Ref. Ares(2015)2768576 - 01/07/2015

FATIMA

FArming Tools for external nutrient Inputs and water MAnagement

D3.3.1: Framework for soil-crops assessment and nutrient management in pilot areas

WP3.3 – Sustainable soil management practices and cropping systems

Rosario Napoli, Roberta Farina, Stefano Canali, Fabio Tittarelli, Bruno Pennelli (CRA-RPS)

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	Aneta RYNIAK				
Project Coordinator	Anna Osann				
Deliverable	D3.3.1 Framework for soil-crops assessment and nutrient management in pilot areas				
Work Package	WP3.3 – Sustainable soil management practices and cropping systems				
Date of Delivery	**Contractual**	1 July 2015	**Actual**	30 June 2015	
Nature	R - Report	**Dissemination Level**	PU		
Lead Beneficiary	06_CRA-RPS				
Lead Author	Rosario Napoli (CRA-RPS)	**Email**	rosario.napoli@entecra.it		
Contributions from					
internal Reviewer 1	Horacio López-Córcoles (ITAP)				
Internal Reviewer 2	José González (UCLM)				
Objective of document	To describe the framework for soil and crop assessment procedures and the nutrient management inside the experimental plan, the sampling schemes in different time series, the data modeling and geostatistical processing of data methodologies.				
Readership/Distribution	All FATIMA Regional Teams; All WP leaders and other FATIMA team members; European Commission / REA				
Keywords	Sustainable management, soil, crop, nutrient, experimental plan, monitoring data, sampling grid				

Document History

Version	Issue Date	Stage	Changes	Contributor
Draft v00	11/05/2015	Draft		
v0.2	1/07/2015	Submission	internal reviewers' and contributors' comments ntegrated	

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Executive summary

This document describes the methodological approach for

a) the characterization of soil types and selection of crop types to be applied in the different pilot areas, depending on local conditions, with particular emphasis on cover crops, taking the basic criterion of a rainfed crop and an irrigated crop.;

b) the selection of the nutrient management plan and the type / amount of compost to be applied inside the theses of compared sustainable and traditional local management (examples of the Italian, Austrian and Spanish Pilot Areas);

c) the size of the grid monitoring and scanning time of the time series, both for in-field trials and for EO ground truthing.

These approaches are currently being tested in several FATIMA pilot areas and will be implemented during the pilot campaigns of 2016-2017 in all pilot areas (except Netherlands, which has a different focus) to varying degrees and adapted to the local characteristics and requirements.

A detailed planning of field activities in all pilot areas will be provided in D5.1 (Campaign Plan).

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1 Framework for soil-crops assessment and nutrient management in pilot areas

1.1 Sustainable soil and nutrient management

1.1.1 State of the art and Deliverable targets

Sustainable agriculture is based on natural resources conservation and on a concept of productivity closely linked to the maintenance of a system oriented to saving energy and resources in the mid-long term, through recycling optimisation, biodiversity enhancing and biological synergy (Colombo, 2000). In a similar way, sustainable soil fertility and nutrient management should be based on the implementation of a complex strategy which provides essential nutrients and water to the plants without or at least minimizing the negative side effects on the environment. Just to mention some of them, soil fertility management tools include soil tillage practices, crop rotations, organic amendments and the introduction of agroecological services providing crops (crops introduced in the agro-system in order to provide or enhance its environmental functions) (ASCs)

Soil C sequestration is of special interest in Mediterranean areas, where rainfed cereal cropping systems are prevalent, inputs of organic matter in soils are low and mostly rely on crop residues, while losses are high due to climatic and anthropic factors such as intensive and non-conservative farming practices. Estimates indicate that 74% of the land in Southern Europe is covered by soil containing less than 2% of organic carbon (i.e. 3.4% organic matter) in the top-soil (Zdruli et al., 2004).

1.1.2 Soil management sustainability in the mid-long term

As a general consideration, it is possible to affirm that soil fertility and an active soil ecosystem is the basis for the feeding of plants. In order to implement a sustainable soil fertility management, a distinction between short term and mid term objectives can be helpful. In the short term period, the main goal of a farmer should be to provide the amount of nutrients requested by the crop in an available mineral form minimizing as much as possible the potential losses. In the mid-long term period, in the Mediterranean soils, the main objective is to maintain or increase soil organic matter content and soil ecosystem activity and diversity, storing in soil nutrients in organic forms which are less subjected to loss in other environmental compartments.

Unfortunately, in the short term, even if the technical approach of calculating the nutrients supply on the basis of the length of the growing period and the expected yields is reasonable, things are a bit more complicated. In general terms, the main problem is the scarce and not foreseeable synchronisation of the availability of nutrients with the need of the plants. In order to by-pass these technical constraints, farmers utilize fertilizers and amendments in large excess respect to the real needs of the plants. This practice, especially in intensified systems of production, determines a high level of nutrients surplus with connected problems of nitrate leaching and denitrification.

In order to improve the sustainability of a production system, a deep analysis of the soil physic-chemical characteristics, of the crop rotation, expected yields and of the main soil fertility management tools traditionally utilized in the area, is needed. The methodology to estimate sustainable management of soil, both under environmental and productivity view, is to use crop and soil modelling over **mid and long term period**. That means to simulate, assuming the same cropping system and nutrient management, what happens after 5-10 years in terms of soil degradation, nutrient leaching in the environment, and rate of production (Figure 1).

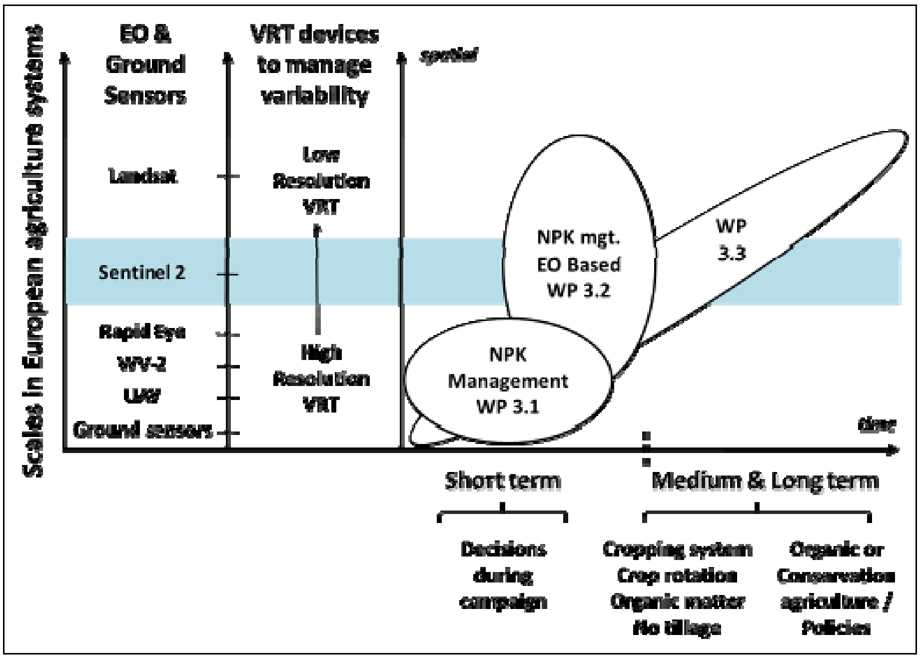


Figure 1. Activity of the WP 3.3. on the medium and long period in the context of space-time scales

1.1.3 Nutrient C and N modeling for preventing soil physical and chemical degradation

Agriculture simulation models integrate the **current state-of-the art of scientific knowledge from many different disciplines**, including crop physiology, agronomy, agrometeorology, soil physics, soil chemistry, soil biology, plant pathology, entomology, economics and many others (Gerrit Hoogenboum, 2012). In the last decades many models on soil and plant systems have been developed, ranging from empirical models, whose equations are based on measured data and could not been extrapolated to different situations, to mechanistic model that attempt to explain the relationship among the elements in the modeled system using the most updated knowledge. The most used models combine mechanistic and empiric elements. Among the models the most common and widely used to simulate soil C and N dynamics and soil-plant system are RothC (Rothamsted C Model; Coleman and Jenkinson, 1996); CENTURY (Parton et al., 1987) and its daily version DayCent; DNDC (Li et al., 1994) and SOCRATES (Grace and Ladd, 1995). These models describe processes, such as transformation, protection and mineralization of SOM, at various levels of detail and with different dependencies on environmental conditions. Among the most used models to simulate the whole agro-ecosystem, DSSAT and WinEPIC play a prominent role.

The WinEPIC user Windows interface for the **EPIC Model** (Blackland Research and Extension Center, Texas Agricultural Experiment Station) has been chosen to be the best and already tested model by CRA-RPS in several research projects and pilot areas. The model will be used to predict the C and N cycles inside the cropping system provided inside the different trials plots.

EPIC (Environmental Policy Integrated Climate) crop simulation model (Williams et al. 1989) has a range of applications that expanded greatly over time including studies of:

- Irrigation;
- Climate change effects on crop yields;
- Nutrient cycling and nutrient loss;
- Wind and water erosion;
- Soil carbon sequestration;
- Economic and environmental;
- Comprehensive regional assessments.

EPIC Model Operation information diagram flux is shown in Figure 2.

- Daily time step.
- Long term simulations (1-4,000 years).
- Soil, weather, tillage and crop parameter data supplied with model.
- Soil profile can be divided into ten layers.
- Choice of actual weather or weather generated from long term averages.
- Homogeneous areas up to large fields or small watersheds.

