Study for the development of a common framework for the quantitative advice of crop nutrient requirements and greenhouse gas emissions and removal assessment at farm level

AGRI-2020-0316 (“FaST Navigator”)

Study report – Annex:

Details of methodology for the nutrient framework

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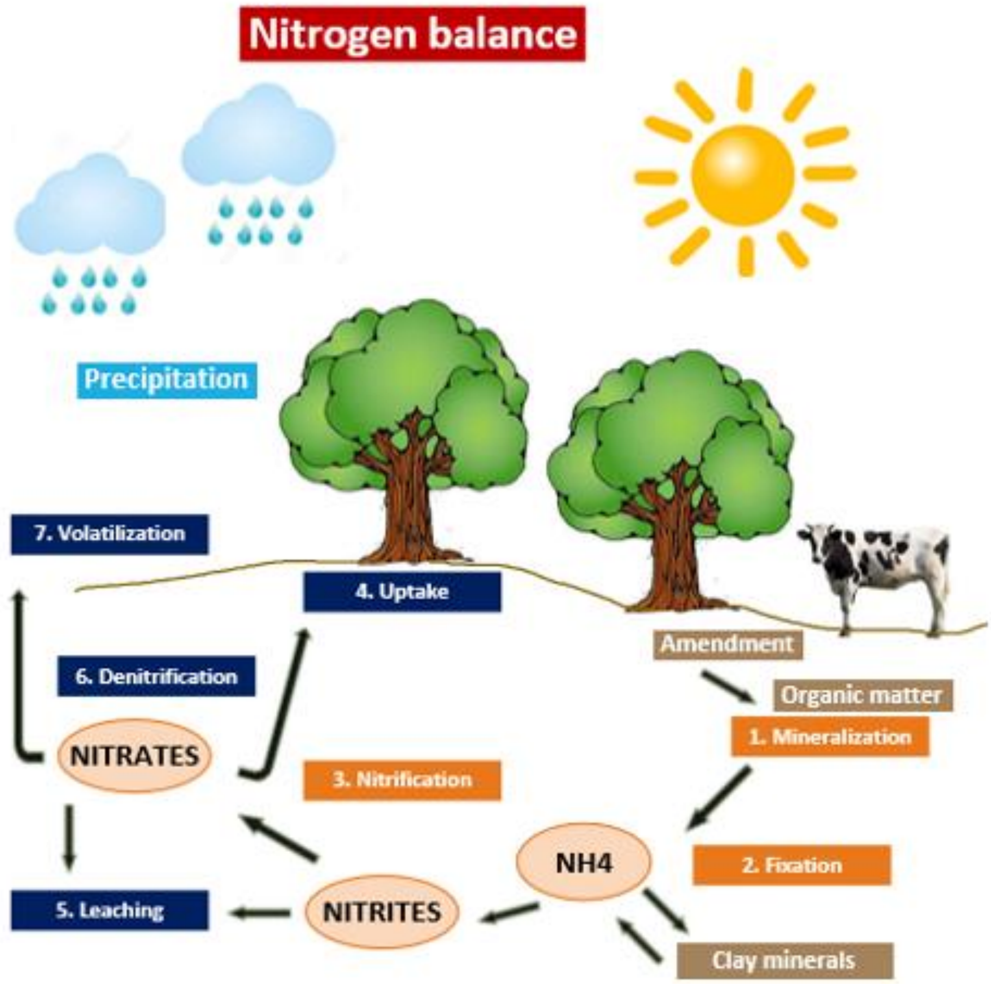
1. NUTRIENT REQUIREMENTS IN FAST NAVIGATOR

The fundamental principle of the nutrient framework is the balance of nutrients. Figure 1 shows a schematic illustration detailing the nitrogen balance, explaining each of the processes mentioned below.



Mineralization	Is the process by which chemicals present in organic matter are descomposed into easily available forms to plants.
Fixation	Nitrogen fixation means the combination of molecular nitrogen with oxygen or hydrogen to obtain oxides or ammonium that can be incorporated into the biosphere.
Uptake	Uptake is a process in which the plants absorbs nitrates from the soil.
Leaching	Nitrate leaching is a naturally process, it occurs when nitrate leaves the soil in drainage water.
Denitrification	Process where nitrate is reduced and produces molecular nitrogen.
Volatilization	Is the transfer of the chemical as a gas through the soil-air interface under environmental conditions.

Figure 1. Nitrogen balance and and a brief description of its component processes.

Nitrogen is an essential nutrient for crops. It is a constituent of proteins, nucleic acids and other intermediate metabolites. If N supply is limiting, crop growth is reduced as well as other important processes like radiation interception and CO2 fixation and more severe N deficiency leads to reduced radiation use efficiency. Therefore, N availability will limit biomass accumulation and yield. There is a range of optimum N concentration, above which excess can cause yield decrease. For example, in indeterminate crops, high N concentration promotes vegetative growth at the expense of reproductive growth which results in a lower harvest rate. Globally, N is the second limiting factor (after water) in crop production.

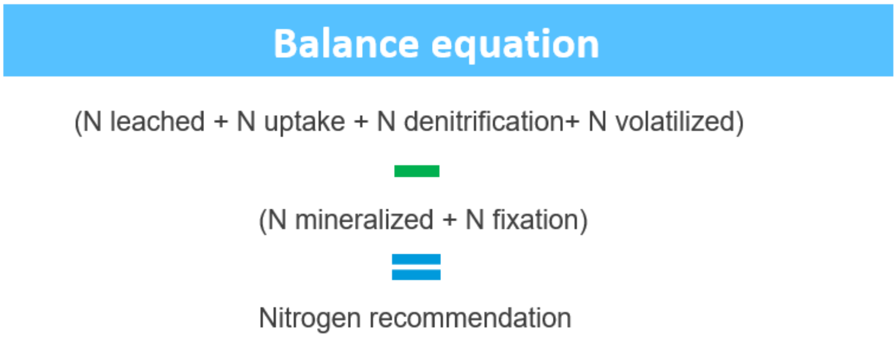


Figure 2. Example of balance equation in F3 tool.

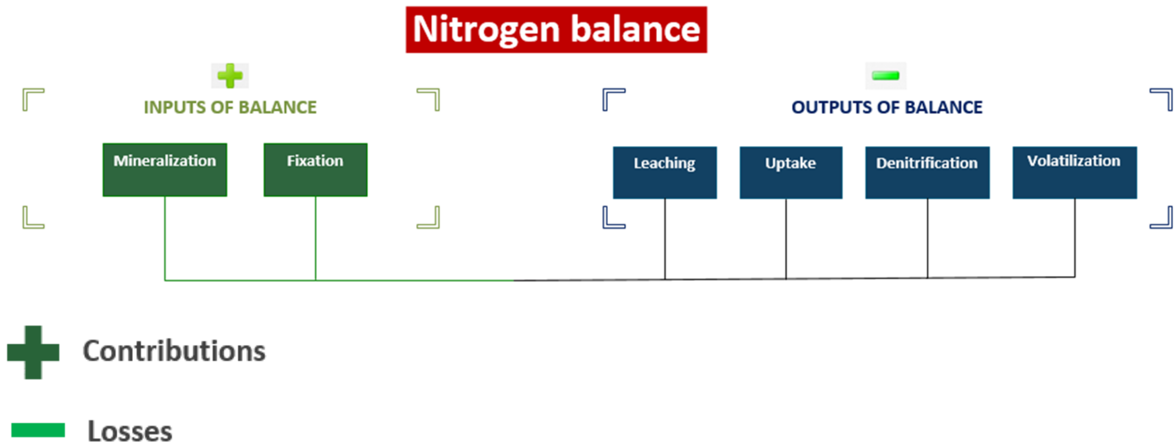


Figure 3. Functioning of the inputs and outputs within the nitrogen balance.

The framework is the principle of nutrient balance, the different elements of the balance are identified and quantified.

The main different between the different lines in Fast tool is the time-scale used in the analysis and the input data.

In line F1, the nutrient balance is implemented at daily scale, together with a daily water balance and using NDVI values for this purpose.

In addition, the algorithm implemented allows the selection of the best fertiliser and can be forced to use the fertilizer decided by the user.

In line F2, the nutrient balance is implemented also at daily scale, together with a daily water balance and the algorithm implemented of the best fertilizer.

In line F3 the nutrient balance is implemented at seasional scale and the algorithm implemented allows the selection of the best fertilizer.

Finally, in line 4 the nutrient balance is implemented at seasonal scale but with a more simplified balance that involves less inputs to be introduced by the user.

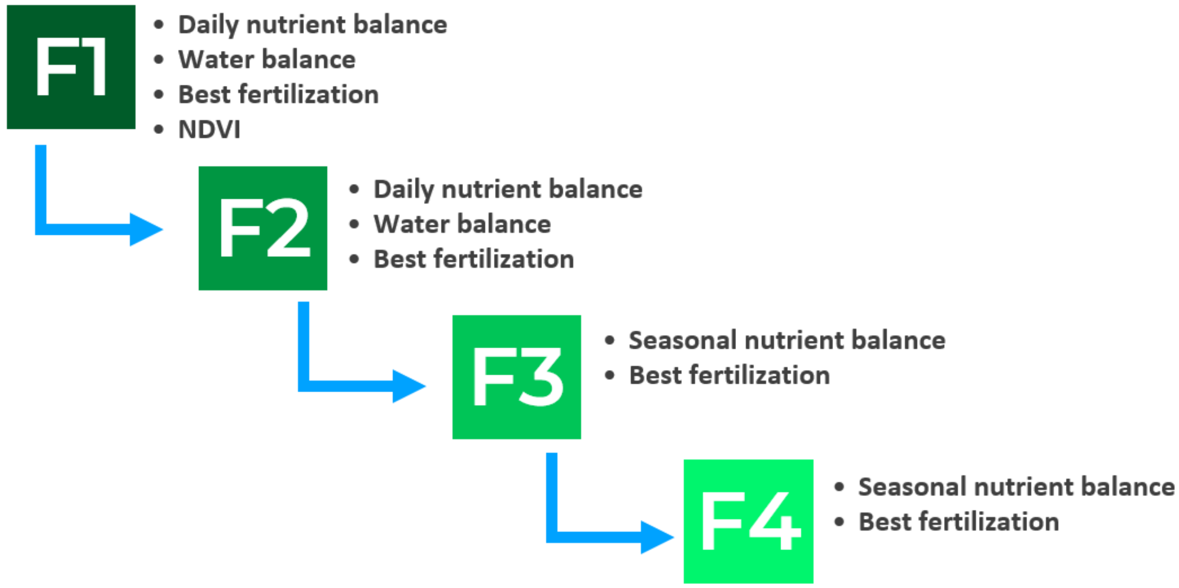


Figure 4. Different lines in the study of Fast Navigator.

