Sentinels Synergy for Agriculture

Deliverable D7.18

Second validation of Irrigated and No-irrigated Maps

V 1.0

The research leading to these results has received funding from the European Union's Horizon 2020 Research and Innovation Programme, under Grant Agreement nº 730074

Document information

Project Number	730074	**Acronym**	SENSAGRI
Full Title	Sentinels Synergy for Agriculture		
Project URL	http://sensagri.eu		
Project Coordinator	José F. Moreno. IPL – University of Valencia (Spain)		
EU Project Officer	Massimo Ciscato		

Deliverable	**Number**	D7.18	**Title**	Second validation of Irrigated and No-irrigated Maps
Work Package	**Number**	WP7	**Title**	Ground Data Collection and Services Validation

Date of Delivery	**Contractual**	M34	**Actual**	M35	
Status	Version 1.0		Final ☐		
Type	R ☒	DEM ☐	DEC ☐	OTHER ☐	ETHICS ☐
Dissemination Level[1]	PU ☒	CO ☐	EU-RES ☐	EU-CON ☐	EU-SEC ☐

Responsible partner	ITACYL			
Responsible Author	**Name**	Vanessa Paredes Gómez	**E-mail**	pargomva@itacyl.es
	Partner	ITACYL	**Phone**	+34 983 419500 ext.809306
Other authors	Annarita D'Addabbo (CNR-IREA), Francesco Mattia (CNR-IREA), Giuseppe Satalino (CNR-IREA), Anna Balenzano (CNR-IREA), Francesco Lovergine (CNR-IREA), David Nafria (Itacyl)			

Abstract (for dissemination)	This document reports on the validation of the classification algorithm developed to classify the SENSAGRI SSM product into binary maps of irrigated/not-irrigated fields. The validation consists of comparing the binary masks with ground data available over the Riaza irrigation district (Castila and Léon, Spain). Results indicate that for winter crops, such as wheat, the best classification performance is achieved before the flowering period, while for summer crops the most indicated period is during their early phenologic stages when the plant is not yet fully developed. Under these conditions a Producer Accuracy better that 80% is achieved.
Keywords	Irrigation, soil moisture complementary product, Sentinel-1 & -2.

Version Log			
Issue Date	**Rev. No.**	**Author**	**Change**
30 September	0.1	Annarita D'Addabbo	First version
5 October	0.2	Vanessa Paredes Gómez	Final revision
10 October	1.0	Antonio Ruiz	Final version

[1] PU = Public; CO = Confidential (Consortium and Commission Services); EU-RES = Restreint UE; EU-CON Confidentiel UE; EU-SEC = Secret UE (Commission Decision 2005/444/EC)

Table of Contents

List of Tables

List of Figures

1. Introduction

1.1. Scope of the document

This document illustrates the validation of the algorithm, developed in D6.12, to classify irrigated/not-irrigated fields using as input the SENSAGRI SSM maps. The algorithm represents one of the SENSAGRI added-value products.

1.2. Notations, abbreviations and acronyms

EO	Error of Omission
FN	False negative
FP	False positive
GD	Ground Data
GNDVI	Green Normalized Difference Vegetation Index
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
OA	Overall accuracy
PA	Producer's Accuracy
SAR	Synthetic Aperture Radar
SSM	Surface Soil Moisture
S1	Sentinel 1
S2	Sentinel 2
TN	True negative
TP	True positive

2. Earth observation for irrigation detection

2.1. Vegetation indexes

Most of the methods proposed to map irrigated /not irrigated areas are based on optical data (e.g., Ozdogan et al., 2010). Different indexes, such as NDVI (Ozdogan et al., 2006), GNDVI and NDWI (Guermazi et al., 2016) have been investigated. Nevertheless, NDVI is probably the most used one as it is an indicator of vegetation greenness (Baret and Guyot, 1991) and it has often been considered a proxy for the crop growth rate. Indeed, observations have shown that irrigated crops often exhibit higher (maximum) NDVI than non-irrigated crops (Wardlow and Egbert, 2008). Under these circumstances, the highest annual peak NDVI for any agricultural crop is associated to an adequate soil water content usually related to sustained irrigation (Pervez & Brown, 2010). In particular, NDVI can identify, with high spatial accuracy, irrigated crops with high water demand in agricultural areas of water scarcity. However, a challenge for optical data is an early detection of irrigated fields and the identification of crops/areas/periods for which irrigation remains supplemental.

In this document, the algorithm developed in D6.12, which classifies the SSM maps at high resolution into irrigated/not-irrigated fields is validated.

The final goal of this activity is to provide adequate information on the spatio-temporal distribution of irrigated agriculture. The approach allows the identification of the irrigation event rather than the effects of irrigation on the crop growth. In this respect, the proposed methodology is complementary to irrigation schemes based on optical data.

In the next session, the methodology proposed to detect irrigated/not irrigated areas from SENSAGRI SSM maps is summarized. Subsequently, the validation activity is described.

2.2. Classification of SSM maps

The proposed methodology is based on the comparison of SSM local statistics, computed at two spatial scales, in order to identify pixels corresponding to irrigated areas. The implemented algorithm is characterized by two parameters: the dimensions n_1 and n_2 (with $n_2 > n_1$) of the windows used to compute the local statistics. In D6.12, different values of n_1 and n_2 have been tested. Their optimal value depends on the average size of the agricultural area analysed. In this document, the validation is carried out over two years (i.e., 2017 & 2018) and a large number of irrigated fields (~750) cropped with winter and summer crops.

3. Validation of Irrigated/not irrigated maps

3.1. Validation strategy and metrics

The validation strategy is based on the comparison between the binary irrigated/not irrigated maps computed by means of the proposed algorithm and the ground data (GD) provided by ITACyL on the Riaza irrigation district.

The following metrics have been considered in order to validate the classification algorithm: the Overall Accuracy (OA), the Producer's Accuracy (PA_{irr}) of the Irrigated Class and the Error of Omission (EO_{nirr}) of the Not Irrigated Class.

In order to properly define these metrics, the contingency table, reported in Table 1, has to be considered, where:

- True Positive (TP) is the number of fields classified as "irrigated" that are "irrigated" in GD;
- False Positive (FP) is the number of fields classified as "irrigated" that are "not irrigated" in GD;
- False Negative (FN) is the number of fields classified as "not irrigated" that are "irrigated" in GD;
- True Negative (TN) is the number of fields classified as "not irrigated" that are "not irrigated" in GD.

Table 1. Contingency table.

