from 0.4 to 1.3 ton/ha.

4.1.4 Location Muzungo

The yield results for Muzungo are shown in Figure 11, which contains only maize fields. The range of the yield calculated for these fields are from 1.2 to 5.5 ton/ha, which are reasonable and similar to the range of Bandula and Engles.

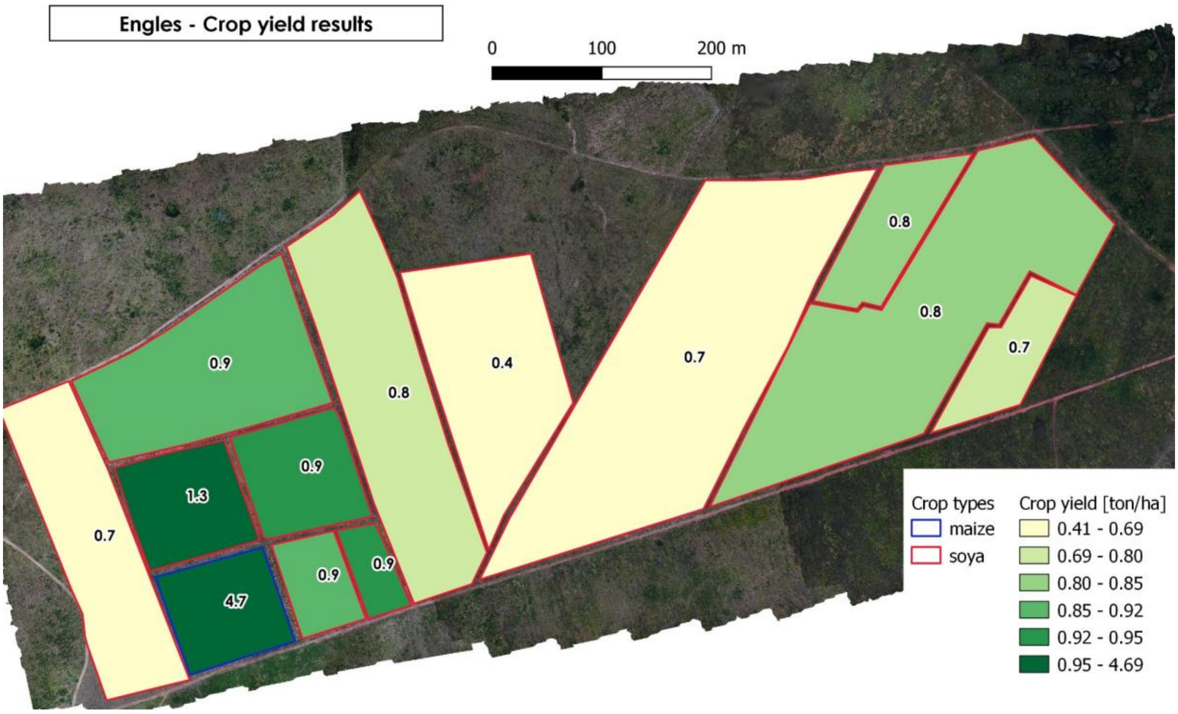


Figure 10 Agricultural productivity assessment for Engles-Vanduzi for maize (milho) and soybean (soya)

