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FArming Tools for external nutrient Inputs and water MAnagement

D 3.2.1 Guidelines for mapping differential N from EO at a range of spatial scales

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

First VERSION (Month 12)

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Executive summary

This document has been prepared in the frame of WP3.2, with the aim of addressing nutrient and water differential diagnosis at a range of scales, setting up the procedure to obtain the required EO-based maps of nutrient requirement variability. Among others, the nitrogen (N) is being considered an important agri-environmental nutrient and this report focuses on provinding maps of N content and uptake in plants as an input for variable rate technology (VRT) tools.

Two models have been proposed for N differential diagnosis:

(i) based on red edge vegetation indices and
(ii) based on N balance in soil.

The red edge vegetation indices are related to N content in plants and allow mapping this variable using the operative EO sensors at different temporal, spatial and spectral scales. Red edge vegetation indices have been selected based on their results determining the N content in crops, according to their suitability for the pilot areas and crops in the field campaigns. Added to this selection, some guidelines have been proposed for their performance and adaptation to sensors characteristics.

On the other hand, the N balance in soil at daily scale provides an estimation of N uptake rates as a diagnostic tool and it also allows a prognosis of the nutrients requirements in crops. The simplified model as presented in this report is detailed in order to be implemented in the pilot areas and for different crops. It is linked with EO data by means of being fed with the accumulated biomass provided by the crop growth models and the depletion in soil from the soil water balance assisted by satellite.

Finally, this report provides the guidelines for better understanding about the application of both methodologies (the red edge-based vegetation indices and soil N balance) in different pilot areas.

The current version (v1.0) reflects the status of M12, with the basic methodology available and functioning. Further calibration and validation may lead to updated methodologies, which will be documented in a subsequent document version.

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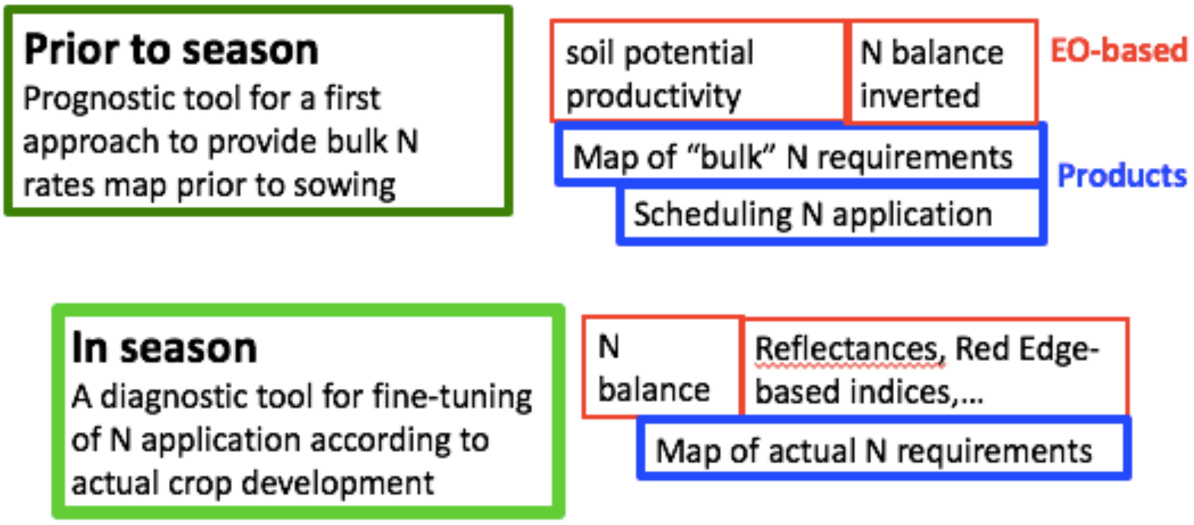
1 Objective and scope of the work

The objective of the work is to develop, test, and implement diagnosis and support tools for variable rate application of nutrients and water at commercial production plot scale and beyond. The information about the nitrogen (N) in crop covers has been identified as a priority nutrient and agri-environmental indicator. For this purpose, two currently available techniques are going to be proposed (see schematic below): on one hand the determination of the nitrogen content in the crop from remote sensing data by means of the red edge-based vegetation indices, and on the other hand, the N balance in soil at daily scale.

The first can be considered a diagnostic method because it allows the determination of the N content in cover at the time of the remote sensing acquisition data. This method allows a reduced cost, non-destructive and synoptic tool for the diagnosis of the distribution of N content within the plot.

The N soil balance at daily scale allows to simulate the rates and predict the requirements of this crop nutrient. Therefore, it is considered a prognostic method.



