# Assessing Differences in Practiced Maize Crop Calendars using Hyper-temporal NDVI data in Rwanda

ALINE MUYIZERE
February, 2016

SUPERVISORS:
Drs. Eduard Westinga
Dr. Ir. C.A.J.M. (Kees) de Bie

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ALINE MUYIZERE
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SUPERVISORS:
Drs. Eduard Westinga (First supervisor)
Dr. Ir. C.A.J.M. (Kees) de Bie (Second supervisor)

THESIS ASSESSMENT BOARD:
Dr. Y.A. Hussin (Chair)
Dr. Ir. B.G.J.S. (Ben) Sonneveld (External Examiner, VU Amsterdam)
Drs. Eduard Westinga (First supervisor)
Dr. Ir. C.A.J.M. (Kees) de Bie (Second Supervisor)

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# ABSTRACT


Crop calendar is an important tool providing relevant information on crop cycles in a specific area. It allows effective planning of various agricultural activities leading to a better agriculture management. The crop calendars are different from an area to another given differences in natural systems and agro-ecosystems characteristics of the areas. However, this was not the case for Rwanda, a country with natural differences from East to West due, mainly, to altitude and rainfall patterns. Focusing on the maize crop, the country has known a single maize crop calendar for the entire country.

This research used hyper-temporal NDVI stratification to study whether there are differences in maize crop calendars in different areas of Rwanda, and also assess if the hyper-temporal NDVI stratification can differentiate the differences in the practiced maize crop calendars in the country. The research used hyper-temporal MODIS NDVI 250 m of 16 days composites data recorded for 10 years (from 2004 till 2014) for land stratification. The NDVI images were stacked together and imploded using unsupervised classification through ISODATA clustering algorithm in Erdas-Imagine software. Through separability analysis, 95 best separable NDVI classes were identified, from which four sample NDVI classes: 24, 54, 70 and 82 were selected given dominance of agriculture in the classes and notable different temporal behaviours between the classes from 2004 till 2014. 45 representative sample areas were selected to represent the four NDVI classes in field data collection.

From the field, maize planting and harvesting times were recorded through the interviews with farmers. 96 farmers were interviewed in NDVI class 24, 113 farmers in NDVI class 54, 105 farmers in NDVI class 70 and 119 farmers in NDVI class 82. Maize crop calendars for each NDVI class were generated from the interviews with farmers.

All the planting and harvestings time data from the field were also classified using K-means unsupervised clustering algorithm in order to produce the groupings of practiced maize crop calendars irrespective of the NDVI classes. 4 practiced maize crop calendars independent of NDVI classes were produced. To assess differences in maize crop calendars for Rwanda, analysis of variance (ANOVA) indicated that the maize crop calendars for NDVI classes were significantly different between the four sample NDVI classes, and also, the practiced maize crop calendars were significantly different between the four maize crop calendars groupings at $p=0.05$.

To analyse the relationship between maize growing seasons and NDVI classes, the chi-square test showed that the number of maize growing seasons was highly related to the clustering of NDVI profiles into NDVI classes at $p = 0.05$. Moreover, to assess spatial stratification of hyper-temporal NDVI data into NDVI classes can differentiate differences in practiced maize crop calendars for Rwanda, chi-square test showed that the practiced maize crop calendars were highly related to the maize crop calendars for NDVI class at $p = 0.05$. Conclusively, spatial stratification of hyper-temporal NDVI data can significantly differentiate differences in practiced maize crop calendars for Rwanda.



Keywords: Hyper-temporal, NDVI data stratification, Crop calendar, Crop growing season

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| | |
|---|---|
| AMIS: | Agricultural Market Information System |
| ESAANet: | East and South African Agribusiness Network |
| FAO: | Food and Agriculture Organization |
| GDP: | Gross Domestic Product |
| GIEWS: | Global Information and Early Warning System |
| GIS: | Geographical Information System |
| IPAQ: | International Physical Activity Questionnaire |
| ISODATA: | Iterative Self Organizing Data Analysis Technique |
| MINAGRI: | Ministry of Agriculture and Animal Resources |
| MINALOC: | Ministry of Local Government |
| MINITERE: | Ministry of Lands Environment, Forests, Water and Mines |
| MODIS: | Moderate Resolution Imaging Spectroradiometer |
| NAEB: | National Agricultural Export Development Board |
| NASA: | National Aeronautics and Space Administration |
| NDVI: | Normalized Difference Vegetation Index |
| NISR: | National Institute of Statistics of Rwanda |
| REMA: | Rwanda Environmental Management Authority |
| RIU: | Research Into Use |
| UN: | United Nations |
| USAID: | United States Agency for International Development |
| USGS: | United States Geological Survey |

# 1. INTRODUCTION

## 1.1. Background and motivation

Agriculture is the most important economic sector in the world. It offers the very basic need; food for the population and plays a key role in the economy of the countries (Christiaensen, Demery, & Kuhl, 2011). In Rwanda, agriculture is regarded as a keystone for the country's population, and a catalyst for economic development (NAEB, 2015). The sector employs about 87% of the working population, making around 46% of the country's GDP, and produces about 80% of the total export revenues (Kanyarukiga, 2004). Eventually, it is very important to know relevant information about agriculture like crops grown, their specific areas, their planting periods, their growing periods and their harvesting periods to ensure sustainable development of the sector and timely interventions in case of need. Most importantly, crop calendar is one of the crucial information needed and used by various stakeholders in this regard.

Crop calendar is a brief way of presenting crop cycle information (Patel & Oza, 2014). In order to promote local crops production for a specific zone, crop calendar provides relevant timely information about crops in that zones, which contribute to the food security (Guo, 2013). More specifically, crop calendar is regarded as "a sequential summary of the dates/periods of essential operations, including land preparation, planting and harvesting for a specific land use; it may apply to a specific plot, but is frequently generalized to characterize a specified area" ( de Bie, 2002).

The information contained in crop calendar is very beneficial to various categories of population, most importantly farmers and agriculture extensionists worldwide in taking a decision regarding agriculture (FAO, 2015). On one hand, the information helps the farmers to take decisions and effective measures for their agricultural products, including market price for their crops (Guo, 2013). On another hand, the information helps the investors to know about periods and cycles of specific crops in different areas, allowing them to plan for optimal time to invest in agriculture. Moreover, governments use the crop calendar information for various planning and decisions making regarding agricultural sector including, for instance, planning for the provision of inputs and seeds to the farmer in the right time (ESAANet, 2007). Regarding the contribution to the economy of a country, crop calendar helps in estimating supply, demand and prices of various agricultural products on global and regional markets (AMIS, 2012).

However, crop calendar is not common. It differs from an area to another and even within the same country. It differs based on differences in ecological conditions including soil types, climate conditions and many other natural factors which influence adaptation and growth of crops in an area (Bailey, 2004; FAO, 1996). In addition, FAO (1996) indicates that these differences make agro-ecological zone be a general unit for crop calendar, where the influencing natural factors are considered not so different. This indicates that effective method for crop calendar development should be able to detect these differences in different areas, especially in the same country.

Different methods have been in use in order to estimate, and thus be able to map different crop calendars for various crops in different parts of the world. Kotsuki and Tanaka (2015) indicate that there exist three different methods to estimate crop calendars: census-based, model-based and satellite (remote sensing) based methods. The methods have points of strength and downfalls. The census-based method collects crops data based on country's administrative units to develop a crop calendar. However this method is time, money and labour consuming, so, it is not applied frequently (UN, 2011). Model-based methods use meteorological data to simulate crops growth for the calendar's development (Vintrou et al., 2014). This method uses forced data and does not incorporate the farmer's decision, which constrains the accuracy of a produced crop calendar (Kotsuki & Tanaka, 2015; Oettli, Sultan, Baron, & Vrac, 2011). Lastly, satellite-based methods use remote sensing data. This method is regarded as powerful regarding the accuracy and possibility of frequent applications because it can observe a variety of areas depending not only on natural conditions but also on farmer's decisions over the area (Kotsuki & Tanaka, 2015). In addition, the method can be applied frequently with up-to-date data.

There exist a variety of remote sensing techniques among which Normalized Difference Vegetation Index (NDVI) data (Rouse, Haas, Schell, & Deering, 1974) has been applied by different scientists in finding differences in cropland. For instance, researchers including de Bie (2002); Upadhyay, Ray and Panigrahy (2008) used NDVI data to map different agricultural land uses. The technique has been optimistically perceived by many scientists for crops mapping, as it is able to differentiate areas with different crop types (Gamon et al., 1995; Ji-hua et al., 1999; Wardlow & Egbert, 2010), and thus be able to identify crops according to their calendars.

Hyper-temporal temporal NDVI data: NDVI data rich in temporal characteristic of an area according to vegetation dynamics through time (de Bie, 2014), have been potential and showed the ability in mapping land use changes, ecosystem's heterogeneity, crops performance, land management, and importantly in mapping different crops' crop calendars (Ali, de Bie, Skidmore, Scarrott, & Lymberakis, 2014; de Bie et al., 2008; de Bie, 2002).

This research applied MODIS hyper-temporal data for 10 years from 2004 to 2014, to detect the differences in practiced maize crop calendars in Rwanda. Maize, one of the important crops contributing a lot to livelihood and food security of the majority of Rwandan population, has been considered as having the same crop calendar in the country (FAO/GIEWS, 2015). However, by applying the NDVI data to find different areas in the country, the research found significantly different maize crop calendars in the different NDVI classes.

### 1.2. Research problem

The great importance of crop calendar requires that it should be accurate: conforming almost exactly to its area's ground reality (Miller, Lanier, & Brandt, 2001) for the ability to serve its contribution to ensure country's food security (AMIS, 2012). Inaccurate crop calendar may lead to food insecurity, due to lack of reliable information about important aspects such as crop cycles, and the right time for planting and harvesting.

In order to have good crop calendar's accuracy, Bailey (2004) and FAO (2015) indicate that the calendar should differ from one place to another depending of differences in natural factors influencing crops growth, including soil, topography, climate conditions, etc… These differences result in an area or a country with a diversity in agro-ecosystems characteristics, which would diversify also the crop calendars.

In regard to Rwanda, the country is made of a complex landscape different from West to East (Twagiramungu, 2006). The natural differences in Rwanda are mainly due to topography, rainfall, landform, soil types (Clay & Dejaegher, 1987). This led to the country to be composed of 12 different agro-ecological zones, which were delineated based on differences in topography, rainfall and soil types. This indicates that the country should have different crop calendars for different crops.

However, even though Rwanda presents major natural differences in different areas, currently, one crop calendar is attributed to the country for maize and sorghum crops (FAO/GIEWS, 2015), as presented in the following figure 1.

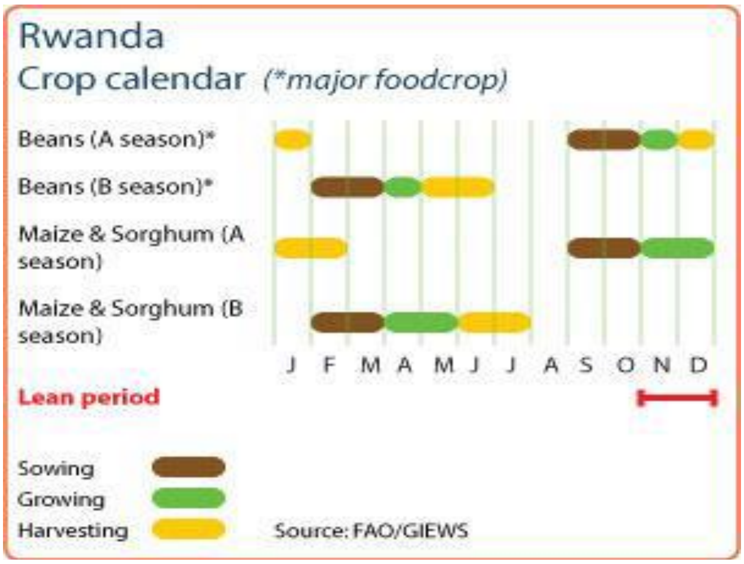


Figure 1: Major crops' calendar for Rwanda (FAO/GIEWS, 2015)

Regarding the differences in country's natural system, the above crop calendar is too generalized. It is not showing the variation exist in the country while the crops are grown in different ways and periods in order to adapt to specific area's local conditions (Westengen & Brysting, 2014). The differences are not only viewed as spatial but also temporal. The farmers' attitudes and decisions change over time in order to adapt to local climate conditions which vary or change in time (Foody & Boyd, 1999). This indicates that there is a need to apply a method which captures both the spatial and temporal differences of different areas, in order to be able to generate different crop calendars for different areas of the country.

Remote sensing methods for crop calendar development is the method with the ability to incorporate areas' both spatial and temporal changes, and actions taken from farmers' decisions including planting and harvesting time (Kotsuki & Tanaka, 2015). In addition, remote sensing methods have been found to be effective in agriculture monitoring (Ji-hua et al., 1999), and cost-effective for crops calendars estimation (Ozdogan, Yang, Allez, & Cervantes, 2010).

One of the remote sensing methods used to monitor crops and capture the spatio-temporal changes of an area based on vegetation cycles over the area, is hyper-temporal NDVI (de Bie et al., 2008). NDVI which is an index characterizing different areas according to the amount of vegetation and their health condition, considers photosynthetic activity over an area and quantifies it using satellites' red and near-infrared bands (Govaerts & Verhulst, 2010).

In order to consider both spatial and temporal changes in crops over different areas of the country, this research used hyper-temporal NDVI data from MODIS, with 250m spatial resolution and regularly available every 16 days as maximum value composite images. To incorporate temporal changes in the country, 10 years data from 2004 to 2014 have been used to classify areas of the country according to similarities in vegetation cover changes over time.

This research aimed at assessing whether the hyper-temporal NDVI stratification can significantly differentiate the differences in practiced crop calendars in Rwanda. The maize crop calendars were generated from interviews with farmers from sample NDVI classes and the calendars were different from one NDVI class to another. Also, practiced maize crop calendars were generated irrespective of NDVI classes and also were different from each other.

## 1.3. Research objectives, research questions and hypothesis

### 1.3.1. General objective

The general objective of this research was to assess if spatial stratification of hyper-temporal NDVI data into NDVI classes can differentiate differences in practiced maize crop calendars for Rwanda.

### 1.3.2. Specific objectives

1. To generate maize crop calendars for different NDVI classes through interviews with farmers
2. To assess the number of growing seasons per NDVI class
3. To generate maize crop calendar groupings and assess if they relate to the different NDVI classes

### 1.3.3. Research questions

1. Do the number of maize growing seasons per year differ from one NDVI class to another?
2. Does the grouping of maize crop calendars relate to maize crop calendars of NDVI classes?

### 1.3.4. Hypotheses

**Hypothesis 1:**

- $H_0$: The number of maize growing seasons is not significantly related to the clustering of NDVI profiles into NDVI classes (at p= 0.05 )
- $H_1$: The number of maize growing seasons is significantly related to the clustering of NDVI profiles into NDVI classes(at p=0.05)

**Hypothesis 2:**

- $H_0$: The grouping of maize crop calendars is not significantly related to the clustering of NDVI profiles into NDVI classes (at P=0.05)
- $H_1$: The grouping of maize crop calendars is significantly related to the clustering of NDVI profiles into NDVI classes(at P=0.05)

# 2. LITERATURE REVIEW

## 2.1. Agriculture in Rwanda

Agriculture in Rwanda is diverse and influenced by different factors. It is influenced by exogenous factors such as biophysical environment factors, government policies and economic conditions (Smit, McNabb, & Smithers, 1999). The authors also indicate that the agriculture is affected by endogenous factors like farmer's experience, perceptions, the location of the farms and financial capacity. The applicability of the combination of these factors characterises agriculture of the region (Iisd, 1997).

### 2.1.1. Exogenous factors influencing agriculture in Rwanda

Rwanda is characterised by a great variety in agriculture due to different exogenous factors (Clay & Dejaegher, 1987). One of the principal cause of diversity in the country is topography which divides Rwanda into three main altitude zones: high altitude in West, medium altitude in the Centre, and low altitude in East (Twagiramungu, 2006). In the Western part of the country, the highest altitude goes beyond 2000 meters, and ranges from 2000 m to 1500 m in Central part, and below 1500 m in Eastern part (Cole & Mcsweeney, 2011). Topography also influences other biophysical environmental factors including temperature, rainfall and soil quality (Chemonics International Inc, 2003).

The temperature, which also affects agriculture by influencing crop growth through photosynthetic activity (NC State University, 2010), varies according to the topography as well. The higher the altitude, the lower the temperature. In the North and Western part of the country, the temperature ranges between $15^0$C and $17^0$C and it can be lower than $0^0$C in some parts of the volcanic region (Rema, 2011). In central medium altitude, temperature varies between $19^0$C and $21^0$C. In lowland of East and South West is high temperature which can go above $30^0$ C. In North and West where the temperature is low, there are longer crops growing seasons compared to other parts of the country (REMA, 2009b).

Likewise, the rainfall which also affects crops by the providing of water, varies following the variation in altitude. The higher the altitude the more the rainfall (Barrow, 2013). The annual rainfall in the North and Western part of the country is 1500 mm, and 900 mm in the East and South East (REMA, 2009b). There is a bimodal pattern of rainfall which causes four seasons: short rain season which starts from September to November, short dry season from December to February of the following year, long rain season starting from March to May, and long dry season which starts from June to August (Brouwer, van Bodegom, Satijn, & Buit, 2015).

The high topography and abundant rain in the Western part of the country are the main factors of soil vulnerability to erosion which most of the times leads to landslide and affects soil fertility (USAID, 2008). The soil in Central plateaus also is prone to erosion, while in lowland soils in East and South Eastern regions like Bugesera are not prone to erosion as their topographical and geological structure allow rain water to infiltrate deeply (MINITERE, 2006).

The areas with similarities in altitude, rainfall and soil, have the similar potential for a particular land use. The areas with the similarities in Rwanda were divided into 12 agro-ecological zones (Clay & Dejaegher, 1987), as presented by the following figure 2.

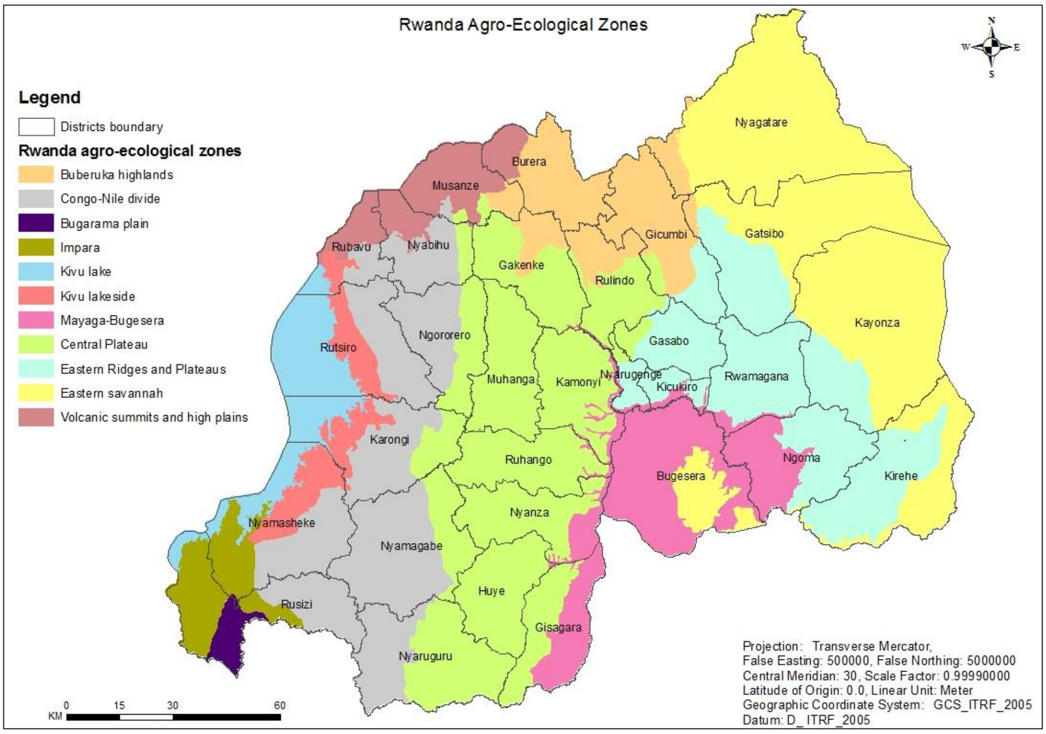



Figure 2: Agro-ecological zones of Rwanda

Figure 2 shows that from West to East of the country, also from South to North, the areas of Rwanda are characterized by different agro-ecological zones. The following table 1 summarizes differences between the 12 agro-ecological zones of Rwanda in terms of altitude, rainfall and soil type.

| No | Agro-ecological zone | Average altitude (m) | Average rainfall (mm) | Soil type |
|---|---|---|---|---|
| 1 | Buberuka highlands | 2000 | 1200 | Oxisols at high altitude |
| 2 | Congo-Nile divide | 2100 | 1600 | Humic acid soils |
| 3 | Bugarama plain | 1100 | 1200 | Alluvial soils |
| 4 | Impara | 1700 | 1400 | Heavy clayey soils derived from basalt |
| 5 | Kivu lake | 1600 | 1100 | Gravely sandy loam soils |
| 6 | Kivu lake side | 1600 | 1200 | Clay loam soil |
| 7 | Mayaga | 1450 | 1050 | Clayey soils derived from shale |
| 8 | Bugesera | 1400 | 900 | Oxisols |
| 9 | Central plateaus | 1700 | 1200 | Humic soils at medium altitude |
| 10 | Eastern ridges and plateaus | 1500 | 950 | Oxisols with high iron oxide |
| 11 | Eastern savannah | 1400 | 850 | Old infertile soils with texture variable |
| 12 | Volcanic summits and high plains | 2200 | 1500 | Ultisols derived from volcanic materials |

Table 1: Characteristics of 12 Rwanda agro-ecological zones (Clay & Dejaegher, 1987)

Farming system in the 12 agro-ecological zones is complex based on a diversity of crops and crops requirements. Each agro-ecological zone counts different crops due to different crops requirements, also, different crops cycles, and time of planting and harvesting are different from a zone to another.

Government policy is another exogenous factor influencing agriculture in the country. For instance, the government formulates and helps in implementation of various agricultural policies in order to address agricultural issues and improve agricultural production at different administrative levels. The policies generally affect positively agriculture but in some cases, the impact may also be negative in case of general policies which normally do not consider natural variability in different administrative units of the country (Tyrchniewicz & Wilson, 1994). An example is of crop intensification program (Cantore, 2011) which failed in some regions of the country at its beginning, because some crops could not adapt in their defined areas by the policy.

### 2.1.2. Endogenous factors influencing agriculture in Rwanda

Endogenous factors; those that farmers can control, also influence agriculture in different aspects. The farmers know historical information about their farms which eventually play a big role in making decisions about appropriate inputs, preferable crop seeds to grow, the right time for ploughing, planting, weeding and harvesting (Iisd, 1997).

In addition to the knowledge and experience of the farmer over his/her farm, there is a financial factor which also influences the farming. Famer's financial capacity gives the farmer option to decide about types and quality of crop seeds and other input to use. It also affects the time of application of the inputs, as farmer tends to buy and uses the inputs early or late, which affects also planting time, according to the financial capacity (ESAANet, 2007).

In a nutshell, the combination of both the exogenous and endogenous factors determines the structure of the country's agriculture and practiced crop calendar (Iisd, 1997)

### 2.1.3. Seasonal agriculture in Rwanda

Rwanda has three agricultural seasons per agricultural year. Season A starts in September of one calendar year and ends in February of the following calendar year. Season B starts in March and ends in July of the same calendar year. Season C starts in August and ends with September of the same calendar year (NISR, 2015a). These seasons are sometimes subject to climate uncertainties and then present differences from one region to another, and from one year to another. Season A and B are the main agricultural seasons for the country (Takeuchi, Shin'ichi, & Marara, 2006). For season C which is composed of months when the country is under a dry period of a year (from June till August), agriculture is practiced in marshlands using residual moisture from previous rainy seasons and through irrigation practices in some areas (FAO/GIEWS, 2015).

### 2.1.4. Maize crop in Rwanda

Maize crop is one of the major crops in Rwanda. It has been identified as a priority crop by the government in the recent program of crop intensification (RIU Rwanda, 2012). The crop has a big positive impact on the country's population in contribution to income generation, food security and poverty reduction in general. With the crop intensification programme, the maize crop increased by 300% in the area where cultivated, and the production increased by more than 400% by 2011 (MINAGRI, 2011).

The crop is cultivated countrywide and mainly intercropped with beans (N2Africa, 2014). It is influenced by various factors including abiotic factors such as climatic conditions resulting in varying rainfall regimes and temperature, soil conditions such as fertility, acidity and vulnerability to erosion (REMA, 2009a).

Maize crop requires the following ecological conditions to grow properly (Chand, 2015; Heisse, 2011; "Maize production," 2013):

- Well drained soils with a worthy resource of nutrients and humidity. In a small quantity of water, the crop cannot survive, instead, it easily fades if it stands in water for a day.
- The crop necessitates optimal rainfall of 200 mm while the first 5 weeks after planting, if not available, irrigation should be applied. It requires both cool and warm areas.
- Regarding the altitude; generally maize crop grows well at all attitudes. But, it is more suitable for the range between 0 and 2, 900 m altitudes above sea level, and $30^0$C is its optimum temperature for growth.

The above mentioned required ecological conditions, explains the reason why Nyagatare district; one of the areas for sample areas by this study in North East of the country, was chosen by institutions such as RIU, as a major maize producing region. This district meets almost all required ecological conditions based on its altitude, temperatures and rainfall (RIU Rwanda, 2012).

Regarding the differences in the above mentioned maize requirements countrywide, it clarifies that also the crop calendars should be different to the different areas of Rwanda.

## 2.2. Currently used methods to generate crop calendars

This section explains different methods used to generate different crop calendars, their strengths and their drawbacks. According to Kotsuki & Tanaka (2015), there are three methods to estimate crop calendar: census based, model based and satellite (remote sensing) based methods. From the three methods, the focus has been remote sensing methods which was applied by this research.

### 2.2.1. The census based method

The census based method estimates crop calendar based on collected agricultural census data from administrative levels such as district, provincial or country level. Crop calendar from this method is highly reliable for the regions where there is sufficient census data but poorly reliable for regions where there is insufficient census data or no census data at all (Kotsuki & Tanaka, 2015). Although the census data are collected on an administrative level, the administrative boundaries are not based on climate conditions which are relevant in determining crop calendars (Manakov & Mikhaylova, 2015). Additionally, the authors argue that administrative boundaries are not stable and their instability is based on political decisions instead of natural behaviour. Also, the census method is criticised for being time consuming, labour-intensive, and it is difficult to replicate the process (HarvestChoice, 2013). Yet, the method has a good ability in separating the mixture of sample crops.

### 2.2.2. Model-based Method

The model-based method determines crop calendars using crop growth models through simulations by the use of meteorological data including weather, temperature, solar radiation, and soil data (Rafi & Ahmad, 2005). One of acknowledged strength of the method, is that it can identify different crop calendars in the same administrative unit, and it can be applicable to future simulation (Kotsuki & Tanaka, 2015). Though, the method requires special skills in modelling, mainly regarding crops and water modelling. This method is applied by various renowned institutions for agricultural development and food security including the Food and Agricultural Organization of the United Nations (Raes, Steduto, Hsiao, & Fereres, 2009).

#### 2.2.3. Satellite based Method

Satellite data-based method has been used in mapping and identifying field crops at country or local level (Bailey & Boryan, 2010). One of the most used remote sensing techniques is NDVI time series data, by which it is possible to monitor crop health conditions; where high NDVI value is related to good crop conditions, and low NDVI indicating bad crop health (Ji-hua et al., 1999). From a variety of NDVI products offered by number of satellites, Wardlow, Egbert and Kastens (2007) showed that spatial-temporal information from MODIS NDVI 250m 16 days composites is suitable to identify crop types and their calendars. NDVI profiles allow crop monitoring from the start of growing period to the end of the growing period (Wardlow & Egbert, 2008).

The NDVI is given by a ratio of satellite red band and satellite near-infrared band as presented by the formulae below:

$$NDVI = \frac{NIR - R}{NIR + R}$$

Where: NIR is Near Infra-Red band
R is Red Band

**Formulae 1: Calculation of NDVI**

# 3. MATERIALS AND METHODS

## 3.1. Study area description

Rwanda is located in central Africa between 1°04’ and 2°51’ latitude South, and 28°45’ and 31°15’ longitude East. The total area of the country is 26,338 km², in which 67.7% is occupied by agriculture. The country is made of different administrative units: 4 provinces and Kigali city, 30 districts, 416 sectors, then cells and villages which are the smallest levels of administration (MINALOC, 2011).

