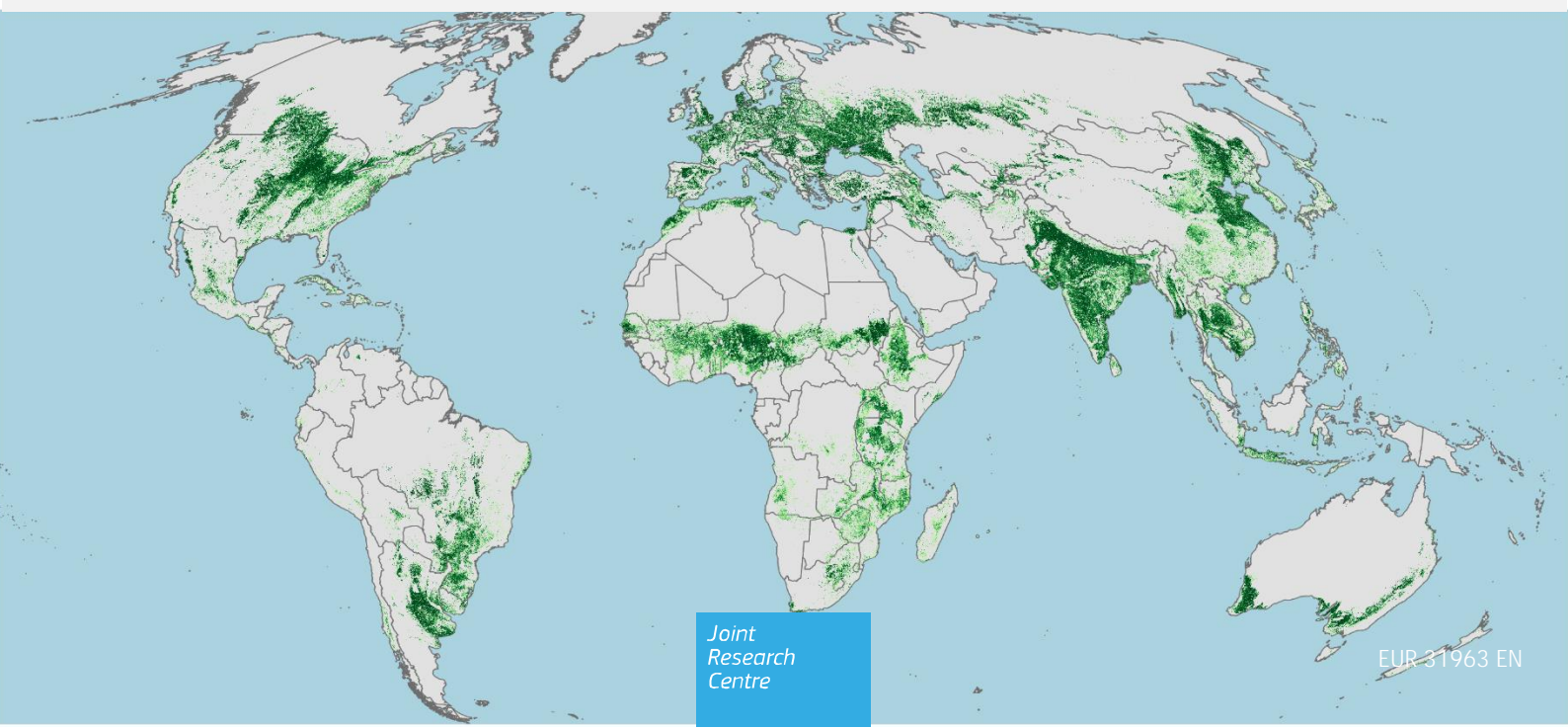




Development of a new cropland and rangeland Area Fraction Image at 500 m for the ASAP system

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Abstract

This document presents a description of the data used and the processing carried out to derive global cropland and rangeland area fraction images at 500 m utilized by the JRC early warning system ASAP (Anomaly hotspot of Agricultural Production, <https://agricultural-production-hotspots.ec.europa.eu/>) version 8.0. A scientific data paper currently under preparation will complement the information reported here.

1 Introduction

Agricultural drought, with its negative effects on agricultural production, is one of the main causes of food insecurity worldwide. Extreme droughts like those that hit the Sahel region in the 70's and 80's, the Ethiopian drought in 1984 and the recent Horn of Africa drought in 2010/2011 and in 2020/2021/2022 have received extensive media attention because they have directly caused hunger and led to the death of hundreds of thousands of people. Crop failures and pasture biomass production losses are the primary direct impact of drought on agricultural sector productivity. Drought-induced production losses cause negative supply shocks, but the amount of incurred economic impacts and the distribution of losses depend on the market structure and the interaction between the supply and demand of agricultural products.

One way to mitigate the impacts of drought is through the provision of timely information from early warning and monitoring systems, which can be used to ensure an appropriate response.

Research context

To provide early warning information at the global level on a near real-time basis, the Food Security Unit of the Joint Research Centre has developed an online early warning system called ASAP (Anomaly hot Spots of Agricultural Production) described in Rembold et al. (2019). ASAP capitalizes on the availability of global datasets of weather and vegetation status from models and remote sensing observations, and on well-established time series analysis methods. The system provides timely overviews of agricultural anomalies available at the global level as inputs to more detailed agricultural monitoring or food security assessments.

ASAP provides ten-day automatic warnings at sub-national level. The automatic warnings are generated globally for crop and rangeland areas. The warnings, together with input indicator maps and a set of additional graphs and statistics, are made available online in the ASAP Warning Explorer (<https://agricultural-production-hotspots.ec.europa.eu/wexplorer/>).

The ASAP global early warning system, as with other early warning systems (Fritz et al. 2019), relies heavily on cropland and rangeland masks to define the areas where anomalies in the various indicators should be considered for early warning purposes. Masks are available at the ASAP global spatial grid reference system (at 1 km resolution in version v7.0) as Area Fraction Images (AFIs): i.e., cropland and rangeland areas are identified by masks expressed as the percentage of the pixel area occupied by the given target, either cropland or rangeland, ranging from 0 to 100%. The scope of this study is to update the ASAP v7.0 AFIs and align these to the new ASAP v. 8.0 reference grid of 500 m spatial resolution. More detailed information, including manuals and reports, can be found in the [documentation page of ASAP \(https://agricultural-production-hotspots.ec.europa.eu/documentation.php\)](https://agricultural-production-hotspots.ec.europa.eu/documentation.php).

The ASAP v. 7.0 AFIs (Pérez-Hoyos et al. 2017) were produced by comparing and then combining existing data sets in 2017. However, there are new global products on land cover and cropland available based on high spatial resolution remote sensing. The aim of this study is to i) review the current products available and assess them for fitness-for-use in the context of ASAP; ii) choose the most appropriate products as inputs to update the cropland and rangeland AFIs; and c) develop and implement a methodology to create improved cropland and rangeland AFIs for use by the ASAP system.

In the next section, cropland and rangeland definitions are provided followed by a review of the products, the methodology used to create the improved cropland and rangeland masks, and the results obtained.

2 Cropland and rangeland definitions

Table 1 presents the definitions for cropland and rangeland used by ASAP v. 7.0 and the definitions to which the improved cropland rangeland maps (used in ASAP v. 8.0) align as closely as possible.

Table 1. Definition for cropland and rangeland used by ASAP (v. 7.0) and the new definitions proposed for the improved cropland and rangeland products in the current ASAP version (v. 8.0).

	ASAP v. 7.0 definition	ASAP v. 8.0 desired definition
Cropland	The land used for cultivation of crops, encompassing both total areas under arable land and permanent crops.	“Arable land” according to the Handbook on Remote Sensing for Agricultural Statistics (GSARS 2017). Arable land is land that is used in most years for growing temporary crops. It includes land used for growing temporary crops during a twelve-month reference period, as well as land that would normally be so used but is lying fallow or has not been sown due to unforeseen circumstances. <u>Arable land does not include land under permanent crops</u> or land that is potentially cultivable but is not normally cultivated. Such land should be classified as “permanent meadows and pastures” if used for grazing or haying, “forest and other wooded land” if overgrown with trees and not used for grazing or haying, or “other area not elsewhere classified” if it becomes wasteland.
Rangeland	“Grassland” according to FAO-GLCshare (Latham 2014). Thus, grasslands included any geographic area dominated by natural herbaceous plants with a cover of 10% or more, irrespective of different human and/or agricultural activities, such as grazing. Woody plants (tree and/or shrubs) can be present with cover was less than 10%.	As there is no universally accepted definition of rangeland, we adopt the following one adapted to the scope (i.e., a remote sensing product that can inform drought assessment and monitoring). The definition we use here comes from Reeves and Mitchell (2011) and merges some components from the USDA and US National Resources Conservation Management (NRCM) definitions. We include pasture and rangeland. Pasture (USDA): Land that is maintained and used for grazing, while NRCM specifies it is grassland. Rangeland: naturally managed land primarily composed of grasses, forbs and shrubs.