A secondary objective of this deliverable is to provide the guidelines for better understanding about the application of both methodologies (the red edge-based vegetation indices and soil N balance) in different pilot areas.

Both methods will provide a diagnosis and a support toolset for wide-area coverage EO-assisted VRT of nutrients and water.

2 Introduction

2.1 WP 3.2 strategy

Precision agriculture is going to be implemented nowadays using the available information about the crops in order to make an efficient and rationale use of water and nutrients. It implies the determination of the fertilizer, the timing and the doses properly distributed in the plot. This information must be coherent to feed up the tools and machinery used in field for the application of the fertilizers.

The WP 3.2 strategy aims at studying how to scale up from experimental plot to commercial production plot and beyond by means of EO, using the detailed trials in 3.1 both for performance evaluation and as ground truthing for the EO-assisted system. Activities will be performed in all pilot areas, with approaches only differeing due to different crops, soils, cropping systems, source of EO data and climatic conditions.

2.2 N differential diagnosis based on the red edge spectral band

The red edge spectral band (700 ± 40 nm) is a transition region (Figure 1) with a rapid change in leaf reflectance caused by the strong pigments absorption in the red and leaf scattering in the NIR spectrum. The behavior of the reflectance in this region of the spectrum has been proved sensitive to crop canopy chlorophyll and consequently to N status (Hatfield et al., 2008). The sensitivity of absorbance related to crop chlorophyll content is much higher in the red edge region than in red, because the radiation penetrates deeper into crop canopy and leaves than the visible light. Therefore, the red edge-based spectral indices can overcome the saturation behavior showed in the NDVI and other red band-based indices.

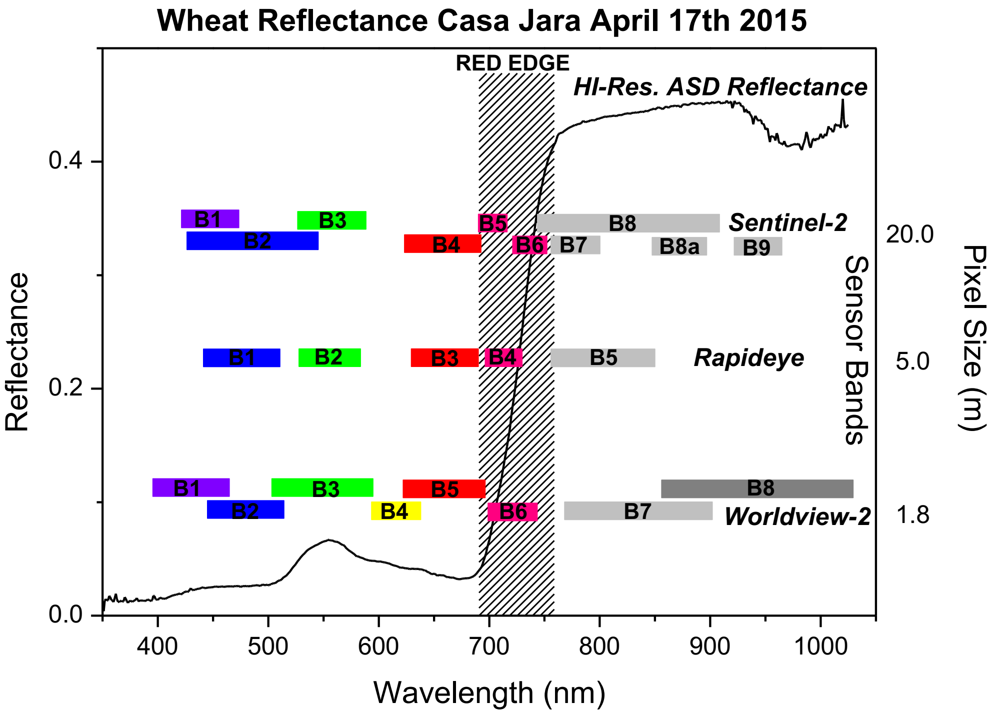


Figure 1.- Multispectral bands configuration over a wheat reflectance spectra acquired in Casa Jara (Albacete, Spain) on April 17th 2015 with a FieldSpec Hi-Res ASD® spectro-radiometer. The bands of the multispectral sensors including one or two bands in the red-edge such as Sentinel-2, Rapideye and Worldview-2 are shown.

