Ref. Ares(2018)1139033 - 28/02/2018

FATIMA

FArming Tools for external nutrient Inputs and water MAnagement

D 3.2.4 Performance assessment of the procedures for wide-area EO-assisted nutrient management

WP3.2 – Upscaling VRT for nutrient and water efficiency and yield optimization

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European Commission

Horizon 2020
European Union funding
for Research & Innovation

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 633945.

Document Information

Grant Agreement Number	**633945**	**Acronym**	**FATIMA**		
Full Title of Project	Farming Tools for external nutrient inputs and water Management				
Horizon 2020 Call	SFS-02a-2014: External nutrient inputs (Research and innovation Action)				
Start Date	1 March 2015	**Duration**	36 months		
Project website	www.fatima-h2020.eu				
Document URL	(insert URL if document is publicly available online)				
REA Project Officer	Arantza Uriarte				
Project Coordinator	Anna Osann				
Deliverable	D 3.2.4 Performance assessment of the procedures for wide-area EO-assisted nutrient management.				
Work Package	WP3.2 – Upscaling VRT for nutrient and water efficiency and yield optimization				
Date of Delivery	**Contractual**	31 Aug. 2017	**Actual**	14 Jul. 2017	
Nature	R - Report	**Dissemination Level**	PU+CO		
Lead Beneficiary	ITAP				
Lead Author	Horacio López	**Email**			
Contributions from	UCLM, Regional teams from all pilots				
internal Reviewer 1	Guido D'urso (Ariespace)				
Internal Reviewer 2	Martine Guérif (INRA)				
Objective of document	To establish the guidelines to realize an adequate nitrogen (N) fertilization and apply it in different pilot areas with different types of infrastructures.				
Readership/Distribution	All FATIMA Regional Teams; All WP leaders and other FATIMA team members; European Commission / REA				
Keywords	Regional meeting, stakeholder, end user, multi-actor community process				

Document History

Version	Issue Date	Stage	Changes	Contributor
V 00	20/07/2017	Draft		Horacio López & Francisco Jara .
V 01	28/08/2017	Mature draft	Integrated version	
V02	27/02/2018	final	Reviewers' comments integrated	

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Executive summary

The aim of the document is to describe the methodologies used to analyze the performance, and the results obtained, in the assessment of the variable rate fertilization management in wide areas and in the short term. The results are based on the methodologies developed for the fertilization advice and crop monitoring using EO-based data. This methodology, as described in the document, is currently operative and it has been applied at the scale of commercial fields in demonstrative experiences, being also possible its application for wide areas.

The results obtained indicated the possibility to provide variable rate fertilization advice using the management zone maps based on the temporal evolution of multispectral vegetation indices from previous campaigns. This methodology combines our best agronomic knowledge and the potentialities of the EO images to describe the within-field variability of crop productivity. In the other hand, the crop performance, in terms of actual crop growth and nitrogen status, can be monitored using a combination of multispectral vegetation indices and Red-Edge based indicators. The operational monitoring of the crop performance for wide areas is possible using the dedicated platforms used in the frame of FATIMA, i.e. SPIDER web-GIS and IRRISAT. These platforms allowed the analysis and distribution, to a wide range of end users, of the information contained in the temporal series of the biophysical parameters and the indicators used for crop monitoring.

Finally, the analysis provided point towards the necessity to adapt the fertilization doses to the crop potential productivity. The results obtained in the operational implementation of the proposed methodologies suggested the relative advantage of VR fertilization in terms of crop productivity. In addition, the adoption of VR strategies can promote the efficiency of the agronomic systems reducing the risks of nitrogen leaching and ground water pollution.

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List of acronyms

DAP	Days after planting
EO	Earth Observation
IV	Vegetation Index
MTCI	MERIS terrestrial chlorophyll index
MZM	Management zone map
NNI	Nitrogen nutrition index
NDVI	Normalized difference vegetation index
PP	Productivity potential
SNB	Simplify Nitrogen Balance
UFN	Nitrogen fertilized unit
VR	Variable rate
VRT	Variable rate technology

List of Tables and Figures

1 Objective and scope

This document has been prepared in the frame of WP3.2. The aim of the document is to describe the methodologies used to analyze the performance, and the results obtained, in the assessment of the fertilization management in wide areas in the short term (Fig. 1). The results are based on the methodology named variable rate treatment (VRT) and it relies on the within-field variability of crop potential yield. Proper references have been made based on the methodologies developed, which have been implemented and analyzed by other partners in the project. This methodology, as described in the document, is currently operative and it has been applied at the scale of commercial fields in demonstrative experiences, being also possible its application for wide areas (see Table 1).

As indicated before, this document deals with the performance assessment, focusing on the methodology used and results and conclusions derived from the operational application of VRT fertilization advice in real-world scenarios. However, the reader is referred to the Deliverable 3.2.3 for an extensive description of the rationale behind the proposed procedures. In summary, this approach integrates land productivity aspects, the influence of environmental conditions, crop and management as well as regulations related with the use of fertilizers for the recommendation of VRT. Participatory evaluation with end-users is included in WP5. In a second step, extensively analyzed in this document, the results of the VRT recommendations are evaluated using indicators of crop performance, including the continuous monitoring of crop growth, the identification of crop failures, the monitoring of nitrogen status and the evaluation of the crop productivity.

The basic information for the VRT methodology (time series of NDVI and weather data) and the most advanced products (management zone maps, fertilization recommendation maps, …) are currently available for the end-users and technicians using the central webGIS-SPIDER.