Delineation of the study area in the country by this research, was based on differentiation of areas according to NDVI data from 2004-2014, as detailed the next sections. The following figure 3 presents the location of four surveyed sample NDVI classes making the study area for the research.

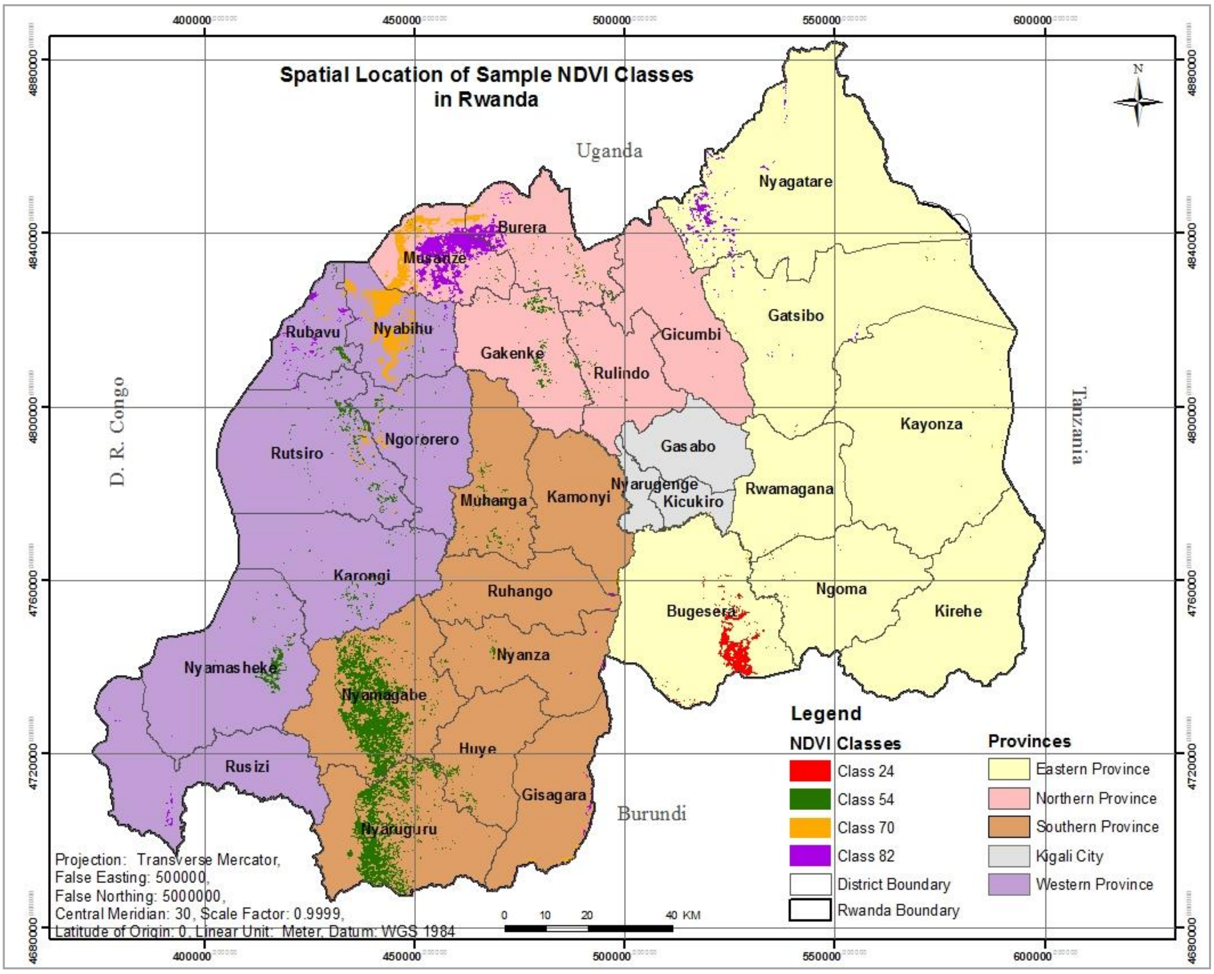



Figure 3: Study area map

## 3.2. Data acquisition and pre-processing

This section presents the data and data processes performed for land stratification, sampling, and collection of the field data in order to respond to research questions and hypotheses. The stratification of land was done through the use of MODIS NDVI images from 2004 till 2014, which were acquired from

USGS/NASA. The stratification of MODIS NDVI data was overlaid with land use data of Rwanda, from which sample NDVI classes were selected and surveyed. The information collected were about maize planting and maize harvesting dates for the agricultural year 2014-2015.

### 3.2.1. MODIS images data collection

MODIS NDVI data were chosen by this research over NDVI products from other different satellites sensors such as SPOT VGT, AVHRR GIMMS and MERIS which are also used for vegetation monitoring (Fensholt, Sandholt, & Stisen, 2006; Tucker, Pinzon, & Brown, 2004; VITO, 2015), because of a better spatial resolution compared to the others, and most importantly the ability in providing useful information on radiometric and biophysical characteristics of surface features (Yin, Udelhoven, Fensholt, Pflugmacher, & Hostert, 2012).

MODIS NDVI data were acquired using MODIS reprojection tool web interface. The tool allowed mosaicking process, as the study area was covered by two different tiles. With the tool, it was possible to specify and limit the download to the geographic area of interest. The product name for the downloaded data is MOD13Q1; referring to MODIS NDVI data with 250 m spatial resolution, with 16 days composites.

### 3.2.2. MODIS images data pre-processing

In order to make the data ready for use, the following pre-processing steps were performed using different software including ENVI 5.2, ERDAS Imagine and Arcgis 10.2

**Step 1: Importing and rescaling:** Downloaded NDVI images were imported into ERDAS imagine, and saved as .img files, and have been rescaled in order to range from 0 to 255 as a normal image digital number. The data were originally ranging from -3,000 to 10,000

**Step 2: Stacking and filtering:** this was done to enable further analysis, by cleaning possible outliers in the data. Using ERDAS IMAGINE 2014, the layer stack was produced containing all downloaded NDVI data from 2004 to 2014, and likewise for the data from 2014 to 2015. The latter images were used to observe the temporal behaviour of NDVI profiles for study area during the agricultural year of focus (2014-2015). By the use of timesat functionality in ENVI software, smoothing and filtering of the data was performed and provided the smoothed NDVI data which were used for the further land classification process.

**Step 3: Classification:** Using ERDAS IMAGINE 2014 software, the unsupervised classification was run for the smoothed layer stack by applying ISODATA clustering algorithm. The algorithm classified the NDVI data based on differences in NDVI values; which correspond to the vegetation cover over different areas of the country from 2004 to 2014. The output signature was used to generate a legend for NDVI profiles of different produced NDVI classes, from which the differences in classes' temporal behaviour was observed.

**Step 4: Converting classified image into polygon:** The process was done using arcmap software, by the help of its toolbox. The conversion into shapefiles allowed subsequent processes that involved combination of the NDVI classes with existing Rwanda land use data shapefiles, in order to determined amount of every land use present in every NDVI class, and then focus on those dominated by agriculture.

**Step 5: Re-projection:** All previous processes were done with original projection system of NDVI data (sinusoidal) in order to ensure the minimal risks of pixels shifts. At final pre-processing step, the data were re-projected into new projection system (transverse Mercator), which was the projection system used by other polygon data used afterwards. It was done in Erdas software; which is more effective for dealing with the sinusoidal projection system.

## 3.3. Data processing

After data pre-processing, sample areas selection was the next step, in order to prepare the field data collection. Unsupervised classification using ISODATA was applied on the data layer stack, and classification was run from 10 to 100 classes as minimum to maximum number of classes. The maximum number of iterations was set to 50 and the convergence threshold was set to 1. After obtaining the results for all NDVI classes from 10 to 100, the separability analysis was performed to decided optimal number of NDVI classes to use for sampling and other processes. Through the separability analysis, 95 NDVI classes were found to be the best separable NDVI classes from 2004-2014 in Rwanda

As the focus of this research was on agricultural areas, existing land use data in Rwanda were overlaid with the 95 NDVI classes to obtain NDVI classes dominated by agriculture. The process resulted in 24 NDVI classes with more than 50% of agriculture.

In order to assess the way the 24 agricultural NDVI classes have been behaving from 2004 till 2014, for the impression of their differences to be observed, the medians of their NDVI values were plotted in excel software.

It was observed that the 24 agricultural NDVI classes have been behaving differently over 10 years. For the purpose of field data collection, four sample NDVI classes have been selected based on notable differences in their median NDVI profiles, so that maximum of the variation existing in the study area in terms of crops cover can be represented. In addition, within each sample NDVI class, 12 sample areas were selected, making final representative sample size to be 48 sample areas for the entire study area. The number of sample areas was due to the possibility to be covered during the field work, because of limited research time. Sample areas were selected randomly, but with restrictions to avoid areas at the edge NDVI class which may influenced by other external classes. Also, sample areas had to be close to the road in order to ease the access while field work. The sample areas were distributed per clusters, to facilitate transport and quick field work process. Three clusters per NDVI class were designed, and a cluster contained four sample areas.

Though, after field work, only 45 sample areas remained useful for the study. Among the three not used sample areas include an area where was no more vegetation due to new industrial construction in the district. In another sample area was an issue of buffaloes escaping from the close national park and eat the planted maize, so farmers gradually do not grow maize time after time. But, in this area was very small patches of maize, but no farmer was found to be interviewed. For the final sample area, there was no presence of maize in the fields. So, the research only used the collected data from the rest 45 sample areas for the analysis.

#### 3.3.1. Field data collection

The field work was conducted in the four sample NDVI classes, within the 45 sample areas, and the focus was on maize crop. The main data collected were dates of planting and harvesting of the maize crop. The data were collected through interview with farmers randomly found inside a sample area, given that they grow maize within the same area.

**Interviewed farmers and sampling technique**

In Rwanda, the average agricultural land is 0.35 ha per person (Premier Consulting Group, 2009). Sample area was of the size of the MODIS NDVI data, which was equal to 231.92 * 230.37 m (5.34 ha), which by average is occupied by 16 farmers. In order to capture much of the variations, interviewed farmers ranged between 50% and 81% of the average farmers per sample area. In total, 433 farmers were interviewed in all 4 sample NDVI classes.

The farmers for interview were randomly selected based on the following conditions: they were found within the sample areas while the field work, and they grew maize in the same sample area for the agricultural year 2014-2015.

The following table 2 presents number of farmers interviewed per each sample area per NDVI class.

| NDVI class | Cluster | Sample area ID* | No. farmers |
|---|---|---|---|
| **24** | 1 | 2411 | 10 |
| | | 2412 | 9 |
| | | 2414 | 11 |
| **Total** | | | **30** |
| | 2 | 2421 | 9 |
| | | 2422 | 10 |
| | | 2423 | 10 |
| **Total** | | | **29** |
| | 3 | 2431 | 11 |
| | | 2432 | 9 |
| | | 2433 | 8 |
| | | 2434 | 9 |
| **Total** | | | **37** |
| **54** | 1 | 5411 | 12 |
| | | 5412 | 10 |
| | | 5413 | 9 |
| | | 5414 | 11 |
| **Total** | | | **42** |
| | 2 | 5421 | 9 |
| | | 5422 | 10 |
| | | 5423 | 8 |
| | | 5424 | 9 |
| **Total** | | | **36** |
| | 3 | 5431 | 9 |
| | | 5432 | 8 |
| | | 5433 | 10 |
| | | 5434 | 8 |
| **Total** | | | **35** |
| **70** | 1 | 7011 | 8 |
| | | 7012 | 9 |
| | | 7013 | 10 |
| | | 7014 | 11 |
| **Total** | | | **38** |
| | 2 | 7021 | 9 |
| | | 7022 | 9 |
| | | 7023 | 9 |
| | | 7024 | 9 |
| **Total** | | | **36** |
| | 3 | 7031 | 10 |
| | | 7033 | 10 |
| | | 7034 | 11 |
| **Total** | | | **31** |
| **82** | 1 | 8211 | 11 |
| | | 8212 | 10 |
| | | 8213 | 9 |
| | | 8214 | 13 |
| **Total** | | | **43** |
| | 2 | 8221 | 10 |
| | | 8222 | 10 |
| | | 8223 | 10 |
| | | 8224 | 9 |
| **Total** | | | **39** |
| | 3 | 8231 | 9 |
| | | 8232 | 9 |
| | | 8233 | 11 |
| | | 8234 | 8 |
| | | | **37** |
| **Overall total** | | | **433** |

Table 2: Number of interviewed farmers per sample area per cluster per NDVI class

* Sample area ID is made by four digits: first two digits are for NDVI class, the third digit is for cluster number within the class, and the fourth digit is for the sample area number within the cluster.

## 3.4. Data analysis and interpretation

To analyse the collected data, first, maize crop calendars for the plots were generated and generalized per sample area, and then to NDVI classes.

Second, the practiced crop calendars as collected from the interviews with farmers were entered into SPSS regardless of which NDVI class they were collected from. Using K-means classification method, the practiced maize crop calendars were grouped into four groupings.

Third, using chi-square test, it was assessed whether the number of maize growing seasons is significantly related to the NDVI classes, and also, it was assessed if the groupings of practiced maize crop calendars as grouped using K-means are significantly related to the maize crop calendars for NDVI classes.

### 3.4.1. Maize calendars for different NDVI classes

Based on interviews with farmers, four maize crop calendars were generated according to the four different NDVI classes. First, single crop calendar was generated per plot, then generalize the calendar on sample areas, and then, the maize crop calendars were generalized per NDVI class.

The following are steps taken to generate the maize crop calendars per NDVI class:

**1$^{st}$ step: Translating date given by farmer into Julian day**

The farmers provided maize planting and harvesting dates in a normal calendar year from January to December. In order to allow crop calendar generation and further statistical analysis, the normal calendar days were transformed into Julian calendar from 1 to 365 days of a year.

**2$^{nd}$ step: Dividing into weeks**

This study generated a weekly interval crop calendars. To do so, the dates from 1 to 365 were transformed into 52 weeks of a year, and then every day of a year was assigned to its corresponding week.

### 3.4.2. Grouping of maize crop calendars

To group practiced maize crop calendars according to their differences irrespective of NDVI classes, the following steps were taken:

**1$^{st}$ step: Determining the number of practiced maize crop calendars groupings**: In order to determine the number of practiced maize crop calendars groupings (K), the agglomerative hierarchical clustering algorithm was applied to the data, to have hierarchy structure of the data (Blei, 2008). This was a prior step to allow application of k-means clustering method, which was applied for the determination of conclusive maize crop calendar groupings.

The method applies different consecutive steps, from grouping nearby points into one group, then groups closest groups into a new bigger group based on the short distance between small groups, and finally builds hierarchical tree called dendrogram; from which all the formed groups from initial stage can be observed (Zhu, 2010). In case of this research, input data were the data as collected from interviews with farmers (planting and harvesting days in Julian days) for all the farmers regardless of their NDVI classes, so that the algorithm groups the similar groups and distinguishes the different ones according to their differences. To identify manageable different groups from the data, a threshold is arbitrarily set at a certain distance in the dendrogram, allowing to identify non-overlapping groupings (Ryan, 2013). From the dendrogram, this study found 4 separable and non-overlapping groupings from the collected data, which were manageable for the study.

**2nd step: Clustering the practiced maize crop calendars into four groupings.** K-means clustering method, an unsupervised classification algorithm which divides n observations into K groups by assigning an observation to a nearest mean (Pham, Dimov, & Nguyen, 2005), was performed over all the collected maize crop calendars data, so that they are grouped into the 4 groupings according to similar (nearest) means.

#### 3.4.3. Analysis of variance, t-test and chi-square test

By this stage, the four practiced maize crop calendars groupings independent of the NDVI classes had been obtained, and there was still observed a relationship between the 4 practiced maize crop calendars groupings and the maize crop calendars per NDVI classes: some maize crop calendars from the same NDVI class were also grouped into the same practiced crop calendar grouping. This led to the next analysis; first, using ANOVA (Miller & Haden, 2006) to assess whether the maize crop calendars for NDVI classes were significantly different, and also assess whether the practiced maize crop calendars groupings were significantly different. Then, Fisher's least significant differences was applied to evaluate specific pairs' differences for NDVI classes and practiced maize crop calendar groupings. For assessing differences in planting and harvesting for season B, t-test instead of ANOVA, was carried out given only two groups for comparison: NDVI class 24 and 82.

Second, Chi-square (Griffiths, Miller, & Suzuki, 2000) test was performed to evaluate whether the number of maize growing seasons are significantly related to the maize crop calendars according to NDVI classes, and also examine whether the practiced maize crop calendar groupings are significantly related to the different maize crop calendars according to NDVI classes. The analysis directed to the conclusion about the ability of NDVI data to differentiate differences in the practiced crop calendars.

For chi-square test, both to assess the relationship between the number of maize gowning seasons and NDVI classes, and between practiced maize crop calendars and NDVI classes, first contingency table was constructed containing frequency number of farmers from different NDVI classes with the same number of maize growing seasons. The second contingency table was constructed containing frequency numbers of farmers from the same practiced maize crop calendar grouping and found in the same maize crop calendars per NDVI class. Then, according to the total number of observations (interviews with farmers), expected values were computed for every cell in the contingency tables by applying the following formulas (Diener-West, 2008):

$$Expected_{ij} = \frac{Row\ Total_i \times Col\ Total_j}{Grand\ Total}$$

**Formula 2: Calculation of expected values in contingency tables**

After getting the expected values, the following formulae was applied to calculate the chi-square value:

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

Where: $\mathbf{X^2}$ is chi-square calculated
**O** is observed value (observed frequency of the same calendar)
**E** is expected value (expected frequency the same calendar)

**Formula 3: Calculation of Chi-square ($X^2$)**

After getting the chi-square value calculated, it was compared with the chi-square critical from the chi-square distribution table. The latter was obtained by taking the degrees of freedom (calculated according to the following formulae 4), at a significance level of 0.05 in order to find whether the relationship was significant (if chi-square calculated was greater than chi-square critical).

$$DF = (r-1)(c-1)$$

Where: ***DF*** is degree of freedom
***r*** is the number of the contingency table's rows
***c*** is the number of the contingency table's columns

**Formula 4: Calculation of degrees of freedom for chi-square test**

### 3.5. Methodology flow chart

The following figure 4 contains a flowchart presenting a sequence of activities carried out in order to reach the objectives and test hypotheses of this research.

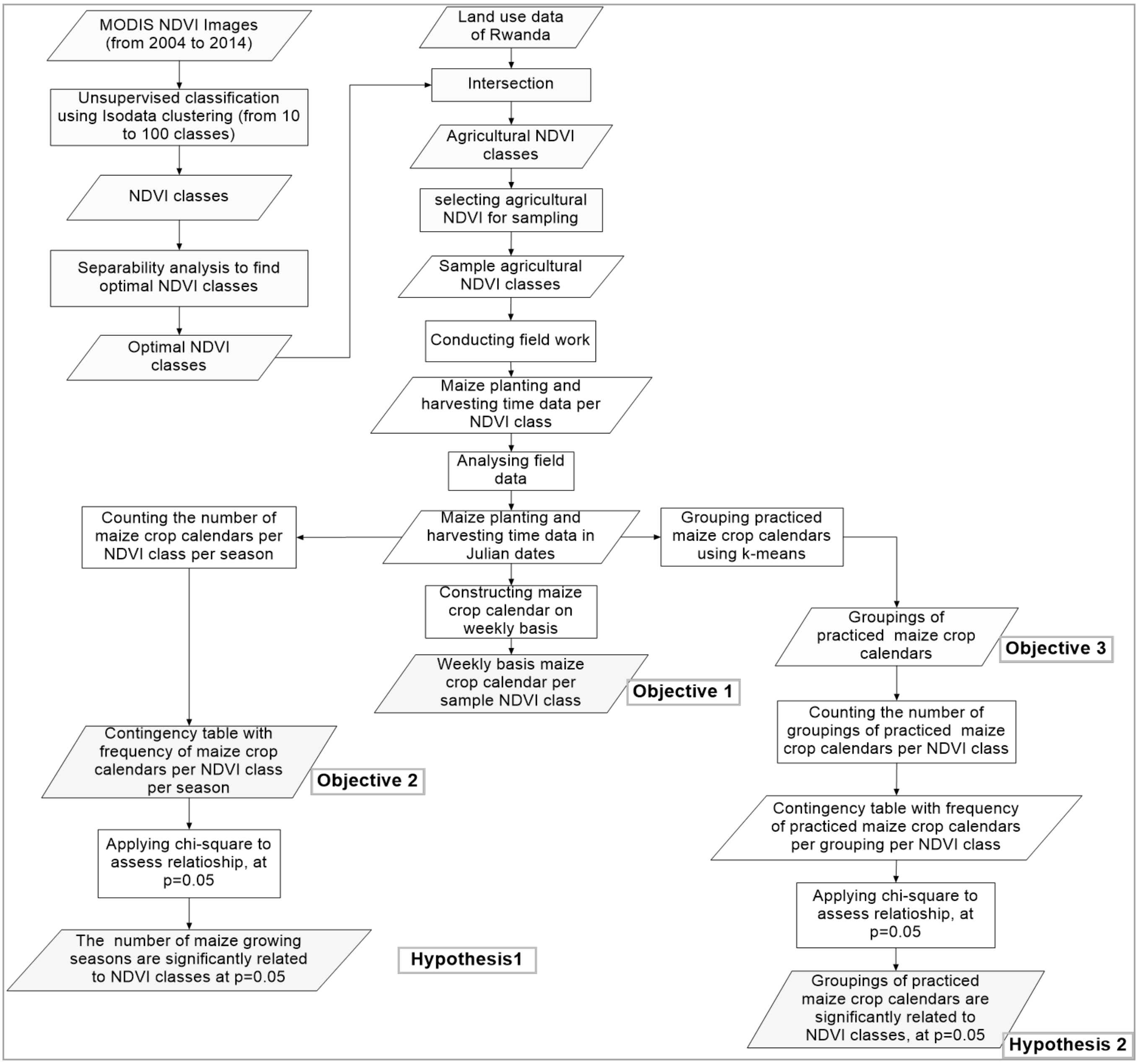



Figure 4: Flow chart of the applied research methodology

# 4. RESULTS

This section presents the results from hyper-temporal MODIS NDVI data stratification process, and the results from the field data analysis to respond to the research's objectives, answer the research questions and test hypotheses.

## 4.1. Hyper-temporal MODIS NDVI data stratification

The hyper-temporal MODIS NDVI data of 10 years from (2004-2014), was stratified using ISODATA unsupervised classification technique. Through the separability analysis, 95 NDVI classes were found to be the best separable NDVI classes from 2004-2014 for Rwanda, as shown by the following figure 5.

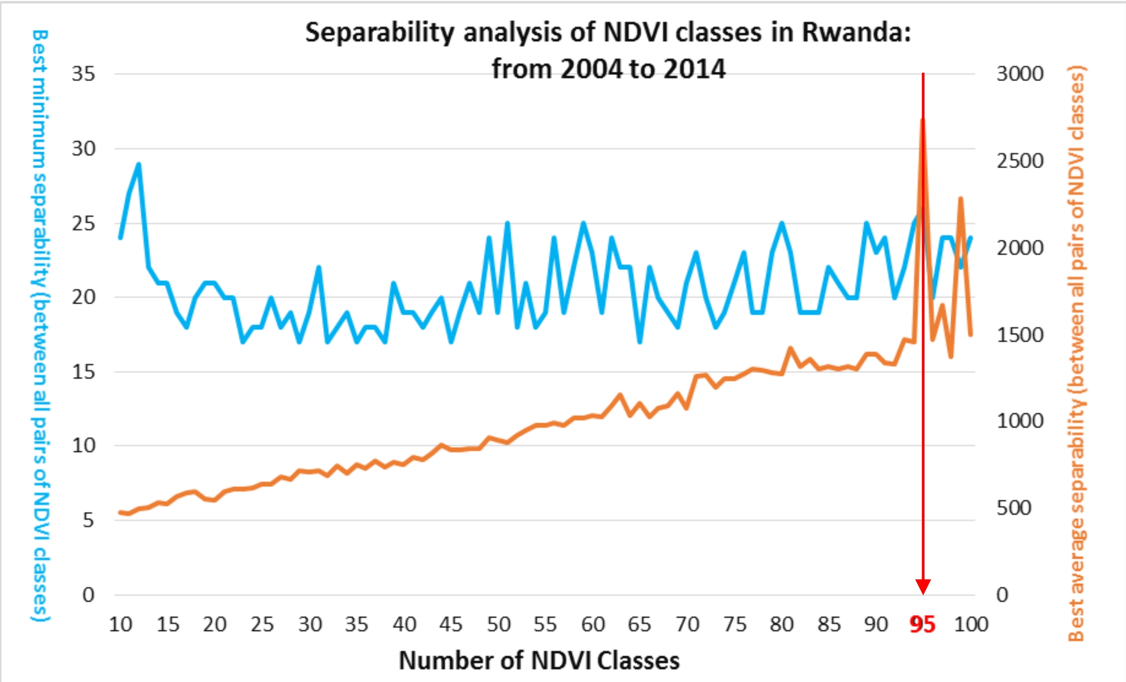



Figure 5: The best separable NDVI classes for MODIS data from 2004 to 2014

The red arrow in figure 5 shows the peaks for both best minimum and best average separability values pointing out 95 to be the best separable NDVI classes for Rwanda

The spatial distribution of the 95 classes in Rwanda is presented by the map in the following figure 6

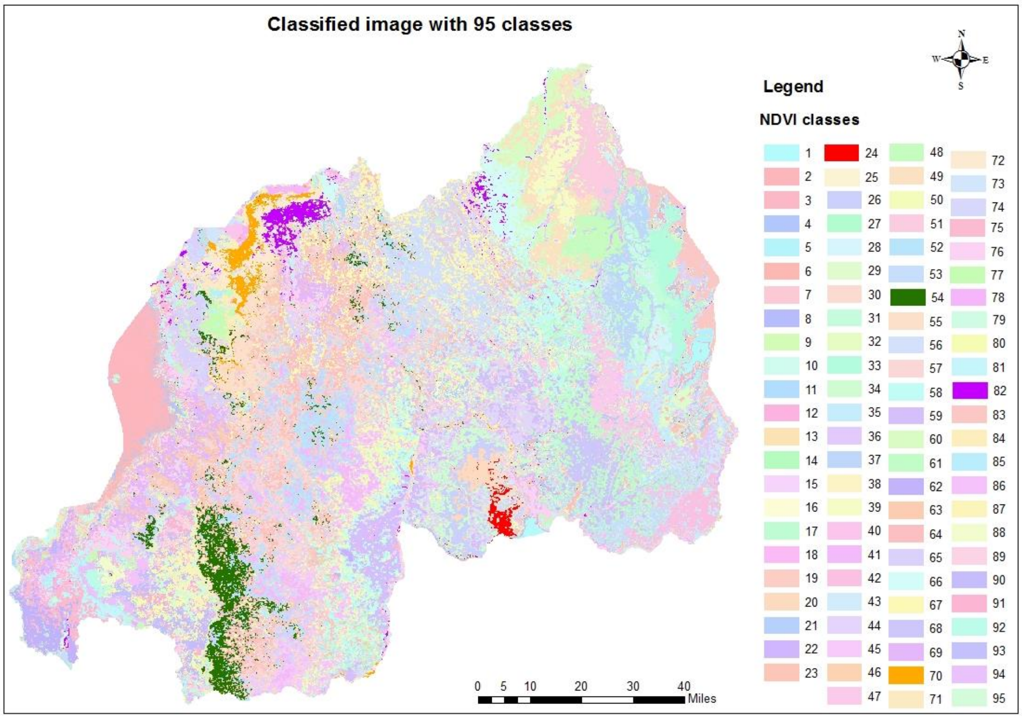



Figure 6: 95 NDVI classes of hyper-temporal MODIS images from 2004 to 2014

As the focus of this research was on agricultural areas, to distinguish NDVI classes with the dominance of agriculture, existing land use data in Rwanda were overlaid with the 95 NDVI. The process resulted in 24 NDVI classes with more than 50% of agriculture. Figure 7 below shows the spatial location of the 24 NDVI classes dominated by agriculture in Rwanda.