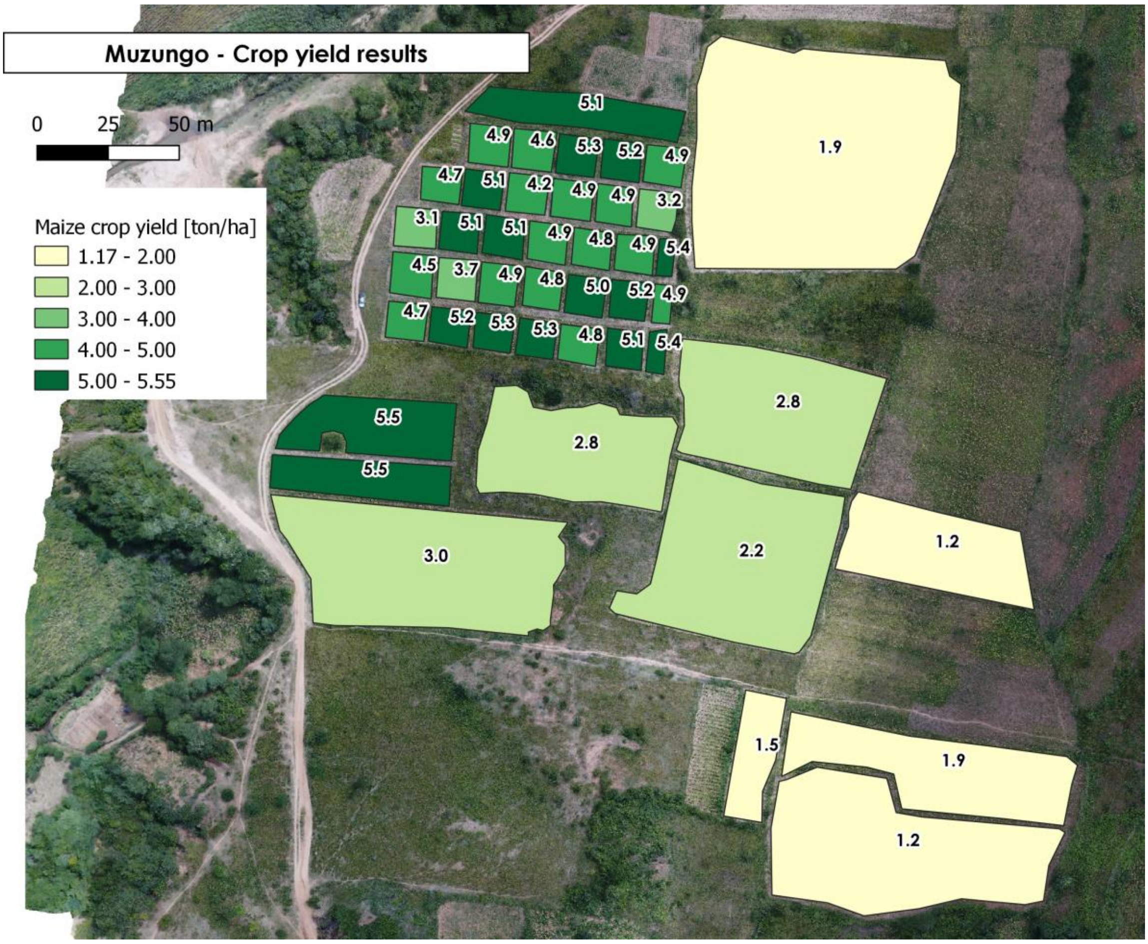


Figure 11 Agricultural productivity assessment for Muzungo for maize

4.2 Assessment of agricultural productivity

The yield analysis was performed for all the locations monitored with the flying sensors. The Maximino location was analyzed but the results were not consistent due to the crop damage that occurred during the season with flooding event. For this reason, the Maximino results are not included in the analysis of agricultural productivity. The Muzungo location consisted of two flying sensor images at the end of the crop development, therefore some discrepancies may occur due to the lack of information during the first part of the crop development.

For each location the surrounding fields were used as representative for conventional agricultural practices. Both the PROMAC fields and the conventional fields were analyzed in the yield assessment with an overview of the results presented in Table 4.

The yield results for maize also incorporated different crop parameters due to the selection of seed varieties in the PROMAC fields. For maize the PROMAC fields indicated a difference in yield from 32% to 148%.

For the other crop types, namely soy, beans, and sesame, the seed varieties were the same for both PROMAC fields and the conventional farming fields. The crop parameters are therefore the same for both fields. The results as shown in Table 4 indicate a difference in crop yield for soy bean of 49%, for beans of 3%, and for sesame of 20%.

In Annex 1 to 4 the location of both the PROMAC and the conventional farming fields are indicated on the maps.

Table 4 Overview of crop yield results for maize, soybeans, and beans at four project locations

	Augusto Charles	Bandula	Engles - Vanduzi	Muzongo
Maize				
Yield PROMAC fields [ton/ha]	4.40	5.38	4.69	4.81
Yield conventional fields [ton/ha]	3.32	2.82		1.94
Change in yield	32%	91%	NA	148%
Soy				
Yield PROMAC fields [ton/ha]	1.30	1.33	0.83	
Yield conventional fields [ton/ha]		0.89		
Change in yield	NA	49%		
Beans				
Yield PROMAC fields [ton/ha]		1.30		
Yield conventional fields [ton/ha]		1.26		
Change in yield		3%		
Sesame				
Yield PROMAC fields [ton/ha]		1.04		
Yield conventional fields [ton/ha]		0.87		
Change in yield		20%		

5 Concluding remarks

This report presents the assessment of the agricultural productivity during the rainy season (2019-2020) for five project locations in the Manica province. These locations were monitored with flying sensors during the growing season at regular (monthly) intervals. The total area that was monitored encompassed 174 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.