		TRUE CONDITION	
		IRRIGATED	**NOT IRRIGATED**
PREDICTED CONDITION	PREDICTED IRRIGATED	TP	FP
	PREDICTED NOT IRRIGATED	FN	TN

The following relations hold:

$$OA = (TP + TN)/(TP + FP + FN + TN)$$

$$\mathrm{PA}_{irr} = \mathrm{TP}/(\mathrm{TP} + \mathrm{FN})$$

$$\mathrm{EO}_{nirr} = \mathrm{FP}/(\mathrm{FP} + \mathrm{TN})$$

3.2. Validation analysis

3.2.1. Test area

The validation analysis has been performed on the Riaza irrigation district, Castilia and León, (Spain), which stretches over 5,232 ha along a canal of 52 km that flows parallel to the Duero River. The main crops are maize, winter straw cereals, potato, sugar beet and alfalfa.

The area includes of 982 cropped fields - with a size ranging from 0.16 ha to 71.3 ha - for which information on land use and irrigation scheduling is available. In the validation analysis, only fields having an area larger than 1 ha have been considered. As a consequence, **752 fields have been analysed**.

3.2.2. In-situ data

The Riaza irrigation district is fully automated and scheduled. A central database records all the irrigation events from all the hydrants connected to the system. Both for 2017 and 2018 and for each field, in-situ data include the start and end time of each scheduled water supply and the amount of water consumption.

In 2017, the first irrigation event is recorded on March 9th and the last one on November 11th. In 2018, the first irrigation event is recorded on March 17th and the last one on November 14th. In 2017, in 991 fields, covering 2637 ha a total of 22.185 irrigation events were recorded. In 2018, in 660 fields covering 1877 ha, the number of recrded events was 13.132.

Meteorological data (hourly recorded) over the area are acquired by the station VA 07 belonging to the Inforiego network (see D7.2). Data are available for 2017 and 2018.

3.2.3. Binary maps

The validation analysis consists of comparing the binary maps of irrigated/not-irrigated fields, obtained per each date from the classification algorithm described in D6.12, with the ground data. The input of the developed algorithm is the SENSAGRI SSM product, characterized by a temporal/spatial resolution of 6 days and $\sim 100\ m$ (corresponding to a pixel size of $\sim 40\ m$). The product is available from April 2017 to late December 2018 (D3.7). More precisely, 44 and 52 SSM maps have been produced in 2017 and 2018, respectively.

However, not all the available data set has been used in the validation. The analysis has been restricted to the irrigation period (i.e. March-November); in addition, dates in which a too small number of fields (i.e. < 10) were irrigated have not been considered. This case mostly occurs at the beginning and at the end of the irrigation period. Therefore, **the actual irrigation period considered ranges from April 3rd until to October 31th in 2017, and from May 4th until to October 31th in 2018**. It is worth noting that in 2018, the growing season was shifted of approximately one month.

In agreement with the analysis carried out in D6.12, those dates in which important precipitations were recorded have not been considered in the validation as the effect of rainfall is to drastically reduce the contrast between irrigated and not-irrigated fields. As an example, Figure 1 and Figure 2 report the mean S1 SSM value, computed over all the fields larger than 1 ha of the Riaza district, together with the daily precipitation, in 2017 and 2018, respectively.

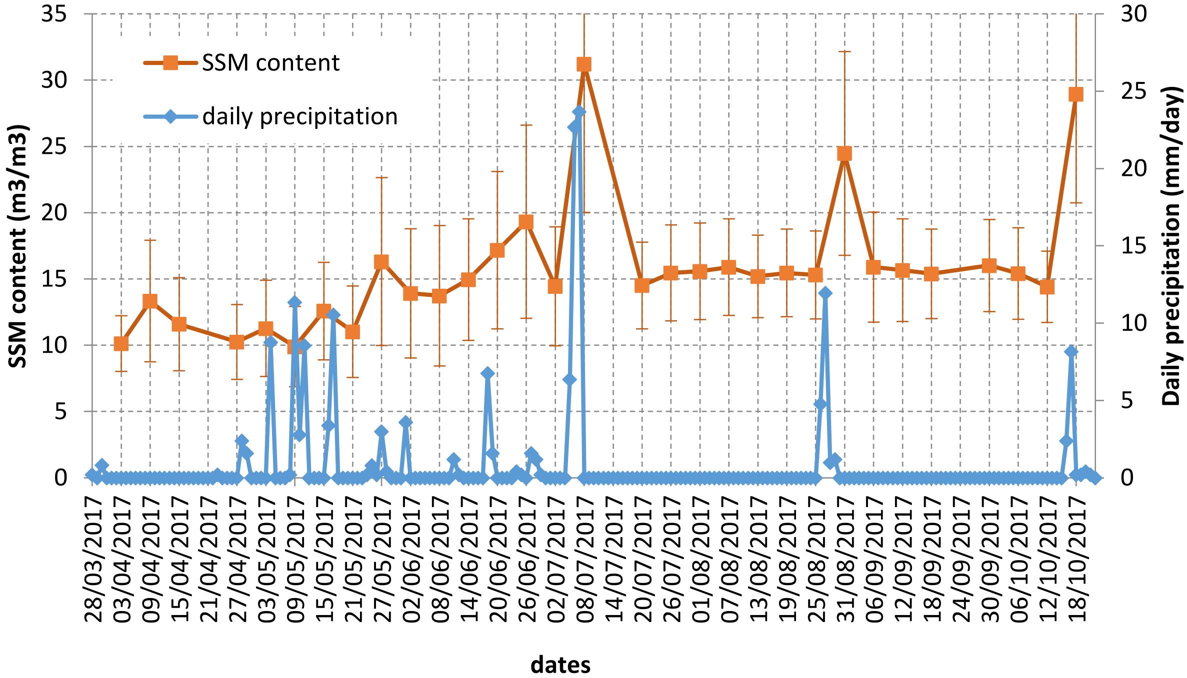


Figure 1. SSM mean value averaged over the whole dataset of Riaza fields and daily precipitation data during the irrigation period in 2017.