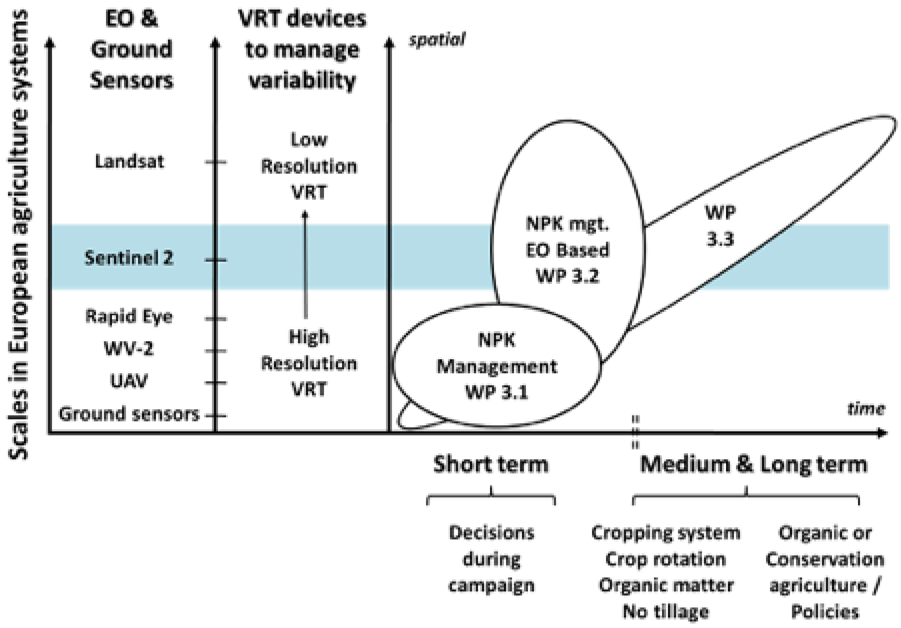

Figure 1.. Placement of FATIMA strategic concept about EO system to provide intelligence for VRT devices, in the context of space-time scales.

Interactions with other WP

WP 1.2. – Socio-economic analysis. The interactions are mainly those aspects related with the implementation of precision farming in real agriculture.

WP 2.1. – Uploading and visualizing N maps in Web GIS platform. The methodologies analyzed in this document are strongly based on the use of dedicated Web-GIS platforms.

WP 2.2. – EO for monitoring plant status and yield. As described in this document the methodologies implemented strongly rely on the use of EO data for the agronomic advice of crop fertilization and the monitoring of crop performance.

WP 3.1. – Variable rate nitrogen management. This document describes the methodologies used and the results obtained in the performance analysis of variable rate nitrogen fertilization.

WP 3.3. – Sustainable soil management and cropping systems. Although the objectives of this document focus in the short-term management, it has connections and interactions with the long-term management.

WP 5. – Pilots and strategic integration. The methodologies developed and applied promote the participation of multiple actors involved in the agronomic sector. The experiments and field experiences have been developed in accordance with multiple farmers, providers of agronomic advice and services.

2 Introduction

The management of the heterogeneity in agricultural fields and its geolocated variability is the main issue of the FATIMA project for the optimization in the use of agricultural inputs. From the point of view of technology, the possibilities of the new machinery improving the spatial distribution of the dose on-the-go, has pushed the development of a new way of geolocated management under the umbrella of precision agriculture. The main aim of the FATIMA project in this subject is the development of a protocol of observation, evaluation and decision making in real time for the management of the within-field variability.

The assessment of heterogeneity needs a holistic view that can evaluate its effects on the overall yield in a time-space continuum. The integration of Earth Observation (EO) optical sensors for monitoring crop variability, i.e. Sentinel-2 and Landsat, has made possible the detailed monitoring of crop growth at the scale of commercial fields and for wide areas. The current temporal and spatial resolution provides up to one image per week with a spatial resolution of 10 m pixel size. The new generation EO optical sensors, initiated with Sentinel-2, opens the possibility to variety of retrieval methods for biophysical and biochemical parameters of crops and to evaluate or even lead VRT applications in small fields with high land fragmentation rate.

Biomass and yield are the key biophysical crop parameters. Biomass accumulation integrates the cumulative effect of crop, soil, weather and management practices during the growing season. These basic processes take place in the soil-plat-atmosphere system and explain the biomass accumulation as a result of transpiration and solar radiation capture by plants. Biomass estimates are of interest for the operational assessment of crop yield, based on partitioning models, and for the characterization of crop development. Yield integrates all aspects and it is strongly related with biomass through the harvest index parameter, which picks up the conversion of biomass in a marketable product. In addition, biomass estimation is of interest for nitrogen fertilization assessment. As Pinter et al., (2003) already indicated, EO approaches exhibit large potential to provide biomass and final yield assessments and show variations across fields. In addition, this data can be obtained regularly during the season, providing temporal information on growth rates and plant response to dynamic weather conditions and management practices. These capabilities are truly exploited in the proposed approaches describing the within-field variability necessary for the definition of management strategies and the continuous monitoring of crop status during the growing season.

Several methodologies developed and upgraded in FATIMA analyzed the assessment of the within-field variability of crop growth using various techniques:

(i) Multispectral vegetation indices have been used in the Spanish area for the assessment of the within-field variability and the recommendation of variable doses prior to the growing season (D.323) and for the implementation of a monitoring system (D.224 and D.323), in order to detect crop failures, and the use of red-edge vegetation indices for the determination of the crop nitrogen status (Nitrogen Nutrition Index, NNI).

(ii) Ground-truth data for wheat and tomato have been used in the Italian area to calibrate Sentinel-2 red edge-based spectral information for estimating and mapping crop N requirement through the NNI;

(iii) Red or red edge-based reflectance data from ground sensors have been used in the Greek area for field-specific calibration methodology and a geospatial model to estimate crop N requirement for winter wheat, cotton and corn at 1-m spatial resolution;

(iv) Remotely sensed parameters are incorporated into simulations of crop growth and development using STICS as crop growth model, based on LAI estimation carried out by INRA team, whereby either as within-season calibration checks of model output or in a feedback loop used to adjust model starting conditions or processes.

This document described the methodologies developed and carried out in the Spanish pilot area. The work has been focused on the recommendation and monitoring of the VRT of nitrogen fertilization for various crops (maize, poppy, garlic, onion, …) and has been extensively developed and evaluated in irrigated wheat. The main objectives: a) to assess demonstrative analysis of the proposed methodologies for variable rate fertilization recommendations and crop performance monitoring working in real-world scenarios and b) to identify of the main weaknesses for future application in wide areas.

The methodology developed for the assessment of crop performance was extensively analyzed during 2016, inducing nitrogen stress in selected areas of the field monitored. The experience described for the Field 2 illustrated the applicability of the proposed methodologies in a real-world scenario, with limited input data for the models used and low margin to implement strong differences with respect to the regular management. The whole procedure, including the recommendation of VRT and the monitoring of crop performance, was analyzed during 2017.

The counselling guidelines regarding the N fertilization and the performance assessment during the FATIMA project was carried out by the partners Aliara, ITAP and UCLM. The experiences obtained in two commercial irrigated fields planted with wheat during the growing seasons 2016 (Field1) and 2017 (Field2) were extensively described in this document to show the results of the assessment. But it should be noted that the methodology reached a very operational status providing advice in several fields in the Pilot Area.