Source: EC-JRC.

However, it should be noted that applying these ‘new’ definitions in the translation of the legends from available land use/land cover maps was not always directly possible. Therefore, for the improved hybrid cropland and rangeland products, we adopted the following definitions when considering existing products:

- Cropland layer: if the available land cover products contain separate classes for annual crops and permanent crops such as tree crops, sugarcane, etc., then we use only the annual crops. If these classes are not separated, then we retain the cropland class regardless. If the base land cover map is detailed enough, then important staple crops that are semi-permanent (i.e., they exceed a twelve-month growing period) such as cassava or other tubers, should be included.

- Rangeland layer: we use the grassland and shrub land classes in the development of the rangeland layer. If a distinction is made in the land cover product between open and closed shrubs, then we use only open shrubs. When possible and in order to separate out desert or very dry land from sparsely vegetated rangeland, we define a minimal vegetation cover percentage of 10%.

3 Review of relevant land cover products

Global maps of land cover derived from satellite-based Earth Observation have existed for almost three decades and represent one of the most important sources of baseline terrestrial information for a wide variety of applications. For instance, they are used as inputs to global models of land use and land use change (Foley et al., 2011; Verburg et al., 2011), in climate modelling (Pielke, 2005), for the assessment of available land for biofuels (Cai et al., 2011), for food security purposes (Liu et al., 2008) and as the basis for crop distribution modelling (You et al., 2009). Applications in other areas such as biodiversity and population are presented in Giri et al. (2005). Over the last 30 years, advances in remote sensing have improved their spatial resolution from 1 km down to 10 m.

For the development of new cropland and rangeland fraction maps at a 500 m resolution, the most recent global and European land cover products are considered with the exception of the ESRI land cover product (<https://livingatlas.arcgis.com/landcover/>) and the Dynamic World product (<https://dynamicworld.app/>). The issue with both of these recent 10 m products is that their definition of cropland/crops does not meet our requirements since they include grasses in their cropland definition.

3.1 Large-scale Existing Cropland Products

To produce the cropland AFI, we focus on five recent global land cover products having a cropland definition that matches the needs of ASAP as outlined above: (1) C-Glops Copernicus global land cover, (2) ESA WorldCover, (3) ESA WorldCereal, (4) GLAD Cropland and (5) CORINE Land Cover. These products are described in more detail below. For each of the five products, the date of the satellite imagery used, the date of production, the sensor(s), the spatial resolution, the overall, user's and producer's accuracy figures and the cropland definitions are provided, along with a general description of the product.

3.1.1 C-Glops Copernicus global land cover (Buchhorn et al. 2020)

Date of satellite data used: 2019

Date of production: 2020

Sensor: PROBA-V

Resolution: 100 m

Data access : <https://land.copernicus.eu/en/products/global-dynamic-land-cover>

Accuracy: overall 85%, user's accuracy 72%, producer's accuracy 80%

Cropland Definition: "Lands covered with temporary crops followed by harvest and a bare soil period (e.g., single and multiple cropping systems). Note that perennial woody crops will be classified as the appropriate forest or shrub land cover type."

Description: The map provides primary land cover information on the spatial distribution of land cover classes such as evergreen closed forest, evergreen open forest, deciduous closed forest, deciduous open forest, mixed forest, shrubs, herbaceous vegetation, croplands, urban/built-up, bare land/space, vegetation, snow and ice, permanent water bodies, temporal water bodies and herbaceous wetlands. Apart from these classes, the map also provides a set of four vegetation continuous fields that provide proportional estimates for vegetation cover types, namely trees, herbaceous vegetation, shrub and

bare ground. These continuous classifications may depict areas of heterogeneous land cover better than the standard (categorical) classifications, and as such, can be tailored to different applications (e.g., forest monitoring, crop monitoring, biodiversity and conservation, environmental monitoring and security in Africa, climate modelling, etc.).

The C-Glops Copernicus global land product also provides fraction images for snow/ice, built-up, lichen/mosses, shrubs, crops and herbaceous vegetation. In particular, the shrub fraction cover could be used to define the rangeland class.

3.1.2 ESA WorldCover (Zanaga et al., 2022)

Date of satellite data: 2021

Date of production: 2022

Sensors: Sentinel 2 and Sentinel 1

Resolution: 10 m

Data access : <https://esa-worldcover.org/en>

Accuracy: overall 77%, user's accuracy 80%, producer's accuracy 80%

Cropland Definition: "Land covered with annual cropland that is sowed/planted and harvestable at least once within the 12 months after the sowing/planting date. The annual cropland produces an herbaceous cover and is sometimes combined with some tree or woody vegetation. Note that perennial woody crops will be classified as the appropriate tree cover or shrub land cover type. Greenhouses are considered as built-up."

Description: Besides a strong focus on users, WorldCover represents a tremendous step forward towards the joint use of Sentinel-1 and Sentinel-2 data for worldwide land cover mapping. With Sentinel-1 and 2 now being at full capacity, WorldCover provides the ideal base to explore the synergetic use of Sentinel-1 and 2 on a global scale for land cover mapping and has resulted in a major step forward for both related science and services. The project was organized in two phases. The main goal of the 1st Phase of WorldCover was to produce a prototype map over 27 macro-regions covering 10% of the Earth's land surface. The exact locations of the 27 macro-regions were selected based on the following criteria: user preference (i.e., areas of interest for the key users), diversity in ecosystem type and variation in cloud cover. The main goal of the 2nd Phase of the WorldCover project was to produce the final global land cover map at a 10 m resolution.

3.1.3 ESA WorldCereal (Van Tricht et al., 2023)

Date of satellite data: 2021

Date of production: 2022

Sensor: Sentinel 2

Resolution: 10 m

Data access : <https://esa-worldcereal.org/en>

Accuracy: overall 97.8%, user's accuracy 88.5%, producer's accuracy 92.1%

Cropland Definition: Annual cropland, including sugar cane.

Description: WorldCereal aims to develop an efficient, agile and robust Earth Observation based system for timely global crop monitoring at field scale. The open source WorldCereal system will be able to: (i) create local to global annual cropland extent maps at 10 m resolution; (ii) update the crop maps on a seasonal basis; (iii) differentiate between actively irrigated and rainfed fields; and (iv) produce global maps of maize and wheat. WorldCereal is a global R&D challenge, aiming to engage the global agricultural community to achieve optimal results. The development of the system to date has been built upon existing initiatives on, e.g., in situ data collection and sharing, algorithm development, IT infrastructures and best practices. In the future, WorldCereal will rely heavily on the operational time series of the Copernicus Sentinel missions, which will allow for unprecedented dynamic crop monitoring at a global scale. With a focus on maize and wheat during the system demonstration, WorldCereal aims to contribute to the global food security challenge as together with rice, these crops form the world's most widely cultivated species, accounting for an estimated 42.5% of the world's food calorie supply based on FAO statistics.

3.1.4 GLAD Cropland (Potapov et al. 2022)

Date of satellite data: 2019

Date of production: 2021

Sensor: Landsat

Resolution: 30 m

Data access : <https://glad.umd.edu/dataset/croplands>

Accuracy: overall 97.2%, user's accuracy 88.5 %, producer's accuracy 86.4%

Cropland Definition: Land used for annual and perennial herbaceous crops for human consumption, forage (including hay) and biofuel. Perennial woody crops, permanent pastures and shifting cultivation are excluded. The fallow length is limited to 4 years for the cropland class.

Description: This dataset represents a globally consistent cropland extent time-series at 30-m spatial resolution. The cropland mapping was done using the consistently processed Landsat satellite data archive from 2000 to 2019. The Landsat time-series data were transformed into multitemporal metrics that describe land surface phenology. These metrics were used as independent variables for a machine learning classification to map global cropland extent. The classification models were locally calibrated using extensive training data collected by visual interpretation of freely available high spatial resolution remotely sensed data. The crop mapping was performed in four-year intervals (2000-2003, 2004-2007, 2008-2011, 2012-2015, and 2016-2019). There is one cropland layer per epoch (five layers in total), with the filename referring to the last year of the interval (2003, 2007, 2011, 2015, and 2019).

3.1.5 Copernicus CORINE Land Cover 2018 for Europe (EEA, 2019)

Date of Satellite Data: 2018

Date of Production: 2020

Sensor: Landsat

Resolution: 100 m, minimum mapping unit 25 hectares

Data access : <https://land.copernicus.eu/pan-european/corine-land-cover/clc2018>

Accuracy: not reported

Cropland definition: Arable land: lands under a rotation system used for annually harvested plants and fallow lands, which are rain-fed or irrigated. Includes flooded crops such as rice fields and other inundated croplands.