In F1-F2 the amount of fertiliser recommended for fertilisation is calculated to prevent the concentration in the soil from falling below a certain threshold (N limit) during the next period, i.e. from the planned fertilisation date to the next fertilisation date.

In F3-F4 the amount of fertiliser is calculated through the best fertiliser block where techno-economic characteristics such as price, fertiliser efficiency, i.e. the percentage of losses associated with each fertiliser and the 25% urea N limitations are involved.

The following chapters focus on each of the processes in the nitrogen balance.

2. NITROGEN UPTAKE

N uptake parallels biomass accumulation and therefore shows a typical sigmoid curve with an initial exponential increase followed by a rapid linear accumulation phase. N concentrations in the different organs are high when plants are young and decrease with age. Therefore, the crop response to N depends not only on the amount absorbed, but also on the translocation capacity to the growing organs (and finally to the grain or harvestable part). The relationship between yield and N uptake is generally linear until maximum yield is reached. After that point, if N is available in the soil, uptake continues, but does not result in higher yields. This limit depends on environmental conditions and crop management. It is therefore calculated considering crop yield, crop type, crop proportion and other residues.

4.1 Models selected for the simulation of the process

Tools F1-F2

In the F1-F2 tools, nitrogen absorption process was implemented in the same way as it has been implemented in the AGROasesor platform. The AGROasesor platform has been a pioneer system in integrating very powerful decision support tools, especially in irrigation and fertilization, performing daily balances of nutrient and water needs in each plot.

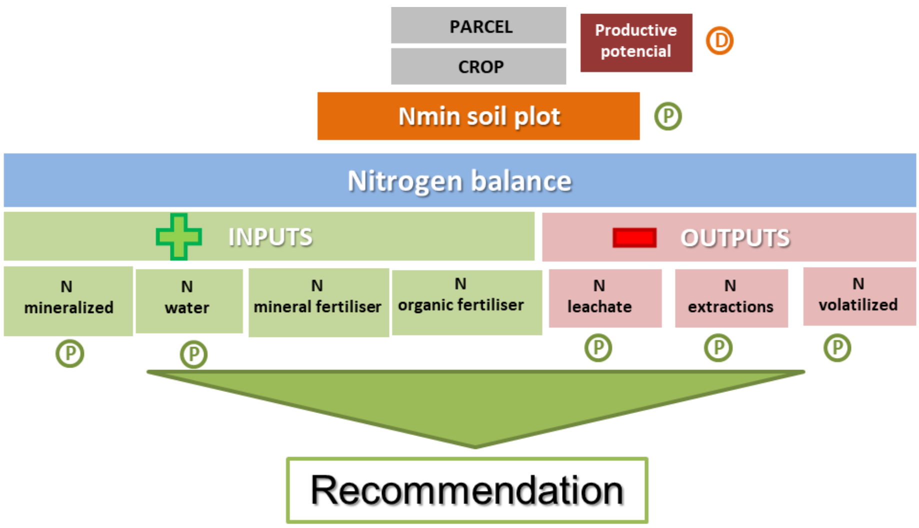


Figure 5. Simplified AGROasesor Nitrogen Balance Model.

For this model, the main parameters considered are:

→ Phenological characteristics.

→ Coefficient kg N per ton produced.

→ Rate of extractions per period.

The model uses a simulation of the phenological cycle of each crop in each season and plot. It is a model based on the calculation of the thermal integral, with real data of the campaign until the date of consultation and historical data until the end of the cycle.

In addition:

→ Potential yield of crops in the specific plot.

→ Daily climatic and meteorological data (Tª med, precipitation, potential evapotranspiration).

The tool provides different N extractions at each phenological stage.

On the platform, the user can enter the observed phenology of his crop indicating the approximate date of the observation. As a minimum, the user must enter the following most representative phenological stages in the observed phenology file: 09, 22, 39, 55, 89.

If the user does not have phenology information, the typical default phenology is used. This phenological stage can be estimated using the thermal integrated calculated (see where:

→ Tmed: average temperature of the day calculated in degrees centigrade.

→ IT: thermal integral is defined as the cumulative temperature required to complete a phenological stage.

→ Tbasemin: is the temperature at which development of the crop stops due to cold.

→ Tbasemax: is the temperature which development of the crop slows down.

Table 2). It is only found on the indicated crops:

- → Barley 2 row
- → Barley 6 row
- → Corn
- → Maize
- → Wheat-Bread-Hard type
- → Wheat-Bread-Soft type
- → Garlic
- → Maize

If the user selects one of these crops it is not necessary to enter the observed phenology file.

Once the phenology is known, a percentage of extractions is associated with each of these phenological stages. Then we will calculate and divide these extractions on a daily basis in the determined phenological period.

From this data, daily extractions will be calculated following the formula described below:

Model equation:

N extracted per day = Total extraction (kg/ha) * N extraction rate (%) / 100

where:

- → Total extraction (kg/ha): dry matter of grain in uptake process *potential yield * N concentration in crop (harvest and residual). Corresponds to the same calculation process as in tools F3-F4:

  Model equation:

  Total extraction (kg/ha) = (h_dm*Nc_h + r_dm*Nc_r)*(1+fnr)

  where:

  - → N extracted: total uptake Nitrogen.
  - → h_dm: dry matter of grain in uptake process.
  - → Nc_h: N concentration in harvested part.
  - → r_dm_med: dry matter of part residual in the uptake process.
  - → Nc_r: N concentration in residual part. Nitrogen concentration in the residue.
  - → fnr: ratio of N in roots / N in shoots. Default value of 0.1.

- → Potential yield is provided by the user and depends on the characteristics of the plot and the usual agro-climatic conditions. It is recommended to enter the value of the average of the three best yields for that plot with that crop.
- → N extractions rate (%): percentage of extractions associated with phenology. Indicates in which periods of the cycle there are more or less percentage of extractions.

Table 1. N extractions rate associated with each BBCH.

BBCH	N extraction rate (%)
0	0,0%

9	0,0%
11	3,4%
12	3,2%
13	3,0%
22	5,0%
31	20,0%
39	20,0%
49	8,0%
51	5,0%
55	5,8%
59	4,0%
65	4,9%
71	6,8%
75	7,0%
83	1,0%
85	1,0%
87	1,0%
89	1,0%

The thermal integral (IT) is calculated using the daily average temperature (Tmed in ºC) and the calculation starts from the date of sowing.

Model equation:

IF Tmed(day)= no data ; IT(day) =0.

IF Tmed(day)< Tbasemin(crop); IT(day)= IT(day-1)+ Tbasemin .

IF Tmed(day)> Tbasemax(crop); IT(day)= IT(day-1)+ Tbasemax .

IF Tmed(day)> Tbasemin and < Tbasemax; IT(day)= Tmed(day)+ IT(day-1)

where:

→ Tmed: average temperature of the day calculated in degrees centigrade.

→ IT: thermal integral is defined as the cumulative temperature required to complete a phenological stage.

→ Tbasemin: is the temperature at which development of the crop stops due to cold.

→ Tbasemax: is the temperature which development of the crop slows down.

Table 2. Example of thermal integrals calculated based on different crops.

Crop type	BBCH 09	BBCH 22	BBCH 39	BBCH 55	BBCH 89
BARLEY_2_ROW	153	350	896	1100	1811
BARLEY_6_ROW	153	350	896	1100	1811
WHEAT_BREAD_SOFT	150	355	1004	1257	2015
WHEAT_BREAD_HARD	150	355	1004	1257	2015
CORN_GRAIN	205	454	1220	1415	2510
MAIZE_SILAGE	205	454	1220	1415	2510
GARLIC	202	453	702	1100	1254

Sowing date	17/12/2021	Estimated date BBCHS	Days since sowing date
BBCH 09	150	17/01/2022	31
BBCH 22	355	20/02/2022	65
BBCH 39	1004	26/04/2022	130
BBCH 55	1257	13/05/2022	147
BBCH 89	2015	21/06/2022	186
Tbasemin	0		
Tbasemax	25		
Crop_type	WHEAT_BREAD_SOFT		

Figure 6. Example of a thermal integral calculation for a wheat.

An example of the different BBCHs will be shown for the case of a barley, so that the user can learn to identify them (images provided by the AGROasesor platform).

Figure 7. BBCH 09 in barley.

Figure 8. BBCH 22 in barley.

Figure 9. BBCH 39 in barley.

Figure 10. BBCH 55 in barley (50% of spikes).

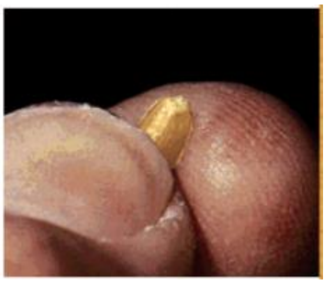


Figure 11. BBCH 89 in barley (grain difficult to split with the thumbnail).

Tools F3-F4

N uptake is estimated considering the crop production, the type of crop, the harvestable part and other residues.

The methodology used in F3-F4 for the absorption process is based on the Fertilicalc model. Fertilicalc is an application for calculating nutrient and fertilizer requirements with data for 150 crops. The conceptual methodology is described in the book “Principles of Agronomy for Sustainable Agriculture” (https://link.springer.com/book/10.1007/978-3-319-46116-8).

The following equation describe the calculations implemented in the F3-F4 tools for the assessment of nitrogen uptake:

Model equation:

N extracted = (h_dm*Nc_h + r_dm*Nc_r)*(1+fnr)

where:

- → N extracted: total uptake Nitrogen.
- → h_dm: dry matter of grain in uptake process.
- → Nc_h: N concentration in harvested part.
- → r_dm_med: dry matter of part residual in the uptake process.
- → Nc_r: N concentration in residual part. Nitrogen concentration in the residue.
- → fnr: ratio of N in roots / N in shoots. Default value of 0.1.