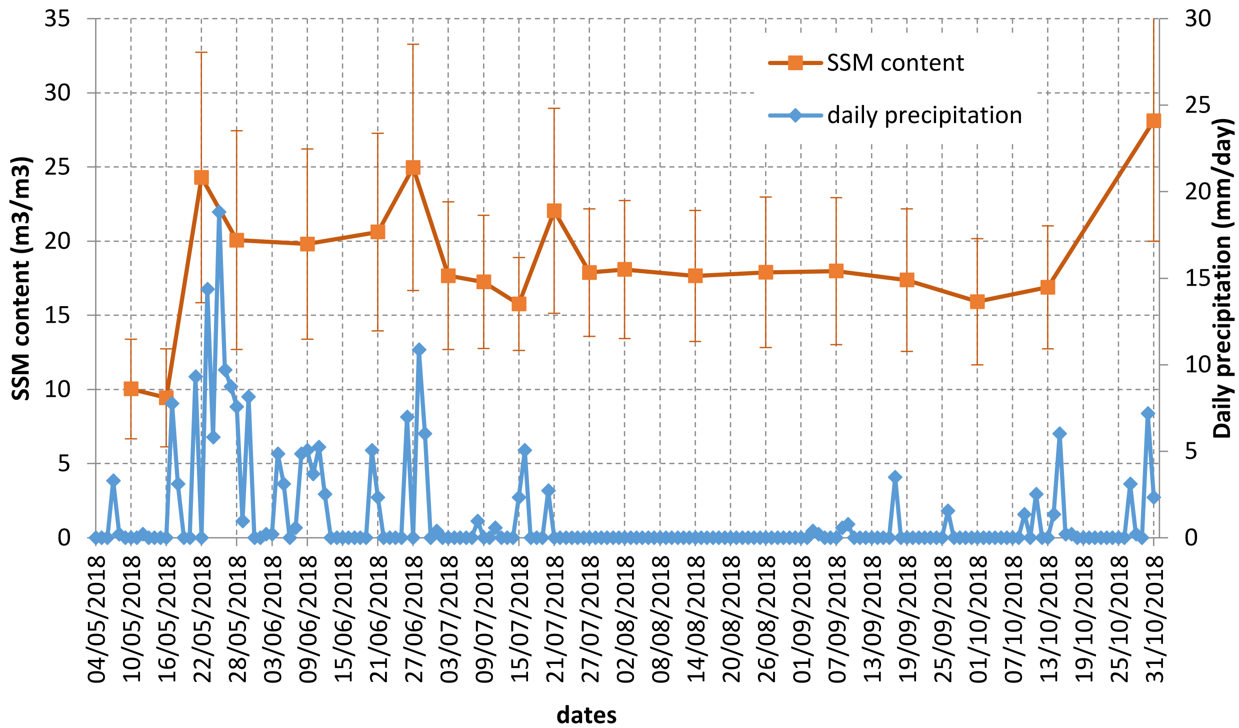


Figure2. SSM mean value averaged over the whole dataset of Riaza fields and daily precipitation data during the irrigation period in 2018.

The images acquired in 2017 on May 9th, 15th and 21th, June 20th, July, 8th, August, 31th and October 18th are affected by rainfall events that took place either on the same day or in the few days before. For this reason, these dates are not considered in the subsequent analysis. Moreover, the image acquired on June 26th is also discarded because the rain event, though modest, was exactly collocated with the S1 passage and therefore, a peak in the estimated SSM is observed.

In summary, 23 dates have been selected in 2017, as not affected by precipitations, and, therefore, retained for the subsequent analysis. They span from April, 3rd until October, 12th.

Analogously, the images acquired in 2018 on May 22th and 28th, June 9th, 21th and 27th, July 9th and 21th, and October 31th are affected by rainfall events. In all, **12 images have been selected in 2018, as not affected by precipitations, and, therefore, retained for the subsequent analysis. They span from May, 5th until October, 13th**.

It is worth noting that in D7.13, an automatic detection of precipitation patterns during the S1 acquisitions has been proposed and could be adopted in the classification of irrigated/not-irrigated fields to identify dates affected by precipitation events.

3.2.4. Reference data

In correspondence of each SSM map, the Irrigated/not Irrigated Ground data (GD) have been defined in the following way: a field is considered as irrigated if and only if it has received a water application within 6 days before the S1 passage. The number of fields considered as irrigated in the GD, for each selected date in 2017 and 2018, is reported in the figure 3 and figure 4, respectively. In addition, the number of fields irrigated within 1 day from the passage is also reported on both figures.

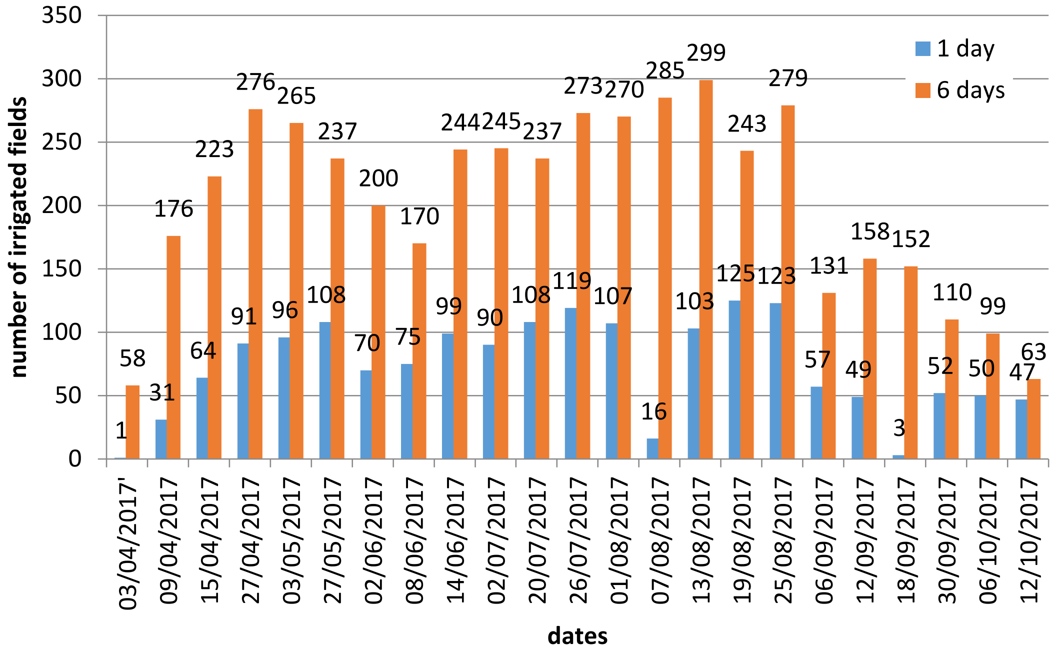


Figure 3. Number of irrigated fields (within 1 day and 6 days before the S1 acquisition) for 2017.