3 Procedures for wide-area EO-assisted nutrient management and performance assessment

In the procedure for wide-area EO-assisted nutrient management at variable rate was needed the description of the within-field variability and the continuous monitoring of crop status during the growing season. It has provided temporal information of growth rates and plant response to dynamic weather conditions and management practices. The information necessary (indicators) for the crop monitoring was timely uploaded in SPIDER web GIS platform and it is accessible for the dissemination and analysis by different actors involved in the process (farmers, technicians and researchers). The procedure has been summarized in the Fig. 2.

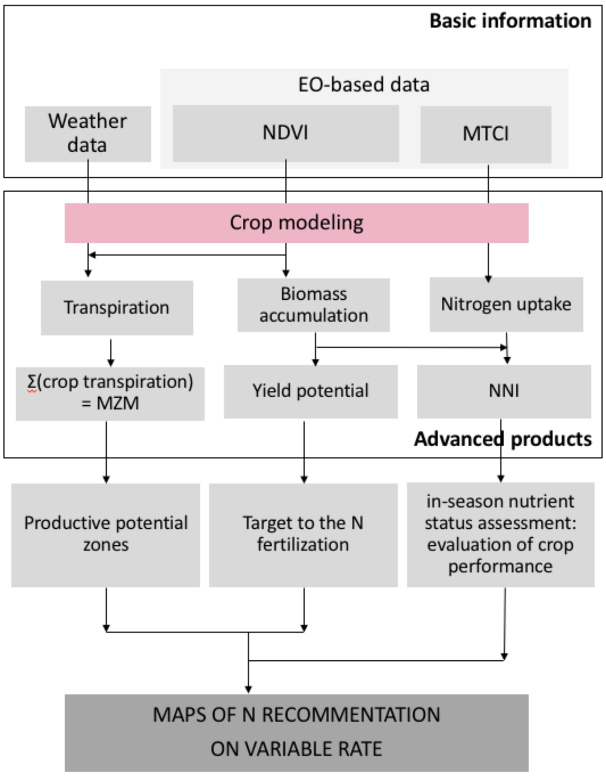

Figure 2.Flow chart of the procedure for the EO-assisted nutrient management.

The EO-based basic indicators used for the in-season monitoring were:

(i) Time series of NDVI and RGB color compositions based on Sentinel 2 and Landsat 8 for the assessment of the spatial variability of crop growth;

(ii) Time series of MTCI for the estimation of the nitrogen content based on Sentinel 2.

The EO-based advanced indicators used for the in-season monitoring were (D.323):

(i) Time series of crop transpiration and its accumulation used to the definition of the spatial variability of productivity potential zones, i.e. zones of management (MZM);

(ii) Time series of NNI derived exclusively from EO data for the assessment of the Nitrogen status and the identification of deficiencies.

In addition to the EO based approach, the assessment of the procedures was complemented with ground samples of aboveground biomass production and plant nitrogen content. The main objectives of these measurements were: to assess the sensitivity of the EO technique to capture spatial and temporal variations in crops growth at high temporal and spatial resolution.

The fields, crop and areas monitored during the FATIMA Project are presented in the Table 1. This document describes the results obtained in two fields cultivated with wheat and monitored during 2016 (Field 1) and 2017 (Field 2). The analyses performed in the Field1 included evaluation of the VR fertilization (see D.224) and the monitoring of crop performance during the growing season presented in this document. The analysis performed in the Field2 corresponded to the operational prescription and application of variable rate fertilization and the monitoring of crop performance during the growing season.

Table 1. Short description of the field campaigns carried-out in the frame of the project

Campaigns	Objectives related with the performance assessment
2015. Preoperational campaign mainly based on Landsat 8.	Application of variable doses in commercial fields considering the within field variability. Analysis of the response of the areas with differences in crop productivity to various nitrogen doses. **8 fields (300 ha) planted with wheat and corn.**
2016. Preoperational campaign combining Landsat 8 and Sentinel 2.	Application of variable doses in commercial fields considering the within field variability. Analysis of the nitrogen deficit indicators based on EO information. **10 fields (400 ha) planted with wheat and corn.**
2017. Demonstrative campaign. Full operative methodology applied in commercial fields.	Application of variable rate fertilization in commercial fields and crop performance assessment based on EO information. **950 ha planted with irrigated cereals (wheat and barley)**
2018. Consolidation campaign. Full operative methodology applied in commercial fields.	Application of variable rate fertilization in rainfed and irrigated commercial fields. **1350 ha planted with irrigated and rainfed cereals.**

3.1 SPIDER webGIS: procedure for wide-area

The central webGIS SPIDER (*System of Participatory Information, Decision-support, and Expert knowledge in River-basin management*) is the central hub used to analyze and share the results and the geographic information obtained for the field experiences in the frame of the project FATIMA. It can be accessed by end-users and technicians involved in the project through the URL http://maps.spiderwebgis.org/login/?custom=fatima, with separated access for each pilot area; the information has been uploaded by the person responsible of the system in each area (Fig. 3).