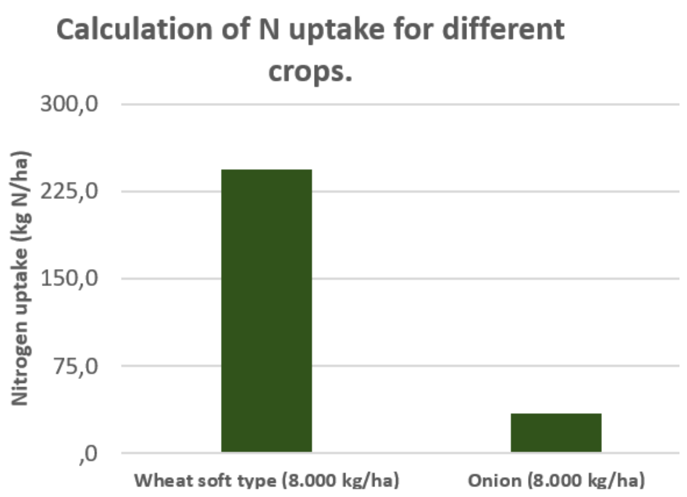


Figure 12. Example of a calculation of N uptake for differents crops in F3 tool.

5 NITROGEN VOLATILIZATION

Ammonium ion in solution is in equilibrium with ammonia (NH3) which is volatile. Ammonia volatilization occurs naturally in soils, but at a slow rate. However, the application of nitrogen fertilizers increases the losses by volatilization depending on the type of fertilizer, the application method, the cation exchange capacity, and climatic factors. The risk of volatilization is generaly higher for the surface application of organic fertilizers since a relevant fraction of nitrogen is in the form of ammonium.

Implementing this process in the FaST Navigator is important from the perspective of the nutrient balance, due to the importance of these emmissions for the N balance and could contribute to create awareness in the end users about the risk of emmissions.

The tool has the functionality to determine the best fertilizer for the user considering the losses produced by this process in addition to other economic-technical criteria.

5.1 Model used for the simulation of the process

Tools F1-F2-F3-F4.

Volatilization is a percentage of the fertilizer applied. Its actual value depends on the fertilizer used, the method of application and soil properties.

The model implemented in the four levels of precision is the one described by FAO. The model works at seasonal scale. The main limitation of the model is the temporal scale that does not allow to distinguish the effect of specific practices implemented at field scale.

The calculation of the kilograms of Nitrogen volatilized (N volatilization) consists of the multiplication of Nitrogen applied by the percentage of vol_losses.

Vol_losses is a percentage calculated by raising to the exponent the sum of the factors associated with certain characteristics of the crop such as pH, CEC, type of fertiliser, whether it is dry or irrigated, the type of climate, the method of application of the fertiliser... The function used is Excel's EXP which returns the constant e raised to the power of the number argument.

The factors selected for the regression analysis were crop type, fertilizer type and application mode, temperature, soil pH and CEC. Table 3 presents the summary of the parameters set for the different classes of factors in the resulting model. The influence of carbon content and soil texture on NH3 volatilization rates is assumed to be included in the CEC factor. The calculations are implemented as follow:

Model equations:

N volatilization= vol_losses (%)* N application of fertilizer (N_brut) (kg N/ha)

vol_losses = exponential of (type_f+ application method) * vol_coeff

vol_coeff = exponential of (factor of water supply + soil pH+ CEC soil+climate factor)

where:

- → N volatisation: Volatilisaiton of nitrogen (kg N/ha). It consists of the multiplication of the total percentage of losses according to the factors described above by the amount of gross nitrogen that is received in the fertilisation applications. Thus, the result will be the amount of nitrogen that is volatilized in kg N/ha.
- → Vol_losses: percentage of losses characterised by a factor associated with the type of fertiliser and its application method. (%).
- → Vol_coeff: percentage of lossess characterised by a factor associated with whether it is rainfed or irrigated, the pH of the soil, its CEC, and a factor associated with temperate climate. (%).

→ Fertilizer type (type_f): different coefficients are applied depending on the type of fertilizer selected.

→ Application method of fertilizer: the model implemented distinguish between top dressing or incorporated.

→ Factor of water supply: factor depends on whether it is rainfed or irrigated.

→ Soil pH: pH of the soil.

→ Soil CEC: Cation exchange capacity.

→ Climate: coefficient based on climatic conditions (only for template weather conditions).

Table 3. Values of the factors in the linear regression model of Volatilization.

	Factor values
Water supply	
Rainfed	-0,045
Irrigated	0
pH	
pH≤5,5	-1,072
5,5<pH≤7,3	-0,933
7,3<pH≤8,5	-0,608
pH>8.5	0
CEC	
CEC≤16	0,088
16<CEC≤24	0,012
24<CEC≤32	0,163
CEC>32	0
Climate	
Temperate climate	-0,402
Tropical climate (not consider)	0
Application method	
Incorporated	-1,895
Top dressing	-1,305

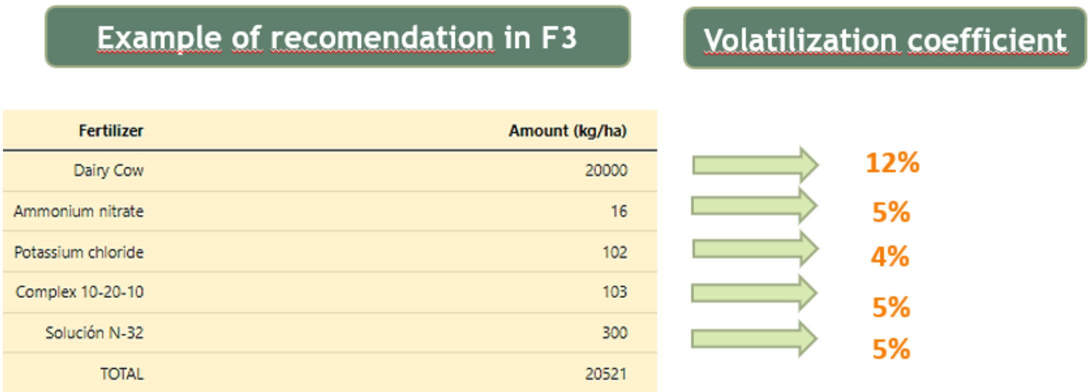


Figure 13. Example of a calculation of volatilization coefficient in F3 tool.

6 NITROGEN DENITRIFICATION

In anaerobic or waterlogged environments, denitrification, and dissimilatory nitrate reduction to ammonium (DNRA) are the two major pathways by which NO2- and NO3- formed by nitrification can be subsequently reduced. Facultatively anaerobic bacteria perform these N transformations, although it has been suggested that some fungi are also capable of denitrification.

Denitrification is but the reduction of nitrate into volatile N compounds and is the major reductive fate of NO3- in most soil environments. It is a respiratory process in which nitrogen oxides are used as terminal electron acceptors in place of O2 and produces gas as the terminal reduction product. Denitrification is a multistep process catalyzed by distinct enzymes for each step.

When the availability of oxygen in the soil is reduced due to high water content, soil compaction or application of easily decomposable organic matter, the rate of denitrification increases. Anaerobic microzones still containing a source of labile carbon appear and many microorganisms (mainly bacteria such as Pseudomonas, Bacillus and Paracoccus, but also some fungi) are able to use NO3 -or NO2- as oxidizing agents releasing gaseous forms of N into the atmosphere:

$$NO_3^- \xrightarrow{\text{Nitrate reductase}} NO_2^- \xrightarrow{\text{Nitrite reductase}} NO \xrightarrow{\text{Nitric oxide reductase}} N_2O \xrightarrow{\text{Nitrous oxide reductase}} N_2$$

Incomplete reduction favours the emission of N2O, a very reactive gas. The reaction is very fast and peaks of N2O emission are observed after the application of organic or synthetic fertilizers. Denitrification was previously considered exclusive of waterlogging conditions, but it is nowdays recognized as a major pathway for N losses to the atmosphere under a wide range of environmental conditions.

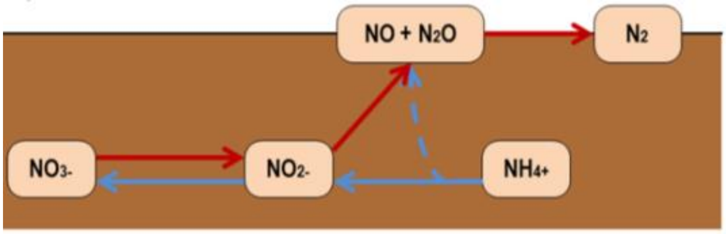


Figure 14. Image of the denitrification process represented by red arrows.

6.1 *Model used for the simulation of the process*

Tools F1-F2-F3-F4

Denitrification depends on the amount of fertiliser application and is simulated following an exponential fan as shown below.

Stehfest and Bouwman (2006) compiled and analyzed the results of 1008 publications reporting measured N2O fluxes measured in agricultural soils. The database (http://www.mnp.nl/images/stehfest_data_tcm61-29733.xls) shows daily fluxes ranging from -2 gN/ha/d to 5400 gN/ha/d, both of which were obtained under temperate temperate climate. The meta-analysis of this database indicates that the factors that significantly influence the intensity of N2O emissions are agronomic practices (nitrogen fertilization, type of crop and form of fertilizers) and soil characteristics (organic carbon content, pH and texture). At the global scale, Stehfest and Bouwman (2006) have validated a linear relationship between flux intensity (kgN-N2O/ha/yr) and the amount of N applied to the plot (kgN/ha/yr), which will be used in the future as a reference value in the methodology for calculating N2O emissions at the national scale proposed by the IPCC.

Other authors, European (van Groenigen et al., 2010) or American (Millar et al., 2010), show a non-linear increase in N2O emissions with fertilizer inputs. These authors have proposed quantitative relationships between the quantities of mineral N applied and N2O emissions.

These functions from the international literature were compared with actual data of N2O emissions from measurements in France 1 as a function of the amount of N applied (Figure 15).

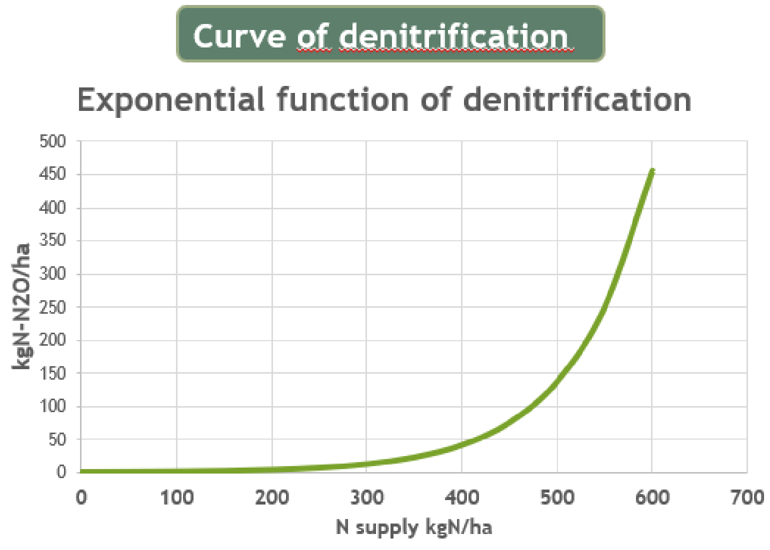


Figure 15. Exponential function of denitrification.