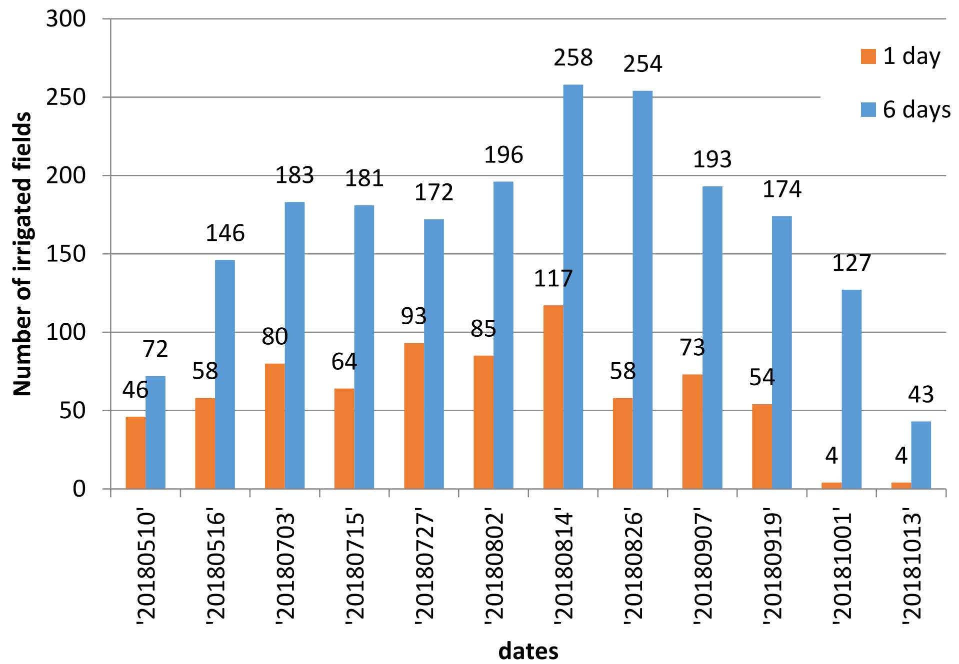


Figure 4. Number of irrigated fields (within 1 day and 6 days before the S1 acquisition) for 2018.

3.2.5. Data analysis

3.2.5.1. The SSM contrast between irrigated and not-irrigated fields

As was emphasised in D6.12, the performance of the proposed algorithm depends on the SSM contrast existing between fields labelled as irrigated and not-irrigated, rather than on the absolute SSM level of the irrigated fields. In this respect, it is important to understand how this contrast depends on the crop phenology, environmental conditions and time span between the irrigation event and the S1 acquisition date. For instance, Figure 5 and Figure 6 show the SSM mean value of fields declared irrigated and not/irrigated in GD within 6 days before the S1 acquisition in 2017 and 2018, respectively. The amount of water supplied per each date is also reported. While in 2017, 23 dates can be analysed, in 2018 only 13 dates are not affected by precipitation. In addition, due to the fact that 2018 was wetter than 2017, in average the level of SSM in 2018 was higher than in 2017.

Concerning the temporal behaviour of the contrast, in D6.12 it has been discussed the seasonal trend and it has been observed that **the best SSM contrast for winter crops, such as wheat, is before flowering, while for summer crops, such as maize, is during their development (before the mature reproductive period)**. In 2017, these two phases took place early in April and in mid-June, respectively. In July and August, most of the summer crops are in their reproductive phase, during which the S1 sensitivity to SSM underneath maize, beet, rapeseed etc. is fairly poor. This trend can be clearly seen in Figure 5, where the SSM contrast tends to disappear from early July to early September.

In 2018, the season and, therefore, also the irrigation practices were approximately one month behind. Then, a certain contrast can be observed until the end of July. However, its level is usually lower than in 2017. Probably, the main reason is that the growing seasons was wetter in 2018 than in 2017. Then, the SSM level is in average higher in 2018 than in 2017. As a consequence, the SSM contrast is lower in 2018 than in 2017. Indeed, **in general it is observed that the higher the average level of SSM, the lower is the contrast between irrigated and not-irrigated fields**.

Figure 7 and Figure 8 show that the SSM contrast improves, both in 2017 and 2018, when the SSM difference between irrigated and not/irrigated in GD within 1 day before the S1 acquisition is computed. However, it remains smaller in 2018 than in 2017.

The physical reason underlying the improving of the contrast when the time span between the irrigation event and the S1 acquisition is 1-day only is the effect of evapotranspiration, which dries the soils progressively, hence decreasing the SSM contrast with time.

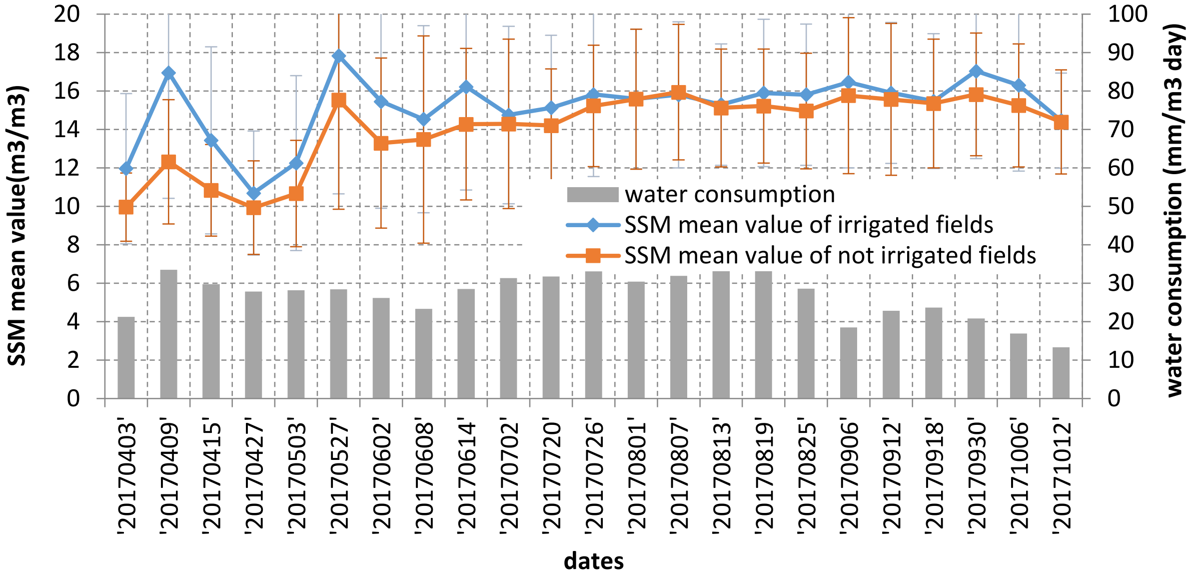


Figure 5. SSM mean value of not irrigated and irrigated fields (within 6 days) for 2017.