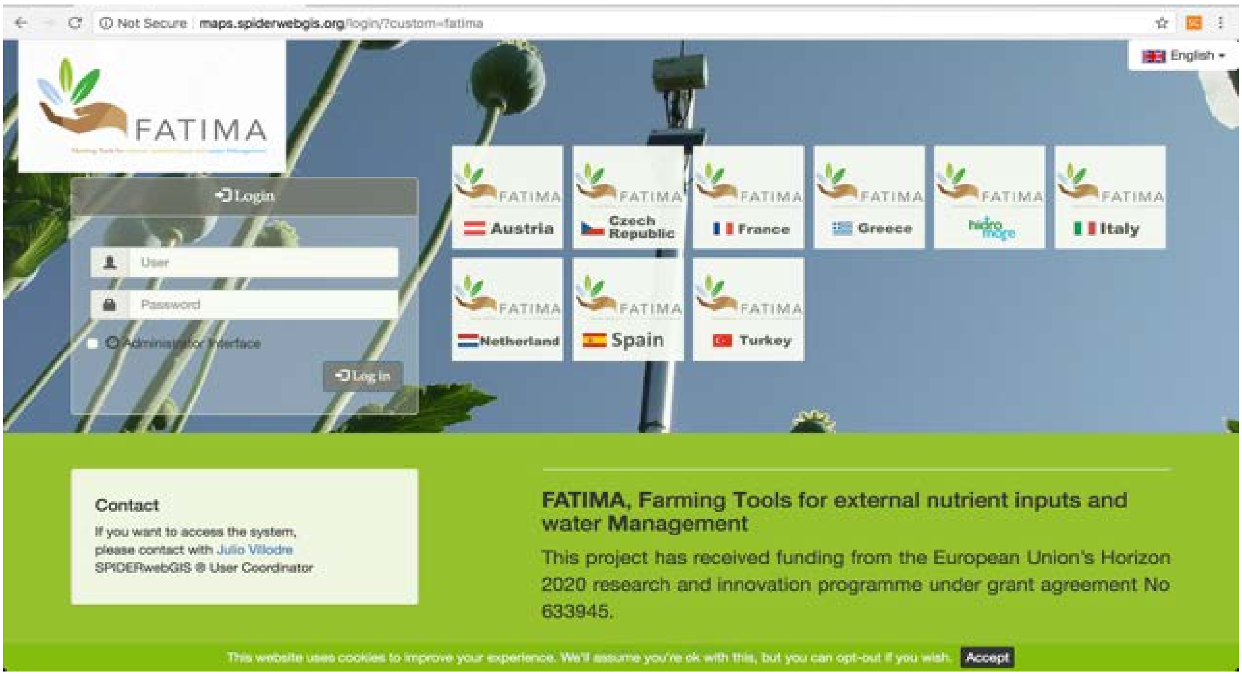

Figure 3. Access page to the FATIMA central SPIDER webGIS.

The basic tools in SPIDER for the analysis of the information is an interactive chart, *Fig. 4*, representing the temporal evolution of the indices and the visualization of various color compositions for the selected dates and derived from satellite images or alternatively a colored representation of the selected indices. These tools allow the analysis of the crop growth during the monitored seasons and the values obtained for the different indicators, paying special attention to the indicator of crop nitrogen status. A major landowner farmer with access to the Internet and mobile phones shall receive personalized information on the crop status of his/her farm holding in the form of color-coded maps (easy-to-understand intuitively). These maps need to be tailored to be adjusted to the Computer/GPS of machinery to drive variable rate application of inputs or adapted to the equipment.

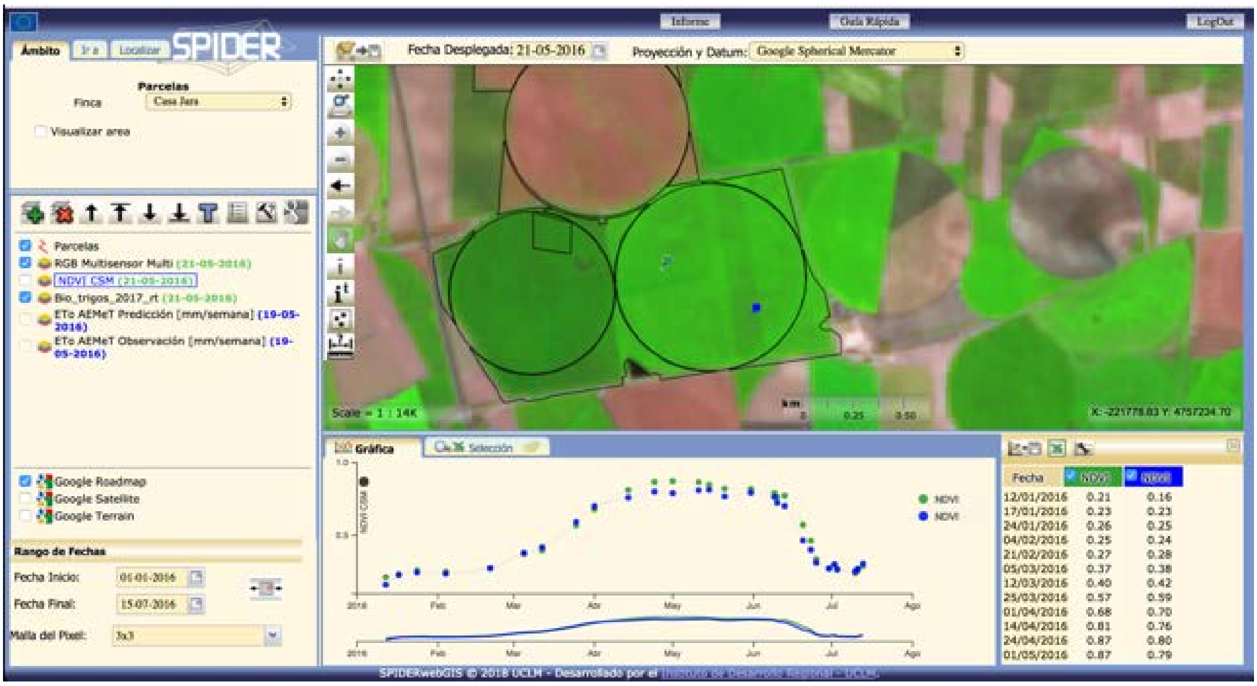

Figure 4.FATIMA central webGIS SPIDER interface with a layer manager and an interactive geospatial and time series information display area.

The summary of the data types available in SPIDER are:

1) Basic GIS layers (roadmap, water bodies, etc.) and the spatial unit of main interest is the field, defined as the minimum agricultural size of a crop canopy proceeding from administrative and land boundaries, where it is possible to manage inputs as water and nutrients in a differential way.

2) EO images time series and derived information products, mainly maps of color composites for crop water and nutrient consumption and requirements in a working hypothesis of 10 m pixel size, daily crop modelling time series (biomass accumulation and nitrogen uptake estimation) and management zone maps (MZM).

3) Models outputs (e.g., HidroMORE spatialized water balance, weather tool): water, nutrient and yield calculators;

4) Sensor networks (soil moisture, plant water status, etc.);

5) Weather forecast.

4 ASSESMENT OF THE PROCEDURES

In this section we described the fields selected for an extensive description and the demonstration of the results obtained. The use of the EO-based indicators for the assessment of crop performance was extensively analyzed in the Field1 (2016) including the evaluation of nitrogen status using ground measurements. The advice of VRT nitrogen requirements in a commercial scheme (real world application) and the assessment of the crop of crop performance was analyzed in the Field2 (2017). The experiences obtained in the Field 2 illustrated the applicability of the proposed approach procedure in a real-world scenario, with limited input data and narrow margin to implement deep-seated differences with respect to the regular management.

4.1 Field description and data collection

The Spanish pilot area is located in the South-East of Spain in the province of Albacete. The climate is Mediterranean with an annual precipitation of 353 mm and an average temperature of 14.3 ºC over the last 30 years. Precipitation occurs during autumn and spring. The mean soil depth of the area was about 50 cm. The plots were irrigated by a central pivot system and the irrigation period was from February to June with a frequency of five days during maximum crop water requirements. Each irrigation dose was about 10 mm with a total of 453 mm during the growing cycle.