Due to this crop spectral behavior of the red, red-edge and near infra-red region, different sensors have been designed to acquire reflectance at different spatial, spectral and temporal resolutions in order to estimate the Chlorophyll and N content in crops. These sensors cover a range from field observations at high spectral resolution with handheld radiometers, to recently launched multispectral medium resolution Sentinel-2, passing through very high resolution proximal remote sensing cameras (Parrot Sequia®) and satellites (Rapideye® and Worldview-2®). The most used models to map crop N content from these sensors are the red edge-based indices that are based on reflectance band combinations. There are many of these indices published in the bibliography as they tackle different objectives and overcome different problems, such as saturation with high crop density, color and brightness variations in soil background, linear behavior with N content, angular view and illumination variation,.. In this report we have selected the red edge indices that better results provide determining the N in crops, based on high impact publications according to their suitability for the pilot areas and crops in the field campaigns. Added to this selection, we focus on their performance and adaptation to sensors characteristics.

According to this strategy, the users will access to N diagnosis maps that can be comparable from different sensors and coherent to feed up the tools and machinery for VRT.

2.3 N differential diagnosis based on the N uptake by the growing plants

In this second method the maps of N requirements will be based on the N balance over the growth cycle considering the N uptake by the growing plants according the rate of accumulation of biomass in their organs and N dilution curves into it (Justes,1994) (Figure 2). In the same way that approach based on red edge-indices, the N balance requires of knowledge of N soil processes and efficiencies in their use (Huggins and Pan, 1993). The biomass accumulation and deep percolation are going to be calculated through EO-fed crop growth model (based on results from WP2.2) and water soil balance using remote sensing inputs as Landsat 8 or Sentinel-2.

This is an independent and complementary approach to the one based on red edge. The parallel application of both procedures provides sound basis about nitrogen cycle monitoring. Both coincide at high spatial resolution scale which eases their comparison. Based on this comparison we assume we can up-scale the procedure beyond N reference field strips using a simplified N soil balance model.