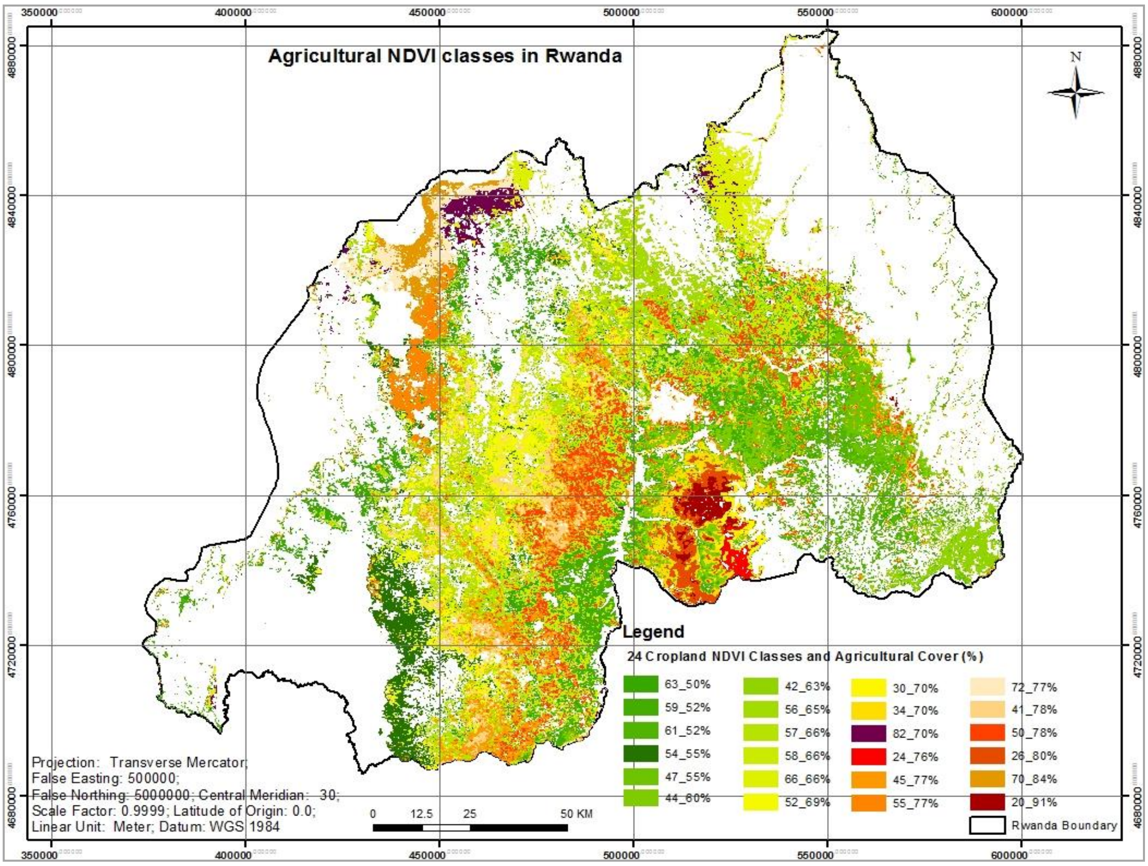



Figure 7: The location of 24 NDVI classes with more than 50% of agriculture

The map in figure 7 showed that agriculture is generally dominant in central part of Rwanda than any other part of the country.

To visualize temporal behaviour of the agricultural NDVI classes, the annual NDVI profiles medians were generated, as presented in the following figure 8

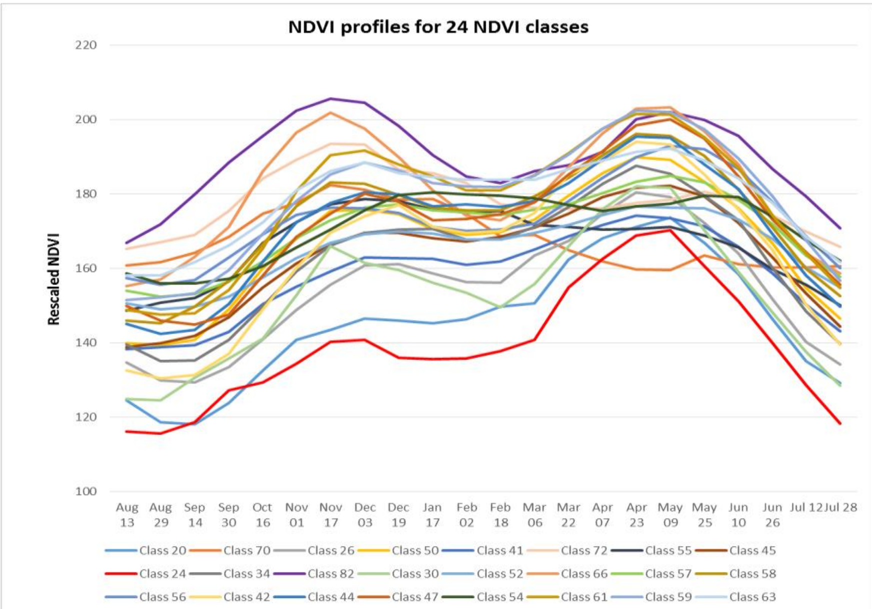



Figure 8: NDVI profiles for 24 NDVI classes with above 50% agriculture

Figure 8 shows differences in temporal behaviour of the agricultural NDVI classes, and also indicates the seasonality (by NDVI peaks) in the classes. From the above figure 8, 4 sample NDVI profiles of 4 NDVI classes were selected based on eminent differences in behaviour in order to represent the rest while field data collection. The profiles of the four selected sample NDVI classes are presented in figure 9 below:

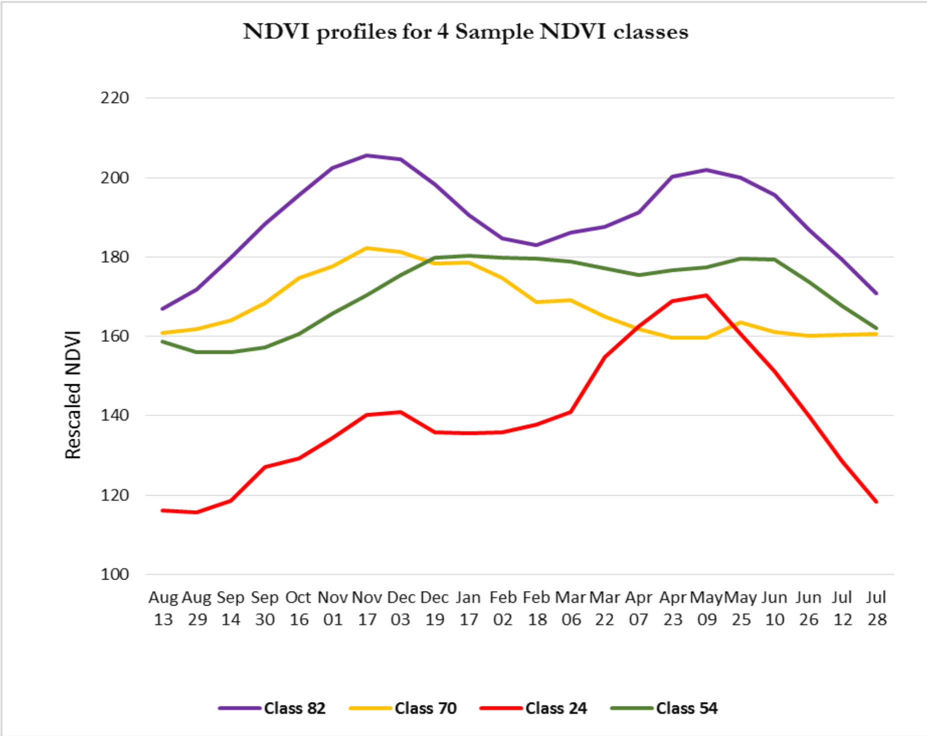



Figure 9: Temporal behaviour of 4 sample NDVI classes

The selected sample NDVI classes in figure 9, had differences that were chosen in order to represent other NDVI classes given different characteristics including: two distinguished agricultural seasons (NDVI class 82), remarkable season A than B (NDVI class 70), remarkable season B than A (NDVI class 24), and no distinguishable seasonality (NDVI class 54). Regarding the spatial location of the four sample NDVI classes, the following figure 10 shows their spatial distribution in the country.

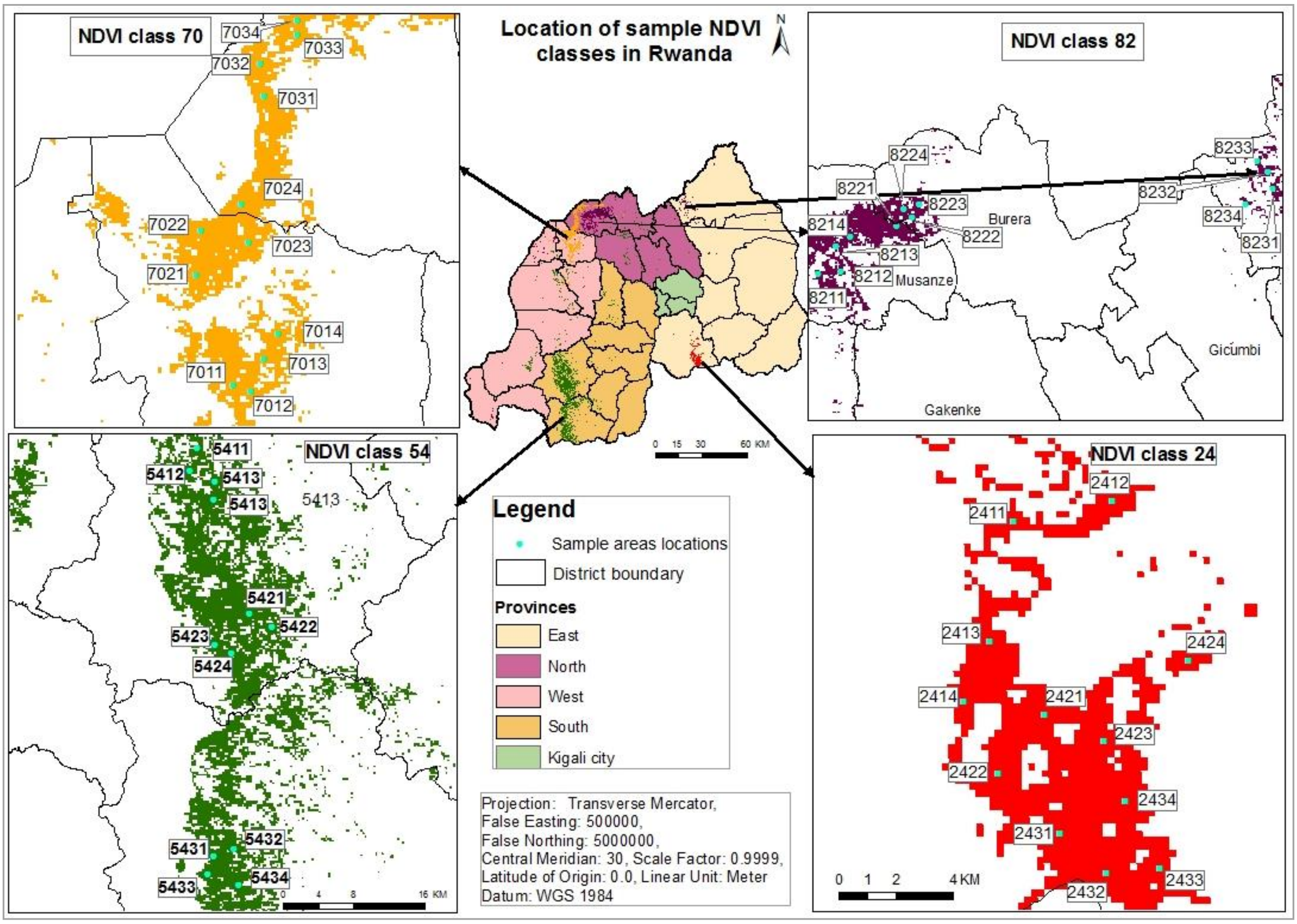



Figure 10: Location of 4 sample NDVI classes and the sample areas in Rwanda

As shown in the above figure 10, the sample areas within NDVI class were distributed according to cluster, as each cluster was containing 4 sample areas represent the cluster and 12 sample areas represent the whole NDVI class.

### 4.2. Maize crop calendars per sample area for different NDVI classes

The Generated maize crop calendars were for one agricultural year of 2014 – 2015, through the interviews with farmers on planting and harvesting time in the four sample NDVI classes (24, 54, 70 and 82). NDVI profiles for sample NDVI classes also were presented to compare their spatial and temporal behaviours and produced maize crop calendars.

#### 4.2.1. Maize crop calendar and NDVI profiles for NDVI class 24

In NDVI class 24, the interviewed farmers were 96. There were 2 maize growing seasons (season A and B) and were no much differences in planting and harvesting time for different sample areas of this class (Appendix 5). For season A, planting started with September 2014 and ended with the first week of October 2014. Harvesting started with the last week of December 2014 and ended with the first week of February 2015. For season B, plating started in the second week of February and finished in the first week of March 2015. Harvesting period started in the last two weeks of May till the third week of June. Figure 11 below presents the maize crop calendar for NDVI class 24, per sample area per cluster.

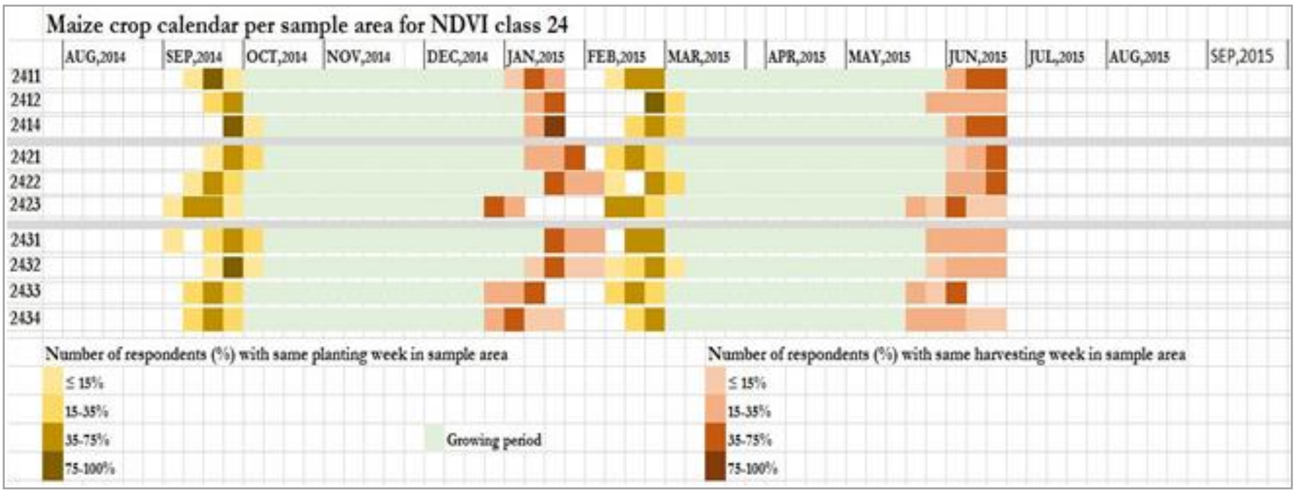



Figure 11: Maize crop calendars per sample area per cluster for NDVI class 24

To compare the above maize crop calendar (figure11) with the sample areas' phenology temporal behaviour, MODIS NDVI data for the agricultural year 2014-2015 (from August 2014 till September 2015) were used and NDVI profile per sample area per cluster were visualized. The profiles visualization is presented in figure 12 below, with highlights in red for sample areas in cluster 1, green for sample areas in cluster 2, and blue for sample areas in cluster 3. For thorough information, the profiles per sample area are presented in appendix 9.

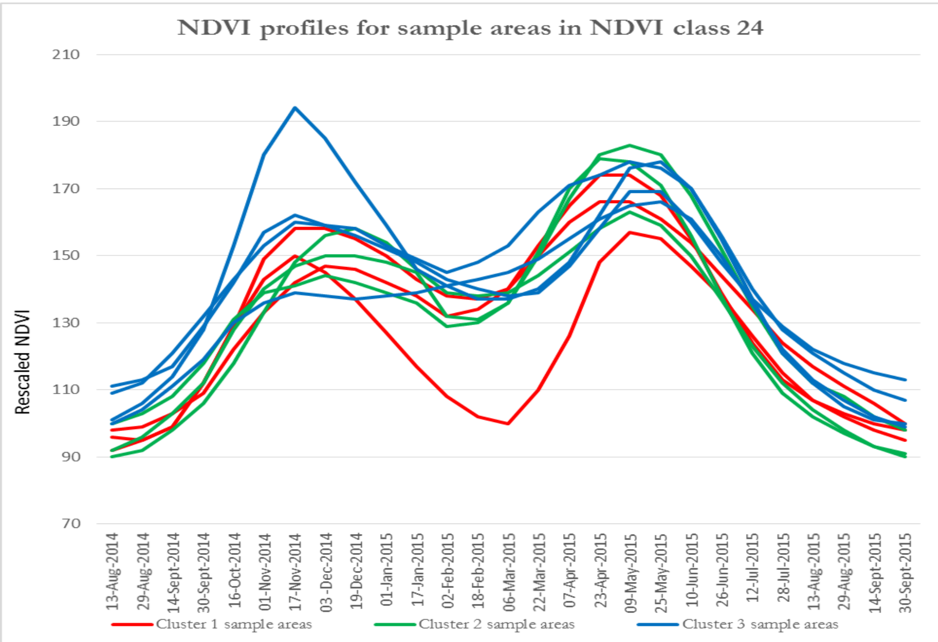



Figure 12: NDVI profiles per cluster for NDVI class 24

As shown in figure 12, the NDVI profiles show two agricultural seasons for the agricultural year 2014-2015 corresponding to the two growing seasons of maize crop calendar for NDVI class 24. However, focusing on the vegetation cover, within the one sample area was many various vegetation covers and the maize crop was not dominant (table 3, 4 and 5). So, the temporal behaviour of NDVI profiles reflected behaviour of a mixture of the vegetation covers, and the maize had a small contribution. The following table 3, 4 and 5 present area in percentage of different land covers sample area per cluster in NDVI class 24, as they were found from the field. The detailed NDVI profiles per sample areas are presented in appendix 9.

| Sample area | **Maize** | Banana | Forest | Bare soil | Sorghum | Sisal | Grass | Cassava | Beans | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| 2411 | **10.91** | 5.82 | 1.50 | 6.42 | 2.87 | 0 | 12.15 | 50.60 | 5.73 | 96.01 |
| 2412 | **5.39** | 10.44 | 9.25 | 2.27 | 5.46 | 0 | 10.36 | 43.91 | 5.07 | 92.15 |
| 2414 | **3.01** | 2.83 | 6.78 | 1.46 | 6.00 | 39.83 | 11.12 | 25.82 | 1.10 | 97.96 |

Table 3: Dominant land covers and their area (%) in cluster 1 of NDVI class 24

Table 3 above shows that cluster 1 of NDVI class 24 was mainly dominated by cassava crop and grass, then maize. The following table 4 shows the percentage of dominant land covers per sample area in cluster 2 of NDVI class 24

| Sample area | **Maize** | Banana | Forest | Ploughed | Sorghum | Grass | Cassava | Total |
|---|---|---|---|---|---|---|---|---|
| 2421 | **8.22** | 0 | 11.03 | 9.81 | 8.73 | 31.01 | 31.20 | 100 |
| 2422 | **8.55** | 0 | 0 | 20.17 | 0 | 68.19 | 3.10 | 100 |
| 2423 | **5.13** | 2.86 | 9.95 | 0 | 10.20 | 21.08 | 50.24 | 99.45 |

Table 4: Dominant land covers and their area (%) in cluster 2 for NDVI class 24

Table 4 shows that grass and cassava were dominant in cluster 2 of NDVI class 24. The following table 5 presents the percentage cover of dominant land covers per sample areas in cluster 3 of class 24.

| Sample area | **Maize** | Banana | Forest | Bare soil | Sorghum | Grass | Cassava | Total |
|---|---|---|---|---|---|---|---|---|
| 2431 | **9.60** | 22.03 | 0 | 2.17 | 9.41 | 0 | 54.44 | 97.66 |
| 2432 | **1.82** | 1.13 | 66.09 | 3.38 | 2.30 | 13.38 | 11.40 | 100 |
| 2433 | **37.05** | 0 | 0 | 3.63 | 11.29 | 4.07 | 34.72 | 96.54 |
| 2434 | **6.48** | 0.38 | 18.69 | 5.19 | 23.03 | 11.69 | 34.41 | 100 |

Table 5: Dominant land covers and their area (%) in cluster 3 for NDVI class 24

Table 5 indicates that cassava was the most dominant crop in cluster 3 of class 24, followed by maize and sorghum.

In brief, they were different land covers in different sample areas per cluster in NDVI class 24 that contributed to the temporal behaviours in figure 12 and appendix 9, and the maize crop had a small contribution. Only maize crop contributed much in one sample area (2433). This indicates that different other crops might have had the same calendar as maize in the year 2014-2015 in NDVI class 24.

#### 4.2.2. Maize crop calendars and NDVI profiles for NDVI class 54

In NDVI class 54, the interviewed farmers were 113, and there was one maize growing season (season A). In the NDVI class 54, planting started with June 2014 and ended in the third week of September the same year. Harvesting started in the last week of December 2014 and ended in the second week of March 2015. The following figure 13 summarises the maize crop calendar per sample area per cluster, with the percentage of respondents with the same calendar per sample area. The crop calendar is presented on a weekly basis for planting and harvesting times.

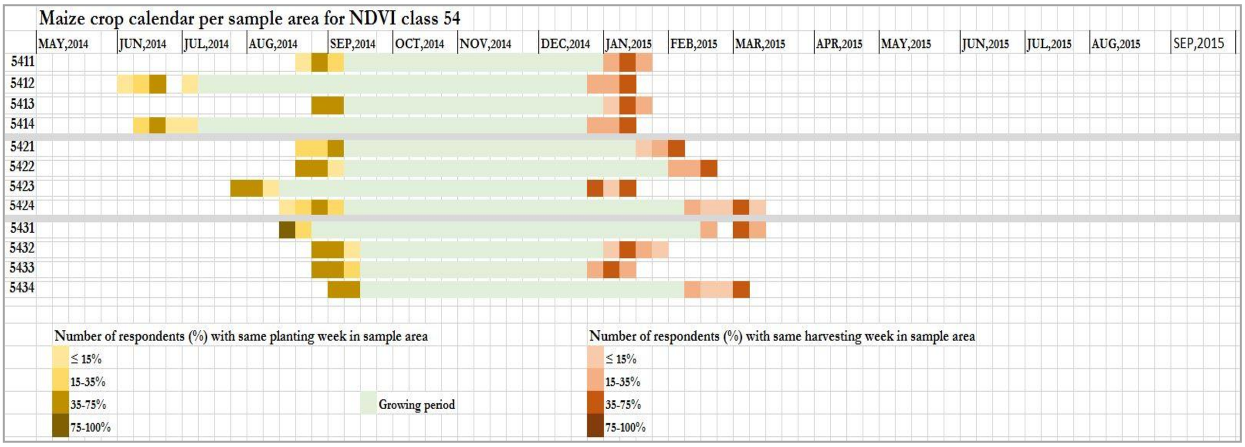



Figure 13: Maize crop calendars per sample area per cluster for NDVI class 54

The farmers from two sample areas (5412 and 5414) in cluster 1 planted maize earlier than others, in the first week of June till the first week of July. The farmers from sample area 5423 were the next, where they started to plant maize in the fourth week of July 2014 till the second week of August 2014. Farmers from the rest of the sample areas did not have much variation. The rest planted from the third week of August 2014 till the third week of September 2014. The harvesting started in the fourth week of September 2014 till the second week of March 2015.

To be compared to the generated maize crop calendars and sample areas' NDVI profiles, MODIS NDVI data from May 2014 till September 2015 were used and the profiles per sample area per cluster were visualized (cluster 1 in red, cluster 2 in green and cluster 3 in blue) as shown in the following figure 14.

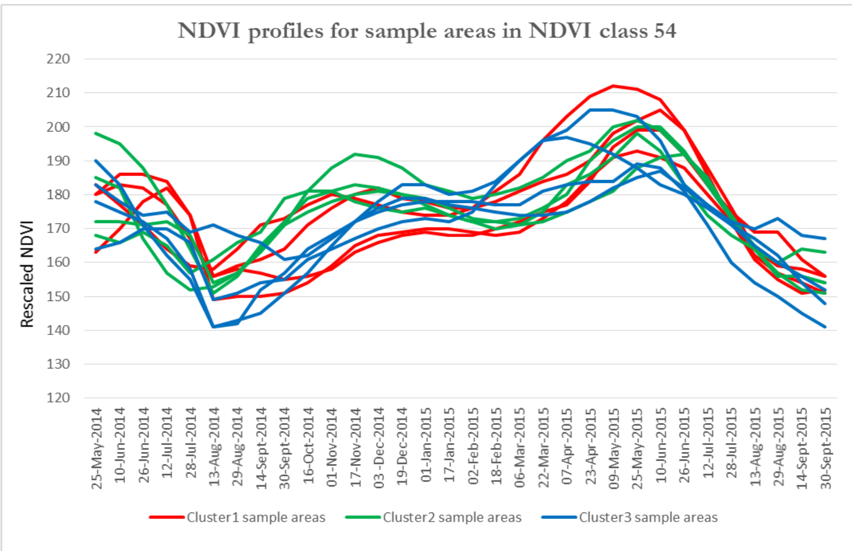



Figure 14: NDVI profiles per cluster for NDVI class 54

As presented by the figure 14, there had been two agricultural seasons in NDVI class 54, though the first season did not show high NDVI peak as the second one. Based on maize crop calendars of this class (figure 13), maize was grown only in season A, a season characterized by low pick in figure 14.

To know about the contribution of the maize crop to the NDVI profiles, the following tables 6, 7 and 8 present dominant land covers and their areas in percentage per sample area per cluster, as observed from the field. The detailed NDVI profiles per sample areas are presented in appendix 10.

| Sample area | **Maize** | Banana | Forest | Eggplant | Sweet potatoes | Peas | Irish potatoes | Grass | Cassava | Beans | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5411 | **8.12** | 11.49 | 5.94 | 5.07 | 13.32 | 3.54 | 3.69 | 19.35 | 11.01 | 14.47 | 96.01 |
| 5412 | **6.28** | 6.55 | 11.48 | 5.63 | 8.17 | 1.97 | 4.35 | 23.35 | 6.87 | 9.74 | 84.40 |
| 5413 | **5.28** | 11.09 | 13.01 | 5.75 | 10.61 | 2.46 | 4.85 | 20.57 | 5.97 | 10.83 | 90.42 |
| 5414 | **1.10** | 5.94 | 14.07 | 0.52 | 11.96 | 1.68 | 1.43 | 26.40 | 4.93 | 21.21 | 89.24 |

Table 6: Dominant land covers and their area (%) in cluster 1 for NDVI class 54

As shown in table 6, cluster 1 of NDVI class 54 was dominated by grass, beans, sweet potatoes and forest. The contribution of maize was small in the cluster. The following table 7 shows the percentage of dominant land covers per sample area in cluster 2 of NDVI class 54

| Sample area | **Maize** | Banana | Forest | Tea | Sweet potatoes | Peas | Irish potatoes | Grass | Beans | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| 5421 | **5.79** | 22.60 | 6.19 | 0 | 13.39 | 2.06 | 0.56 | 18.00 | 19.77 | 88.35 |
| 5422 | **6.83** | 8.39 | 14.93 | 0 | 19.40 | 1.69 | 7.22 | 18.95 | 12.43 | 89.84 |
| 5423 | **7.69** | 5.44 | 6.84 | 13.84 | 9.28 | 3.81 | 9.32 | 18.69 | 14.09 | 89.00 |
| 5424 | **4.01** | 6.79 | 29.61 | 13.70 | 4.28 | 3.59 | 6.37 | 14.31 | 10.74 | 93.39 |

Table 7: Dominant land covers and their area (%) in cluster 2 of NDVI class 54

From table 7, it was realized that, though maize had some contribution to the NDVI profiles in cluster 2 of NDVI class 54, the cluster was dominated by beans, grass and sweet potatoes. The following table 8 presents the percentage of dominant land covers per sample area in cluster 3 of NDVI class 54.

| Sample area | **Maize** | Banana | Forest | Wheat | Sweet potatoes | Peas | Irish potatoes | Grass | Beans | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| 5431 | **6.57** | 5.64 | 4.73 | 3.25 | 15.27 | 4.62 | 7.10 | 21.44 | 12.64 | 81.24 |
| 5432 | **6.26** | 1.98 | 35.98 | 2.00 | 9.21 | 2.20 | 3.22 | 16.47 | 15.09 | 92.42 |
| 5433 | **24.53** | 0.50 | 20.73 | 3.16 | 10.14 | 3.52 | 12.11 | 13.74 | 4.05 | 92.48 |
| 5434 | **9.10** | 2.73 | 22.39 | 0 | 7.65 | 3.30 | 5.75 | 13.26 | 14.12 | 78.30 |

Table 8: Dominant land covers and their area (%) in cluster 3 of NDVI class 54

Also, cluster 3 was dominated by beans, grass and sweet potatoes as indicated by table 8. Maize still contributed less to the NDVI profiles. This indicated that the two seasonality profiles in figure 14 might have been determined mainly by many other land covers, with a small contribution of maize.