Field1 has an area of 37 ha and was planted with bread wheat var. Califa. The treatments implemented to monitor the effects of several doses of nitrogen were located in a 100 m bandwidth across and in other small area (Fig. 5a). The N doses were: 173 total UFN in the band (N-), 265 total UFN in the over-fertilized area (N+) and 220 total UFN in the rest of the field (N). The total amount of N was divided into 6 applications throughout the crop cycle combining solid spreader and fertirrigation (Table 2). The variable dose was made in the top dressing (TD) 21 days after planting (DAP) this date corresponds to the top dressing 1 (TD1), when the crop was in stage BBCH 10: emergence (Table 2). As indicated, the treatments implemented in the Field 1 allowed to analyze the advantage of VRT fertilization (see D.224) and the in-season crop monitoring methods by using EO-based information. In addition, ground samples were obtained in measurement locations (Fig. 5a). The sampling areas have been located on the deficit N band (N-) coinciding with low productivity potential zones (PP) (Lpp_N-, location 6), medium PP (Mpp_N-, location 2) and high PP (Hpp_N-, location 4). The over-fertilized areas (N+) were located in the Hpp zone (Hpp_N+, locations 7 and 8). The sampling areas with average fertilization (N) were located in areas with low PP (Lpp_N, location 1), medium PP (Mpp_N, location 5) and high PP (Hpp_N, location 3). The productivity potential zones have been defined based on the MZM of a previous growing cycle of barley during 2014.

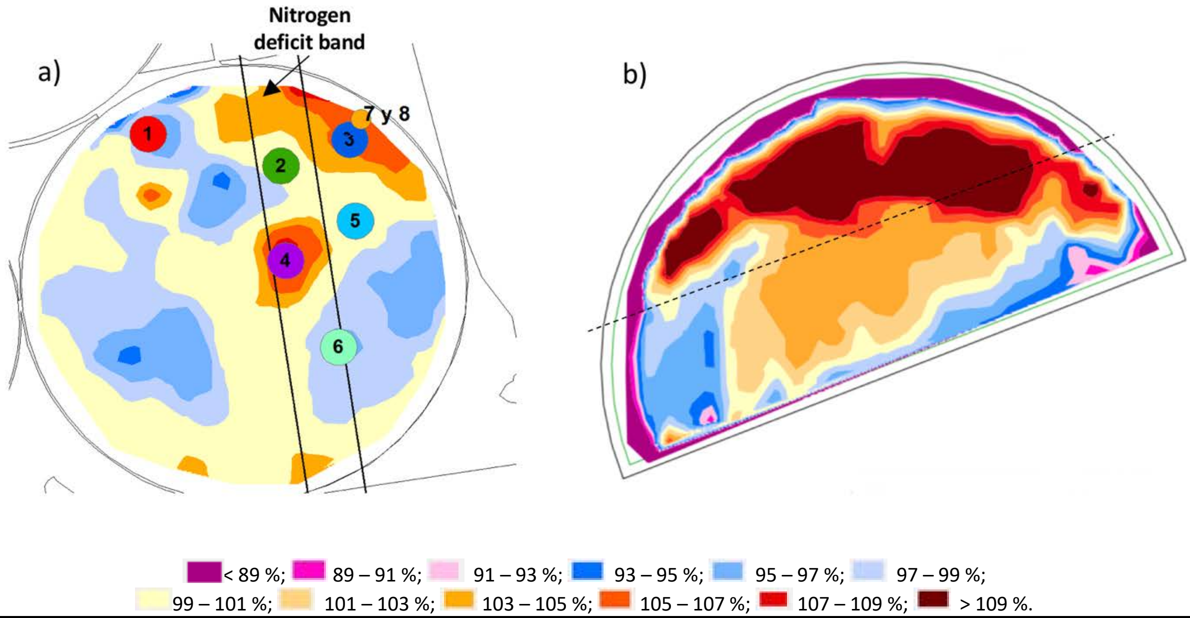

Figure 5. Measurement locations over the maps of management zones (MZM) classified by the differences in the potential productivity: a) Field1 MZM based on barley during 2014; b) Field2 MZM based on corn during 2016.

Table 2. Nitrogen fertilization management on the wheat study plots during 2016 and 2017 campaigns, respectively.

		BD	TD 1	TD 2	TD 3	TD 4	TD 5	ΣUFN
Field1 2016	**DAP**	1	21	63	96	111	138	
	Phenology (BBCH)		10	22	30 – 33	41 – 43	65	
		Doses (UFN)						
	Farm doses		100					220
	Infra-N fertilized (UFN)	14	53	27	21	36	22	173
	Over-N fertilized (UFN)		145					265
Field2 2017	**DAP**		28	68	89			
	Phenology (BBCH) (a/b)		30/29	58/43				
		Doses (UFN)						
	High PP (UFN)		78	78	78			289
	Medium PP (UFN) – farm doses	54	69	69	69			261
	Low PP (UFN)		60	60	60			233

BD: basal dressing N application; TD: top dressing N application. Sowing dates: Field1 January 11th 2016 and Field2 January 2nd 2017.

Field2 has an area of 25 ha and it was planted with two bread wheat varieties Atomo in the northern half and Califa in the southern half (*Fig. 5b*). The top-dressing applications were done at variable rate based on the farm dose (69 UFN): 28 DAP (TD1), 68 DAP (TD2) and 89 DAP (TD3). The variability in the doses depended on the productivity potential derived from the MZM (Fig. 5b), the minimum area manageable by the farmer and the limitations of the spreader used. The VRT application was performed with an adapted common spreader able to spread only three different doses of fertilizers (Fig. 6). The total N doses applied of each productivity potential zone were 233 UFN (Lpp), 261 UFN (Mpp) and 289 UFN (Hpp). The total amount of N was divided into 6 applications throughout the crop cycle combining solid spreader and fertirrigation (Table 2).