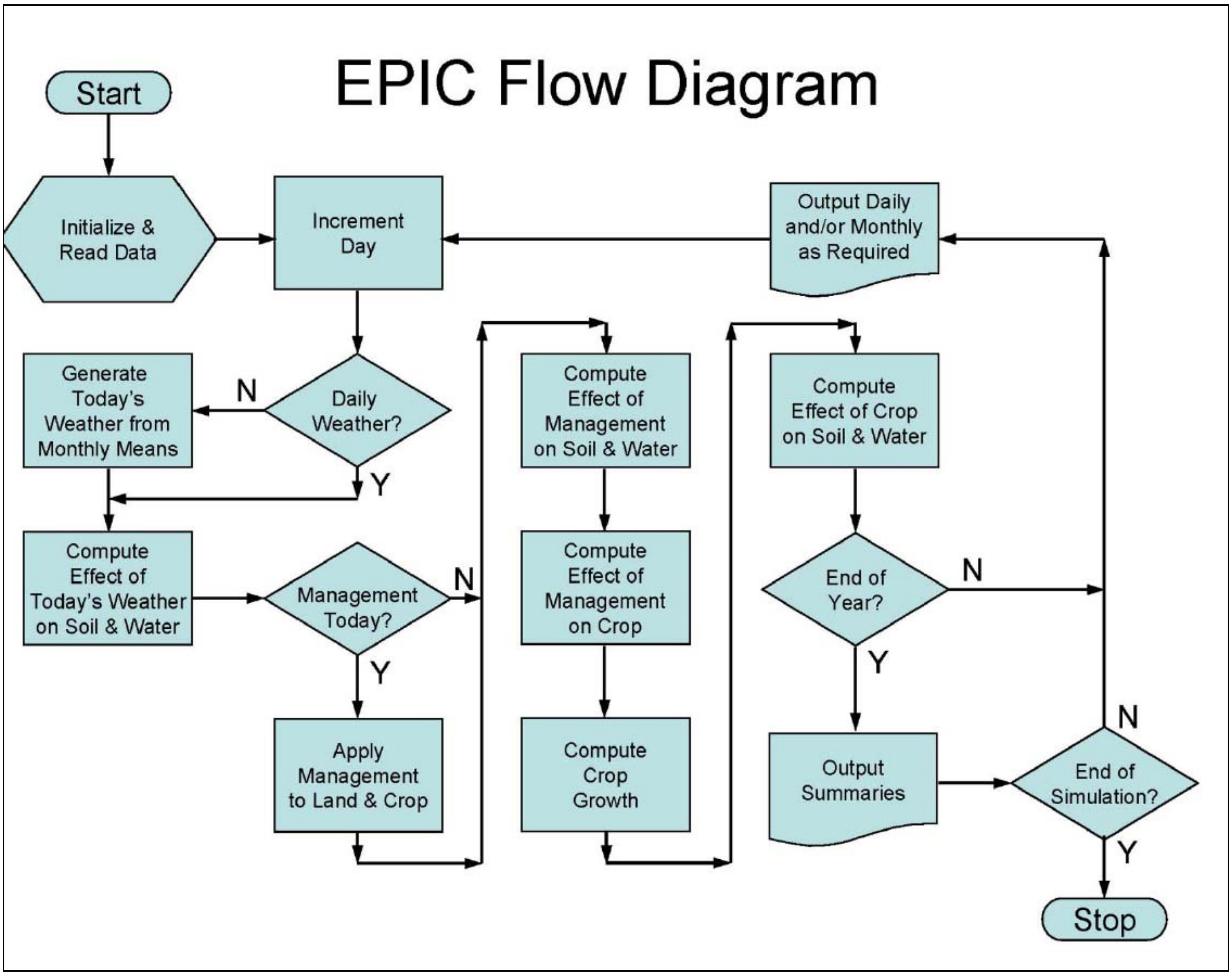


Figure 2. EPIC general flow diagram of the internal tools operational sequences

1.2 Soil and crops characterization, nutrient management plan and monitoring methodologies

1.2.1 Experimental plots in the Regional Pilot Areas for soil-crop assessment and nutrient management

Workpackage 3.3 (WP3.3) aims to monitor the state of the soil-plant system relating to the nutrient management. Corresponding field trials will be conducted in most FATIMA pilot areas. As a point of reference, this document describes in detail the experiments to be carried out in the Pilot Area of Italy (Tarquinia), which serves as the test-bed for the WP3.3 methodology. We also describe the experiments to be conducted in Austria (Marchfeld) and Spain (La Mancha), with different Trial Plots arrangement and also nutrient N management schemes, in order to assess a comparable use of standard ground check for EO and/or Proximal sensing up scaling.

Size of the Plots, according to the monitoring activity for model the N and C cycle in the soil-crop system and to the EO ground check, was established as a minimum area of 0.5 hectares for each experimental plot. This is the minimum size that is acceptable to be able to use the measures on the ground in connection to the detail of pixels of the types of remote sensing images, as well as Sentinel - 2 (10 m) and Landsat 8 (30 m).

1.2.1.1 Italian Pilot Area geographic outlines and experimental site location

The Italia Pilot Area (figure 3) is located inside the "Consorzio di Bonifica Maremma Etrusca" (Center Italy, Lazio Region), in a coastal area mainly constituted by medium and low marine terraces formed in Quaternary (Pleistocene) and recent coastal plain with some local lowlands interested by limited salt intrusion (area of the "Saline"). Most of the Consorzio di Bonifica (around 85%) area fall inside the Vulnerable Nitrate Area (ZVN), with law prescription about the N imput on the soils, coming both from livestock and agricultural fertilizer, of maximum 170 N kg/ha/year.

Irrigated agricultural areas represent the 56% of the total administrative area (about 4.700 ha), mainly with supply mode by using river and artificial channel waters. The Consorzio di Bonifica manage an irrigation infrastructural network, to sustain some crops: maize, tomatoes, vegetables, alfalfa, orchards. Rainfed crops are present with cereals (mainly winter wheat), olive trees and Vineyards.

Soil types developed on marine terraces are clay sandy loam and clay silt loam Luvisols, Cambisols, and Mollisols, with some sandy loam Fluvisols in the small flat alluvial areas of the small river borders. On the flat coastal areas sandy loam Arenosols and Mollisols are the most widespread soils.

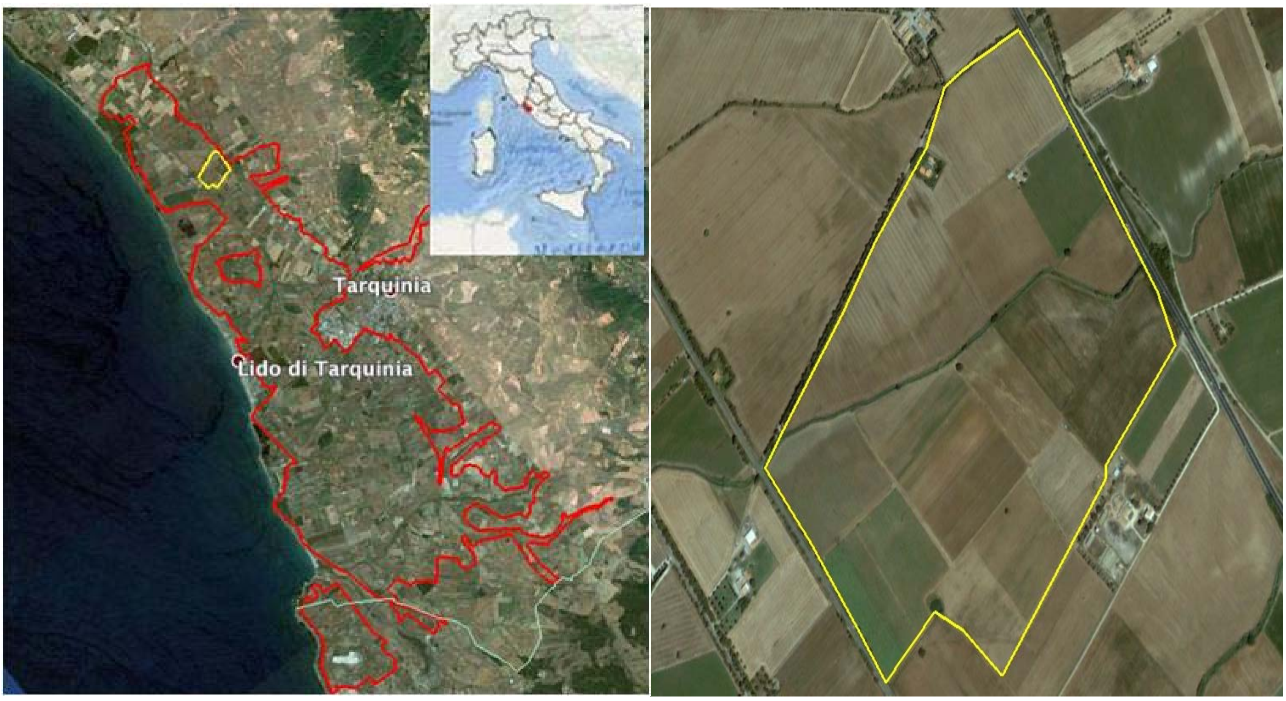


Figure 3. Localization of the Pilot area and the experimental Farm (yellow border)

Crop type	***Average fertilizer application (kg N ha year); organic or mineral; solid or liquid***
Winter wheat	100-120 mostly mineral
Maize	120 mostly mineral
Tomato	170-200 (53% intake in mineral form, 47% intake by fertirrigation)
Vegetable	170-200 mostly by fertirrigation
Alfalfa	no
Orchards	170-200 mostly by fertirrigation

1.2.1.2 Italian Cropping systems, nutrient management and experimental plan

Soil fertility management of the crop rotation wheat-tomato in the Tarquinia area is traditionally managed by the use of synthetic mineral fertilizers. In order to improve the level of sustainability of this production system either in the short and in the mid-long term period, the following changes in the agronomic management of the rotation will be carried out. For the tomato crop, we propose to increase the level of complexity of the traditional system of production by cultivating vetch (or other legume to be green manured) in the autumn-winter period before tomato transplanting together with an organic amendment like compost.

In order to evaluate the effective improvement of the sustainability of the proposed modified system of production, a field experiment in which the experimental factor is the origin of N (from synthetic nitrogen fertilizer and from green manure + compost) will be carried out (Table 1). For the wheat crop, in order to reduce the potential nitrate leaching of the traditional system of production, we propose to compare three different types of N fertilizer (synthetic, slow release and organic N fertilizers). In order to evaluate the effective improvement of the sustainability of the proposed modified system of production a field experiment in which the experimental factor is the N type of fertilizer utilized (synthetic, slow release and organic N fertilizers) will be carried out. The Green manure cover crop type will be the Field bean (Vicia faba L.).

Compost will come from Local industry production, nearby Tarquinia. This is a compost derived by the re-use of vegetal residues coming mainly from local agro-forestry activity. The rate of Compost to be applied in the Experiment A, will be of **15 tons per hectare**, at the beginning of the Trial, that is just before planting the “Green Manure” Cover Crop.

Table 1. Summary table for the different experimental trials

Experimental Trial	***N. of Plots***	***Type of crop***	***Treatments***
A (different N origin)	2	Green Manure (Field Bean) – Tomato	2 levels: BNF (cover crop + compost), SNF (sinthetic fertiliser)
B (N fertilizer type)	3	Winter Wheat	3 levels: SNF (synthetic standard), (SRN) slow release, (ORN) Organic

The timeline for the provided experimental activity will be conducted during two years, as reported in the following table 2.

Table 2. General timeline for the Italian Trials

Timeline

		2015										2016												2017											
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
		m	a	m	j	j	a	s	o	n	d	j	f	m	a	m	j	j	a	s	o	n	d	j	f	m	a	m	j	j	a	s	o	n	d
exp a	field 1								field beans							tomato																			
	field 2																				field beans							tomato							
exp b	field 1									wheat																									
	field 2																					wheat													

The general monitoring plan provides to have a scheduled time to collect and monitor the status soil and crops, according to the list reported in the following table 3.

Table 3. List of the type of measurements for soil and crops provided for the WP 3.3. Italian experimental area

Measurements and monitoring target	**Type of measurement and unit of measure**	**Collection method**	**Type of data acquisition**
SOIL	Moisture content (% in Volume)	Continuous from field sensors (1 dataset every 30	Data Logger download

		minutes)	
SOIL	Temperature (C°)	Continuous from field sensors (1 dataset every 30 minutes)	Data Logger download
SOIL	N-NO3 content of soil percolation water	Micro Lysimeter sampling (every two-three weeks)	Lab. Analysis
SOIL	Dry and at Field Capacity Bulk density (g/cm^3)	Undisturbed core sampling	Lab. Analysis
SOIL	Total Organic Carbon (TOC) and Total N (g/kg^{-1})	Disturbed sampling	Lab. Analysis
SOIL	soil available P (g/kg^{-1})	Disturbed sampling	Lab. Analysis
SOIL	soil exchangeable K (g/kg^{-1})	Disturbed sampling	Lab. Analysis
SOIL	soil mineral N (g/kg^{-1})	Disturbed sampling	Lab. Analysis
COMPOST	compost C, N (g/kg^{-1})	Disturbed sampling	Lab. Analysis
CROP	cover crop biomass (kg/ha)	Disturbed sampling	Lab. Analysis
CROP	cover crop C (g/kg^{-1})	Disturbed sampling	Lab. Analysis
CROP	cover crop N (g/kg^{-1})	Disturbed sampling	Lab. Analysis
CROP	crop N status by Chlorophyll leafs content (SPAD502 meter units)	Non invasive in field measurement	Data Logger download
CROP	crop residues biomass (kg/ha)	Disturbed sampling	Lab. Analysis
CROP	crop residues C (g/kg^{-1})	Disturbed sampling	Lab. Analysis
CROP	crop residues N (g/kg^{-1})	Disturbed sampling	Lab. Analysis
CROP	Total Yield (kg/ha)	Disturbed sampling	Lab. Analysis
CROP	yield C ($g/kg^{-1}/ha$)	Disturbed sampling	Lab. Analysis
CROP	yield N ($g/kg^{-1}/ha$)	Disturbed sampling	Lab. Analysis

1.2.1.3 Austrian Pilot Area geographic outlines and experimental site location

Pilot Area for experimental trials is the Lower Austria Marchfeld Area (figure 4), located on the western part of the country and extended for 900 km². Marchfeld is the most relevant agricultural area in Austria, and about 65000 ha of the area are used for agricultural production; around 30% of the area is irrigated, mostly (90%) with sprinkler systems, mainly metal pipes; fruit trees and berries are irrigated with drip irrigation.