Description: CORINE Land Cover (CLC) was specified in the 1980s to standardize data collection on land in Europe, in order to support environmental policy development. CLC data provides information on the biophysical characteristics of the Earth's surface. Images acquired by Earth Observation satellites are used as the main source of data to derive land cover and land use information. The implementation of CLC follows a bottom-up approach, meaning that national teams produce the database for their own country, and these data are integrated at the European level. Project management is provided by the European Environment Agency (EEA) and 39 countries participated in CLC2012. Despite limitations in spatial resolution, CLC has become the primary spatial data source on land for the EEA. It is widely used for indicator development, environmental modelling and land cover/land use change analysis in the European context. Other Commission Services (e.g. DG Environment, DG Agriculture) also rely on CLC. Page-view statistics show that CLC is one of the most popular EEA databases. The basic parameters of CLC have not changed during its lifetime.

3.2 Large-scale Rangeland Products

Among the products considered for the cropland mask listed in Section 3.1, C-Glops and WorldCover were retained for rangeland, as they provide a suitable definition of grassland and shrubland. Particularly, both products define shrubland as a class dominated by plants being less than 5 m tall, with a presence of scattered trees below 10% and herbaceous plants present at any density. Grassland includes areas dominated by natural herbaceous plants with a cover of 10% or more (grasslands, prairies, steppes, savannahs, pastures) irrespective of different human and/or animal activities. In addition to those and only for European countries, we included the Copernicus Grassland High Resolution Layer for 2018 at 10 m spatial resolution (HRL 2018 GRA).

3.2.1 Copernicus Grassland High Resolution Layer for 2018

Date of Satellite Data: 2018

Date of Production: 2020

Sensor: Sentinel-2

Resolution: 10 m + 100 m

Data access : <https://land.copernicus.eu/en/products/high-resolution-layer-grassland/grassland-2018>

Accuracy: overall 93.95%

Rangeland definition: this grassy and non-woody vegetation baseline product includes all kinds of grasslands: managed grassland, semi natural grassland and natural grassy vegetation. It is a binary status layer for the 2018 reference year mapping grassland and all non-grassland areas in 10m and (aggregated) 100m pixel size. *Description*: The HRL Grassland 2018 raster product provides a basic land cover classification with two thematic classes (grassland / non-grassland), covering the EEA38 area and the United Kingdom. The production of the High Resolution Grassland layers was

coordinated by the European Environment Agency (EEA) in the frame of the EU Copernicus programme.

4 Selection of input products for the cropland AFI

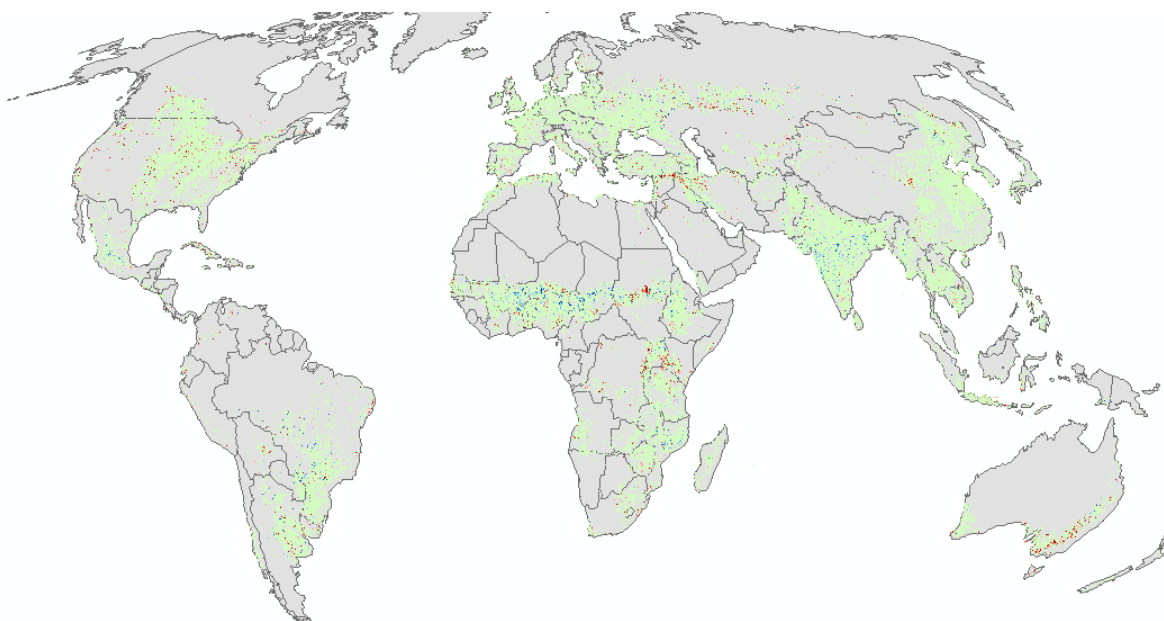
The rationale for the product choice was based on a combination of fitness-for-purpose, i.e., the suitability of the cropland definition, and the accuracy of the maps.

High spatial resolution products were selected as candidates for primary input layers. However, the accuracy of the WorldCover product is lower than the other products and was therefore excluded. Hence, for cropland, we decided to use the two products with the highest accuracy, i.e., GLAD Cropland and WorldCereal. Furthermore, both products are more recent (2019 for GLAD Cropland and 2020/21 for WorldCereal) than the other products reviewed, which also justifies their use.

In a preliminary analysis, we computed the cropland Area Fraction Image (AFI) at 500 m from each of the two selected layers. First, we defined a 500 m nominal scale reference in EPSG:4326 as a grid having origin at -180.004464285714988,75.004464285715002 and size 0.004464285715000,-0.004464285715000 decimal degrees, matching the Terra/Aqua MODIS FPAR Smoothed ~500m product, which is being used in the ASAP system. Second, we superimposed it to the two layers. For each grid cell, we calculated the area fraction as $AF_{crop} = \frac{\sum_{i=1}^n A_i}{A_g} \cdot 100$, where A_i are the areas of the n pixels (or fraction of pixels) of the relevant product labelled as crop and falling within each grid cell having area A_g . We then compared the two resulting AFIs. Figure 1 shows where the difference between the two AFI is less than 50% in green. A 50%-75% disagreement is shown in light red (where WorldCereal does not show cropland compared to the GLAD Cropland product, which does) and light blue (where WorldCereal shows cropland compared to the GLAD Cropland product, which does not). 75-100% disagreement is shown in dark red (where WorldCereal does not show cropland compared to the GLAD Cropland product, which does) and dark blue (where WorldCereal shows cropland compared to the GLAD Cropland product, which does not).

Such comparison clearly shows a degree of agreement between the two products (see Figure 1, shown in green).

Figure 1. Comparison of the GLAD Cropland and WorldCereal cropland extent products showing agreement (in green), 50-75% disagreement (light red and blue) and 75-100% disagreement (dark red and blue).



Source: IIASA/EC-JRC.

Due to the need of the JRC Food Security team to be consistent with European Agri4Cast crop yield monitoring products, the selection and hybridization of these two layers do not apply to the European Union. Here, we directly sourced the CORINE 2018 used by the Agri4Cast team for the elaboration of their crop monitoring bulletins. Specifically, classes 211 (non-irrigated arable land), 212 (irrigated arable land) and 213 (rice fields) from CORINE 2018 were selected for the European Union extent.

5 Selection of input products for the rangeland AFI

The use of the fractional grassland and shrubland layer derived from the C-Glops product at a 100 m resolution was initially considered. However, this product was eventually discarded due to the presence of some large-scale artifacts in the Horn of Africa and a non-negligible amount of rangeland ($AFI \gg 0$) in deserts and agricultural areas.

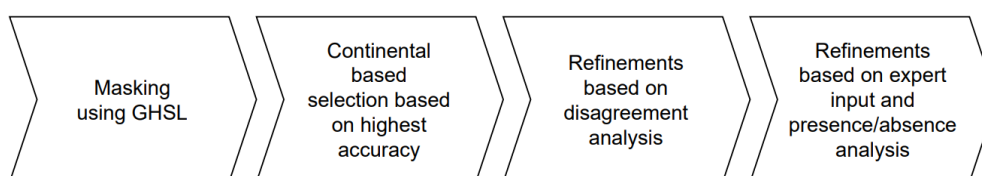
Instead, the WorldCover v2 2021 product was found to be suitable for this purpose. This product provides grassland and shrubland classes that are relevant for defining the rangeland AFI. For consistency reasons with other operational activities of the JRC Food Security Unit, for Europe we used the Copernicus Grassland High Resolution Layer for 2018 (HRL 2018 GRA) at 10 m spatial resolution (<https://land.copernicus.eu/en/products/high-resolution-layer-grassland>).