#### 4.2.3. Maize crop calendars and NDVI profiles for NDVI class 70

In NDVI class 70, 105 farmers were interviewed. Maize crop was grown also for one agricultural season (season A). There were many variations in planting time (Appendix 7). Planting started in the last week of April 2014 and end in the first week of August 2014. Growing period started in the third week of May 2014 and ended in the first week of January 2015. Harvesting started in the second week of December

2014 and ended with January 2015. The following figure 15 summarizes maize crop calendars per sample area per cluster in NDVI class 70, according to the interviews with farmers in this NDVI class.

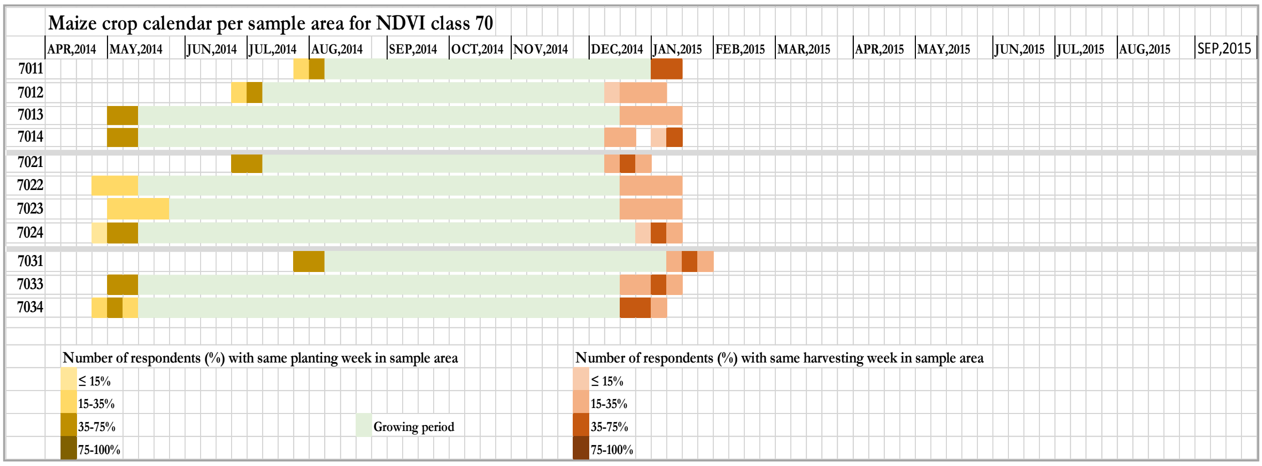



Figure 15: Maize crop calendars per sample area per cluster for NDVI class70

Considering the NDVI profiles temporal behaviours in NDVI class 70, they behaved differently from other 3 sample NDVI classes. Also, as shown by maize crop calendar in figure 15, sample areas crop calendars were also different from other NDVI classes' maize crop calendars. The following figure 16 presents the NDVI profiles per sample areas with highlights of cluster 1 sample areas in red, cluster 2 sample areas in green, and cluster 3 sample areas in blue.

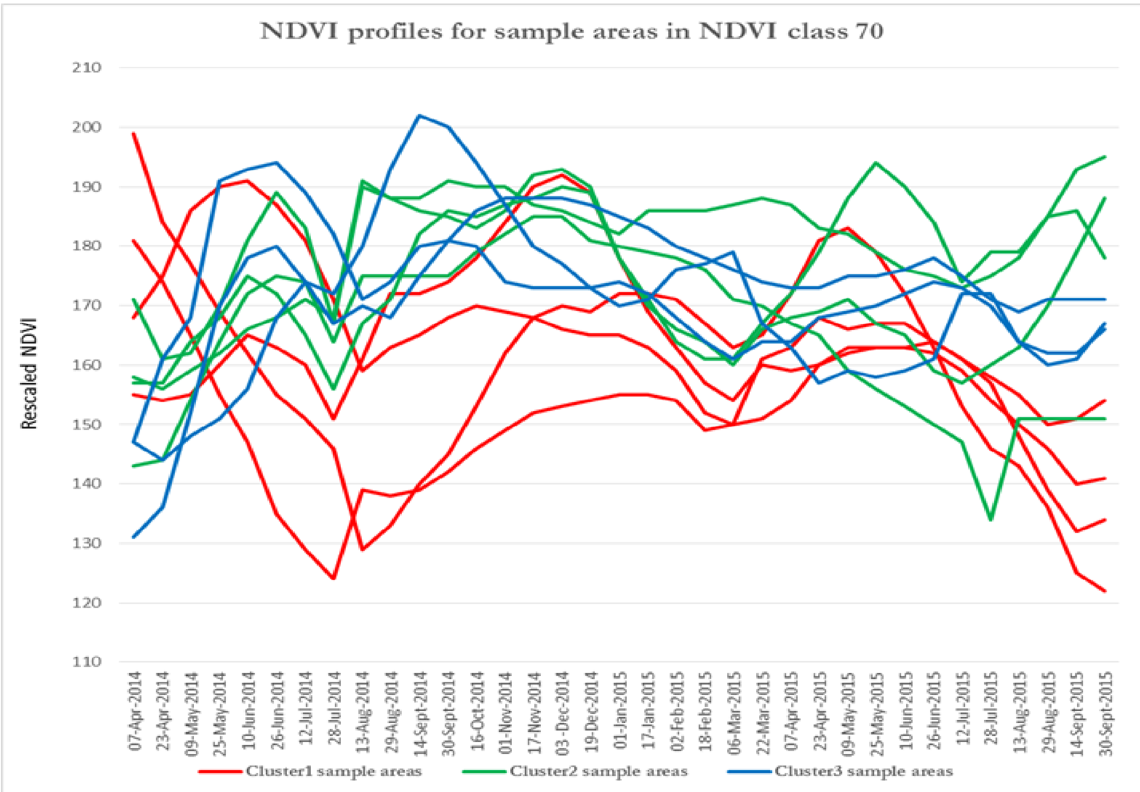



Figure 16: NDVI profiles per cluster for NDVI class 70

As shown in figure 16, most of the sample areas had two phenological growing seasons, though maize was grown for only one growing season (figure 15). Maize might not have had a great influence on the profiles given its small area coverage in the sample areas, as presented by the following tables 9, 10 and 11. The detailed NDVI profiles per sample areas in NDVI class 70 are presented in appendix 11.

| Sample area | **Maize** | Forest | Tea | Peas | Irish potatoes | Grass | Beans | Total |
|---|---|---|---|---|---|---|---|---|
| 7011 | **4.81** | 8.58 | 0 | 7.03 | 53.79 | 13.68 | 5.20 | 93.10 |
| 7012 | **12.94** | 2.46 | 0 | 8.71 | 15.99 | 10.91 | 48.75 | 99.76 |
| 7013 | **3.44** | 6.98 | 22.77 | 0.51 | 9.35 | 6.69 | 43.53 | 93.28 |
| 7014 | **8.79** | 9.82 | 0 | 2.88 | 11.06 | 9.66 | 44.16 | 86.36 |

Table 9: Dominant land covers and their area (%) in cluster 1 of NDVI class 70

As shown by table 9, cluster 1 of NDVI class 70 was dominated by beans, irish potatoes and grass. The following table 10 shows the percentage of dominant land covers per sample area in cluster 2 for NDVI class 70.

| Sample area | **Maize** | Forest | Pyrethrum | Peas | Irish potatoes | Grass | Beans | Total |
|---|---|---|---|---|---|---|---|---|
| 7021 | **2.40** | 6.99 | 26.76 | 1.73 | 37.13 | 8.02 | 12.22 | 95.25 |
| 7022 | **3.01** | 5.19 | 8.48 | 2.37 | 57.53 | 9.85 | 5.09 | 91.51 |
| 7023 | **23.88** | 0.61 | 1.47 | 1.62 | 31.05 | 9.00 | 30.03 | 97.68 |
| 7024 | **4.25** | 13.63 | 27.00 | 3.16 | 29.35 | 11.87 | 9.39 | 98.64 |

Table 10: Dominant land covers and their area (%) in cluster 2 of NDVI class 70

Table 10 shows that cluster 2 of NDVI class 70 was dominated by irish potatoes, beans and pyrethrum though maize was dominant only in sample area 7023. The following table 11 shows the percentage of dominant land covers per sample area in cluster 3 of NDVI class 70

| Sampled area | **Maize** | Forest | Pyrethrum | Irish potatoes | Grass | Beans | Total |
|---|---|---|---|---|---|---|---|
| 7031 | **14.87** | 5.68 | 24.98 | 24.72 | 10.86 | 6.11 | 87.23 |
| 7033 | **3.95** | 3.69 | 61.34 | 19.55 | 6.75 | 4.72 | 100 |
| 7034 | **5.01** | 3.16 | 39.34 | 32.99 | 8.35 | 9.21 | 98.07 |

Table 11: Dominant land covers and their area (%) in cluster 3 of NDVI class 70

Table 11 shows that cluster 3 was dominated by pyrethrum, irish potatoes and maize. The contribution of maize also is not dominant like in the other clusters of the class. So, NDVI profiles in figure 16 had a great influence from other crops than maize.

#### 4.2.1. Maize crop calendars and NDVI profiles for NDVI class 82

In NDVI class 82, the interviewed farmers were 119 among whom 82 farmers planted maize in one agricultural season (season A) and were from two first clusters (1 & 2), and other 37 farmers planted maize in two agricultural seasons (season A and B) and were from cluster 3, as detailed per single plot crop calendars in class 82 in Appendix8. Generally, for season A, planting started with August and ended with the third week of September 2014. Harvesting started in the last week of December 2014 and finished with February 2015.

For season B in cluster 3 of class 82, planting started in mid-February and ended with the second week of March 2015. Growing period started with March and ended in the third week of June 2015, and harvesting started with the second week of June 2015 till mi-July of the same year. The following figure 17 summarizes information about maize planting and harvesting time per sample area in class 82 as from interviews with farmers.

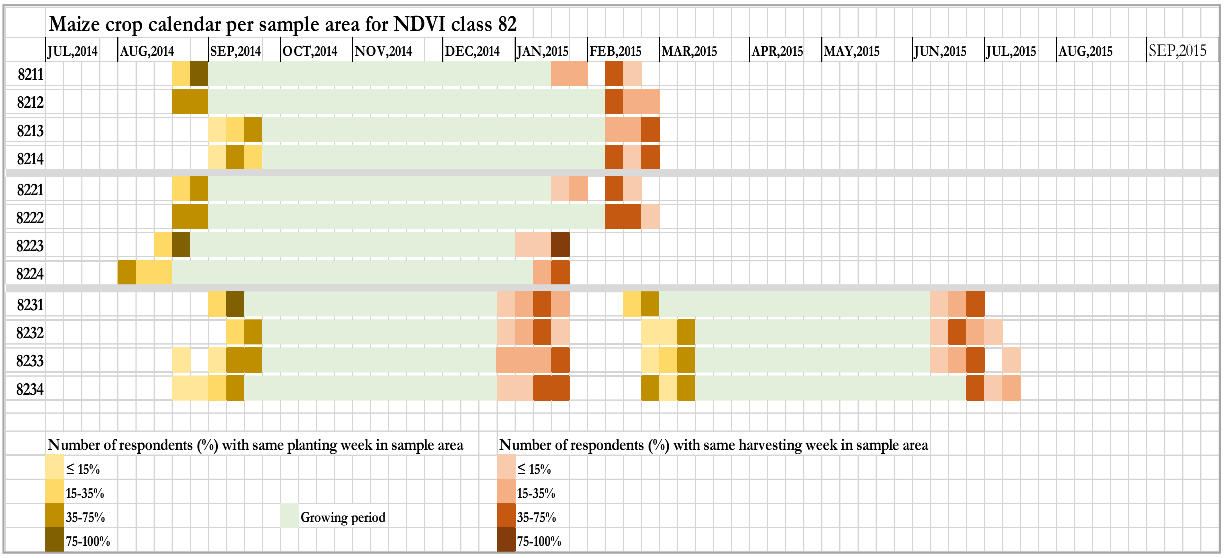



Figure 17: Maize crop calendars per sample area per cluster for NDVI class 82

In this NDVI class 82 also, in regard to sample areas temporal behaviours, the behaviours were observed through their NDVI profiles from MODIS NDVI data from last week of July 2014 till the end of the agricultural year 2015. In this NDVI class, NDVI profiles were behaving almost similar and showed two agricultural seasons for the agricultural year 2014-2015, as shown in the following figure 18 with highlights of cluster 1 sample areas in red, cluster 2 sample areas in green, and sample areas of cluster 3 in blue.

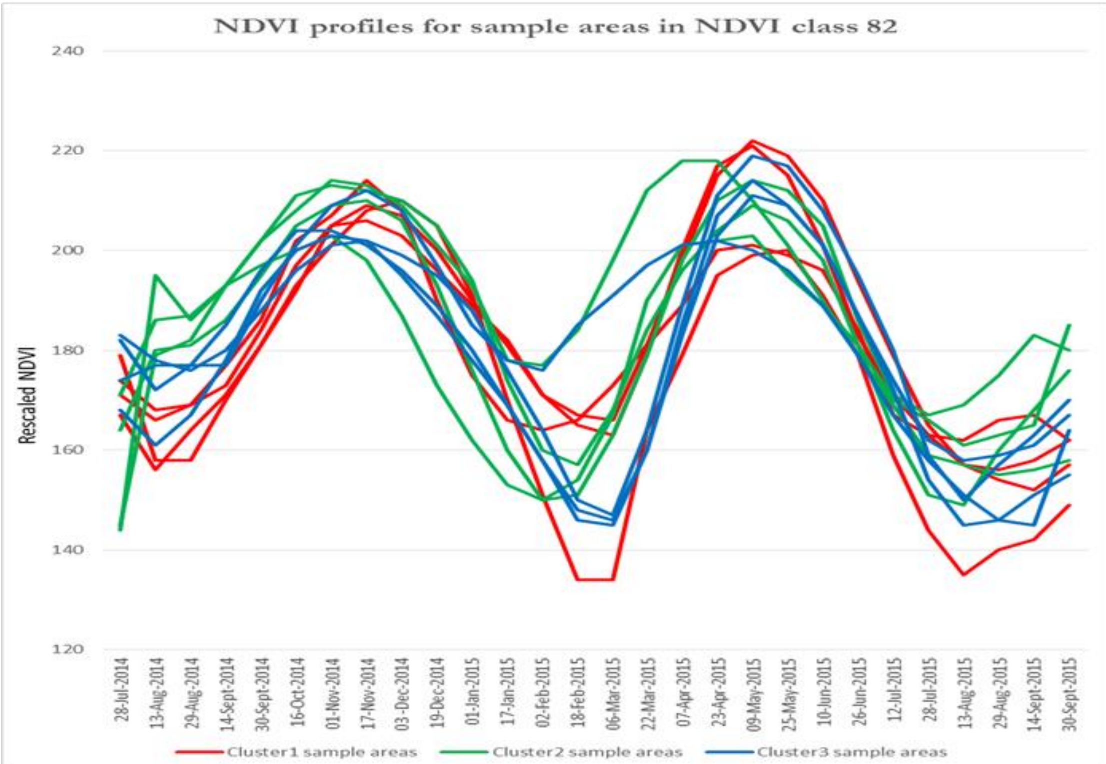



Figure 18: NDVI profiles for NDVI class 82 (From August 2014 to August 2015)

Though the figure 18 presents two phenological growing seasons for NDVI class 82, referring to its maize crop calendars in figure 17; in 8 sample areas farmers responded that maize crop was cultivated only for one agricultural season (season A) in the year 2014 – 2015, while in the rest four sample areas maize was cultivated for two seasons (both in season A and B). Regarding the contribution of maize to the NDVI profiles, the following table 12, 13 and 14 present dominant land covers and their area in percentage per sample area per cluster, as observed from the field. The detailed NDVI profiles per sample areas in NDVI class 82 are presented in appendix 12.

| Sample areas | **Maize** | Banana | Forest | Sorghum | Irish potatoes | Grass | Beans | Total |
|---|---|---|---|---|---|---|---|---|
| 8211 | **47.64** | 6.87 | 6.83 | 0 | 1.30 | 6.34 | 26.88 | 95.86 |
| 8212 | **20.84** | 3.05 | 23.53 | 0 | 3.01 | 4.31 | 37.13 | 91.86 |
| 8213 | **16.93** | 0 | 3.06 | 0 | 2.08 | 1.48 | 74.46 | 98.02 |
| 8214 | **13.73** | 5.56 | 0.93 | 59.73 | 7.89 | 0 | 10.65 | 98.49 |

Table 12: Dominant land covers and their area (%) in cluster 1of NDVI class 82

As shown by table 12, cluster 1 of NDVI class 82 was dominated by beans and maize. The table 13 below presents dominant land covers and their percentage in cluster 2.

| Sample areas | **Maize** | Banana | Forest | Baresoil | Sorghum | Irish potatoes | Grass | Beans | Total |
|---|---|---|---|---|---|---|---|---|---|
| 8221 | **1.91** | 4.11 | 8.90 | 0.30 | 32.19 | 2.59 | 4.04 | 44.93 | 98.97 |
| 8222 | **6.23** | 4.12 | 5.38 | 1.48 | 45.83 | 3.10 | 5.16 | 27.81 | 99.11 |
| 8223 | **21.90** | 0 | 11.32 | 0 | 7.24 | 8.44 | 4.51 | 46.61 | 100 |
| 8224 | **6.59** | 3.57 | 2.58 | 0.55 | 65.52 | 2.68 | 3.15 | 14.73 | 99.38 |

Table 13: Dominant land covers and their area (%) in cluster 2 for NDVI class 82

Table 13 shows that beans and sorghum were the dominant land covers in cluster 2 of NDVI class 82. The following table 14 shows the percentage of dominant land covers and their area in percentage per sample are in cluster 2 for NDVI class 82.

| Sample areas | **Maize** | Banana | Forest | Sorghum | Irish potatoes | Grass | Cassava | Beans | Total |
|---|---|---|---|---|---|---|---|---|---|
| 8231 | **24.67** | 3.43 | 3.42 | 18.47 | 2.18 | 5.65 | 2.16 | 32.19 | 92.16 |
| 8232 | **21.76** | 25.67 | 0 | 13.02 | 5.26 | 3.74 | 0.71 | 28.35 | 98.51 |
| 8233 | **8.76** | 33.67 | 4.08 | 9.23 | 2.98 | 2.00 | 0 | 28.34 | 89.05 |
| 8234 | **12.11** | 19.16 | 2.52 | 16.55 | 0.78 | 4.56 | 3.74 | 33.98 | 93.40 |

Table 14: Dominant land covers and their areas in cluster 3 of NDVI class 82

Table 14 shows that cluster 3 of NDVI class 82 was dominated by beans, banana, maize and sorghum. From table 12, 13 and 14, it was realized that it was in NDVI class 82 where maize dominated some sample areas. So, maize might have contributed much to the NDVI profiles in figure 18, but also, influence from other vegetation was high because the figure shows two distinguished seasons, but maize crop was planted only in one season in cluster 1 and 2 of the class.

To summarize the crop calendars per NDVI classes, the following figure 19 presents overall maize crop calendars summarized per the sample NDVI classes.

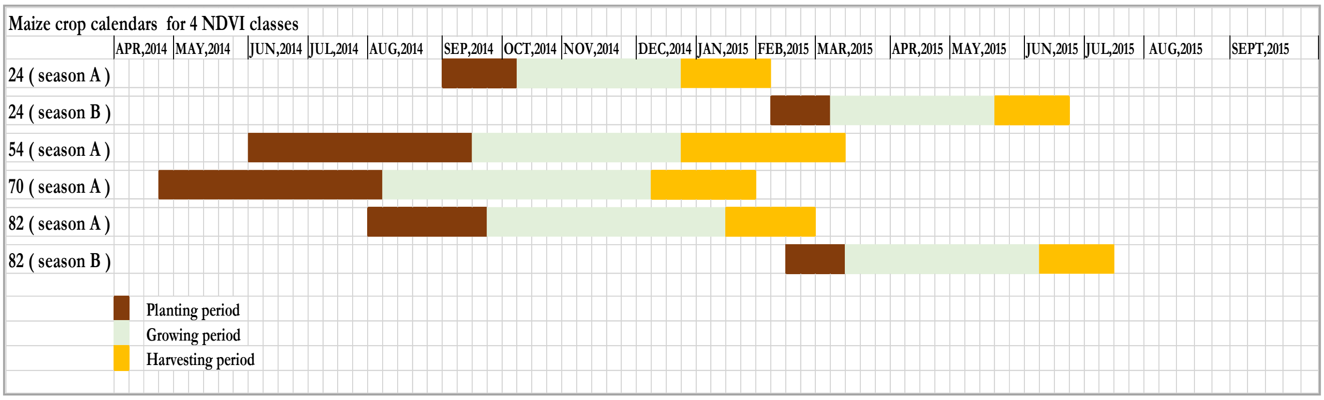



Figure 19: Generalized maize crop calendars for the 4 sample NDVI classes

Figure 19 shows that, in general, there were different maize crop calendars in different NDVI classes. NDVI classes 24 and 82 had two maize growing seasons, and the rest had only one maize growing season.

From the results of maize crop calendars, NDVI profiles and dominant land covers per NDVI class, the following observations were made:

- The start of maize planting and end of planting time were different from one NDVI class to another, but not much differences between NDVI class 24 and NDVI class 82.
- The start of maize harvesting and end of harvesting time also were different from one NDVI class to another, but also, no much differences were between NDVI class 24 and NDVI class 82.
- The NDVI profiles of the same NDVI class were behaving almost similar for all NDVI classes except for NDVI class 70, and there were different from one NDVI class to another.
- In regard to the dominant land covers per NDVI class, there were almost similar trends in the data in clusters of the same NDVI class. But, every NDVI class had particular dominant crops.
- Maize was not dominant in most of the sample areas. So, it had small contribution to the behaviour of NDVI profiles of different sample areas. This resulted in the fact that the number of maize growing seasons as from interviews with farmers was not conforming to the temporal behaviours of all the different sample areas in NDVI profiles. This showed the big influence in NDVI profiles from other variety of crops.

### 4.3. Assessment of relationship between number of maize growing seasons and NDVI classes

As observed from previous results, there was only one maize growing season in NDVI class 54 and 70 and partly NDVI class 82, and two growing seasons in NDVI class 24 and partly in NDVI class 82. To assess whether the number of maize growing seasons significantly relate to NDVI class, in order to respond to the second objective of the study and test the first hypothesis, the chi-square test was carried out.

To perform the test, first, a contingency table was constructed establishing the relationship between maize growing seasons and NDVI classes, according to the frequency number of plots with the same number of growing seasons per NDVI class (table 15). The table also contains the expected values per every cell, according to the total number of interviewed farmers found in the same NDVI class with the same number of maize growing season:

| NDVI class / Number of Seasons | 24 | 54 | 70 | 82 | **Total** |
|---|---|---|---|---|---|
| 1 | 0 / 66.5 | 113 / 78.3 | 105 / 72.7 | 82 / 82.4 | 300 |
| 2 | 96 / 29.5 | 0 / 37.7 | 0 / 32.3 | 37 / 36.6 | 133 |
| **Total** | 96 | 113 | 105 | 119 | **433** |

Table 15: Contingency table of observed and expected frequency of maize growing seasons per NDVI class

From table 15, values in black are the number of plots with the same number of maize growing seasons and located in the same NDVI class as from interviews with farmers. The values in red are the expected number of farmers with the same number of maize growing season and found in the same NDVI class. The expected values were given by a ratio between the product of total farmers with the same number of growing seasons and total number of farmers found in the same NDVI class, and the grand total (formulae 2).

From the values in table 15, chi square test was performed. Chi square value was calculated by applying formulae 3 from methodology section, and was found to be:

$\chi^2 =$ 316 at p = 0.05.

In order to assess whether the results are significant, chi-square critical was looked up from chi-square distribution table, with degrees of freedom =3 (given formulae 4) at p = 0.05. The chi square critical was found to be 7.815 on the chi square distribution table (appendix 13).

By comparing the results, the chi-square calculated was greater than chi-square critical. So, the number of maize growing periods was significantly related to the clustering of NDVI profiles into NDVI class at p=0.05.

### 4.4. Practiced maize crop calendars and maize crop calendars for NDVI classes

After that the hierarchical clustering showed that it is possible to cluster the interviews with farmers into four groupings, k-means clustering algorithm was then performed on the data, and the four practiced crop calendars groupings were identified irrespective of NDVI classes. Then, the number of plots in the same practiced maize crop calendar grouping were put together and related to the NDVI class where they are located, as presented in the following table 16.

| NDVI classes / Grouping | 24 | 54 | 70 | 82 |
|---|---|---|---|---|
| 1 | 0 | 18 | 75 | 0 |
| 2 | 96 | 0 | 0 | 37 |
| 3 | 0 | 50 | 30 | 25 |
| 4 | 0 | 45 | 0 | 57 |

Table 16: Number of plots with same practiced maize crop calendar per NDVI class

From the interviews with farmers, the four practiced maize crop calendars were generated in the four groupings, as presented in the following figure 20.

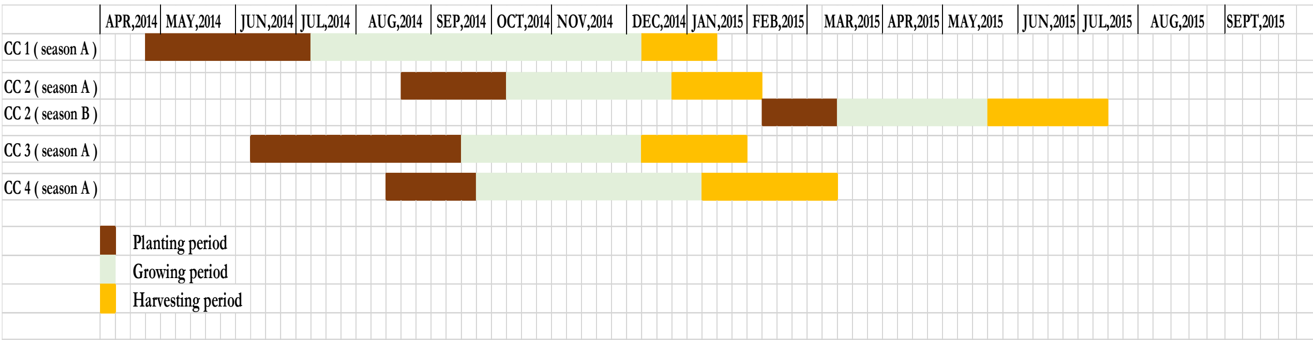



Figure 20: Four groupings of practiced maize crop calendars

From figure 20, it was observed that three groupings (CC1, CC3, and CC4) had only one maize growing season, whereas only one grouping (CC3) had two maize growing seasons according to the k-means unsupervised classification.

To continue the analysis, it was considered important to analyse how significantly different the maize crop calendars are, for both NDVI classes and practiced crop calendar groupings. This was in order to see if significant differences in practiced maize crop calendar, can be significantly detected by NDVI class; an analysis made later through assessing whether there is a strong relationship between the practiced maize crop calendars and NDVI classes.

### ✓ Analysis of variance and t-test for crop calendars between NDVI classes

One way ANOVA was carried out following the number of seasons per NDVI class. First, it was carried out for season A planting dates (in Julian calendar) for the four sample NDVI classes as presented in table 18 below:

| | | | | | | |
|---|---|---|---|---|---|---|
| Anova: Single Factor | | | | | | |
| | | | | | | |
| SUMMARY | | | | | | |
| *Groups* | *Count* | *Sum* | *Average* | *Variance* | | |
| NDVI class 24 | 96 | 25514 | 265.7708 | 33.12588 | | |
| NDVI class 54 | 113 | 25704 | 227.469 | 863.7513 | | |
| NDVI class 70 | 105 | 15812 | 150.5905 | 1225.763 | | |
| NDVI class 82 | 119 | 29204 | 245.4118 | 183.329 | | |
| | | | | | | |
| | | | | | | |
| ANOVA | | | | | | |
| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
| Between Groups | 787931.7 | 3 | 262643.9 | 452.5082 | 1.8E-132 | 2.625699 |
| Within Groups | 248999.3 | 429 | 580.418 | | | |
| | | | | | | |
| Total | 1036931 | 432 | | | | |

Table 17: One-way ANOVA results on season A planting dates between four NDVI classes

Table 17 shows that the four NDVI classes were significantly different in terms of maize planting time for season A in the year 2014-2015 at p=0.05, given that F statistic (452.5) which was greater than F critical

(2.6), and p-value (3.6 E-128) which was smaller than p (0.05). Moreover, the pairwise analysis also showed that all the pairs of the NDVI classes are significantly different in terms of planting time, as presented in appendix 14.