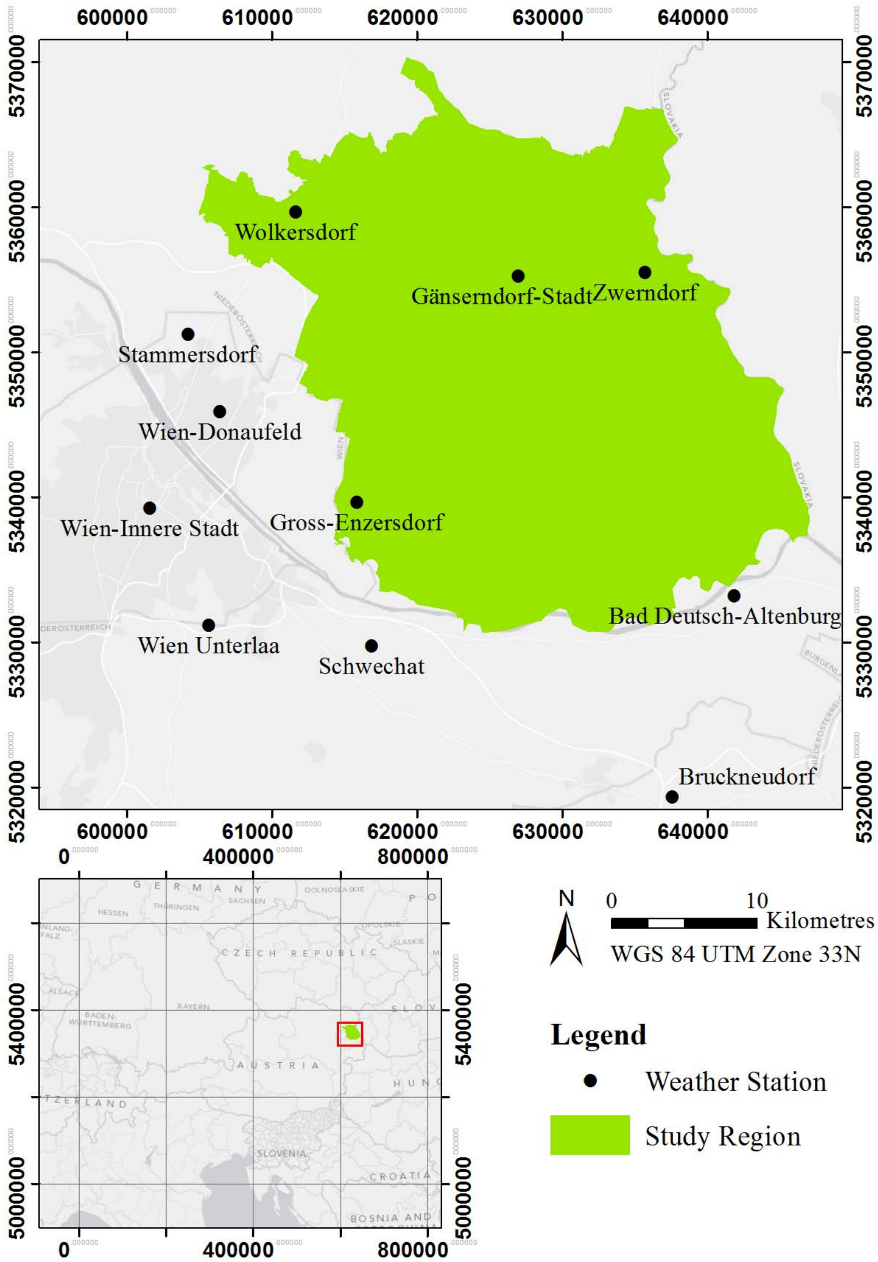


Figure 4. Location of Marchfeld Area.

The dominant soil types are Chernozem and Fluvisol, based on the Food and Agriculture Organization (FAO) World Soil Classification. The general soil conditions are characterized by a humus-rich A horizon and a sandy C horizon, followed by fluvial gravel from the former river bed of the Danube. The region is characterized by a semi-arid climate with an average annual precipitation of 500–550 mm that can drop to 300 mm making it the driest region of Austria. Precipitation during the growing season (April–September) is 200–440 mm. Irrigation in Lower Austria has made it possible to establish a variety of crops thus contributing to the importance of Marchfeld in agricultural production. Crop types are mostly Winter wheat, vegetables (11%), Sugar beet (10%), Maize and Potatoes (7%).

Crop type	Average fertilizer application (kg N ha year); organic or mineral; solid or liquid

Winter wheat	120 kg N mostly mineral in the Marchfeld
Vegetables	110-200 kg N (vegetables)
Sugar beet	100 kg N
Maize	130 kg N
Potatoes	90 kg N

1.2.1.1 Austrian Cropping systems, nutrient management and experimental plan

Austrian Pilot Area experimantal plan is organized focusing on the quantitative N fertilization rates trials rather than qualitative, as for the Italian Trials (table 4). In **2015** AGES conducts 4 small plot field trials:

- 2 long-term field trials in the Marchfeld with different N fertilization stages: winter wheat (Haringsee and Breitstetten): A (Table 4)
- Tillage trial (conventional ploughing, reduced tillage, minimum tillage/conservation agriculture) in the Marchfeld: maize: B (Table 4)
- Compost trial in Upper Austria: maize: C (Table 4)

In 2016 and 2017 three commercial plot experiments will be established with 4 mineral N variants (including 0, medium, optimum) with 3 replications, respectively, all at P, K fixed at optimum.

The long-term tillage field experiment in the pilot area and a long-term compost trial (175 kg N/ha with different kinds of composts) in a further Austrian area will be continued. The amounts are given according to the Austrian fertilizer recommendations and depend on the different crops (winter wheat, sugar beet, maize), but they are not higher than 200 kg N/ha).

Table 4. Summary table for the different Austrian experimental trials

Experimental Trial	***N. of Plots***	***Type of crop***	***Treatments***
A (N stages) at site Haringsee and Breitstetten **Small plots**	2 experiments	winter wheat	Fixed mineral N fertilisation stages: 70, 95, 120 145 kg N
B (Long term tillage) **Small plots**	1	maize	with fixed 120 kg N
C (Long term compost trial) **Small plots**	1	maize	1 to 4) 0, 40, 80, 120 kg N/ha 5) urban organic waste compost from domestic organic waste (OWC) corresponding to 175 kg N

			ha^{-1} 6) Green waste compost (GWC) corresponding to 175 kg N ha^{-1} 7) Cattle manure compost (MC) corresponding to 175 kg N ha^{-1} 8) sewage sludge compost (SSC) corresponding to 175 kg N ha^{-1}, 9) OWC corresponding to 175 kg N ha^{-1} + 80 kg mineral N ha^{-1}, 10) GWC corresponding to 175 kg N ha^{-1} + 80 kg mineral N ha^{-1}, 11) MC corresponding to 175 kg N ha^{-1} + 80 kg mineral N ha^{-1}, and 12) SSC corresponding to 175 kg N ha^{-1} + 80 kg mineral N ha^{-1}

In 2016 and 2017 three commercial plot experiments (plot size 90x90 m) will be established with 4 mineral N variants (including 0, medium, optimum) with 3 replications, respectively, all at P, K fixed at optimum. Each year winter wheat, maize and sugar beet will be grown.

Table 6. List of the type of measurements for soil and crops provided inside the WP 3.3. Austrian experimental area

Measurements and monitoring target	Type of measurement and unit of measure	Collection method	Type of data acquisition
SOIL	Total Organic Carbon (TOC) and Total N (g/kg^{-1})	Disturbed sampling	Lab. Analysis
SOIL	soil available P (g/kg^{-1})	Disturbed sampling	Lab. Analysis
SOIL	soil available K (g/kg^{-1})	Disturbed sampling	Lab. Analysis
SOIL	soil mineral N (g/kg^{-1})	Disturbed sampling	Lab. Analysis
COMPOST	compost C, N (g/kg^{-1})	Disturbed sampling	Lab. Analysis
CROP	cover crop biomass (kg/ha)	Disturbed sampling	Lab. Analysis
CROP	cover crop C (g/kg^{-1})	Disturbed sampling	Lab. Analysis
CROP	cover crop N (g/kg^{-1})	Disturbed sampling	Lab. Analysis
CROP	crop N status by Chlorophyll leafs content (SPAD502 meter units): only wheat	Non invasive in field measurement	Data Logger download
CROP	Total Yield (kg/ha)	Disturbed sampling	Lab. Analysis

CROP	yield C (g/kg^{-1}/ha)	Disturbed sampling	Lab. Analysis
CROP	yield N (g/kg^{-1}/ha)	Disturbed sampling	Lab. Analysis
CROP	N-Pilot measurements, reflectometer	Non invasive in field measurement	Data Logger download

1.2.1.2 Spanish Pilot area geographic outlines and experimental site location

La Mancha Oriental Area (figure 5) in Spain belongs 92 % to the region of Castilla-La Mancha, 7% to the region of Valencia and 1% to the region of Murcia. The total extent of the pilot area is 8,500 km2 with an irrigated area of 102,029 ha. Four type of soils can be found in the area attending the Soil Survey Staff: (i) the Alfisols that occupy an extent of 5%, located in the SE and NE, on fluvial terraces, used for rainfed crops and good drainage due to their content on gravels. (ii) The Aridisols, that occupy 40% of the central area, limiting the crop production on raifed crops but with moderate to high yield on irrigated crops. (iii) The Inceptisols occupy 50% of the area and they are located randomly along the aquifer, they are used for productive agriculture; on slope areas they can suffer high levels of erosion. (iv) The Entisols are less than 5% of the area and they are located NE. The climate is characterized by a high variation between seasons according to the Mediterranean-continental type. The averages temperatures vary between January (coldest month) about 4 ºC to July (hottest) about 25 ºC. The climatic records show an average temperature of 13.6 ºC with 2,800 hours of insolation per year. Average annual precipitations are 350 mm/year, with a distribution of 82 mm/year on winter, 124 mm/year on spring, 60 mm/year on summer and 100 mm/year in autumn. The oscillation between dry and wet years ranges from 124 mm/year to 750 mm/year.

The irrigation system is furrow with about 1%, sprinkler about 15%, pivot 60% and drip 25% of the area. The main irrigated crops are wheat/barley 40 %, maize 20 %, alfalfa 10 %, onions 6 %, garlics 5 %, vineyard 4% and others.

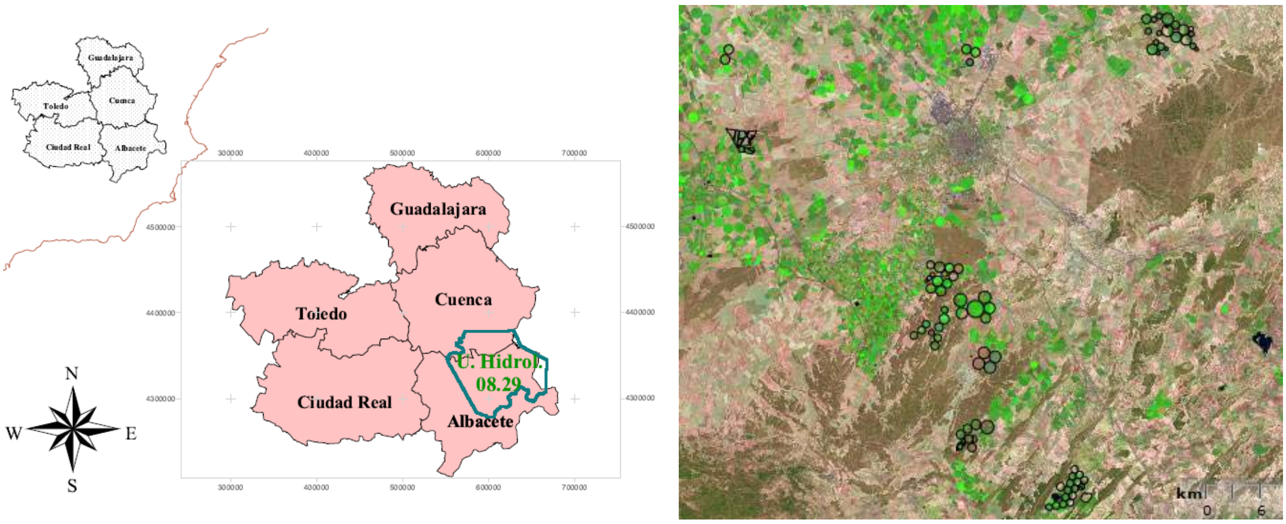


Figure 5. Localization of the La Mancha Oriental Area (green line on left figure) and the plots used for extensive campaigns (black lines on right figure).