6 Methodology

6.1 Development of the cropland AFI

The development of the improved cropland AFI was achieved in three main steps and one preliminary step, as outlined in Figure 2 and further described in the sections below.

Figure 2. Methodological steps.



Source: EC-JRC.

6.1.1 Preliminary: Masking using GHSL

Prior to the production of the hybrid map, both the GLAD Cropland and WorldCereal products were masked in urban areas by integrating the JRC's GHSL (Global Human Settlement Layer) for the year 2020 (see <https://ghsl.jrc.ec.europa.eu/>) in order to ensure that no misclassification of cropland takes place in built-up areas (here defined as GHS-BUILT-S greater than 10 %). Hence, any misclassification of cropland in urban areas was suppressed.

6.1.2 Step 1: Continental selection based on the highest accuracy

In the first step, the continental accuracy metrics were examined and the map layer (either GLAD Cropland or WorldCereal) that had the highest accuracy for each continent was selected. Both Users and Producers Accuracy were examined in this screening. The percent accuracy achieved for Users (UA) and Producers (PA) accuracy in different continents are reported in Table 2.

Table 2. Accuracy metrics in the different continents for the two map layers.

	GLAD		WorldCereal	
	UA	PA	UA	PA
Africa	77.3	70.6	76.8	85.9
South West Asia	87.5	89.2		
South East Asia	86.5	84.1		
Asia (as whole including some parts of Russia)			85.3	93.9
Australia and Oceania	88.5	86.4	91.1	96.1
Europe and North Asia	93.6	86.1		
Europe			96.6	92.9
North America	90.9	94.7	95.6	93.3
South America	94.5	92.0	95.7	90.4

Source: UMD / Vito.

Note that the definition of the regions in the GLAD and WorldCereal products does not always match, e.g., for Asia. Thus, accuracy numbers from multiple regions had to be considered and some additional expert judgement had to be used to decide which map product would be more accurate in such cases.

As a result, WorldCereal was selected as the base layer for most continents, namely: Europe, South America, Africa, Australia and Oceania. GLAD was instead selected for North America and Asia. For Asia, only UA was used as the criterion since the geographical extent of the Asia accuracy assessment for WorldCereal included large parts of Russia with no crop. Therefore, the PA appeared to be a biased indicator when comparing WorldCereal to GLAD (in which Russia is completely excluded). For North America, GLAD was selected upon evaluation by agricultural experts and due to a better PA.

6.1.3 Step 2: Refinements based on disagreement analysis

In the second step, we undertook a disagreement analysis between the GLAD Cropland and WorldCereal products to detect hotspots of disagreement, and thus focus the analysis on areas where the difference was large and spatially relevant.

Disagreement was computed on the crop area fractions computed over a 500 m grid (e.g., if one map showed a 90% cover and the other 70%, the disagreement was 20%).

We then analysed all the areas having a disagreement greater than 80% for a contiguous area larger than 5000 ha (50 km²), regardless of its shape. These areas were visually inspected by operators using the Geo-Wiki interface. The map in Figure 3 outlines the areas of disagreement globally between the two data sources.

Figure 3. Disagreement hotspots (more than 80%) of the GLAD Cropland and WorldCereal cropland extent at different densities. Reddish colours indicate areas where the GLAD cropland map shows more crop density than WorldCereal; bluish colours show the opposite.

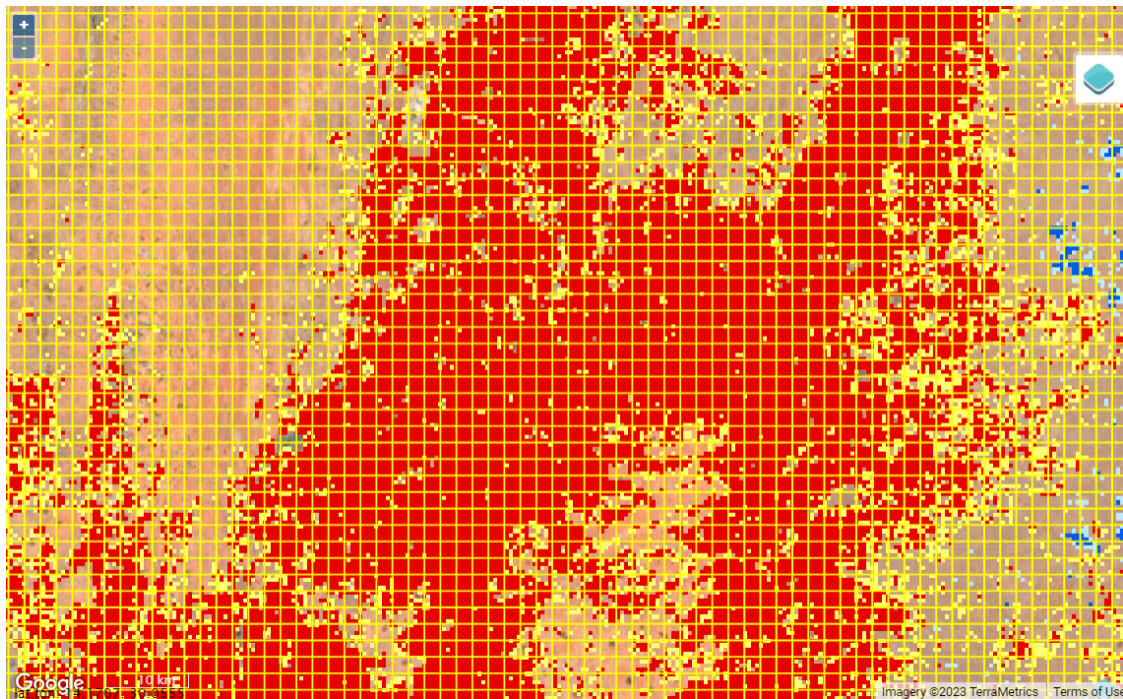


Source: IIASA.

We then used a map correction tool in Geo-Wiki that allowed operators to select the correct underlying cropland map based on detailed visual inspection of freely available high-resolution satellite imagery.

In order to speed up and facilitate the work of the analyst, a 2 km grid was overlaid on the maps and satellite imagery, and the operator was then requested to evaluate which of the two layers was correct. Eventually, the operators manually assigned the correct label (WorldCereal or GLAD) to each cell of the grid, based on the visual analysis of freely available very high resolution imagery. Figure 4 shows a sample of the grid over a continuous disagreement area.

Figure 4. A screenshot from the Geo-wiki tool that indicates areas in disagreement (in red) where GLAD shows cropland and WorldCereal shows no presence of cropland. The underlying 2x2 km grid in which the manual corrections were done is also shown.



Source: IIASA.

In the example presented in Figure 4, the WorldCereal product was not showing cropland although it is clearly present as shown in the close-up in Figure 5.

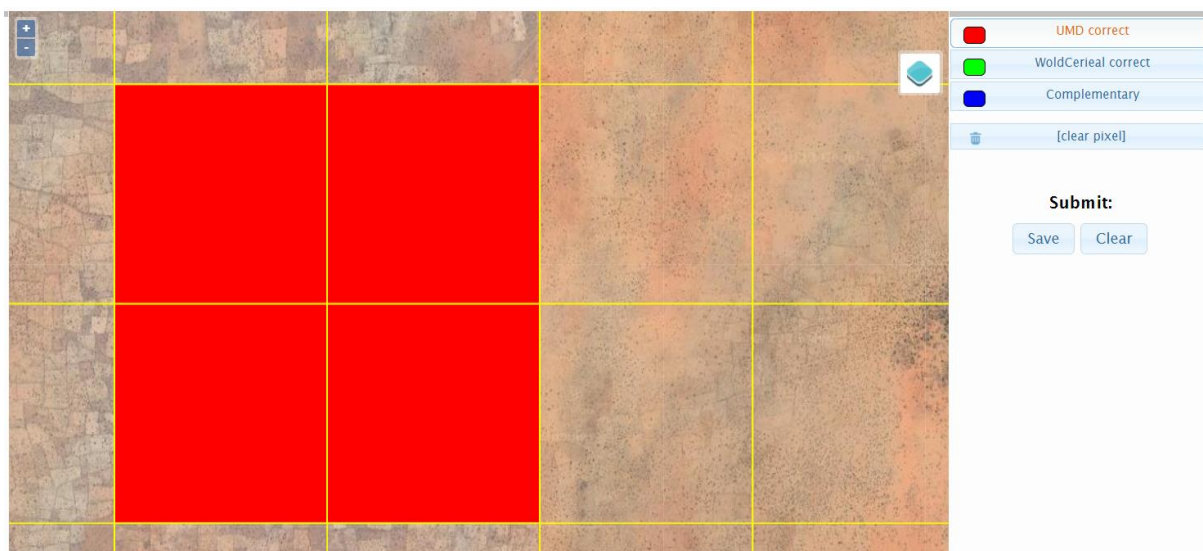
Figure 5. A screenshot from the Geo-Wiki tool. A 2x2 km grid is overlaid on very high-resolution satellite imagery to help operators determine which product is correct at this location.



