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Development of a national and sub-national crop calendars data set compatible with remote sensing derived land surface phenology

Technical description of the selection method used for building the crop calendars data set of the Anomaly hot Spots of Agricultural Production (ASAP)

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Contents

Abstract

Crop calendars are a fundamental component of agricultural production monitoring systems since they help analysts to focus on the seasons when different crop types are actually growing in the field. The Earth Observation based early warning system ASAP (Anomaly hot Spots of Agricultural Production) uses land surface phenology (LSP) metrics as proxy for crop calendars and applies parameters, such as the start and end of the season (SOS and EOS respectively) to define the period of active agricultural vegetation growth at pixel level. However, such information is not crop specific and it remains therefore relevant to use crop calendars from independent sources providing crop specific key phenological timings, such as sowing, growing and harvesting. Several institutions, including FAO and USDA make available crop calendars at the national level, which are widely used for agricultural monitoring.

The LSP derived SOS and EOS metrics can be associated with sowing and harvesting from such crop calendars. This report describes a method for the attribution of each growing season derived from LSP to a crop type listed in existing crop calendars. Based on a set of rules, we compare the growing seasons derived from LSP with the timings of the crop calendars, and select those crops where a match between LSP and crop calendar information is found. Agricultural statistics, including harvested area and production, are used in order to verify the correct identification and relevance of crop types by country.

The method also allows to downscale the existing national level crop calendars to the sub-national level. It therefore makes available sub-national level crop calendars, which are highly valuable for crop monitoring at that scale. The resulting crop calendars are available in the ASAP download section:

https://mars.jrc.ec.europa.eu/asap/download.php

1 Introduction

The JRC has recently developed an on-line early warning system called ASAP (Anomaly hot Spot of Agricultural Production), which provides timely warnings of agricultural production deficits in countries at high risk of food insecurity worldwide (Rembold et al., 2018). In particular, ASAP provides information at two levels of spatial and temporal aggregation. The first level refers to a 10-day time step automatic warning classification at the subnational administrative level. The second level involves the monthly verification of these warnings by agricultural analysts to identify agricultural production hotspots at national level.

For the interpretation of the warnings and the final identification of hot-spot countries, as well as for the scaling from first subnational level warning to national, the analysts consider several factors and critical information, amongst them crop calendars (Meroni et al., 2018).

The chronological sequence of the occurrence of different phenological stages of a crop in its growth cycle defines the so-called crop calendar (Patel and Oza, 2014). Crop calendars provide information about the timing of crop sowing, growing and harvesting periods.

For the present analysis, different sources of crop calendar information (i.e. FAO, 2005; USDA, 1994; IRRI GriSP,2013) were employed. Typically these calendars list the timing of planting and harvesting of the main crop types at country level. However, as pointed out by Sacks et al. (2010), few deficiencies exist in presently available crop calendar databases, such as: (i) they generally present only national-level averages and (ii) the data are made available in graphic format, making direct input into global crop models impossible.

Some exception exists, for example, FAO also provides (FAO, 2011) crop calendars for approximately 30 African countries, by agro-ecological zones within each country, that are defined in terms of climate, landform and soil characteristics. However, a unique layer mapping the agro-ecological zones used is not available, hampering their use in applications needing geospatial information.

The use of high temporal resolution satellite data has been emerging as an important tool to study crop phenology (You et al., 2013). Remote sensing sensors provide a regular, consistent and reliable measurement of vegetation response at various growth stages of crop (Patel and Oza, 2014). The spatio-temporal development of the vegetated land surface as revealed by satellite sensors is referred to as Land Surface Phenology (LSP, de Beurs and Henebry, 2004). LSP metrics typically describe (de Beurs and Henebry, 2010): (i) time of onset of greening, (ii) time of onset of senescence, (iii) timing of the maximum development during the growing season, and (iv) growing season length.

As the ASAP automatic warning classification system generates warnings related to all crop types that are in the growing phase in a given spatial unit at the time of analysis, it is important to provide more specific information to the analysts regarding the specific crop types that are likely to be present. Using moderate to coarse time series vegetation index, such as MODIS NDVI, phenological timing such as start of season (SOS) and end of season (EOS) can be estimated per pixel and for all vegetated areas (Meroni et al., 2014).

Whitcraft et al. (2015), using MODIS surface reflectance imagery, derived the timing of the agricultural growing season for all major crops within a given geographical area, providing the SOS of the earliest cropping cycle and EOS for the latest cropping cycle.

In this study, we developed a method for attributing a crop type to the main crop seasons recognized within an ASAP unit by using LSP. This process includes the recognition of the main phenological patterns in an ASAP unit, that is, the timing of the main growing seasons present in a unit. A crop mask (Pérez-Hoyos et al., 2017a, Pérez-Hoyos et al., 2017b) is used to retrieve LSP for the crop areas in the ASAP unit of interest. The main seasons present in the unit are then labelled with a specific crop type, based on the match between its LSP timing and to the crop calendar information.

The objective of this study is to link geographical information about main growth stages from LSP to the crop type information from crop calendars. This link is established identifying those LSP timings (for each ASAP unit of interest) that correspond to one of the crops and crop seasons listed in the crop calendar (for the country to which the ASAP unit belongs to). For a better understanding and evaluation of the cultivations identified in both levels of analysis, we also analyzed the agricultural statistics for major food crops such as sown and harvested area, and production quantity.

The result of the aforementioned process is the compilation of two crop calendar databases referring to the different spatial levels: the country level and ASAP subnational unit level. These databases contain the range of sowing and harvesting periods for each major crop that can be associated with Earth Observation (EO) derived phenology. Such information is published on the ASAP web page in the form of graphical calendars.

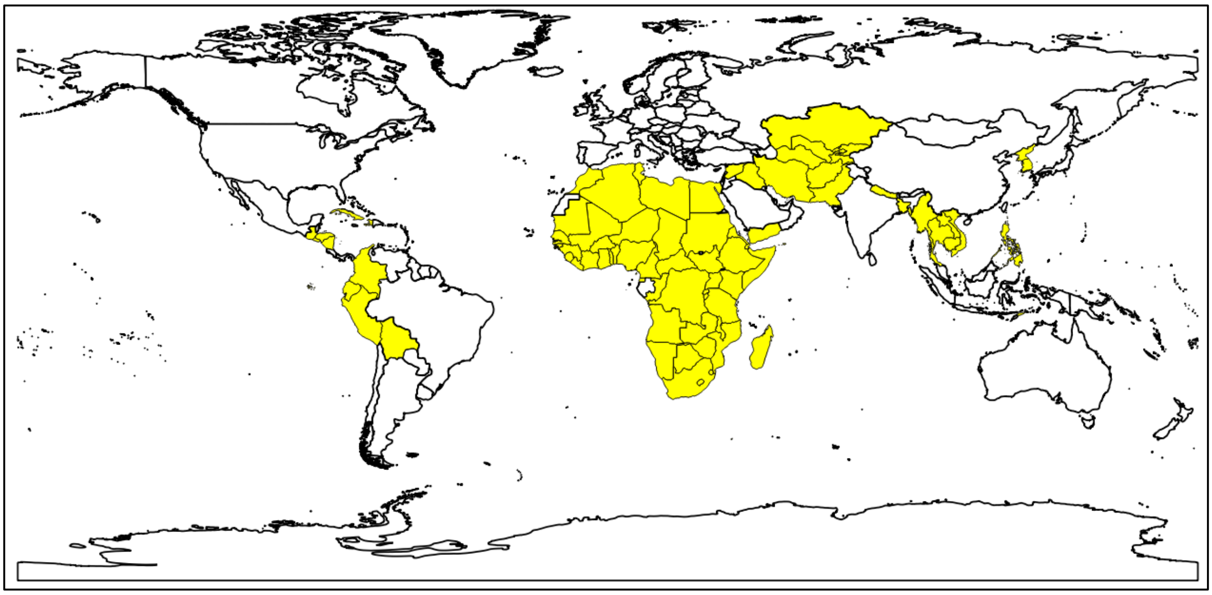
This technical report is organized as follows. In Section 2, we describe the spatial units of analysis, as well as the available crop calendar information and agricultural statistical data. Furthermore, the methods used for computation of remote sensing phenology are shortly described. In section 3, we outline the method for attributing a crop type to main crop seasons recognized on LSP, whereas section 4 presents the results of this process. Finally, conclusions and future improvements are presented in section 5.

2 Data

2.1 Geographical domain

The compilation of crop calendar information was performed for 80 countries (Figure 1), where food security and rural development are a priority sector for the European Development Fund programming and for countries that are monitored by the GEOGLAM Crop Monitor for Early Warning (Rembold et al., 2018). Target countries include most of the African countries and selected ones in Central America, Caribbean region, and Central and South East Asia. The national and subnational boundaries rely on the Global Administrative Units Layers (GAUL) of the Food and Agriculture Organization of the United Nations (FAO, 2014), where GAUL0 represents country level, while GAUL1 the first subnational level. It should be noted that, the GAUL1 units have been adapted to the specific needs of the early warning system with minor modifications, forming the ASAP unit (Rembold et al., 2018).

Figure 1. Food security priority countries for which the crop calendars were compiled are shown in yellow.



Source: FAO, JRC analysis

2.2 Crop calendars and agricultural statistics

Crop calendars, defining the dates for planting and harvesting specific crops, were obtained from three sources: 1) the United Nations Food and Agriculture Organization (FAO, 2005); 2) the United States Department of Agriculture (USDA,1994); and, 3) the International Rice Research Institute (IRRI; GriSP,2013). FAO crop calendars cover many countries worldwide, with an emphasis on developing countries, especially in Africa, while USDA focuses on Europe, Asia and North America (Sacks et al.,2010). IRRI provides rice calendars for 81 out of the 117 rice-producing countries (GriSP, 2013). All of the above-mentioned sources provide data at national level, with the exception of some large countries divided into two or three regions (e.g. south, north). FAO, IRRI and USDA crop calendars will hereafter referred to as “crop calendars”.

For all 80 countries of interest, agricultural statistical data are available, in particular the area harvested, the production quantity and yield, provided by the statistical database of FAOSTAT (FAO, 1998) for 173 crops, covering the years 1961-2016.

Table 1 lists the information at the first subnational administrative level (GAUL 1) that was used in the analysis. This type of information is important to support the process of attribution of a crop type to the LSP extracted at the subnational level. In fact, the knowledge of which crop is present (and with which abundance) can be used to downscale to crop calendar information available only at the country level. Most of such data were acquired from CountryStat (2005), a web-based information system for food and agriculture statistics at national and subnational level. Other sources refer to countries' offices of statistics, ministry of agriculture, or other types of governmental agencies.

Table 1. Statistical data for subnational level. Type of data available and source.

Countries	**Type of data**	**Source**
Afghanistan, Angola, Benin, Burkina Faso, Burundi, Gambia, Ghana, Guinea-Bissau, Kazakhstan, Lesotho, Mozambique, Nigeria, Swaziland, Togo, Zambia	Distribution of primary crop production	CountryStat
Angola, Gambia, Ghana, Guinea-Bissau, Togo, Zambia	Distribution of area harvested for primary crops	CountryStat
Afghanistan, Angola, Mozambique, Nigeria	Distribution of area sown for primary crops	CountryStat
Uganda	Area and Production of major crops by Season	CountryStat
Bangladesh	Estimates of area, yield and production for major crops	Bangladesh Bureau of Statistics
Eritrea	Area, production and yield	Crop and Food Security Assessment Mission
Ethiopia	Estimate of area and production of Grain crops	The Federal Democratic Republic of Ethiopia, Central Statistical Agency
Niger	Area, production and yield	Republique du Niger, Ministere de l'agriculture, Direction des Statistiques
Rwanda	Yield and production of main crops, Sowing dates per crop	National Institute of Statistics of Rwanda
Ecuador	Area sown, harvested and production of major crops, Detailed crop calendars for main producing	Ministerio de Agricultura y Ganaderia del Ecuador (MAG)

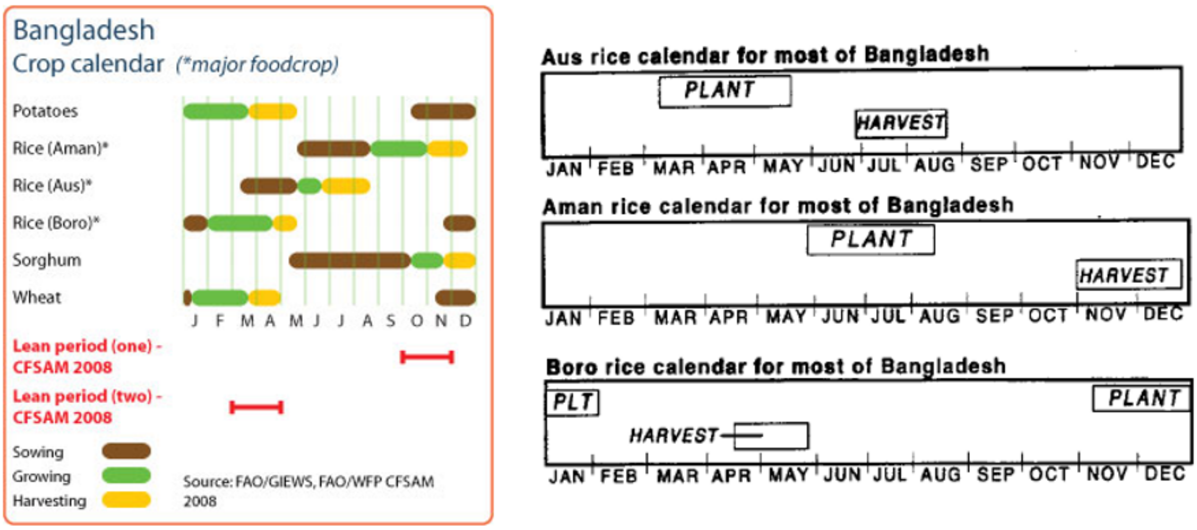
	subnational levels	
Peru	Area sown and harvested for each crop, Calendars for sowing and harvesting in the form of histograms	Ministerio de Agricultura y Riego del Peru (MAR)
Cuba	Production for main crops	Oficina Nacional de Estadisticas de Cuba e Informacion (ONEI)
Haiti	Crop calendars for each livelihood zone for major crops	Coordination Nationale de la Securite Alimentaire (CNSA)
Nicaragua	Maps presenting the main cultivation zones for different crops	El Instituto Nicaragüense de Tecnología Agropecuaria (INTA)

Source: JRC analysis

2.3 Digitization of calendars by spatial units

The FAO and USDA crop calendars present the data in graphical format, with bars spanning the typical agricultural seasons, where dates are given in months and dekads (i.e. 10-day periods covering the full calendar year with 36 dekads) (Figure 2).

Figure 2. FAO (left) and USDA (right) Crop Calendar for Bangladesh



Source: FAO (GIEWS), USDA (1994)

The process of digitization resulted in a table with the range for sowing and harvesting period for each of the 80 countries (an example in Table 2). The same process was employed for the crop calendars from USDA. The temporal resolution for FAO and USDA calendar is the dekad. IRRI instead provides the months of planting and harvesting for rice production seasons for each country (Table 3).

Although indicated in FAO calendars, the growing period appears to span over the residual time between the prescribed sowing and harvesting period. For example, sorghum presents a five-month period for sowing, while growing lasts only one month. Therefore, we focus only on sowing and harvesting for this study, without taking into consideration the growing period presented in FAO calendars.

Table 2. Digitized data from FAO Crop Calendar for Namibia

Crop	Sowing		Harvesting	
	min	max	min	max
Potatoes	29	36	9	14
Rice (Aman.)	15	23	31	35
Rice (Aus)	8	14	18	23
Rice (Boro)	33	3	12	14
Sorghum	14	28	33	36
Wheat	32	1	9	12

Source: FAO (GIEWS), JRC analysis

Table 3. IRRI Crop Calendar for Bangladesh

Crop	Planting	Harvesting
Rice (Aus)	April - May	July - Aug
Rice (Aman)	April - May	Nov - Dec
Rice (Boro)	Dec - Feb	April - May

Source: GriSP (2013)

2.4 Satellite derived phenology

Land surface phenology used in the ASAP system is defined by the satellite-derived phenology computed on the long-term average of 10-day MODIS NDVI data produced by BOKU University (Klisch and Atzberger, 2016) starting from to MOD13A2 and MYD13A2 V006 16-day Global data at 1 km resolution. Phenology was extracted using the SPIRITS software (Eerens et al., 2014, Rembold et al., 2015) applied to the historical average of the smoothed NDVI over the period 2013-2016. The software uses an approach based on thresholds on the green up and decay phases as described in White et al. (1997).

From the phenological analysis, the following key parameters are retrieved for each land pixel (Rembold et al., 2018):

— number of growing season per year (i.e. one or two);

— start of season (SOS, occurring at the time at which NDVI grows above the 25% the ascending amplitude of the seasonal profile);

— time of maximum NDVI (TOM);

— start of senescence period (SEN, when NDVI drops below 75% of the descending amplitude);

— end of the season (EOS, when NDVI drops below 35%).

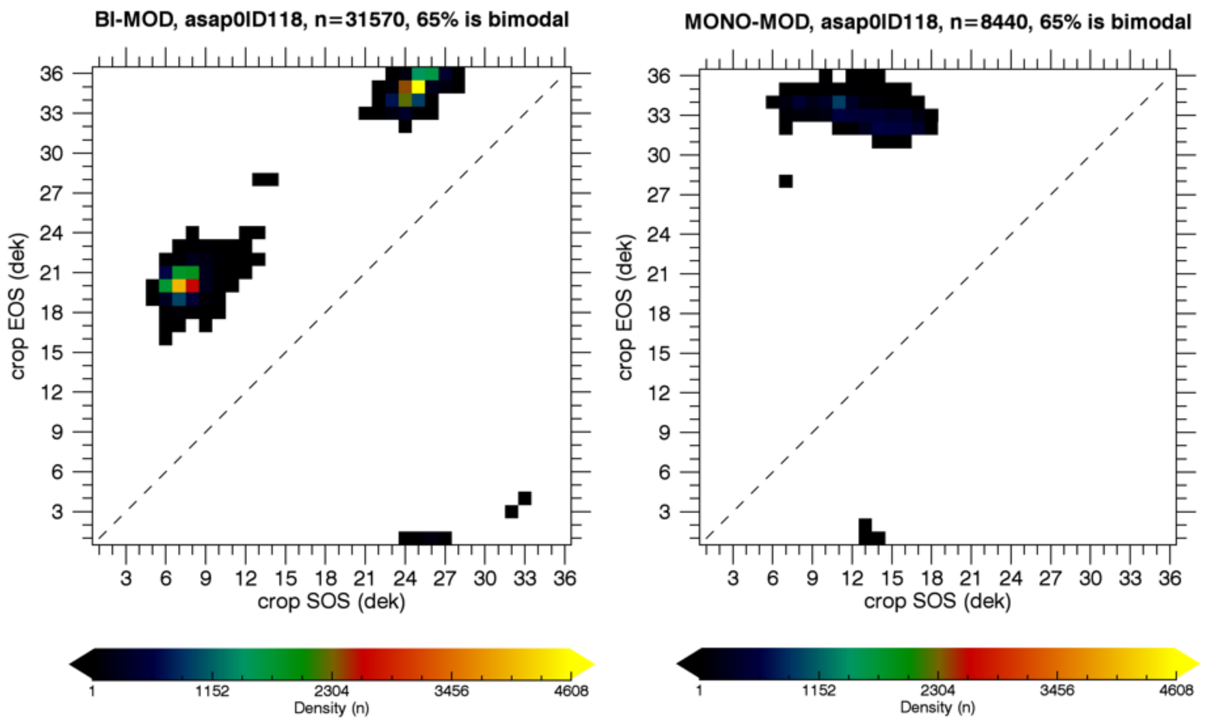
Mono- and bi-modal seasons (i.e. one and two growing cycles per solar year, respectively) may be present within an ASAP unit (Meroni et al., 2018). For the purpose of matching crop calendars with LSP phenology we focused on the following phenological timings: start of season (SOS) and end of season (EOS).

We use the ASAP crop mask to selectively extract only phenological information regarding crops. The ASAP crop mask is hybrid mask obtained merging multiple land cover products together to produce an integrated product that represents the best characterization of cropland at a particular location. In Africa, six global (GLC2000, MODIS land cover 2010, GlobCover 2009, GLCNMO 2008, LC-CCI 2010 and GlobeLand30) and 16 regional land cover datasets were compared at the country level using multi-criteria decision analysis to select the most appropriate one (Pérez-Hoyos et al., 2017a, Pérez-Hoyos et al., 2017b). Outside Africa, regional datasets were used where available, otherwise the six global datasets plus LCCI 2015 and FAO GLC-SHARE were compared and the optimal one was selected based on their accuracy and the comparison with FAOSTAT data. Crop presence in ASAP crop mask is expressed as area fraction image (AFI, the percentage of the grid cell occupied). In this work, we set a threshold of 25% crop cover to derive the binary mask of crop presence that was used to extract LSP.