Crop type	***Average fertilizer application (kg N ha year); organic or mineral; solid or liquid***

Wheat/	220
Barley	160
Vineyards	35
Maize	280
Alfalfa	40
Onion	220

1.2.1.3 Spanish Cropping systems, nutrient management and experimental plan

Table 7. Summary table for the different experimental trials

Experimental Trial	***N. of Plots***	***Type of crop***	***Treatments***
A (different N)	7	Winter Wheat	3 levels
B (different N)	3	Maize	3 levels

Figure 5a shows the general temporal sampling strategy, based on the crop phenological development, for the example of maize. Figure 5b shows the corresponding spatial sampling strategy.

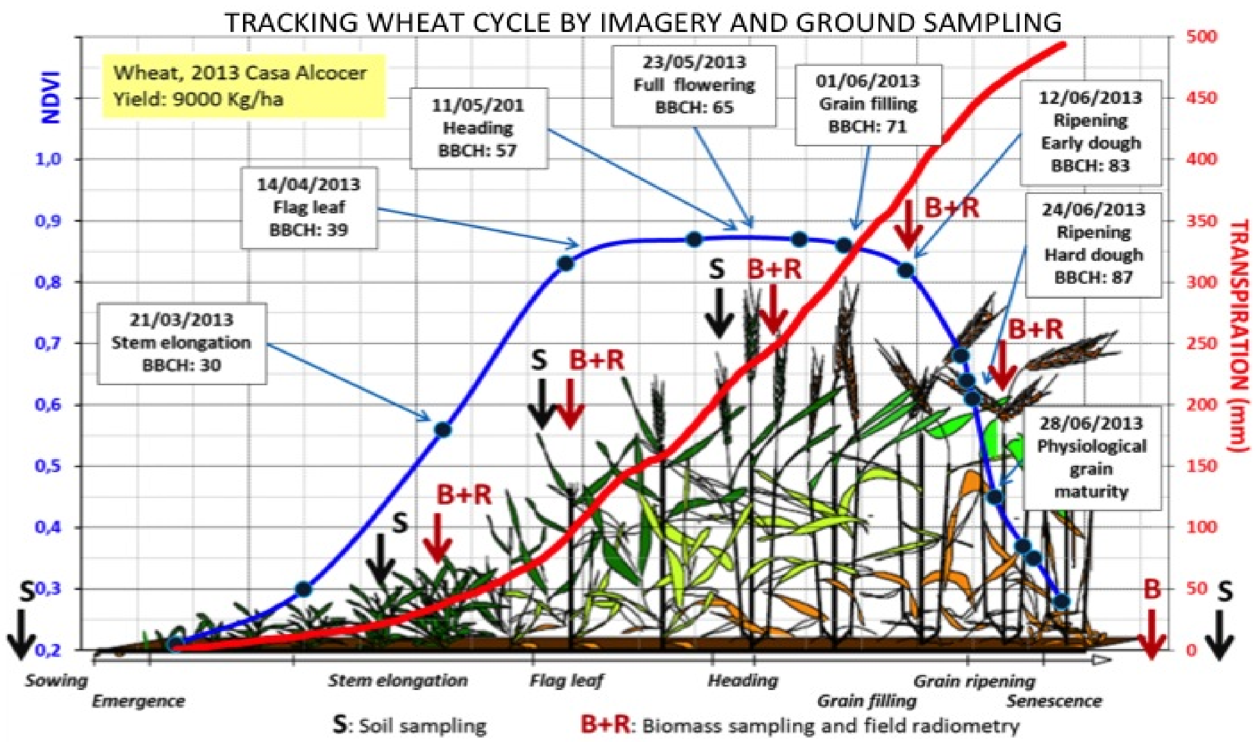


*Figure 5a. Typical wheat crop cycle in the Spanish pilot area as it is described by a time series of multispectral satellite imagery through NDVI (blue points). Accumulated transpiration across the cycle (red line) is calculated by using the relationship ∑Kcb(NDVI) * ETo for daily values. Phenology is described according BBCH scale.*

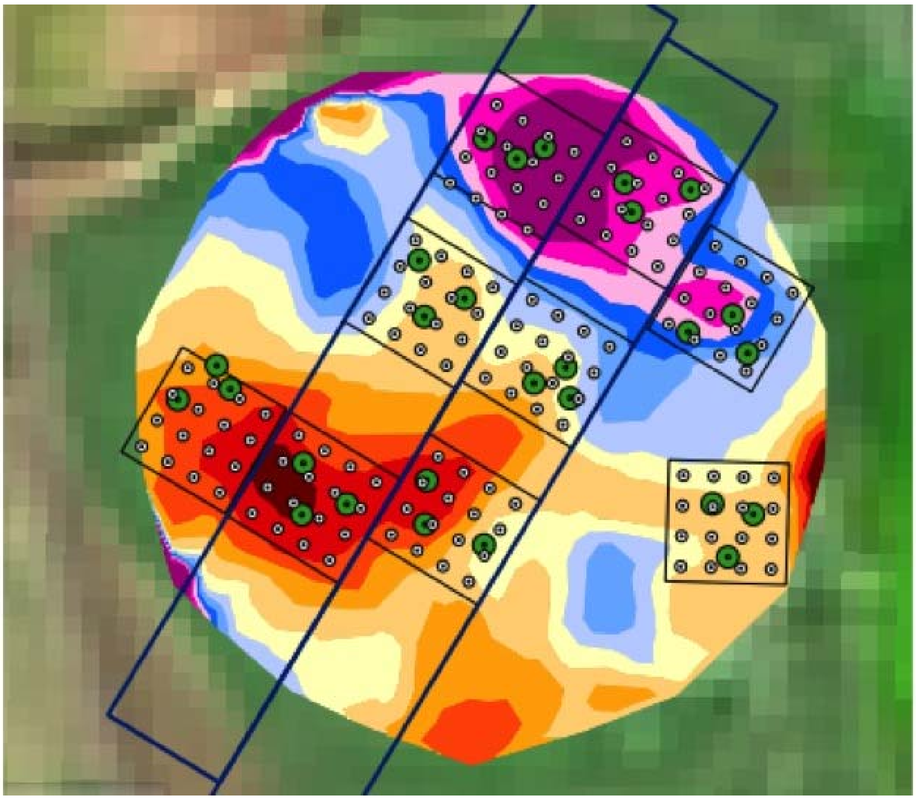


Figure 5b. Yield potential mapped by EO iamges (scale red-blue-purple:low-mid-high) variability within the plot in Casa Jara farm (La Mancha pilot area, Spain), taking into account the last two years data. Large rectangles represent the bands of N supply. In the figure there are plotted the unit samples for soil (small points) and biomass (large points).

The sampling timeline for maize and wheat trials according to this strategy is given in Tables 8 and 9.

Table 8. General timeline for the Spanish wheat Trials

ID	Task Name
1	**Protocolo Trigo**
2	Operaciones de cultivo (fecha, dosis, et
3	**Muestreo 1 (presiembra)**
7	Fecha nascencia (Z11-Z12)
8	Valoración nascencia-implantación
9	Medidas radiométricas
10	Daños de enfermedades, plagas y accid
11	Fecha inicio ahijamiento (Z21-Z22)
12	IAF
13	Cobertera 1
14	**Muestreo 2 (Z29)**
19	Fecha inicio encañado (Z31)
20	Cobertera 2
21	Fecha final encañado: h bandera (Z39)
22	**Muestreo 3 (Z39)**
27	Cobertera 3
28	Fecha de espigado (Z55)
29	Fecha Inicio llenado grano (Z7.01-Z7.1)
30	**Muestreo 4 (Z71)**
33	Fecha Grano lechoso temprano (Z73)
34	Altura de la planta (con espiga)
35	Fecha de maduración fisiológica (Z89)
36	Mapa de cosecha. Producción y
37	**Muestreo 5 (Z90)**

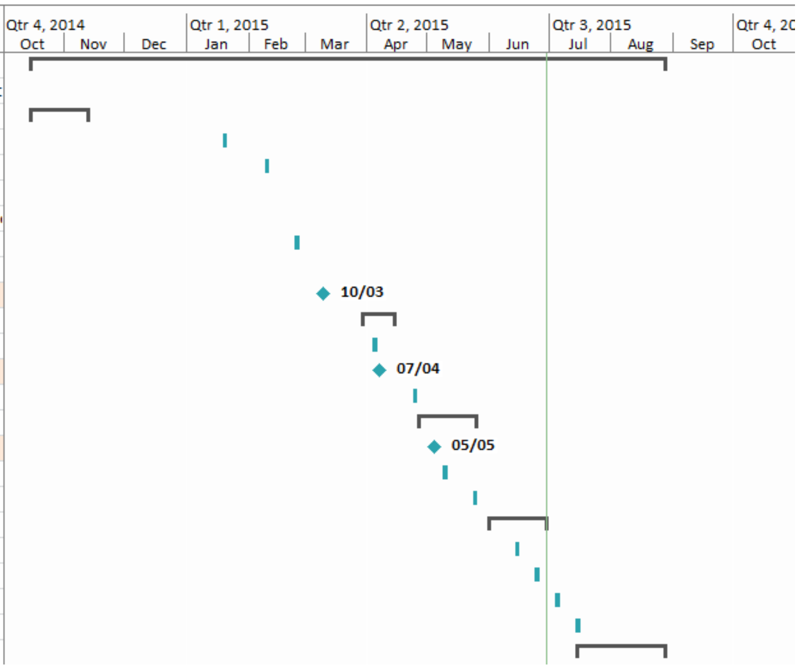
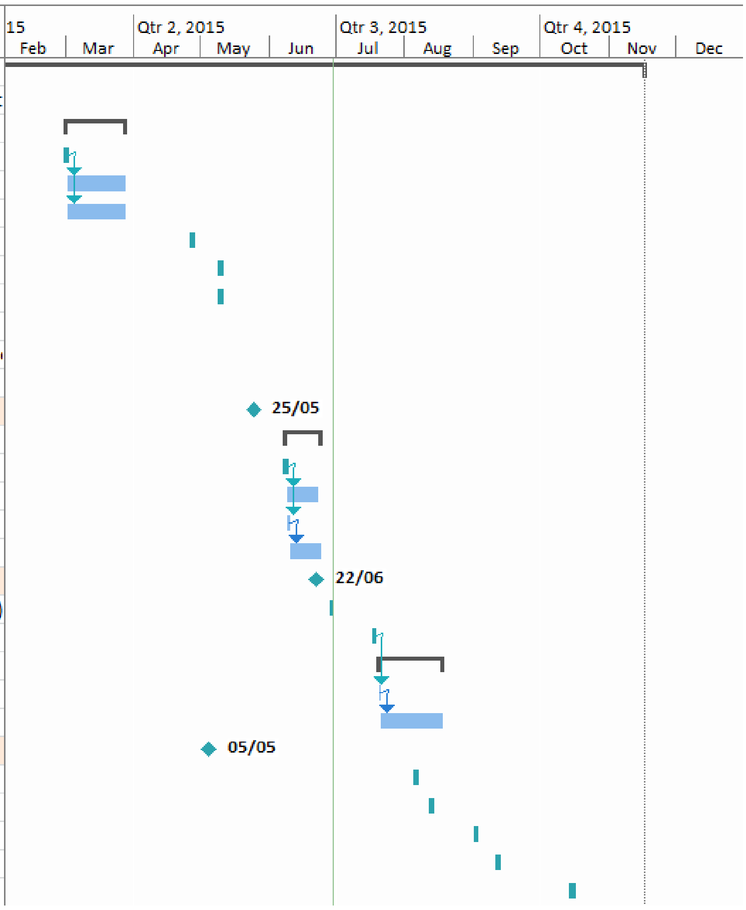


Table 9. General timeline for the Spanish maize Trials

ID	Task Name
46	**Protocolo Maíz**
47	Operaciones de cultivo (fecha, dosis, et
48	**Muestreo 1 (presiembra)**
49	Muestreo suelo
50	Análisis completo suelo
51	Análisis completo agua.
52	Fecha emergencia (VE)
53	Valoración nascencia-implantación
54	Fecha de N hoja desplegada (Vn)
55	Medidas radiométricas
56	Daños de enfermedades, plagas y accid
57	IAF
58	Cobertera 1
59	**Muestreo 2 (V6)**
60	Biomasa aérea
61	Análisis foliar
62	Muestreo suelo
63	Análisis Nmin y MO
64	Cobertera 2
65	Fecha de Nueve hojas desplegadas (V9)
66	Fecha de Floración masculina (VT)
67	**Muestreo 3 (VT)**
68	Biomasa aérea
69	Análisis foliar
70	Cobertera 3?
71	Fecha de Grano perlita (R2)
72	Fecha de Grano lechoso (R3)
73	Altura de la planta (con espiga) y
74	Fecha de maduración fisiológica (R6)
75	Mapa de cosecha. Producción y



The general monitoring plan provides to have a scheduled time to collect and monitor the status soil and crops, according to the list reported in the following table 10.