Second, one-way ANOVA was carried out between the four NDVI classes using season A harvesting days, as presented in table 18 below:

| Anova: Single Factor | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| SUMMARY | | | | | | |
| *Groups* | *Count* | *Sum* | *Average* | *Variance* | | |
| NDVI class 24 | 96 | 36377 | 378.9270833 | 97.12094298 | | |
| NDVI class 54 | 113 | 43860 | 388.1415929 | 480.6940582 | | |
| NDVI class 70 | 105 | 38328 | 365.0285714 | 104.6626374 | | |
| NDVI class 82 | 119 | 46681 | 392.2773109 | 307.3715995 | | |
| | | | | | | |
| | | | | | | |
| ANOVA | | | | | | |
| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
| Between Groups | 47921.89048 | 3 | 15973.96349 | 62.17468076 | 2.14291E-33 | 2.625699 |
| Within Groups | 110218.9871 | 429 | 256.9207159 | | | |
| | | | | | | |
| Total | 158140.8776 | 432 | | | | |

Table 18: One-way ANOVA results for season A harvesting dates between four NDVI classes

Table 18 shows that sample NDVI classes are different in terms of harvesting time in season A in the year 2014-2015 at p=0.05 given that F statistic (62.2) was greater than F critical (2.6), and p-value (2.14 E-33) was smaller than p (0.05). Furthermore, the pairwise comparison showed that all the NDVI classes' pairs are significantly different in terms of harvesting times, as presented in appendix 15.

Third, the analysis was carried out on maize planting times in season B. Given that the NDVI classes with season B were only two: NDVI class 24 and 82, so, the t-test was carried out, as presented in the following table 19.

| t-Test: Two-Sample Assuming Unequal Variances | | |
|---|---|---|
| | | |
| | *NDVI class24* | *NDVI class 82* |
| Mean | 50.83 | 61.30 |
| Variance | 36.62 | 43.49 |
| Observations | 96 | 37 |
| Hypothesized Mean Di | 0 | |
| df | 61 | |
| t Stat | -8.39 | |
| P(T<=t) one-tail | 0.00 | |
| t Critical one-tail | 1.67 | |
| P(T<=t) two-tail | 0.00 | |
| t Critical two-tail | 2.00 | |

Table 19: T-test results for season B planting dates between NDVI class 24 and 82

T-test results in table 19 showed that, though both NDVI class 24 and NDVI class 82 had two maize growing seasons, they were significantly different in terms of planting dates at p=0.05, given the p-value that was smaller than the p (0.05).

Lastly, a t-test was carried out between NDVI class 24 and 82 in terms of season B harvesting time. The results are presented in the following table 20.

| t-Test: Two-Sample Assuming Unequal Variances | | |
|---|---|---|
| | | |
| | *NDVI class 24* | *NDVI class 82* |
| Mean | 162.16 | 176.84 |
| Variance | 73.69 | 47.25 |
| Observations | 96 | 37 |
| Hypothesized Mean Difference | 0 | |
| df | 81 | |
| t Stat | -10.27 | |
| P(T<=t) one-tail | 0.00 | |
| t Critical one-tail | 1.66 | |
| P(T<=t) two-tail | 0.00 | |
| t Critical two-tail | 1.99 | |

Table 20: T-test results for season B harvesting dates between NDVI class 24 and 82

The t-test results in table 20 show that, also, NDVI class 24 and class 82 were significantly different in terms of harvesting dates of season B, at p = 0.05.

In summary, the results in tables 17, 18, 19 and 20 show that the crop calendars for the four NDVI classes were significantly different in terms of planting and harvesting dates at p = 0.05.

- ✓ **Analysis of variance for practiced maize crop calendars**

One way ANOVA was carried out between the four groupings of practiced maize crop calendars to assess whether they are significantly different as they were grouped differently. First, the analysis was carried out in terms of season A planting dates, as presented in the following table 21:

| Anova: Single Factor | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| SUMMARY | | | | | | |
| *Groups* | *Count* | *Sum* | *Average* | *Variance* | | |
| CC 1 | 93 | 12823 | 137.8817204 | 417.3228144 | | |
| CC 2 | 133 | 34957 | 262.8345865 | 64.91182502 | | |
| CC 3 | 105 | 23517 | 223.9714286 | 458.7972527 | | |
| CC 4 | 102 | 24937 | 244.4803922 | 103.9154533 | | |
| | | | | | | |
| | | | | | | |
| ANOVA | | | | | | |
| *ource of Variatioi* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
| Between Groups | 931758.6275 | 3 | 310586.2092 | 1266.885984 | 1E-212 | 2.6256992 |
| Within Groups | 105172.4349 | 429 | 245.1571909 | | | |
| | | | | | | |
| Total | 1036931.062 | 432 | | | | |

Table 21: One-way ANOVA results for season A plating dates of practiced maize crop calendars groupings

As presented by table 21, the four practiced maize crop calendars were significantly different in terms of season A planting dates at p=0.05. Also, the pairwise comparison showed that all pairs of the practiced maize crop calendars are significantly different in terms of planting time, at p=0.05, as presented in appendix 16.

Second, the analysis was carried to assess the difference in terms of season A harvesting dates, as presented in table 22 below:

| | | | | | | |
|---|---|---|---|---|---|---|
| Anova: Single Factor | | | | | | |
| | | | | | | |
| SUMMARY | | | | | | |
| *Groups* | *Count* | *Sum* | *Average* | *Variance* | | |
| CC 1 | 93 | 33897 | 364.4839 | 71.23072 | | |
| CC 2 | 133 | 50219 | 377.5865 | 89.59285 | | |
| CC 3 | 105 | 39286 | 374.1524 | 91.11117 | | |
| CC 4 | 102 | 41844 | 410.2353 | 113.2312 | | |
| | | | | | | |
| | | | | | | |
| ANOVA | | | | | | |
| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
| Between Groups | 118849.5 | 3 | 39616.49 | 432.5496 | 2.7E-129 | 2.625699 |
| Within Groups | 39291.4 | 429 | 91.58834 | | | |
| | | | | | | |
| Total | 158140.9 | 432 | | | | |

Table 22: One-way ANOVA results for season A harvesting dates of practiced maize crop calendars groupings

Table 22 shows that, also, the four practiced crop calendar groupings were significantly different in terms of season A harvesting dates. Moreover, the pairwise comparison, in appendix 17, showed that all pairs of the practiced maize crop calendars are significantly different in terms of planting time, at p=0.05.

The season B was not analysed because only one practiced crop calendar (CC 2) had season B, indicating one of its uniqueness among other practiced crop calendars groupings.

In summary, table 21 and 22 show that, as the k-means clustering algorithm separated the practiced maize crop calendars into 4 groupings, the groupings were also significantly different in terms of planting and harvestings dates. Furthermore, only one crop calendar, among the four, had two maize growing seasons.

### 4.5. Assessment of relationship between practiced maize crop calendars and NDVI classes

As observed from previous sections, there were significant differences in practiced maize crop calendars and also in the maize crop calendars for NDVI classes. To assess if NDVI classes can significantly detect the differences existing in the practiced crop calendars, the chi-square test was performed in order to evaluate whether there is a relationship between crop calendars by NDVI classes and the practiced maize crop calendars. The following table 23 presents the constructed contingency table, with observed values from interviews with farmers and expected values, in order to run the test.

| NDVI class<br>Grouping | 24 | 54 | 70 | 82 | **Total** |
|---|---|---|---|---|---|
| 1 | 0<br>20.6 | 18<br>24.3 | 75<br>22.6 | 0<br>25.6 | 93 |
| 2 | 96<br>29.5 | 0<br>34.7 | 0<br>32.3 | 37<br>36.6 | 133 |
| 3 | 0<br>23.3 | 50<br>27.4 | 30<br>25.5 | 25<br>28.9 | 105 |
| 4 | 0<br>22.6 | 45<br>26.6 | 0<br>24.7 | 57<br>28 | 102 |
| **Total** | 96 | 113 | 105 | 119 | 433 |

Table 23: Contingency table of observed and expected frequency of practiced maize crop calendar per NDVI class

From table 23, values in black are the number of plots with the same observed practiced maize crop calendars per NDVI class, and the values in red are the expected number of plots with the same practiced maize crop calendars per NDVI class. Then, chi-square value was calculated using formulae 3, and was:

$\chi^2 =$ 519.56 at p = 0.05.

Looking up the chi-square critical in the chi-square distribution table (appendix 13) using 9 as a degree of freedom at p=0.05, the chi-square critical was 16.919. By comparison, the chi-square calculated is much greater than the chi-square critical. So, the results were highly significant, indicating that the practiced maize crop calendars are highly related to the maize crop calendars for NDVI classes, at p = 0.05.

In summary, the previous results showed that the spatial stratification of hyper-temporal NDVI data into NDVI classes can significantly differentiate differences in practiced maize crop calendars.

# 5. DISCUSSION

In this section, the findings are discussed and compared with previous studies in line with the research objectives and hypotheses.

## 5.1. Maize crop calendars of sample NDVI classes through interviews with farmers

For the first objective, crop calendars for sample NDVI classes were produced. The generated crop calendars were for the agricultural year 2014-2015 through the interviews with farmers. The research found that maize crop had different crop calendars in the 4 different sample NDVI classes, with differences in duration of one agricultural activity to another, from one area to another, as detailed in the results section.

The obtained results of crop calendars by this research were compared to the existing maize and sorghum crop calendar for Rwanda by FAO/GIEWS (2015). The existing crop calendar shows that in season A, maize is planted in September and October, and then the two crops undergo a growing period of two months from November to December, and harvesting time takes place afterward also for two months from January to February. In season B, planting takes place in February and March, and then the growing period takes place from April to May, and finally harvesting takes place from June to July.

On another side of comparing the results of this research with the general agricultural seasons in Rwanda: season A, season B and season C as detailed by NISR (2015), there were found also differences. Especially, agricultural seasons in NDVI classes 54 and 70 were very different from the Rwanda three general agricultural seasons. For NDVI classes 24 and 82, there were no much differences though there were still some differences. The differences might have been the effect of differences in applied methodologies for mapping the crops calendars.

Considering the methodologies applied, the three normal agricultural seasons in Rwanda are based on surveyed data at administrative level NISR (2015). One of the side effects of the method is that the demarcation of administrative boundaries do not consider environmental conditions and temporal variation which are the base for different crop calendars (Eagleson, Escobar, & Williamson, 2000).

The methodology as applied by this research on the other hand, one of the main advantages of using hyper-temporal NDVI data for land stratification for crop calendars mapping is that there is consideration of the natural relevant factors like climate conditions, soil characteristics, human activities on ground and consideration of areas' spatial temporal change (de Bie et al., 2008) which influence different crop calendars.

As said by Clay and Dejaegher (1987) and FAO (1996), in Rwanda there is a lot of diversity based on its topography, environmental factors including soil characteristic, land forms and other climatic conditions such as temperature and rainfall. The factors lead to much diversity in agriculture as well. But, in addition to the climate conditions, agriculture is controlled by human decisions (Iisd, 1997). This was observed by this research where maize crop calendars were produced based on the data from interviews with farmers, and it was found that in some cases were big differences even between the neighbouring farmers located in the same sample area (Appendices: 5, 6, 7, and 8).

Referring to de Bie (2002), while defining crop calendar he mentioned that a parcel can have its own crop calendar but the calendar is often generalized to a specific area. In this regard, though there were differences at plot and sample area level, the maize crop calendars were generalized to NDVI class level (figure 11, 13, 15 and 17) which led to less detailed crop calendars.

By generalizing different agricultural activities (planting and harvesting) of different sample areas in one maize crop calendar at NDVI class level, obviously, there was a loss of information. Additionally, due to the generalization, there were cases where successive agricultural periods for a certain activity (like planting and growing period, or growing period and harvesting) happened simultaneously in the same agricultural season. The example is presented in figure 19, where in NDVI class 82 planting time for season B started while harvesting of season A was not finished yet.

Regarding the agricultural seasons in the country, they were also different from NDVI class to another. Season A was the most important period for maize cultivation, where for the sample NDVI classes all farmers cultivated maize in season A. For season B, only farmers from NDVI class 24 and 82 planted maize. Specifically, all interviewed farmers in NDVI class 24 cultivated maize in both season A and B, but for NDVI class 84, all farmers cultivated maize in season A but only 31% cultivated maize for season B. This finding was similar to the findings in 2014-2015 season A for Rwanda national agricultural survey report, where maize was among the main and dominant crops in season A in the country. For season A of the year 2014-2015, maize crop occupied 12.3% of the country's cultivated area and 5.2% for season B (NISR, 2015b).

In brief, this research found different maize crop calendars for different NDVI classes. Also, as shown by their NDVI profiles, the sample NDVI classes' temporal behaviours were different. As observed on the field in the dates from 9th October till 5th November, 2015, in some areas of NDVI class 54 and NDVI class 70 were maize crops in leaf growing stages (V7 and V10) and maize crops in tasseling stage (VT and R1), while for NDVI class 24 and NDVI class 82 the maize crops were only on leaf growth stage (V3, V7 and V10) (Odell's World, 2010).

## 5.2. Relationship between practiced crop calendars and crop calendars per NDVI classes

Regarding the maize growing seasons in Rwanda, it was found that the number maize growing seasons is significantly related to the NDVI class. This indicates that different areas in Rwanda have different number of maize growing seasons. It was observed that among the surveyed sample NDVI classes, two classes: 54 and 70 had only one maize growing season (Season A) for the year 2014-2015 whereas another NDVI class: 24 had two maize growing seasons and the NDVI class 82 had partly (69%) only one maize growing season (season A) and partly (31%) two maize growing season (both season A and B).

These differences in a number of maize growing season per year in different NDVI classes answered the first research question about whether the number of maize growing seasons per year differ from one NDVI class to another. In addition, the number of maize growing seasons was found to highly relate to the NDVI classes by this research, using chi-square test.

Furthermore, the maize crop calendars for NDVI classes were significantly different in terms of planting time and harvesting time. This diversity in maize crop calendars with significant differences in different areas in Rwanda indicates that in case a crop calendar would be generalized to the country level, there are many significant differences that would be ignored, leading to different consequences in case of using the generalized crop calendar for various agricultural interventions in the country.

Likewise, the practiced maize crop calendar groupings as grouped by k-means unsupervised classification, were found to be significantly different in terms of planting and harvesting times. For the practiced maize crop calendars, only one grouping had two maize growing seasons. Still, this emphasised the significant differences in maize crop calendars for different areas in Rwanda.

In order to relate the significant differences in the practiced maize crop calendars groupings and the significant differences in maize crop calendars for NDVI classes, the chi-square test showed that there is a strong relationship between practiced maize crop calendars groupings and crop calendars per NDVI classes. This answered the second research question about whether the groupings of maize crop calendars relate to maize crop calendars of NDVI classes. Moreover, it revealed the ability of hyper-temporal NDVI stratification to capture the differences existing in the practiced maize crop calendars in Rwanda.

This relationship is explained by the fact the crop calendar is a reflection of a particular crop and cropping system seasonal progression from planting to harvesting in a certain area (HarvestChoice, 2013), and also the hyper-temporal stratification bases on area's vegetation cover photosynthetic activity in order to classify the land into different NDVI classes (Govaerts & Verhulst, 2010).

# 6. CONCLUSIONS AND RECOMMENDATIONS

## 6.1. Conclusions

Conclusively, this research showed that there were more than one maize crop calendars for Rwanda. The research showed, also, the potential of hyper-temporal MODIS NDVI data to classify different areas with different maize crop calendars in Rwanda. Each NDVI class had different maize crop calendars, and also there existed different practiced maize crop calendars with different maize growing seasons.

Moreover, the research found that the number of maize growing seasons were highly related to the maize crop calendars for NDVI classes at $p = 0.05$. Similarly, the practiced maize crop calendars were highly related to the maize crop calendars for NDVI classes at $p = 0.05$. Hence, the spatial stratification of hyper-temporal NDVI data into NDVI classes can significantly differentiate differences in practiced maize crop calendars in Rwanda.

## 6.2. Recommendations

From this research, the following recommendations are suggested for prospective researchers:

- Assessing differences in practiced maize crop calendars for Rwanda using other 20 NDVI classes dominated with agriculture which were not used for this study due to time limitations.
- Assessing differences in practiced crop calendars for Rwanda for other seasonal main crops in Rwanda such as beans, sorghum, and irish potatoes, using hyper-temporal NDVI stratification.
- Mapping differences in practiced crop calendars in Rwanda at detailed level including more information about agricultural activities such as land preparation time and weeding.
- Derive different crop calendars of a specific crop using NDVI profiles from NDVI hyper-temporal data, taking a study area to be an area where the crop of interest is dominant.
- To know different crops and their growing seasons in order to be aware of how different crops contribute to their NDVI profiles of their areas, and relate crop calendars of dominant crops to their respective areas' NDVI profiles.

# LIST OF REFERENCES


Ali, A., de Bie, C. a J. M., Skidmore, a. K., Scarrott, R. G., & Lymberakis, P. (2014). Mapping the heterogeneity of natural and semi-natural landscapes. *International Journal of Applied Earth Observation and Geoinformation*, *26*(1), 176–183. http://doi.org/10.1016/j.jag.2013.06.007

AMIS. (2012). AMIS crop calendar. Retrieved July 29, 2015, from http://www.amis-outlook.org/fileadmin/user_upload/amis/docs/Crop_Calendar/121206-AMIS-online-crop-calendar_REDUCED3.pdf

Bailey, J. T., & Boryan, C. G. (2010). Remote sensing applications in agriculture at the USDA national agricultural statistics service, *22030*, 14. Retrieved from http://www.fao.org/fileadmin/templates/ess/documents/meetings_and_workshops/ICAS5/PDF/ICASV_2.1_048_Paper_Bailey.pdf

Bailey, R. (2004). Role of landform in differentiation of ecosystems at the mesoscale (landscape mosaics), (1993), 22.

Barrow, M. (2013). The mountain environment. Retrieved January 8, 2016, from http://www.primaryhomeworkhelp.co.uk/mountains/climate.htm

Blei, D. M. (2008). Hierarchical clustering. Princeston.

Brouwer, M., van Bodegom, A. J., Satijn, B., & Buit, G. L. (2015). *Climate change profile: Rwanda*. Kigali.

Cantore, N. (2011). *The crop intensification program in Rwanda: a suitability analysis*. London.

Chand, S. (2015). Maize cultivation: suitable geographical conditions required for maize cultivation. Retrieved from http://www.yourarticlelibrary.com/cultivation/maize-cultivation-suitable-geographical-conditions-required-for-maize-cultivation/25501/

Chemonics International Inc. (2003). *Rwanda environmental threats and opportunities*. Retrieved from http://www.encapafrica.org/documents/biofor/Rwanda_2003.pdf

Christiaensen, L., Demery, L., & Kuhl, J. (2011). The (evolving) role of agriculture in poverty reduction-An empirical perspective. *Journal of Development Economics*, *96*(2), 239–254. http://doi.org/10.1016/j.jdeveco.2010.10.006

Clay, D. C., & Dejaegher, Y. M. J. (1987). Agro-ecological zones: The development of reginal classification scheme for Rwanda. *Tropicultura*. Retrieved from http://www.tropicultura.org/text/v5n4/153.pdf

Cole, M., & Mcsweeney, R. (2011). Rwanda s Climate : Observations and Projections, (July).

de Bie, C. A. J. M. (2002). Novel approaches to use RS-products for mapping and studying agricultural land use systems.

de Bie, C. A., Khan, M. R., Toxopeus, A. G., Venus, V., & Skidmore, A. K. (2008). Hypertemporal image analysis for crop mapping and change detection. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B7. Beijing 2008*, *2*, 803–814. Retrieved from http://isprsserv.ifp.uni-stuttgart.de/proceedings/XXXVII/congress/7_pdf/5_WG-VII-5/13.pdf de Bie, K. (2014). Integrating census data with hyper-temporal NDVI data, to prepare detailed crop intensity and crop growing period maps. Addis Abeba.

Diener-West, M. (2008). Use of the Chi-Square Statistic. Retrieved from http://ocw.jhsph.edu/courses/fundepiii/pdfs/lecture17.pdf

Eagleson, S., Escobar, F., & Williamson, I. (2000). Hierarchical spatial reasoning applied to the automated design of administrative boundaries using GIS.

ESAANet. (2007). Crop guide. Retrieved September 23, 2015, from http://www.esaanet.com/reports/index.php?option=com_content&view=article&id=619:kenya-relief-as-ncpb-begins-distribution-of-subsidised-fertiliser-after-delay&catid=43:crop-guide&directory=133

FAO. (1996). Agro-ecological zoning guidelines, 78. Retrieved from https://www.mpl.ird.fr/crea/taller-colombia/FAO/AGLL/pdfdocs/aeze.pdf

FAO. (2015). Crop Calendar. Retrieved July 30, 2015, from http://www.fao.org/agriculture/seed/cropcalendar/welcome.do

FAO/GIEWS. (2015). *GIEWS Country brief- Rwanda*. Retrieved from http://www.fao.org/giews/countrybrief/country/RWA/pdf/RWA.pdf

Fensholt, R., Sandholt, I., & Stisen, S. (2006). Evaluating MODIS, MERIS, and VEGETATION vegetation indices using in situ measurements in a semiarid environment. *IEEE Transcations on Geoscience and Remote Sensing*, *44*(7). Retrieved from http://hydrology1.nmsu.edu/Teaching_Material/Agro500/Refernces/SpecIssuePapers/Fensholt et al 2006 Veg_Indices_Arid.pdf

Foody, G. M., & Boyd, D. S. (1999). Fuzzy mapping of tropical land cover along an environmental gradient from remotely sensed data with an arti ® cial neural network, *35*, 23–35.

Gamon, J. A., Field, C. B., Goulden, M. L., Griffin, K. L., Hartley, A. E., Joel, G., … Valentini, R. (1995). Relationships between NDVI, canopy structure, and photosynthesis in three Californian vegetation types. *Ecological Applications*, *5*(1), 28–41. Retrieved from http://www.creaf.uab.es/global-ecology/Pdfs_UEG/EcolAppl1995.pdf

Govaerts, B., & Verhulst, N. (2010). *The Normalized Difference Vegetation Index (NDVI) Greenseeker handheld sensor: toward the integrated evaluation of crop management*. Leuven. Retrieved from http://www.plantstress.com/methods/Greenseeker.PDF

Griffiths, A. J. F., Miller, J. H., & Suzuki, D. T. (2000). Chi-square test. In *An introduction to genetic analysis* (7th ed.). New York: W. H. Freeman. Retrieved from http://www.ncbi.nlm.nih.gov/books/NBK21907/

Guo, Z. (2013). Mapping the planting dates: An effort to retrive crop phenology information from MODIS NDVI time series in Africa. *International Geoscience and Remote Sensing Symposium (IGARSS)*, 3281–3284. http://doi.org/10.1109/IGARSS.2013.6723528

HarvestChoice. (2013). *A time to sow: how HarvestChoice is mapping the life cycle of crops*. Washington, DC. Retrieved from http://harvestchoice.org/node/8862

Heisse. (2011). *Maize production*. Kampala. Retrieved from http://teca.fao.org/sites/default/files/technology_files/MAIZE PRODUCTION_0.pdf

Iisd. (1997). *Agriculture and climate change: A prairies perspective*. Toronto.

Ji-hua, M., Bing-fang, W., Monitoring, C. C., Trend, D., Pei, L., Jiulin, S., … Aeronautics, N. (1999). Study on the Crop Condition Monitoring Methods. *Archives*, 945–950.

Kanyarukiga, S. G. (2004). Strategic plan of agriculture transformation financing , coordination and monitoring and evaluation, (October), 1–27. Retrieved from http://www.ifad.org/english/operations/pf/rwa/i671rw/web/theme/coordination.pdf

Kotsuki, S., & Tanaka, K. (2015). SACRA – a method for the estimation of global high-resolution crop calendars from a satellite-sensed NDVI. *Hydrology and Earth System Sciences*, *19*(11), 4441–4461. http://doi.org/10.5194/hess-19-4441-2015

Maize production. (2013). Retrieved from http://www.naads.or.ug/files/downloads/MAIZE Production guide.doc.pdf

Manakov, A. G., & Mikhaylova, A. A. (2015). Changes in the Territorial and Administrative Division of Northwest Russia over the Soviet Period, *5*, 37–40.

Miller, J., & Haden, P. (2006). *Statistical analysis with the general linear model*. San Francisco.

Miller, P., Lanier, W., & Brandt, S. (2001). *Using growing degree days to predict plant stages*. Montana. Retrieved from http://store.msuextension.org/publications/AgandNaturalResources/MT200103AG.pdf

MINAGRI. (2011). *National post-harvest staple crop strategy*. Kigali.

MINALOC. (2011). Administrative units. Retrieved January 8, 2016, from http://www.minaloc.gov.rw/index.php?id=450

MINITERE. (2006). *National adaptation programmes of action to climate change*. Kigali.

N2Africa. (2014). *Better beans: through good agricultural practices*.

NAEB. (2015). *Profiling and mapping suitable land for horticulture in Rwanda*. Kigali.

NC State University. (2010). Temperature relation to agriculture/K-12: How does this relate to agriculture?

NISR. (2015a). *Seasonal agricultural survey 2013 (Version 2)*.

NISR. (2015b). *Seasonal agricultural survey 2014*.

Odell's World. (2010). Corn growth stages. Retrieved December 20, 2015, from http://odells.typepad.com/blog/corn-growth-stages.html

Oettli, P., Sultan, B., Baron, C., & Vrac, M. (2011). Are regional climate models relevant for crop yield prediction in West Africa? *Environmental Research Letters*, *6*(1), 014008. http://doi.org/10.1088/1748-9326/6/1/014008

Ozdogan, M., Yang, Y., Allez, G., & Cervantes, C. (2010). Remote sensing of irrigated agriculture: opportunities and challenges. *Remote Sensing*. http://doi.org/10.3390/rs2092274

Patel, J. H., & Oza, M. P. (2014). Deriving crop calendar using NDVI time-series. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XL-8*(December), 869–873. http://doi.org/10.5194/isprsarchives-XL-8-869-2014

Pham, D. T., Dimov, S. S., & Nguyen, C. D. (2005). Selection of K in K-means clustering. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*. http://doi.org/10.1243/095440605X8298

Premier Consulting Group. (2009). Land Reform in Rwanda - Technology & the Land Tenure Regularisation Process -. *Matrix*, (May).

Raes, D., Steduto, P., Hsiao, C. T., & Fereres, E. (2009). *AquaCrop-The FAO crop model to simulate yield response to water*. Rome.

Rafi, Z., & Ahmad, R. (2005). Wheat crop model based on water balance for agrometeorological crop monitoring. *Pakistan Journal of Meteorology Vol*, *2*(3), 23–33. Retrieved from http://www.pmd.gov.pk/rnd/rnd_files/vol2_Issue3/3. WHEAT CROP MODEL BASED ON WATER BALANCE FOR AGROMETEOROLOGICAL CROP MONITORING.pdf

REMA. (2009a). Overview of the agriculture sector. Retrieved December 8, 2015, from http://www.rema.gov.rw/soe/chap3.php

REMA. (2009b). Rwanda state of environment and outlook, 98. Retrieved from http://www.rema.gov.rw/soe/

Rema. (2011). Atlas of Rwanda's Changing Environment — Implications for Climate Change Resilience, 92. Retrieved from http://na.unep.net/siouxfalls/publications/REMA.pdf

RIU Rwanda. (2012). Maize innovation platform and warrantage. Retrieved November 17, 2015, from http://www.researchintouse.com/programmes/riu-rwanda/riu-rw41innovplat-maize.html

Rouse, J. W. J., Haas, R. H., Schell, J. A., & Deering, D. W. (1974). Monitoring vegetation systems in the great plains with Erts. *Third Earth Resources Technology Satellite-1 Symposium*, *I: Technic*(NASA SP-351).

Ryan, T. (2013). Clustering 2: Hierarchical clustering. Retrieved from http://www.stat.cmu.edu/~ryantibs/datamining/lectures/05-clus2-marked.pdf

Smit, B., McNabb, D., & Smithers, J. (1999). Agricultural adaptation to climatic variation. Retrieved from http://www.uoguelph.ca/gecg/images/userimages/Smit et al. (1996)_Climatic Change.pdf

Takeuchi, Shin'ichi, & Marara, J. (2006). Characteristics of agriculture and rural areas in Rwanda.