SOS and EOS timings for each crop pixel within a given country and ASAP unit were extracted for all the countries of interest. Density scatterplots were produced for all units. For example, Figure 3 shows the scatterplot of the timing of SOS (x axis) vs. the timing of EOS (y axis). Timing is expressed in dekads. It is noted that both SOS and EOS are circular variables expressed on a 1 to 36 dekads interval. Therefore, a timing of 1 is not far from a timing of 36. The colour of the grid cells in these plots represents the number of pixels having the SOS and EOS combination of the cell. Colours from black to green, red and finally yellow indicate greater number of pixels.

Scatterplots were produced for national level (Gaul0) and ASAP unit level separately for the area showing mono-modal seasonality (one growing cycle per solar year) and the area showing bi-modal seasonality (two cycles per year).

Figure 3. Example bi-modal (left) and mono-modal (right) density scatterplot for Togo (Gaul_0)



Source: JRC analysis

3 Methods

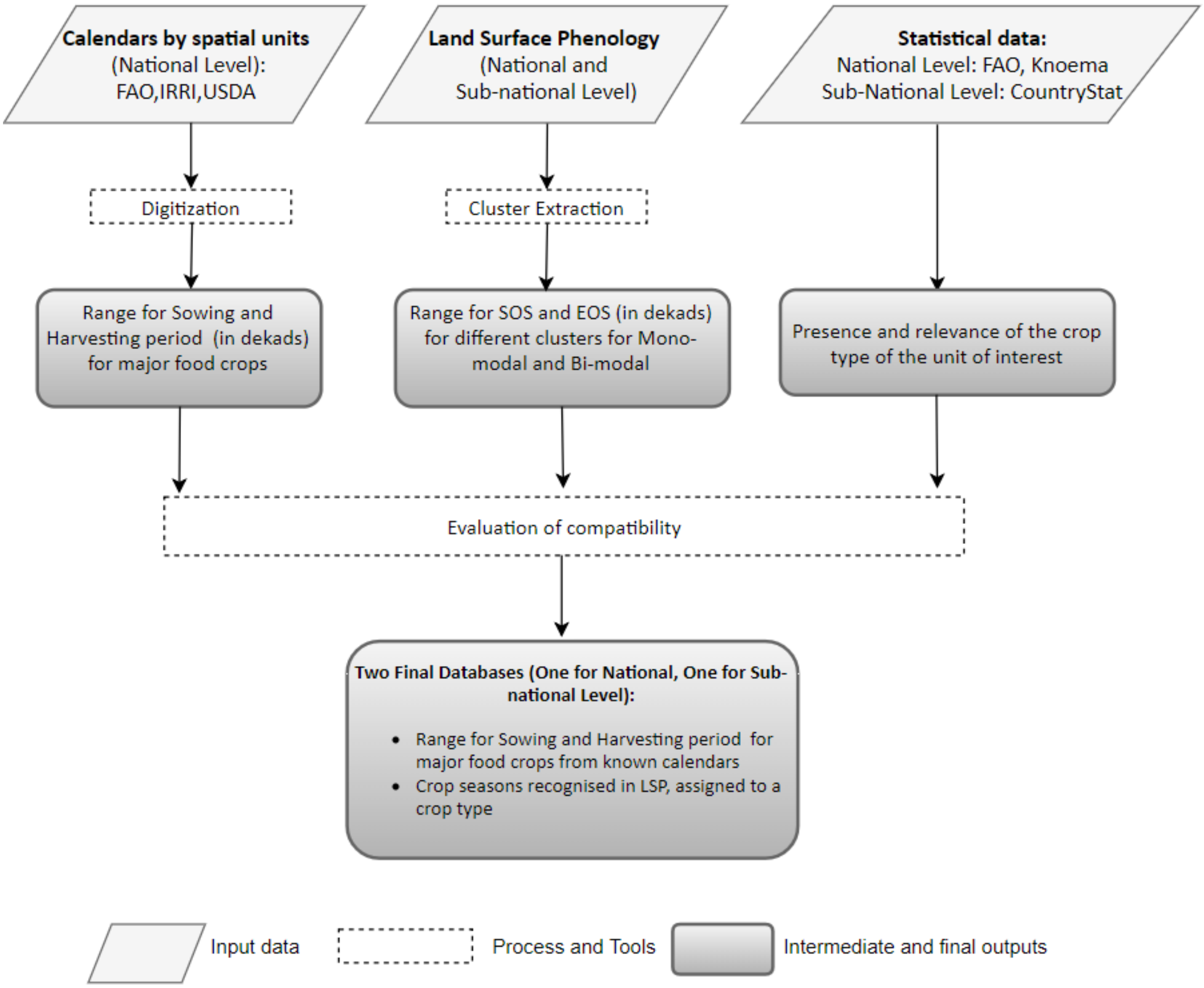
The flowchart of Figure 4 shows the steps followed for the attribution of a crop type to a main crop season recognized on LSP scatterplots. After processing the initial data, namely digitization for the crop calendars and cluster extraction from LSP, we obtained the following data (expressed in dekads): (i) the range for sowing and harvesting period for major food crops from the calendars, and (ii) the range for SOS and EOS for each identified cluster.

The process of finding the match between the crop types listed in the crop calendars and the LSP information is an iterative one. First, we analyzed the LSP data for the spatial unit of interest and we identified potential clusters of data characterized by similar SOS and EOS. Second, we compared this information to that of the crop calendars, listing the growing period of the crop types present in the spatial unit.

Finally, we evaluated the compatibility between the time of occurrence of SOS and EOS, derived from LSP, with the sowing and harvesting times indicated by the crop calendars and refined the first characterization of LSP clusters. When a LSP cluster was found compatible with the crop calendar timing for a specific crop, we labelled that cluster as that specific crop. Subnational statistical data (see Table 1) were used in this step to confirm or exclude the presence of a given crop type at the subnational level.

The mentioned steps are explained in detail in the following sections.

Figure 4. Data processing flowchart for the attribution of a crop type to main crop season recognized on LSP



Source: JRC analysis

3.1 Cluster extraction

In this section, we describe the method used for the identification of the main phenological seasons on the LSP derived from the remote sensing phenology analysis. For this purpose, we use the density scatterplots SOS vs. EOS. In such scatterplots, data points tend to cluster around some [SOS, EOS] couples, meaning that a large fraction of the pixels within the unit tends to have a growing season period characterized by similar start and end timings. These clusters are interpreted as main crop seasons. Variability around those key timings is expected as the same crop may have different SOS and/or EOS within the unit, for instance due to crops growing at different latitude, altitude, etc. Variability may also originate from the presence of different crops with different but overlapping seasonal timing.

A cluster is here loosely defined as dense area of the data space. For the cluster to be considered as a potential crop season, it must represent at least 5% of the total number of pixels represented by the crop mask in the specific unit of interest.

Clusters are visually identified on the scatterplot and their range of SOS and EOS is defined. It is noted that the range for SOS and EOS for the main growing seasons identified in LSP might be subjective when two clusters overlap. In this case, there is a degree of ambiguity regarding where one season ends and another starts.

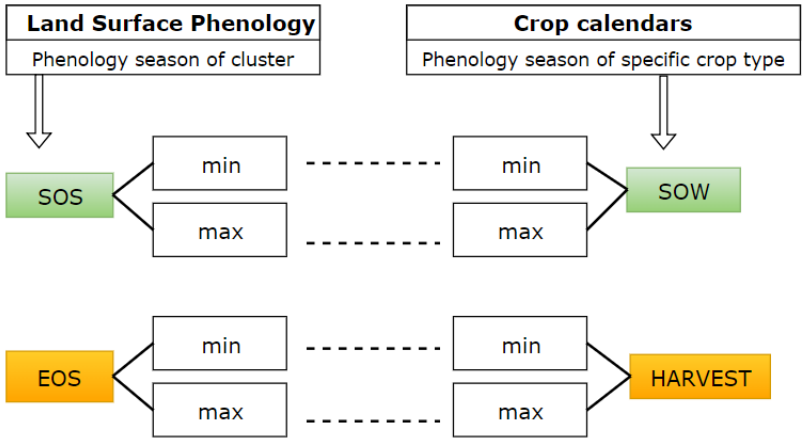
The result of this process is to identify the range of SOS and EOS, for the seasons present in the spatial unit of interest. A detailed example is presented in Section 4.1.

3.2 Comparison of LSP and FAO phenological seasons

A comparison between the crop calendars and the LSP phenology is performed, in order to evaluate if the season timings are compatible and if the LSP seasons can be matched with a specific crop listed in the crop calendars.

As already mentioned, LSP and crop calendars provide a range for the start and end of the growing season. These are sowing and harvesting for the crop calendars, and SOS and EOS for LSP. We assume that timing of SOS and EOS, derived from LSP can be matched with that of sowing and harvesting, derived from the known calendars, respectively. As shown in Figure 5, the match was established between the following: (i) min of SOS date and min of sowing date, (ii) max of SOS date and max of sowing date, (iii) min of EOS date and min of harvesting date, and (iv) max of EOS date and max of harvesting date.

Figure 5. Flowchart describing the timing of the phenology seasons that should match between LSP and Crop calendars



Source: JRC analysis

The range for SOS and EOS should be between the boundaries of sowing and harvest, respectively, in order to have a match. For this comparison, however, a margin of 3 dekads was considered an acceptable difference between crop calendars and LSP seasons and the rules for the comparison are presented in Table 4. In this table $SOS_{min,}$ SOS_{max}, $EOS_{min,}$ EOS_{max} refer to the minimum and maximum range of each cluster identified in LSP and $Sowing_{min,}$ $Sowing_{max}$, $Harvesting_{min,}$ $Harvesting_{max}$ refer to the minimum and maximum range of the respective timings in the crop calendars. This threshold was set considering the study of Brown and de Beurs (2008), where satellite derived estimates of the start of the season and ground observations of sowing dates for the semi-arid ecosystem of West Africa were compared and the root mean square error was between 12 to 26 days for all datasets used. The 3 dekads difference is considered an acceptable threshold, as SOS/EOS and Sowing/Harvesting, respectively, are closely related but still might represent slightly different phases of the plant's growth. In fact, SOS, defined as occurring at the time at which NDVI grows above the 25% the ascending amplitude of the seasonal profile, would obviously temporally follow sowing.

Table 4. Rules in order for LSP and crop calendars to match.

LSP	Rule
SOS_{min}	$\geq Sowing_{min}$ - 3
SOS_{max}	$\leq Sowing_{max}$ + 3
EOS_{min}	$\geq Harvesting_{min}$ - 3
EOS_{max}	$\geq Harvesting_{max}$ + 3

Source: JRC analysis

If the comparison between LSP and crop calendar complies with the mentioned rules, then a crop type listed in the calendar will be attributed to the LSP season.

Agricultural statistics, such as sown and harvested area, as well as production, are valuable during this step of the analysis and especially when the method is applied to the subnational level. For each country and each subnational level (see Table 1), the available statistical data were averaged and depicted in graphs for an easier interpretation. Based on this information, we could verify the correct identification of a crop type in LSP.

3.3 Limitations

Attributing a crop type to identified LSP seasons is a challenging task, since the subject of the analysis are large geographical areas, countries and subnational units, which are characterized by diversity in land cover types. In some cases, seasons identified on LSP scatterplots could not be matched with a crop from the crop calendars and vice versa.

Moreover, as found by Zhang et al. (2006), crops might have multiple growth and senescence cycles under different agricultural practices, so the same crop type may exhibit different LSP phenology in different locations with different management. Increased cropping intensity of a specific crop, meaning the number of times that a crop is grown in a single year in a particular field, can create difficulties in distinguishing the phenology for the crops, as for example in Vietnam where there might be 7 cycles of rice in 2 years, while the LSP retrieval method used here can handle a maximum of two growing seasons per year.

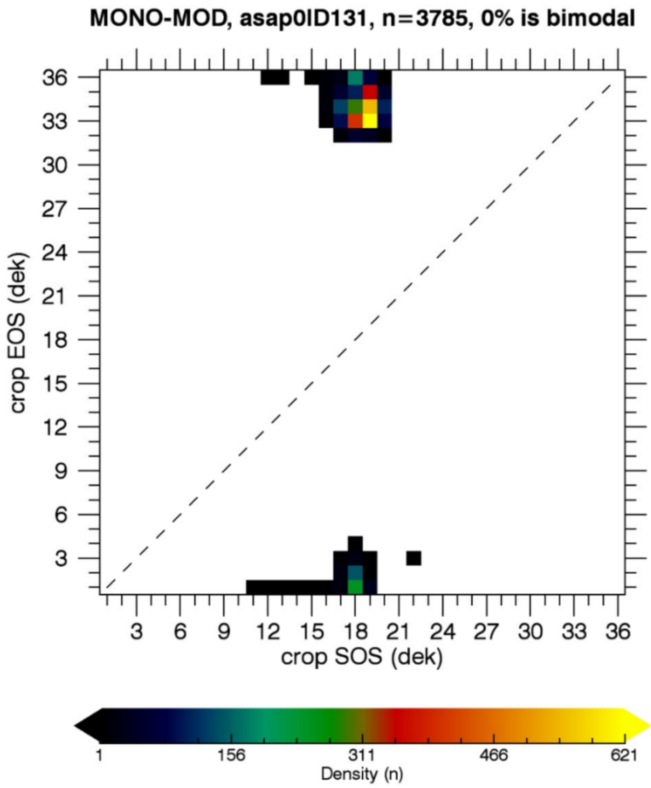
Furthermore, discrimination between crops is complex due to the fact that different crop types may have similar development patterns and growth calendars (Peña-Barragán et al., 2011). Finally, irrigated areas, perennial crops and forests have a relatively stable phenological cycle, presenting low seasonal variation of the NDVI, resulting in uncertain LSP characterization.

4 Results

4.1 Detailed example

As an example to illustrate the methodology used, Figure 6 shows the SOS vs. EOS density scatterplot for the crops in Gambia. The crops of the country are strictly mono-modal as indicated in the scatterplot (percentage of bi-modal area indicated in top right corner). It is possible to identify a single cluster showing a maximum density at [SOS, EOS] equal [19,33] and extending roughly in the region characterized by SOS ranging from dekad 16 to 20 and EOS between 32 to 3. The cluster can be retained as it represents more than 5% of the total number of crop pixels.

Figure 6: Cluster detection for Gambia (Gaul0, Mono-modal)



Source: JRC analysis

In crop calendars, we have information about typical sowing and harvesting periods. In the FAO crop calendar, we recognize four crops that can potentially match the observed cluster (Table 5). Three of them have the same seasonal characteristics (i.e. millet, sorghum and rice), meaning sowing between 16 to 21 dekad and harvesting between 28 to 32 dekad (for rice 33 dekad). One of them, groundnut, is characterized by sowing between 16 to 21 and harvesting between 31 to 6. It is noted that maize indicated by the FAO calendar is not clearly visible in LSP phenology.

Table 5. Digitized data from FAO Crop Calendar for Gambia

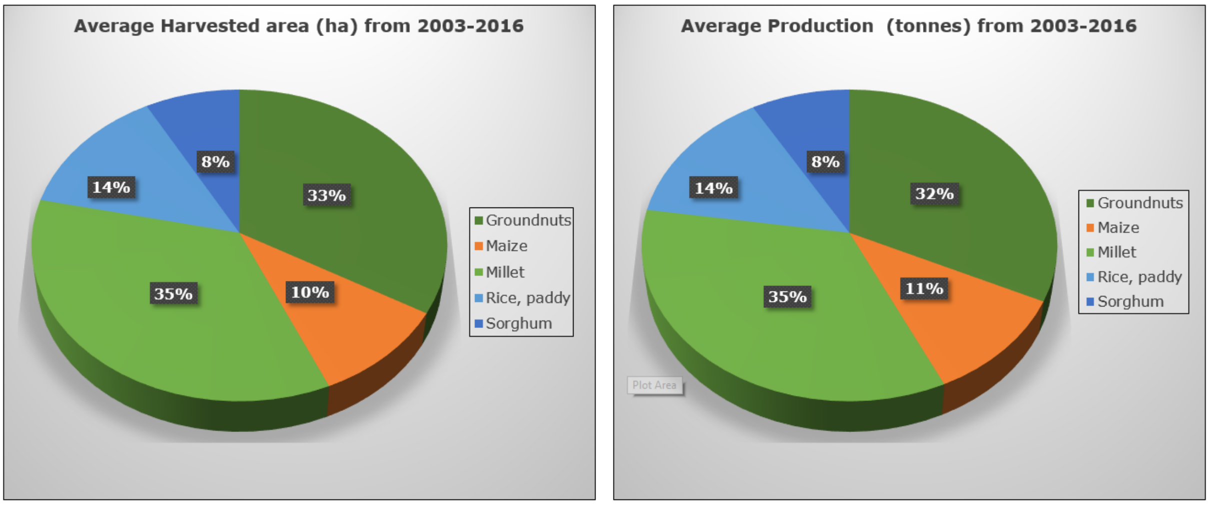
Crop	Sowing		Harvesting	
	min	max	min	max
Groundnut	16	21	31	6

Maize	13	21	25	30
Millet	16	21	28	32
Rice	16	21	28	33
Sorghum	16	21	28	32

Source: FAO (GIEWS), JRC analysis

Agricultural statistics were particularly important at this stage of the analysis, as the knowledge of the area harvested, as well as the quantity produced for each crop, was used to verify the presence of a crop type. FAOSTAT data (Figure 7), averaged for the years 2003-2016, confirm that these crop types are present.

Figure 7. Average harvested area (left) and average production (right) for Gambia, for FAO main crops, from 2003 to 2016 (source for the data: FAOSTAT)



Source: FAOSTAT, JRC analysis

With this information at hand, we interpreted this large cluster of LSP as being originated by two seasonal timings, corresponding to four crop types with overlapping season. As a result, two main growing seasons are identified in LSP for Gambia (Table 6).

Table 6. Growing seasons identified in LSP for Gambia

Crop	Sowing		Harvesting	
	min	max	min	max
Season 1	16	20	32	34
Season 2	16	20	32	3

Source: JRC analysis

Considering the rules set in the section of methods, the growing seasons in LSP were compared with FAO calendar and evaluated compatible with the timing of the growing season of four crops from FAO calendar (Table 7).

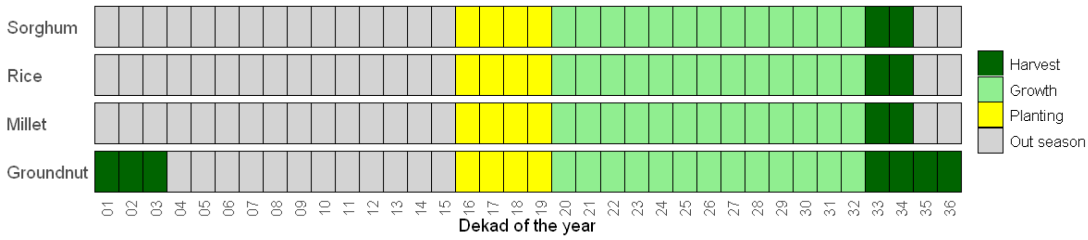
Table 7. LSP and FAO matching seasons for Gambia (Gaul 0)

Countries		FAO				*Land Surface Phenology*			
	Crop	SOW		HARV		*SOS*		*EOS*	
		min	max	min	max	*min*	*max*	*min*	*max*
Gambia	Groundnut	16	21	31	6	*16*	*20*	*32*	*3*
	Maize	13	21	25	30				
	Millet	16	21	28	32	*16*	*20*	*32*	*34*
	Rice	16	21	28	33	*16*	*20*	*32*	*34*
	Sorghum	16	21	28	32	*16*	*20*	*32*	*34*

Source: JRC analysis

Finally, the following ASAP- adapted calendar is published on the on-line platform of ASAP, presenting the four crops listed in the FAO crop calendar that match with LSP. In the legend of the calendar, the growth stages presented, planting and harvesting, are associated with SOS and EOS, respectively. The residual interval period has been labelled as "growth", similarly to the FAO crop calendars. It is noted that the actual growth period can indeed extend from any planting to any sowing dekad.

Figure 8. ASAP adapted-calendar for Gambia published online



Source: https://mars.jrc.ec.europa.eu/asap/country.php?cntry=90

The described procedure is then applied at the ASAP unit level (i.e. mostly subnational administrative units), for all 80 counties. This level of application is of interest because it allows tailoring the national level calendar to the subnational administrative level. Downscaling the FAO calendar from national level to the subnational ASAP units of a country, where different conditions regarding climate and soil may occur, will provide geographically more detailed information about crops grown and their development stages. Calendars with the different crops present for each ASAP unit are presented in the following section (Section 4.2).

4.2 Overview for the 80 countries

The final databases, one for the national level and one for the subnational level, hereafter referred to as national db and subnational db, respectively, contain the seasons derived from LSP and matched with specific crops from FAO crop calendars. It should be noted that differences between the crop calendars and LSP phenology are expected, especially for the ASAP unit, since the calendars refer to the whole country, while across the ASAP units of a country different climate and cropping conditions may occur.