Table 10. List of the type of measurements for soil and crops provided for the WP 3.3. Spanish experimental area

Measurements and monitoring target	Type of measurement and unit of measure	Collection method	Type of data acquisition
SOIL	Moisture content (% in Volume)	Continuous from field sensors (1 dataset every 30 minutes)	Data Logger download
SOIL	Dry and at Field Capacity Bulk density (g cm^{-3})	Undisturbed core sampling	Lab. Analysis
SOIL	Total Organic Carbon (TOC) and Total N (%)	Disturbed sampling	Lab. Analysis
SOIL	soil available P (mg kg^{-1})	Disturbed sampling	Lab. Analysis
SOIL	soil exchangeable K (meq $100g^{-1}$)	Disturbed sampling	Lab. Analysis
SOIL	soil mineral N (g kg^{-1})	Disturbed sampling	Lab. Analysis
SOIL	Sand (%)	Disturbed sampling	Lab. Analysis
SOIL	Silt (%)	Disturbed sampling	Lab. Analysis
SOIL	Clay (%)	Disturbed sampling	Lab. Analysis
SOIL	pH	Disturbed sampling	Lab. Analysis
SOIL	Electrical conductivity 1/5 (mmhos cm^{-1})	Disturbed sampling	Lab. Analysis
SOIL	Electrical conductivity saturated paste (mmhos cm^{-1})	Disturbed sampling	Lab. Analysis
SOIL	Chlorides (mg kg^{-1})	Disturbed sampling	Lab. Analysis
SOIL	Sulphides (mg kg^{-1})	Disturbed sampling	Lab. Analysis
SOIL	Total calcium carbonate (%)	Disturbed sampling	Lab. Analysis
SOIL	Active lime (%)	Disturbed sampling	Lab. Analysis
SOIL	Na (meq $100g^{-1}$)	Disturbed sampling	Lab. Analysis
SOIL	Ca (meq $100g^{-1}$)	Disturbed sampling	Lab. Analysis
SOIL	Mg (meq $100g^{-1}$)	Disturbed sampling	Lab. Analysis
SOIL	Depth (m)	Undisturbed sampling	Field data
COMPOST	compost C, N (g/kg^{-1})	Disturbed sampling	Lab. Analysis
CROP	cover crop biomass (kg/ha)	Disturbed sampling	Lab. Analysis
CROP	cover crop C (g/kg^{-1})	Disturbed sampling	Lab. Analysis
CROP	cover crop N (g/kg^{-1})	Disturbed sampling	Lab. Analysis
CROP	crop N status by Chlorophyll leafs content (SPAD502 meter units)	Non invasive in field measurement	Data Logger download
CROP	crop residues biomass (kg/ha)	Disturbed sampling	Lab. Analysis

CROP	crop residues C (g/kg^{-1})	Disturbed sampling	Lab. Analysis
CROP	crop residues N (g/kg^{-1})	Disturbed sampling	Lab. Analysis
CROP	Total Yield (kg/ha)	Disturbed sampling	Lab. Analysis
CROP	yield C ($g/kg^{-1}/ha$)	Disturbed sampling	Lab. Analysis
CROP	yield N ($g/kg^{-1}/ha$)	Disturbed sampling	Lab. Analysis

1.2.2 Soil characterization, monitoring schemes and sampling techniques for soil and crops

1.2.2.1 Soil characterization

As starting activity is necessary to perform soil characterization of the pilot areas in order to control a) the homogeneity of the type of soil as well as the chemical and physical general characteristics inside the plots/experimental area;

b) for each type of soil surveyed it's necessary to measure the "time 0" situation, according to all the soil parameters will be object of monitoring activity. This statement is fundamental for the following evaluation processes and to producing thematic maps of the Nutrient status over the time.

The soil survey is to be realized by: a) if a detailed (1:25.000-1:50.000 scale) and recent soil map is present, it's possible to conduct a preliminary soil survey only by speditive observations, as by Hand auger holes and/or minipits, to link the survey to the existing soil types reported on the map, and to collect the soil samples to perform the analytical measures; b) if there is not an available soil map, it's necessary to dig a soil profile almost for each plot (by side of), and describe the most important characteristics/features:

- Horizons (type and depth)
- Internal features (colour, moisture, aggregate type and size, concretions/mottles, field texture, redoximorphic features, accumulation/depletion features as cutans, gravel size and percentage, etc.)
- Drainage (both internal and external),
- porosity (size and percentage),
- slickensides and cracks
- Pressure faces

The soil features previous listed could be described by using the Guidelines for soil description of FAO (fourth edition, Rome 2006). Representative soil samples are to be collected for each soil horizon and measured in lab, for a general chemical and physical characterization necessary to classify the soil with the World Reference Base for soil resources Classification System (WRB, 2014 edition).

The parameters to be measured are:

- Texture (almost three classes)
- Bulk density
- Total Organic Carbon
- Total Nitrogen
- pH in water (1:2.5)
- Total Cation Exchange Capacity
- Electrical Conductivity (EC 1:2.5) for soil salinity
- Exchangeable Basis (Ca, Mg, Na, K)
- Phosphate retention (only for andic materials in volcanic environment)
- Al and Fe oxalate (only for andic materials in volcanic environment)

Table 11. Asessment of soil data actually available in the pilot areas

Pilot Area	Soil Map area, edition date, editor, available (yes/no)	Survey and mapping Scale	Type of soil analysis present
Italy (Tarquinia)	Soil map of Tarquinia-Montalto ZVN area, 2015, CRA-RPS, yes	1:25.000, 1:50.000	Soil basic chemical and physical datasets, hydrological characterization for STU
Austria (Marchfeld)	Lower Austrian soil map	1:25,000	Soil types and basic parameters
Spain (La Mancha Oriental)	Soil map of La Mancha, 2012, yes	1:1,000,000	Soil types and basic parameters

1.2.2.2 Monitoring schemes for soil and crops – Italy

The monitoring schemes refers to the parameters list previously described, which relate to the soils and crops. The schemes were developed for two types of measures:

- Sampling at fixed time and analized by Laboratory equipments
- In field measures (soil moisture and temperature and N content/deficiencies by chlorophyll leaf measures)

1.2.2.2.1 Sampling to fixed time

With reference to the figure of the General Timeline, the detailed monitoring scheme is reported in the following tables 12 and 13.

Table 12. Monitoring and sampling time series for the Experiment A during all the trial scheduled program.

Experiment A –Irrigated tomato with 2 levels: BNF (cover crop + compost), SNF (synthetic fertiliser)		
Parameter	total replicates for Plot/Trial	Timing (number of the week from the FATIMA start time)

N-NO3 water in soil	3(*)	11,12,13,14,15,16,17,18/20,21,22,23,24,25,26,27,28,29,30
soil bulk density	8	7,14,18,19,26,30
soil TOC C and N	8	8, 18, 20, 30
soil availbale P	8	15, 27
soil exhangeable K	8	15, 27
soil mineral N	8	8, 15, 16, 17, 18, 20, 27, 28, 29, 30
compost C, N	4	8, 20
cover crop biomass	4	14, 26
cover crop C	4	14, 26
cover crop N	4	14, 26
crop N status (spad)	4	15, 16, 17, 18, 27, 28, 29, 30
crop residues biomass	4	18, 30
crop residues C	4	18, 30
crop residues N	4	18, 30
yield	4	18, 30
yield C	4	18, 30
yield N	4	18, 30

(*) three samples collected inside the micro lysimeters at different depths

Table 13. Monitoring and sampling time series for the Experiment A during all the trial scheduled program.

Experiment B – Rainfed winter wheat with 3 levels: SNF (synthetic standard), (SRN) slow release, (ORN) Organic		
Parameter	total replicates for Plot/Trial	Timing (week from the FATIMA prj start)
N-NO3 water in soil	3(*)	11,12,13,14,15,16,17,18/20,21,22,23,24,25,26,27,28,29,30
soil bulk density	8	7,14,18,19,26,30
soil TOC C and N	8	8, 18, 20, 30
soil availbale P	8	15, 27
soil exhangeable K	8	15, 27
soil mineral N	8	8, 15, 16, 17, 18, 20, 27, 28, 29, 30
compost C, N	4	8, 20
cover crop biomass	4	14, 26
cover crop C	4	14, 26

cover crop N	4	14, 26
crop N status (spad)	4	15, 16, 17, 18, 27, 28, 29, 30
crop residues biomass	4	18, 30
crop residues C	4	18, 30
crop residues N	4	18, 30
yield	4	18, 30
yield C	4	18, 30
yield N	4	18, 30

(*) three samples collected inside the micro lysimeters at different depths

The distribution of the sampling grid points for the soils and crops parameters reported in the above table is showed in the following schemes (figure 6 and 7), both for the continuous measures in the field (soil moisture and temperature) and the scheduled crop and soil monitoring by samples collection.

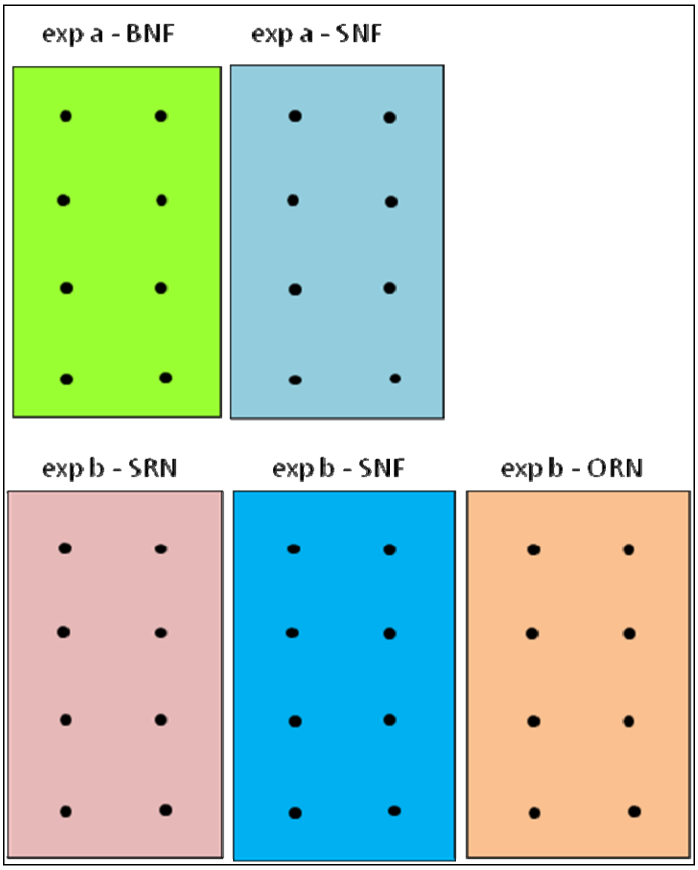


Figure 6. Soil bulk density, Total Organic Carbon (TOC), total and mineral N, avaliable P and exchangeable K grid samplig scheme inside the different experimental trial plots