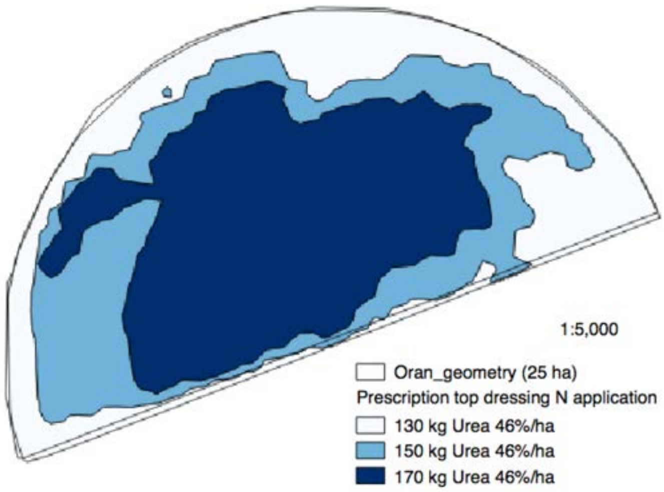

Figure 6. Prescription map used to define top-dressing VRT fertilization in Field2.

4.2 Results of nitrogen recommendation and in-season crop monitoring EO – based approaches

A selection of time series of satellite Sentinel-2 are shown in the Figures 7 and 9. The time series represent the crop development of the wheat during the growing cycles in the Field1 and Field2 during 2016 and 2017, respectively. The development curves values described by wheat in each sampling area is shown by NDVI values at the bottom of each figure. The information shown in Fig. 7 and Fig. 9 was obtained from SPIDER web-GIS, so this information was available for the main actors in the project: researchers, technicians, and farmers.

Field 1.

Differences between the zones with different management (treatments) can be appreciated in the NDVI from April, full canopy cover and BBCH 30 – stem elongation. This behavior seems to be permanent from flag leaf stage, 15th April, and stays until the physiological maturity, NDVI 0.45, reached on June 20th with a certain lag between zones based on field observations. The maximum NDVI values reached in that period were between 0.81 – 0.89, these differences were apparently not significantly enough to show nutrient stress. However, the NNI seems to be much more sensitive that the NDVI. The lowest values, NNI = 0.3-0.7, were located in the infra-fertilized band and, specifically, in the low PP zone, NNI = 0.3 - 0.5 (Fig. 7). In the point of maximum NDVI, i.e. 15th April, flag leaf stage, as the maximum established photosynthetic activity, the general value for the whole plot was between 0.7 - 0.9 excluding the infra-fertilized area (Fig. 7). Moreover, the nitrogen contents measured in the ground samples were under the optimum level described by Justes et al., 1994 (Fig. 8), the critical threshold for NNI value has been set at NNI ≤ 0.9., and the effect of the increase of N dose on the harvest grain was very positive, increasing grain yield around 1.7 t/ha.

The results obtained indicated the capability of the methodology developed for the continuous monitoring of nitrogen status using EO-based information. These results opened the possibility to monitor crop N status in the species analyzed (mainly wheat) for wide areas using exclusively EO data. During the current growing season (2018) the NNI is computed and timely published in SPIDER web-GIS for the monitoring of the N status of the fields where VRTs have been implemented.

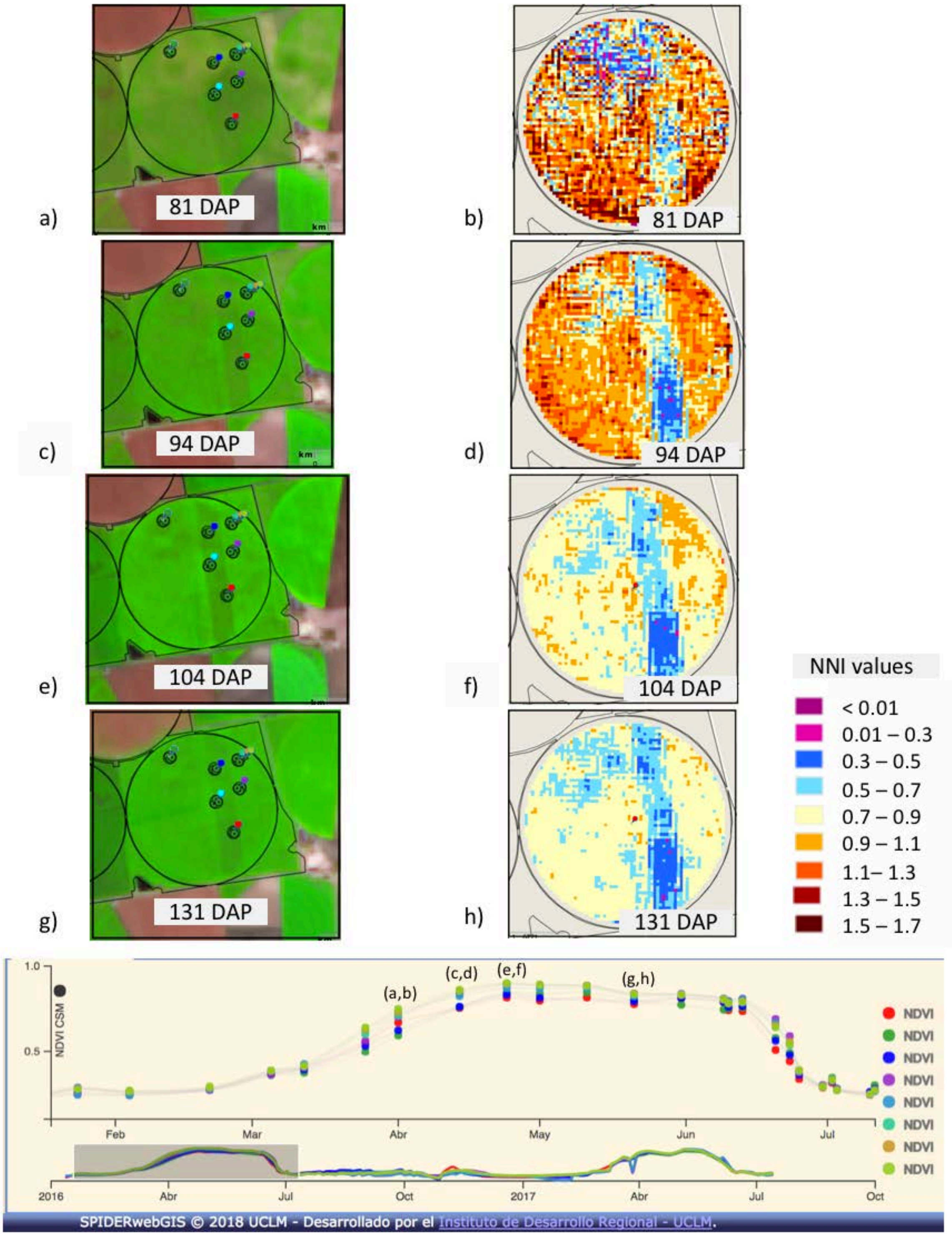

Figure 7. Maps of the time series of Sentinel 2 RGB color composition (a, c, e and g) and NNI maps (b, d, f and h) for selected dates during 2016 campaign in Field1. The lower chart shows the temporal evolution of the NDVI for the locations monitored.