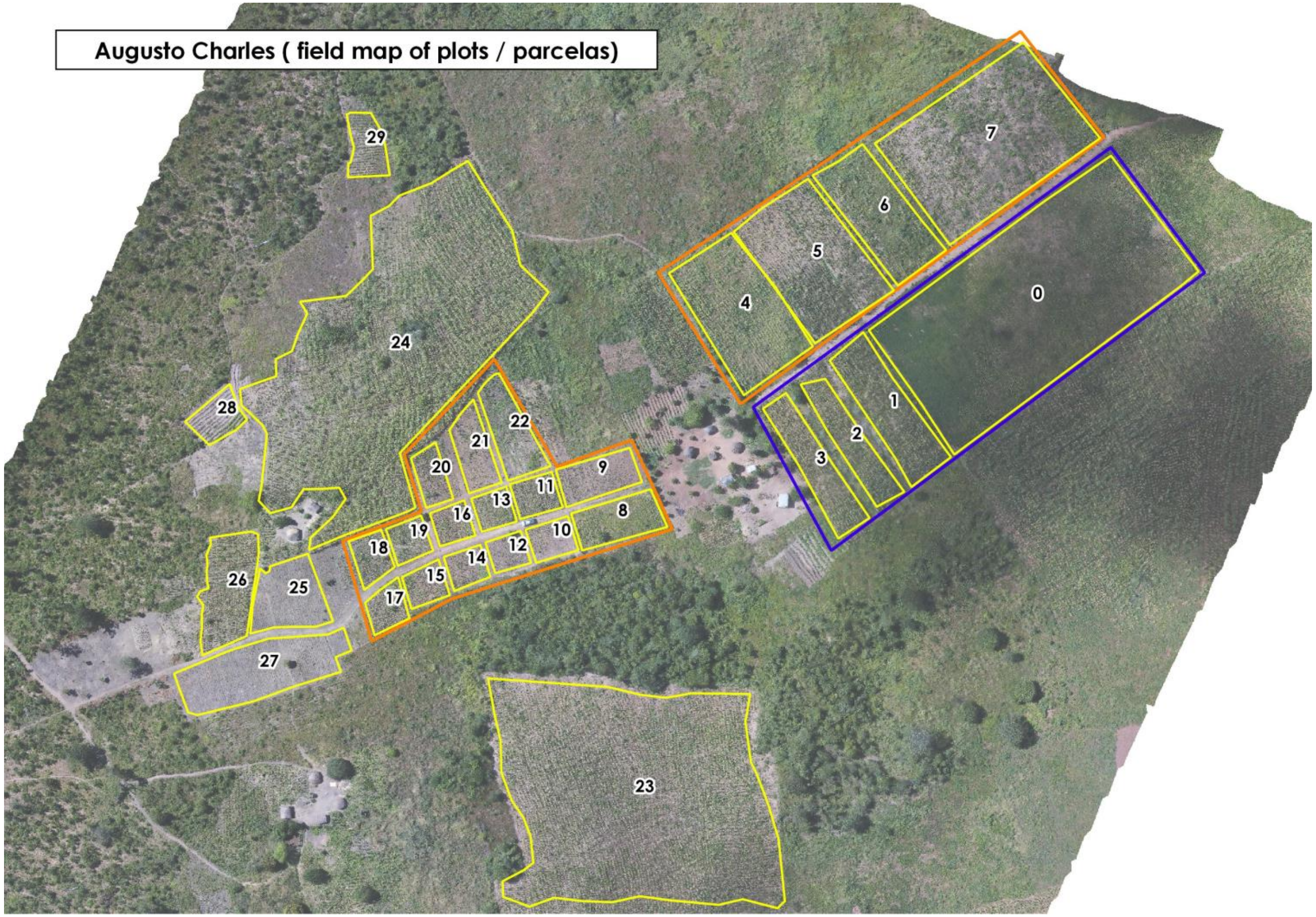
The productivity assessment shows the spatial variability in production between fields. Values for maize ranged the most in the Augusto Charles location with the lowest values being 0.7 ton/ha and the highest over 8 ton/ha. However, the yields of over 6 ton/ha are less reasonable and require further field clarifications. The yield potential of the hybrid maize varieties was 3 to 5 ton/ha, which was also mostly found in the results of the yield analysis.