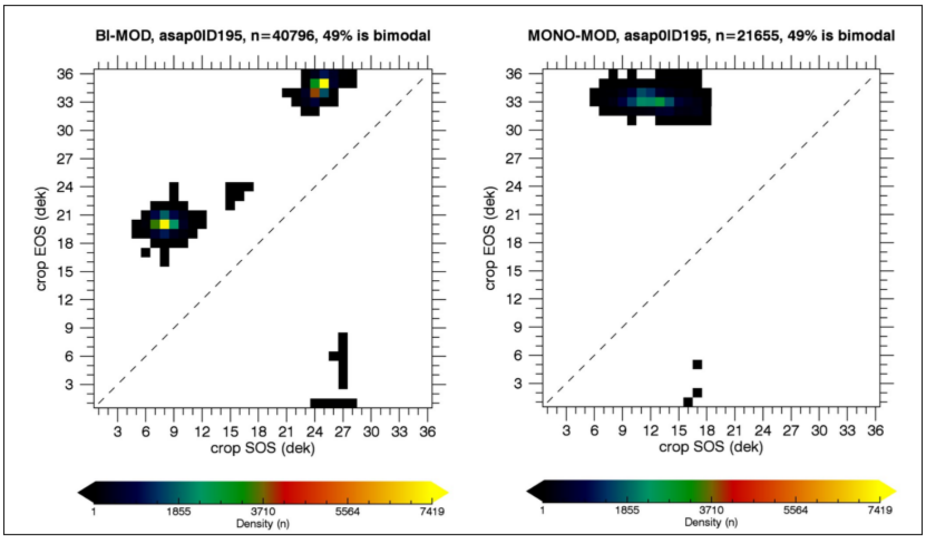
As an example of national db, data for Benin is shown in Table 8. In this country, there are two growing cycles per solar year and the percentage of bimodal crops is 49%. The first columns of the table are the crop calendars, while the last columns show the timing of the LSP seasons that matched one or more crop type listed in the crop calendar (FAO one in Benin). The empty shaded cells indicate that there was no LSP season matching the growing season of the corresponding FAO crop. In Figure 9, satellite derived phenology is depicted for bi-modal and mono-modal seasons in the country of Benin. The bi-modal season of LSP phenology agrees with the FAO calendar for Maize (Main), Maize (Second) and Yams and mono-modal with Cassava, Irrigated Rice and Millet & Sorghum.

Table 8. Example of national db for Benin

	FAO					IRRI					*Land Surface Phenology*			
	Crop	SOW		HARV		Crop	SOW		HARV		*SOS*		*EOS*	
		min	max	min	max		min	max	min	max	*min*	*max*	*min*	*max*
Benin	Cassava	13	18	34	3						*10*	*15*	*32*	*34*
	Irrigated Rice	13	21	31	3	Irrigated Rice	13	21	31	3	*10*	*15*	*32*	*34*
	Maize (Main)	7	12	22	27						*6*	*10*	*19*	*22*
	Maize (Second)	22	27	34	3						*23*	*26*	*33*	*36*
	Millet & Sorghum	13	21	28	33						*10*	*15*	*32*	*34*
	Rice	10	15	22	27	Main	10	15	22	27				
	Yams	4	9	19	3						*6*	*10*	*19*	*22*

Source: JRC analysis

Figure 9. Bi-modal (left) and Mono-modal (right) season for Benin (GAUL 0)

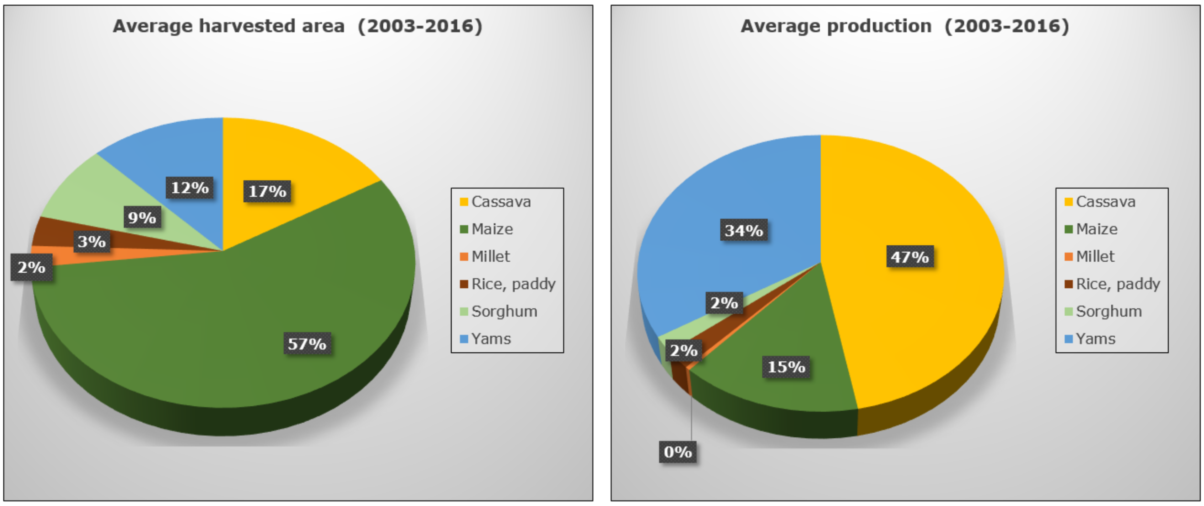


Source: JRC analysis

It should be noted that there is an agreement between LSP phenology and FAO calendar, for all crops in the FAO calendar except for Rice, which is grown in limited areas in Benin (Figure 10).

In Figure 10, the left panel presents the average harvested area and the right panel the average production for the years 2003-2016, for the six crops present in the FAO calendar. Maize represents the crop with the largest harvested area in average and is correctly identified in LSP's phenology. The average production for Cassava and Yams also indicates that both of these crops are of importance and the matching of LSP with the corresponding crop types from FAO is verified. Finally, sorghum and millet, together, present an average harvested area that is present in LSP.

Figure 10. Average harvested area (left) and average production (right) for Benin, for FAO main crops, from 2003 to 2016



Source: FAOSTAT, JRC analysis

Another example of the national db is shown in Table 9 for the Syrian Arab Republic. In the first columns the FAO crop calendar is presented and in the last columns the timing of the LSP seasons that matched with crop types listed in the FAO calendar. The mono-modal season of LSP phenology agrees with the FAO calendar for Barley and Wheat.

Table 9. Example of national db for Syrian Arab Republic

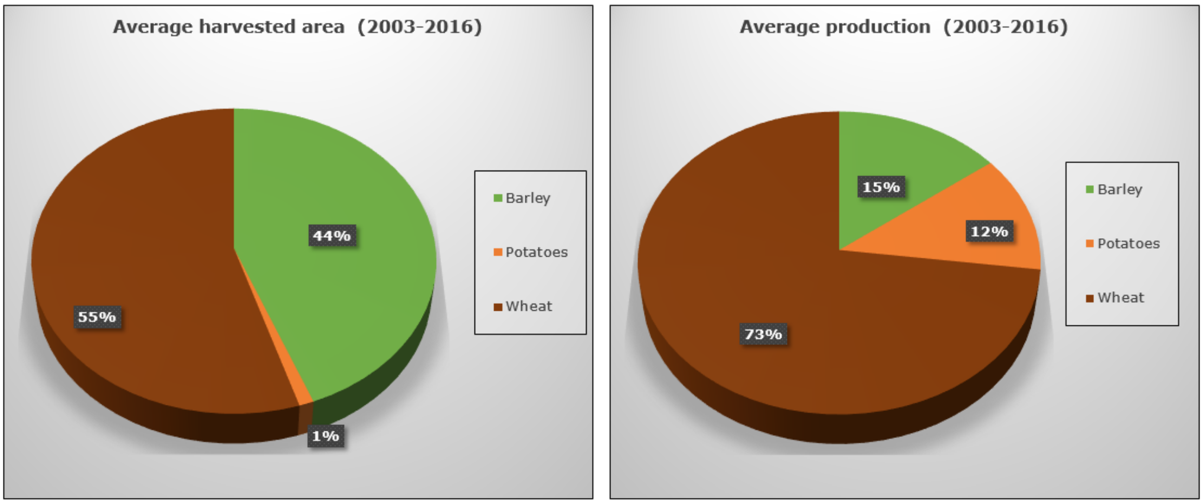
Countries	**FAO**					***Land Surface Phenology***			
	Crop	SOW		HARV		*SOS*		*EOS*	
		min	max	min	max	*min*	*max*	*min*	*max*
Syria	Barley	29	1	14	18	*29*	*1*	*13*	*18*
	Potatoes	8	14	15	29				
	Rice	11	14	26	30				
	Wheat	29	2	14	20	*29*	*1*	*13*	*18*

Source: JRC analysis

The good agreement between LSP and FAO can be verified by the agricultural statistical data represented in Figure 11 for the four crops present in the FAO calendar. Rice is indeed not present in these statistics that were extracted for the years 2003-2016. Available data from FAOSTAT indicate that rice was a minor cultivation from 1961-1996, with an average harvested area of 364 ha and average production of 930 tonnes for the respective years. A possible explanation is that crop calendars are not updated regularly, so they might not always represent the current crop practices applied in a country, also they do not include information about the relevance of single crops in terms of national production.

It is evident that the average harvested area graph is dominated by two cultivations, barley and wheat, while potatoes account for only 1%. Wheat also displays the largest average production compared with the other two crops. Based on this data, we could verify the correct identification of two crops in corresponding to LSP phenology: barley and wheat.

Figure 11. Average harvested area (left) and average production (right) for Syria, for FAO main crops, for years 2003-2016



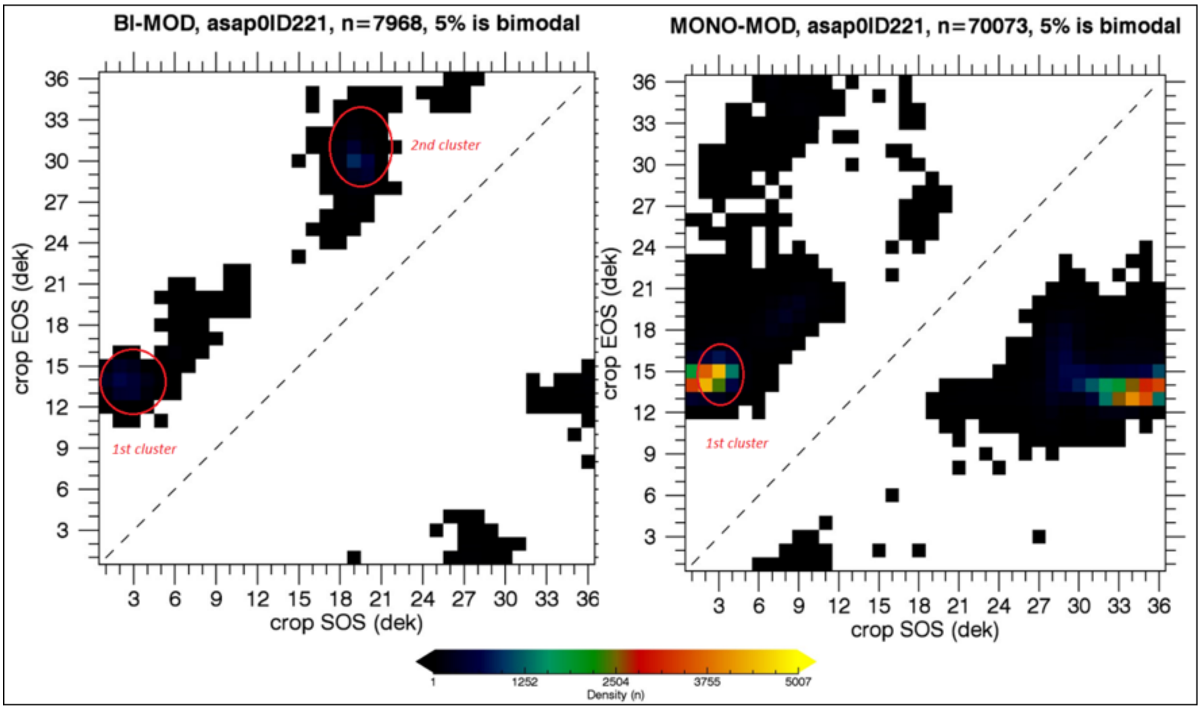
Source: FAOSTAT, JRC analysis

As mentioned in section 3.3, LSP seasonality may not find a match with some crops listed in the crop calendars. For Syria, for example, there were three crop seasons identified in LSP, that did not match with crops from the FAO calendar. These three crop seasons are presented in Figure 12 (red circles). The first cluster recognized in LSP's mono-modal season extends roughly in the region characterized by SOS ranging from dekad 2 to 4 and EOS between 13 to 16 (Figure 12, right). This means that most likely other crops are grown in the country which are not included in the FAO crop calendar, or that the crops included there have more crop cycles. The latter situation is common for irrigated areas.

Moreover, the other two clusters recognized in LSP's bi-modal season extend roughly in the region characterized by SOS ranging from dekad 1 to 6 and EOS between 12 to 16 (1st cluster in bi-modal graph-Figure 12), while the 2nd has SOS ranging from 18-20 and EOS 27-34 (2nd cluster in bi-modal graph-Figure 12).

The second cluster identified in bi-modal LSP might represent cotton cultivation, that has a sowing period between middle April to middle May and harvesting period between middle August to end of November. The other two clusters that are not identified might represent an extension of the phenology of the main growing crops, barley and wheat.

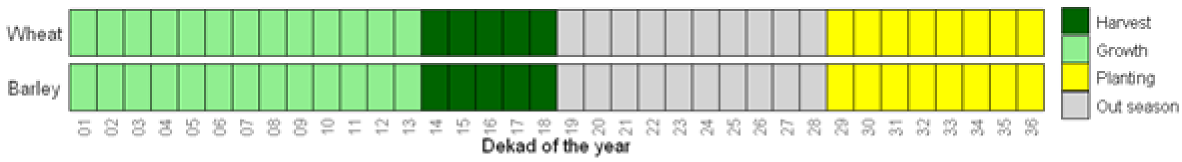
Figure 12. Identification of clusters representing unknown seasons in LSP phenology for Syrian Arab Republic (Gaul 0) (Left:Bi-modal, Right:Mono-modal)



Source: JRC analysis

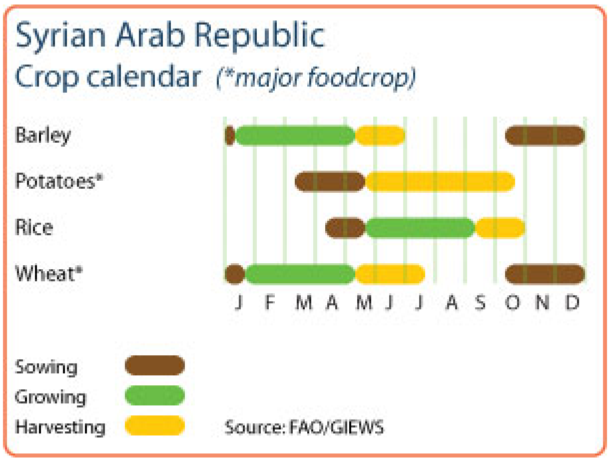
The resulting calendar is shown in Figure 13, along with the original FAO calendar for the country (Figure 14). Wheat's and Barley's cultivations were identified in LSP phenology and matched with crops from FAO calendar, as mentioned above, and the phenology seasons are present in both calendars. On the contrary, Potatoes' and Rice's phenological seasons are only present in FAO calendar.

Figure 13. ASAP adapted-calendar for Syria published online



Source: https://mars.jrc.ec.europa.eu/asap/country.php?cntry=155

Figure 14. FAO crop calendar for Syria



Source: FAO (GIEWS)

A subset of the subnational db is presented in Table 10 for Ethiopia, where it can be noted that in each region different crops are present and match with crops listed in the national FAO calendar. This result is in line with the complexity of Ethiopian agriculture, which involves significant variations in crops grown across the different regions of the country (Taffesse et al.2012). In Figure 15 and 16, the scatterplots for bi-modal and mono-modal seasons are displayed for Ethiopia's regions of Yem, Wolayita, Western and West Wellega. For Yem and Wolayita regions, there are both mono- and bi-modal seasons, while for Western and West Wellega there are only mono-modal seasons. For Yem and Wolayita, the bi-modal season detected by the LSP agrees with the FAO calendar for "all Cereals (Belg)" and oats and the mono-modal with maize and sorghum, while for Western and West Wellega the mono-modal season of the LSP agrees with the FAO calendar for "barley ,teff & wheat (meher)" and millet.

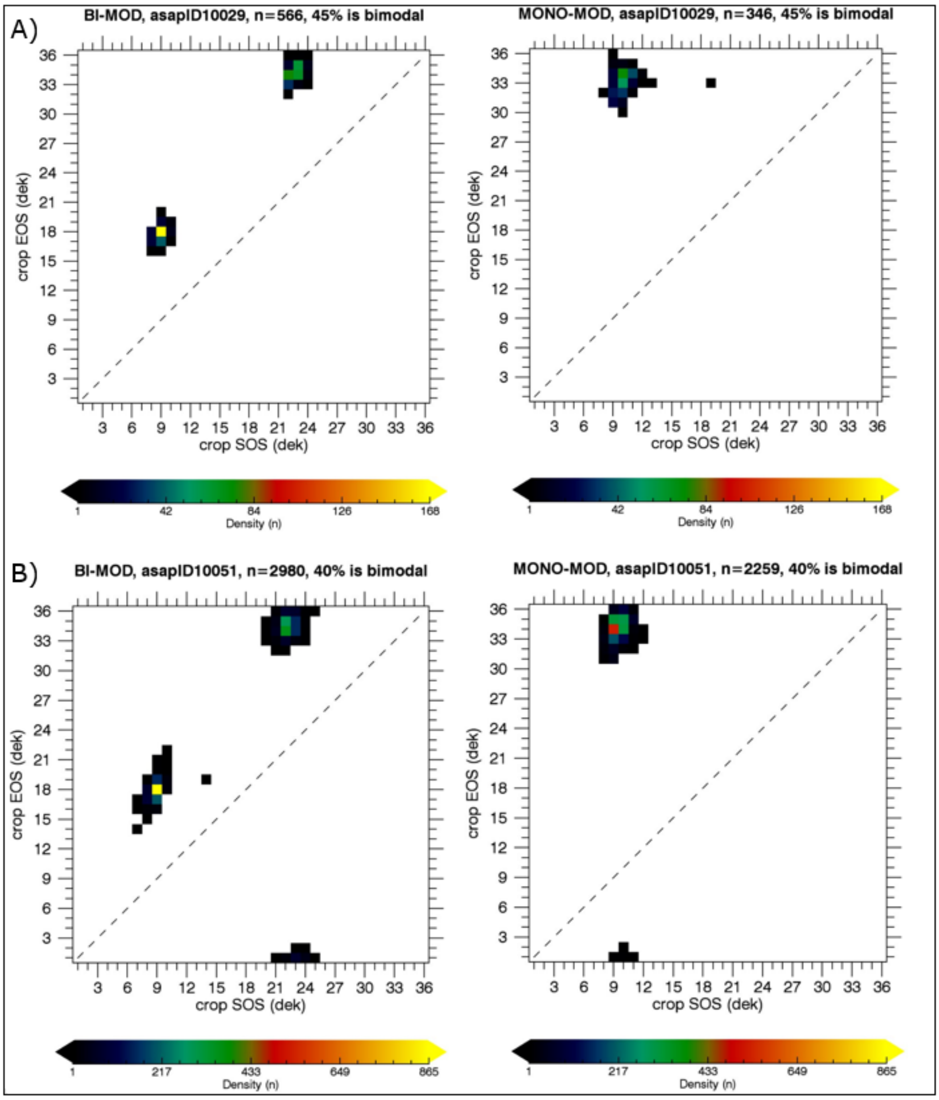
Table 10. Example of subnational db for Ethiopia (subset of the table, not all regions presented)

Countries	**ASAP unit**	**FAO calendar**					***Land Surface Phenology***			
		Crop	**SOW**		**HARV**		***SOS***		***EOS***	
			min	max	min	max	*min*	*max*	*min*	*max*
Ethiopia	Yem	All Cereals (Belg)	4	9	16	24	*8*	*9*	*17*	*18*
		Barley,Teff & Wheat (Meher)	13	18	31	36				
		Maize (Meher)	7	14	28	34	*9*	*11*	*31*	*35*
		Millet (Meher)	13	18	31	2				
		Oats (Meher)	11	24	28	3	*22*	*23*	*33*	*36*
		Sorghum (Meher)	7	14	28	34	*9*	*11*	*31*	*35*