Source: IIASA.

Figure 6 then shows how a 4x4 km area (consisting of four 2x2 km grid cells) was corrected in favour of the GLAD layer.

Figure 6. A screenshot from the Geo-Wiki tool showing the area that has been manually corrected in favor of the GLAD product.

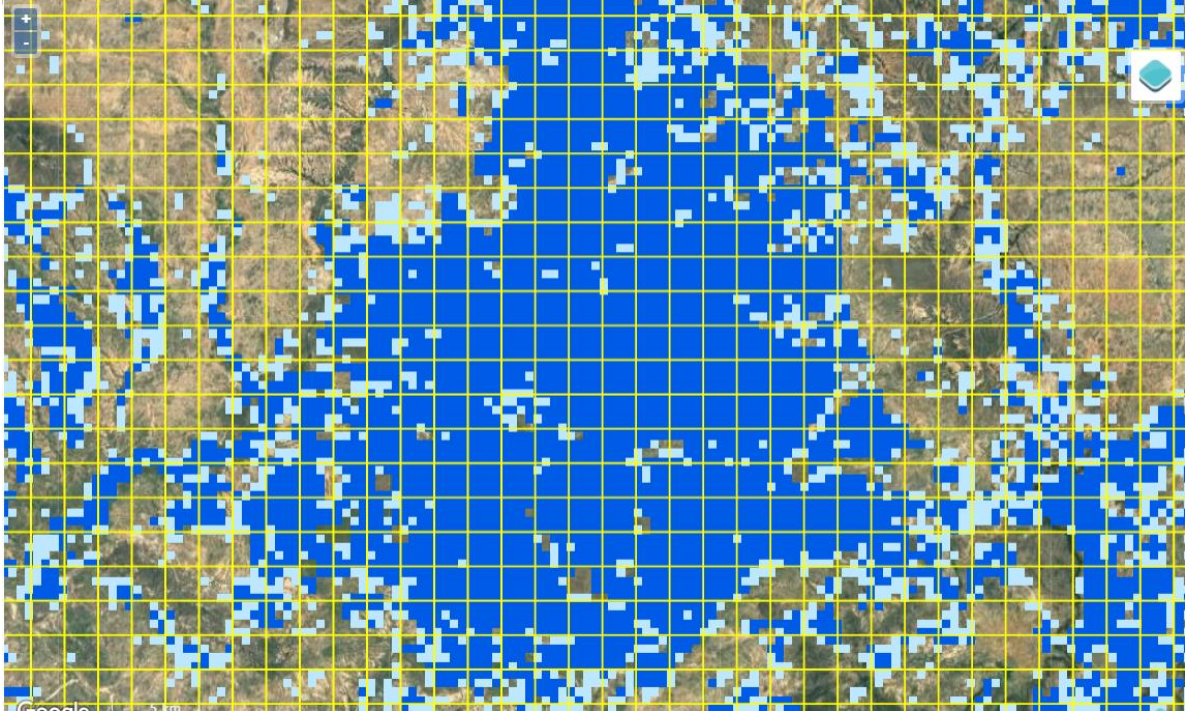


Source: IIASA.

Another example of disagreement is shown in Figure 7, which corresponds to an area where WorldCereal showed a high percentage of cropland and GLAD either showed a low percentage of

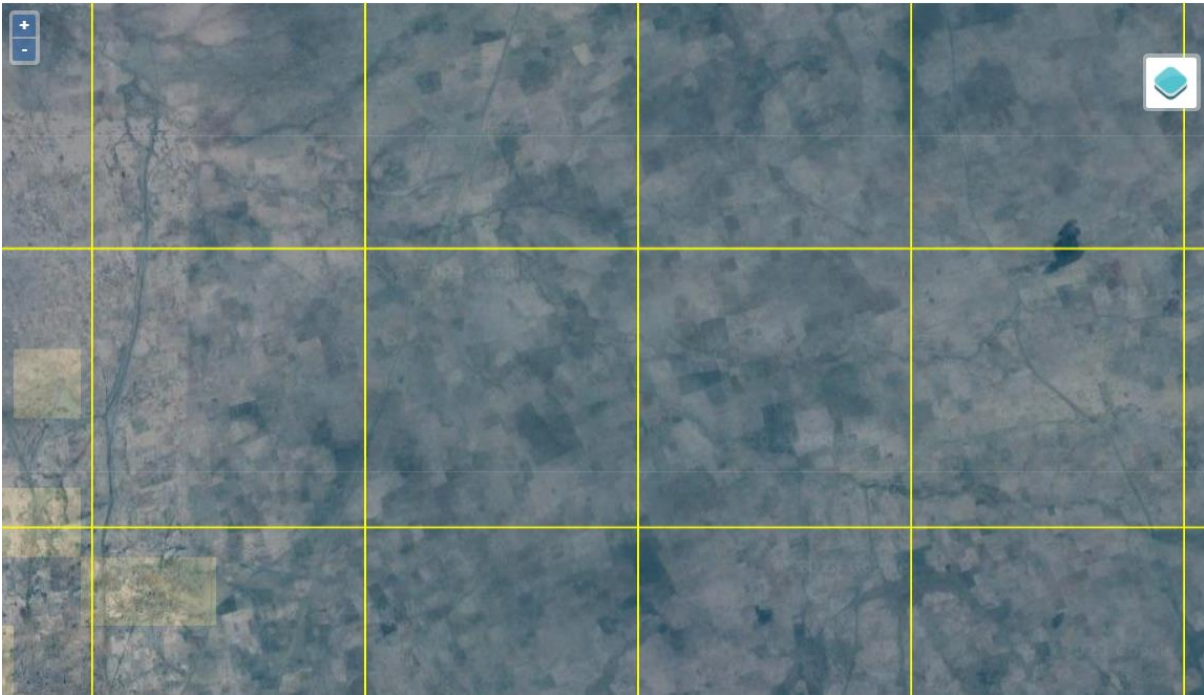
cropland or none. Where cropland was found (see Figure 8), the areas were labelled green (WorldCereal) as shown in Figure 9.

Figure 7. Screenshot from the Geo-Wiki tool. A 2x2 km grid is overlaid on areas of disagreement (blue) between the WorldCereal and GLAD products.



Source: IIASA.

Figure 8. Screenshot from the Geo-Wiki tool showing the presence of cropland from high-resolution satellite imagery.

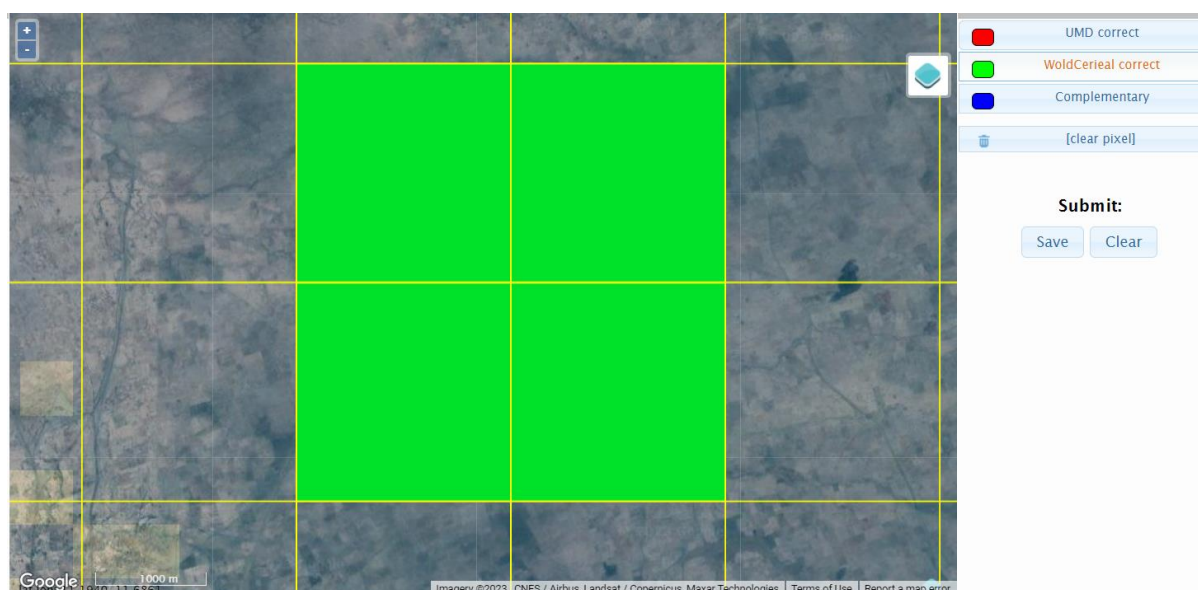


Source: IIASA.