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: Augusto Charles, Bandula, and Muzungo, the comparison is made using field notes, the field boundaries, and the flying sensor imagery. The comparison showed an increase in maize yield due to conservations agricultural and also hybrid seed varieties of 32% up to 148%. For the other crop types, soy, beans, and sesame, an increase in yield of 49%, 3%, and 20% was found.

In conclusion, this report provides a method for estimating 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.

The yield analysis shows the important of gathering more field data for achieving accurate results on the crop development and yield reports. This will improve the quality of the results for the following analysis.

Annex 1 – Field Data Augusto Charles



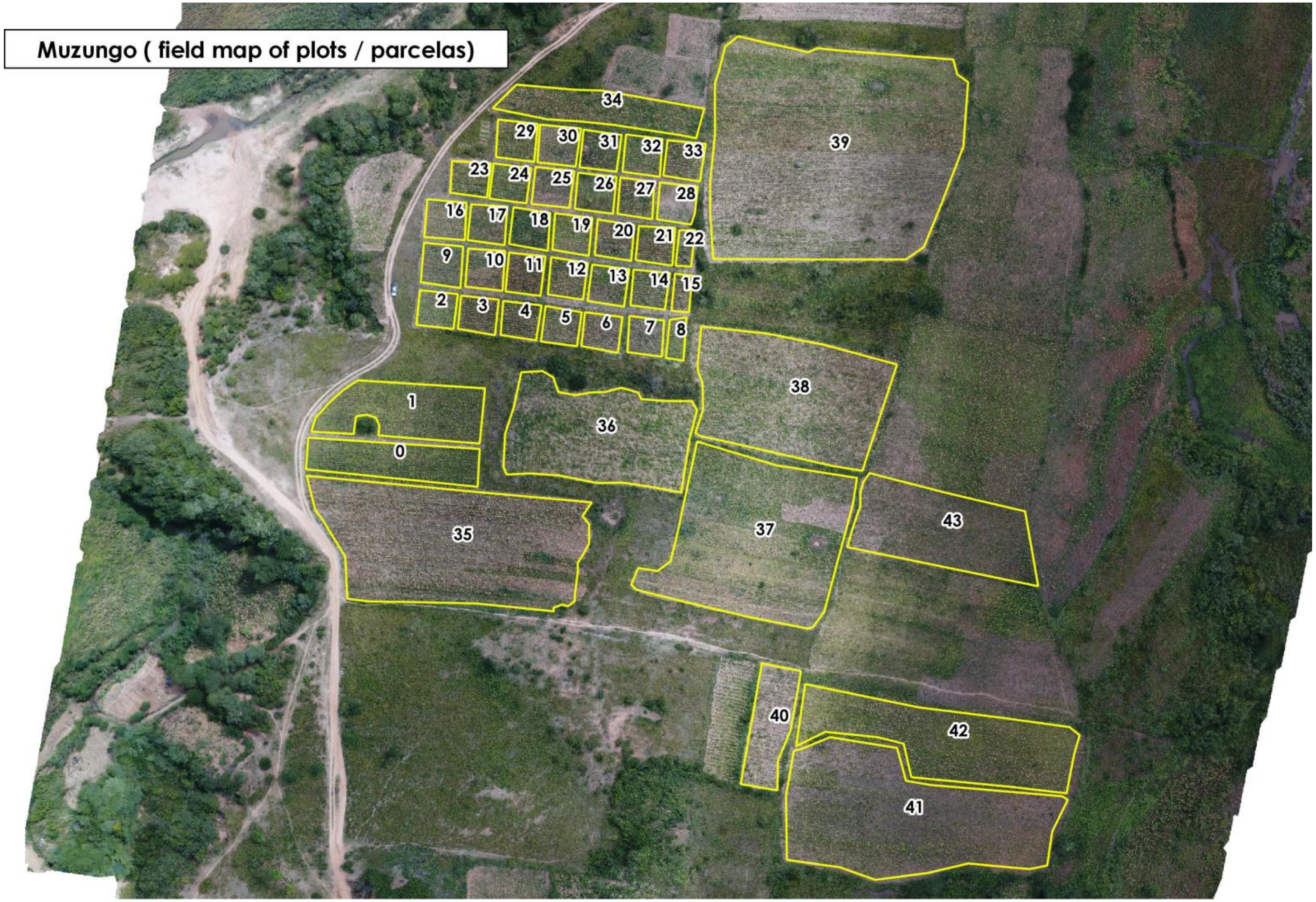
Plot ID	PROMAC?	Crop	PlantDate	HarvestDate	Practices	Variety
0	yes	Soy	2019-12-22	2020-04-01	Conservation Agriculture using troughts	SAFARI
1	yes	maize	2019-11-23	2020-05-15	Conservation Agriculture using troughts	PAN-3M
2	yes	maize	2019-11-23	2020-05-15	Conservation Agriculture using troughts	PAN-3M
3	yes	maize	2019-11-23	2020-05-15	Conservation Agriculture using troughts	PAN-3M
4	yes	maize	2019-11-23	2020-04-01	Conservation Agriculture using troughts	PAN-3M
5	yes	maize	2019-12-05	2020-05-01	Conservation Agriculture using troughts	PAN-3M
6	yes	maize	2019-11-23	2020-04-01	Conservation Agriculture using troughts	PAN-3M
7	yes	maize	2019-11-23	2020-04-01	Mulching, minimum tillage, ripper	ZM-523
8	yes	maize	2019-11-23	2020-04-15	Conservation Agriculture using troughts	PAN-3M