Wolayita	All Cereals (Belg)	4	9	16	24	*8*	*9*	*16*	*19*
	Barley,Teff & Wheat (Meher)	13	18	31	36				
	Maize (Meher)	7	14	28	34	*8*	*11*	*31*	*36*
	Millet (Meher)	13	18	31	2				
	Oats (Meher)	11	24	28	3	*21*	*23*	*33*	*1*
	Sorghum (Meher)	7	14	28	34	*8*	*11*	*31*	*36*
Western	All Cereals (Belg)	4	9	16	24				
	Barley,Teff & Wheat (Meher)	13	18	31	36	*14*	*20*	*30*	*36*
	Maize (Meher)	7	14	28	34				
	Millet (Meher)	13	18	31	2	*14*	*20*	*30*	*36*
	Oats (Meher)	11	24	28	3				
	Sorghum (Meher)	7	14	28	34				
West Wellega	All Cereals (Belg)	4	9	16	24				
	Barley,Teff & Wheat (Meher)	13	18	31	36	*11*	*14*	*34*	*1*
	Maize (Meher)	7	14	28	34	*9*	*14*	*34*	*36*
	Millet (Meher)	13	18	31	2	*11*	*14*	*34*	*1*
	Oats (Meher)	11	24	28	3				
	Sorghum (Meher)	7	14	28	34	*9*	*14*	*34*	*36*

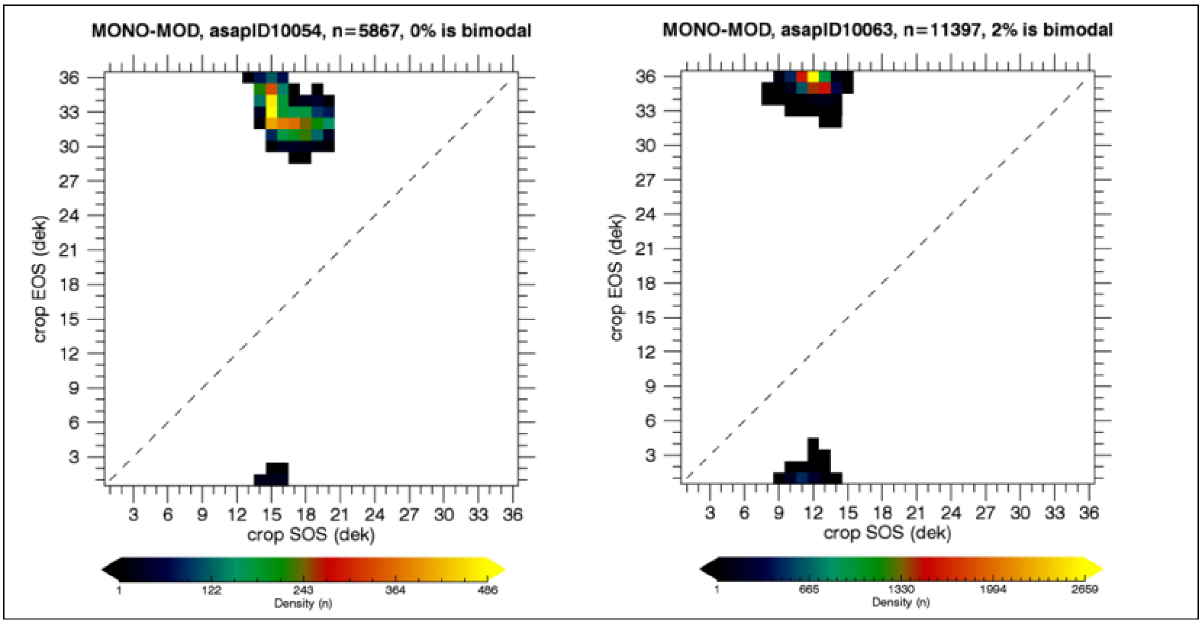
Source: JRC analysis

Figure 15. (a) Bi-modal and Mono-modal for Yem region; (b) Bi-modal and Mono-modal for Wolayita region



Source: JRC analysis

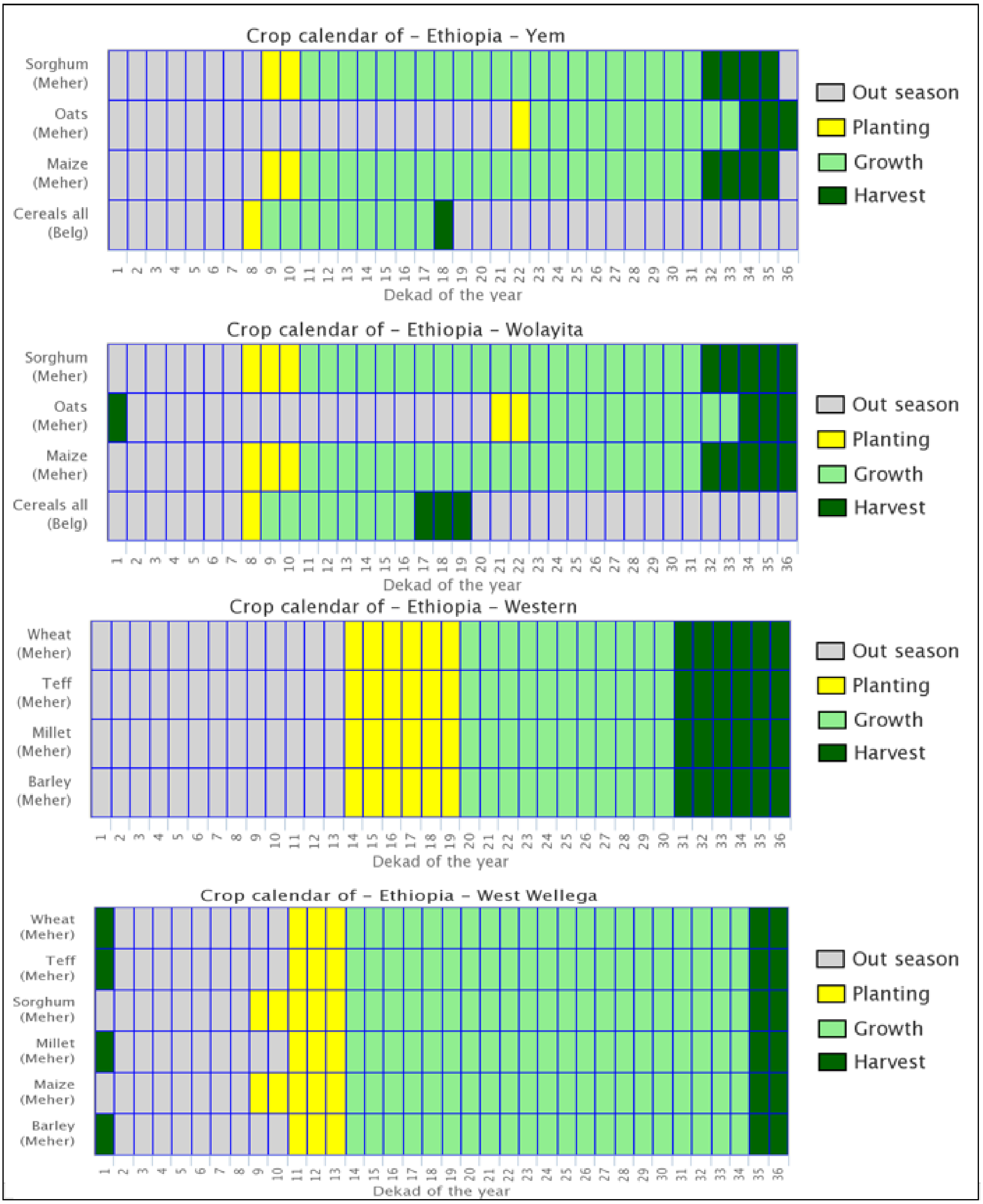
Figure 16. Mono-modal for Western (left) and Mono-modal for West Wellega (right)



Source: JRC analysis

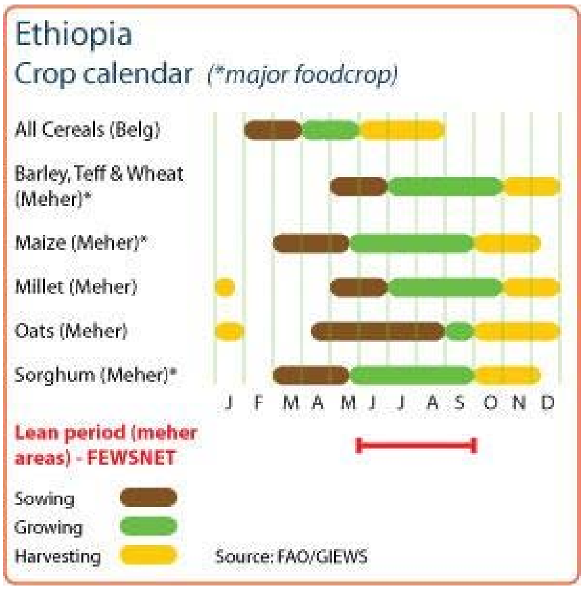
The differences between the regions are evident in the resulting crop calendars for the aforementioned four regions (Figure 17). Different crops are present in each region, while even if the same type of cultivation is present, the phenology might differ slightly. In Figure 18, the FAO calendar for Ethiopia is presented and the necessity for region specific calendars is evident. The figures illustrate the variations in crop cycles in terms of duration of planting and harvesting, but also of different onset and offset of the seasons. For example, as it can be noticed, oats' (meher) planting period for Yem and Wolayita regions, has a much smaller interval, only one or two dekads, than in FAO's calendars, where the interval is 13 dekads. The same applies for harvesting period, where the interval is three or four dekads, comparing to 12 dekads in FAO calendar. Moreover, for wheat (meher) in West Wellega's calendar (Figure 17), the interval for planting and harvesting is 3 dekads, comparing to 6 dekads in FAO calendar (Figure 18). This example illustrates well how, by using LSP phenology we are able to scale down the national-level FAO calendar to the first subnational administrative level used by ASAP.

Figure 17. ASAP adapted-calendar for four ASAP units of Ethiopia published online



Source: https://mars.jrc.ec.europa.eu/asap/map.php?goto=79

Figure 18. FAO crop calendar for Ethiopia



Source: FAO (GIEWS)

Another example of subnational db is presented in Table 11 for Togo, where the main crops identified in the LSP phenology and matched for each subnational level of Togo are shown in the last column of the table (grey cells indicate no match).

Table 11. Example of subnational db for Togo

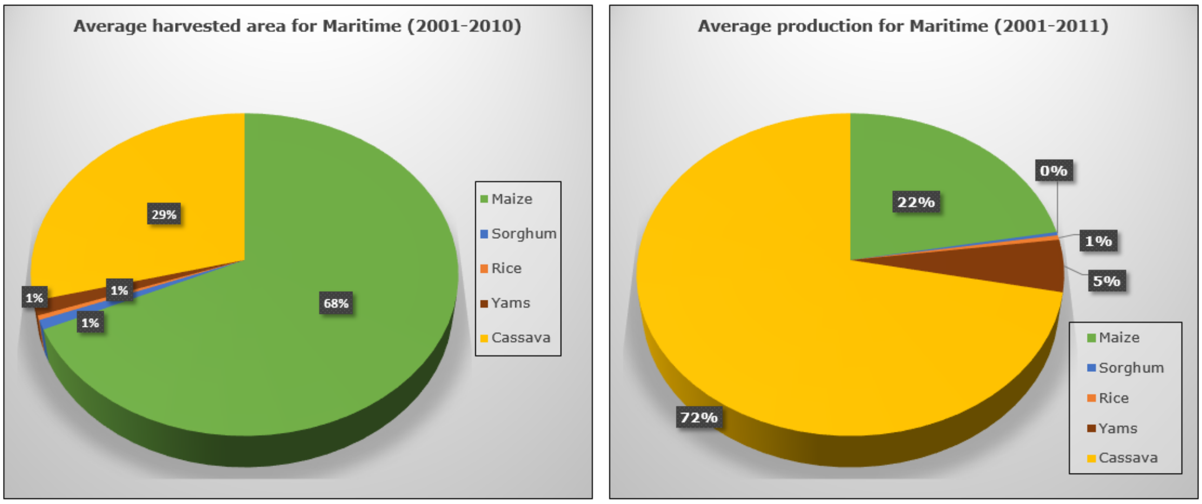
Countries	**ASAP unit**	**FAO calendar**					***Land Surface Phenology***			
		Crop	**SOW**		**HARV**		***SOS***		***EOS***	
			min	max	min	max	*min*	*max*	*min*	*max*
Togo	Savanes	Cassava	13	18	34	36				
		Maize (Main)	7	12	22	27				
		Maize (Second)	22	27	34	3				
		Millet & Sorghum	13	21	28	33	*12*	*17*	*32*	*34*
		Rice	13	15	30	32	*12*	*17*	*32*	*34*
		Yams	4	9	19	3				
	Plateaux	Cassava	13	18	34	36				
		Maize (Main)	7	12	22	27	*6*	*9*	*19*	*22*
		Maize (Second)	22	27	34	3	*23*	*26*	*33*	*36*

	Millet & Sorghum	13	21	28	33				
	Rice	13	15	30	32				
	Yams	4	9	19	3	*6*	*9*	*19*	*22*
Maritime	Cassava	13	18	34	36				
	Maize (Main)	7	12	22	27	*6*	*10*	*19*	*23*
	Maize (Second)	22	27	34	3	*24*	*28*	*35*	*1*
	Millet & Sorghum	13	21	28	33				
	Rice	13	15	30	32				
	Yams	4	9	19	3	*6*	*10*	*19*	*23*
Kara	Cassava	13	18	34	36				
	Maize (Main)	7	12	22	27	*6*	*10*	*19*	*21*
	Maize (Second)	22	27	34	3	*23*	*25*	*33*	*35*
	Millet & Sorghum	13	21	28	33				
	Rice	13	15	30	32				
	Yams	4	9	19	3	*6*	*10*	*19*	*21*
Centrale	Cassava	13	18	34	36				
	Maize (Main)	7	12	22	27	*6*	*10*	*18*	*22*
	Maize (Second)	22	27	34	3	*23*	*25*	*33*	*35*
	Millet & Sorghum	13	21	28	33				
	Rice	13	15	30	32				
	Yams	4	9	19	3	*6*	*9*	*18*	*22*

Source: JRC analysis

Statistical data from CountryStat for each ASAP unit were available for this country. In Figure 19, for ASAP unit Maritime the average harvested area and the average production are presented for the years 2001-2010 and 2001-2011 respectively. These data verify the presence of maize in this unit, while the rest of the crops only account for a small percent. Cassava represents a crop with an average harvested area of 29% and an important average production of 72%. However, cassava is hardly identified in the LSP phenology, since in most countries it does not have a well-defined crop calendar, as it is a perennial crop that can be harvested at any time in the year.

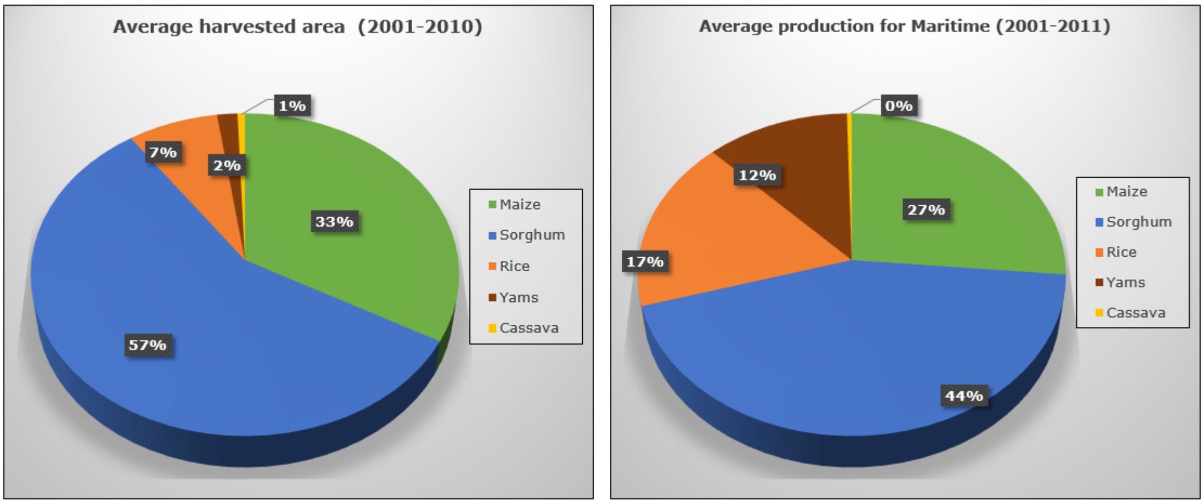
Figure 19. Average harvested area (left) and average production (right) for Maritime



Source: CountryStat, JRC analysis

Another example of statistical data for Savanes unit in Togo is shown in Figure 20, where Sorghum represents on average 57% of the area harvested for the years 2001 - 2010 and 44% of the average production. Based on this data, sorghum is correctly detected in LSP phenology. However, there is also a significant presence of Maize representing 33% of average area harvested, but there is no season in LSP phenology matching FAO's Maize phenology.

Figure 20. Average harvested area for Savanes from 2001 to 2010 for FAO main crops



Source: CountryStat, JRC analysis

The crop calendars that resulted for each region from the process of attributing crop types to LSP, are presented in Figure 21. In four out of five regions, the same crops are present, while in Savanes the crop calendar is different.

Figure 21. Selection of FAO crop calendars matching with LSP phenology in Togo for all regions

Source: https://mars.jrc.ec.europa.eu/asap/map.php?goto=243

An additional example of subnational db is presented in Table 12 for Nigeria (only four selected subnational level units are reported). Scaling down the national crop calendar to subnational units with LSP allows differentiating the crop types among the various units. This scaling is supported and verified by the statistical data provided from CountryStat for each subnational level (Figure 22), showing the types of crop and their relative importance in each region.

Table 12. Example of subnational db for Nigeria (part of the table, not all regions presented)

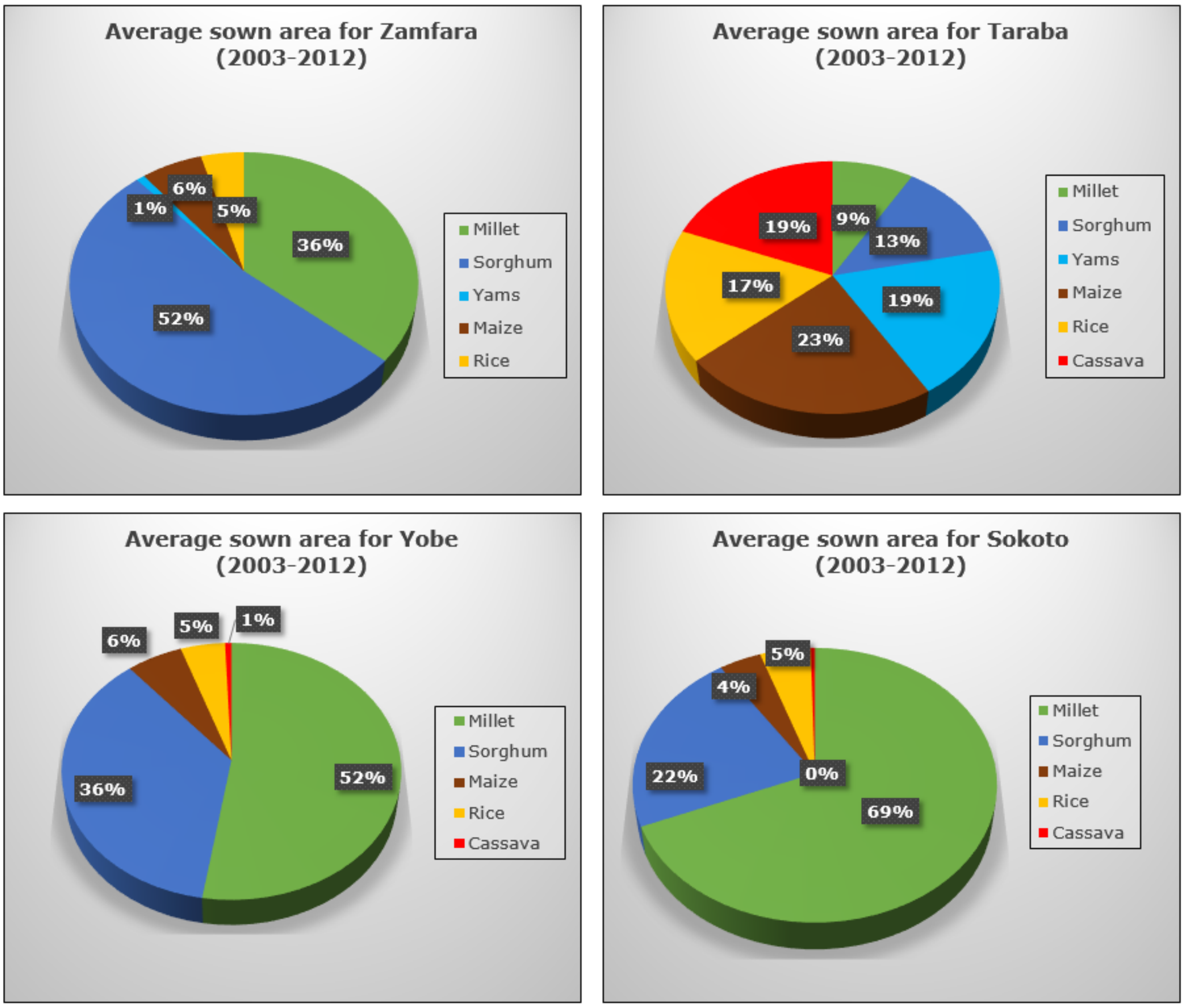
Countries	**ASAP unit**	**FAO calendar**					***Land Surface Phenology***			
		Crop	**SOW**		**HARV**		***SOS***		***EOS***	
			min	max	min	max	*min*	*max*	*min*	*max*
Nigeria	Zamfara	Cassava (South)	13	18	34	3				
		Irrigated Rice	13	27	28	3				
		Maize (North/main)	13	18	22	27				
		Maize (Second)	22	27	34	3				
		Maize (South/main)	7	12	16	24				
		Millet	16	18	25	30				
		Rainfed rice	10	21	22	30				
		Sorghum	13	21	25	33	*11*	*19*	*32*	*35*
		Yams	4	9	19	3				
	Yobe	Cassava (South)	13	18	34	3				
		Irrigated Rice	13	27	28	3				
		Maize (North/main)	13	18	22	27				
		Maize (Second)	22	27	34	3				
		Maize (South/main)	7	12	16	24				
		Millet	16	18	25	30	*17*	*19*	*29*	*32*
		Rainfed rice	10	21	22	30	*17*	*19*	*29*	*32*
		Sorghum	13	21	25	33	*17*	*19*	*29*	*34*
		Yams	4	9	19	3				
	Taraba	Cassava (South)	13	18	34	3				
		Irrigated Rice	13	27	28	3	*23*	*26*	*34*	*36*
		Maize (North/main)	13	18	22	27				

	Maize (Second)	22	27	34	3	*23*	*26*	*34*	*36*
	Maize (South/main)	7	12	16	24	*8*	*12*	*19*	*22*
	Millet	16	18	25	30				
	Rainfed rice	10	21	22	30				
	Sorghum	13	21	25	33	*10*	*15*	*33*	*35*
	Yams	4	9	19	3				
Sokoto	Cassava (South)	13	18	34	3				
	Irrigated Rice	13	27	28	3				
	Maize (North/main)	13	18	22	27				
	Maize (Second)	22	27	34	3				
	Maize (South/main)	7	12	16	24				
	Millet	16	18	25	30				
	Rainfed rice	10	21	22	30				
	Sorghum	13	21	25	33	*17*	*19*	*30*	*34*
	Yams	4	9	19	3				

Source: JRC analysis

From Figure 22, it is evident that in Zamfara, sorghum represents the largest sown area and is indeed present in LSP. For Yobe, sorghum, millet and rice are correctly identified in LSP phenology and matched with FAO calendar. For Taraba, rice, maize and sorghum are correctly identified, while Yams and Cassava are not detected in LSP. For Sokoto, sorghum is correctly identified and matched with FAO calendar, while millet's and maize's phenology was not identified in LSP.