Tucker, C. J., Pinzon, J. E., & Brown, M. E. (2004). Global inventory modeling and mapping studies (GIMMS) satellite drift corrected and NOAA-16 incorporated Normalized Difference Vegetation Index (NDVI). Retrieved November 15, 2015, from http://iridl.ldeo.columbia.edu/SOURCES/.UMD/.GLCF/.GIMMS/.NDVIg/.global/.dataset_documentation.html

Twagiramungu, F. (2006). Environmental Profile of Republic of Rwanda. Retrieved from http://www.vub.ac.be/klimostoolkit/sites/default/files/documents/rwanda-environmental-profile.pdf

Tyrchniewicz, A., & Wilson, A. (1994). *Sustainable development for the great plains: policy analysis*. Winnipeg, Manitoba. Retrieved from https://www.iisd.org/pdf/sd_for_gp.pdf

United Nations. (2011). Report on the results of a survey on census methods used by countries in the 2010 census round. *Working Paper: UNSD/DSSB/1*, 69. Retrieved from http://unstats.un.org/unsd/census2010.htm\nFor

Upadhyay, G., Ray, S. S., & Panigrahy, S. (2008). Derivation of crop phenological parameters using multi-date SPOT-VGT-NDVI data: A case study for Punjab. *Journal of the Indian Society of Remote Sensing*, *36*(1), 37–50. http://doi.org/10.1007/s12524-008-0004-4

USAID. (2008). Rwanda environmental threats and opportunities sssessment 2008 update. Retrieved from http://pdf.usaid.gov/pdf_docs/Pnadn537.pdf

Vintrou, E., Bégué, A., Baron, C., Saad, A., Seen, D. Lo, & Traoré, S. B. (2014). A comparative study on satellite- and model-based crop phenology in West Africa. *Remote Sensing*, *6*(2), 1367–1389. http://doi.org/10.3390/rs6021367

VITO. (2015). Copernicus global land service. Retrieved November 14, 2015, from http://land.copernicus.eu/global/products/ndvi

Wardlow, B. D., & Egbert, S. L. (2008). Large-area crop mapping using time-series MODIS 250 m NDVI data: An assessment for the U.S. Central Great Plains. *Remote Sensing of Environment*, *112*(3), 1096–1116. http://doi.org/10.1016/j.rse.2007.07.019

Wardlow, B. D., & Egbert, S. L. (2010). A comparison of MODIS 250-m EVI and NDVI data for crop mapping: a case study for southwest Kansas. *International Journal of Remote Sensing*, *31*(3), 805–830. http://doi.org/10.1080/01431160902897858

Wardlow, B., Egbert, S., & Kastens, J. (2007). Analysis of time-series MODIS 250 m vegetation index data for crop classification in the U.S. Central Great Plains. *Remote Sensing of Environment*, *108*(3), 290–310. http://doi.org/10.1016/j.rse.2006.11.021

Westengen, O. T., & Brysting, A. K. (2014). Crop adaptation to climate change in the semi-arid zone in Tanzania: the role of genetic resources and seed systems. *Agriculture & Food Security*, *3*(1), 3. http://doi.org/10.1186/2048-7010-3-3

Yin, H., Udelhoven, T., Fensholt, R., Pflugmacher, D., & Hostert, P. (2012). How normalized difference vegetation index (NDVI) trends from advanced very high resolution radiometer (AVHRR) and système probatoire d'observation de la terre vegetation (SPOT VGT) time series differ in agricultural areas: An inner mongolian case study. *Remote Sensing*, *4*(11), 3364–3389. http://doi.org/10.5829/idosi.mejsr.2012.12.3.64113

Zhu, X. (2010). Clustering. Retrieved from http://pages.cs.wisc.edu/~jerryzhu/cs769/clustering.pdf

# APPENDICES

| Sample area | Plant A | Harvest A | Plant B | Harvest B |
|---|---|---|---|---|
| **2411** | 15-Sep-14 | 05-Jan-15 | 15-Feb-15 | 05-Jun-15 |
| **2411** | 20-Sep-14 | 10-Jan-15 | 10-Feb-15 | 12-Jun-15 |
| **2411** | 20-Sep-14 | 10-Jan-15 | 15-Feb-15 | 05-Jun-15 |
| **2411** | 20-Sep-14 | 10-Jan-15 | 15-Feb-15 | 15-Jun-15 |
| **2411** | 30-Sep-14 | 10-Jan-15 | 15-Feb-15 | 12-Jun-15 |
| **2411** | 20-Sep-14 | 10-Jan-15 | 25-Feb-15 | 20-Jun-15 |
| **2411** | 20-Sep-14 | 10-Jan-15 | 25-Feb-15 | 20-Jun-15 |
| **2411** | 20-Sep-14 | 15-Jan-15 | 25-Feb-15 | 20-Jun-15 |
| **2411** | 20-Sep-14 | 15-Jan-15 | 25-Feb-15 | 20-Jun-15 |
| **2411** | 20-Sep-14 | 15-Jan-15 | 15-Feb-15 | 15-Jun-15 |
| | | | | |
| **2412** | 20-Sep-14 | 10-Jan-15 | 25-Feb-15 | 15-Jun-15 |
| **2412** | 20-Sep-14 | 10-Jan-15 | 25-Feb-15 | 01-Jun-15 |
| **2412** | 25-Sep-14 | 10-Jan-15 | 01-Mar-15 | 15-Jun-15 |
| **2412** | 20-Sep-14 | 15-Jan-15 | 20-Feb-15 | 20-Jun-15 |
| **2412** | 25-Sep-14 | 15-Jan-15 | 20-Feb-15 | 10-Jun-15 |
| **2412** | 25-Sep-14 | 15-Jan-15 | 01-Mar-15 | 01-Jun-15 |
| **2412** | 25-Sep-14 | 15-Jan-15 | 20-Feb-15 | 20-Jun-15 |
| **2412** | 25-Sep-14 | 20-Jan-15 | 20-Feb-15 | 05-Jun-15 |
| **2412** | 25-Sep-14 | 20-Jan-15 | 25-Feb-15 | 10-Jun-15 |
| | | | | |
| **2414** | 25-Sep-14 | 10-Jan-15 | 25-Feb-15 | 10-Jun-15 |
| **2414** | 25-Sep-14 | 15-Jan-15 | 20-Feb-15 | 15-Jun-15 |
| **2414** | 25-Sep-14 | 15-Jan-15 | 20-Feb-15 | 20-Jun-15 |
| **2414** | 25-Sep-14 | 15-Jan-15 | 25-Feb-15 | 20-Jun-15 |
| **2414** | 25-Sep-14 | 15-Jan-15 | 20-Feb-15 | 20-Jun-15 |
| **2414** | 30-Sep-14 | 15-Jan-15 | 25-Feb-15 | 20-Jun-15 |
| **2414** | 30-Sep-14 | 20-Jan-15 | 03-Mar-15 | 15-Jun-15 |
| **2414** | 05-Oct-14 | 20-Jan-15 | 01-Mar-15 | 20-Jun-15 |
| **2414** | 25-Sep-14 | 20-Jan-15 | 25-Feb-15 | 15-Jun-15 |
| **2414** | 25-Sep-14 | 20-Jan-15 | 01-Mar-15 | 10-Jun-15 |
| **2414** | 05-Oct-14 | 20-Jan-15 | 03-Mar-15 | 20-Jun-15 |
| | | | | |
| **2421** | 20-Sep-14 | 10-Jan-15 | 20-Feb-15 | 20-Jun-15 |
| **2421** | 30-Sep-14 | 10-Jan-15 | 10-Feb-15 | 20-Jun-15 |
| **2421** | 01-Oct-14 | 15-Jan-15 | 20-Feb-15 | 20-Jun-15 |
| **2421** | 30-Sep-14 | 15-Jan-15 | 20-Feb-15 | 20-Jun-15 |
| **2421** | 25-Sep-14 | 20-Jan-15 | 10-Feb-15 | 15-Jun-15 |
| **2421** | 25-Sep-14 | 25-Jan-15 | 15-Feb-15 | 10-Jun-15 |
| **2421** | 25-Sep-14 | 25-Jan-15 | 15-Feb-15 | 15-Jun-15 |
| **2421** | 01-Oct-14 | 25-Jan-15 | 15-Feb-15 | 20-Jun-15 |
| **2421** | 25-Sep-14 | 25-Jan-15 | 15-Feb-15 | 25-Jun-15 |
| | | | | |
| **2422** | 15-Sep-14 | 15-Jan-15 | 10-Feb-15 | 10-Jun-15 |
| **2422** | 20-Sep-14 | 15-Jan-15 | 25-Feb-15 | 15-Jun-15 |
| **2422** | 20-Sep-14 | 20-Jan-15 | 20-Feb-15 | 15-Jun-15 |
| **2422** | 25-Sep-14 | 20-Jan-15 | 01-Mar-15 | 20-Jun-15 |
| **2422** | 20-Sep-14 | 25-Jan-15 | 20-Feb-15 | 20-Jun-15 |
| **2422** | 20-Sep-14 | 25-Jan-15 | 01-Mar-15 | 20-Jun-15 |
| **2422** | 25-Sep-14 | 25-Jan-15 | 25-Feb-15 | 20-Jun-15 |
| **2422** | 20-Sep-14 | 30-Jan-15 | 20-Feb-15 | 20-Jun-15 |
| **2422** | 25-Sep-14 | 30-Jan-15 | 25-Feb-15 | 10-Jun-15 |
| **2422** | 20-Sep-14 | 30-Jan-15 | 28-Feb-15 | 20-Jun-15 |
| | | | | |
| **2423** | 11-Sep-14 | 01-Jan-15 | 25-Feb-15 | 13-Jun-15 |
| **2423** | 22-Sep-14 | 03-Jan-15 | 07-Feb-15 | 26-May-15 |
| **2423** | 27-Sep-14 | 05-Jan-15 | 05-Feb-15 | 11-Jun-15 |
| **2423** | 13-Sep-14 | 24-Dec-14 | 15-Feb-15 | 26-May-15 |
| **2423** | 13-Sep-14 | 24-Dec-14 | 15-Feb-15 | 07-Jun-15 |
| **2423** | 05-Sep-14 | 26-Dec-14 | 09-Feb-15 | 22-May-15 |
| **2423** | 22-Sep-14 | 26-Dec-14 | 17-Feb-15 | 28-May-15 |
| **2423** | 13-Sep-14 | 28-Dec-14 | 17-Feb-15 | 30-May-15 |
| **2423** | 20-Sep-14 | 31-Dec-14 | 23-Feb-15 | 05-Jun-15 |
| **2423** | 22-Sep-14 | 31-Dec-14 | 09-Feb-15 | 28-May-15 |

**Appendix 1:** Data from the interviews with farmers for 24 NDVI class

| Sample area | Plant A | Harvest A | Plant B | Harvest B |
|---|---|---|---|---|
| **2431** | 05-Oct-14 | 15-Jan-15 | 15-Feb-15 | 15-Jun-15 |
| **2431** | 20-Sep-14 | 15-Jan-15 | 20-Feb-15 | 05-Jun-15 |
| **2431** | 27-Sep-14 | 18-Jan-15 | 25-Feb-15 | 19-Jun-15 |
| **2431** | 25-Sep-14 | 20-Jan-15 | 15-Feb-15 | 21-Jun-15 |
| **2431** | 27-Sep-14 | 20-Jan-15 | 17-Feb-15 | 30-May-15 |
| **2431** | 23-Sep-14 | 20-Jan-15 | 15-Feb-15 | 10-Jun-15 |
| **2431** | 25-Sep-14 | 25-Jan-15 | 22-Feb-15 | 16-Jun-15 |
| **2431** | 29-Sep-14 | 25-Jan-15 | 25-Feb-15 | 31-May-15 |
| **2431** | 20-Sep-14 | 01-Feb-15 | 25-Feb-15 | 07-Jun-15 |
| **2431** | 01-Oct-14 | 01-Feb-15 | 20-Feb-15 | 15-Jun-15 |
| **2431** | 03-Sep-14 | 01-Feb-15 | 25-Feb-15 | 19-Jun-15 |
| | | | | |
| **2432** | 25-Sep-14 | 10-Jan-15 | 25-Feb-15 | 20-Jun-15 |
| **2432** | 25-Sep-14 | 20-Jan-15 | 15-Feb-15 | 30-May-15 |
| **2432** | 20-Sep-14 | 20-Jan-15 | 25-Feb-15 | 10-Jun-15 |
| **2432** | 25-Sep-14 | 20-Jan-15 | 15-Feb-15 | 15-Jun-15 |
| **2432** | 25-Sep-14 | 20-Jan-15 | 01-Mar-15 | 12-Jun-15 |
| **2432** | 25-Sep-14 | 20-Jan-15 | 10-Feb-15 | 20-Jun-15 |
| **2432** | 25-Sep-14 | 25-Jan-15 | 25-Feb-15 | 15-Jun-15 |
| **2432** | 25-Sep-14 | 25-Jan-15 | 20-Feb-15 | 20-Jun-15 |
| **2432** | 05-Oct-14 | 04-Feb-15 | 15-Feb-15 | 10-Jun-15 |
| | | | | |
| **2433** | 20-Sep-14 | 01-Jan-15 | 15-Feb-15 | 30-May-15 |
| **2433** | 20-Sep-14 | 05-Jan-15 | 15-Feb-15 | 05-Jun-15 |
| **2433** | 25-Sep-14 | 10-Jan-15 | 25-Feb-15 | 05-Jun-15 |
| **2433** | 30-Sep-14 | 10-Jan-15 | 15-Feb-15 | 05-Jun-15 |
| **2433** | 15-Sep-14 | 10-Jan-15 | 15-Feb-15 | 05-Jun-15 |
| **2433** | 20-Sep-14 | 10-Jan-15 | 25-Feb-15 | 05-Jun-15 |
| **2433** | 20-Sep-14 | 26-Dec-14 | 10-Feb-15 | 25-May-15 |
| **2433** | 15-Sep-14 | 31-Dec-14 | 10-Feb-15 | 25-May-15 |
| | | | | |
| **2434** | 20-Sep-14 | 01-Jan-15 | 22-Feb-15 | 10-Jun-15 |
| **2434** | 20-Sep-14 | 02-Jan-15 | 20-Feb-15 | 30-May-15 |
| **2434** | 22-Sep-14 | 04-Jan-15 | 15-Feb-15 | 01-Jun-15 |
| **2434** | 20-Sep-14 | 05-Jan-15 | 25-Feb-15 | 05-Jun-15 |
| **2434** | 15-Sep-14 | 05-Jan-15 | 20-Feb-15 | 25-May-15 |
| **2434** | 25-Sep-14 | 10-Jan-15 | 20-Feb-15 | 20-Jun-15 |
| **2434** | 30-Sep-14 | 15-Jan-15 | 25-Feb-15 | 15-Jun-15 |
| **2434** | 15-Sep-14 | 25-Dec-14 | 15-Feb-15 | 25-May-15 |
| **2434** | 19-Sep-14 | 30-Dec-14 | 18-Feb-15 | 03-Jun-15 |

**Appendix 1** (continued): Data from the interviews with farmers for NDVI class 24

| Sample area | Plant A | Harvest A | Plant B | Harvest B |
|---|---|---|---|---|
| **5411** | 05-Sep-14 | 01-Jan-15 | _ | _ |
| **5411** | 06-Sep-14 | 02-Jan-15 | _ | _ |
| **5411** | 30-Aug-14 | 05-Jan-15 | _ | _ |
| **5411** | 05-Sep-14 | 08-Jan-15 | _ | _ |
| **5411** | 30-Aug-14 | 10-Jan-15 | _ | _ |
| **5411** | 31-Aug-14 | 10-Jan-15 | _ | _ |
| **5411** | 30-Aug-14 | 10-Jan-15 | _ | _ |
| **5411** | 30-Aug-14 | 10-Jan-15 | _ | _ |
| **5411** | 25-Aug-14 | 12-Jan-15 | _ | _ |
| **5411** | 06-Sep-14 | 12-Jan-15 | _ | _ |
| **5411** | 09-Sep-14 | 15-Jan-15 | _ | _ |
| **5411** | 05-Sep-14 | 15-Jan-15 | _ | _ |
| | | | | |
| **5412** | 18-Jun-14 | 01-Jan-15 | _ | _ |
| **5412** | 20-Jun-14 | 02-Jan-15 | _ | _ |
| **5412** | 05-Jun-14 | 05-Jan-15 | _ | _ |
| **5412** | 15-Jun-14 | 08-Jan-15 | _ | _ |
| **5412** | 15-Jun-14 | 10-Jan-15 | _ | _ |
| **5412** | 11-Jun-14 | 10-Jan-15 | _ | _ |
| **5412** | 20-Jun-14 | 10-Jan-15 | _ | _ |
| **5412** | 05-Jul-14 | 12-Jan-15 | _ | _ |
| **5412** | 20-Jun-14 | 25-Dec-14 | _ | _ |
| **5412** | 20-Jun-14 | 31-Dec-14 | _ | _ |
| | | | | |
| **5413** | 06-Sep-14 | 05-Jan-15 | _ | _ |
| **5413** | 20-Aug-14 | 08-Jan-15 | _ | _ |
| **5413** | 03-Sep-14 | 08-Jan-15 | _ | _ |
| **5413** | 30-Aug-14 | 10-Jan-15 | _ | _ |
| **5413** | 25-Aug-14 | 10-Jan-15 | _ | _ |
| **5413** | 30-Aug-14 | 10-Jan-15 | _ | _ |
| **5413** | 05-Sep-14 | 12-Jan-15 | _ | _ |
| **5413** | 05-Sep-14 | 15-Jan-15 | _ | _ |
| **5413** | 09-Sep-14 | 20-Jan-15 | _ | _ |
| | | | | |
| **5414** | 22-Jun-14 | 05-Jan-15 | _ | _ |
| **5414** | 20-Jun-14 | 05-Jan-15 | _ | _ |
| **5414** | 15-Jun-14 | 08-Jan-15 | _ | _ |
| **5414** | 15-Jun-14 | 09-Jan-15 | _ | _ |
| **5414** | 20-Jun-14 | 10-Jan-15 | _ | _ |
| **5414** | 15-Jun-14 | 10-Jan-15 | _ | _ |
| **5414** | 05-Jul-14 | 10-Jan-15 | _ | _ |
| **5414** | 30-Jun-14 | 10-Jan-15 | _ | _ |
| **5414** | 20-Jun-14 | 25-Dec-14 | _ | _ |
| **5414** | 20-Jun-14 | 30-Dec-14 | _ | _ |
| **5414** | 20-Jun-14 | 31-Dec-14 | _ | _ |
| | | | | |
| **5421** | 25-Aug-14 | 20-Jan-15 | _ | _ |
| **5421** | 20-Aug-14 | 22-Jan-15 | _ | _ |
| **5421** | 30-Aug-14 | 25-Jan-15 | _ | _ |
| **5421** | 05-Sep-14 | 01-Feb-15 | _ | _ |
| **5421** | 31-Aug-14 | 01-Feb-15 | _ | _ |
| **5421** | 03-Sep-14 | 01-Feb-15 | _ | _ |
| **5421** | 05-Sep-14 | 01-Feb-15 | _ | _ |
| **5421** | 09-Sep-14 | 02-Feb-15 | _ | _ |
| **5421** | 30-Aug-14 | 04-Feb-15 | _ | _ |
| | | | | |
| **5422** | 20-Aug-14 | 01-Feb-15 | _ | _ |
| **5422** | 20-Aug-14 | 02-Feb-15 | _ | _ |
| **5422** | 25-Aug-14 | 05-Feb-15 | _ | _ |
| **5422** | 20-Aug-14 | 10-Feb-15 | _ | _ |
| **5422** | 25-Aug-14 | 10-Feb-15 | _ | _ |
| **5422** | 06-Sep-14 | 12-Feb-15 | _ | _ |
| **5422** | 05-Sep-14 | 12-Feb-15 | _ | _ |
| **5422** | 30-Aug-14 | 15-Feb-15 | _ | _ |
| **5422** | 30-Aug-14 | 15-Feb-15 | _ | _ |
| **5422** | 30-Aug-14 | 15-Feb-15 | _ | _ |

**Appendix 2:** Data from the interviews with farmers for NDVI class 54

| Sample area | Plant A | Harvest A | Plant B | Harvest B |
|---|---|---|---|---|
| **5423** | 02-Aug-14 | 01-Jan-15 | _ | _ |
| **5423** | 10-Aug-14 | 10-Jan-15 | _ | _ |
| **5423** | 02-Aug-14 | 10-Jan-15 | _ | _ |
| **5423** | 05-Aug-14 | 10-Jan-15 | _ | _ |
| **5423** | 01-Aug-14 | 10-Jan-15 | _ | _ |
| **5423** | 25-Jul-14 | 25-Dec-14 | _ | _ |
| **5423** | 28-Jul-14 | 30-Dec-14 | _ | _ |
| **5423** | 25-Jul-14 | 31-Dec-14 | _ | _ |
| | | | | |
| **5424** | 05-Sep-14 | 10-Feb-15 | _ | _ |
| **5424** | 06-Sep-14 | 10-Feb-15 | _ | _ |
| **5424** | 25-Aug-14 | 15-Feb-15 | _ | _ |
| **5424** | 25-Aug-14 | 25-Feb-15 | _ | _ |
| **5424** | 15-Aug-14 | 29-Feb-15 | _ | _ |
| **5424** | 03-Sep-14 | 29-Feb-15 | _ | _ |
| **5424** | 30-Aug-14 | 01-Mar-15 | _ | _ |
| **5424** | 30-Aug-14 | 03-Mar-15 | _ | _ |
| **5424** | 06-Sep-14 | 09-Mar-15 | _ | _ |
| | | | | |
| **5431** | 15-Aug-14 | 15-Feb-15 | _ | _ |
| **5431** | 15-Aug-14 | 15-Feb-15 | _ | _ |
| **5431** | 20-Aug-14 | 29-Feb-15 | _ | _ |
| **5431** | 25-Aug-14 | 29-Feb-15 | _ | _ |
| **5431** | 20-Aug-14 | 29-Feb-15 | _ | _ |
| **5431** | 20-Aug-14 | 01-Mar-15 | _ | _ |
| **5431** | 13-Aug-14 | 03-Mar-15 | _ | _ |
| **5431** | 18-Aug-14 | 04-Mar-15 | _ | _ |
| **5431** | 15-Aug-14 | 09-Mar-15 | _ | _ |
| | | | | |
| **5432** | 30-Aug-14 | 05-Jan-15 | _ | _ |
| **5432** | 30-Aug-14 | 09-Jan-15 | _ | _ |
| **5432** | 05-Sep-14 | 10-Jan-15 | _ | _ |
| **5432** | 08-Sep-14 | 10-Jan-15 | _ | _ |
| **5432** | 15-Sep-14 | 10-Jan-15 | _ | _ |
| **5432** | 27-Aug-14 | 15-Jan-15 | _ | _ |
| **5432** | 05-Sep-14 | 20-Jan-15 | _ | _ |
| **5432** | 25-Aug-14 | 25-Jan-15 | _ | _ |
| | | | | |
| **5433** | 30-Aug-14 | 01-Jan-15 | _ | _ |
| **5433** | 03-Sep-14 | 01-Jan-15 | _ | _ |
| **5433** | 01-Sep-14 | 05-Jan-15 | _ | _ |
| **5433** | 06-Sep-14 | 05-Jan-15 | _ | _ |
| **5433** | 15-Sep-14 | 08-Jan-15 | _ | _ |
| **5433** | 15-Sep-14 | 10-Jan-15 | _ | _ |
| **5433** | 08-Sep-14 | 12-Jan-15 | _ | _ |
| **5433** | 27-Aug-14 | 25-Dec-14 | _ | _ |
| **5433** | 05-Sep-14 | 27-Dec-14 | _ | _ |
| **5433** | 30-Aug-14 | 31-Dec-14 | _ | _ |
| | | | | |
| **5434** | 03-Sep-14 | 10-Feb-15 | _ | _ |
| **5434** | 15-Sep-14 | 10-Feb-15 | _ | _ |
| **5434** | 05-Sep-14 | 15-Feb-15 | _ | _ |
| **5434** | 03-Sep-14 | 28-Feb-15 | _ | _ |
| **5434** | 10-Sep-14 | 29-Feb-15 | _ | _ |
| **5434** | 12-Sep-14 | 29-Feb-15 | _ | _ |
| **5434** | 05-Sep-14 | 01-Mar-15 | _ | _ |
| **5434** | 15-Sep-14 | 04-Mar-15 | _ | _ |

**Appendix 2**(continued)**:** Data from the interviews with farmers for NDVI class 54

| Sample area | Plant A | Harvest A | Plant B | Harvest B |
|---|---|---|---|---|
| **7011** | 23-Jul-14 | 01-Jan-15 | _ | _ |
| **7011** | 02-Aug-14 | 03-Jan-15 | _ | _ |
| **7011** | 25-Jul-14 | 05-Jan-15 | _ | _ |
| **7011** | 05-Aug-14 | 05-Jan-15 | _ | _ |
| **7011** | 01-Aug-14 | 08-Jan-15 | _ | _ |
| **7011** | 28-Jul-14 | 10-Jan-15 | _ | _ |
| **7011** | 25-Jul-14 | 10-Jan-15 | _ | _ |
| **7011** | 05-Aug-14 | 12-Jan-15 | _ | _ |
| | | | | |
| **7012** | 02-Jul-14 | 01-Jan-15 | _ | _ |
| **7012** | 30-Jun-14 | 05-Jan-15 | _ | _ |
| **7012** | 08-Jul-14 | 10-Dec-14 | _ | _ |
| **7012** | 05-Jul-14 | 17-Dec-14 | _ | _ |
| **7012** | 05-Jul-14 | 20-Dec-14 | _ | _ |
| **7012** | 05-Jul-14 | 20-Dec-14 | _ | _ |
| **7012** | 30-Jun-14 | 25-Dec-14 | _ | _ |
| **7012** | 25-Jun-14 | 25-Dec-14 | _ | _ |
| **7012** | 02-Jul-14 | 30-Dec-14 | _ | _ |
| | | | | |
| **7013** | 12-May-14 | 01-Jan-15 | _ | _ |
| **7013** | 10-May-14 | 05-Jan-15 | _ | _ |
| **7013** | 08-May-14 | 10-Jan-15 | _ | _ |
| **7013** | 03-May-14 | 10-Jan-15 | _ | _ |
| **7013** | 05-May-14 | 10-Jan-15 | _ | _ |
| **7013** | 10-May-14 | 19-Dec-14 | _ | _ |
| **7013** | 10-May-14 | 20-Dec-14 | _ | _ |
| **7013** | 01-May-14 | 25-Dec-14 | _ | _ |
| **7013** | 05-May-14 | 27-Dec-14 | _ | _ |
| **7013** | 08-May-14 | 30-Dec-14 | _ | _ |
| | | | | |
| **7014** | 08-May-14 | 01-Jan-15 | _ | _ |
| **7014** | 10-May-14 | 08-Jan-15 | _ | _ |
| **7014** | 05-May-14 | 10-Jan-15 | _ | _ |
| **7014** | 10-May-14 | 10-Jan-15 | _ | _ |
| **7014** | 10-May-14 | 10-Jan-15 | _ | _ |
| **7014** | 01-May-14 | 10-Jan-15 | _ | _ |
| **7014** | 10-May-14 | 12-Jan-15 | _ | _ |
| **7014** | 05-May-14 | 10-Dec-14 | _ | _ |
| **7014** | 08-May-14 | 15-Dec-14 | _ | _ |
| **7014** | 01-May-14 | 20-Dec-14 | _ | _ |
| **7014** | 12-May-14 | 22-Dec-14 | _ | _ |
| | | | | |
| **7021** | 25-Jun-14 | 10-Dec-14 | _ | _ |
| **7021** | 05-Jul-14 | 10-Dec-14 | _ | _ |
| **7021** | 30-Jun-14 | 17-Dec-14 | _ | _ |
| **7021** | 25-Jun-14 | 18-Dec-14 | _ | _ |
| **7021** | 05-Jul-14 | 20-Dec-14 | _ | _ |
| **7021** | 30-Jun-14 | 20-Dec-14 | _ | _ |
| **7021** | 05-Jul-14 | 25-Dec-14 | _ | _ |
| **7021** | 08-Jul-14 | 30-Dec-14 | _ | _ |
| **7021** | 05-Jul-14 | 30-Dec-14 | _ | _ |
| | | | | |
| **7022** | 05-May-14 | 01-Jan-15 | _ | _ |
| **7022** | 05-May-14 | 05-Jan-15 | _ | _ |
| **7022** | 25-Apr-14 | 10-Jan-15 | _ | _ |
| **7022** | 10-May-14 | 20-Dec-14 | _ | _ |
| **7022** | 01-May-14 | 20-Dec-14 | _ | _ |
| **7022** | 25-Apr-14 | 22-Dec-14 | _ | _ |
| **7022** | 05-May-14 | 25-Dec-14 | _ | _ |
| **7022** | 10-May-14 | 25-Dec-14 | _ | _ |
| **7022** | 28-Apr-14 | 30-Dec-14 | _ | _ |