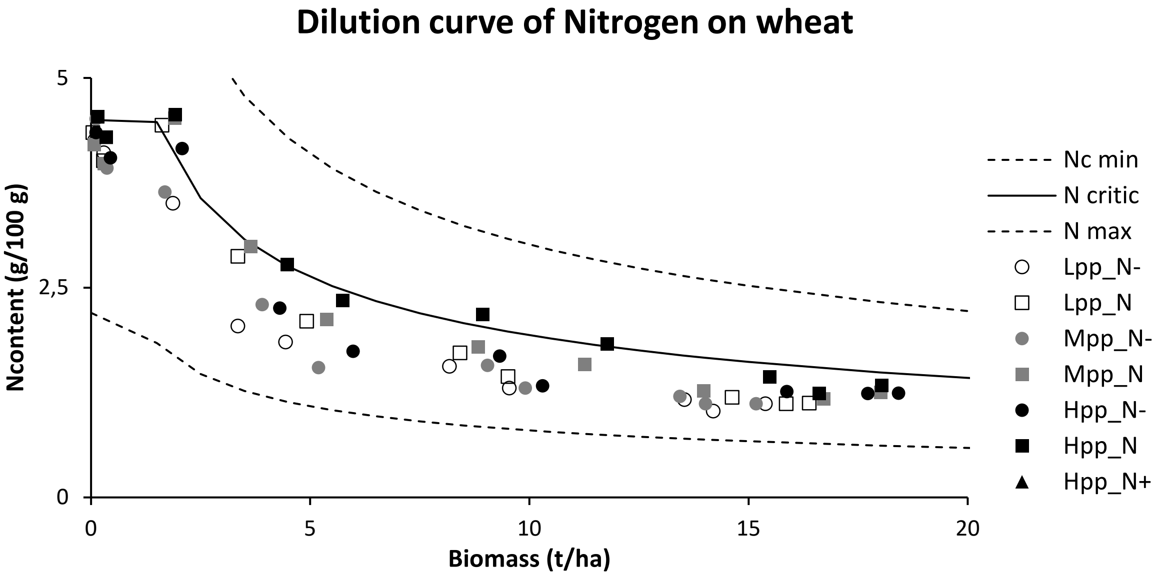

Figure 8. The measured points have been plotted separated by treatments: farmer doses of 220 UFN (N), infra fertilized 173 UFN (N-), over fertilized 265 UFN (N+); and by production potential: Low (Lpp), medium (Mpp) and high (Hpp).

Field 2.

In Field2, the satellite images provided information on plant and soil. Two types of soil were observed in the RGB images obtained before the crop sowing (Fig. 9a), with more bright soils in the north in comparison with the dark soils in the shout. Although soil samples were not collected, we detected a higher sand content in soil in the northern area. The influence of the soil on the crop was seen from emergence. The RGB color composites and NDVI values reflected a higher development in the northern part of the field (see Figure 9b) from the beginning of the growing cycle. However, both areas reached similar NDVI values (around 0.9) during the plateau period. During the crop senescence, the effect of the soil was also appreciated and the crop growing in the sandy soil finished the growing cycle several days before.

In contrast to the differences obtained in the NDVI values, the time series of NNI did not reflect clear differences associated to the soil type. The field monitored was homogeneous in terms of NNI, maintaining NNI values over 0.9 during most of the growing cycle (see Fig. 9). The methodology used detected nitrogen deficit in the shout of the field from DAP 89. The spatial pattern of the N deficit corresponds to the differences between cultivars, Atomo and Califa, and further studies should analyze the differences in N requirements for both varieties. Furthermore, and due to the soil effect, the homogeneous behavior of crop in the middle southwest is more evident than in the mid northeast through the whole cycle. As indicated, the current management in the field includes the use of sprinkler irrigation for the latter nitrogen applications and the deficiencies observed was not compensated increasing the N dose in these areas.

The results obtained in the Field2 exemplified the operational aspects of the EO-based approach for the continuous monitoring of N status. In addition, the high productivity obtained in the field (10.4 t grain/ha) argued toward the relative advantage of VRT fertilization for the improvement of crop productivity without increasing the N doses over the average doses used in the area. It should be noted that the average production or irrigated wheat in the province of Albacete is around 5500 Kg/ha and the maximum productions in the area rarely exceed 10 tons/ha (López-Urrea et al., 2009). Further analysis will be oriented to the consolidation of this conclusions using the datasets obtained during the previous demonstrative campaigns.