9	yes	maize	2019-11-23	2020-04-01	Conservation Agriculture using troughts	PAN-3M
10	yes	maize	2019-11-23	2020-04-01	Conservation Agriculture using troughts	PAN-3M
11	yes	maize	2019-11-23	2020-04-15	Conservation Agriculture using troughts	PAN-3M
12	yes	maize	2019-11-23	2020-04-01	Conservation Agriculture using troughts	PAN-3M
13	yes	maize	2019-11-23	2020-04-15	Conservation Agriculture using troughts	PAN-3M
14	yes	maize	2019-11-23	2020-04-01	Conservation Agriculture using troughts	PAN-3M
16	yes	maize	2019-11-23	2020-05-01	Conservation Agriculture using troughts	PAN-3M
15	yes	maize	2019-11-23	2020-04-01	Conservation Agriculture using troughts	PAN-3M
17	yes	maize	2019-11-23	2020-05-01	Conservation Agriculture using troughts	PAN-3M
18	yes	maize	2019-11-23	2020-05-01	Conservation Agriculture using troughts	PAN-3M
19	yes	maize	2019-11-23	2020-05-01	Conservation Agriculture using troughts	PAN-3M
20	yes	maize	2019-11-23	2020-05-01	Conservation Agriculture using troughts	PAN-3M
21	yes	maize	2019-11-23	2020-05-01	Conservation Agriculture using troughts	PAN-3M
22	yes	maize	2019-11-15	2020-03-01	Conservation Agriculture using troughts	PAN-3M
23	no	maize	2019-11-20	2020-05-01	Conventional Agriculture	Local Maize
24	no	maize	2019-11-20	2020-05-15	Conventional Agriculture	Local Maize
25	yes	maize	2019-12-15	2020-05-01	Conservation Agriculture using troughts	PAN-3M
26	no	maize	2019-11-20	2020-05-01	Conventional Agriculture	Local Maize
28	no	maize	2020-01-15	2020-05-01	Conventional Agriculture	Local Maize
29	no	maize	2019-11-20	2020-05-01	Conventional Agriculture	Local Maize

Annex 2 – Field Data Bandula

Bandula (field map of plots / parcelas)