**Appendix 3:** Data from the interviews with farmers for NDVI class 70

| Sample area | Plant A | Harvest A | Plant B | Harvest B |
|---|---|---|---|---|
| **7023** | 05-May-14 | 01-Jan-15 | _ | _ |
| **7023** | 15-May-14 | 05-Jan-15 | _ | _ |
| **7023** | 15-May-14 | 10-Jan-15 | _ | _ |
| **7023** | 01-May-14 | 17-Dec-14 | _ | _ |
| **7023** | 10-May-14 | 20-Dec-14 | _ | _ |
| **7023** | 25-May-14 | 20-Dec-14 | _ | _ |
| **7023** | 05-May-14 | 25-Dec-14 | _ | _ |
| **7023** | 10-May-14 | 25-Dec-14 | _ | _ |
| **7023** | 25-May-14 | 30-Dec-14 | _ | _ |
| | | | | |
| **7024** | 08-May-14 | 01-Jan-15 | _ | _ |
| **7024** | 10-May-14 | 03-Jan-15 | _ | _ |
| **7024** | 01-May-14 | 05-Jan-15 | _ | _ |
| **7024** | 05-May-14 | 05-Jan-15 | _ | _ |
| **7024** | 25-Apr-14 | 05-Jan-15 | _ | _ |
| **7024** | 01-May-14 | 05-Jan-15 | _ | _ |
| **7024** | 10-May-14 | 10-Jan-15 | _ | _ |
| **7024** | 05-May-14 | 10-Jan-15 | _ | _ |
| **7024** | 10-May-14 | 25-Dec-14 | _ | _ |
| | | | | |
| **7031** | 25-Jul-14 | 10-Jan-15 | _ | _ |
| **7031** | 05-Aug-14 | 10-Jan-15 | _ | _ |
| **7031** | 01-Aug-14 | 10-Jan-15 | _ | _ |
| **7031** | 05-Aug-14 | 15-Jan-15 | _ | _ |
| **7031** | 25-Jul-14 | 15-Jan-15 | _ | _ |
| **7031** | 02-Aug-14 | 20-Jan-15 | _ | _ |
| **7031** | 25-Jul-14 | 20-Jan-15 | _ | _ |
| **7031** | 25-Jul-14 | 20-Jan-15 | _ | _ |
| **7031** | 25-Jul-14 | 25-Jan-15 | _ | _ |
| **7031** | 02-Aug-14 | 25-Jan-15 | _ | _ |
| | | | | |
| **7033** | 01-May-14 | 01-Jan-15 | _ | _ |
| **7033** | 05-May-14 | 01-Jan-15 | _ | _ |
| **7033** | 08-May-14 | 05-Jan-15 | _ | _ |
| **7033** | 05-May-14 | 05-Jan-15 | _ | _ |
| **7033** | 10-May-14 | 10-Jan-15 | _ | _ |
| **7033** | 01-May-14 | 10-Jan-15 | _ | _ |
| **7033** | 10-May-14 | 20-Dec-14 | _ | _ |
| **7033** | 12-May-14 | 22-Dec-14 | _ | _ |
| **7033** | 12-May-14 | 25-Dec-14 | _ | _ |
| **7033** | 10-May-14 | 30-Dec-14 | _ | _ |
| | | | | |
| **7034** | 05-May-14 | 01-Jan-15 | _ | _ |
| **7034** | 25-Apr-14 | 05-Jan-15 | _ | _ |
| **7034** | 25-Apr-14 | 05-Jan-15 | _ | _ |
| **7034** | 05-May-14 | 20-Dec-14 | _ | _ |
| **7034** | 12-May-14 | 20-Dec-14 | _ | _ |
| **7034** | 05-May-14 | 20-Dec-14 | _ | _ |
| **7034** | 05-May-14 | 22-Dec-14 | _ | _ |
| **7034** | 30-Apr-14 | 25-Dec-14 | _ | _ |
| **7034** | 10-May-14 | 25-Dec-14 | _ | _ |
| **7034** | 10-May-14 | 30-Dec-14 | _ | _ |
| **7034** | 25-Apr-14 | 30-Dec-14 | _ | _ |

**Appendix 3**(continued)**:** Data from the interviews with farmers for NDVI class 70

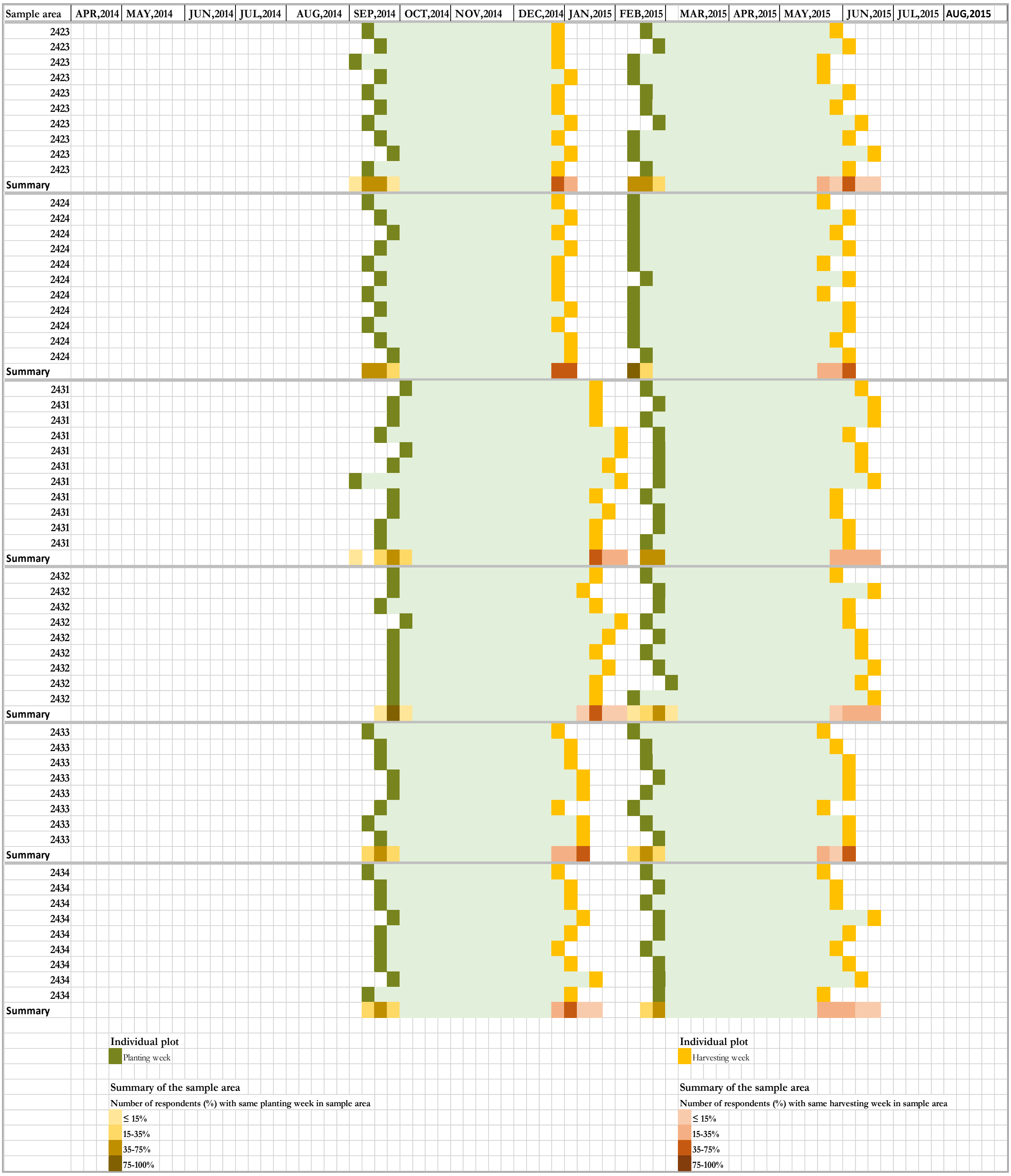
| Sample area | Plant A | Harvest A | Plant B | Harvest B |
|---|---|---|---|---|
| **8211** | 06-Sep-14 | 20-Jan-15 | _ | _ |
| **8211** | 25-Aug-14 | 20-Jan-15 | _ | _ |
| **8211** | 25-Aug-14 | 25-Jan-15 | _ | _ |
| **8211** | 06-Sep-14 | 25-Jan-15 | _ | _ |
| **8211** | 31-Aug-14 | 05-Feb-15 | _ | _ |
| **8211** | 30-Aug-14 | 05-Feb-15 | _ | _ |
| **8211** | 30-Aug-14 | 10-Feb-15 | _ | _ |
| **8211** | 30-Aug-14 | 10-Feb-15 | _ | _ |
| **8211** | 06-Sep-14 | 10-Feb-15 | _ | _ |
| **8211** | 06-Sep-14 | 10-Feb-15 | _ | _ |
| **8211** | 30-Aug-14 | 15-Feb-15 | _ | _ |
| | | | | |
| **8212** | 25-Aug-14 | 10-Feb-15 | _ | _ |
| **8212** | 30-Aug-14 | 10-Feb-15 | _ | _ |
| **8212** | 25-Aug-14 | 10-Feb-15 | _ | _ |
| **8212** | 30-Aug-14 | 10-Feb-15 | _ | _ |
| **8212** | 30-Aug-14 | 10-Feb-15 | _ | _ |
| **8212** | 30-Aug-14 | 10-Feb-15 | _ | _ |
| **8212** | 25-Aug-14 | 15-Feb-15 | _ | _ |
| **8212** | 20-Aug-14 | 15-Feb-15 | _ | _ |
| **8212** | 31-Aug-14 | 25-Feb-15 | _ | _ |
| **8212** | 20-Aug-14 | 25-Feb-15 | _ | _ |
| | | | | |
| **8213** | 20-Sep-14 | 05-Feb-15 | _ | _ |
| **8213** | 18-Sep-14 | 10-Feb-15 | _ | _ |
| **8213** | 15-Sep-14 | 10-Feb-15 | _ | _ |
| **8213** | 10-Sep-14 | 12-Feb-15 | _ | _ |
| **8213** | 15-Sep-14 | 15-Feb-15 | _ | _ |
| **8213** | 23-Sep-14 | 20-Feb-15 | _ | _ |
| **8213** | 05-Sep-14 | 25-Feb-15 | _ | _ |
| **8213** | 20-Sep-14 | 25-Feb-15 | _ | _ |
| **8213** | 23-Sep-14 | 25-Feb-15 | _ | _ |
| | | | | |
| **8214** | 05-Sep-14 | 08-Feb-15 | _ | _ |
| **8214** | 10-Sep-14 | 08-Feb-15 | _ | _ |
| **8214** | 10-Sep-14 | 10-Feb-15 | _ | _ |
| **8214** | 23-Sep-14 | 10-Feb-15 | _ | _ |
| **8214** | 15-Sep-14 | 10-Feb-15 | _ | _ |
| **8214** | 20-Sep-14 | 11-Feb-15 | _ | _ |
| **8214** | 20-Sep-14 | 15-Feb-15 | _ | _ |
| **8214** | 15-Sep-14 | 15-Feb-15 | _ | _ |
| **8214** | 15-Sep-14 | 20-Feb-15 | _ | _ |
| **8214** | 10-Sep-14 | 20-Feb-15 | _ | _ |
| **8214** | 05-Sep-14 | 22-Feb-15 | _ | _ |
| **8214** | 15-Sep-14 | 25-Feb-15 | _ | _ |
| **8214** | 20-Sep-14 | 25-Feb-15 | _ | _ |
| | | | | |
| **8221** | 20-Aug-14 | 15-Jan-15 | _ | _ |
| **8221** | 15-Aug-14 | 25-Jan-15 | _ | _ |
| **8221** | 20-Aug-14 | 25-Jan-15 | _ | _ |
| **8221** | 15-Aug-14 | 25-Jan-15 | _ | _ |
| **8221** | 20-Aug-14 | 05-Feb-15 | _ | _ |
| **8221** | 15-Aug-14 | 05-Feb-15 | _ | _ |
| **8221** | 25-Aug-14 | 10-Feb-15 | _ | _ |
| **8221** | 25-Aug-14 | 10-Feb-15 | _ | _ |
| **8221** | 25-Aug-14 | 10-Feb-15 | _ | _ |
| **8221** | 25-Aug-14 | 25-Feb-15 | _ | _ |
| | | | | |
| **8222** | 20-Aug-14 | 05-Feb-15 | _ | _ |
| **8222** | 30-Aug-14 | 05-Feb-15 | _ | _ |
| **8222** | 25-Aug-14 | 10-Feb-15 | _ | _ |
| **8222** | 30-Aug-14 | 10-Feb-15 | _ | _ |
| **8222** | 30-Aug-14 | 10-Feb-15 | _ | _ |
| **8222** | 25-Aug-14 | 15-Feb-15 | _ | _ |
| **8222** | 01-Sep-14 | 15-Feb-15 | _ | _ |
| **8222** | 25-Aug-14 | 15-Feb-15 | _ | _ |
| **8222** | 20-Aug-14 | 15-Feb-15 | _ | _ |
| **8222** | 30-Aug-14 | 25-Feb-15 | _ | _ |

**Appendix 4:** Data from the interviews with farmers for NDVI class 82

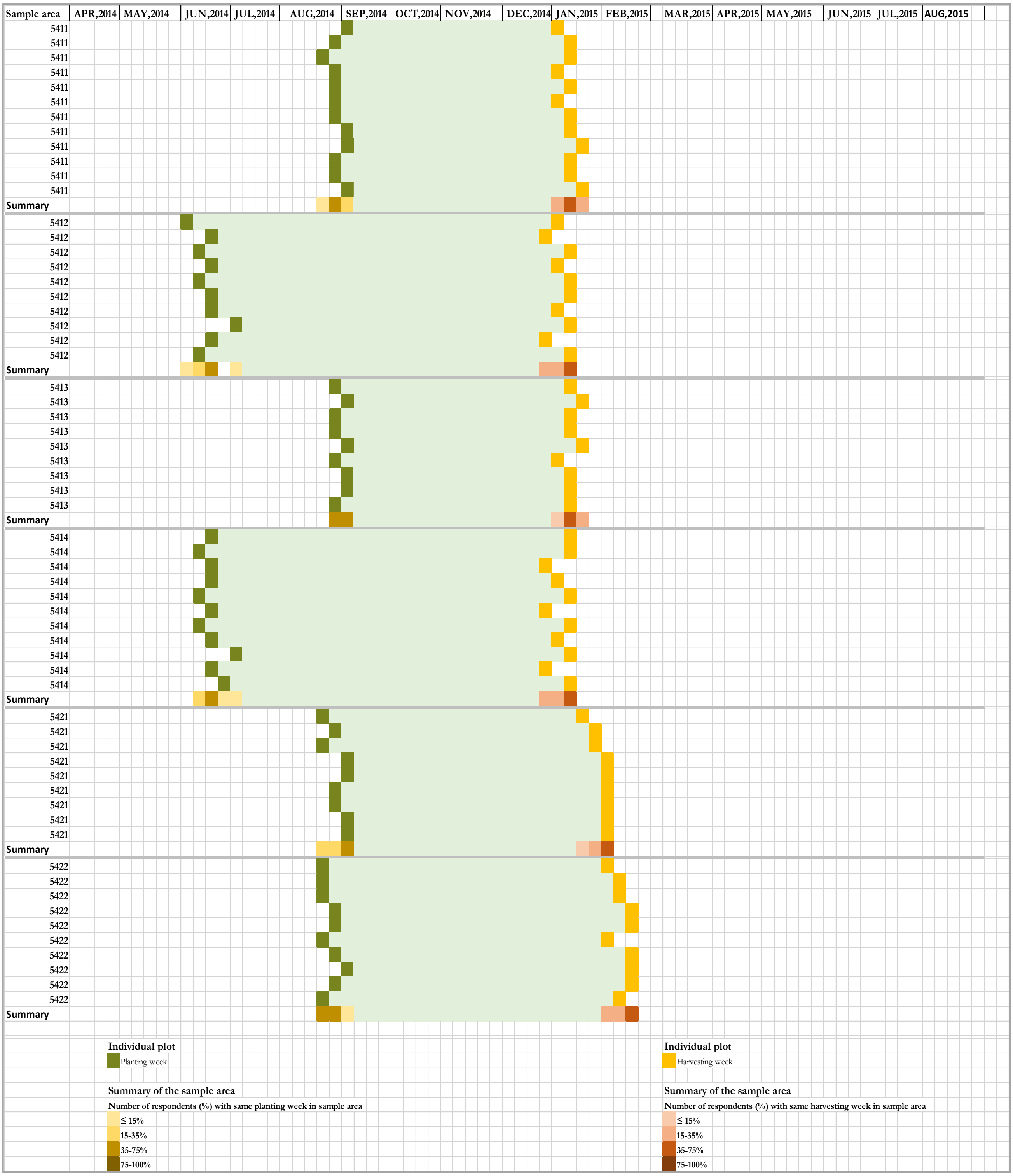
| Sample area | Plant A | Harvest A | Plant B | Harvest B |
|---|---|---|---|---|
| **8223** | 20-Aug-14 | 05-Jan-15 | | |
| **8223** | 15-Aug-14 | 10-Jan-15 | | |
| **8223** | 20-Aug-14 | 15-Jan-15 | | |
| **8223** | 20-Aug-14 | 15-Jan-15 | | |
| **8223** | 25-Aug-14 | 15-Jan-15 | | |
| **8223** | 25-Aug-14 | 15-Jan-15 | | |
| **8223** | 25-Aug-14 | 15-Jan-15 | | |
| **8223** | 25-Aug-14 | 20-Jan-15 | | |
| **8223** | 15-Aug-14 | 20-Jan-15 | | |
| **8223** | 20-Aug-14 | 20-Jan-15 | | |
| | | | | |
| **8224** | 10-Aug-14 | 08-Jan-15 | | |
| **8224** | 06-Aug-14 | 10-Jan-15 | | |
| **8224** | 15-Aug-14 | 10-Jan-15 | | |
| **8224** | 01-Aug-14 | 15-Jan-15 | | |
| **8224** | 10-Aug-14 | 15-Jan-15 | | |
| **8224** | 02-Aug-14 | 15-Jan-15 | | |
| **8224** | 05-Aug-14 | 20-Jan-15 | | |
| **8224** | 15-Aug-14 | 20-Jan-15 | | |
| **8224** | 02-Aug-14 | 20-Jan-15 | | |
| | | | | |
| **8231** | 12-Sep-14 | 01-Jan-15 | 25-Feb-15 | 20-Jun-15 |
| **8231** | 15-Sep-14 | 05-Jan-15 | 25-Feb-15 | 22-Jun-15 |
| **8231** | 10-Sep-14 | 10-Jan-15 | 25-Feb-15 | 30-Jun-15 |
| **8231** | 10-Sep-14 | 10-Jan-15 | 25-Feb-15 | 30-Jun-15 |
| **8231** | 10-Sep-14 | 10-Jan-15 | 15-Feb-15 | 25-Jun-15 |
| **8231** | 05-Sep-14 | 10-Jan-15 | 25-Feb-15 | 30-Jun-15 |
| **8231** | 15-Sep-14 | 15-Jan-15 | 15-Feb-15 | 15-Jun-15 |
| **8231** | 15-Sep-14 | 20-Jan-15 | 25-Feb-15 | 25-Jun-15 |
| **8231** | 05-Sep-14 | 25-Dec-14 | 25-Feb-15 | 20-Jun-15 |
| | | | | |
| **8232** | 20-Sep-14 | 01-Jan-15 | 10-Mar-15 | 30-Jun-15 |
| **8232** | 23-Sep-14 | 05-Jan-15 | 05-Mar-15 | 05-Jul-15 |
| **8232** | 20-Sep-14 | 05-Jan-15 | 01-Mar-15 | 25-Jun-15 |
| **8232** | 22-Sep-14 | 08-Jan-15 | 10-Mar-15 | 15-Jun-15 |
| **8232** | 10-Sep-14 | 10-Jan-15 | 10-Mar-15 | 25-Jun-15 |
| **8232** | 10-Sep-14 | 10-Jan-15 | 10-Mar-15 | 20-Jun-15 |
| **8232** | 23-Sep-14 | 12-Jan-15 | 03-Mar-15 | 20-Jun-15 |
| **8232** | 20-Sep-14 | 20-Jan-15 | 25-Feb-15 | 22-Jun-15 |
| **8232** | 15-Sep-14 | 30-Dec-14 | 08-Mar-15 | 20-Jun-15 |
| | | | | |
| **8233** | 10-Sep-14 | 01-Jan-15 | 25-Feb-15 | 25-Jun-15 |
| **8233** | 23-Sep-14 | 05-Jan-15 | 05-Mar-15 | 10-Jul-15 |
| **8233** | 15-Sep-14 | 08-Jan-15 | 03-Mar-15 | 25-Jun-15 |
| **8233** | 15-Aug-14 | 10-Jan-15 | 10-Mar-15 | 15-Jun-15 |
| **8233** | 20-Sep-14 | 10-Jan-15 | 05-Mar-15 | 22-Jun-15 |
| **8233** | 10-Sep-14 | 15-Jan-15 | 10-Mar-15 | 20-Jun-15 |
| **8233** | 10-Sep-14 | 20-Jan-15 | 01-Mar-15 | 25-Jun-15 |
| **8233** | 15-Sep-14 | 20-Jan-15 | 10-Mar-15 | 30-Jun-15 |
| **8233** | 23-Sep-14 | 20-Jan-15 | 05-Mar-15 | 25-Jun-15 |
| **8233** | 05-Sep-14 | 25-Dec-14 | 05-Mar-15 | 20-Jun-15 |
| **8233** | 15-Sep-14 | 30-Dec-14 | 10-Mar-15 | 30-Jun-15 |
| | | | | |
| **8234** | 09-Sep-14 | 05-Jan-15 | 05-Mar-15 | 05-Jul-15 |
| **8234** | 05-Sep-14 | 10-Jan-15 | 10-Mar-15 | 25-Jun-15 |
| **8234** | 15-Sep-14 | 10-Jan-15 | 01-Mar-15 | 25-Jun-15 |
| **8234** | 30-Aug-14 | 10-Jan-15 | 05-Mar-15 | 10-Jul-15 |
| **8234** | 10-Sep-14 | 15-Jan-15 | 10-Mar-15 | 15-Jul-15 |
| **8234** | 15-Sep-14 | 20-Jan-15 | 20-Feb-15 | 25-Jun-15 |
| **8234** | 15-Sep-14 | 20-Jan-15 | 25-Feb-15 | 25-Jun-15 |
| **8234** | 25-Aug-14 | 30-Dec-14 | 25-Feb-15 | 30-Jun-15 |