Overall, they fall within the range proposed by different functions by different functions in the literature, in particular the function proposed by van Groenigen et al. (2010) (low limit) and the function proposed by Millar et al. (2010) (high limit). These functions are exponentials, and this form of relationship has also recently retained in the work of Philibert et al. (2012). We therefore implemented in the tool the function resulting from this meta-analysis:

Model equation:
Deni_loss (NO2) = 0.34*e ^ (0.012* N application of fertilizer (kg N/ha).

where:

→ Deni_loss is denitrification losses in the application of fertilization (kg N/ha).

→ N application is the Nitrogen applied from the fertilization (kg N/ha).

1 https://www.inrae.fr/sites/default/files/pdf/fca5a7a52c8f363553b99654d5bae121.pdf

Table 4. Example of values of Deni_loss.

N application (kg N /ha)	Deni_loss (NO_2)
0	0
50	1
100	1
150	2
200	4
250	7
300	12
350	23
400	41
450	75
500	137
550	250
600	455

7 NITROGEN LEACHING

Nitrate leaching is a natural process, it occurs when nitrates leave the soil in drainage water. The consequences of N losses from agricultural systems to water bodies are a major societal concern in developed countries, with particular attention to nitrate contamination of aquifers and excessive N availability in lakes and estuaries.

7.1 Model used for the simulation of the process

Tools F1-F2

For tools F1-F2 the model based on the AGROasesor tool has been implemented. The leaching module includes nitrogen losses to the soil due to deep percolation following precipitation and irrigation events. The potential contribution of runoff and erosion to N losses are not considered in the models implemented. The leaching process is calculated for the profile (0-30 cm).

The tool implements a soil water balance at daily scale for the lines F1 and F2. The water balance considers crop evapotranspiration (ETP), precipitation (P), irrigation (I) and soil water holding capacity. This balance can be implemented usiong tabulated values of crop coefficient (Kc) or crop coefficients derived from remote sensing earth observation satellites.

Nitrogen leached is calculated on daily basis and based on the water drained through the soil, considering the water holding capacity of the soil.

Model equation:

Daily N leaching = -DP* NO3 (ppm)

where:

→ Daily N leaching: amount of nitrogen leached per day.

→ DP: water deep percolation, water drained bellow the soil layer considered (mm)

→ NO3: Nitrate soil concentration (ppm).

Model equation:

IF N mineral soil < 0 ; NO3 (ppm) = **0.**

NO3 (ppm): N mineral soil * 1000000/ (depth_f1*100*100*100* density_s *1000* (1-Stony (ratio) * (1+ N_NH4)).

where:

→ N mineral soil: total amount of nitrogen available in the soil (kg N/ha).

→ N_NH4 : this is the ratio between N and NH4 in the soil test data provided by a laboratory. It would be 20% if we do not have Ammoniacal Nitrogen data in our soil analysis, in the case of having both data, both Nitric Nitrogen and Ammoniacal Nitrogen would be the quotient between both expressed as a percentage.

→ depth_f1: depth of soil. In the tool it is parameterised with a value of 0.3 metres but the user can change it.

→ density_s: bulk density (associated in soil_texture).

→ Stony (ratio): corresponds to the stoniness of the soil, normally a default value of 0.15 is set, but it can be modified by the user.

Tools F3-F4

The model implemented for the F3.F4 tools is from the book "The Principles of Agronomy for Sustainable Agriculture" (https://link.springer.com/book/10.1007/978-3-319-46116-8). This model calculates the Nitrogen leached depending on the agro-climatic zones, seasonal rainfall, annual rainfall, and soil characteristics such as soil drainage.

The model implemented in the tool includes the associations between these soil characteristics and soil textures. In addition, the annual rainfall and seasons have been parameterized with the agro-climatic zones of the study establishing 5 different zones. The user can modify all the parameterisations made in the study. The calculations involved in the implementation of this model are detailed below.

Details of this classification attending to the potential runoff potential:

→ Group A is sand, loamy sand or sandy loam types of soils. It has low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sands or gravels and have a high rate of water transmission.

→ Group B is silt loam or loam. It has a moderate infiltration rate when thoroughly wetted and consists chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.

→ Group C soils are sandy clay loam. They have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine structure.

→ Group D soils are clay loam, silty clay loam, sandy clay, silty clay or clay. This HSG has the highest runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface and shallow soils over nearly impervious material.

The tool evaluates the risk of leaching through the leaching Index (LI, in mm) which is an estimate of the amount of percolation below a soil depth of 1 m and was proposed by the USDA (Williams and Kissel 1991).

Figure 16. Agro-climates zones in F3 tool.

Model equation:

N leached = N init* (1-exp(-LI/ Z * Θmean))

where:

- → N leached: N losses by leaching (kg N/ha).
- → Ninit: initial N content (kg N/ha).
- → LI: leaching Index.
- → Z: soil depth (mm).
- → Θmean: average water content in the soil (m3m-3).

Model equation of leaching index:

LI= PI*SI

where:

- → PI: percolation Index.
- → SI: seasonal Index.

Model equation of percolation index:

IF P-10160/CN' + 101.6 > 0.

PI= $(P-10160/CN' +101.6)^2/ (P+15240/ CN'-152.4)$

where:

- → P: annual rainfall (mm).
- → CN': curve number with values for hydrologic groups A, B, C and D, respectively.If the condition stated is not met then PI=0.

Model equation of seasonal index:

$$SI = (2 * P_W/P)^{1/3}$$

where:

→ Pw: total rainfall (mm) during autumn and winter (1 October-31 March in N latitudes, 1 April-30 September in S latitudes).

→ P: annual rainfall (mm).

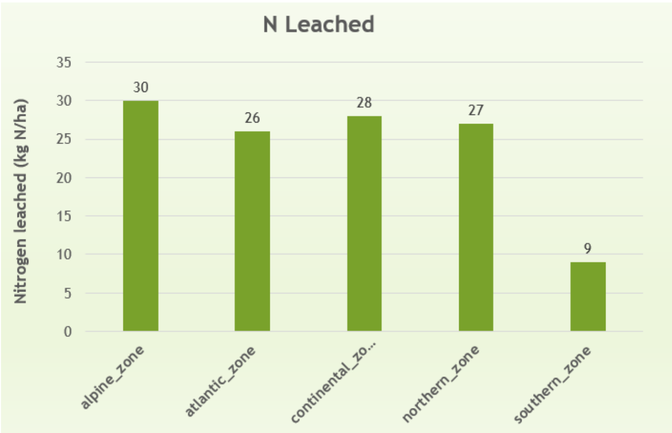


Figure 17. Calculation of N leached as a function of the different agro-climatic zones of the study.

Some of the parameters used in the leaching process have been associated with soil texture. A table showing the different associations is shown below. Average Θmean values are taken for each soil texture.

Table 5. Associations of parameters in the leaching process.

Soil texture	Hydrologic soil groups (CN')	Rate of drainage	θFC – θWP Θmean		
			Min	**Max**	**Prom**
Sand	A	Very high	0,05	0,11	**0,08**
Loamy sand	A	Very high	0,06	0,12	**0,09**
Sandy loam	B	High	0,11	0,15	**0,12**
Loam	B	High	0,13	0,18	**0,13**
Silty loam	C	Medium	0,13	0,19	**0,14**
Silt	C	Medium	0,16	0,2	**0,15**
Clay loam	C	Medium	0,06	0,12	**0,14**
Sandy clay loam	D	Medium	0,06	0,12	**0,13**
Silty clay loam	D	Low	0,13	0,18	**0,13**
Sandy clay	D	Low	0,06	0,12	**0,15**
Silty clay	D	Low	0,13	0,19	**0,13**
Clay	D	Very low	0,12	0,2	**0,14**

8 NITROGEN MINERALIZATION

Mineralization is the process by which chemicals present in organic matter are decomposed into easily available forms of N uptaked by plants.

8.1 Model used for the simulation of the process

F1-F2 tools

The model implemented in these lines were based on AGROasesor and calculates mineralization process at daily scale. The variables used in the calculation includes crop evapotranspiration, precipitation, irrigation, average temperature, soil water retention capacity and crop management (rainfed/irrigation). The model implemented distinguish between mineralization of soil organis matter (MO) and or organic ammendments (e.g., organic fertilisers). The models implemented are presented in the following equations.

Mineralization of soil organic matter:

Mineralisation is the transformation of soil organic matter through a process that leads to the formation of mineral salts, in which the fertilising elements are assimilated by plants.

Model equation:

Daily Mine N = coeff_mine * Nc_mine * slowing_mine (%)* Coef_red

where:

→ Daily Mine N: daily mineralized N (kg N/ha).

→ coeff_mine: mineralization coeffcieint based on SOM. The values used are tabulated and depend on the soil organic matter in (kg N/ha).

→ Nc_mine: mineralization coefficient based on daily average temperature. The values used are tabulated and depend on the daily average temperature.

→ Slowing mine: additional coefficient included to reduce the mineralization process, an initial value of 0.1 was included based on the experience. This coefficient is applied when the daily extractions of the crop have a value of 0.

→ Coef_red: additional coefficient included to reduce the mineralization process. (Value : 0.5).

Table 6. Mineralization coefficient used for soil depth lower than 0.3 m.

Classification of soil mineralization	Soil Organic Matter	Mineralization Coefficient
High	SOM >2,5 %.	0.22
Medium	2,5% >= SOM >=1 %.	0.1
Low	SOM < 1 %.	0.07

Table 7. Mineralization coefficient based on daily average temperature.