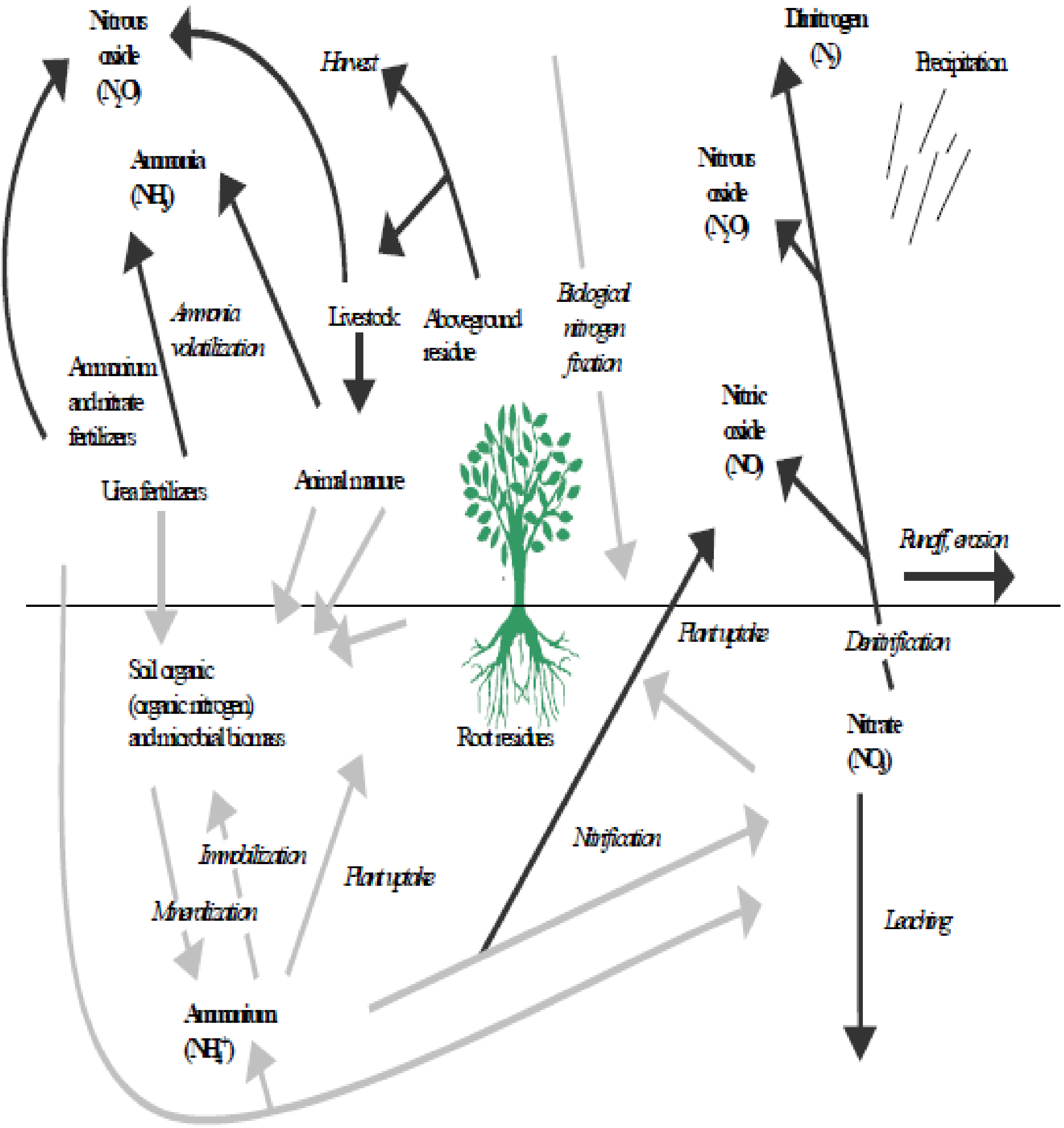


Figure 2.-The Nitrogen cycle. Source: OECD (2001) Environmental Indicators for Agriculture-Volume 3: Methods and Results, Publication Service, Paris, France.

In this report, the basic guidelines for a simple N balance model are provided in order to simulate the crop N uptake at daily basis and to recommend the crop N necessities.

3 Red Edge-based Spectral Vegetation Indices

In the recent decades many spectral indices have been proposed to estimate chlorophyll leaf concentration and hence crop nitrogen (N) status. However, most of the indices based on red radiation lose their sensitivity under high aboveground biomass conditions. The commonly used normalized difference vegetation index (NDVI) becomes saturated at moderate to high canopy coverage conditions. It has been proved that for wheat

NDVI loss its sensitivity when aboveground biomass of winter wheat was higher than 3736 kg·ha-1 (Li et al, 2010). In case of corn the red-based vegetation indices lost their sensitivity at the V10-VT growth stages under moderate to high aboveground biomass and high N rate conditions (Shaver et al., 2010).

Thus, previous experiments showed that the named normalized difference red edge index (NDRE) (Fitzgerald et al., 2006) that is defined in the form of the NDVI but with the red band replaced by an red edge band, was a reliable indicator of chlorophyll or N status. The red edge chlorophyll index ($\mathrm{CI}_{\text{red edge}}$), was designed to predict chlorophyll content of maize and soybean, and also with sensitivity to N content (Li et al., 2014). The canopy chlorophyll content index (CCCI) is based on the theory of two-dimensional planar domain and it uses the red edge band, was proposed as a superior method to estimate N-related indicators for cotton, wheat and broccoli (Fitzgerald, 2010). It has been applied to corn showing promising results for estimating summer maize plant N concentration and uptake at the V6 and V7 and V10-V12 stages (Li et al., 2014). Wu et al., (2008) have proposed a combination of indices based on the Modified Chlorophyll Absorption Ratio Index (MCARI), the Transformed Chlorophyll Absorption in Reflectance Index (TCARI), and the Optimized Soil-Adjusted Vegetation Index that using NIR, red edge, and green bands such as MCARI/OSAVI and TCARI/OSAVI, were more linearly related to maize chlorophyll content than indices based on NIR. Another important factor for the N determination in the crops by remote sensing techniques are the angular variation on the illumination and observation. This effect is due to the vertical gradient in leaf N distribution in a plant canopy, with the lower shaded leaves generally having lower N content than the upper illuminated leaves, leading to variation in canopy structure, which has a significant impact on directional performance of Vegetation Indices. Thus, in order to improve the predictive accuracy of N content and the angular stability, He et al. (2016) have recently defined the Angular Insensitivity Vegetation Index (AIVI). This index shows high correlations (r2 over 0.9) with N content in wheat, for a range of high spectral resolution reflectance measurements (±40º) zenith angles referred to the nadir. As can be seen, those indices have been defined to be sensitive to the cover amount and N content but normalizing other effects such as soil brightness and color variation, avoiding saturation effects or improving angular stability. All of these indices are defined in Table 1.

Table 1.-Red edge-based spectral vegetation indices used in estimation of nitrogen status. R_λ represents the reflectance at the wavelength center λ.

Vegetation Index	Formula	Use	Reference
Normalized difference red edge index (NDRE)	$(R_{790}-R_{720})\big/(R_{790}+R_{720})$	Sensitive in variations of Clorophyll and N.	Fitzgerald et al. (2010)
Red edge chlorophyll index ($\mathrm{CI}_{\text{red edge}}$)	$\frac{R_{790}}{R_{720}}-1$	Estimation of N plant uptake at different bandwidths.	Gitelson et al. (2005)
MERIS terrestrial chlorophyll index (MTCI)	$(R_{750}-R_{710})\big/(R_{710}-R_{680})$	N plant concentration after heading. N uptake	Dash and Curran (2004)