**Appendix 4**(continued)**:** Data from the interviews with farmers for NDVI class 82

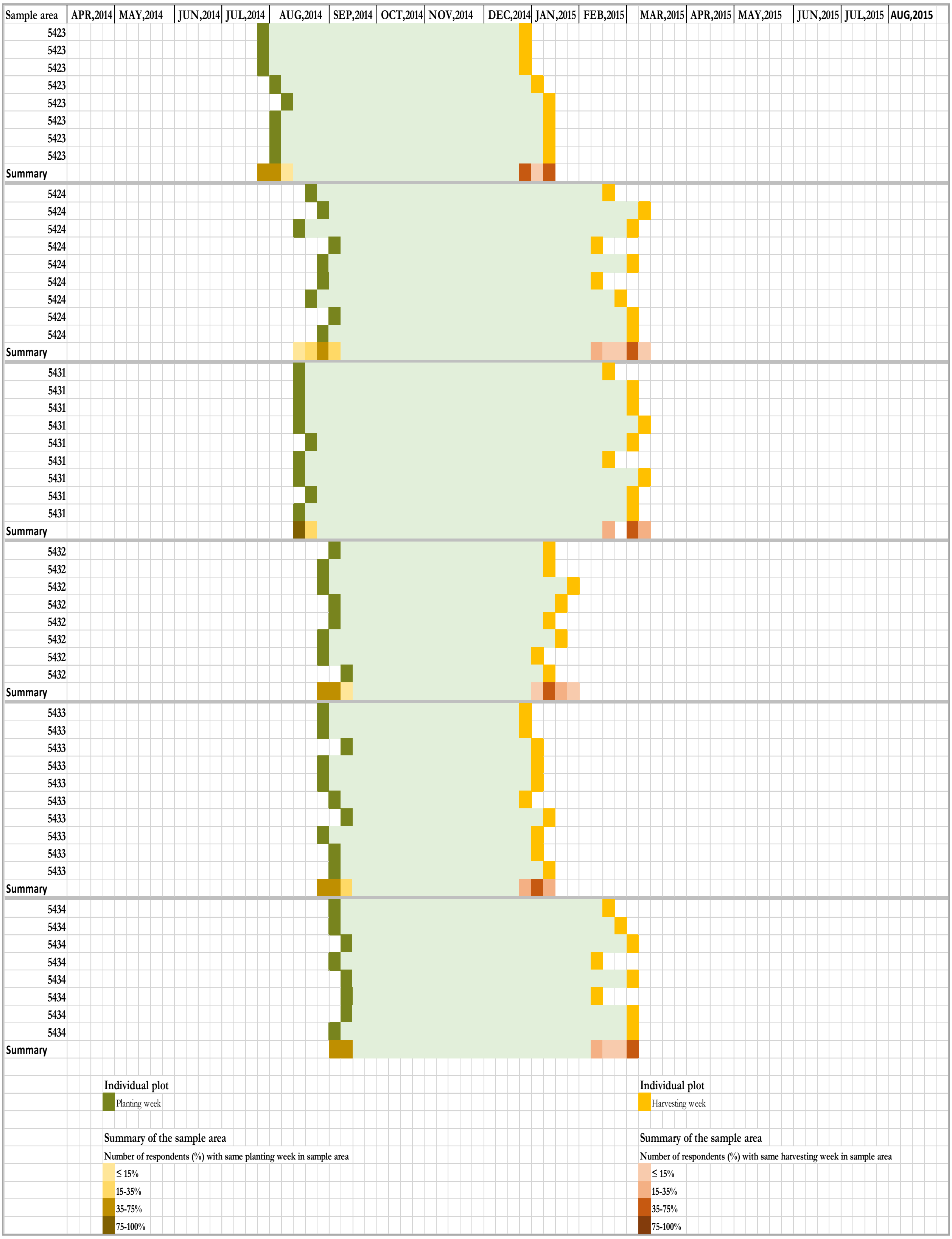

**Appendix 5**: Maize crop calendars for each plot of interviewed farmer in NDVI class 24



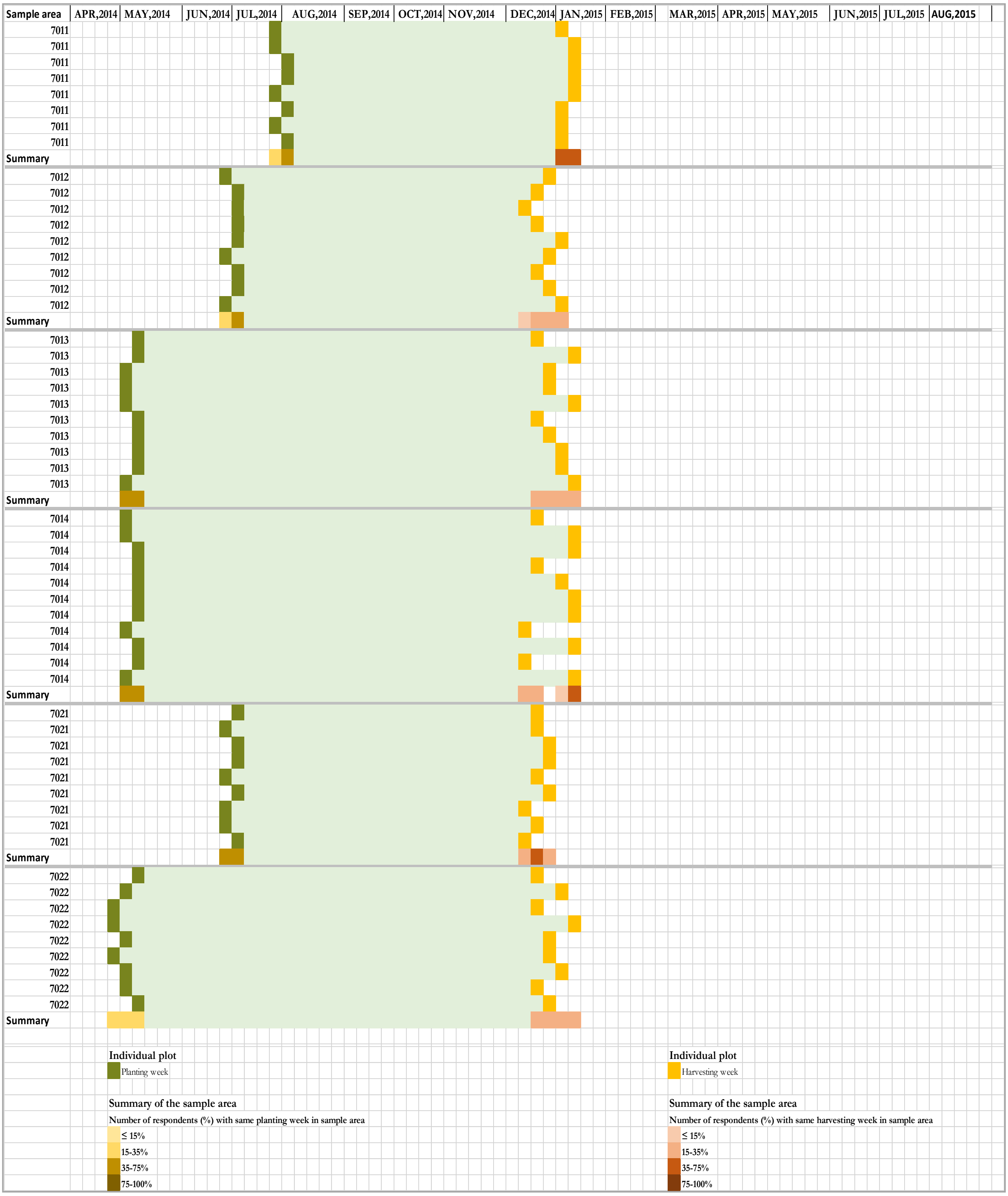

**Appendix 5**(continued): Maize crop calendar for each plot of interviewed farmer in NDVI class 24




**Appendix 6:** Maize crop calendar for each plot of interviewed farmer in 54 NDVI class

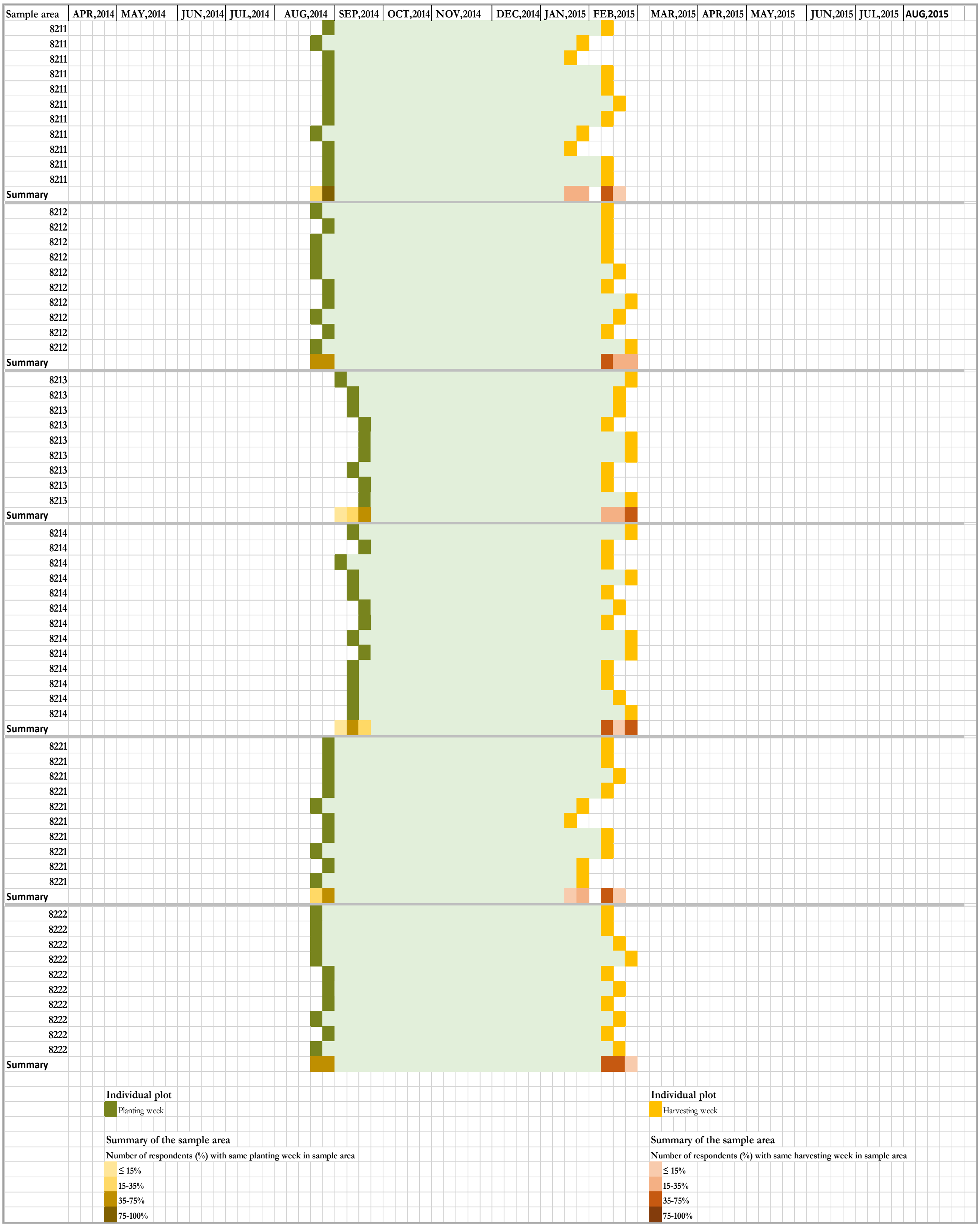



**Appendix 6**(continued)**:** Maize crop calendar for each plot of interviewed farmer in 54 NDVI class

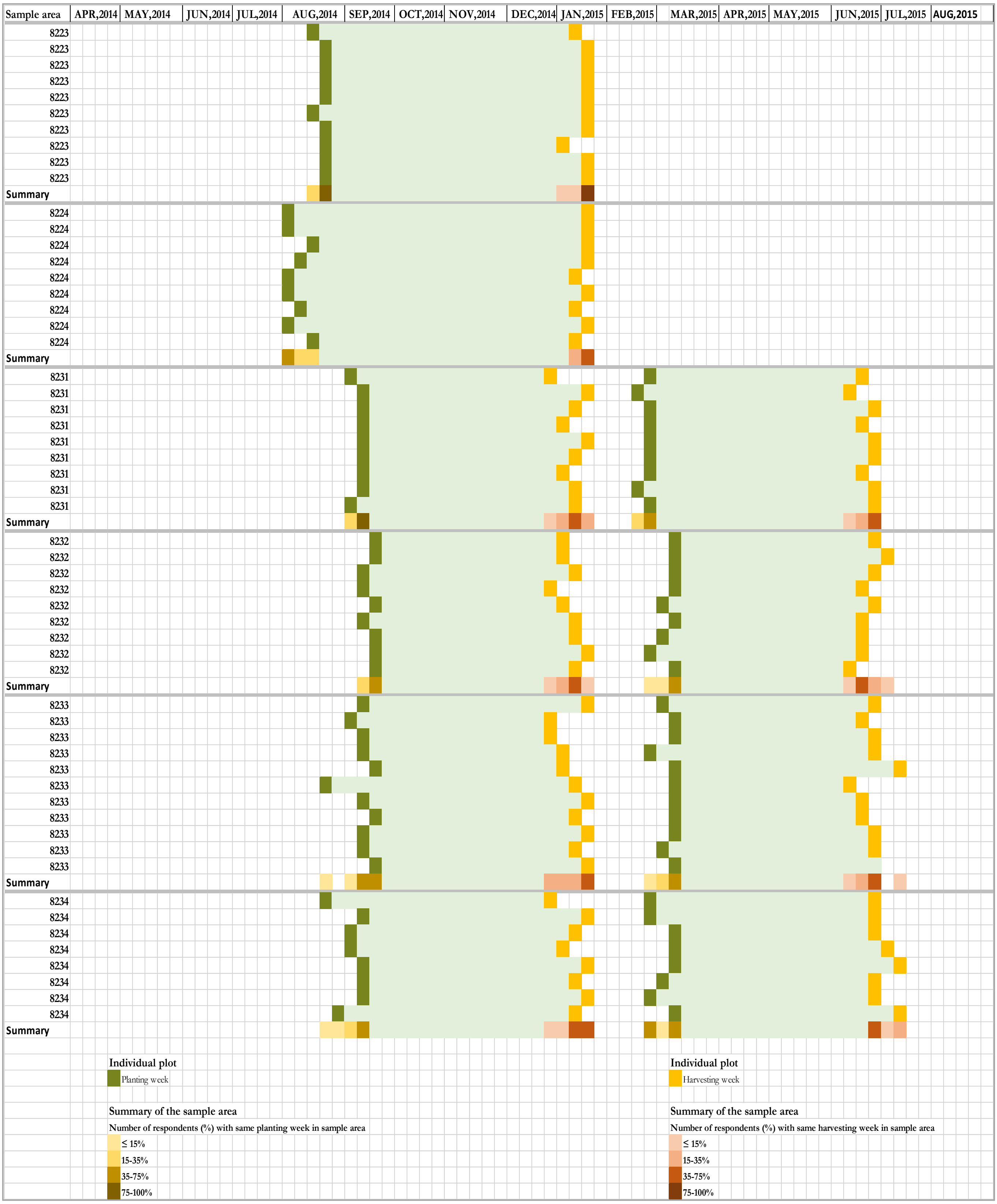



**Appendix 7:** Maize crop calendar for each plot of interviewed farmer in 70 NDVI class

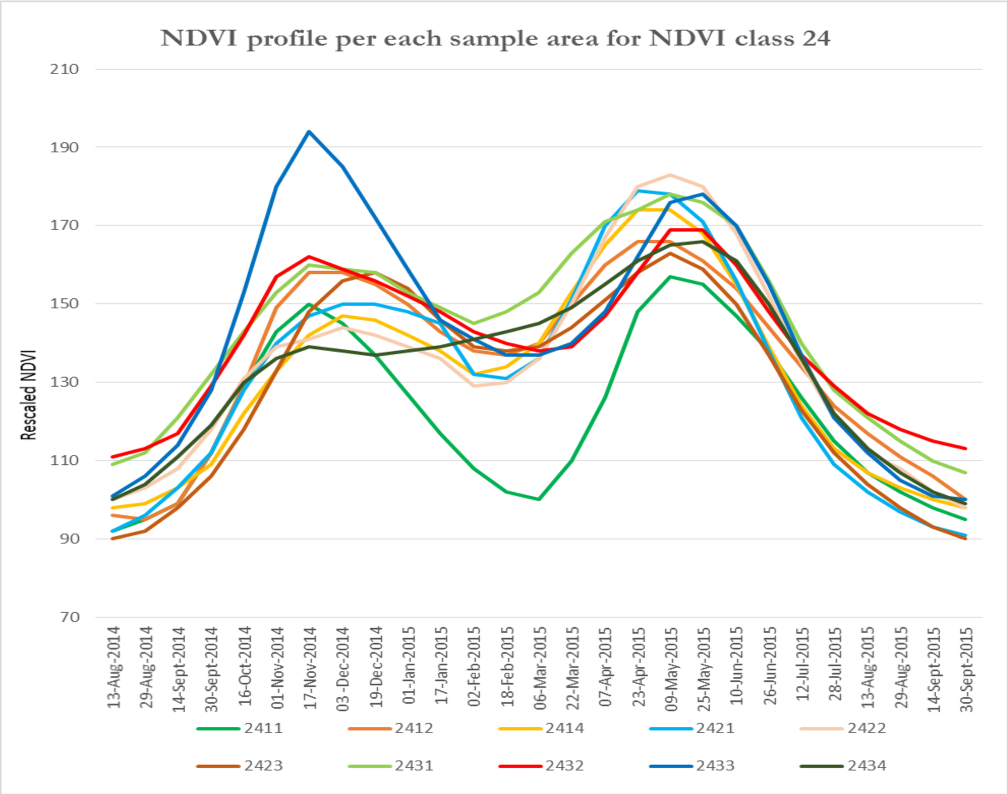

**Appendix 7** (continued)**:** Maize crop calendar for each plot of interviewed farmer in 70 NDVI class



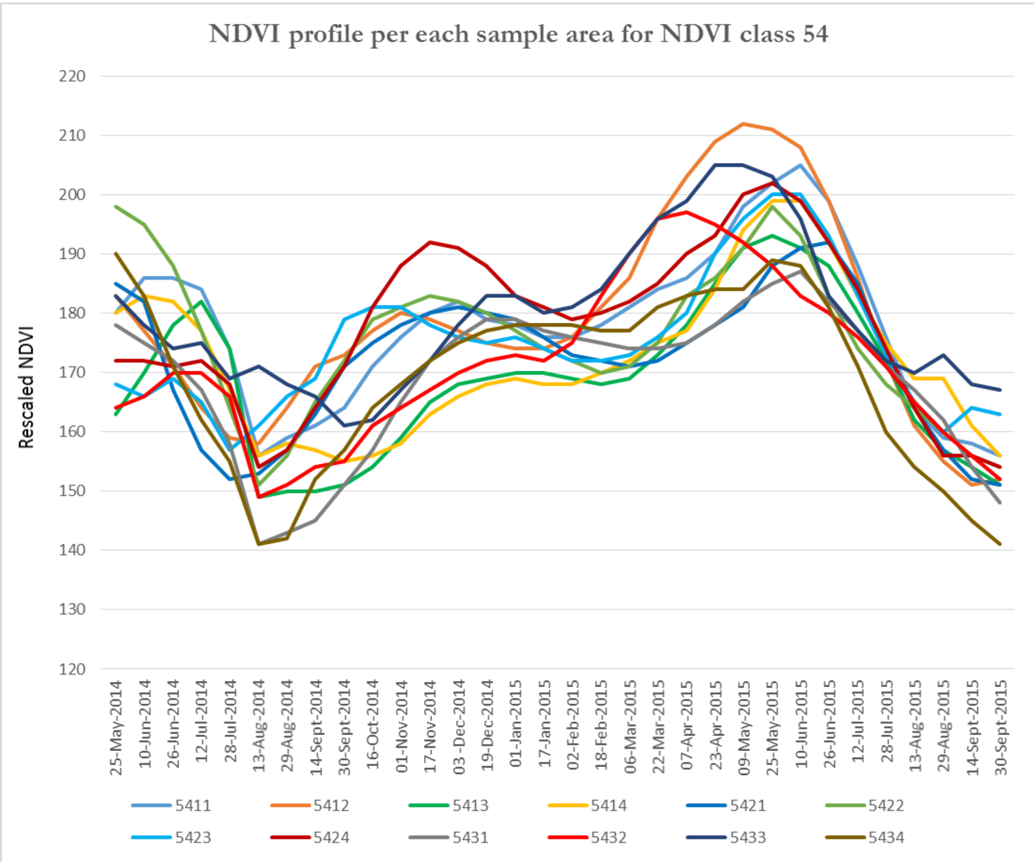

**Appendix 8**: Maize crop calendar for each plot of interviewed farmer in 82 NDVI class



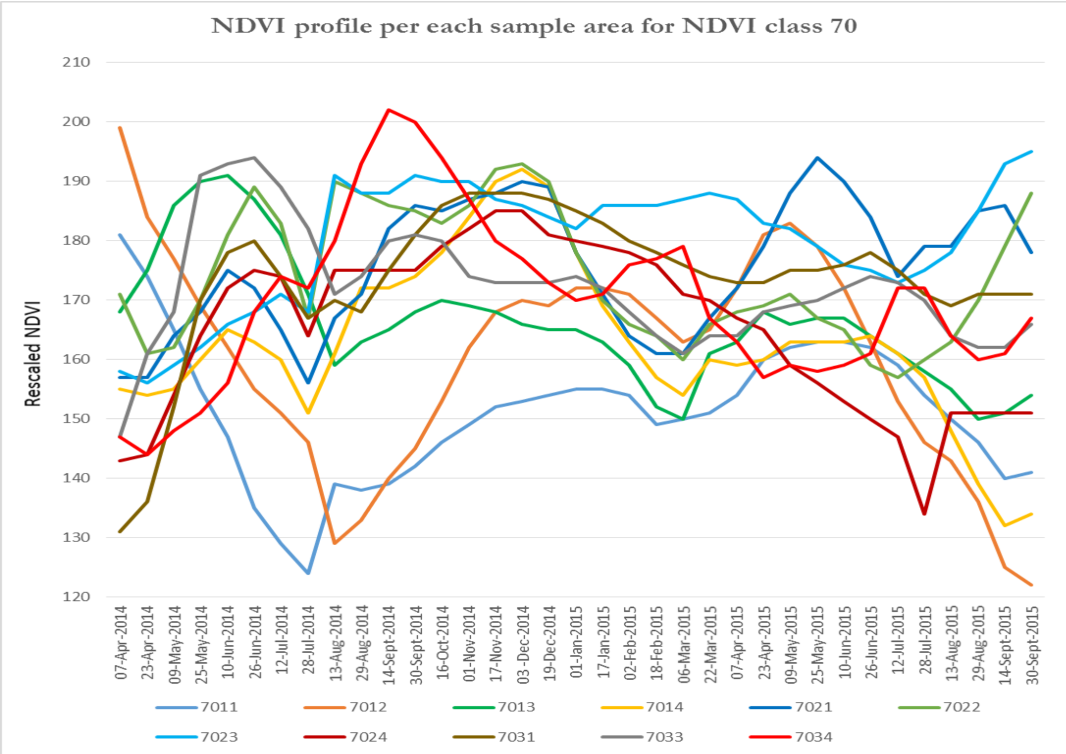

**Appendix 8** (continuous): Maize crop calendar for each plot of interviewed farmer in 82 NDVI class



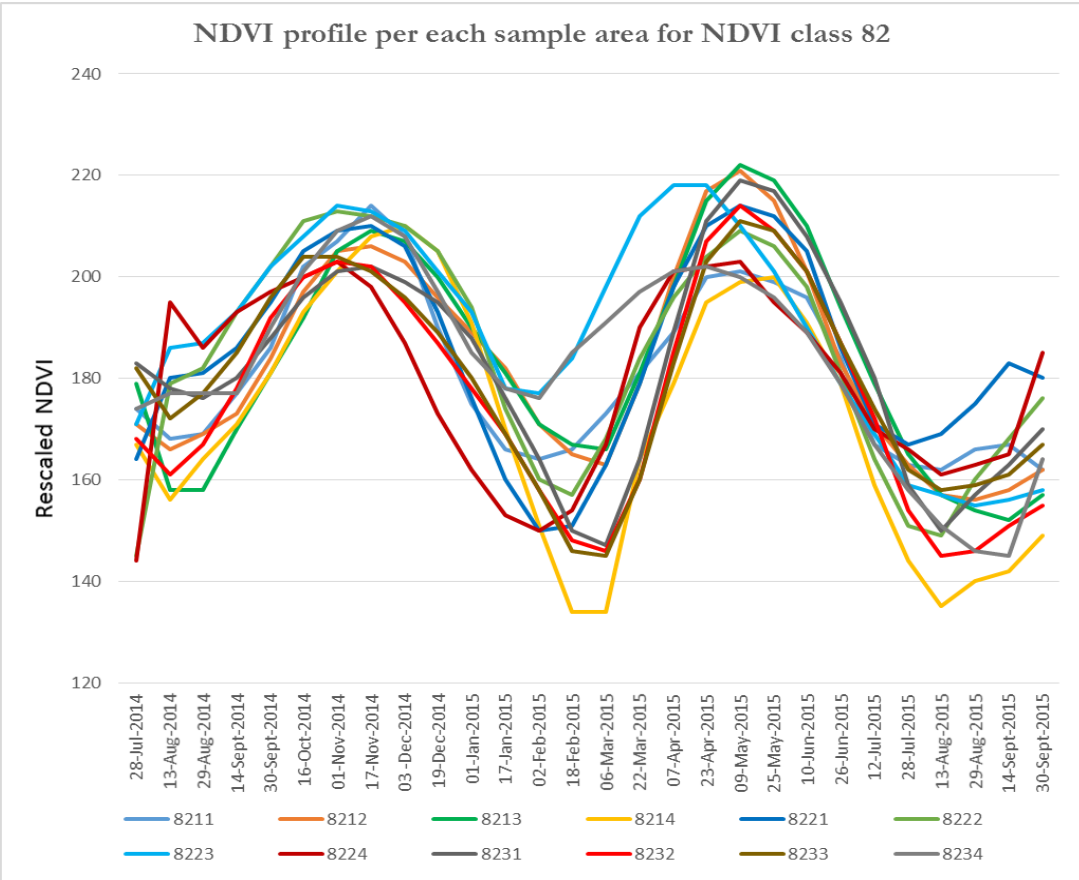

**Appendix 9**: NDVI profiles per sample area for NDVI class 24




**Appendix 10**: NDVI profiles per sample area for NDVI class 54




**Appendix 11**: NDVI profiles per sample area for NDVI class 54




**Appendix 12**: NDVI profiles per sample area for NDVI class 54

| | Level of Significance $\alpha$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| df | 0.200 | 0.100 | 0.075 | 0.050 | 0.025 | 0.010 | 0.005 | 0.001 | 0.0005 |
| 1 | 1.642 | 2.706 | 3.170 | 3.841 | 5.024 | 6.635 | 7.879 | 10.828 | 12.116 |
| 2 | 3.219 | 4.605 | 5.181 | 5.991 | 7.378 | 9.210 | 10.597 | 13.816 | 15.202 |
| 3 | 4.642 | 6.251 | 6.905 | 7.815 | 9.348 | 11.345 | 12.838 | 16.266 | 17.731 |
| 4 | 5.989 | 7.779 | 8.496 | 9.488 | 11.143 | 13.277 | 14.860 | 18.467 | 19.998 |
| 5 | 7.289 | 9.236 | 10.008 | 11.070 | 12.833 | 15.086 | 16.750 | 20.516 | 22.106 |
| 6 | 8.558 | 10.645 | 11.466 | 12.592 | 14.449 | 16.812 | 18.548 | 22.458 | 24.104 |
| 7 | 9.803 | 12.017 | 12.883 | 14.067 | 16.013 | 18.475 | 20.278 | 24.322 | 26.019 |
| 8 | 11.030 | 13.362 | 14.270 | 15.507 | 17.535 | 20.090 | 21.955 | 26.125 | 27.869 |
| 9 | 12.242 | 14.684 | 15.631 | 16.919 | 19.023 | 21.666 | 23.589 | 27.878 | 29.667 |
| 10 | 13.442 | 15.987 | 16.971 | 18.307 | 20.483 | 23.209 | 25.188 | 29.589 | 31.421 |
| 11 | 14.631 | 17.275 | 18.294 | 19.675 | 21.920 | 24.725 | 26.757 | 31.265 | 33.138 |
| 12 | 15.812 | 18.549 | 19.602 | 21.026 | 23.337 | 26.217 | 28.300 | 32.910 | 34.822 |
| 13 | 16.985 | 19.812 | 20.897 | 22.362 | 24.736 | 27.688 | 29.820 | 34.529 | 36.479 |
| 14 | 18.151 | 21.064 | 22.180 | 23.685 | 26.119 | 29.141 | 31.319 | 36.124 | 38.111 |
| 15 | 19.311 | 22.307 | 23.452 | 24.996 | 27.488 | 30.578 | 32.801 | 37.698 | 39.720 |
| 16 | 20.465 | 23.542 | 24.716 | 26.296 | 28.845 | 32.000 | 34.267 | 39.253 | 41.309 |
| 17 | 21.615 | 24.769 | 25.970 | 27.587 | 30.191 | 33.409 | 35.719 | 40.791 | 42.881 |
| 18 | 22.760 | 25.989 | 27.218 | 28.869 | 31.526 | 34.805 | 37.157 | 42.314 | 44.435 |
| 19 | 23.900 | 27.204 | 28.458 | 30.144 | 32.852 | 36.191 | 38.582 | 43.821 | 45.974 |
| 20 | 25.038 | 28.412 | 29.692 | 31.410 | 34.170 | 37.566 | 39.997 | 45.315 | 47.501 |
| 21 | 26.171 | 29.615 | 30.920 | 32.671 | 35.479 | 38.932 | 41.401 | 46.798 | 49.013 |
| 22 | 27.301 | 30.813 | 32.142 | 33.924 | 36.781 | 40.289 | 42.796 | 48.269 | 50.512 |
| 23 | 28.429 | 32.007 | 33.360 | 35.172 | 38.076 | 41.639 | 44.182 | 49.729 | 52.002 |
| 24 | 29.553 | 33.196 | 34.572 | 36.415 | 39.364 | 42.980 | 45.559 | 51.180 | 53.480 |
| 25 | 30.675 | 34.382 | 35.780 | 37.653 | 40.646 | 44.314 | 46.928 | 52.620 | 54.950 |
| 26 | 31.795 | 35.563 | 36.984 | 38.885 | 41.923 | 45.642 | 48.290 | 54.053 | 56.409 |
| 27 | 32.912 | 36.741 | 38.184 | 40.113 | 43.195 | 46.963 | 49.645 | 55.477 | 57.860 |
| 28 | 34.027 | 37.916 | 39.380 | 41.337 | 44.461 | 48.278 | 50.994 | 56.894 | 59.302 |
| 29 | 35.139 | 39.087 | 40.573 | 42.557 | 45.722 | 49.588 | 52.336 | 58.302 | 60.738 |
| 30 | 36.250 | 40.256 | 41.762 | 43.773 | 46.979 | 50.892 | 53.672 | 59.704 | 62.164 |
| 40 | 47.269 | 51.805 | 53.501 | 55.759 | 59.342 | 63.691 | 66.766 | 73.403 | 76.097 |
| 50 | 58.164 | 63.167 | 65.030 | 67.505 | 71.420 | 76.154 | 79.490 | 86.662 | 89.564 |
| 60 | 68.972 | 74.397 | 76.411 | 79.082 | 83.298 | 88.380 | 91.952 | 99.609 | 102.698 |
| 70 | 79.715 | 85.527 | 87.680 | 90.531 | 95.023 | 100.425 | 104.215 | 112.319 | 115.582 |
| 80 | 90.405 | 96.578 | 98.861 | 101.880 | 106.629 | 112.329 | 116.321 | 124.842 | 128.267 |
| 90 | 101.054 | 107.565 | 109.969 | 113.145 | 118.136 | 124.117 | 128.300 | 137.211 | 140.789 |
| 100 | 111.667 | 118.498 | 121.017 | 124.342 | 129.561 | 135.807 | 140.170 | 149.452 | 153.174 |

**Appendix13:** Chi-square distribution table

| NDVI classes pairs | Absolute value of means differences | LSD | Conclusion |
|---|---|---|---|
| 24, 54 | 38.30 | 6.63 | There are significant differences |
| 24, 70 | 115.18 | 6.75 | There are significant differences |
| 24, 82 | 20.36 | 6.56 | There are significant differences |
| 54, 70 | 76.88 | 6.48 | There are significant differences |
| 54, 82 | 17.94 | 6.28 | There are significant differences |
| 70, 82 | 94.82 | 6.40 | There are significant differences |

**Appendix 14:** Pairwise comparison for planting dates of NDVI classes maize crop calendars, at p=0.05

| NDVI classes pairs | Absolute value of means differences | LSD | Conclusion |
|---|---|---|---|
| 24, 54 | 9.21 | 4.41 | There are significant differences |
| 24, 70 | 13.90 | 4.49 | There are significant differences |
| 24, 82 | 13.35 | 4.36 | There are significant differences |
| 54, 70 | 23.11 | 4.31 | There are significant differences |
| 54, 82 | 13.35 | 4.18 | There are significant differences |
| 70, 82 | 27.25 | 4.26 | There are significant differences |

**Appendix 15:** Pairwise comparison for harvesting dates of NDVI classes maize crop calendars, at p=0.05

| Pairs of Practiced maize crop calendar groupings | Absolute value of means differences | LSD | Conclusion |
|---|---|---|---|
| CC1, CC2 | 124.95 | 4.20 | There are significant differences |
| CC1, CC3 | 86.09 | 4.42 | There are significant differences |
| CC1, CC4 | 106.60 | 4.45 | There are significant differences |
| CC2, CC3 | 38.86 | 4.06 | There are significant differences |
| CC2, CC4 | 18.35 | 4.09 | There are significant differences |
| CC3, CC4 | 20.51 | 4.32 | There are significant differences |

**Appendix 16:** Pairwise comparison for planting dates for practiced maize crop calendar groupings, at p=0.05

| Pairs of Practiced maize crop calendar groupings | Absolute value of means differences | LSD | Conclusion |
|---|---|---|---|
| CC1, CC2 | 13.10 | 2.57 | There are significant differences |
| CC1, CC3 | 9.67 | 2.70 | There are significant differences |
| CC1, CC4 | 45.75 | 2.72 | There are significant differences |
| CC2, CC3 | 3.43 | 2.48 | There are significant differences |
| CC2, CC4 | 32.65 | 2.50 | There are significant differences |
| CC3, CC4 | 36.08 | 2.64 | There are significant differences |

**Appendix 17:** Pairwise comparison for harvesting dates for practiced maize crop calendar groupings, at p=0.05