T med (ºC)	Nc_mine
Tmed >19,	Nc_mine =1.0 * Tmed
19> Tmed >18,	Nc_mine =0.9 * Tmed
18> Tmed >17,	Nc_mine =0.8 * Tmed
17> Tmed >16,	Nc_mine =0.7 * Tmed
16> Tmed >15,	Nc_mine =0.6 * Tmed
15> Tmed >14,	Nc_mine =0.4 * Tmed
14> Tmed >13,	Nc_mine =0.3 * Tmed
Tmed<=13,	Nc_mine =0

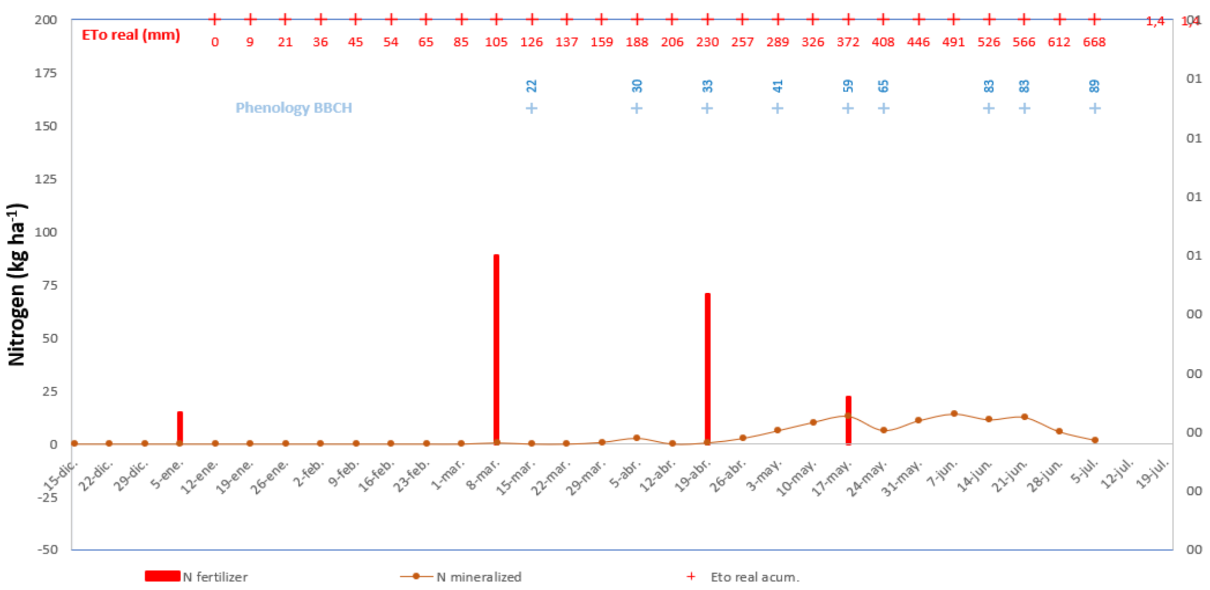


Figure 18. Example of the trajectory of mineralisation in F1-F2.

Mineralization of organic amendments:

Model equation:

Daily Mine O = (Coef_b * (Dfin - Dini) + Coef_a * (- Dappl * Ln (Dfin - Dappl) + Dappl * Ln (Dini - Dappl) - Dini * Ln (Dini - Dappl) + Dfin * Ln (Dfin - Dappl) + Dini - Dfin)) * N_fin / 100

where:

→ Daily Mine O: daily mineralized N from organic amendments (kg N/ha)

→ Coef_b: mineralization coefficient.

→ Dfin - Dini: days between the application of organic amendments. This process is carried out on a daily basis, so Dfin - Dini is equal to 3 since Dini is the day after the consultation and Dfin is the day before. It is carried out on a daily basis so, the consultation day would be the current day, the initial day would be the day before the consultation date and the final day would be the day following the present day or consultation day.

→ Coef_a: diluition coefficient based on the diluition curve of the different organic amendments.

→ Dappl: date of the application of the organic amendment. For daily balances Dappl is the date of the consultation (calculation).The consultation day is the day that is considered present in the daily balance sheet, i.e. current day.

→ N_fin: net quantity of N applied in the soil with the organic amendment.

Table 8. Coefficients for assessment of mineralization of organis amendments.

Type of fertilizer	Coef a	Coef b	Type of fertilizer	Coef a	Coef b
Cow manure	-0,042	0,3354	Poultry Broiler	-0,083	0,5893
Dairy Cow	-0,042	0,3354	Poultry Turkey	-0,083	0,5893
Dairy Heifer	-0,042	0,3354	Poultry Duck	-0,083	0,5893
Beef Cow	-0,042	0,3354	Poultry Goose	-0,083	0,5893
Beef Feeder	-0,042	0,3354	Other Horse	-0,083	0,5893
Beef Stocker	-0,042	0,3354	Other Sheep	-0,042	0,3354
Swine Manure	-0,133	0,9055	Other Goat	-0,042	0,3354
Swine Finishing	-0,133	0,9055	Other Rabbit	-0,18	1,196
Swine Growing	-0,133	0,9055	Digestato	-0,18	1,196
Swine Nursery	-0,133	0,9055	Sludge EDAR	-0,083	0,5893
Swine Gestating sow	-0,133	0,9055	Poultry slurry	-0,18	1,196
Swine Sow and litter	-0,133	0,9055	Rabbit slurry	-0,18	1,196
Poultry Manure	-0,083	0,5893	Pig slurry	-0,18	1,196
Poultry Layer	-0,083	0,5893	Cattle slurry	-0,180	1,196

Tools F3-F4

The mineralization model for these lines (F3-F4) was based on the CARM model. In this case, the model considers soil organic matter, humidity and soil texture. The calculation procedure uses actual data of soil organic matter and inputs of organic amendments while the effect of the other components is considered through different parameters.

Model equation:

Nc mine SOM = N mine (kg N/ha)* humidity factor

where:

→ Nc mine SOM: daily mineralized N from organic matter in the soil (kg N/ha)

→ N mine: mineralisation of organic matter considering the actual soil content and soil texture.

→ Humidity factor: reduction coefficient based on the agroclimatic zone.

Table 9. Mineralisation of organic matter considering the actual soil content and soil texture (kg N /ha).

		Textures of soil		
Interval	**SOM (%)**	**Sand**	**Loam**	**Clay**
0-0.5	0	13	10	8
0.5-1	0.5	25	20	15
1-1.5	1	38	30	23
1.5-2	1.5	50	40	30
2-2.5	2	68	50	38
>2.5	2.5	83	65	50

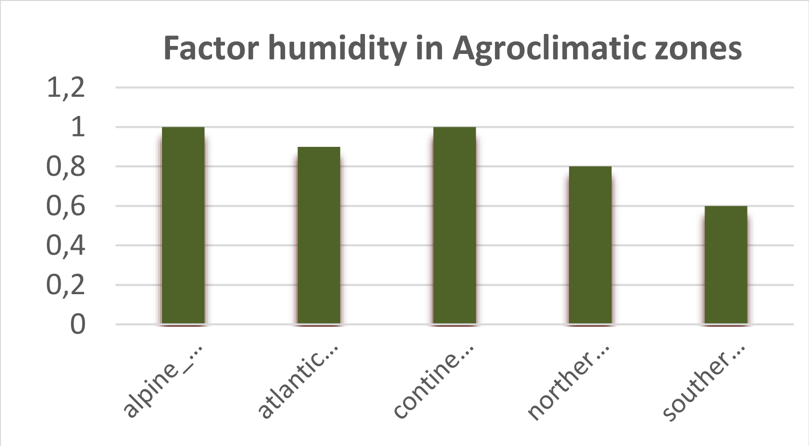


Figure 19. Different wetting factors for each agro-climatic zone.

9 CALCULATION OF NITROGEN IN IRRIGATION WATER

It consists of the additional N provided with the irrigation water. This contribution could be relevant in areas with high N contents in the water.

Model equation:

Irrigation N input = net irrigation applied * N water content (14/(100*62))

where:

→ Irrigation N input: additional input of N from irrigation water (kg N/ha)

→ Net irrigation applied: net irrigation dose. Irrigation perceived in the crop during its cycle.

→ N water content: NO3 (ppm) entered by the end user.

10 NITRIFICATION

Nitrification is an aerobic formation of nitrates from organic matter and depends on climatic conditions and is simulated in the proposed models considering agro-climatic zones. In general, Northern and colder areas lead to higher nitrification. Nitrification is one of the most important processes in the transformation of nitrogen (N) in the soil. nitrogen (N) in the soil. Through this process, the ammonium ($NH4$ +), coming from the mineralisation of organic matter or applied fertiliser, is rapidly transformed into nitrate ($NO3$). rapidly into nitrate ($NO3$-) by nitrifying micro-organisms.

This process does not involve either inputs or outputs in the nitrogen cycle since it is the transformation of N compounds. It has only been considered in the F1-F2 tools as part of the assessment of mineralization. The values considered in this work are presented in the Table 10. The nitrification process is related to the elimination of the bacteria that are responsible for the oxidation of nitrite to nitrate. This will depend on certain agro-climatic characteristics. Therefore, in the Fast Navigator study for F1-F2 tools, these conditions were used as a starting point and a period of days was established in which we estimate that this nitrification takes place. The process being more significant in higher areas than in lower areas. In Spain it could be considered a process that has little impact.

Table 10. Nitrification is associated with agro-climatic zones.

Agroclimate zone	Nitrification in days
Alpine zone	12
Atlantic zone	9
Continental zone	7
Northern zone	15
Southern zone	3

11 Potassium and Phosphorus requirements

The same methodology has been used for the different lines implemented in the tool. The calculations of the K and P requirements are detailed below.

11.1 Potassium requirements

Estimates of K requirements are based on FertiliCalc and are provided for the entire crop rotation. The estimation of K requirements (Krate) is similar to the P requirements but considering an efficiency factor (fk). For this nutrient, B values are assumed to be the same for the different soil K tests. To avoid an excess of Krate, the model considers a maximum value of 275 kg K /ha **(K_crop_max**: 275 kg K/ha). K calculations are made for a soil depth of 30 cm and the calculation includes threshold values of the usual availability indices (Delgado, 2016).

The user must enter the amount of initial K in the soil.

Model equation:

K_exported= h_dm_med* Kc_h+ r_dm_med*(1-fmc_r)* Kc_r *export_r

where:

→ K_exported: amount of potassium exported from the soil (kg K/ha).

→ h_dm_med: dry matter of grain in uptake process.

→ Kc_h: K concentration in harvested part.

→ r_dm_med: dry matter of part residual in the uptake process.

→ Kc_r: K concentration in residual part.

→ fmc_r: fraction of residues (dry matter) left in the field after harvest with roots.
Default value: 0.15.

→ export_r: percentage of residues exported in soil (%) (input by the user).

Each strategy contains different formulas and will therefore yield different results. Therefore, it is important that the user selects the strategy that best corresponds to his or her needs.The following is a description of the formulas involved in these strategies chosen by the user.

Strategys:

1. Sufficiency strategy: the tool will propose the application of P or K only when the soil test level is below the defined threshold value for fertilizer response for the specific test used to assess the nutrient availability in soil.