The areas shown in Figure 8 were manually labelled in green, which indicates that WorldCereal was correct in this area.

In addition to the binary selection, a 'Complementary' class was defined for situations in which both maps should be used. However, this label was eventually not used as we focused on disagreements of more than 80%. Therefore, the maps were less likely to be complementary since, at this threshold, one map would have shown cropland while the other would not. In the future, we could further refine this label that if we wanted to focus on areas featured by lower fractions of disagreement.

Figure 9. Screenshot from the Geo-Wiki tool showing an area that has been manually corrected in favor of the WorldCereal product.



Source: IIASA.

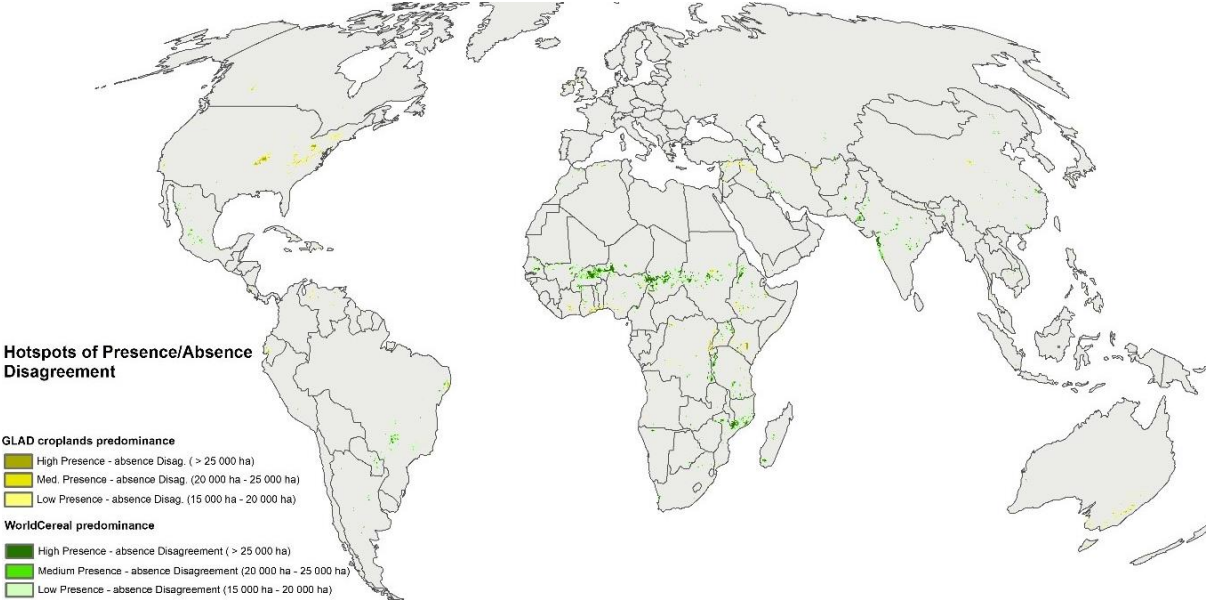
6.1.4 Step 3: Further refinements based on JRC input and a presence and absence analysis

Even though the approach described above improved the cropland AFI substantially, further refinements were made. First, the resulting AFI was analysed by a group of five JRC-ASAP analysts, each of them covering the ASAP analysis in different regions of the world. The qualitative analysis was also driven by the comparison of the ASAP v. 7.0 cropland AFI with the one developed here. Although the new AFI was considered much more realistic than the current one, a total of 52 areas distributed globally were found to be poorly classified (reported in Annex 1), again based on a visual inspection of freely available high resolution imagery. All of these areas were double checked by additional experts using Geo-Wiki, and if needed, locations were corrected, also using other available products in the cases where neither GLAD or WorldCereal were considered realistic. In some cases, for example, both WorldCereal and GLAD showed the presence of crops, hence not falling in the disagreement hotspots described in the previous section. However, upon checking with very high-resolution imagery (around 2020), no crops were present, indicating a commission error. For these locations, areas of cropland were removed. There were also locations where both WorldCereal and GLAD products missed the presence of cropland, indicating an omission error. In these cases, where

crop was actually present according to the visual analysis of high resolution imagery and correctly depicted in other LC products (e.g., WorldCover), cropland was added to the AFI and the global product was used to fill in the missing cropland. It is also noted that crops were sometimes detected by visual interpretation but none of the products classified them correctly. In these cases, the WorldCover grassland class was used instead as it delineated cropland areas well and was therefore used for this purpose.

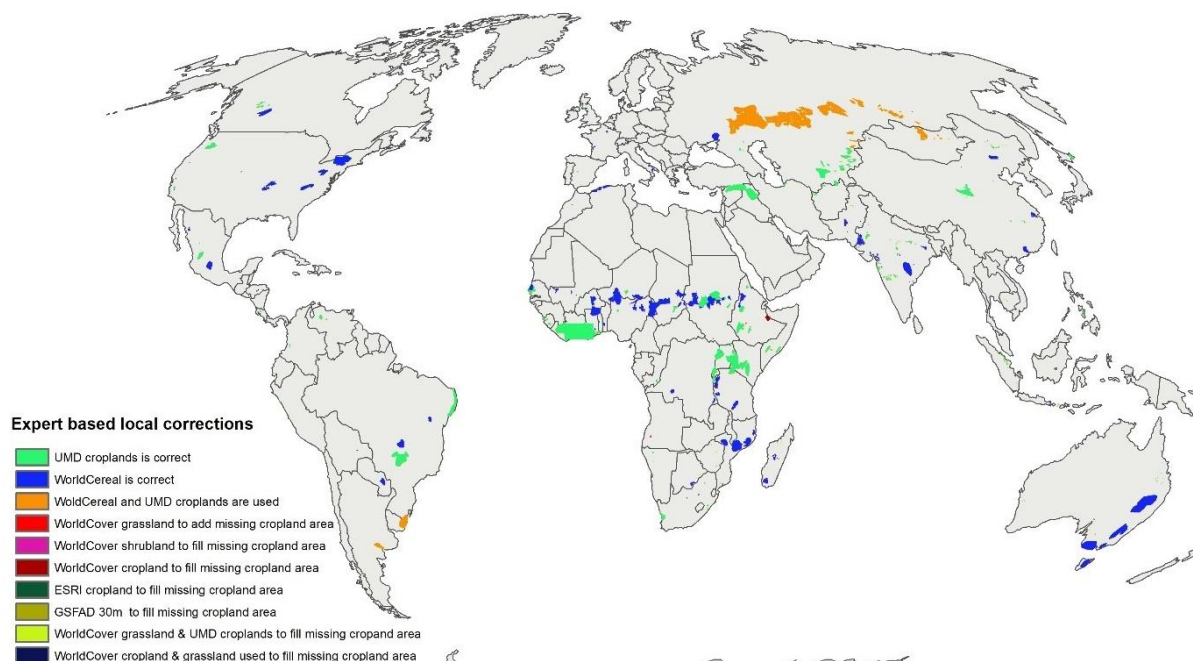
A final correction was made for large omission errors (> 15,000 ha) found in either GLAD or World Cereals; one of the two layers with more cropland was then selected as the primary layer at the continental level. All these areas were screened and if necessary, corrected with the Geo-Wiki tool. All areas for which further refinement was performed according to the omission criterion above are shown Figure 10. All corrections and the products used for the correction of both JRC feedback and omission analysis are shown in Figure 11. Note that some colours cannot be clearly seen since relatively small in size.

Figure 10. Hotspots of disagreement, including those reported by experts and those determined by the presence/absence analysis.



Source: IIASA.

Figure 11. Hotspots of disagreement, including those reported by experts and those determined by the presence/absence analysis.



Source: IIASA.

6.2 Development of the rangeland AFI

The functional definition of Rangeland is specific to the ASAP Early Warning System. Such a warning system should focus on all areas where grazing can happen, and this clearly includes grassland and shrubland. In addition, as ASAP monitors rangeland for food security purposes, the key aspect is the capacity of an area to sustain livestock. We are thus interested in creating an AFI that provides the relevance of the pixel in producing biomass to support animal grazing when aggregating at the administrative level.