		before heading.	
Canopy chlorophyll content index (CCCI)	$(NDRE - NDRE_{MIN}) / (NDRE_{MAX} - NDRE_{MIN})$	N plant concentration after heading. N uptake across growth stages.	Fitzgerald et al. (2010)
Transformed chlorophyll absorption in reflectance index/Optimized soil-adjusted vegetation index (TCARI/OSAVI)	$\dfrac{3 \cdot \left[(R_{700} - R_{670}) - 0.2 \cdot (R_{700} - R_{550}) \left({R_{700}}/{R_{670}}\right)\right]}{1.16 \cdot (R_{800} - R_{670}) / (R_{800} + R_{670} + 0.16)}$	Sensitive in variations of Clorophyll and N.	Haboudane et al. (2002)
Modified chlorophyll absorption in reflectance index/Optimized soil-adjusted vegetation index (MCARI/OSAVI)	$\dfrac{[(R_{700} - R_{670}) - 0.2 \cdot (R_{700} - R_{550})] \left({R_{700}}/{R_{670}}\right)}{1.16 \cdot (R_{800} - R_{670}) / (R_{800} + R_{670} + 0.16)}$	Sensitive in variations of Clorophyll and N.	Haboudane et al. (2002)
Red edge-based transformed chlorophyll absorption in reflectance index/Optimized soil-adjusted vegetation index (TCARI/OSAVI_RE)	$\dfrac{3 \cdot \left[(R_{750} - R_{705}) - 0.2 \cdot (R_{750} - R_{550}) \cdot \left({R_{750}}/{R_{705}}\right)\right]}{1.16 \cdot (R_{750} - R_{705}) / (R_{750} + R_{705} + 0.16)}$	Estimation of N plant uptake at different bandwidths.	Wu et al. (2008)
Red edge-based modified chlorophyll absorption in reflectance index/Optimized soil-adjusted vegetation index (MCARI/OSAVI_RE)	$\dfrac{[(R_{750} - R_{705}) - 0.2 \cdot (R_{750} - R_{550})] \left({R_{750}}/{R_{705}}\right)}{1.16 \cdot (R_{750} - R_{705}) / (R_{750} + R_{705} + 0.16)}$	Estimation of N plant uptake at different bandwidths.	Wu et al. (2008)

Angular Insensitivity Vegetation Index (AIVI)	$\frac{R_{445} \cdot (R_{720} + R_{735}) - R_{573} \cdot (R_{720} - R_{735})}{R_{720} \cdot (R_{573} + R_{445})}$	Stability estimating N at different view zenith angles.	He et al- (2016)

The origin of the vegetation indices is based on basic studies in laboratory or with high spectral resolution field or even with hyperspectral aircraft sensors. Then the bands at high spectral resolution as defined in the Table 1 are referred to bandwidths around 2 nm. Nevertheless, when applied to multispectral sensors they must be resampled and adapted to the bandwidths that range from 15 to 100 nm (Table 2). The performance of the red edge-based indices to predict N content or uptake in plants can be affected by the bandwidth (Li et al., 2014, Shibanda et al., 2015). The transformation of the narrow-band into broad-band red edge-based indices are shown in Table 3 for each of the satellites.

Table 2.- Spectral bands of medium to high resolution sensors including the red edge: MSI on board of Sentinel-2, Rapideye and Worldview-2.

Multi Spectral Instrument (MSI) on Sentinel-2			
Spectral Band	Center Wavelength (nm)	Band width (nm)	Spatial Resolution (m)
B1	443	20	60
B2	490	65	10
B3	560	35	10
B4	665	30	10
B5	705	15	20
B6	740	15	20
B7	783	20	20
B8	842	115	10
B8a	865	20	20
B9	945	20	60
B10	1380	30	60
B11	1610	90	20
B12	2190	180	20
Rapid Eye Bands			
B1	475	35	5
B2	555	35	5
B3	658	28	5
B4	710	20	5
B5	805	45	5
Worldview-2 (at nadir)			
P	627	180	0.46
B1	427	31	1.85
B2	478	36	1.85
B3	546	40	1.85
B4	608	24	1.85
B5	659	35	1.85
B6	724	25	1.85
B7	833	68	1.85
B8	949	93	1.85

Table 3.- Transformation of the narrow-band into broad-band red edge-based indices for each of the satellites selected.