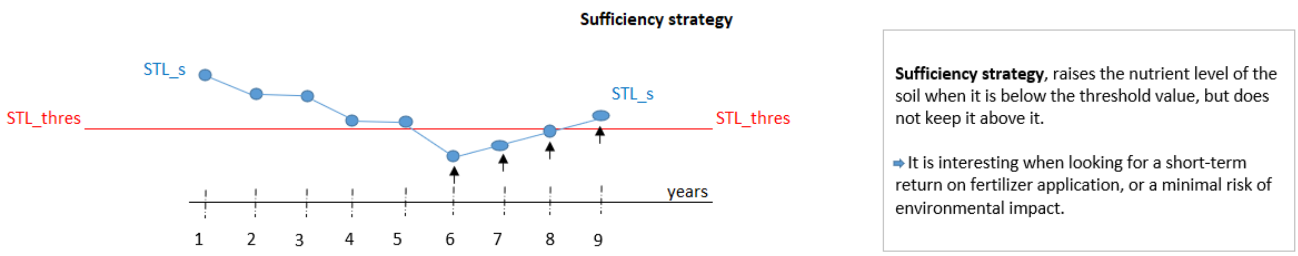


Figure 20. Sufficiency strategy.

Model equation:
Sufficiency strategy (kg K/ ha) =10* density_s*depth_s*(Kc_s_thres_min-Kc_s)* fK* STL/STLt min / K_nyears_min

where:

→ Sufficiency strategy: the tool will propose the application of P or K only when the soil test level is below the defined threshold value for fertilizer response for the specific test used to assess the nutrient availability in soil. Is the results of kg K/ha in the **Sufficiency strategy.**

→ density_s: soil bulk density.

→ depth_s: soil depth. If the user does not have this information, a default value is set. Default value : 0.3 m.

→ Kc_s_thres_**min:** limit for Kc_s for B&M strategy reduced or minimum fertilizer.(Definition in point 2).

→ Kc_s: soil K concentration. The user enters this data provided by a soil analysis.

→ fK: correction factor associated with soil texture. Efficiency factor, which ranges from 1.1 to 5 depending on the clay content of the soil (increases with increasing clay) (see table of associations).

→ STL/STLt min: **STL**: K available in the soil based on soil tests and **STLt:** the threshold value.

IF Kc_s < Kc_s_thres_min, **STL/STLt min** takes the value of **1** and if not the value of **0.**

→ K_nyears_min: The number of years over which the exported K is distributed. The conceptual equation follows:

Model equations of K_nyears_min:

IF K_crop_min > K_crop_max;   If this condition is not met, the result is equal to **1.**

K_nyears_min= K_crop_min /K_crop_max

→ **K_crop_min**=K_exported*STL/2STLtmin+10*density_s*depth_s*(Kc_s_thres_min-Kc_s)*fK* STL/STLt min

→ **K_crop_max**=BMmin_result(kgK/ha)*STL/2STLtmax+10*density_s*depth_s*(Kc_s_thres_max-Kc_s)*fK*STL/STLt max

where:

→ K_crop_max: maximum dose of nutrient K in one season.

→ K_crop_min: minimum dose of nutrient K in one season.

→ K_exported: amount of potassium exported from the soil (kg K/ha).

→ STL/2STLt**min: STL**: K available in the soil based on soil tests and **STLt:** the threshold value.

IF Kc_s > 2* Kc_s_thres_min; STL/2STLtmin takes the value of **0.5** and if not the value of **0.**

→ density_s: soil bulk density.

→ depth_s: soil depth. If the user does not have this information, a default value is set. Default value : 0.3 m.

→ Kc_s_thres_**min:** limit for Kc_s for B&M strategy (reduced o minimum fertilizer).

→ Kc_s: soil K concentration. The user enters this data provided by a soil analysis.

→ fK: correction factor associated with soil texture. Efficiency factor, which ranges from 1.1 to 5 depending on the clay content of the soil (increases with increasing clay) (see table of associations).

→ STL/STLt min: **STL**: K available in the soil based on soil tests and **STLt:** the threshold value.

IF Kc_s < Kc_s_thres_min; **STL/STLt min** takes the value of **1** and if not the value of **0.**

→ K_crop_max: maximum dose of nutrient K in one season. Parameterised 275 kg K/ha.

→ BMmin_result (kg K/ha): results of amount K in the B&M minimum strategy.

→ STL/**2**STLt max: **IF Kc_s >2 * Kc_s_thres_max**; **STL/2STLtmax** takes the value of **0.5** and if not the value of **0.**

→ depth_s: soil depth. If the user does not have this information, a default value is set. Default value : 0.3 m.

→ Kc_s_thres_**max**: limit for Kc_s for B&M strategy (maximum yield).

→ fK: correction factor associated with soil texture. Efficiency factor, which ranges from 1.1 to 5 depending on the clay content of the soil (increases with increasing clay) (see table of associations).

→ STL/STLt max: **IF Kc_s < Kc_s_thres_max** ; **STL/STLt max** takes the value of **1** and if not the value of **0.**

Kc_h	0,46%	
Kc_r	1,20%	
Kc_s	250,0	ppm
Kc_s_thres_min	150	ppm
STL/STLt min	0	
STL/2 STLt min	1,0	
K_crop'_min	139	
K_nyears_min	1	
Kc_s_thres_max	175	ppm
STL/STLt max	0	
STL/2 STLt max	1,0	
K_crop'_max	139	
K_nyears_max	1	
fK	1,6	
K_exported	139	
Strategies	**Amount K**	
Sufficiency (minimum fertilizer)	**0**	

Figure 21. Example of a sufficiency strategy calculation.

2. Buildup and maintenance (reduced or minimum fertilizer) strategy: the tool will propose the compensation of P and K exported from the farm and to progressively rise the level to the threshold values (only if the current level is below the threshold).

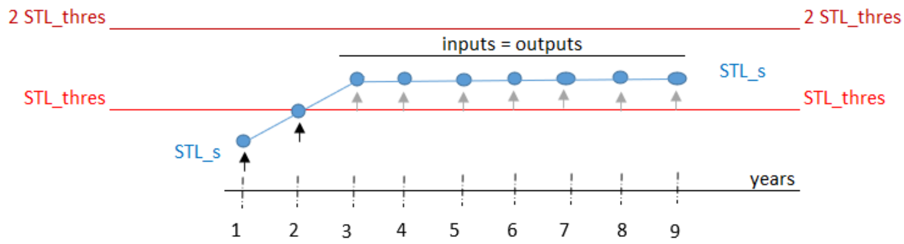


Figure 22. Buildup and maintenance (minimum fertilizer) strategy.

Model equation:

B&M minimum = (K_exported * STL/2 STLt**min** +10* density_s *depth_s*(Kc_s_thres_**min**- Kc_s)* fK * STL/STLt **min** / K_nyears_**min**

where:

→ K_exported: amount of potassium exported from the soil (kg K/ha).

→ STL/2STLtmin: **STL:** K available in the soil based on soil tests and **STLt**: the threshold value. **IF Kc_s > 2* Kc_s_thres_min; STL/2STLtmin** takes the value of **0.5** and if not the value of **0.**

→ density_s: soil bulk density.

→ depth_s: soil depth. If the user does not have this information, a default value is set. Default value : 0.3 m.

→ Kc_s_thres_**min:** limit for Kc_s for B&M strategy (reduced o minimum fertilizer).

→ Kc_s: soil K concentration. The user enters this data provided by a soil analysis.

→ fK: correction factor associated with soil texture. Efficiency factor, which ranges from 1.1 to 5 depending on the clay content of the soil (increases with increasing clay) (see table of associations).

→ STL/STLt min: **STL**: K available in the soil based on soil tests and **STLt:** the threshold value. **IF Kc_s < Kc_s_thres_min**, **STL/STLt min** takes the value of **1** and if not the value of **0.**

→ K_nyears_min: the number of years over which the exported K is distributed. The conceptual equation follows.

(The explanation of the variables has already been described in point 1).

Model equations of K_nyears_min:

IF K_crop_min > K_crop_max;   If this condition is not met, the result is equal to **1.**

K_nyears_min= K_crop_min /K_crop_max

→ **K_crop_min**=K_exported*STL/2STLtmin+10*density_s*depth_s*(Kc_s_thres_min-Kc_s)*fK* STL/STLt min

→ **K_crop_max**=BMmin_result(kgK/ha)*STL/2STLtmax+10*density_s*depth_s*(Kc_s_thres_max-Kc_s)*fK*STL/STLt max

Kc_h	0,46%	
Kc_r	1,20%	
Kc_s	250,0	ppm
Kc_s_thres_min	150	ppm
STL/STLt min	0	
STL/2 STLt min	1,0	
K_crop'_min	139	
K_nyears_min	1	
Kc_s_thres_max	175	ppm
STL/STLt max	0	
STL/2 STLt max	1,0	
K_crop'_max	139	
K_nyears_max	1	
fK	1,6	
K_exported	139	

Strategies	Amount K
Sufficiency (minimum fertilizer)	0
Buildup & maintenance (reduced fertilizer)	139

Figure 23. Example of a buildup and maintenance (reduced or minimum fertilizer) strategy.

3. **Buildup and maintenance (maximum yield)** strategy: similar to the previous strategy but now using the parameters leading to maximum yield.

> **Model equation:**
>
> **B&M maximum** = K_exported * STL/2 STLt**max** +10* density_s *depth_s*(Kc_s_thres_**max**-Kc_s)* fK * STL/STLt **max** / K_nyears_**max**

where:

- → K_exported: amount of potassium exported from the soil (kg K/ha).
- → STL/**2**STLt max: **IF Kc_s >2 * Kc_s_thres_max**; **STL/2STLtmax** takes the value of **0.5** and if not the value of **0.**
- → density_s: soil bulk density.
- → depth_s: soil depth. If the user does not have this information, a default value is set. Default value : 0.3 m.
- → Kc_s_thres_**max**: limit for Kc_s for B&M strategy (maximum yield).
- → Kc_s: soil K concentration. The user enters this data provided by a soil analysis.
- → fK: correction factor associated with soil texture. Efficiency factor, which ranges from 1.1 to 5 depending on the clay content of the soil (increases with increasing clay) (see table of associations)
- → STL/STLt max: **IF Kc_s < Kc_s_thres_max** ; **STL/STLt max** takes the value of **1** and if not the value of **0.**

→ K_nyears_max: the number of years over which the exported K is distributed. The conceptual equation follows:

Model equation:

IF K_crop_max>275 kg K/ha;   If this condition is not met, the result is equal to **1.**

K_nyears_max = K_crop_max /275 kg K/ha;

where:

→ K_crop_max: maximum dose of nutrient K in one season.