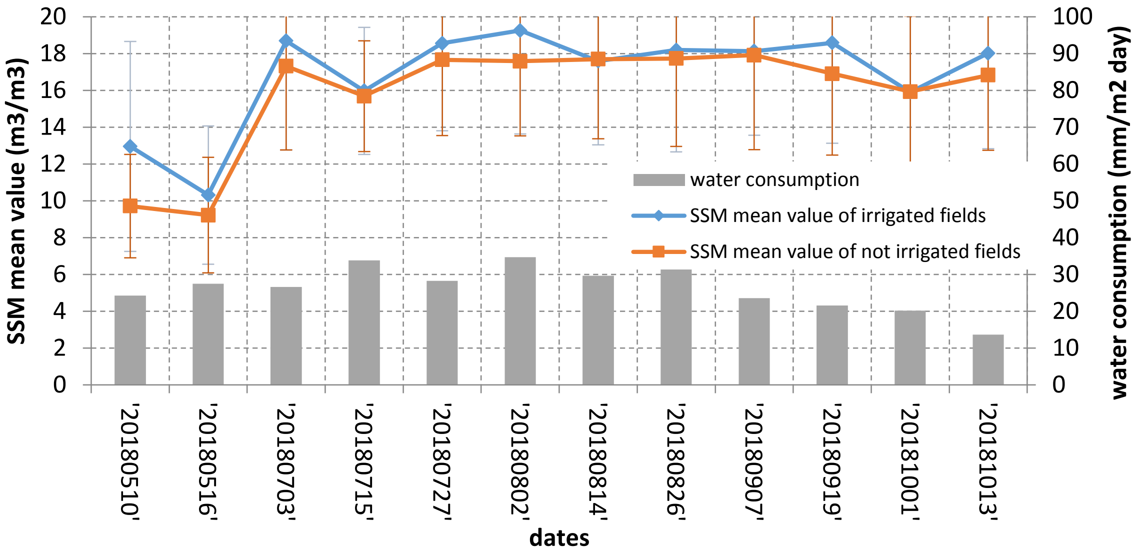


Figure 6. SSM mean value of not irrigated and irrigated fields (within 6 days) for 2018.

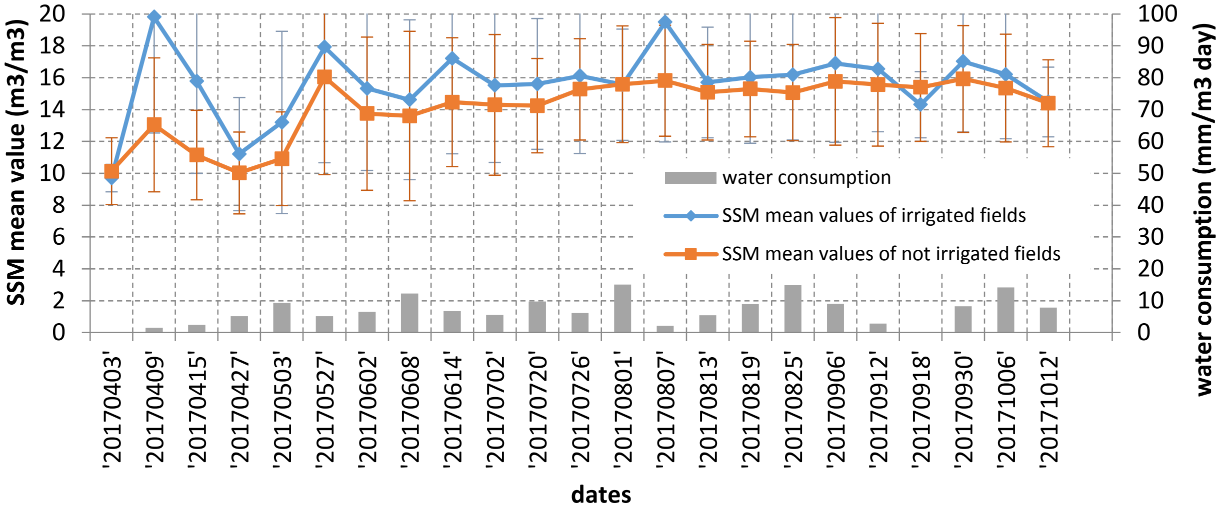


Figure 7. SSM mean value of not irrigated and irrigated fields (within 1 day) in 2017.

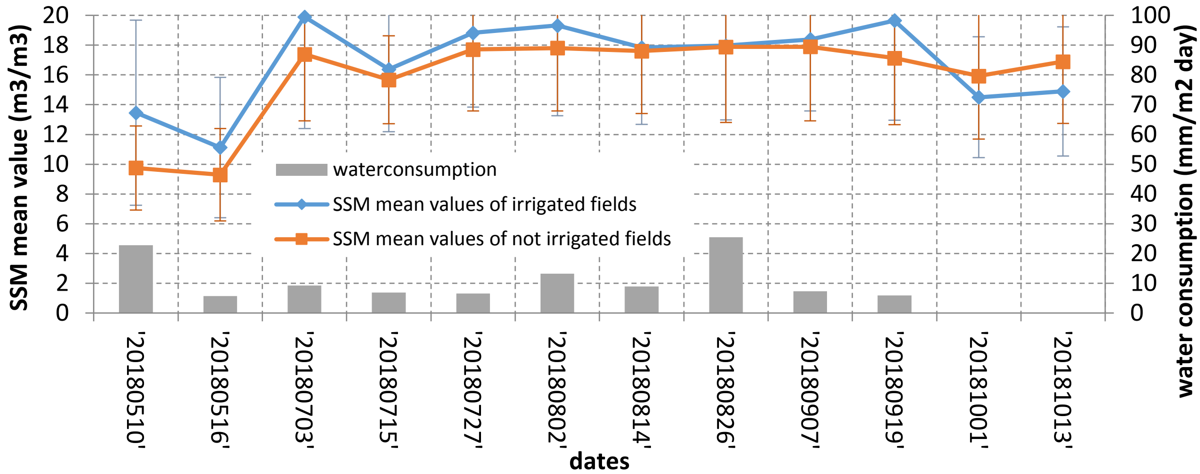


Figure 8. SSM mean value of not irrigated and irrigated fields (within 1 day) in 2018.

3.2.5.2. The impact of the size of inner and outer windows

In the document D6.12 different values of n_1 and n_2 window dimensions have been tested on the two analysed images. Here this analysis has been systematically carried out by considering the whole data set acquired both in 2017 and 2018. The couples of values indicated with a "X" in Table 2 have been chosen for n_1 and n_2 by considering the dimensions of the fields in the Riaza district. Indeed, there are many fields whose size is smaller than the 7x7 window, but there are also some fields exceeding this size. With respect to the study carried out in D6.12, a 15x15 window has also been considered in order to take into account the presence of larger fields.

For each analysed SSM map, different values of OA, PA_{irr} and EO_{nirr} have been obtained and the best ones not always corresponded to the same pair of n_1 and n_2 values. In Figure 9, the number of times in which each couple of n_1 and n_2 values corresponds to the best OA, both in 2017 and 2018.

The fields declared irrigated are those in the reference data, i.e. irrigated within 6 days before the S1 acquisition. Generally, for n_1=7 and n_2=15, the best PA_{irr} values are obtained together with the worst EO_{nirr} values. Therefore, this set of values never corresponds to the best OA. For this reason, a multi-windows approach has been considered in this study. This is in agreement with D6.12, where few pairs of windows, i.e., 7-35, 7-125 and 35-125, have been considered. In this validation, a field is assigned as 'irrigated' if in at least one of the tests – with a specific window pair - it has been labelled as 'irrigated'.

Table 2. Dimensions of windows used to compute local statistic.