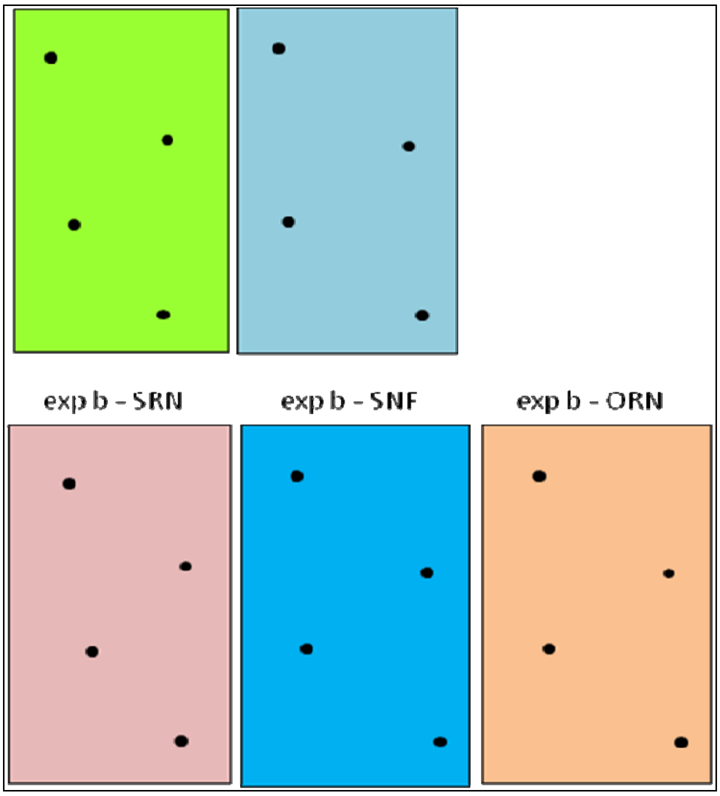


Figure 7. Cover crop and Compost C and N content, crop residues biomass, C and N content, yeld and yeld C and N grid samplig scheme inside the different experimental trial plots

1.2.2.2.2 In field measures

The field measures will monitor some soil hydrological and physical parameters necessary to support further crop and nutrient modeling activity. Besides, soil moisture content data will be useful also as ground truth to validate the EO irrigation models and predictions to be made inside the WP 2.2. activity plan. Soil moisture and soil surface temperature will be held in continuous mode with a sensor network as showed in the figure below. The type of probes for soil moisture monitoring are based on a Dielectric indirect Method called Frequency Domain Reflectometer (FDR). There will be put in the filed two FDR types:

- **PProbe PR2** (Delta-T Devices Ltd., Cambridge, UK): tube of 1 meter with six electric sensors (rings) at 10, 20, 30, 40, 60 and 100 cm of depth (figure 8)

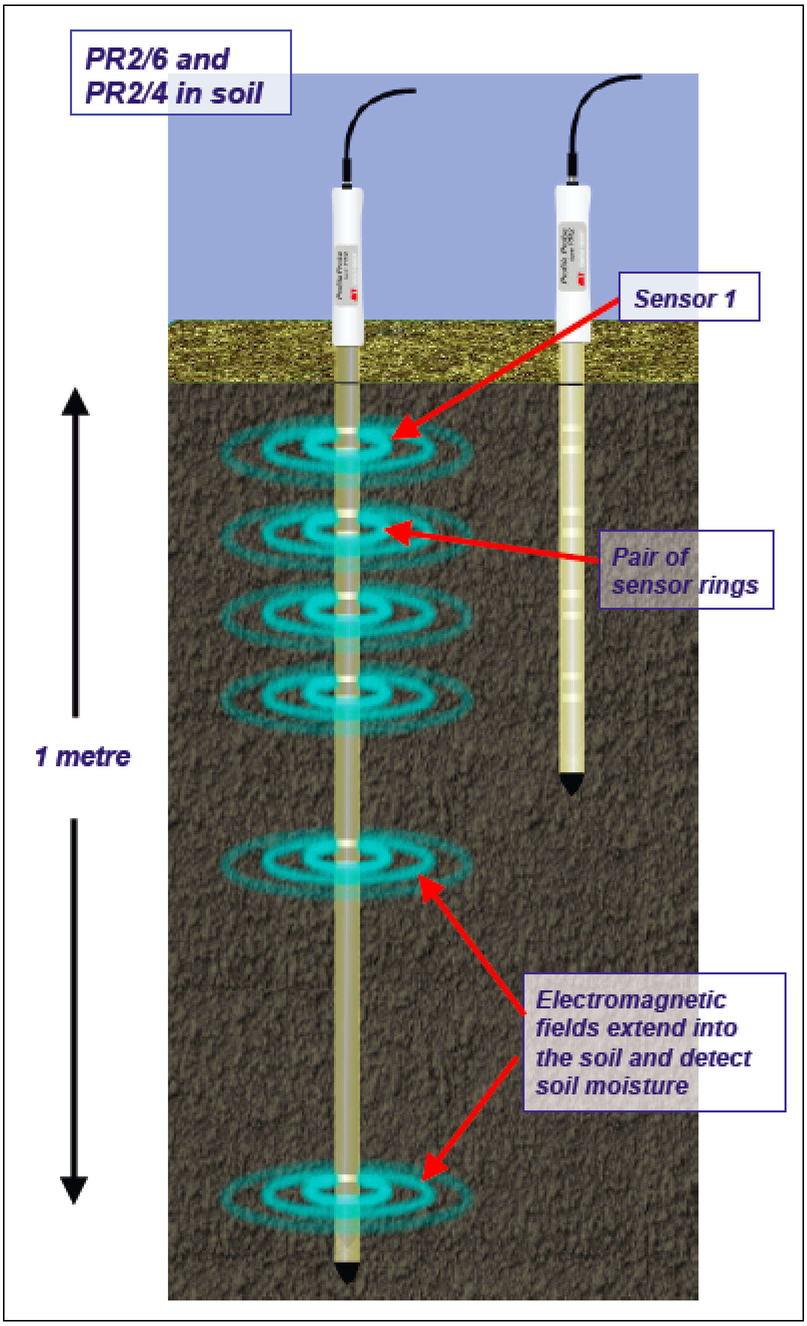


Figure 8. PR2 Probe in situ working mode

- **SM150** (Delta-T Devices Ltd., Cambridge, UK): FDR with two steel rods for soil moisture measures (to be installed at 30 cm of depth in the topsoil)
- **SM300** (Delta-T Devices Ltd., Cambridge, UK): as the previous, but with a thermistor for soil temperature measures (figure 9)

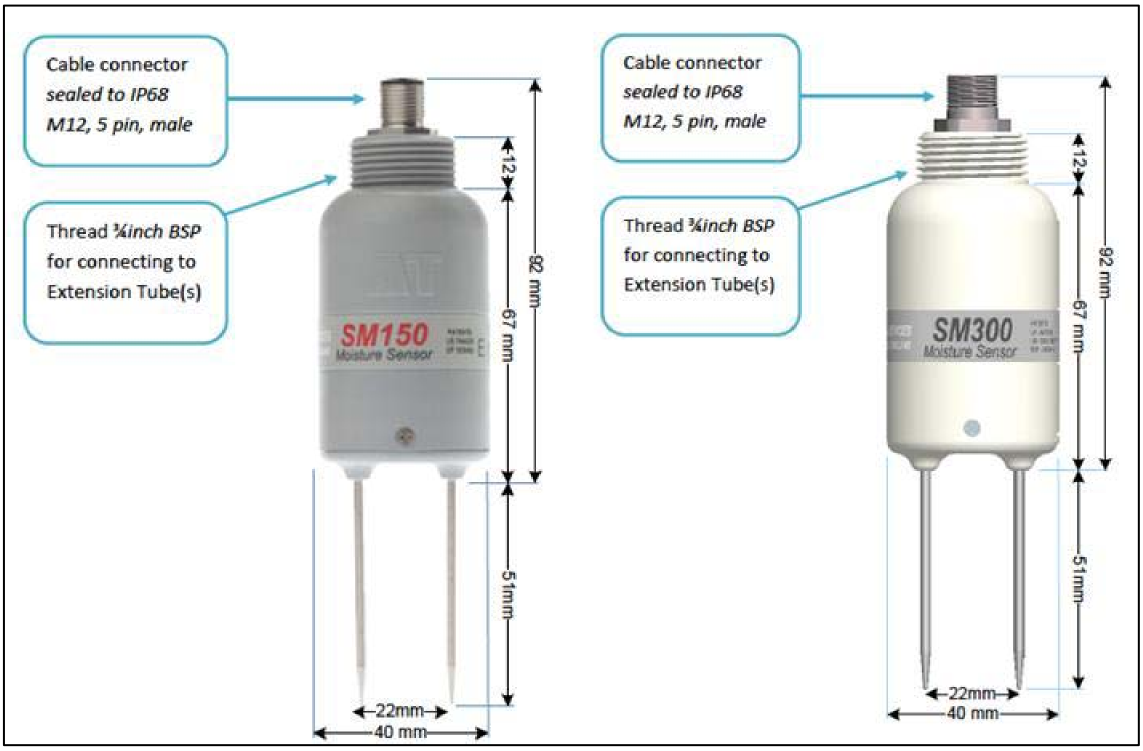


Figure 9. SM150 (soil moisture) and SM300 (soil moisture and temperature) equipments

- Accuracy of measures are a) for SM150/300: Soil moisture accurate to ± 2.5%; Soil temperature to ± 0.5°C over 0-40°C; b) for PProbe PR2: Soil moisture accurate to ± 2.5%

<u>Working principle of FDR:</u> the electrical capacitance of a capacitor that uses the soil as a dielectric depends on soil water content. When this capacitor (made of metal plates or rods imbedded in the soil or in access tubes) is connected to an oscillator to form an electrical circuit, changes in soil moisture can be detected by changes in the circuit operating frequency. In FDR, the oscillator frequency is controlled within a certain range to determine the resonant frequency (at which the amplitude is greatest), which is a measure of water content in the soil. When an electrical field is applied, the soil around the electrodes (or around the tube with electric cells for the PProbe) forms the dielectric of the capacitor to complete the oscillating circuit. In some cases, an access tube is used to allow multiple sensors to measure soil moisture at different depths.

All the soil moisture and temperature probes are connected with a multiple **GP2 Data Logger Controller** (Delta-T Devices Ltd., Cambridge, UK). The GP2 has 12 differential analogue input channels2, four event/digital counter channels and a serial input channel for a WET sensor. Each sensor can be read at a different rate, from 1 second to >1000 days. Multiple recording rates are possible for any combination of measurements. Multiple recording types are provided:- average, minimum, maximum, total, integral, wind-rose, conditional. The logger can hold about 2.5 million readings (figure 10).