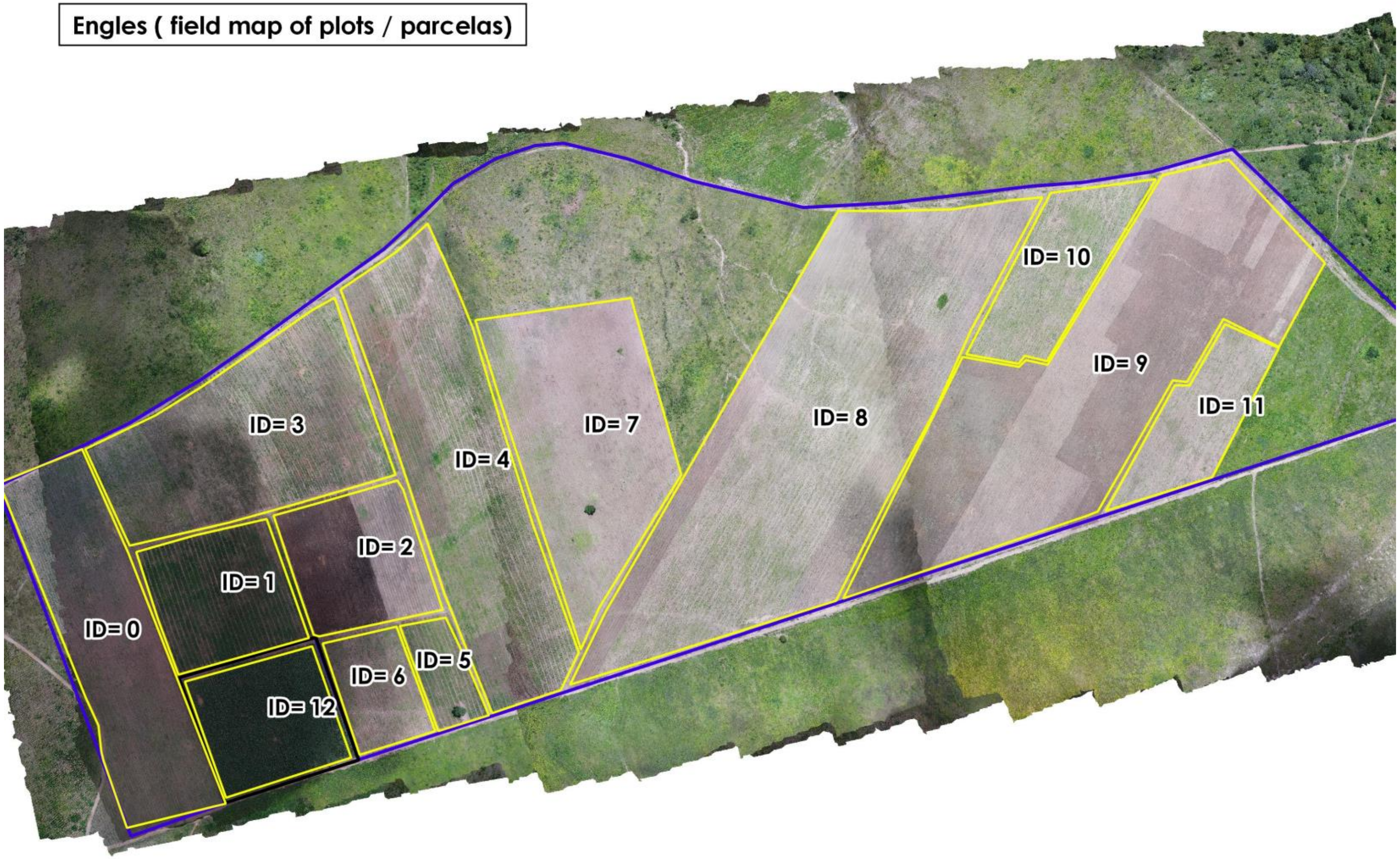
Plot ID	PROMAC?	Crop	PlantDate	HarvestDate	Practices	Variety
0	no	Sesame	2020/01/31	2020/05/01	conventional Agriculture	LINDI
1	yes	Sesame	2020/01/31	2020/05/01	mulching, minimum tillage, ripper AC	LINDI
2	no	Sesame	2020/01/31	2020/05/01	conventional Agriculture	LINDI
3	yes	Sesame	2020/01/31	2020/05/01	mulching, minimum tillage, ripper AC	LINDI
4	no	Beans	2020/01/31	2020/04/20	conventional Agriculture	IT-16
5	yes	Beans	2020/01/31	2020/04/20	mulching, minimum tillage, ripper AC	IT-16
6	no	Beans	2020/01/31	2020/04/20	conventional Agriculture	IT-16
7	yes	Beans	2020/01/31	2020/04/20	mulching, minimum tillage, ripper AC	IT-16
8	yes	Maize	2019/12/01	2020/05/01	mulching, minimum tillage, ripper AC	PAN-02M
9	yes	Soy	2019/12/01	2020/05/01	mulching, minimum tillage, ripper AC	SAFARI
10	yes	Beans	2019/12/01	2020/05/01	mulching, minimum tillage, ripper AC	IT-16
11	yes	Beans	2019/12/01	2020/05/01	conservation Agriculture using troughs	IT-16
12	yes	Maize	2019/12/01	2020/05/01	conservation Agriculture using troughs	ZM-523
13	yes	Beans	2020/01/15	2020/05/15	mulching, minimum tillage, ripper AC	IT-16
14	no	Maize	2019/12/01	2020/05/01	conventional Agriculture	Local maize
15	no	Soy	2020/02/15	2020/05/15	conventional Agriculture	SAFARI
16	no	Sesame	2020/02/15	2020/05/15	conventional Agriculture	LINDI
17	no	Maize	2019/12/01	2020/04/20	conventional Agriculture	Local maize
18	no	Maize	2019/12/01	2020/05/01	conventional Agriculture	Local maize
19	no	Maize	2020/01/05	2020/05/15	conventional Agriculture	Local maize