Index	Sentinel-2* *(Clevers & Gitelson, 2013)*	Rapideye *(Ramoelo et al., 2012)*	Worldview-2** *(Li et al, 2014)*
NDRE	${}^{(B7-B5)}/_{(B7+B5)}$	${}^{(B5-B4)}/_{(B5+B4)}$	${}^{(B7-B6)}/_{(B7+B6)}$
CI$_{\text{red edge}}$	$\frac{B7}{B5}-1$	$\frac{B5}{B4}-1$	$\frac{B7}{B6}-1$
MTCI	${}^{(B6-B5)}/_{(B6-B4)}$	${}^{(B5-B4)}/_{(B4-B3)}$	${}^{(B7-B6)}/_{(B6-B5)}$
TCARI/OSAVI	$\frac{3\cdot\left[(B5-B4)-0.2\cdot(B5-B3)\cdot\left({}^{B5}/_{B4}\right)\right]}{{}^{1.16\cdot(B7-B4)}/_{(B7+B4+0.16)}}$	$\frac{3\cdot[(B4-B3)-0.2\cdot(B4-B2)\cdot\left({}^{B4}/_{B3}\right)}{{}^{1.16\cdot(B5-B3)}/_{(B5+B3+0.16)}}$	$\frac{3\cdot\left[(B6-B5)-0.2\cdot(B6-B3)\cdot\left({}^{B6}/_{B5}\right)\right]}{{}^{1.16\cdot(B7-B5)}/_{(B7+B5+0.16)}}$
MCARI/OSAVI	$\frac{[(B5-B4)-0.2\cdot(B5-B3)]\left({}^{B5}/_{B4}\right)}{{}^{1.16\cdot(B7-B4)}/_{(B7+B4+0.16)}}$	$\frac{[(B4-B3)-0.2\cdot(B4-B2)]\left({}^{B4}/_{B3}\right)}{{}^{1.16\cdot(B5-B3)}/_{(B5+B3+0.16)}}$	$\frac{[(B6-B5)-0.2\cdot(B6-B3)]\left({}^{B6}/_{B5}\right)}{{}^{1.16\cdot(B7-B5)}/_{(B7+B5+0.16)}}$
TCARI/OSAVI_RE	$\frac{3\cdot\left[(B6-B5)-0.2\cdot(B6-B3)\cdot\left({}^{B6}/_{B5}\right)\right]}{{}^{1.16\cdot(B6-B5)}/_{(B6+B5+0.16)}}$	$\frac{3\cdot\left[(B5-B4)-0.2\cdot(B5-B2)\cdot\left({}^{B5}/_{B4}\right)\right.}{{}^{1.16\cdot(B7-B6)}/_{(B5+B4+0.16)}}$	$\frac{3\cdot[(B7-B6)-0.2\cdot(B7-B3)\cdot\left({}^{B7}/_{B6}\right)]}{{}^{1.16\cdot(B7-B6)}/_{(B7+B6+0.16)}}$
MCARI/OSAVI_RE	$\frac{[(B6-B5)-0.2\cdot(B6-B3)]\left({}^{B6}/_{B5}\right)}{{}^{1.16\cdot(B6-B5)}/_{(B6+B5+0.16)}}$	$\frac{[(B5-B4)-0.2\cdot(B5-B2)]\left({}^{B5}/_{B4}\right)}{{}^{1.16\cdot(B7-B6)}/_{(B5+B4+0.16)}}$	$\frac{[(B7-B6)-0.2\cdot(B7-B3)]\left({}^{B7}/_{B6}\right)}{{}^{1.16\cdot(B7-B6)}/_{(B7+B6+0.16)}}$
AIVI	$\frac{B1\cdot(B5+B6)-B3\cdot(B5-B6)}{B5\cdot(B3+B1)}$	--	--

*Due to the presence of B5 and B6 in the red edge in Sentinel-2, the B5 can be changed to (B5+B6)/2 in order to use a band centering the transition of the red edge at the wavelength of 720 nm.

**The satellite WV-2 has two bands in the NIR region (B7 and B8), instead of using B7 some authors propose the combination of B7 and B8.

4 Methodology of N Balance

4.1 N fertilization strategy

The farmer usually decides the nitrogen fertilization strategy based on their knowledge and experience, as well as the recommendations provided by the technical advisory entities. It consists of approximately determining the amount of fertilizer (dose), the number of applications (fractionation), type of fertilizer (source) and the application dates (phenological stage).

Based on this strategy, a recommendation and advice for each programmed application will be provided based on the daily balance of N. The Operational N balance of ITAP will be used during the 2016 experimental campaign at pixel scale, in real time, as a first approximation.

4.2 Simplifications and assumptions

The N in the soil is considered as a type of reservoir model, ie, as a reservoir of nutrients intended for use by the plant.

Movement of N, mainly in the form of nitrates, is carried by the convection process of water flow: transporting the mass of N occurs in the fluid displacement of water molecules due to density differences. When they move to a new reservoir, it is assumed that there is an immediate and complete mixing with nitrates previously present in that reservoir (Brisson et al, 1998).