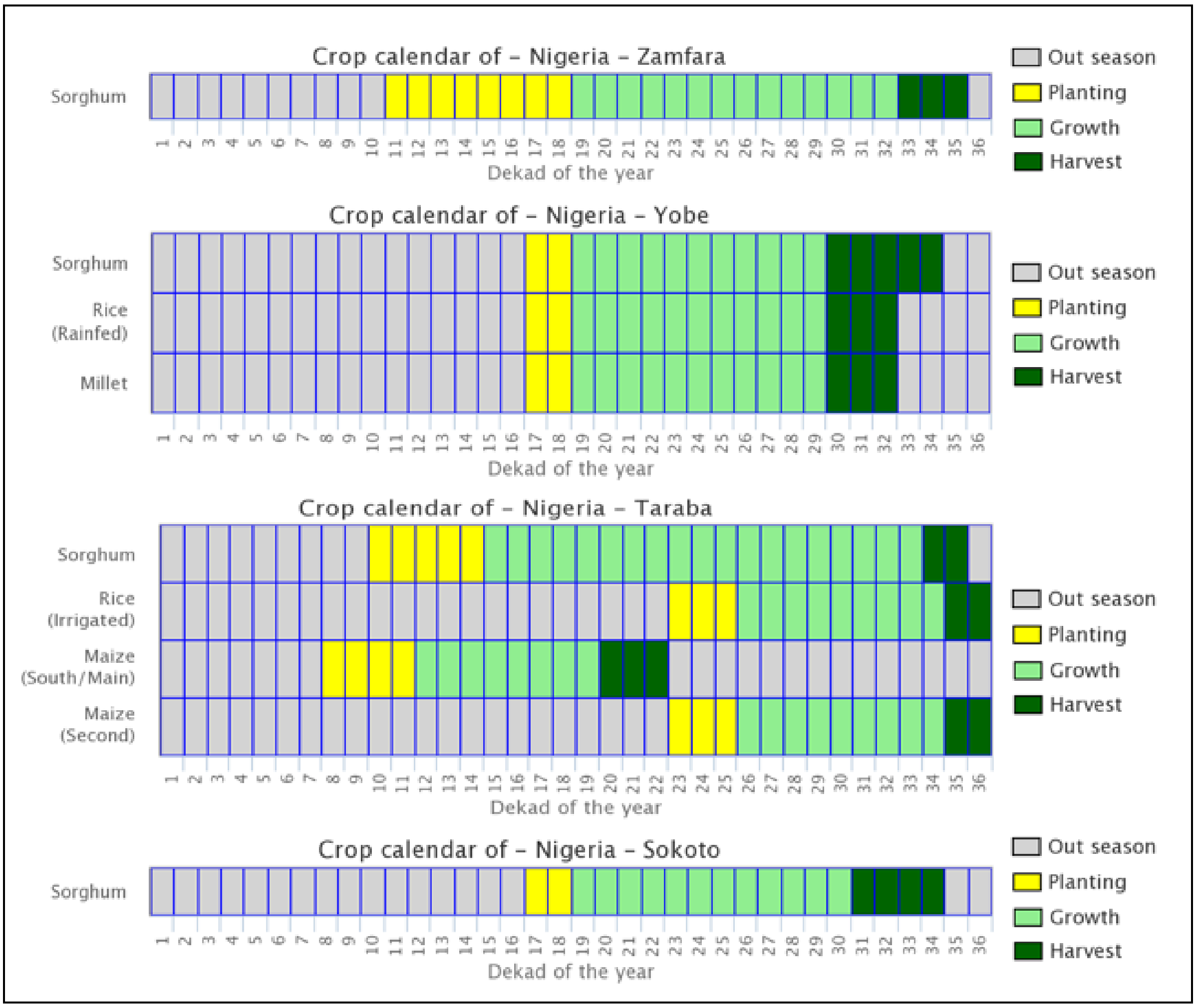
Figure 22. Distribution of average area sown for Zamfara (top left), Taraba (top right), Yobe (bottom left) and Sokoto (bottom right) from 2003 to 2012



Source: CountryStat, JRC analysis

The need for crop calendars, available for the subnational level, can be easily understood, thanks to the differences in the resulting calendars (Figure 23) for the subnational levels of Nigeria, presented in the table above. Even in regions, like Zamfara and Sokoto, that have the same cultivation present, there is a difference in the timing of planting. In Zamfara, planting starts in the 11th dekad, while in Sokoto in the 17th. Knowledge about these differences between regions is a significant and additional information for agricultural analysts.

Figure 23. Selection of FAO crop calendars matching with LSP phenology in Nigeria for four regions



Source: https://mars.jrc.ec.europa.eu/asap/map.php?goto=182

4.3 Observed shortcomings

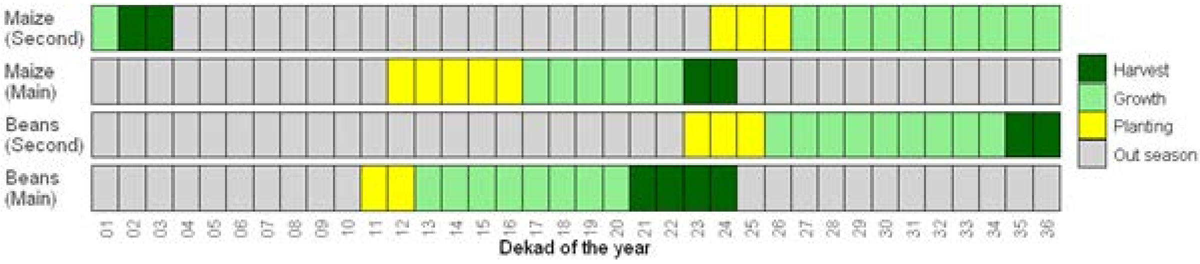
There are a few countries where there is a phenology season retrieved from LSP, that does not match with any crop type from crop calendars and represents a large percentage of the crop mask of the area. El Salvador is an example of a country that has four seasons that matched with FAO calendar, but also one long season derived from satellite data that is not represented in the crop calendars. As it can be seen from Table 13, there is a match between LSP's bi-modal season and FAO's first four crops and the resulting calendar published in ASAP's webpage is depicted in the following figure (Figure 24).

Table 13. Example of national db for El Salvador

Country		FAO				LSP			
	Crop	SOW		HARV		*SOS*		*EOS*	
		min	max	min	max	*min*	*max*	*min*	*max*
El Salvador	Beans (Main)	13	15	22	24	*11*	*13*	*20*	*24*
	Beans (Second)	22	24	34	36	*23*	*26*	*34*	*36*
	Maize (Main)	13	18	22	33	*12*	*17*	*22*	*24*
	Maize (Second)	25	27	1	6	*24*	*27*	*1*	*3*
	Maize (Third)	34	36	4	6				
	Rice (Main)	13	18	31	3				
	Rice (Second)	1	6	7	12				
	Sorghum	16	21	34	5				

Source: JRC analysis

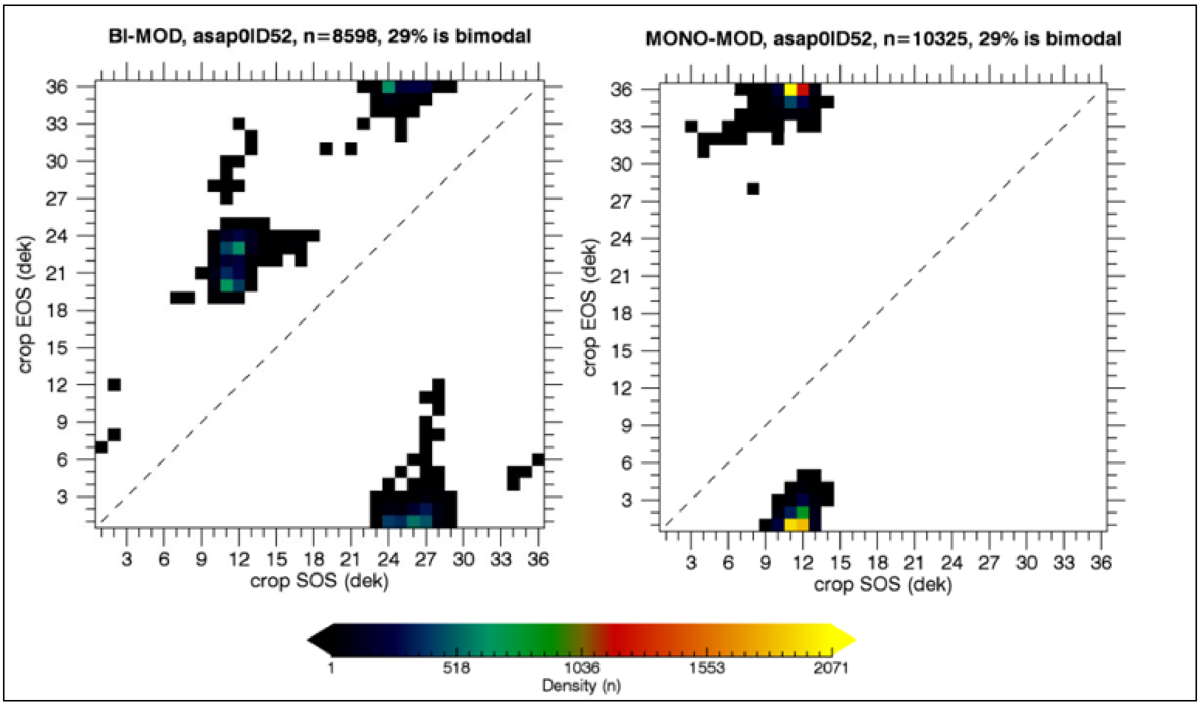
Figure 24. ASAP-adapted calendar for El Salvador published online



Source: https://mars.jrc.ec.europa.eu/asap/country.php?cntry=155

However, there is a mono-modal season in LSP phenology that represents almost 70% of the country's crop mask and is not compatible with any crop season from FAO calendar. The unknown mono-modal season is represented by the cluster (Figure 25, right panel) that has a range for SOS from 10 to 13 dekad and for EOS from 34 to 3 dekad. An explanation could be related to a possible failure of LSP retrieval method to resolve mixed pixels and mixed modalities.

Figure 25. Bi-modal and Mono-modal for El Salvador (Gaul 0)



Source: JRC analysis

An additional example of national db for Turkmenistan is presented in Table 14. This country did not have any LSP seasons that matched with crop calendars. The seasons that were identified in LSP are presented in Table 15, with mono-modal season 1 corresponding to 65% of Turkmenistan's crop mask. The phenology derived from the scatterplots for bi-modal and mono-modal season for Gaul 0, is displayed in Figure 26.

Table 14. Example of national db for Turkmenistan

Country	**FAO**					***LSP***			
	Crop	**SOW**		**HARV**		***SOS***		***EOS***	
		min	max	min	max	*min*	*max*	*min*	*max*
Turkmenistan	Coarse Grains (Spring)	10	18	22	27				
	Maize	10	18	22	27				

	Wheat (Winter)	24	32	16	23	

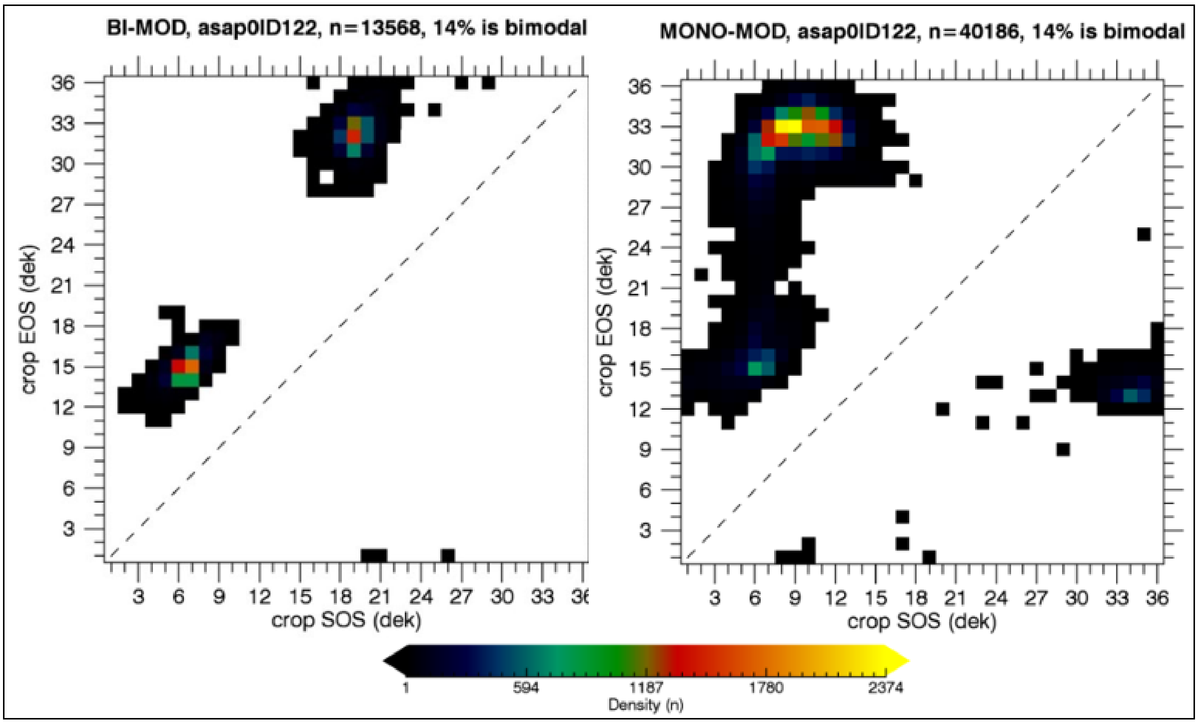
Source: JRC analysis

Table 15. LSP phenology seasons for Turkmenistan

Seasons	**SOS**		**EOS**	
	min	max	min	max
Bi-modal 1	4	9	13	17
Bi-modal 2	18	21	30	35
Mono-modal 1	**6**	**13**	**29**	**35**
Mono-modal 2	4	8	14	19

Source: JRC analysis

Figure 26. Bi-modal and Mono-modal for Turkmenistan (Gaul 0)



Source: JRC analysis

Based on the set of rules that we described in the previous section, the crop seasons derived from LSP cannot be matched with any crop type listed in FAO calendar. In Figure 27, LSP mono-modal season 1 and the phenology for coarse grains and maize from FAO are presented. In this figure, LSP's SOS and FAO's sowing range are presented with different shades of green, while LSP's EOS and FAO's harvesting range are presented with different shades of yellow. There is a similarity between the two phenology cycles, but based on the rules that we set, no match can be established. For sowing, LSP's phenology starts and ends earlier than FAO, with the two calendars having a common period from dekad 10 until dekad 13. For harvesting, FAO's phenology starts and ends earlier than LSP.

Figure 27. LSP's mono-modal season 1 and FAO's coarse grains and maize phenology representation for comparison reasons

Source: JRC analysis

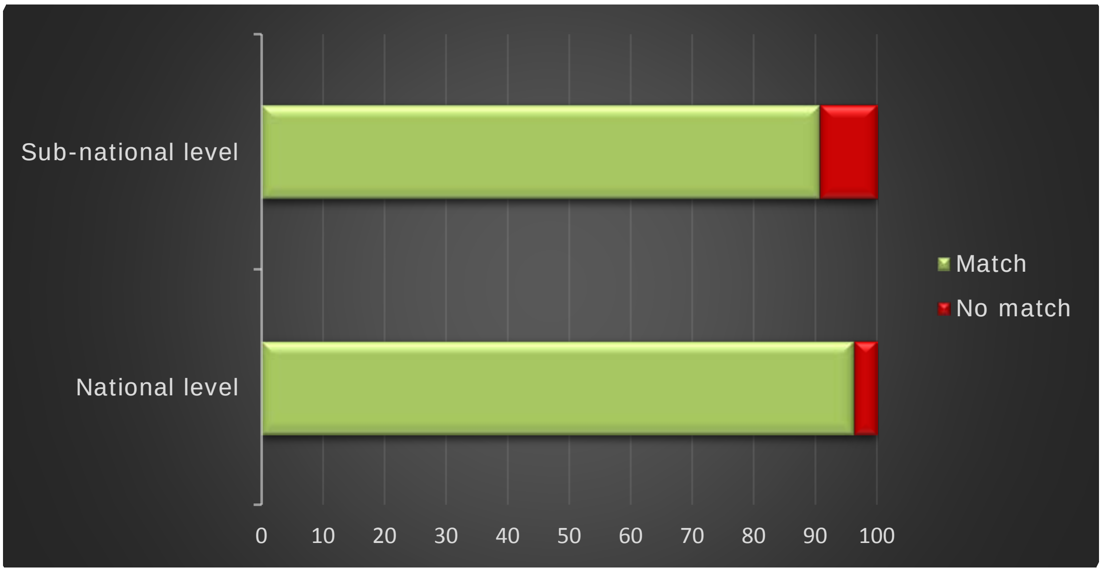
The difference in the calendars and the resulting absence of match between FAO's and LSP's phenology, can be attributed to the mixture of winter and spring crops, having as a result LSP's sowing staring earlier. The late harvest can be attributed to the phenology cycle of cotton that has a harvesting season between 27 to 32 dekad (according to USDA).

4.4 Overall statistics of matching crop calendars

FAO provides national level crop calendars for all of the 80 countries of interest, while from IRRI there are available rice calendars for 48 countries and from USDA for 20 countries. Since FAO provides data for all countries, we proceeded in an evaluation of the degree of agreement between FAO calendars and LSP seasons. Figure 28 presents the percent of countries and ASAP units that had at least one crop listed in the FAO calendar that matched with LSP (green bar) and the percentage of no match at all could be established (red bar). For the comparison we took into account only the ASAP units with crop mask cover area larger than 100km^2 (1097 ASAP units with crop mask out of total 1241).

At the national level, a high percent of match is achieved, meaning that for most countries at least one crop is represented by the LSP. For the subnational level the percent is slightly lowered. Overall, the percentage for at least one crop type present in LSP is high for both spatial levels of analysis.