$n_1 \backslash n_2$	15	35	125
7	X	X	X
15	---	X	X
35	---	---	X

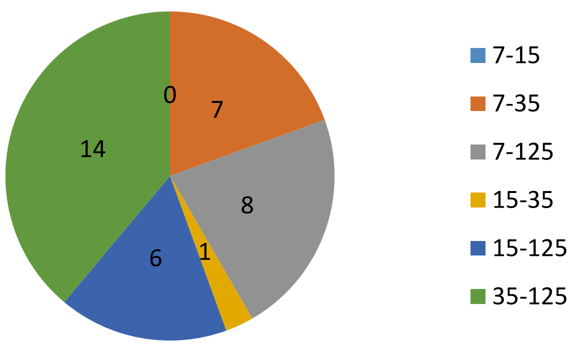


Figure 9. Number of times in which each setting (n_1; n_2) corresponds to the best OA in the whole data set.

3.2.5.3. The performance of the classification algorithm

Figure 10 and Figure 11 report the time series of OA and PA_{irr} values obtained in 2017 and 2018, respectively. The PA_{irr} both in 2017 and in 2018 has been computed considering the fields irrigated within 1 day from the S1 passage. In 2017, the value correspondent to April 3rd 2017 has not been considered because only 1 field is irrigated within 1 day from the S1 passage.

In 2017, the analysis focuses on the period between April and end of June, while in 2018 between mid-May and end of July. This is because of the temporal behaviour of the SSM contrast, discussed in 3.2.5.1, and also because many fields cropped with sugar beet, potato, maize etc., are masked later on in the summer season. As illustrated in D3.8, the masking is due to the fact that most of the aforementioned summer crops are dominated by volume scattering in C-band.

It has also been observed that the masking may introduce additional classification errors. Indeed, it happens that some fields that are irrigated according to the ground data, but incorrectly classified, are partially masked. Likely, the portion of the field masked is also the one irrigated.

In agreement with the considerations about the contrast in 2017 and 2018 in 3.2.5.1, both OA and PA_{irr} overall are better in 2017 than in 2018. In both years, the best performance is obtained early in the season, i.e. April and May, respectively, the OA is ~ 0.7 and the PA_{irr} is ~ 0.9.

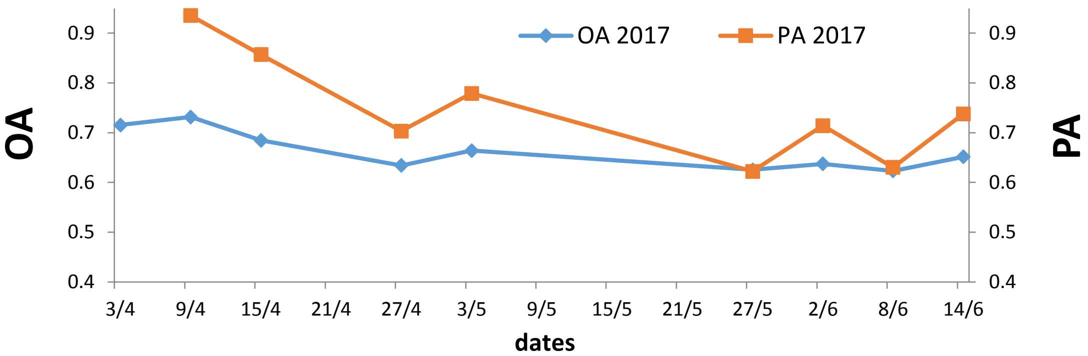


Figure 10. OA & PAirr computed from early April to mid of June in 2017 with the multi windows approach.

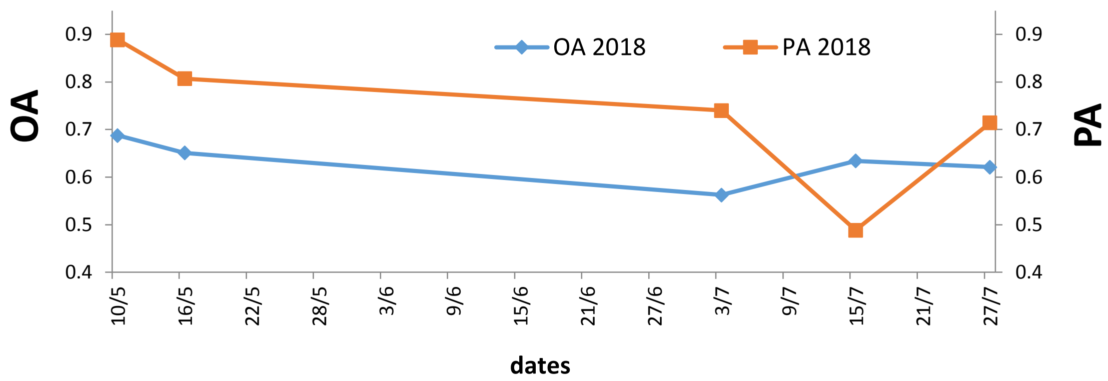


Figure 11. OA & PAirr computed from mid-May to end of July in 2018 with the multi windows approach.

3.2.5.4. The PA_{irr} per crop

The PA_{irr} has also been evaluated per few specific crops, such as wheat and barley (winter crops) and maize (summer crop). The analysis has been limited to 2017 as the algorithm performance in the two years is fairly well correlated, as shown in Figure 10 and Figure 11.

The number of fields declared irrigated in GD in 2017, for each crop, is reported in Figure 12.

Wheat is irrigated mainly from early April to mid-June, while barley from early April to early May and Maize from end-April to mid-September. Figures 13 and Figure 14 show the PA_{irr} for the selected crops and for those dates in which at least 15% of fields are declared irrigated.

In April, a fairly good PA_{irr} ($> 80\%$) is achieved for all the selected crops. PA_{irr} increases when considering the fields irrigated within 1 day. On April, 27th, barley shows the lowest PA_{irr} value, which likely reflects the poor OA (see Figure 10) estimated on the same date.

The EO_{nirr} for 2017 - using the multi-windows approach - is shown in Figure 15. In average its level is $\sim 30\%$, while the lowest performance is found in June and August. A similar behaviour is obtained in 2018.

Together with the EO_{nirr}, we have further analysed the fields that are classified as irrigated, but are labelled as not irrigated in June and August 2017.

In general, these fields exhibit values of SSM as high as those of fields correctly classified, but only over a part ($\geq 10\%$) of the entire field. Only few fields present an irrigated surface larger than 50%.