For **transformation processes C / N**, the soil is fully characterized by its content of organic matter (OM). This characterization is used to estimate the rate of potential mineralization of the humified organic matter. The rate of decomposition of waste and the microbial mass depend on the C / N of crop residues, temperature and soil moisture.

Nitrogen uptake is calculated as a comparison between the soil supply and its demand from the crop. Crop demand is the maximum absorption, defined by the regulatory mechanisms of the plant when the supply of nitrogen near the roots is not limited. This is the product of the daily growth rate and the rate of N uptake by the crop during the growing season.

Providing nitrogen by soil – root system is the result of integrating the contribution of each soil horizon considered. The current nitrogen absorption is assumed to be equal to the minimum supply or to the minimum demand. If the N offered by the soil is limiting the demand, then the current absorption is equal to the supply. Otherwise absorption equals demand.

It is important to note that in this nitrogen balance the capillary rise or denitrification losses are not taken into account.

4.3 Nitrogen Balance

The terms of the balance in the root zone are:

$$N_{Mi} = N_{Mi-1+} N_{Wi} + N_{Oi} + N_{Fi} + N_{Li} + N_{Ci} + N_{Di} \qquad (1)$$

where:

N_{Mi}	kg ha^{-1}	mineral nitrogen content in different soil horizons during the period i
N_{Mi-1}	kg ha^{-1}	mineral nitrogen content in different soil horizons during the period i-1
N_{Wi}	kg ha^{-1}	nitrogen provided with irrigation water during the period i
N_{Oi}	kg ha^{-1}	nitrogen mineralized during the period i
N_{Fi}	kg ha^{-1}	nitrogen supplied by fertilization during period i
N_{Li}	kg ha^{-1}	Leaching of nitrates during the period i
N_{Ci}	kg ha^{-1}	Nitrogen uptake during the period i
N_{Di}	kg ha^{-1}	Denitrified nitrogen during the period i

4.3.1 Mineral N in soil

The measurement of soil mineral nitrogen is recommended several times throughout the growing season for improving the accuracy of the model. It is especially recommended at pre-plant, ahead of time in order to allow a recommendation of basal dressing.

$$N_M = \sum_{j=1}^{n} N_{Mj} = 10 \sum_{j=1}^{n} Z_j \cdot d_{aj} \cdot C_j \cdot \left(1 - P_{R_j}\right) \tag{2}$$

where:

N_M	kg ha^{-1}	mineral nitrogen content in different soil horizons
N_{Mj}	kg ha^{-1}	mineral nitrogen in the root zone j
Z_j	m	root depth in zone j
d_{aj}	t m^{-3}	bulk density of the root zone j
C_j	mg N kg^{-1}	mineral nitrogen concentration (nitrate and ammonia) in the root zone j
P_{Rj}	%	stone content in the root zone j

4.3.2 Nitrogen supplied with water during irrigation

The nitrogen supplied in the water during the irrigation period i (N_{Wi}), is worked out by means of the expression:

$$N_{Wi} = 1000 \cdot \frac{14}{64} \cdot C_{Wi} \cdot V_{Wi} \tag{3}$$

where:

N_{Wi}	kg ha^{-1}	nitrogen in water supplied during the irrigation in the period i
C_{Wi}	mg l^{-1}	nitrate concentration in water supplied during irrigation in the period i
V_{Wi}	m^3 ha^{-1}	volume water supplied during the irrigation in the period i

4.3.3 Mineralized Nitrogen

The nitrogen mineralized in the period i (N_{Wi}) is worked out by means of the expression:

$$N_{Oi} = T_i \cdot K_t \cdot \sum K_{h,j} \cdot K_{O,j} \tag{4}$$

where:

N_{Oi}	kg ha^{-1}	mineralized nitrogen during the period i
T_i	°C	average air temperature at 2 m during the period i

K_T	-	mineralization rate coefficient based on soil temperature.
$K_{h,i}$	-	mineralization rate coefficient based on soil moisture at horizon j.
$K_{O,i}$	kg ha^{-1} °C^{-1}	mineralization rate based on the soil organic matter content at horizon j.

4.3.4 Nitrogen supplied during fertilization

The nitrogen provided by the mineral fertilization is subject to a few proper efficiencies of the application of fertilizer (Huggins& Pan, 1993) and of the type of fertilizer (volatilizations, etc). The volatilization has some importance in certain organic contributions and in applications of mineral ammonia fertilizers. In these cases, a common rate is in about 10 kg/ha.

The contributions by the organic N are included in the mineralized N.