Annex 3 – Field Data Muzungo



Plot ID	PROMAC?	Crop	PlantDate	HarvestDate	Practices	Variety
0	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
1	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
2	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
3	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
4	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
5	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
6	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
7	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
8	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
9	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
10	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
11	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
12	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
13	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
14	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
15	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
16	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
17	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
18	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
19	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
20	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
21	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
22	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
23	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
24	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
25	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
26	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
27	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
28	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
29	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
30	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
31	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
32	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
33	yes	maize	2020/01/01	2020/05/15	Conservation Agriculture using troughs	PAN-3M01
34	yes	maize	2020/01/01	2020/05/15	mulching, minimum tillage, ripper	ZM-523
35	yes	maize	2020/01/01	2020/05/15	mulching, minimum tillage, ripper	ZM-523
36	no	maize	2020/01/01	2020/05/15	Conventional Agriculture	Local Maize
37	no	maize	2020/01/01	2020/05/15	Conventional Agriculture	Local Maize
38	no	maize	2020/01/01	2020/05/15	Conventional Agriculture	Local Maize
39	no	maize	2020/01/01	2020/05/15	Conventional Agriculture	Local Maize
40	no	maize	2020/01/01	2020/05/15	Conventional Agriculture	Local Maize
41	no	maize	2020/01/01	2020/05/15	Conventional Agriculture	Local Maize
42	no	maize	2020/01/01	2020/05/15	Conventional Agriculture	Local Maize
43	no	maize	2020/01/01	2020/05/15	Conventional Agriculture	Local Maize

Annex 4 – Field Data Engles



Plot ID	PROMAC?	Cultura	PlantDate	HarvestDat	Practicas	Variedad
0	yes	soya	05/02/2020	15/05/2020	Mulching, minimum tillage, ripping	SAFARI
1	yes	soya	22/01/2020	30/04/2020	Mulching, minimum tillage, ripping	SAFARI
2	yes	soya	28/01/2020	30/04/2020	Mulching, minimum tillage, ripping	SAFARI
3	yes	soya	05/02/2020	15/05/2020	Mulching, minimum tillage, ripping	SAFARI
4	yes	soya	28/01/2020	30/04/2020	Mulching, minimum tillage, ripping	SAFARI
5	yes	soya	28/01/2020	30/04/2020	Mulching, minimum tillage, ripping	SAFARI
6	yes	soya	05/02/2020	15/05/2020	Mulching, minimum tillage, ripping	SAFARI
7	yes	soya	05/02/2020	15/05/2020	Mulching, minimum tillage, ripping	SAFARI
8	yes	soya	05/02/2020	15/05/2020	Mulching, minimum tillage, ripping	SAFARI
9	yes	soya	05/02/2020	15/05/2020	Mulching, minimum tillage, ripping	SAFARI
10	yes	soya	28/01/2020	05/05/2020	Mulching, minimum tillage, ripping	SAFARI
11	yes	soya	05/01/2020	05/05/2020	Mulching, minimum tillage, ripping	SAFARI
12	yes	maize	03/01/2020	15/05/2020	Mulching, minimum tillage, ripping	PAN-53