Kc_h	0,46%	
Kc_r	1,20%	
Kc_s	250,0	ppm
Kc_s_thres_min	150	ppm
STL/STLt min	0	
STL/2 STLt min	1,0	
K_crop'_min	139	
K_nyears_min	1	
Kc_s_thres_max	175	ppm
STL/STLt max	0	
STL/2 STLt max	1,0	
K_crop'_max	139	
K_nyears_max	1	
fK	1,6	
K_exported	139	
Strategies	**Amount K**	
Sufficiency (minimum fertilizer)	0	
Buildup & maintenance (reduced fertilizer)	139	
Buildup & maintenance (maximum yield)	139	

Figure 24. Example of a buildup and maintenance (maximum yield) strategy.

4. Maintenance strategy: if no soil tests are available, this alternative consisting of adding fertilizers to compensate for the P and K exported by harvested parts of crops. Here we assume that the user considers that P and K levels in the soil are not limiting for crop yields, the approach being a “zero balance”.

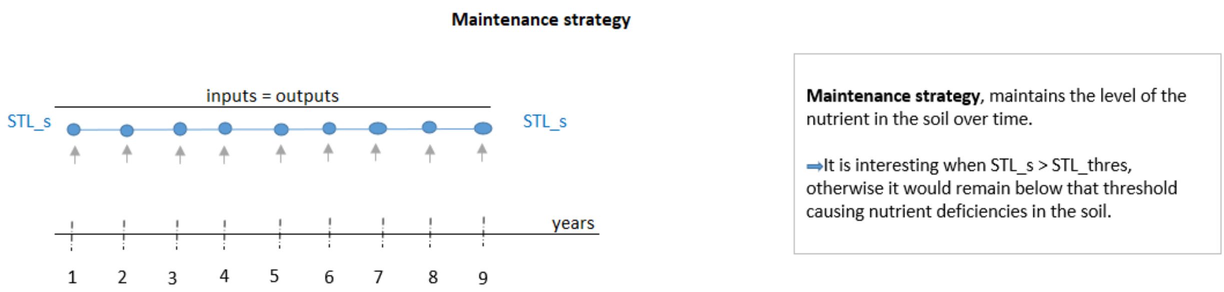


Figure 25. Maintenance strategy

Model equation:

Maintenance = K_exported (kg K/ ha)

where:

→ K_exported: amount of potassium exported from the soil (kg K/ha).

Kc_h	0,46%	
Kc_r	1,20%	
Kc_s	250,0	ppm
Kc_s_thres_min	150	ppm
STL/STLt min	0	
STL/2 STLt min	1,0	
K_crop'_min	139	
K_nyears_min	1	
Kc_s_thres_max	175	ppm
STL/STLt max	0	
STL/2 STLt max	1,0	
K_crop'_max	139	
K_nyears_max	1	
fK	1,6	
K_exported	139	

Strategies	Amount K
Sufficiency (minimum fertilizer)	0
Buildup & maintenance (reduced fertilizer)	139
Buildup & maintenance (maximum yield)	139
Maintenance (soil analysis not avalable)	139

Figure 26. . Example of a maintenance strategy.

Table 11. Summary of equations for different user strategies.

Strategies	Equations
1.Sufficiency	=10* density_s*depth_s*(Kc_s_thres_min-Kc_s)* fK* STL/STLt min / K_nyears_**min**
2. B&M: minimum	=(K_exported * STL/2 STLt**min** +10* density_s *depth_s*(Kc_s_thres_**min**- Kc_s)* fK * STL/STLt **min** / K_nyears_**min**
3. B&M: maximum	=(K_exported * STL/2 STLt**max** +10* density_s *depth_s*(Kc_s_thres_**max**-Kc_s)* fK * STL/STLt **max** / K_nyears_**max**
4.Maintenance	= K_exported

Parameterisation of the variables associated with soil texture and implemented

Table 12. Parameterisation of the variables associated with soil texture.

Soil texture	Bulk density (density_s)	Correction factor fK	Pc_s_thres (ppm)	Kc_s_thres (ppm)
Sand	1,49	1,15	9	100
Loamy sand	1,49	1,15	9	100
Sandy loam	1,45	1,15	11	162,5
Loam	1,42	1,6	11	162,5
Silty loam	1,32	1,6	11	162,5

Soil texture	Bulk density (density_s)	Correction factor fK	Pc_s_thres (ppm)	Kc_s_thres (ppm)
Silt	1,3	1,6	11	162,5
Clay loam	1,6	1,6	11	162,5
Sandy clay loam	1,42	2	11	162,5
Silty clay loam	1,4	2	11	162,5
Sandy clay	1,51	2	11	162,5
Silty clay	1,38	3,75	11	162,5
Clay	1,39	3,75	16	250

11.2 Phosphorus requirements

The small differences between PK is the variable fK that is taken into account in K and the limit of P_crop_max (100 kg P /ha).

The user must enter the amount of initial P in the soil as well as the method of analysis of this initial P.

Table 13. Values of the coefficient converting values of a given soil P test into its equivalent for the Olsen method.

Pc Method	k
Olsen	1
Ammonium lactate	0,25
Mehlich III	0,36
Bray	0,47
Ammonium acetate+ EDTA	0,48
Calcium lactate	0,49
Calcium lactate acetate	0,52
Paper strip	1,5
Acid ammonium acetate	1,6
H2O	3,8
Saturated water	15
CaCl2	25

Model equation:

P_exported= h_dm_med* Pc_h+ r_dm_med*(1-fmc_r)* Pc_r *export_r

where:

- → P_exported: amount of potassium exported from the soil (kg P/ha).
- → h_dm_med: dry matter of grain in uptake process.
- → Pc_h: P concentration in harvested part.
- → r_dm_med: dry matter of part residual in the uptake process.
- → Pc_r: P concentration in residual part.
- → fmc_r: fraction of residues (dry matter) left in the field after harvest with roots.

  Default value : 0.15.
- → export_r: percentage of residues exported in soil (%) (input by the user).

Depending on the strategy, some values are taken or others. The following is a description of the formulas involved in these strategies chosen by the user.

Strategys:

1. Sufficiency strategy:

Model equation:

Sufficiency strategy (kg P/ ha) =10* density_s*depth_s*(Pc_s_thres_min-Pc_s)* STL/STLt min / P_nyears_min

where:

- → density_s: soil bulk density.
- → depth_s: soil depth. If the user does not have this information, a default value is set. Default value : 0.3 m.
- → Pc_s_thres_**min:** limit for Pc_s for B&M strategy (reduced o minimum fertilizer).
- → Pc_s: soil P concentration. The user enters this data provided by a soil analysis.
- → STL/STLt min: **STL**: P available in the soil based on soil tests and **STLt:** the threshold value. **IF Pc_s < Pc_s_thres_min**, **STL/STLt min** takes the value of **1** and if not the value of **0.**
- → P_nyears_min: The number of years over which the exported P is distributed. The conceptual equation follows:

Model equations of P_nyears_min:

IF P_crop_min >P_crop_max; If this condition is not met, the result is equal to **1.**

P_nyears_min= P_crop_min /P_crop_max

- → **P_crop_min**=P_exported*STL/2STLtmin+10*density_s*depth_s*(Pc_s_thres_min-Pc_s)*STL/STLt min
- → **P_crop_max**=BMmin_result(kgP/ha)*STL/2STLtmax+10*density_s*depth_s*(Pc_s_thres_max-Pc_s)*STL/STLt max

where:

- → P_crop_max: maximum dose of nutrient P in one season.
- → P_crop_min: minimum dose of nutrient P in one season.
- → P_exported: amount of P exported from the soil (kg P/ha).
- → STL/2STLt**min: STL**: P available in the soil based on soil tests and **STLt:** the threshold value. **IF Pc_s > 2* Pc_s_thres_min; STL/2STLtmin** takes the value of **0.5** and if not the value of **0.**
- → density_s: soil bulk density.

→ depth_s: soil depth. If the user does not have this information, a default value is set. Default value: 0.3 m.

→ Pc_s_thres_**min**: limit for Pc_s for B&M strategy (reduced o minimum fertilizer).

→ Pc_s: soil P concentration. The user enters this data provided by a soil analysis.

→ STL/STLt min: **STL**: K available in the soil based on soil tests and **STLt:** the threshold value. **IF Pc_s < Pc_s_thres_min**; **STL/STLt min** takes the value of **1** and if not the value of **0.**

→ P_crop_max: maximum dose of nutrient P in one season.

→ BMmin_result (kg P/ha) : results of amount P in the B&M minimum strategy.

→ STL/**2**STLt max: **IF Pc_s >2 * Pc_s_thres_max**; **STL/2STLtmax** takes the value of **0.5** and if not the value of **0.**

→ depth_s: soil depth. If the user does not have this information. Default value : 0.3 m.

→ Pc_s_thres_**max**: limit for Pc_s for B&M strategy (maximum yield).

→ STL/STLt max: **IF Pc_s < Pc_s_thres_max**; **STL/STLt max** takes the value of **1** and if not the value of **0.**

Pc_h	0,37%	
Pc_r	0,06%	
Pc_s	4	ppm
Pc_s_thres_min	10	ppm
STL/STLt min	1	
STL/2 STLt min	1,0	
P_crop'_min	59	
P_nyears_min	1	
Pc_s_thres_max	12	ppm
STL/STLt max	1	
STL/2 STLt max	1,0	
P_crop'_max	67	
P_nyears_max	1	
P_exported	31	
Strategies	Amount P	
Sufficiency (minimum fertilizer)	28	

Figure 27.Example of a maintenance strategy.

2. Buildup and maintenance (minimum fertilizer) strategy:

Model equation:

B&M minimum = (P_exported * STL/2 STLt**min** +10* density_s *depth_s*(Pc_s_thres_**min**- Kc_s)* STL/STLt **min** / P_nyears_**min**

where:

→ P_exported: amount of P exported from the soil (kg P/ha).

→ STL/2STLtmin: **STL:** P available in the soil based on soil tests and **STLt**: the threshold value.

IF Pc_s > 2* Pc_s_thres_min; STL/2STLtmin takes the value of **0.5** and if not the value of **0.**

→ density_s: soil bulk density.

→ depth_s: soil depth. If the user does not have this information, a default value is set. Default value : 0.3 m.

→ Pc_s_thres_**min:** limit for Pc_s for B&M strategy (reduced o minimum fertilizer).

→ Pc_s: soil P concentration. The user enters this data provided by a soil analysis.

→ STL/STLt min: **STL**:P available in the soil based on soil tests and **STLt:** the threshold value.