Figure 28. National and subnational level agreement between FAO crop calendars and LSP



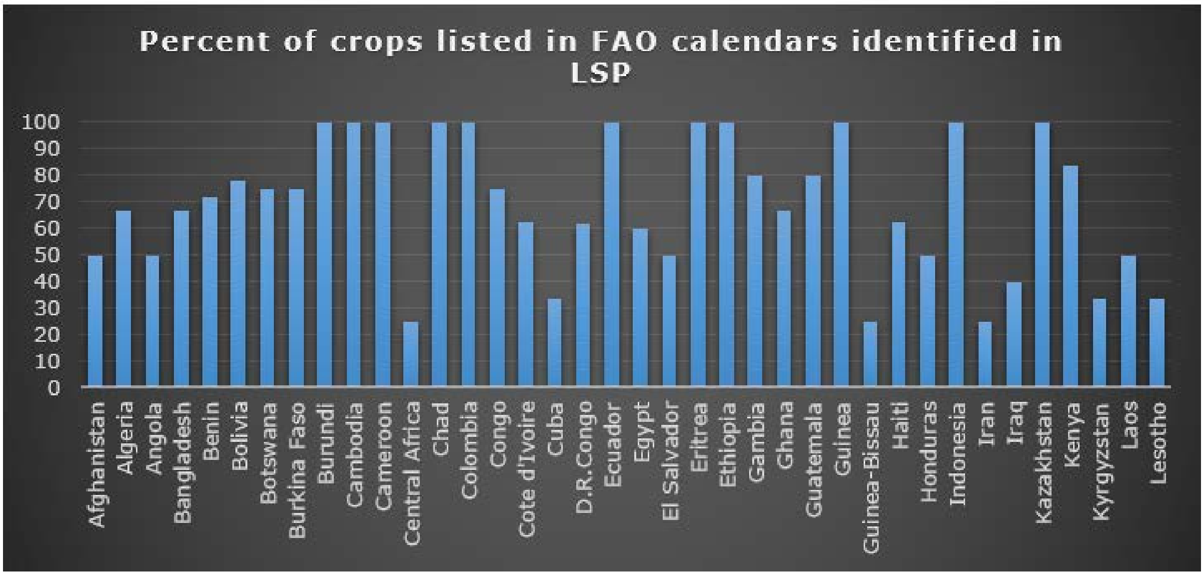
Source: JRC analysis

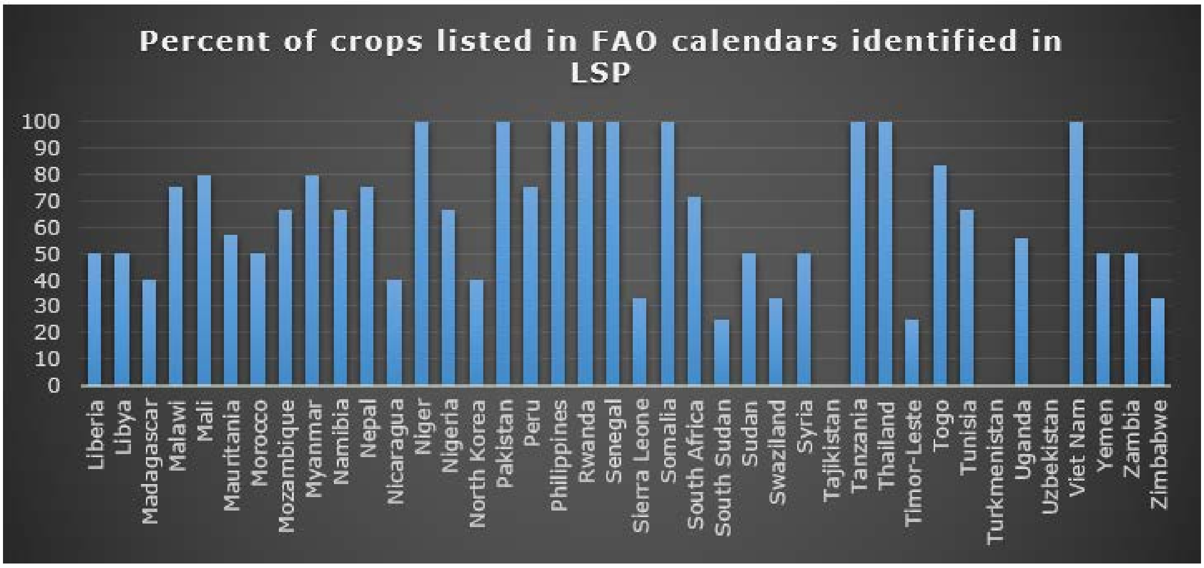
Figure 29 shows the percent of crops listed in the FAO crop calendar that were identified by LSP for each country. For most of the countries, more than half of the crops present in

FAO were retrieved by LSP. As it can be seen from Figure 29, for 20 countries all crops listed in FAO calendar were matched with LSP seasons.

It should be noted however that three countries in Central Asia, Tajikistan, Turkmenistan and Uzbekistan, had no match with FAO calendars. Central Asia consists of a variety of agro-ecological zones (De Pauw, 2010), that are even more complex due to the wide range of altitudes, while the regional differences in terms of dependency on irrigation water for agriculture are large (Sommer et al., 2013). Seasons detected in LSP for the above mentioned countries have an earlier start and end of the season than the ones described in the crop calendars, resulting in a failed match.

Figure 29. Percent of crops for each country that were listed in FAO crop calendar and were identified in LSP (above: first 40 countries, below: last 40 countries)



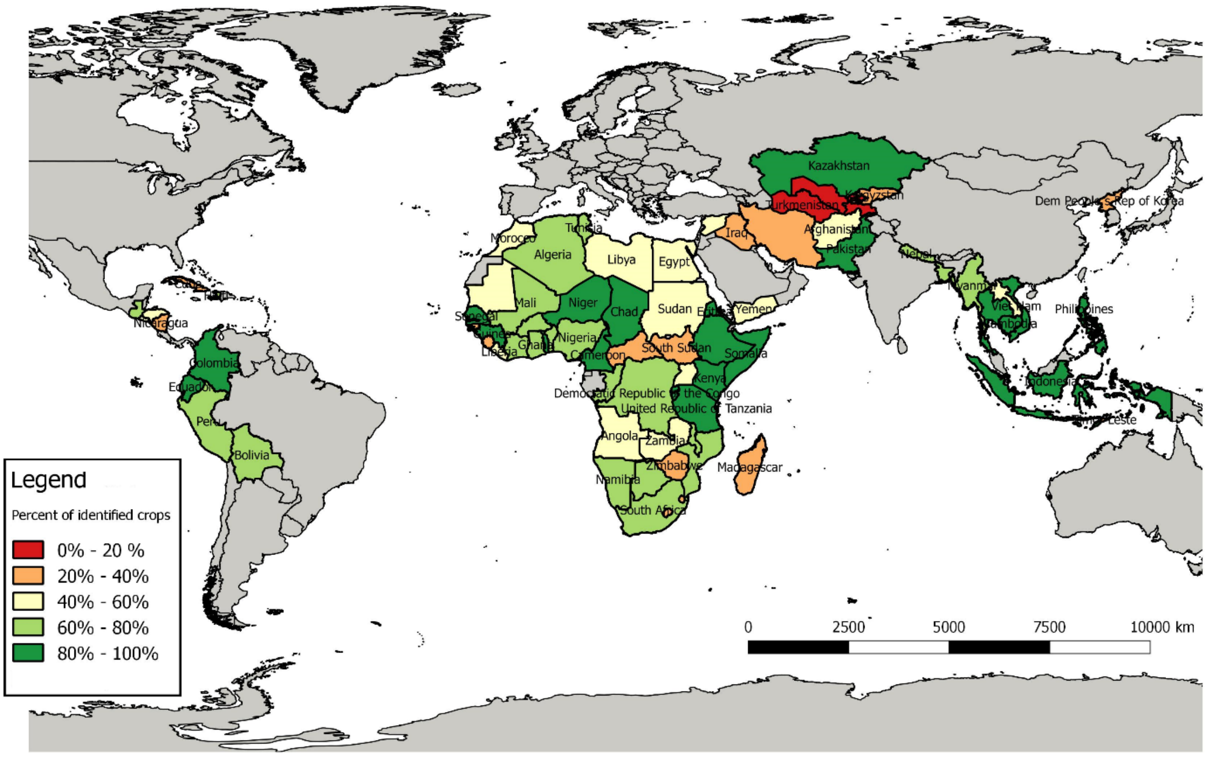


Source: JRC analysis

Additionally, in Figure 30, a thematic map depicting the percent of crops listed in the FAO crop calendars that were identified by LSP, in order to have a spatial overview. A good match has been achieved for most countries in Africa, for South America and Southeast Asia, while the countries in Central Asia that had no match are shown in red.

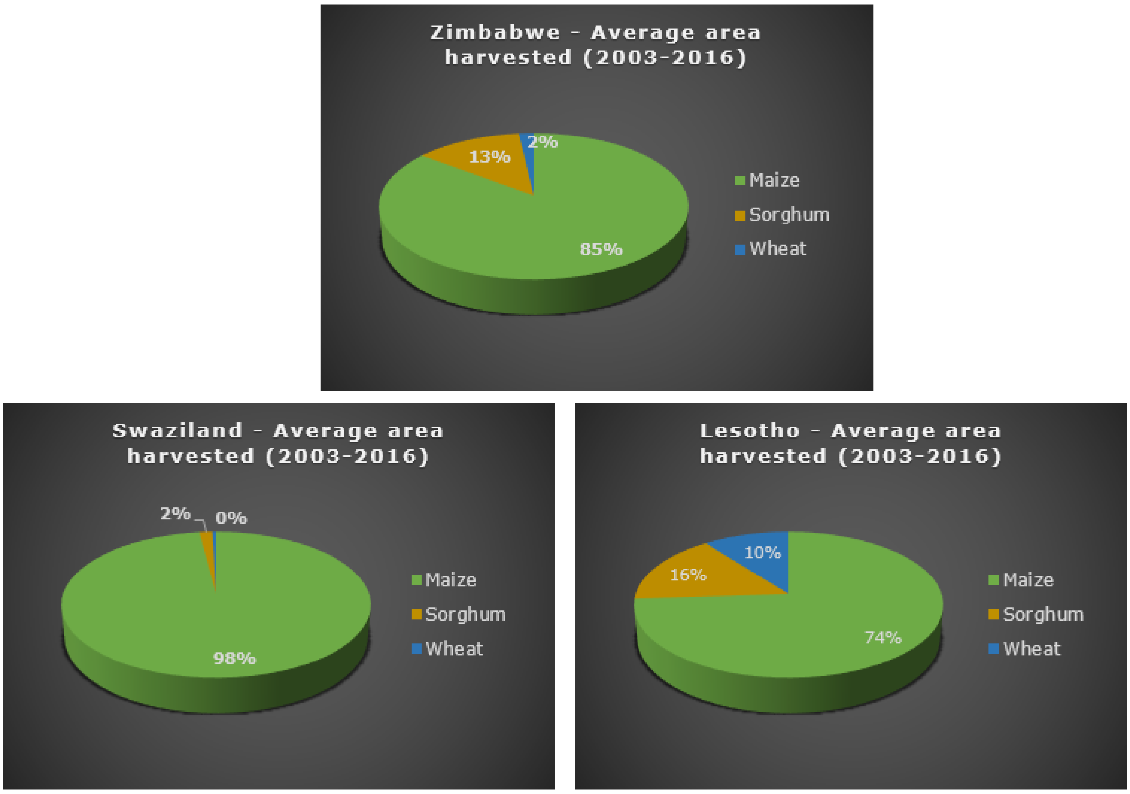
In Southern Africa, the countries with a relatively low matching percent (orange colour) are Zimbabwe, Swaziland and Lesotho. For these countries, three crops are listed in the FAO calendars, maize, sorghum and wheat, but in LSP only maize is identified. That can be partially explained by the fact that maize is a major food crop in these countries as it can be seen in Figure 31, which presents the vast majority of harvested area for the years 2003-2016 among the three crops listed in the FAO calendar.

Figure 30. Thematic map of the percent of crops for each country that were listed in FAO crop calendars and were identified in LSP



Source: JRC analysis

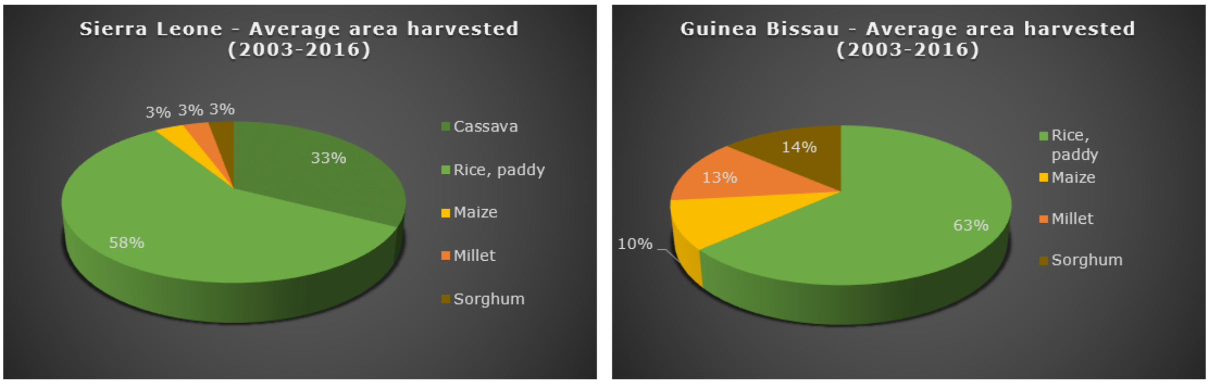
Figure 31. Average harvested area for Zimbabwe (top), Swaziland (bottom, left) and Lesotho (bottom, right)



Source: FAOSTAT, JRC analysis

In West Africa, two countries have a relatively small percent, Sierra Leone and Guinea Bissau. For Sierra Leone, 2 out of 6 crops listed in FAO were identified by LSP (rice and cassava), and for Guinea- Bissau 1 out of 4 (rice). The statistical data from FAOSTAT (Figure 32) confirm that the crops found in LSP are the dominant food crops.

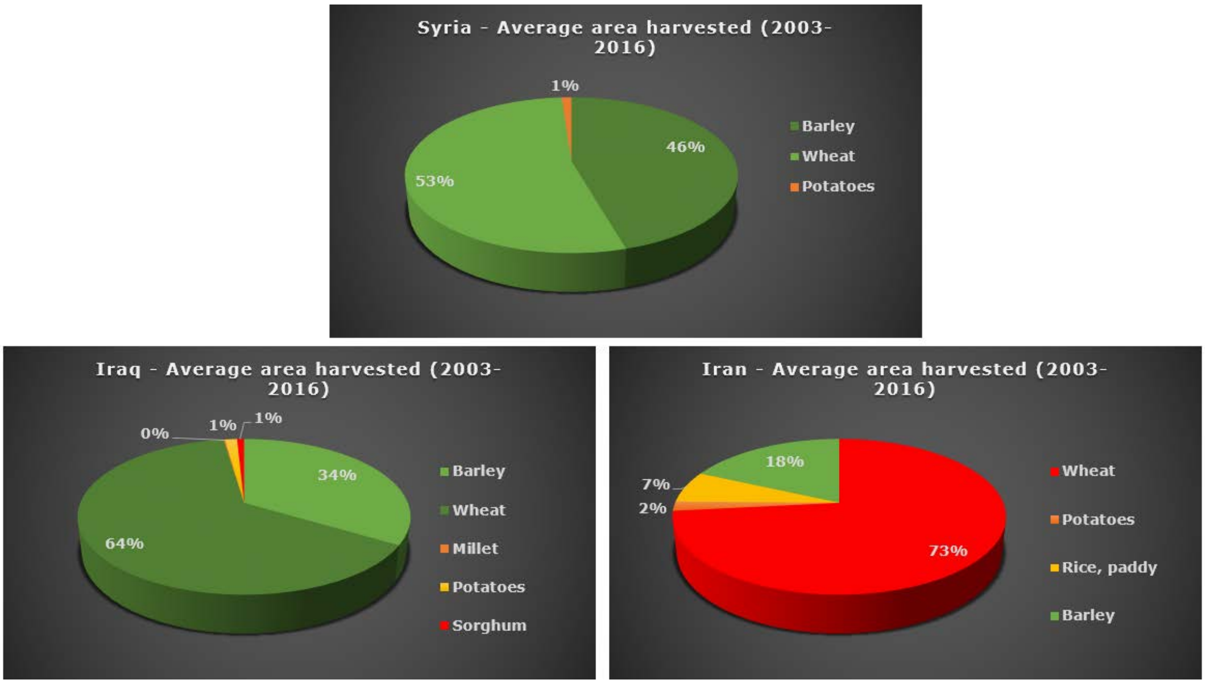
Figure 32. Average harvested area for Sierra Leone (left) and Guinea Bissau (right)



Source: FAOSTAT, JRC analysis

For the Middle East, Iran and Iraq are the two countries having a lower percent of identified crops, while Syria belongs to the third class with an average match (white color) (Figure 30). For Iraq, 2 out of 5 crops listed in FAO were identified in LSP (barley and wheat). The statistical data (Figure 33) verify that these two crops are the main food crops present in the country, while the other three crops listed in FAO calendar, millet, potatoes and sorghum, represent a very small part of the harvested area. For Iran, however, wheat that is the dominant cereal crop (Figure 33), was not identified in LSP. For Syria, the two major food crops (Figure 33), barley and wheat, were correctly identified in LSP, while the third crop listed in the FAO calendar (potatoes) represents a very small percent of the average harvested area and were not retrieved from LSP.

Figure 33. Average harvested area for Syria (top), Iraq (bottom, left) and Iran (bottom, right)

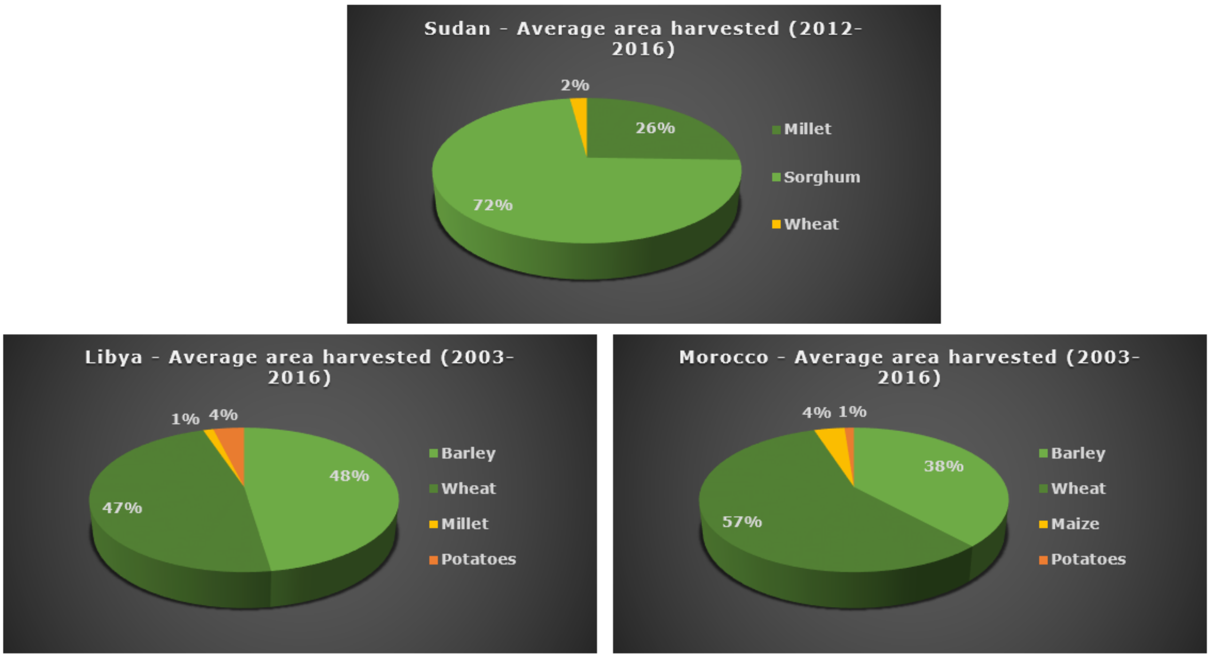


Source: FAOSTAT, JRC analysis

In Southern Africa, Madagascar is a country with a low percent of matching seasons with FAO calendar and this is an expected result, since the agro-climatic complexity in the country leads to land surface phenology that deals with a mixture of land cover types or crops that are grown more than twice in a solar year.

In North Africa, Morocco, Libya and Sudan have an average match with FAO crop calendars (white colour, Figure 30). However, the statistics (Figure 34) confirm the identification of the major crops by LSP, like millet and sorghum for Sudan and barley and wheat for Libya and Morocco.

Figure 34. Average harvested area for Sudan (top), Libya (bottom, left) and Morocco (bottom, right)



Source: FAOSTAT, JRC analysis

To conclude, the method resulted in an overall good identification of major food crops reported in existing crop calendars by LSP. While, as visible in Figure 30, a few countries remain with a low level of agreement between the crops listed in FAO and seasons from LSP. These countries are spatially clustered and belonging to similar agro-climatic conditions, for example in Central Asia or to a lower extent in Southern Africa.