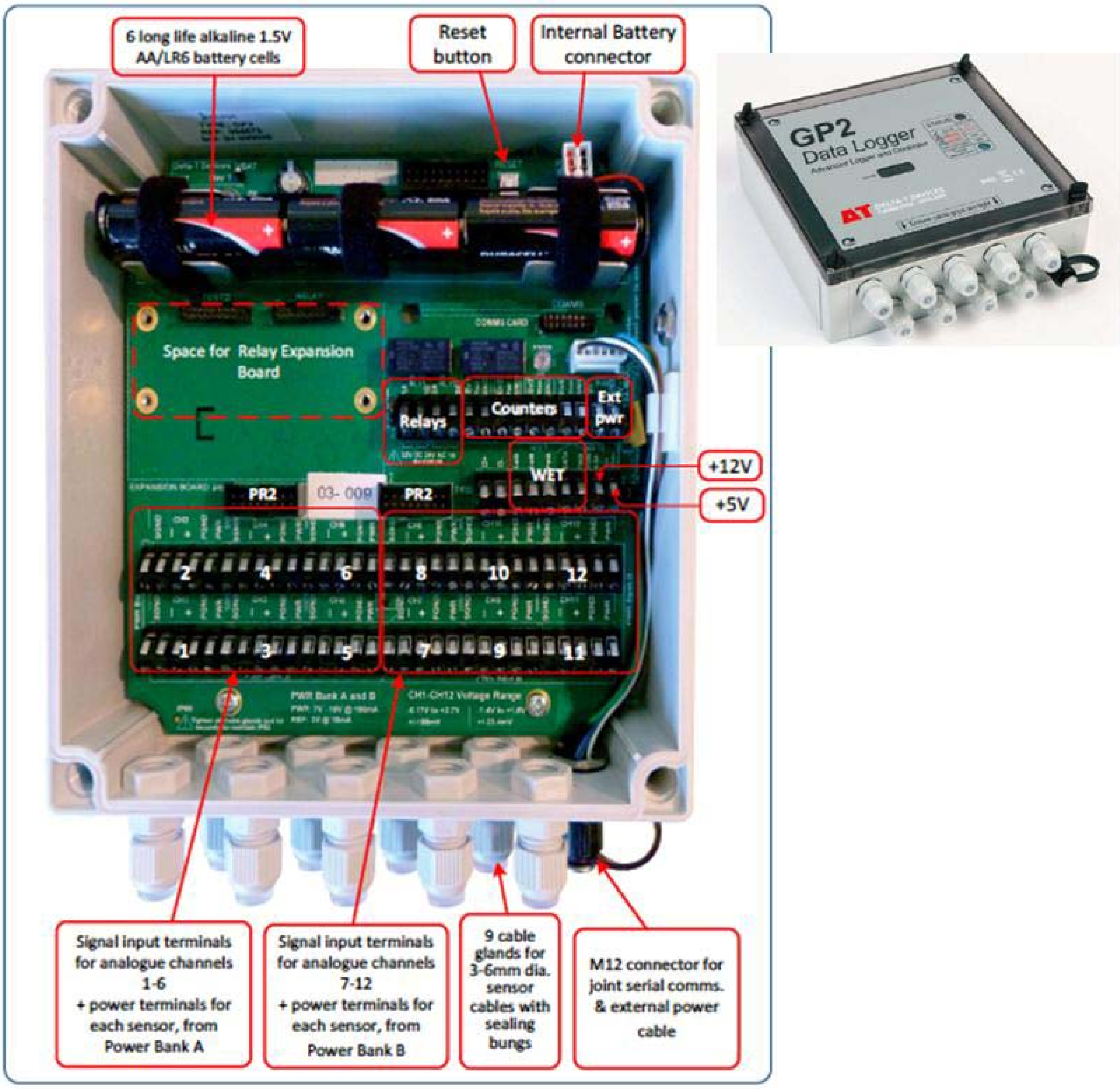


Figure 10. Layout of the GP2 Data Logger Controller

In our experimental monitoring network for each trial Plot (figure 11) we will measure 5 points with a central point at six depth with PR2 (10,20,30,40,60, 100 cm) 2 points at 30 cm depth with SM150 (soil moisture) and 2 points at 30 cm depth with SM300 (soil Moisture + temperature).

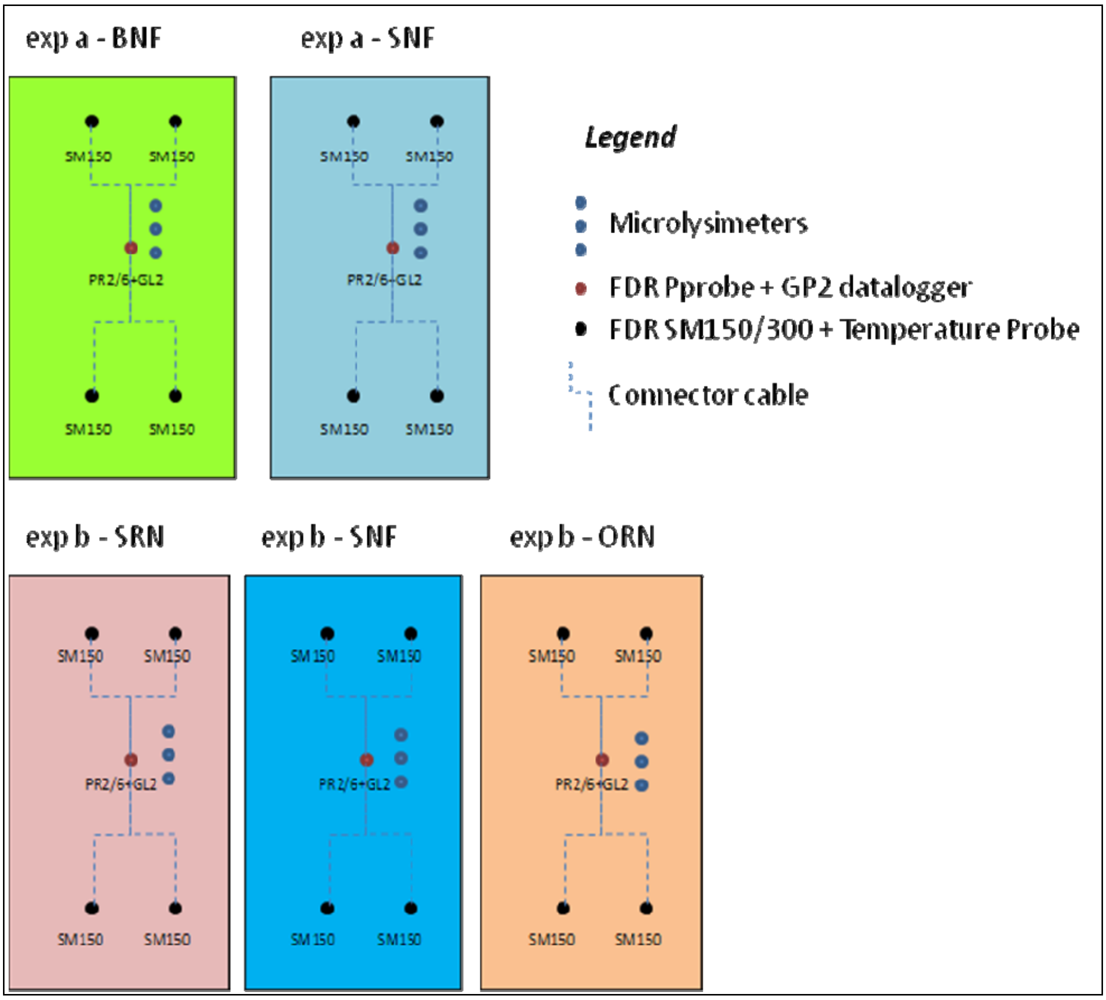


Figure 11. Soil moisture and temperature monitoring sensors network scheme and mycrolisimeter for collecting percolation water (N-NO3) inside the different experimental trial plots

1.3 Size of the grid monitoring and scanning time of the time series for EO ground check

Size of the experimental trials, according to the monitoring activity for model the N and C cycle in the soil-crop system and to the EO ground check, has been established in a minimum size of 0.5 ha for each Trial Plot. This is the minimum area necessary to compare the EO evaluations with the provided platforms types (Sentinel-2 and Landsat) with the ground measures monitoring grids.

1.3.1 Standard ground check for EO and/or Proximal sensing upscaling

The target of this activity is to monitor the Nitrogen content variations and/or deficiencies in the crops canopy (leaves), trough indirect measurements of the Chlorophyll content, with two different approachs:

- Optical measurements with handled devices at single leaf level (Chlorophyll Meters)
- Spectroradiometer measurements at ground level (Field Spec) in the "red-edge" range of wavelength.

1.3.2 Optical measurements with Chlorophyll Meters

Non invasive measures at crop canopy level will be taken with a handled device. Some of different types of this kind of equipments were evaluated, according to the strong relation between Chlorophyll content and Nitrogen content at crop leaf level (Errecart et al., 2012; Confalonieri et al., 2014; Alì et al., 2015; Arregui et al., 2006; Hong-Li et al., 2015), sometimes related also to the soil moisture conditions monitored by in-field sensors (Juan-Juan et al., 2011).

The chlorophyll meter could indicates the current plant N status, but to establish the crop N requirement the chlorophyll meter requires calibration for different genotypes, plant growth stages, and environmental conditions, since these factors may aff ect (i) the relationship between chlorophyll meter value to chlorophyll content per leaf, (ii) relationship between leaf chlorophyll content and leaf N content, or (iii) the relationship between leaf N content and amount of fertilizer N (.Samborski et al., 2009)

The most commonly used devices are:

- SPAD 502DL Plus Chlorophyll Meter (Spectrum Technologies, Inc., Aurora, IL – USA) with Data Logger & RS-232
- MC-100 Clorophyll concentration Meter (Apogee Instruments Inc., Logan Utah – USA) with Data Logger & RS-232

Some differences are reported in using this two different type of devices. Both the instruments work by taking non-invasive measurement, simply clamp the meter over leafy tissue, and receive an indexed chlorophyll content, to be traduced in the real Chlorophyll content by using a given equation. SPAD502DL Plus has been reported in most of the studies about correlation between Cl and N, for a wide range of crops, both permanent (fruit trees and Vineyards) and seasonal erbaceous (maize, wheat, vegetables, tomato, potato, etc.). However, MC-100 is a new instrument that is going to be used more and more often in recent times because of the wider measurement area on the leaf (9 mm of diameter).

Moreover, this device provides an estimate given by the chlorophyll in **µmol of chlorophyll per m2 of leaf surface**, in addition to the CCI values and SPAD units. The most important aspect, than previous measurement methods, is that the values are linearly related to the actual presence of chlorophyll (figure 12). This patent pending meter is a significant improvement over older style meters, which output indexes that are non-linearly related to leaf chlorophyll.

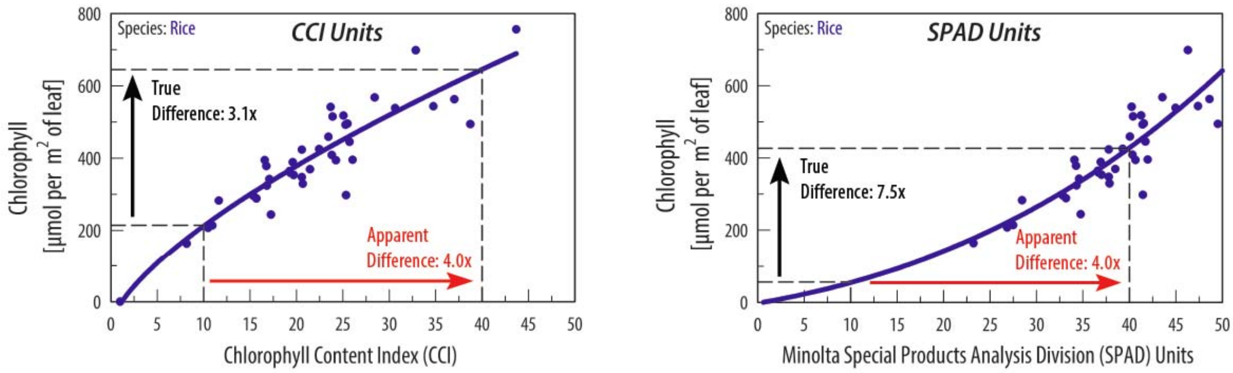


Figure 12. CCI (Chlorophyll Content Index) and SPAD units show non linear correlation between lectures and Chlorophyll content (from Parry et alii, 2014)

1.3.2.1 Sampling protocol

In many research studies the sampling protocol to collect representative measurements at leaf level was reported, according to different type of crops and leaves, during the crop growing season (Houborg et al., 2009; Perry and Davenport, 2007; Houborg et al., 2013; Fox and Walthall, 2008). Most of the sampling methods refer to several "sampling spots", depending on the size and number of trial Plots, and on the size of the Remote sensing images to be correlated with.

The number and type of leaves measurements proposed inside the crop canopy were based both on random and fixed methods; indeed, the number and position of measurements inside a single leaf was also considered with different qualitative and/or quantitative approach (Wu et al., 2007; Houborg et al., 2009).

It has been demonstrated by statistical analisys that the relationship between the number of leaves used and the difference between estimated and applied N suggests that there is a limit for improvement with additional leaves, at perhaps 25–30 leaves. While the estimates improved with the number of leaves used, they did not seem to be sensitive to the time during the growing season that the measurements were made (Perry and Davenport, 2007).