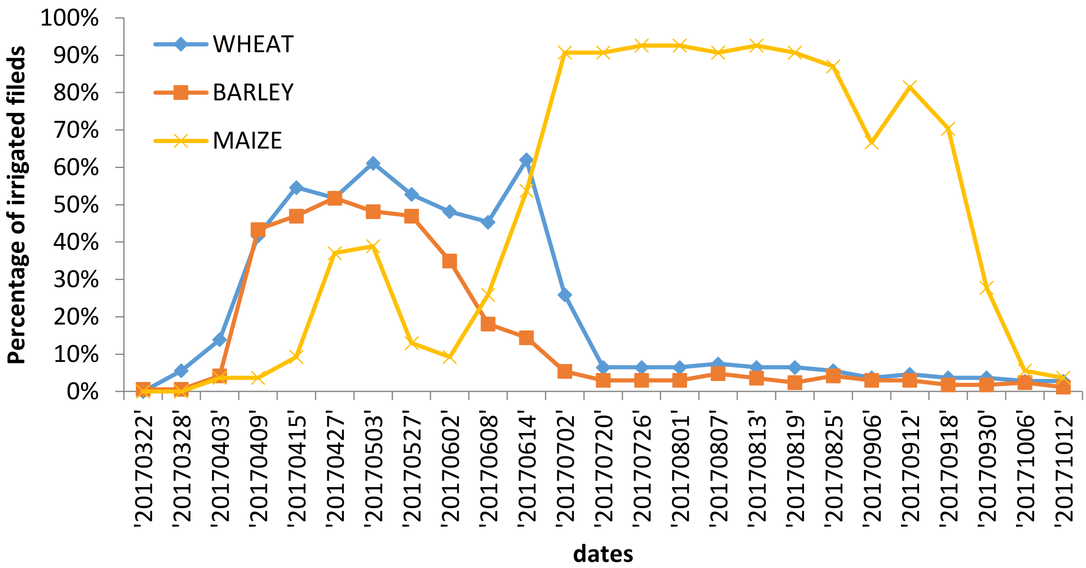
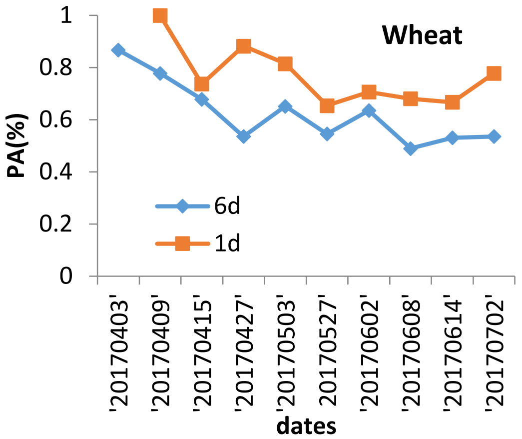


Figure 12. Percentage of fields declared as irrigated in each date on Riaza, crop by crop, in 2017.



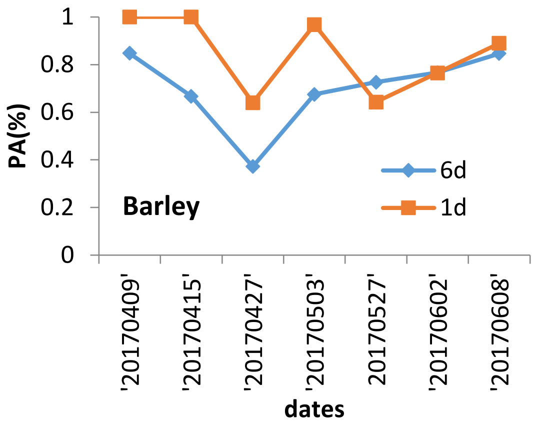


Figure 13. PA_{irr} computed respect to field irrigated in GD within 6 and 1 day for winter crops: wheat and barley.

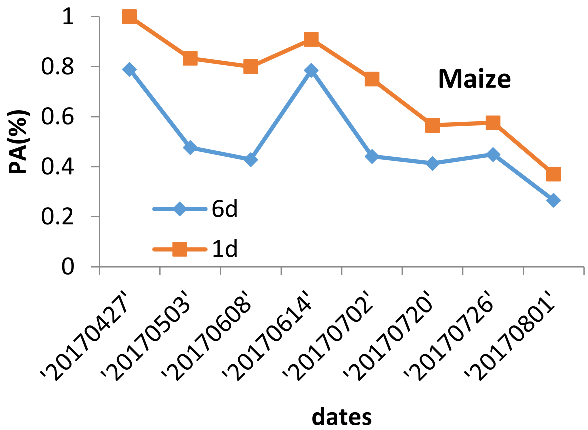


Figure 14. PA_{irr} computed respect to field irrigated in GD within 6 and 1 day for maize.

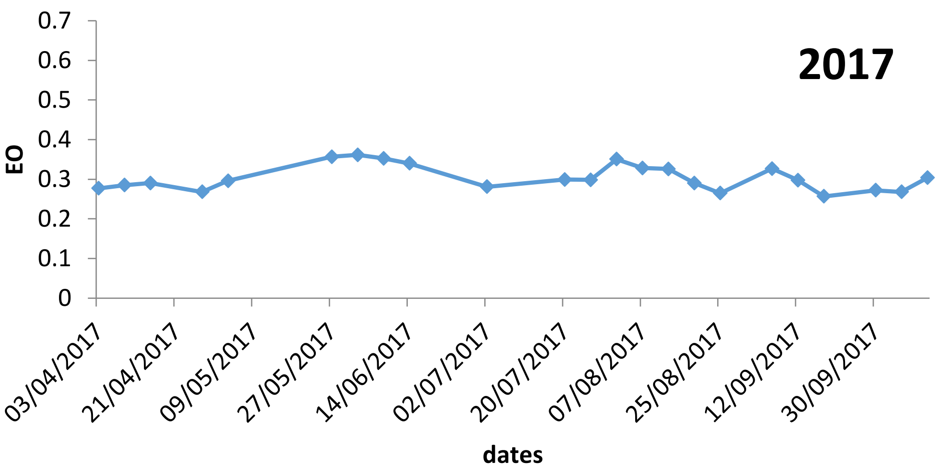


Figure 15. EO_{nirr} computed for each considered date in 2017.

3.2.5.5. Correlation between water consumption and SSM

One of the expected use of SSM maps over irrigates areas is the retrieval of quantitative information about water consumption. In this section, the correlation between water consumption and SSM mean value has also been investigated in two dates in 2017: April 9th and August 25th. Figure 16 reports SSM observed on April 9th versus the amount of irrigated water applied within 1 day (light blue diamonds) and 3 days (grey triangles) before the S1 acquisition. In the first case the coefficient of determination is $R^2 \sim 0.7$ and the correlation is significant ($p < 0.05$), whereas in the second case $R^2 \sim 0.2$ no significant correlation is found. This outcome confirms the crucial role of the time span between the irrigation event and the S1 acquisition. After three days, it seems that the SSM observed is still wetter than that of not-irrigated fields but it is almost independent on the amount of water applied.

Figure 17 reports SSM observed on August 25th versus the amount of irrigated water applied within 1 day (light blue diamonds). The coefficient of determination is lower than in April, i.e. $R^2 \sim 0.4$ for 8 observations.