5 Conclusions and way forward

Motivated by the need of offering to ASAP analysts and users information regarding the types of crops grown in the ASAP unit at the time at which the analysis is performed, we developed a method of attributing a crop type to main crop seasons recognized on LSP, resulting in national and subnational specific calendars for 80 countries of interest. With the proposed method, we are able to provide a characterization of crop types that is coherent with the ASAP methodology, that largely relies on EO derived LSP.

The resulting crop calendars, matching with LSP phenology, are made available online in the ASAP download section. Regarding the national level of analysis, there was a good agreement between the crop calendars and the earth observation derived phenology. Statistical data of harvested area and production proved a useful source for ranking the importance of crops identified in LSP. Concerning the subnational level of analysis, a good degree of agreement was achieved and statistical data, where available, also provided useful means of verification. In some cases, limitations were found to define a crop calendar for a country or at subnational level, such as for example for three countries in Central Asia, Tajikistan, Uzbekistan and Turkmenistan, where crop calendars could not be defined.

Future improvements of the methodology are planned and include a higher automation of the process, using standard algorithms for clustering and cluster ranges definition, a set up of iterative rules to find the best match between timing of crop calendars and LSP also taking into account statistical data of harvested area and production.

The automation is expected to facilitate the application of the described rules to the SOS/EOS scatterplots in a more quantitative way and will help testing possible improvements. An automated cluster definition algorithm for the detection of the crop seasons in LSP will eliminate any subjective interpretation involved in the procedure of defining the ranges of the clusters. Moreover, using iterative rules and taking also into account the agricultural statistics, will allow to implement more flexible thresholds in the cases that a crop type is not identified in LSP, but is a major food crop in the country or the ASAP unit according to the statistics. The automation will also allow to update the results in case new remote sensing phenology data or new crop calendars become available.

Concerning the visualization of the calendars in the ASAP platform we will include crop statistics from FAOSTAT in order to enable analysts to understand the representativeness of the crop calendars selected with the method described in this report.

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Annex

National database of crop calendars

This database contains for all 80 countries the range for sowing and harvesting for each crop type listed in FAO, IRRI and USDA crop calendars. In the last column, named “Land Surface Phenology” are presented the crop seasons derived from LSP and matched with a crop type from the calendars. The empty spaces in this column indicate no match with the corresponding crop type.

Countries	FAO					IRRI					USDA					*Land Surface Phenology*			
	Crop	SOW		HARV		Crop	SOW		HARV		Crop	SOW		HARV		*SOS*		*EOS*	
		min	max	min	max		min	max	min	max		min	max	min	max	*min*	*max*	*min*	*max*
Afghanistan	Maize	13	15	22	24														
	Rice	13	18	28	33	Rice	13	18	28	33						*17*	*20*	*26*	*33*
	Spring Wheat	7	12	22	27											*5*	*9*	*22*	*27*
	Winter Grains (Wheat & Barley)	28	33	13	18														
Algeria	Barley	29	2	17	20						Barley	31	36	13	17	*27*	*2*	*15*	*18*
	Rice	8	17	26	29														
	Sorghum & Wheat	29	2	17	23						Winter Wheat	31	36	13	17	*27*	*2*	*15*	*18*
Angola	Maize	25	31	7	12											*25*	*31*	*15*	*18*
	Millet	31	36	13	18											*29*	*33*	*15*	*18*
	Potatoes	23	26	2	14														
	Rice	29	35	8	14														
	Sorghum	31	1	13	18											*31*	*33*	*15*	*18*
	Wheat	13	15	28	30														
Bangladesh	Potatoes	29	36	9	14														
	Rice (Aman)	15	23	31	35	Rice (Aman)	10	15	31	36	Rice (Aman)	16	22	31	36	*15*	*23*	*29*	*36*
	Rice (Aus)	8	14	18	23	Rice (Aus)	10	15	19	24	Rice (Aus)	7	14	19	23	*4*	*13*	*16*	*23*

Countries	FAO					IRRI					USDA					***Land Surface Phenology***			
	Crop	**SOW**		**HARV**		**Crop**	**SOW**		**HARV**		**Crop**	**SOW**		**HARV**		***SOS***		***EOS***	
		min	**max**	**min**	**max**		**min**	**max**	**min**	**max**		**min**	**max**	**min**	**max**	***min***	***max***	***min***	***max***
Bangladesh	Rice (Boro)	33	3	12	14	Rice (Boro)	34	6	10	15	Rice (Boro)	31	3	11	15	*34*	*6*	*10*	*15*
	Sorghum	14	28	33	36											*15*	*28*	*33*	*36*
	Wheat	32	1	9	12														
Benin	Cassava	13	18	34	3											*10*	*15*	*32*	*34*
	Irrigated Rice	13	21	31	3	Irrigated Rice	13	21	31	3						*10*	*15*	*32*	*34*
	Maize (Main)	7	12	22	27											*6*	*10*	*19*	*22*
	Maize (Second)	22	27	34	3											*23*	*26*	*33*	*36*
	Millet & Sorghum	13	21	28	33											*10*	*15*	*32*	*34*
	Rice	10	15	22	27	Rice	10	15	22	27									
	Yams	4	9	19	3											*6*	*10*	*19*	*22*
Bolivia	Barley (First)	7	12	19	24														
	Barley (Second)	34	3	15	17											*34*	*36*	*13*	*17*
	Maize	26	32	8	14											*27*	*34*	*11*	*16*
	Potatoes	28	33	11	14											*27*	*34*	*11*	*16*
	Rice	28	33	2	9	Rice	28	33	4	9						*29*	*36*	*7*	*11*
	Soybean	31	33	11	14											*31*	*34*	*11*	*16*
	Sweet Potatoes	34	36	14	23											*32*	*36*	*14*	*23*
	Wheat (Andinean)	32	35	12	15											*32*	*35*	*12*	*15*
	Wheat (East plains)	10	15	26	29														
Botswana	Maize	32	3	12	18											*30*	*34*	*14*	*19*
	Millet	32	35	14	17											*30*	*34*	*14*	*19*
	Sorghum	34	3	13	18											*32*	*34*	*14*	*18*
	Wheat	13	15	28	30														

Countries		**FAO**					**IRRI**					**USDA**					***Land Surface Phenology***			
	Crop	**SOW**		**HARV**		**Crop**	**SOW**		**HARV**		**Crop**	**SOW**		**HARV**		***SOS***		***EOS***	
		min	**max**	**min**	**max**		**min**	**max**	**min**	**max**		**min**	**max**	**min**	**max**	***min***	***max***	***min***	***max***
Burkina Faso	Maize	10	18	22	33											*12*	*18*	*31*	*33*
	Millet	13	21	25	36	Rice Main	13	18	28	33						*13*	*19*	*31*	*35*
	Rice	34	36	7	12	Rice Off	1	6	13	18									
	Sorghum	13	21	7	12											*13*	*19*	*31*	*35*
Burundi	Beans (A season)	25	30	34	3											*26*	*30*	*1*	*4*
	Beans (B season)	4	9	13	18	Rice Main	28	36	13	18						*6*	*9*	*18*	*19*
	Maize & Sorghum (A season)	25	30	1	6											*26*	*31*	*1*	*8*
	Maize & Sorghum (B season)	4	9	16	21											*6*	*9*	*18*	*21*
Cambodia	Maize	13	18	25	30											*13*	*18*	*19*	*27*
	Rice (Dry S.)	31	3	7	12	Rice (Dry S.)	34	3	10	15	Rice (Dry S.)	31	5	10	18	*30*	*2*	*6*	*10*
	Rice (Main Wet S.)	16	29	34	6	Rice (Main Wet S.)	16	21	31	3	Rice (Main Wet S.)	12	19	25	32	*21*	*29*	*34*	*5*
Cameroon	Cassava	13	18	34	3											*12*	*18*	*34*	*3*
	Maize (Main)	7	18	19	30											*7*	*11*	*18*	*23*
	Maize (Second)	22	27	34	3											*23*	*27*	*33*	*2*
	Millet & Sorghum	13	21	28	33											*12*	*19*	*29*	*33*
	Rice	13	21	31	36	Rice	13	18	28	33						*12*	*19*	*31*	*36*
	Yams	4	9	19	3	Rice Off	1	6	13	18						*8*	*11*	*32*	*36*
Central Africa	Cassava	10	27	1	36											*8*	*17*	*32*	*36*
	Maize (South)	7	16	17	27														
	Maize (Centre)	10	16	17	27														

Countries	**FAO**					**IRRI**					**USDA**					***Land Surface Phenology***			
	Crop	**SOW**		**HARV**		**Crop**	**SOW**		**HARV**		**Crop**	**SOW**		**HARV**		***SOS***		***EOS***	
		min	**max**	**min**	**max**		**min**	**max**	**min**	**max**		**min**	**max**	**min**	**max**	***min***	***max***	***min***	***max***
Central Africa	Millet & Sorghum (North)	13	18	22	30														
	Groundnuts (South/Centre)	10	15	19	27														
	Groundnuts (North)	13	18	22	30														
	Rice (South)	13	21	22	33											*13*	*17*	*32*	*33*
	Rice (Centre/North)	13	18	22	30														
Chad	Maize	16	21	25	30											*16*	*20*	*28*	*30*
	Millet	13	21	25	30											*16*	*20*	*28*	*30*
	Rice	16	21	22	33	Rice	16	21	28	36						*14*	*20*	*28*	*35*
	Sorghum	16	21	25	33	Rice Off	1	6	13	18						*14*	*20*	*28*	*35*
Colombia	Barley	2	14	17	26											*7*	*14*	*17*	*26*
	Maize	5	11	22	27											*7*	*11*	*22*	*27*
	Rice	5	8	23	29	Rice Summer	7	12	19	24						*7*	*10*	*23*	*29*
	Sorghum	2	11	14	23	Rice Winter	22	30	1	9						*7*	*11*	*14*	*23*
	Soybean	23	26	35	5											*22*	*26*	*35*	*7*
	Wheat	6	12	17	26											*7*	*12*	*17*	*26*
Congo	Cassava	10	24	25	9														
	Maize (Main)	25	30	34	3											*25*	*29*	*34*	*4*
	Maize (Second)	4	9	16	21											*2*	*9*	*16*	*21*
	Yams	4	9	19	36											*4*	*11*	*19*	*21*
Côte d'Ivoire	Cassava (1st year,2nd year)	7	15	1	18											*5*	*10*	*15*	*18*
	Maize (Main)	7	12	22	27											*6*	*10*	*20*	*22*

Countries	**FAO**					**IRRI**					**USDA**					***Land Surface Phenology***			
	Crop	**SOW**		**HARV**		**Crop**	**SOW**		**HARV**		**Crop**	**SOW**		**HARV**		***SOS***		***EOS***	
		min	**max**	**min**	**max**		**min**	**max**	**min**	**max**		**min**	**max**	**min**	**max**	***min***	***max***	***min***	***max***
Côte d'Ivoire	Maize (Second)	22	27	34	3											*21*	*27*	*34*	*2*
	Millet	13	21	28	33														
	Rice	10	21	25	36	Rice Main, north	13	18	28	36						*8*	*12*	*33*	*36*
	Sorghum	13	21	28	33	Rice Main,south	10	15	25	33									
	Yams	4	9	19	36	Rice Off	34	6	10	18						*4*	*10*	*17*	*22*
Cuba	Maize (Main)	16	26	27	36														
	Maize (Second)	31	36	7	12														
	Potatoes	31	36	4	12						Sugarcane	31	16	31	16				
	Rice (Main)	7	20	21	36	Rice (Main)	10	21	19	24						*8*	*14*	*19*	*22*
	Rice (Second)	34	6	7	21	Rice (Second)	34	6	7	18									
	Sweet Potatoes	18	23	29	2											*23*	*25*	*33*	*3*
D.R.Congo	Cassava (North)	10	24	25	9											*21*	*24*	*33*	*5*
	Cassava (South)	28	6	7	27											*1*	*6*	*14*	*20*
	Maize (Centre/main)	19	27	31	3											*21*	*27*	*31*	*3*
	Maize (Centre/second)	31	3	7	15														
	Maize (Extreme/south)	31	36	7	15														
	Maize (North/Main)	16	21	28	33														
	Maize (North/Second)	4	9	16	21											*4*	*9*	*16*	*21*
	Maize (South/Main)	25	30	1	6											*25*	*30*	*1*	*6*

Countries		FAO					IRRI						USDA					*Land Surface Phenology*			
	Crop	SOW		HARV		Crop	SOW		HARV		Crop	SOW		HARV		*SOS*		*EOS*	
		min	max	min	max		min	max	min	max		min	max	min	max	*min*	*max*	*min*	*max*
D.R.Congo	Maize (South/Second)	1	6	13	18											*1*	*6*	*14*	*18*
	Millet & Sorghum	10	18	25	33														
	Rice (North)	19	24	31	33	Rice (North)	1	9	16	21						*1*	*9*	*16*	*21*
	Rice (South)	34	3	13	15	Rice (South)	25	30	4	9									
	Yams	4	9	19	36											*4*	*9*	*19*	*21*
Ecuador	Barley	30	9	10	25											*32*	*4*	*18*	*27*
	Maize	26	35	18	25											*32*	*36*	*18*	*26*
	Rice	29	5	12	20	Rice	34	6	10	18						*1*	*5*	*15*	*15*
	Wheat	2	9	13	26	Rice Summer	13	21	25	36						*2*	*4*	*18*	*26*
Egypt	Barley	32	35	11	14											*29*	*35*	*9*	*14*
	Maize	12	14	29	32														
	Millet	11	17	23	29											*15*	*19*	*23*	*29*
	Rice	12	19	29	32	Rice	13	15	28	30									
	Wheat	31	33	13	16						Wheat	25	33	10	24	*25*	*35*	*9*	*15*
El Salvador	Beans (Main)	13	15	22	24											*11*	*13*	*20*	*24*
	Beans (Second)	22	24	34	36											*23*	*26*	*34*	*36*
	Maize (Main)	13	18	22	33											*12*	*17*	*22*	*24*
	Maize (Second)	25	27	1	6											*24*	*27*	*1*	*3*
	Maize (Third)	34	36	4	6														
	Rice (Main)	13	18	31	3														
	Rice (Second)	1	6	7	12														
	Sorghum	16	21	34	5														
DPRK	Rice	12	16	27	30	Rice	13	18	25	30						*9*	*16*	*28*	*32*

Countries		FAO					IRRI					USDA				*Land Surface Phenology*			
	Crop	SOW		HARV		Crop	SOW		HARV		Crop	SOW		HARV		*SOS*		*EOS*	
		min	max	min	max		min	max	min	max		min	max	min	max	*min*	*max*	*min*	*max*
DPRK	Maize	10	13	24	28											*9*	*16*	*28*	*32*
	Soybean	10	13	24	28											*9*	*16*	*28*	*32*
	Sorghum	10	15	26	29											*9*	*16*	*28*	*32*
	Potatoes	13	16	25	27														
	Potatoes (early season)	7	10	18	20														
	Sweet Potatoes	8	10	23	26														
	Millet	16	18	27	29														
	Winter Wheat/Barley	28	32	16	18														
	Spring Wheat/Barley	7	9	16	18														
Eritrea	Barley	16	23	32	36											*17*	*20*	*29*	*36*
	Maize	16	21	31	35											*17*	*20*	*29*	*36*
	Millet & Sorghum	16	21	31	36											*17*	*20*	*29*	*36*
	Wheat	19	21	33	36											*17*	*20*	*29*	*36*
Ethiopia	All Cereals (Belg)	4	9	16	24											*7*	*10*	*14*	*23*
	Barley,Teff & Wheat (Meher)	13	18	31	36											*13*	*20*	*30*	*36*
	Maize (Meher)	7	14	28	34											*7*	*12*	*30*	*36*
	Millet (Meher)	13	18	31	2											*13*	*20*	*31*	*2*
	Oats (Meher)	11	24	28	3											*19*	*25*	*28*	*3*
	Sorghum (Meher)	7	14	28	34											*7*	*14*	*30*	*34*
Gambia	Groundnut	16	21	31	6											*16*	*20*	*32*	*3*
	Maize	13	21	25	30														

Countries	FAO					IRRI					USDA					*Land Surface Phenology*			
	Crop	SOW		HARV		Crop	SOW		HARV		Crop	SOW		HARV		*SOS*		*EOS*	
		min	max	min	max		min	max	min	max		min	max	min	max	*min*	*max*	*min*	*max*
Gambia	Millet	16	21	28	32											*16*	*20*	*32*	*34*
	Rice	16	21	28	33	Rice	13	18	28	33						*16*	*20*	*32*	*34*
	Sorghum	16	21	28	32	Rice Off	1	6	13	18						*16*	*20*	*32*	*34*
Ghana	Cassava (1st year,2nd year)	7	15	1	18											*4*	*10*	*15*	*24*
	Maize (North,main)	16	18	22	30														
	Maize (Second)	22	27	34	3											*23*	*28*	*34*	*2*
	Maize (South,main)	7	12	22	27											*7*	*10*	*20*	*24*
	Millet & Sorghum	13	21	28	33											*13*	*17*	*31*	*33*
	Rice(North)	13	21	28	36	Rice(North)	13	18	28	33						*13*	*17*	*31*	*36*
	Rice(South)	10	15	25	30	Rice(Off)	1	6	13	18									
	Yams	4	9	22	36											*4*	*10*	*20*	*24*
Guatemala	Maize & Sorghum (Main)	10	15	22	33											*10*	*15*	*20*	*32*
	Maize & Sorghum (Second)	22	27	31	6											*23*	*28*	*34*	*6*
	Potatoes	16	18	26	29														
	Rice	10	18	25	30											*10*	*18*	*25*	*30*
	Wheat	11	17	26	32											*11*	*17*	*26*	*32*
Guinea	Cassava (1st year,2nd year)	9	18	1	21											*7*	*14*	*16*	*21*
	Maize	13	18	28	33											*13*	*17*	*32*	*35*
	Millet	13	18	28	33											*13*	*17*	*32*	*35*
	Rice	13	24	28	3	Rice	10	18	25	33						*13*	*17*	*32*	*3*
	Sorghum	13	18	28	33	Rice Off	34	6	10	18						*13*	*17*	*32*	*35*

Countries	FAO					IRRI					USDA					*Land Surface Phenology*			
	Crop	SOW		HARV		Crop	SOW		HARV		Crop	SOW		HARV		*SOS*		*EOS*	
		min	max	min	max		min	max	min	max		min	max	min	max	*min*	*max*	*min*	*max*
Guinea	Yams	7	12	22	3											*7*	*12*	*32*	*2*
Guinea-Bissau	Maize	13	18	25	30														
	Millet	13	18	25	30														
	Rice	16	24	28	3	Rice	13	24	28	3						*14*	*18*	*35*	*5*
	Sorghum	13	18	25	30														
Haiti	Beans (Main)	7	12	16	18											*7*	*12*	*16*	*18*
	Beans (Second)	19	24	28	30														
	Beans (Third)	31	36	4	6														
	Maize (Main)	7	12	16	24											*7*	*12*	*16*	*24*
	Maize (Second)	4	9	16	21											*8*	*9*	*16*	*21*
	Rice (Main)	4	12	16	27	Rice (Main)	4	12	16	24						*7*	*12*	*16*	*24*
	Rice (Second)	22	27	31	36	Rice (Second)	22	27	31	36									
	Sorghum	16	27	1	3											*22*	*26*	*36*	*5*
Honduras	Maize (Main)	13	18	25	28											*11*	*15*	*20*	*28*
	Maize (Second)	22	27	34	6											*24*	*26*	*35*	*6*
	Maize (Third)	34	3	7	12														
	Sorghum	13	21	31	3											*10*	*14*	*34*	*3*
	Rice (Main)	20	21	28	30														
	Rice (Secondary)	5	6	13	15														
Indonesia	Maize (Dry S.)	10	15	21	27						Maize (Dry S.)	17	23	29	35	*10*	*15*	*21*	*27*
	Maize (Rainy S.)	28	36	4	9	Main, Java and South Sumatra	28	9	4	18	Maize (Rainy S.)	31	36	7	12	*28*	*36*	*4*	*9*

Countries	FAO					IRRI					USDA					*Land Surface Phenology*			
	Crop	SOW		HARV		Crop	SOW		HARV		Crop	SOW		HARV		*SOS*		*EOS*	
		min	max	min	max		min	max	min	max		min	max	min	max	*min*	*max*	*min*	*max*
Indonesia	Rice (Main)	28	36	4	12	Main,Sulawesi	13	18	22	30	Rice (Main)	29	3	7	17	*28*	*36*	*4*	*12*
	Rice (Off-season)	8	15	19	29	Main,Sumatra	19	27	31	36	Rice (Second)	19	24	30	35	*8*	*15*	*19*	*29*
Iran	Barley	26	2	7	9											*26*	*2*	*10*	*12*
	Potatoes	14	14	26	26														
	Rice	13	18	24	27	Rice	13	18	25	30									
	Wheat	25	31	16	20						Wheat	25	33	10	24				
Iraq	Barley	29	35	11	17											*29*	*36*	*10*	*16*
	Millet	8	14	20	26														
	Potatoes	4	6	16	18	Rice	16	21	25	30									
	Sorghum	8	14	17	26														
	Wheat	32	35	14	20						Wheat	25	33	10	24	*32*	*35*	*12*	*16*
Kazakhstan	Barley(Spring)	10	15	22	27						Barley(Spring)	10	15	22	28	*9*	*11*	*29*	*31*
	Cereals	13	18	25	30											*9*	*11*	*29*	*31*
	Wheat (Spring)	13	15	23	27						Wheat (Spring)	13	15	23	27	*9*	*11*	*29*	*31*
											Sunflower seed	*12*	*15*	*26*	*30*				
											Sugarbeets	*10*	*14*	*25*	*30*				
											Winter Wheat	*23*	*28*	*20*	*24*				
											Rye	*23*	*26*	*19*	*23*				
Kenya	Beans (Long rains)	8	12	25	30											*9*	*12*	*24*	*27*
	Maize (Long rains)	7	12	28	36											*9*	*12*	*28*	*36*
	Millet (Long rains)	7	11	16	30											*7*	*11*	*16*	*27*