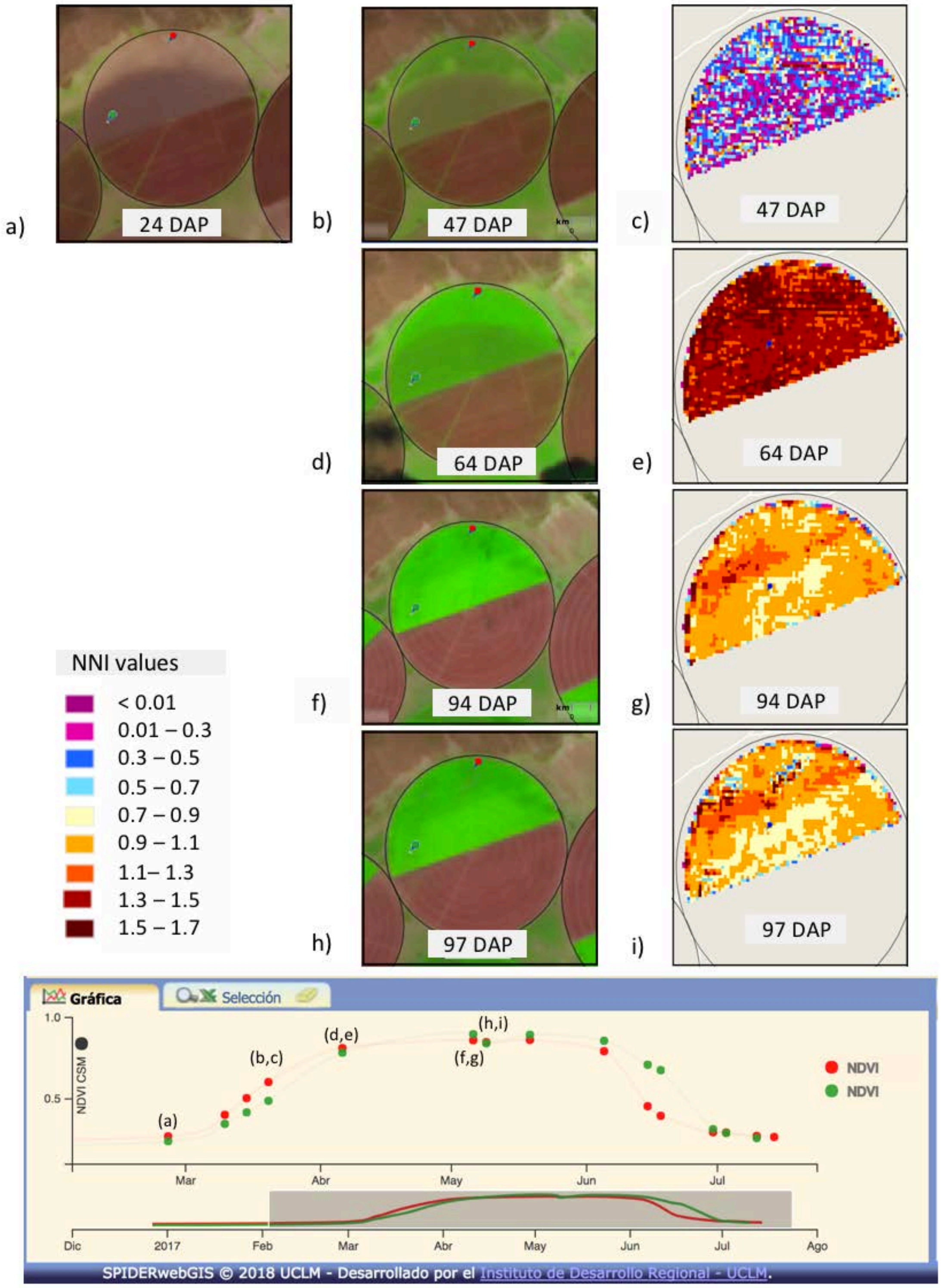

Figure 9.. *Maps of the time series of Sentinel 2 RGB color composition (a, b, d, f and h) and NNI maps (c, e, g and i) for selected dates during 2017 campaign in Field2. The lower chart shows the temporal evolution of the NDVI for two locations with contrasted differences in the soil.*

5 CONCLUSION

The experiences obtained have demonstrated the aptitude of the indicators based on EO data for the continuous monitoring of crop growth (NDVI) and N status (NNI). The methodology is currently operational and it is used to analyze the crop performance in a wide area where the fertilization has been recommended based on the procedures developed in the frame of the project. SPIDER-web-GIS has been a key tool for the analysis and distribution of the information necessary for crop monitoring.

The experience gained in the project indicated that the main weakness of the methodologies developed are the necessity of well consolidated facilities and qualified personnel for the generation of the needed information in real time. It should be noted that for wheat and many herbaceous crops, the common fertilization strategies provided few opportunities to manage the within-field variability during the growing season. Most of the fertilization is applied during the development stages, when the plants barely cover the ground, while the main differences in the fields monitored appeared after the flag leaf stages, when the farmers prefer fertirrigation applications.

These conclusions emphasize the need to improve the specific methods for the assessment of N fertilization in early stages as is the case of the VRT fertilization based on MZM. The results indicated that the implementation of VRT optimized the crop productivity and lead high productions without increasing the N doses. However, this point should be confirmed in further analysis. The MZM and the use of EO monitoring has additional potentialities, including the implementation of variable rate irrigation; could provide guidance for the adequate spatial distribution of soil sampling attending to the variability of crop growth and the effect of soil characteristic in the reflectance values at satellite scale, as analyzed in this document.

Beyond to the operational aspect of the performance assessment procedures, the experiences described provide evidence of the opportunity to implement variable rate fertilization treatments in the pilot area and should be analyzed in other areas as well.

6 References

Dinnes, Dana L. et al. 2002. "Nitrogen Management Strategies to Reduce Nitrate Leaching in Tile-Drained Midwestern Soils." *Agronomy Journal* 94(1): 153–71. https://dl.sciencesocieties.org/publications/aj/abstracts/94/1/153 (July 20, 2017).

González-Piqueras, J., Lopez-Corcoles, H., Sánchez, S., Villodre, J., Bodas, V., Campos, I., Calera, A. (2017). Monitoring crop N status by using red edge-based indices. *Advances in Animal Biosciences, 8*(2), 338-342.

Justes E., Mary B., Meynard J.M., Machet J.M. y Thelier-Huche L. 1994. Determination of a critical nitrogen dilution curve for winter wheat crops. Ann. Bot. 74: 397- 407.

Lemaire, G., Plénet, D., & Grindlay, D. (1997). Leaf N Content as an Indicator of Crop N Nutrition Status. In G. Lemaire (Ed.), Diagnosis of the Nitrogen Status in Crops (pp. 189-199). Berlin, Heidelberg: Springer Berlin Heidelberg.

Lobell, D. B., Ortiz-Monatesrio, J.I., Sibley, A. M., Sohu, V.S., 2013. Satellite detection of earlier wheat sowing in India and implications fro yield trends. Agric. Syst. 115, 137 – 143.

López-Urrea, R.; Montoro, A.; González-Piqueras, J.; López-Fuster, P.; Fereres, E. Water use of spring wheat to raise water productivity. *Agric. Water Manag.* 2009, *96*, 1305–1310

Moll, R.H., E.J. Kamprath, and W.A. Jackson. 1982. "Analysis and Interpretation of Factors Which Contribute to Efficiency of Nitrogen Utilization." Agronomy journal 74: 562–564

Monteith, J.L., 1972. Solar radiation and productivity in tropical ecosystems. J. Appl. Ecol. 9, 747 – 766.

Perry, C., Steduto, P., Allen, R.G., Burt, C.M., 2009. Increasing productivity in irrigated agriculture: agronomic contraints and hydrological realities. Agric. Water Manag. 96, 1517 – 1524.

Pinter, P.J.J., Harfield, J.L.L., Schepers, J.S.S., Barnes, E.M.M. Moran, M.S.S., Daughtry, C.S.T.S.T., Upchurch, D.R.R., 2003. Remote sensing for crop management. Photogramm. Eng. Remote Sens. 69, 647 – 664.