IF Pc_s < Pc_s_thres_min, **STL/STLt min** takes the value of **1** and if not the value of **0.**

→ P_nyears_min: the number of years over which the exported K is distributed. The conceptual equation follows:

(The explanation of the variables has already been described in point 1).

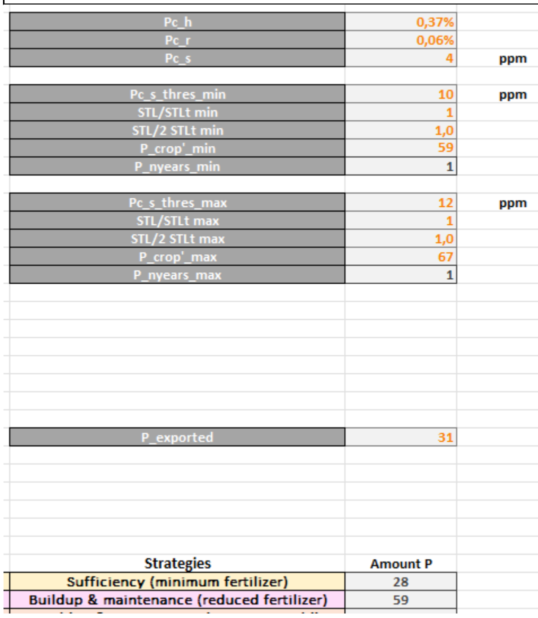
Model equations of P_nyears_min:

IF P_crop_min > P_crop_max;   If this condition is not met, the result is equal to **1.**

P_nyears_min= P_crop_min /P_crop_max

→ **P_crop_min**=P_exported*STL/2STLtmin+10*density_s*depth_s*(Pc_s_thres_min-Pc_s)* STL/STLt min

→ **P_crop_max**=BMmin_result(kgK/ha)*STL/2STLtmax+10*density_s*depth_s*(Pc_s_thres_max-Pc_s)* STL/STLt max



Pc_h	0,37%	
Pc_r	0,06%	
Pc_s	4	ppm
Pc_s_thres_min	10	ppm
STL/STLt min	1	
STL/2 STLt min	1,0	
P_crop'_min	59	
P_nyears_min	1	
Pc_s_thres_max	12	ppm
STL/STLt max	1	
STL/2 STLt max	1,0	
P_crop'_max	67	
P_nyears_max	1	
P_exported	31	

Strategies	Amount P
Sufficiency (minimum fertilizer)	28
Buildup & maintenance (reduced fertilizer)	59

Figure 28. Example of Buildup and maintenance (minimum fertilizer) strategy.

3. Buildup and maintenance (maximum yield) strategy:

> **Model equation:**
>
> **B&M maximum** = P_exported * STL/2 STLt**max** +10* density_s *depth_s*(Pc_s_thres_**max-**Pc_s) * STL/STLt **max** / P_nyears_**max**

where:

- → P_exported: amount of potassium exported from the soil (kg P/ha).
- → STL/**2**STLt max: **IF Pc_s >2 * Pc_s_thres_max**; **STL/2STLtmax** takes the value of **0.5** and if not the value of **0.**
- → density_s: soil bulk density.
- → depth_s: soil depth. If the user does not have this information, a default value is set. Default value : 0.3 m.
- → Pc_s_thres_**max**: limit for Pc_s for B&M strategy (maximum yield).
- → Pc_s: soil P concentration. The user enters this data provided by a soil analysis.
- → STL/STLt max: **IF Pc_s < Pc_s_thres_max** ; **STL/STLt max** takes the value of **1** and if not the value of **0.**
- → P_nyears_max: the number of years over which the exported K is distributed. The conceptual equation follows:

> **Model equation:**
>
> IF P_crop_max>100 kg P/ha; If this condition is not met, the result is equal to **1.**
>
> **P_nyears_max (years)** = P_crop_max /100 kg P/ha;

where:

- → P_crop_max: maximum dose of nutrient K in one season.

Pc_h	0,37%	
Pc_r	0,06%	
Pc_s	4	ppm
Pc_s_thres_min	10	ppm
STL/STLt min	1	
STL/2 STLt min	1,0	
P_crop'_min	59	
P_nyears_min	1	
Pc_s_thres_max	12	ppm
STL/STLt max	1	
STL/2 STLt max	1,0	
P_crop'_max	67	
P_nyears_max	1	
P_exported	31	
Strategies	Amount P	
Sufficiency (minimum fertilizer)	28	
Buildup & maintenance (reduced fertilizer)	59	
Buildup & maintenance (maximum yield)	67	

Figure 29. Example of Buildup and maintenance (maximum yield) strategy.

4. Maintenance strategy:

Model equation:

Maintenance strategy = P_exported (kg P/ ha)

where:

→ P_exported: amount of potassium exported from the soil (kg P/ha).

Pc_h	0,37%	
Pc_r	0,06%	
Pc_s	4	ppm
Pc_s_thres_min	10	ppm
STL/STLt min	1	
STL/2 STLt min	1,0	
P_crop'_min	59	
P_nyears_min	1	
Pc_s_thres_max	12	ppm
STL/STLt max	1	
STL/2 STLt max	1,0	
P_crop'_max	67	
P_nyears_max	1	
P_exported	31	

Strategies	Amount P
Sufficiency (minimum fertilizer)	28
Buildup & maintenance (reduced fertilizer)	59
Buildup & maintenance (maximum yield)	67
Maintenance (soil analysis not avalable)	31

Figure 30. Example of Maintenance strategy.

11.3 Soil water balance using NDVI standard or actual NDVI values.

Line F1 allows the soil water balance to be calculated using vegetation indices derived from time series of remotely sensed earth observation images. The first option proposed is the use of standard or tabulated NDVI values. These values correspond to the standard curve for irrigated crops developed during the FATIMA project but "modelled" in Kc FAO format, i.e., fixing constant values (we fix both the date and the NDVI value) for the inflection points between the early, mid, and late development periods. Therefore, the application of this line under different agronomic conditions will require adaptation of the standard curves, e.g., by adapting the dates and length of the growing periods, as well as the maximum and minimum values.

The NDVI values at these turning points for irrigated soft wheat in La Mancha were set at 0.3, 0.87 and 0.45 respectively. For each zone, the type of curve would be the result of adapting the dates of the turning points and the corresponding values for NDVI at these dates (these data are modified in the tab NDVI type).

Table 14. NDVI tipical values for irrigated soft wheat.

Fecha	NDVI Multisensor Multi
05/01/2015	0.300
10/03/2015	0.300
20/04/2015	0.870
10/06/2015	0.870
30/06/2015	0.450

The alternative to this model is the inclusion of real NDVI data obtained by the end-user. This option is highly recommended for crops other than wheat and cultivated areas. These values are those observed through the SPIDER WEB GIS platform.

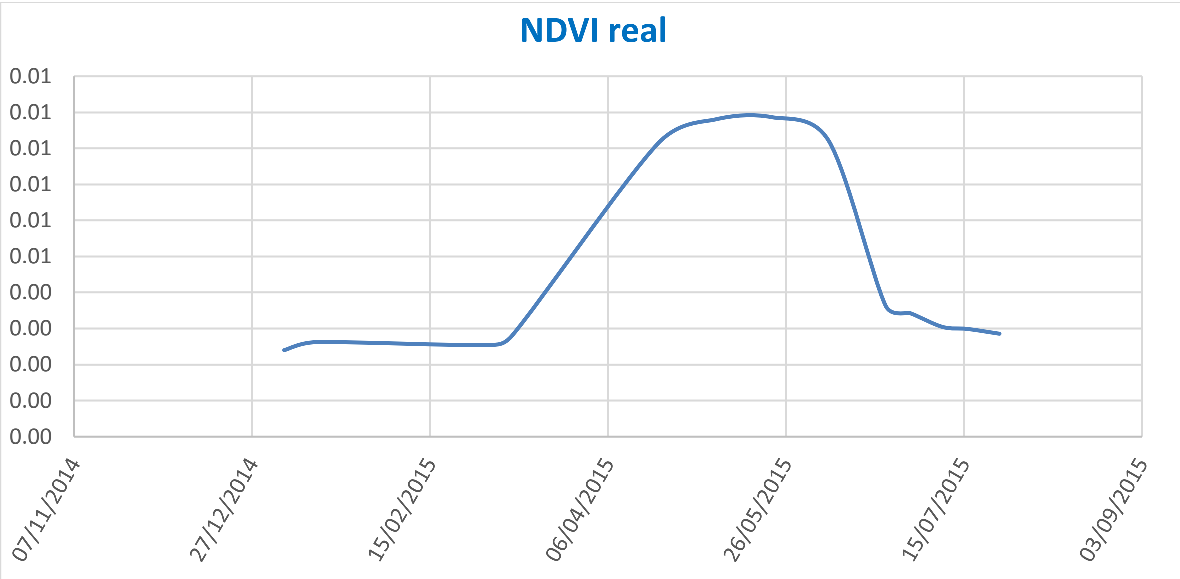


Figure 31. Example of NDVI real.

The NDVI values of the standard curve are interpolated and converted in daily Kc values using the following equation:

Model equation:

Kc= 1,5* NDVI daily-0,2

12 SUMMARY OF THE MINIMUM INPUTS

The complete information can be found in the Excel sheet of the conditions:

https://docs.google.com/spreadsheets/d/18iO8nI68jFz5-r5mG-p4Qpvtza5f-qTV/edit#gid=1818653837

13 RESULT OF THE NITROGEN BALANCE

Model equation:

N_rate= N limit – N mineral soil

where:

- → N_rate: N rate is the result of the nitrogen balance and this being the daily requirement in kg N/ha.
- → Nlimit: consists of a fixed value of Nitrogen depending on the crop cycle, being 25 at the beginning of the cycle, 40 in the middle of the cycle and returning to 25 at the end of the cycle
- → N mineral soil: total amount of nitrogen available in the soil (kg N/ha).

Model equation:

N_mineral_soil(i) = N_mineral_soil(i-1) + N_ mineralised(i) + N_water(i) + N_curve(i) + N_extr_(i) + N_l(i) + N_fert + Ndesni(i).

where:

- → i : day.
- → N_ mineralised (i) : result of the daily mineralisation process (kg N/ ha).
- → N_water(i) : result of the daily Nitrogen in irrigation water (kg N/ ha).
- → N_curve(i) : result of the daily mineralization of organic amendments (kg N/ ha).
- → N_extr_(i) : result of the daily extraccions (kg N/ ha).
- → N_l(i) : result of the daily leaching (kg N / ha).
- → N_fert : final perceived nitrogen from fertilisation (kg N / ha).
- → Ndesni(i) : result of the daily denitrification process (kg N/ ha).