Countries	**FAO**					**IRRI**					**USDA**					***Land Surface Phenology***			
	Crop	**SOW**		**HARV**		**Crop**	**SOW**		**HARV**		**Crop**	**SOW**		**HARV**		***SOS***		***EOS***	
		min	**max**	**min**	**max**		**min**	**max**	**min**	**max**		**min**	**max**	**min**	**max**	***min***	***max***	***min***	***max***
Kenya	Sorghum (Long rains)	4	12	22	27											*7*	*11*	*22*	*27*
	Wheat (Long rains)	14	18	28	33														
	Barley, Maize,Millet & Sorghum, Beans (Short rains)	28	33	4	9											*28*	*33*	*4*	*5*
Kyrgyzstan	Maize	10	18	22	27														
	Wheat(Spring)	10	15	25	30											*6*	*12*	*29*	*33*
	Wheat(Winter)	24	28	16	23														
Laos	Rice (Dry Season)	1	3	10	12	Rice (Dry Season)	34	3	10	18	Rice (Dry Season)	31	5	10	18				
	Rice (Wet Season)	15	20	28	36	Rice (Wet Season)	13	21	31	36	Rice (Wet Season)	12	19	25	32	*13*	*22*	*32*	*3*
Lesotho	Maize	28	36	13	18											*28*	*34*	*13*	*17*
	Sorghum	31	36	14	18														
	Wheat	13	15	31	33														
Liberia	Cassava (1st year,2nd year)	7	15	1	18														
	Rice	10	21	25	36	Rice	10	21	25	36						*23*	*26*	*35*	*1*
	Yams	4	9	19	36											*5*	*9*	*17*	*19*
Libya	Barley	29	32	11	14											*28*	*35*	*10*	*14*
	Millet	8	8	20	23														
	Potatoes	2	5	14	17														
	Wheat	29	32	13	17											*29*	*35*	*12*	*14*
Madagascar	Maize	31	36	8	12	Rice	28	33	10	18									

Countries	FAO					IRRI					USDA					*Land Surface Phenology*			
	Crop	SOW		HARV		Crop	SOW		HARV		Crop	SOW		HARV		*SOS*		*EOS*	
		min	max	min	max		min	max	min	max		min	max	min	max	*min*	*max*	*min*	*max*
Madagascar	Potatoes	26	32	5	14	Vatomandry,east	28	33	16	21									
	Rice	31	2	10	18	Hosy,east coast	10	18	28	33						*30*	*2*	*15*	*20*
	Sorghum	34	36	13	15	Asara,west coast	31	33	1	3						*32*	*1*	*21*	*24*
	Wheat	13	15	31	33	Atriatry,west coast	4	6	13	15									
						Jeby,west coast	19	21	28	30									
Malawi	Maize	27	32	12	17											*30*	*34*	*14*	*17*
	Rice	32	36	13	19	Rice	31	36	13	21						*30*	*36*	*14*	*21*
	Sorghum	34	36	16	18											*34*	*36*	*16*	*18*
	Wheat	4	8	20	24														
Mali	Irrigated Rice	28	36	7	12														
	Maize	13	21	25	33	Rice Main	13	21	28	36						*12*	*21*	*29*	*35*
	Millet	13	21	25	33	Rice Off	1	9	13	21						*12*	*21*	*29*	*35*
	Rainfed Rice	16	21	33	3	Deepwater Rice	19	24	34	3						*16*	*21*	*33*	*3*
	Sorghum	13	21	25	33											*12*	*21*	*29*	*35*
Mauritania	Low lying area crops	28	30	4	6														
	Irrigated Rice	16	20	28	33	Irrigated Rice	16	21	28	33						*18*	*21*	*28*	*34*
	Maize	19	24	28	33											*18*	*21*	*28*	*34*
	Millet	19	24	28	33											*18*	*21*	*28*	*34*
Countries	**FAO**					**IRRI**					**USDA**					***Land Surface***			

Countries	FAO					IRRI					USDA					Land Surface Phenology			
	Crop	SOW		HARV		Crop	SOW		HARV		Crop	SOW		HARV		SOS		EOS	
		min	max	min	max		min	max	min	max		min	max	min	max	min	max	min	max
Mauritania	Off-season Rice	28	36	7	12	Off-season Rice	28	36	7	12									
	Sorghum	19	24	28	36											18	21	28	2
	Walo crops	31	33	7	12														
Morocco	Barley	32	35	14	20						Barley	31	36	13	17	30	35	10	20
	Maize	5	5	17	21														
	Potatoes	26	26	5	11														
	Wheat	32	35	14	17						Wheat	31	36	13	17	30	35	10	17
Mozambique	Maize	28	36	9	15											31	34	19	23
	Sorghum	31	36	13	18	Rice Main	31	3	13	18						30	36	14	18
	Wheat	13	15	28	30														
Myanmar	Maize	26	34	2	10											34	36	6	10
	Potatoes	5	13	17	26											9	13	17	20
	Rice (Main)	13	18	28	35	Rice (Main)	16	24	31	3	Rice (Main)	13	18	28	35	20	24	30	4
	Rice (Second)	31	36	8	17	Rice (Second)	31	36	10	15	Rice (Second)	31	36	8	17	34	36	6	10
	Wheat	27	33	6	13														
Namibia	Maize	34	36	16	18											32	36	14	18
	Millet/Sorghum	34	3	16	18											32	36	14	18
	Wheat	13	17	28	32														
Nepal	Maize	4	14	23	27														
	Millet	17	22	27	35											17	22	27	35
	Rice	15	22	30	35	Rice	13	24	28	36	Main (Wet)	11	17	25	32	13	22	28	35
	Wheat	30	34	8	18						Second (Dry)	31	5	10	15	32	36	7	10

																	Phenology		
	Crop	**SOW**		**HARV**		**Crop**	**SOW**		**HARV**		**Crop**	**SOW**		**HARV**		***SOS***		***EOS***	
		min	**max**	**min**	**max**		**min**	**max**	**min**	**max**		**min**	**max**	**min**	**max**	***min***	***max***	***min***	***max***
Nicaragua	Beans (Main)	13	15	19	24											*12*	*16*	*19*	*24*
	Beans (Second)	25	27	31	36														
	Maize (Main)	13	18	22	27											*13*	*18*	*22*	*27*
	Maize (Second)	22	27	31	33														
	Maize & Beans (Third)	31	36	7	9														
	Rice (Highland)	16	18	28	33	Rice(Highland)	16	18	28	33						*13*	*18*	*24*	*30*
	Rice (Irrigated/Main)	1	6	10	18	Rice (Irrigated/Main)	1	6	10	33									
	Rice(Irrigated/Second)	19	27	31	33														
	Sorghum (Main)	13	18	25	30											*14*	*20*	*25*	*33*
	Sorghum (Second)	22	27	31	36														
Niger	Cowpea	16	22	25	32											*17*	*20*	*28*	*36*
	Groundnut	16	20	28	33											*17*	*20*	*28*	*36*
	Maize	16	19	26	30											*17*	*20*	*28*	*36*
	Millet	17	20	25	30	Deepwater Rice	19	24	34	3						*17*	*20*	*28*	*36*
	Rainfed rice	16	21	22	33	Other rice,main	16	21	28	36						*17*	*20*	*28*	*36*
	Sorghum	17	22	26	31											*17*	*20*	*28*	*36*
Nigeria	Cassava (South)	13	18	34	3														
	Irrigated Rice	13	27	28	3											*23*	*27*	*33*	*3*
	Maize (North/main)	13	18	22	27	Rice Main,south	10	15	22	30									
Countries	**FAO**					**IRRI**					**USDA**					***Land Surface***			

Countries	FAO					IRRI					USDA					*Land Surface Phenology*			
	Crop	**SOW**		**HARV**		**Crop**	**SOW**		**HARV**		**Crop**	**SOW**		**HARV**		***SOS***		***EOS***	
		min	**max**	**min**	**max**		**min**	**max**	**min**	**max**		**min**	**max**	**min**	**max**	***min***	***max***	***min***	***max***
Nigeria	Maize (Second)	22	27	34	3	Main,north	16	21	31	36						*23*	*27*	*33*	*3*
	Maize (South/main)	7	12	16	24	Off,south	31	36	7	12						*6*	*13*	*18*	*23*
	Millet	16	18	25	30	Off,north	1	6	13	18						*16*	*19*	*28*	*32*
	Rainfed rice	10	21	22	30											*11*	*19*	*29*	*32*
	Sorghum	13	21	25	33											*11*	*19*	*29*	*35*
	Yams	4	9	19	3														
Pakistan	Barley	29	32	8	12											*30*	*34*	*8*	*12*
	Maize	11	23	26	33											*14*	*23*	*26*	*33*
	Millet	17	23	26	31						Sugarcane	4	9	31	36	*17*	*23*	*26*	*31*
	Potatoes	2	7	11	16											*1*	*7*	*10*	*16*
	Rice	15	21	27	34	Rice	13	21	28	33	Rice	15	21	27	35	*15*	*21*	*27*	*34*
	Sorghum	17	21	25	30											*17*	*21*	*25*	*30*
	Wheat (winter)	28	35	10	16						Wheat (winter)	28	35	10	16	*30*	*36*	*9*	*15*
Peru	Barley	30	8	11	23											*30*	*4*	*13*	*23*
	Maize (white)	25	36	10	24											*28*	*36*	*13*	*24*
	Maize (yellow)	22	33	4	21											*24*	*33*	*13*	*21*
	Potatoes	11	20	23	35														
	Rice	35	8	14	23											*34*	*5*	*14*	*23*
	Sorghum	11	24	25	35														
	Soybean	29	36	11	17											*29*	*36*	*13*	*17*
	Wheat	32	8	11	26											*32*	*5*	*13*	*23*
Philippines	Maize (Main)	10	17	20	26	Rice Wet, north	13	21	28	36	Maize (Main)	10	17	19	26	*10*	*17*	*19*	*26*

																	Phenology			
	Crop	**SOW**		**HARV**		**Crop**	**SOW**		**HARV**		**Crop**	**SOW**		**HARV**		***SOS***		***EOS***		
		min	**max**	**min**	**max**		**min**	**max**	**min**	**max**		**min**	**max**	**min**	**max**	***min***	***max***	***min***	***max***	
Philippines	Maize (Second)	29	35	5	14	Rice Dry, north	1	9	13	18	Maize (Second)	29	36	5	11	*28*	*36*	*4*	*11*	
	Potatoes	8	20	22	32											*10*	*20*	*22*	*32*	
	Rice (Main)	10	17	26	35	Rice Wet, south	28	36	7	15	Rice (Main)	10	17	26	35	*11*	*17*	*26*	*35*	
	Rice (Second)	29	35	2	11	Rice Dry, south	13	18	31	36	Rice (Second)	29	35	2	11	*28*	*35*	*2*	*11*	
Rwanda	Beans (A season)	25	30	34	3	Rice First wet	25	30	1	6						*25*	*30*	*34*	*3*	
	Beans (B season)	4	9	13	18	Rice Second wet	4	9	13	18						*6*	*9*	*18*	*19*	
	Maize & Sorghum (A season)	25	30	1	6											*25*	*30*	*1*	*6*	
	Maize & Sorghum (B season)	4	9	16	21											*6*	*9*	*18*	*21*	
Senegal	Groundnut	16	21	31	6											*16*	*21*	*31*	*5*	
	Maize	16	21	25	32											*16*	*21*	*30*	*34*	
	Millet & Sorghum	18	21	25	33	Rice Off	4	9	16	21						*18*	*21*	*30*	*33*	
	Rice	16	24	31	3	Rice	16	21	28	36						*16*	*21*	*31*	*3*	
Sierra Leone	Cassava (1st year,2nd year)	7	15	1	18											*7*	*13*	*18*	*21*	
	Maize	13	21	28	33															
	Millet	13	21	28	33															
	Rice	10	21	25	36	Rice	10	21	25	3						*23*	*25*	*35*	*3*	
	Sorghum	13	18	28	33															
	Yams	4	9	19	36															

Countries		FAO					IRRI					USDA				***Land Surface Phenology***			
	Crop	**SOW**		**HARV**		**Crop**	**SOW**		**HARV**		**Crop**	**SOW**		**HARV**		***SOS***		***EOS***	
		min	**max**	**min**	**max**		**min**	**max**	**min**	**max**		**min**	**max**	**min**	**max**	***min***	***max***	***min***	***max***
Somalia	Maize and Sorghum(Der)	27	29	1	3											*27*	*30*	*36*	*4*
	Maize and Sorghum(Gu)	10	12	22	24											*9*	*12*	*17*	*25*
South Africa	Barley	11	17	29	35											*11*	*16*	*29*	*35*
	Maize(East)	29	32	11	13						Maize(East)	27	36	11	18	*29*	*32*	*11*	*13*
	Maize(West)&Sorghum	34	3	16	18														
	Millet	24	35	11	20											*24*	*35*	*11*	*20*
	Sorghum	34	3	16	18														
	Soybean	29	35	11	17											*29*	*35*	*11*	*17*
	Wheat	13	17	28	33						Wheat	12	21	28	36	*13*	*16*	*28*	*33*
South Sudan	Maize,Mille Sorghum(South/.ain)	7	12	19	24														
	Maize,Mille Sorghum(South/second)	22	27	34	3														
	Maize (Unimodal)	10	15	22	30														
	Maize & Sorghum(Unimodal)	10	15	31	36											*10*	*15*	*31*	*36*
Sudan	Millet & Sorghum	16	21	31	36											*14*	*22*	*29*	*36*
	Wheat	31	33	7	9														
Swaziland	Maize	28	33	13	15											*27*	*31*	*15*	*18*
	Sorghum	34	36	16	18														
Countries		**FAO**					**IRRI**					**USDA**				***Land Surface***			

																Phenology			
	Crop	**SOW**		**HARV**		**Crop**	**SOW**		**HARV**		**Crop**	**SOW**		**HARV**		***SOS***		***EOS***	
		min	**max**	**min**	**max**		**min**	**max**	**min**	**max**		**min**	**max**	**min**	**max**	***min***	***max***	***min***	***max***
Swaziland	Wheat	13	15	31	33														
Syria	Barley	29	1	14	18											*29*	*1*	*13*	*18*
	Potatoes	8	14	15	29														
	Rice	11	14	26	30														
	Wheat	29	2	14	20											*29*	*1*	*13*	*18*
Tajikistan	Coarse Grains (Spring)	10	18	22	27														
	Wheat (Winter)	24	32	16	23														
Tanzania	Maize (Vuli/Bimodal)	25	30	1	5											*25*	*31*	*1*	*5*
	Maize,Sorghum & Millet (Maika/Bimodal)	6	9	19	24											*6*	*9*	*17*	*24*
	Maize & Sorghum (Maimu/Unimodal)	31	36	13	18	Rice (Msimu/Unimodal)	34	6	13	21						*30*	*36*	*13*	*20*
	Rice (Msimu/Unimodal)	34	3	13	18	Rice Off	16	21	31	36						*34*	*36*	*13*	*20*
Thailand	Maize	11	17	20	26	Rice North & Central,major	13	21	31	36	Maize	11	17	19	26	*9*	*15*	*18*	*26*
	Rice (Main)	13	24	28	3	Rice North & Central,minor	34	3	13	18	Rice (Main)	13	24	28	3	*11*	*24*	*31*	*5*
	Rice (Second)	1	7	12	18	Rice South, major	25	33	7	15	Rice (Second)	1	7	13	18	*1*	*8*	*12*	*20*
	Sorghum	11	24	25	35	Rice South, minor	10	15	22	27						*13*	*26*	*30*	*36*
Timor-Leste	Maize (Main)	31	36	4	12														
Countries		**FAO**					**IRRI**					**USDA**				***Land Surface***			

																	Phenology		
	Crop	**SOW**		**HARV**		**Crop**	**SOW**		**HARV**		**Crop**	**SOW**		**HARV**		***SOS***		***EOS***	
		min	**max**	**min**	**max**		**min**	**max**	**min**	**max**		**min**	**max**	**min**	**max**	***min***	***max***	***min***	***max***
Timor-Leste	Maize (Off Season)	13	21	25	33														
	Rice (Main)	34	6	13	21	Rice (Main)	34	3	13	21						*32*	*35*	*18*	*23*
	Rice (Off season)	10	18	22	36	Rice (Off season)	10	18	22	36									
Togo	Cassava	13	18	34	36														
	Maize (Main)	7	12	22	27											*6*	*11*	*20*	*23*
	Maize (Second)	22	27	34	3											*23*	*27*	*33*	*1*
	Millet & Sorghum	13	21	28	33											*13*	*17*	*31*	*34*
	Rice	13	15	30	32	Rice	13	15	28	33						*13*	*17*	*31*	*34*
	Yams	4	9	19	3											*6*	*11*	*18*	*23*
Tunisia	Barley	29	35	14	17						Barley	31	36	13	17	*27*	*35*	*13*	*17*
	Potatoes	3	6	15	18														
	Wheat	29	35	16	18						Wheat	31	36	13	17	*27*	*35*	*13*	*17*
Turkmenistan	Coarse Grains (Spring)	10	18	22	27	Rice Main	10	15	22	27	Cotton	11	15	27	32				
	Maize	10	18	22	27														
	Wheat (Winter)	24	32	16	23														
Uganda	Beans (South/main)	4	9	16	21											*6*	*9*	*16*	*21*
	Beans (South/Second)	25	30	34	3														
	Cassava (North)	10	15	25	9	Rice First	4	6	16	18									
	Maize & Millet (South/Second)	25	30	34	3	Rice Second	22	24	34	36						*25*	*30*	*36*	*3*
	Maize (North)	10	15	22	27											*9*	*14*	*19*	*27*
Countries		**FAO**					**IRRI**					**USDA**					***Land Surface***		

																	Phenology		
	Crop	**SOW**		**HARV**		**Crop**	**SOW**		**HARV**		**Crop**	**SOW**		**HARV**		***SOS***		***EOS***	
		min	**max**	**min**	**max**		**min**	**max**	**min**	**max**		**min**	**max**	**min**	**max**	***min***	***max***	***min***	***max***
Uganda	Maize (South/main)	4	9	16	21											*6*	*9*	*16*	*21*
	Millet (North)	10	15	25	30														
	Millet (South/main)	4	9	16	24											*6*	*9*	*16*	*24*
	Sweet Potato (North)	10	15	25	9														
Uzbekistan	Cereals (Winter)	24	32	16	23														
	Coarse Grains (Spring)	10	18	22	27														
	Maize	10	18	22	27														
Vietnam	Rice 10th Month/North	17	26	27	36	Rice Main	13	24	25	36	Rice 10th Month/North	16	22	25	33	*17*	*24*	*27*	*36*
											Rice 10th month South	17	29	33	4				
	Rice Summer/Autumn	10	20	21	30	Rice Summer/Autumn	10	18	22	27	Rice Summer/Autumn	13	18	23	31	*10*	*18*	*19*	*30*
	Rice Winter/Spring North	32	7	12	18	Rice Winter/Spring	34	6	10	18	Rice Winter/Spring North	32	10	15	21	*1*	*9*	*12*	*20*
	Rice Winter/Spring South	33	7	9	14						Rice Winter/Spring South	33	7	9	14	*35*	*5*	*9*	*14*
Yemen	Wheat	16	18	25	27														
	Sorghum	7	15	25	33											*7*	*16*	*30*	*33*
Zambia	Maize	30	34	12	17											*28*	*34*	*13*	*19*
	Millet	35	35	17	20														
	Sorghum	32	2	13	18											*32*	*35*	*13*	*18*
Countries		**FAO**					**IRRI**					**USDA**					***Land Surface***		

																Phenology			
	Crop	**SOW**		**HARV**		**Crop**	**SOW**		**HARV**		**Crop**	**SOW**		**HARV**		***SOS***		***EOS***	
		min	**max**	**min**	**max**		**min**	**max**	**min**	**max**		**min**	**max**	**min**	**max**	***min***	***max***	***min***	***max***
Zambia	Wheat	13	17	28	32														
Zimbabwe	Maize	31	36	13	18											*29*	*34*	*14*	*21*
	Sorghum	34	3	16	18														
	Wheat	13	17	28	32														

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