For sustaining livestock, the herbaceous component is obviously fundamental. Nevertheless, areas of shrub are also used for grazing in semi-arid areas. However, shrub biomass productivity is smaller than that of grassland. Shrub biomass may be large, but annual productivity is typically lower than grassland (Gherardi and Sala, 2015). In addition, only some shrubs may be palatable and then only some for some species, like camels or goats. During a severe drought, shrub may be more persistent and greener than grassland but with very low productivity. This is an additional reason to give pure shrubs less weight in our functional definition of rangeland maps.

Taking into account the greater importance of the herbaceous layer, we propose to define our rangeland AFI by considering both grassland and shrubland but giving more credit (i.e., weight) to grassland.

For this purpose, the use of fractions of grasslands and shrublands derived from the C-Glops product at a 100 m resolution was considered but finally discarded for the following reasons: the presence of some large-scale artefacts in the Horn of Africa, and the non-negligible presence of rangeland

(AFI>>0) in deserts and agricultural areas. We therefore inspected the suitability of the ESA World Cover at 10 m v200. The definitions of the two classes are reported below.

Grassland - This class includes any geographic area dominated by natural herbaceous plants (plants without persistent stem or shoots above ground and lacking definite firm structure): (grasslands, prairies, steppes, savannahs, pastures) with a cover of 10% or more, irrespective of different human and/or animal activities, such as: grazing, selective fire management etc. Woody plants (trees and/or shrubs) can be present assuming their cover is less than 10%. It may also contain uncultivated cropland areas (without harvest/ bare soil period) in the reference year.

Shrubland - This class includes any geographic area dominated by natural shrubs having a cover of 10% or more. Shrubs are defined as woody perennial plants with persistent and woody stems and without any defined main stem being less than 5 m tall. Trees can be present in scattered form if their cover is less than 10%. Herbaceous plants can also be present at any density. The shrub foliage can be either evergreen or deciduous.

In the development of the rangeland AFI, the two classes have been weighted differently. Before resampling the 10 m layers to 500 m, a cover fraction of 100% has been assigned to grassland, while shrubland has been considered to have a cover fraction of 50%. The 500 m Rangeland AFI for the ASAP system was then derived using these weights.

To ensure consistency with JRC Agri4Cast monitoring in the EU, for Europe we directly sourced the 10 m Copernicus Grassland High Resolution Layer (<https://land.copernicus.eu/pan-european/high-resolution-layers/grassland/status-maps/grassland-2018?tab=download>).

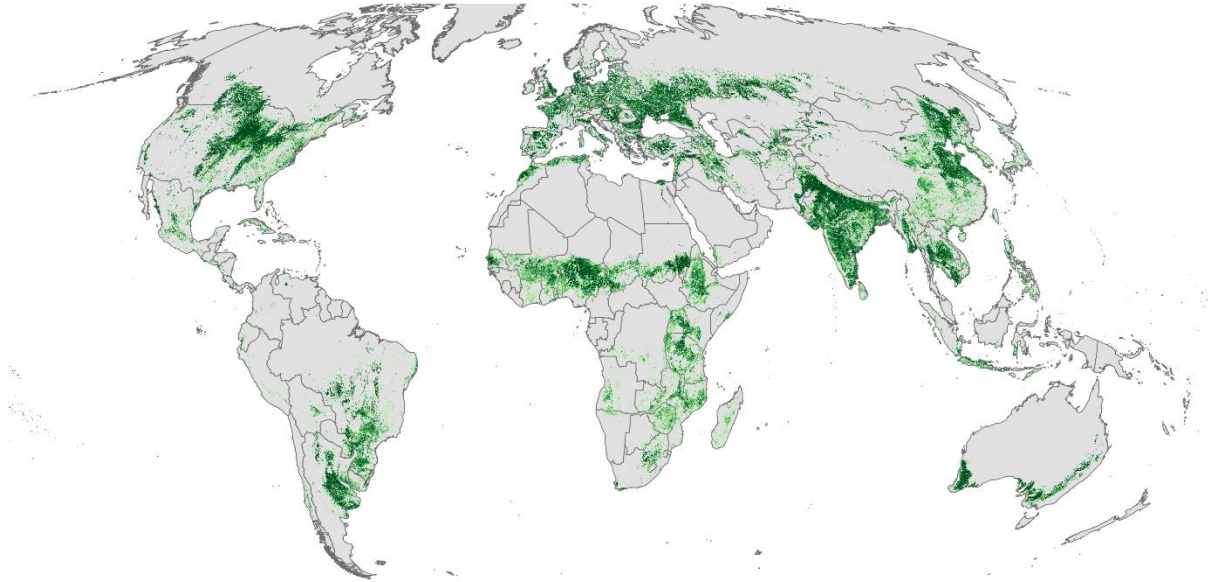
Finally, as we give more credit to the new cropland AFI, we limited the %AFI of rangeland by subtracting the percentage of crop present at the same location, and determined using the methodology at section 6 of the present report. The final area fraction was therefore derived as $AF_{final} = \min(AF_{rangeland}, 100 - AF_{crop})$.

The resulting rangeland AFI was found to be realistic by the ASAP analysts. In contrast to the cropland AFI, no further validation or correction using Geo-Wiki was required.

7 The Final Cropland and Rangeland AFIs

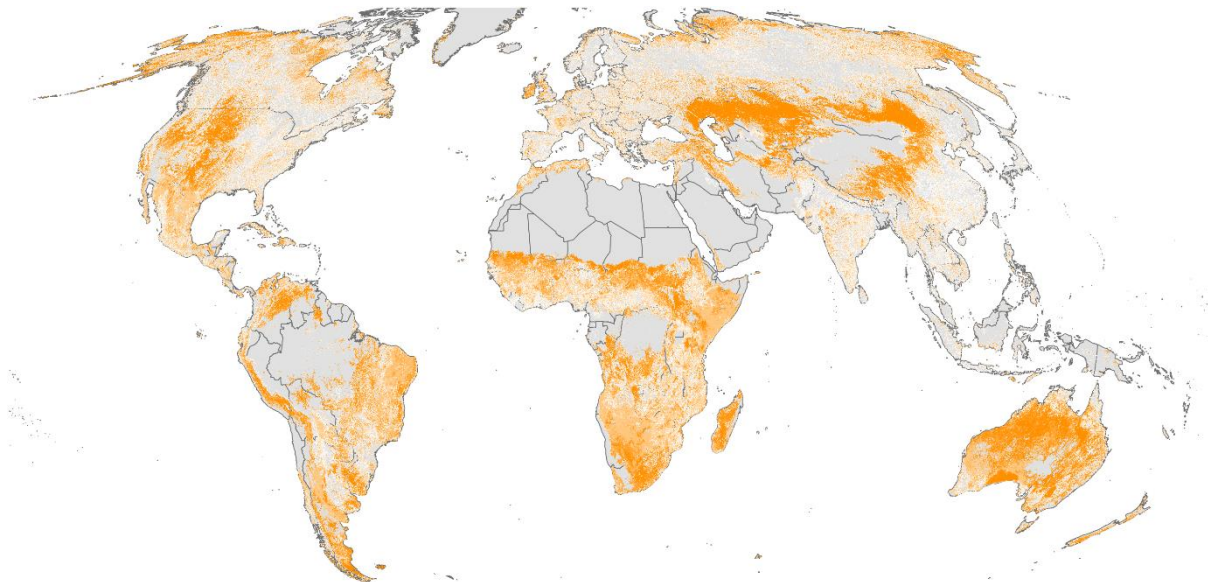
The final cropland and rangeland percentage AFIs at a 500 m resolution are shown in Figure 12 and Figure 13, respectively.

Figure 12. Final crop AFI.



Source: EC-JRC.

Figure 13. Final rangeland AFI.



Source: EC-JRC.

8 Discussion

This report describes the development of the new reference layers for cropland and rangeland for the ASAP v.8 system. The methodology relies on the production of hybrid maps, starting from available individual layers. By conducting an initial analysis of discrepancies, the methodology allows for a more efficient determination of accuracy between different maps. Visual assessments of disagreement zones through an examination of very-high-resolution imagery was applied.

The current map's 500-meter resolution is adequate for numerous uses, such as food security. Potential complications include discrepancies in definitions of the input layers (e.g., whether fallow land is counted) and alignment problems between satellite images. Nevertheless, as a next step, testing and validating enhancements at a higher resolution could be beneficial. It's important to note that the resolution of 500 meters is already sufficient for capturing the presence of cropland or non-cropland across extensive regions where large-scale discrepancies still exist.

It is also worth mentioning that some variations between maps may stem from minor differences in defining herbaceous annual cropland. For instance, the GLAD Cropland definition typically includes herbaceous perennial crops and forage, while the WorldCereal definition partially includes them (e.g., sugarcane). The most pronounced disparity between the two datasets, however, lies in the representation of fallow land.