The nitrogen supplied by the fertilization in the period i (N_{Fi}) decides by means of the expression:

$$N_{Fi} = \sum_{j=1}^{J} Nfb_{i,j} \cdot EAF_{i,j} \cdot EDNf_{i,j} \tag{5}$$

where:

N_{Fi}	kg ha^{-1}	nitrogen supplied by fertilization in period i
$Nfb_{i,j}$	kg ha^{-1}	gross nitrogen supplied by the fertilizer j during the period i
$EAF_{i,j}$	-	Efficiency in the application of the fertilizer j during the period i
EDNfi,j	-	Efficiency in the availability of N applied by fertilizer j during the period i

4.3.5 Leaching Nitrogen

It starts from the assumption that in saturated soil conditions, all the mineral nitrogen is dissolved in the water. Therefore a volume of percolated water to the sub-root zone will have its estimated concentration of Nmin at that time.

$$N_{Li} = DP_i \cdot C_j \tag{6}$$

donde:

NL_i	kg ha^{-1}	nitrogen leached in period i
DP_i	mm	loss of water from the root zone by deep percolation in the period i
C_j	mg N kg^{-1}	mineral nitrogen concentration (nitrate and ammonia) in the root zone j

The daily value of DP_i will be got from the water balance performed on each pixel (D3.2.2).

4.3.6 Nitrogen uptake

The hypothesis is that the extraction of nutrients by the crop is proportional to the biomass and the concentration of N on it decreases along with its growth and development. The rate of absorption is proportional to the growth stage of the crop.

Nutrient uptake by the crop, therefore, is determined by the biomass estimated by EO depending on the NDVI accumulated up to the balance date. The N dilution curve of each of the species and varietal group provide the expected concentration of N at any given time.

$$N_{Ci} = W_i \cdot C_{Wi} \tag{7}$$

where:

N_{Ci}	kg ha^{-1}	nitrogen uptake by the crop during the period i
W_i	kg ha^{-1}	crop biomass accumulated up to date i and expressed as dry matter.
C_{Wi}	g N/100g^{-1}	nitrogen concentration in the biomass of the culture at day i, expressed as % of dry matter.

4.3.6.1 N dilution curves

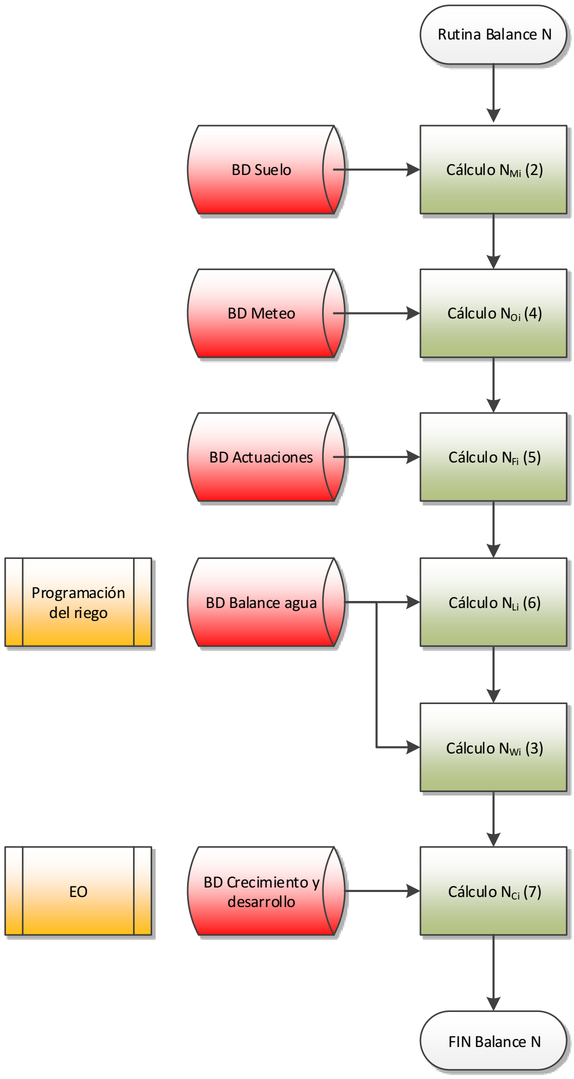
The N dilution curves from Justes et al. (1997) will be applied for wheat (Lemaire, 1997; Justes *et al.*, 1994; Justes *et al.*, 1997). The addition of dilution curves for major crops will be phased in throughout the project.

It would be desirable to check their suitability for each agri-environment, cycles, etc. during the different campaigns and pilot areas of the project.

4.3.7 Denitrified Nitrogen

Under the conditions of cultivation in Castilla La Mancha, in plots with good drainage where no flooding occurs, the determination of the denitrified nitrogen can be neglected. Denitrification is much more important in waterlogged, acidic and cold soils (Howarth *et al.*, 2002).

Figure 3. Diagram of the simplified N balance.



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