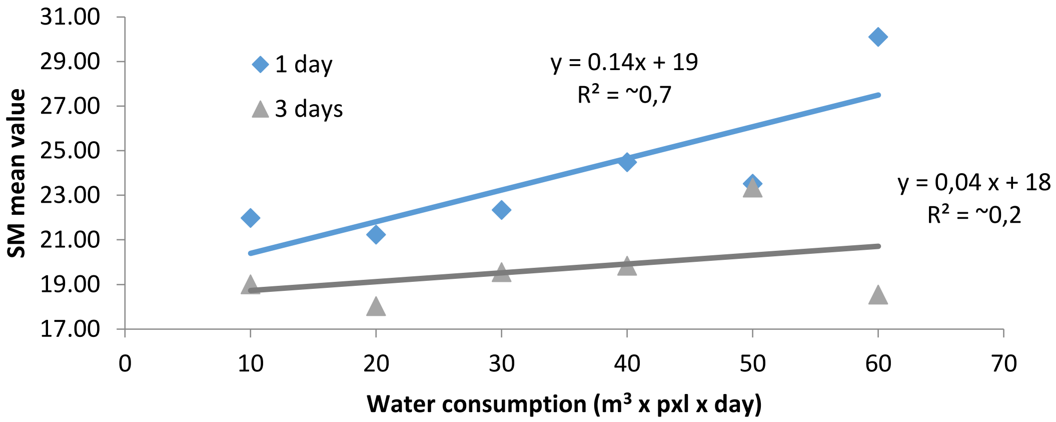


Figure 16. SSM mean values versus the water consumption within 1 (diamonds) and 3 days (triangles) on April 9th, 2017.

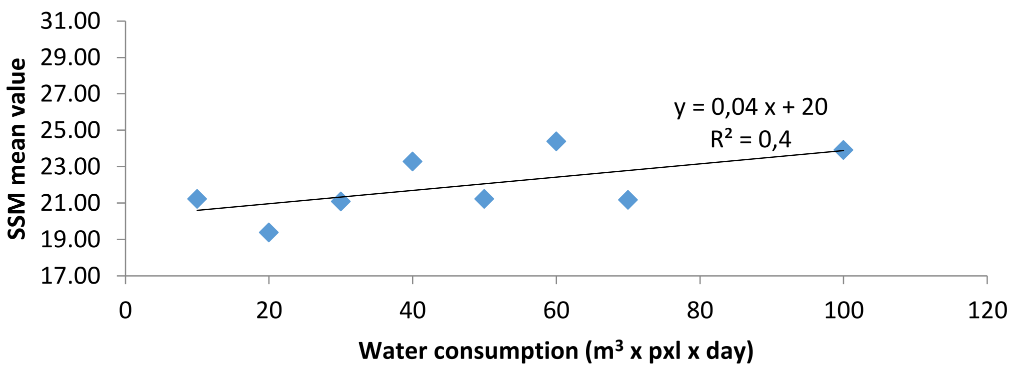


Figure 17. SSM mean values versus the water consumption within 1 day on August 25th, 2017.

4. Summary

The validation of the algorithm proposed to classify Irrigated /not-irrigated fields using SENSAGRI SSM maps has been carried out on data acquired over the Riaza district (Castilla and Léon, Spain) in 2017 and 2018. 23 SSM maps in 2017 and 12 in 2018 have been analysed.

The validation consisted of comparing the binary maps produced by the classification algorithm – described in D6.12 – with the ground data available over the Riaza irrigation district.

The main outcome of the validation study can be summarized as follows. Firstly, the algorithm performance strongly depends on the time-dependent contrast existing between the SSM content of irrigated and not-irrigated fields. This contrast in turn mainly depends on i) the balance between the amount of water supplied and the evapotranspiration rate and ii) the development of crops, particularly in the summer season. **In periods characterized by relatively high SSM contrast (e.g. April 2017), remarkably good classification performance is observed (e.g. PA_{irr} ~95-85%).** Conversely, in periods characterized by a fairly low SSM contrast the algorithm performance is quite poor.

A more detailed analysis has been performed by considering the PA_{irr} for few specific crops, such as wheat, barley and maize, which all together represent the 43% of the Riaza crops. The analysis has been focused on 2017, when a larger data set is available. This implies a better possibility to study how the PA_{irr} changes with the plant phenology. Results indicate that for winter crops the best performance is achieved before the flowering period, while for summer crops the most appropiate period is during the early phenologic stages when the plants are not fully developed. Under these conditions, a $PA_{irr} > 80\%$ is achieved. **This result suggests that irrigation detection by SSM maps could be very useful for an early detection of irrigated areas, which can be valuable information for water management in case of shortage of water**.

Future work will be dedicated to exploit the time series of binary masks in order to produce monthly irrigated /not irrigated maps and improve the OA by using the temporal information to reduce the number of FP and FN events.

Reference documents

SENSAGRI Deliverable D3.7: Final SSM products over test sites in Europe.
SENSAGRI Deliverable D3.8: Final SSM Algorithm Theoretical Basis Document.
SENSAGRI Deliverable D6.12: Proof of concept of irrigated/ not irrigated area product version 3.
SENSAGRI Deliverable D7.2: Report on the site description and instrumentation used.
ENSAGRI Deliverable D7.13: Validation of Tillage Change Maps.

References

Baret, Fred, and Gerard Guyot. "Potentials and limits of vegetation indices for LAI and APAR assessment." Remote sensing of environment 35.2-3 (1991): 161-173.

Crow, W. T., Berg, A. A., Cosh, M. H., Loew, A., Mohanty, B. P., Panciera, R., ... & Walker, J. P. (2012). Upscaling sparse ground-based soil moisture observations for the validation of coarse-resolution satellite soil moisture products. Reviews of Geophysics, 50(2).

Guermazi, E., Bouaziz, M. & Zairi, M.(2016). Water irrigation management using remote sensing techniques: a case study in Central Tunisia. Environmental Earth Sciences. vol. 75:202. https://doi.org/10.1007/s12665-015-4804-x.

Ozdogan, M., Woodcock, C.E., Salvucci, G.D. & Demir,H. (2006). Changes in summer irrigated crop area and water use in Southestern Turkey from 1993 to 2002: Implications for current and future water resources. Water Resources Management. vol.20. pp.467–488.

Ozdogan, M., Yang, Y., Allez, G. & Cervantes, C. (2010). Remote Sensing of Irrigated Agricolture: Opportunities and Challenges. Remote Sensing. vol.2. pp.2272-2304.

Pervez, M.S & Brown, J.F. (2010). Mapping irrigated lands at 250-m scale by merging MODIS data and National Agricultural Statistics. Remote Sensing. vol.2. pp.2388-2412.

Wardlow, Brian D., and Stephen L. Egbert. "Large-area crop mapping using time-series MODIS 250 m NDVI data: An assessment for the US Central Great Plains." Remote sensing of environment 112.3 (2008): 1096-1116.