Future improvements and updates will consider newly available products, such as WorldCereal phase 2.

Concentrating on areas with significant map discrepancies can also expedite map improvement, yet the present analysis indicates that these discrepancies are not always localized to such 'hotspot' areas. Addressing all areas of disagreement would be substantially more challenging and require greater effort. An alternative strategy would involve leveraging crowdsourcing to manage smaller, specific areas not covered by the hotspots. By engaging the wider agricultural community through platforms like Geo-Wiki, the products can be further refined through collective contributions.

The accuracy of the maps are under assessment at the date of compilation of the present report and will be discussed on a submitted peer reviewed paper.

9 Conclusions

This report reviewed the current products available to produce an improved cropland and rangeland fraction map at 500 m resolution for the ASAP Global Early Warning System. Based on this review, the most appropriate products were chosen.

For the hybrid cropland layer, the GLAD Cropland and WorldCereal products were considered. The methodology was outlined for how the products were merged and then further improved, correcting the inaccurate areas identified by expert ASAP analysts. The latter stage of refinement targeted areas with omission errors.

Concerning the rangeland layer, the ESA World Cover product at 10 m v200 was used, considering grassland and shrubland classes with different weights. Limited to the European continent, the rangeland product was derived using the Copernicus Grassland High Resolution Layer 2018.

The resolution of the layers, 500m, is matching the requirements of the ASAP system, which is currently operating at the same resolution. For what concerns accuracy, since the individual maps already meet the requirements, the hybrid layers produced will also fulfil them, as the methodology allows to achieve better accuracy than the individual input maps.

Entering the ASAP pipeline, the hybrid maps are going to support all the activities of crop monitoring, particularly food security related, enabling the generation of near real time information on crop growing conditions for early detection of possible production deficits.

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List of abbreviations and definitions

Abbreviations	Definitions
AFI	Area Fraction Image
ASAP	Anomaly hotspot of Agricultural Production
CGLOPS	Copernicus Global Land Operations
CLC	Corine Land Cover
CORINE	Coordination of Information on the Environment
ESA	European Space Agency
ESRI	Environmental System Research Institute
GHS-BUILT-S	Global Human Settlement Built-up Surface
GHSL	Global Human Settlement Layer
GALD	Global Land Analysis and Discovery
GLC	Global Land Cover
GRA	Grassland
GSARS	Global Strategy on Agricultural and Rural Statistics
HRL	High Resolution Layer
NRCM	National Resources Conservation Management
PROBA	Project for On-Board Autonomy
USDA	United States Department of Agriculture

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Annex 1. List of countries and co-ordinates where both the WorldCereal and GLAD Cropland products did not correctly represent cropland

Country	Coordinates (long, lat)	JRC Comment	Comment/Confirmed Final correction
Angola	14.23699, -14.95362	Absent AFI	WorldCover grassland was added Missing cropland area
Botswana	27.50416, -22.75434	Low AFI	WorldCover grassland & GLAD Cropland to fill missing cropland
CAR	19.47314, 6.1086	Absent AFI, GLAD present (looks underestimated)	No map added value
Chad	18.84681, 12.78019	Commission error, AFI too high in arid shrubs	WorldCereal is correct
DRC	19.81583, 3.19804	Absent AFI, GLAD present (and overestimating)	No map added value
Eritrea	38.8861, 15.46629	Low AFI (GLAD has crop)	GLAD Cropland is correct
Ethiopia	37.056302, 10.967767	Low/absent AFI	GLAD Cropland is correct
Ethiopia	37.805838, 7.872322	Low/absent AFI	WorldCover grassland to add missing cropland area
Ethiopia	43.43969, 9.563	Low AFI	WorldCover cropland to fill missing cropland area
Kenya	34.101407, -0.764135	AFI missing crop area	GLAD Cropland is correct
Kenya	39.333459, -4.400261	AFI missing crop area	Not clear if crops are temporal or permanent, not included
Lybia	24.03595, 31.97066	Low AFI in crop area	No map added value
Malawi	34.03204, -11.5635	Missing crop area	WorldCover shrubland to fill missing cropland area
Malawi	34.975909, -16.069618	Missing crop area	WorldCover shrubland to fill missing cropland area
Morocco	-6.42382, 32.67487	High AFI in arid rangeland	Not included
Mozambique	33.892659, -24.659716	Low AFI	WorldCover grassland to add missing cropland area
Namibia	14.80626, -18.22598	High AFI in the desert	GLAD Cropland is correct
Namibia	15.1971, -20.1096	AFI in the desert	GLAD Cropland is correct

Country	Coordinates (long, lat)	JRC Comment	Comment/Confirmed Final correction
Rwanda, Burundi and area around lakes	29.403662, -2.184407	Big area showing consistent underestimation of crops	GLAD Cropland is correct
Sierra Leone, Liberia, Ivory coast, SW Ghana	None (entire countries)	No global product has crop data	GLAD Cropland is correct
Somalia	43.3911, 2.946	Very low AFI (WC low, GLAD high)	GLAD Cropland is correct
Somalia	43.5046, 3.0487	Very low AFI (WC low, GLAD high)	GLAD Cropland is correct
Somalia	43.99864, 2.622325	Very low AFI (WC low, GLAD high)	WorldCover grassland to add missing cropland area
South Africa	18.270109, -31.779607	AFI in shrubs	GLAD Cropland is correct
South Africa	24.82861, -34.04155	Low AFI in dense cropped area	GLAD Cropland is correct
South Africa	25.004462, -33.67788	Missing crop area	ESRI Cropland to fill missing cropland area
South Sudan	29.488529, 4.894798	Low/absent AFI	WorldCover shrubland to fill missing cropland area
Sudan	22.744399, 13.398058	AFI too high in arid shrub	WorldCereal is correct
Sudan	25.3839, 13.82216	AFI too low in cropped area	WorldCereal is correct
Sudan	25.573125, 13.960606	AFI too low in cropped area	WorldCereal is correct
Sudan	25.81541, 14.39405	AFI too low in cropped area	WorldCover grassland to add missing cropland area
Sudan	30.90468, 13.62523	AFI too high in desert area	GLAD Cropland is correct
Syria	35.7413, 33.1219	Large bubble of high AFI over arid rangeland	WorldCover grassland to add missing cropland area
Tanzania	30.23225, -4.94773	Overestimation	WorldCover cropland to fill missing cropland area
Uganda	33.98719, 3.39042	Very high AFI (WC high, GLAD low). Looks like WC was wrongly selected.	GLAD Cropland is correct
Uganda	44.0114, 2.6256	Low AFI	WorldCover grassland to add missing cropland area

Country	Coordinates (long, lat)	JRC Comment	Comment/Confirmed Final correction
Yemen	43.487176, 14.661932	IIASA includes forest & natural vegetation (i.e., mountains) in Raymah (region not analyzed by ASAP)	WorldCover cropland to fill missing cropland area
Zimbabwe	29.894673, -16.681638	Underestimation	WorldCover grassland & GLAD Cropland to fill missing cropland area
Zimbabwe	31.16298, -18.25186	Underestimation	WorldCover grassland & GLAD Cropland to fill missing cropland area
Zimbabwe	31.4715, -17.60574	Underestimation	WorldCover grassland & GLAD Cropland to fill missing cropland area
KHM	103.06788, 11.87991	Not a crop, but roadworks (minor area)	WorldCover grassland to add missing cropland area
Haiti	-72.2704, 19.21507	Missing crop areas	GFSAD 30 m to fill missing cropland area
Haiti	-72.555718, 19.747989	Missing crop areas	WorldCover grassland to add missing cropland area
Haiti	-72.823062, 18.242406	Missing crop areas	WorldCover grassland to add missing cropland area
Haiti	-73.85465, 18.16004	Missing crop areas & underestimation	GLAD Cropland is correct
Kazakhstan	46.82184, 46.76035	Crop on barren land	GLAD Cropland is correct
Ecuador	-79.4988, -2.1451	Missing crop area and underestimation	GLAD Cropland is correct
Ecuador	-80.685, -5.3941	Underestimation	WorldCover cropland to fill missing cropland area
El Salvador	-88.0413, 13.5342	Underestimation & missing crop areas	WorldCover grassland to add missing cropland area
El Salvador	-89.198568, 13.49366	Underestimation & missing crop areas	WorldCover grassland to add missing cropland area
Honduras	-85.92512, 14.76792	Underestimation	WorldCover cropland & grassland used to fill missing cropland area
Honduras	-87.251651, 13.619065	Missing crop areas	GLAD Cropland is correct

Source: IIASA / EC-JRC.

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