In our sampling scheme we decide to fix the sampling spots corresponding with the sampling point to be used to measure the N content by lab analysis (Nitrogen Analyzer),as well as to measure all the N contents both in soil and in the crop biomass/residues.

Each sampling spot is constituted by a square area of generally 1-2 m^2, inside of which are to be taken a lot of measures according to: a) representative measures of the total plants and leaves amount; b) representative number of measures for each leaf.

Because he analytical data will be used as input in modelling the N cycle during all the crop growing season, the comparison with the N indirect leaf content by Chlorophyll Meter will be used for two targets:

- Validate the accuracy of Leaf non-invasive measures, evaluating the best N correlation to be connected with EO correspondent N evaluations by readings in the "red-edge" range;
- Consequently, use the readings of N at canopy levels in comparison with the model prediction for the whole N cycle and status in the soil-crop system. This activity will be the basis to build some correlation algorithms between EO lectures at red-edge range and the ground N variations in the whole crop and soil.

The sampling scheme is reported in the following figure 13.

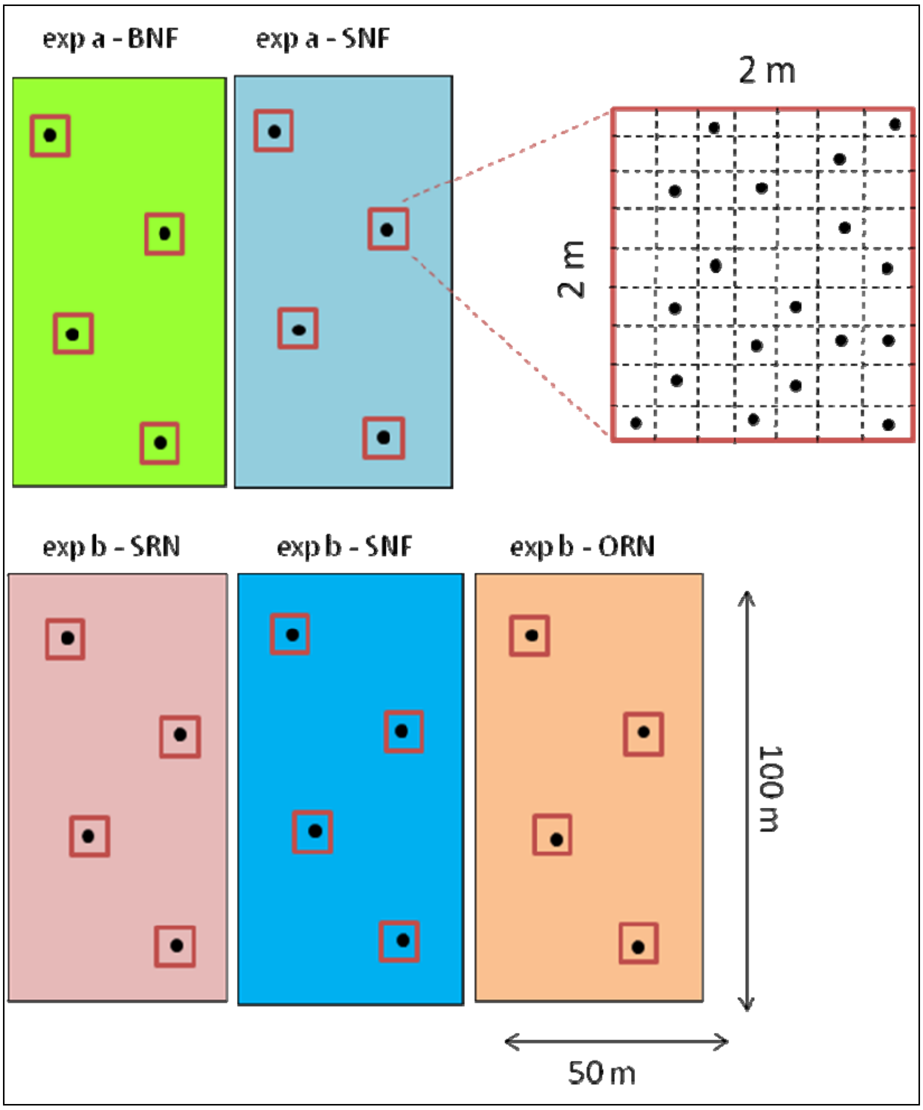


Figure 13. Sampling scheme for the non invasive crop canopy measurements

Sampling method inside the single Plot: For each of the 4 square samplig area (2x2m) a sampling grid was designed and a random total sample corresponding to a 30% of all possible points extracted with the Arc GIS Tool Geostatistical Analyst, with a range of 18-20 plants. For each plant 3-5 leafs will be measured collecting the mean value of 4-6 measures for single leaf.

1.3.3 Spectroradiometric measurements in the "red-edge" range

NIR reflectance spectroscopy is a method that makes use of the near infrared region of the electromagnetic spectrum from about 700 to 2500 nanometers. By measuring light scattered off of and through a sample, NIR reflectance spectra can be used to quickly determine a material's properties without altering the sample. The equipment that will be used is the ASD Inc. FIELD SPEC Spectro-radiometer. ASD FIELD SPEC has taken NIR technology a step further with the Goetz spectrometer, a hybrid system that uses a combination of visible and NIR regions (Vis/NIR) to include wavelengths from 350 nm to 2500 nm.

In the Pilot experimental area of Italy, will be performed a time series of ground measurements with the FIELD SPEC instrument, under the supervision of the expert group of ARIESPACE.

1.3.3.1 Sampling protocol

To plan the ground measurements, we must take into account to calibrate the resolution depends on the distance of FieldSpec tool-target. Usually using an FOV of 25 ° (maximum possible) to a heigh form the ground of 1 meter (compatible with the positioning of the instrument in the field) it is observed a circular area of about 40 cm. The measuring range "reliable" and '400-900 nm.

On this basis, data will be acquired in the same spot areas monitored with the Optical Chlorophyll Meters device (figure 14). In each sampling area, there will be acquired from 3 to 5 FIELD SPEC lectures in the VIS/NIR range.

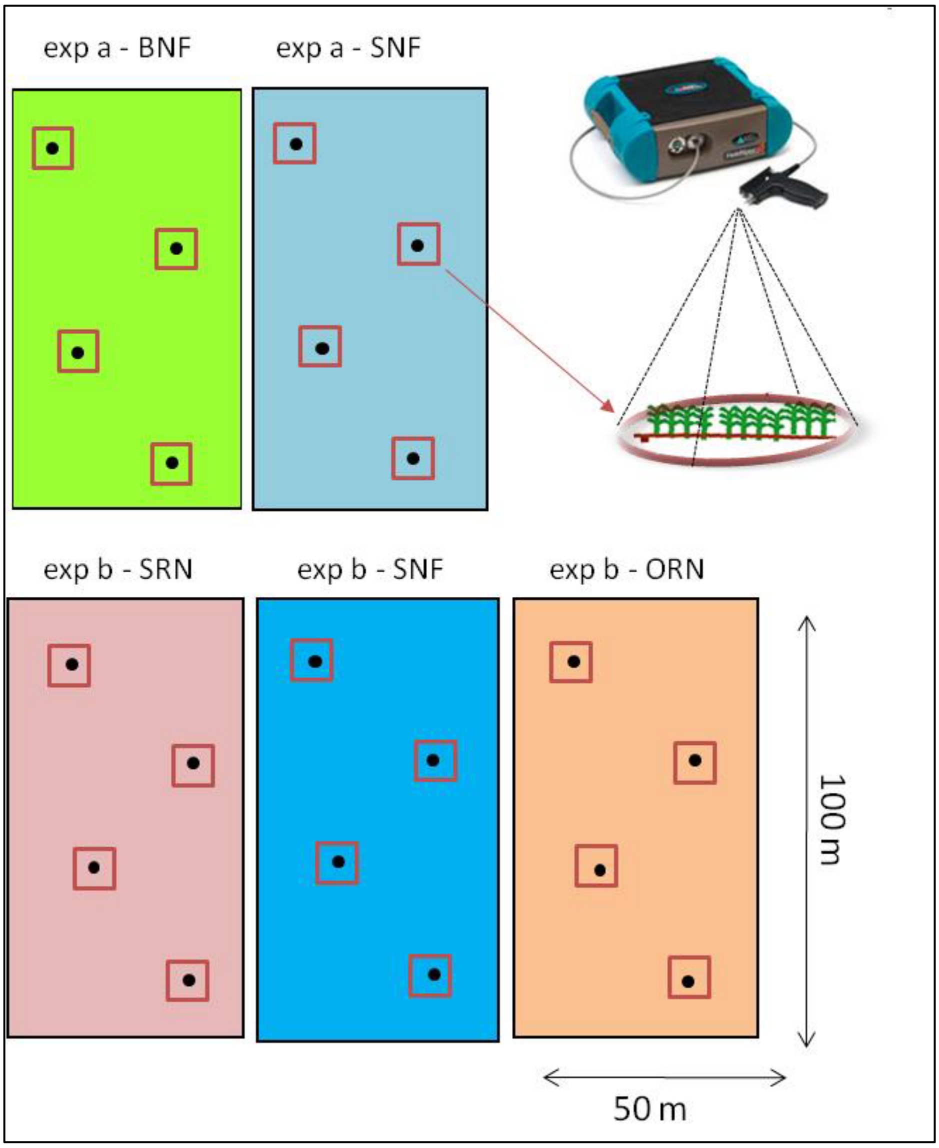


Figure 14. Sampling points for Field Spec Radiometric measurements in the Italian Plots

1.4 Geoprocessing and/or modelling methodologies and tools to evaluate monitoring datasets

1.4.1 Geoprocessing techniques and tools

Following the sampling grid schemes assessment showed in the previous section, some different kinds of Geostatistical techniques will be used at Plot level to interpolate the data and obtain raster maps with continuous data. Geostatistical methods can be used to generate maps and to assess the uncertainty of the predicted values as an alternative to a detailed survey.

In particular, Kriging and cokriging are geostatistical techniques used for interpolation (mapping and contouring) purposes. Both methods are generalized forms of univariate and multivariate linear regression models, for estimation at a point, over an area, or within a volume. They are linear-weighted averaging methods, similar to other interpolation methods; however, their weights depend not only on distance, but also on the direction and orientation of the neighbouring data to the unsampled location.

Another advantage of kriging is that the variogram, computed as a part of the kriging process, provides useful information about how the measured values of the variable z may be expected to relate to each other (Plant R., 2001). In particular, it tells how far apart two points must be before the values measured at those points are uncorrelated (this is called the range in geostatistical terminology). The range can be useful in deciding the spacing of a sampling grid. McBratney and Pringle (1997) give a summary of variogram data for a variety of soil properties including pH, clay content, and mineral nutrient levels.

The most relevant to use at Plot scale will be:

- Ordinary kriging (OK)
- Empirical Bayesian Kriging (EBK)
- Indicator Kriging (IK)

1.4.1.1 Ordinary kriging (OK)

Ordinary Kriging is a kriging method in which the weights of the values sum to unity. It uses an average of a subset of neighbouring points to produce a particular interpolation point. It assumes a constant but unknown mean. And also assumes that the estimated semi-variogram is the true one of the observed data.

1.4.1.2 Empirical Bayesian Kriging (EBK)

This approach has the advantage of being able to interpolate non-stationary data for large areas and is considered a more accurate method than ordinary kriging for small datasets (figure 15). Indeed, it is a geostatistical interpolation method that automates variogram estimation with minimal manual interference based on the sample distribution of the estimators of the variogram function. The conventional geostatistical methods calculate the variogram from known data locations and fit the best model to this empirical variogram. Any single variogram model generated from the previous step is then used to make predictions at unknown locations. Thus, the method does not take into account the uncertainty of variogram estimation, which may result in underestimation of the standard error (SE) of prediction. The EBK method differs from ordinary kriging because it can account for the error introduced by estimating the underlying variogram. Thus, with the EBK method we can account for the uncertainty of estimation.

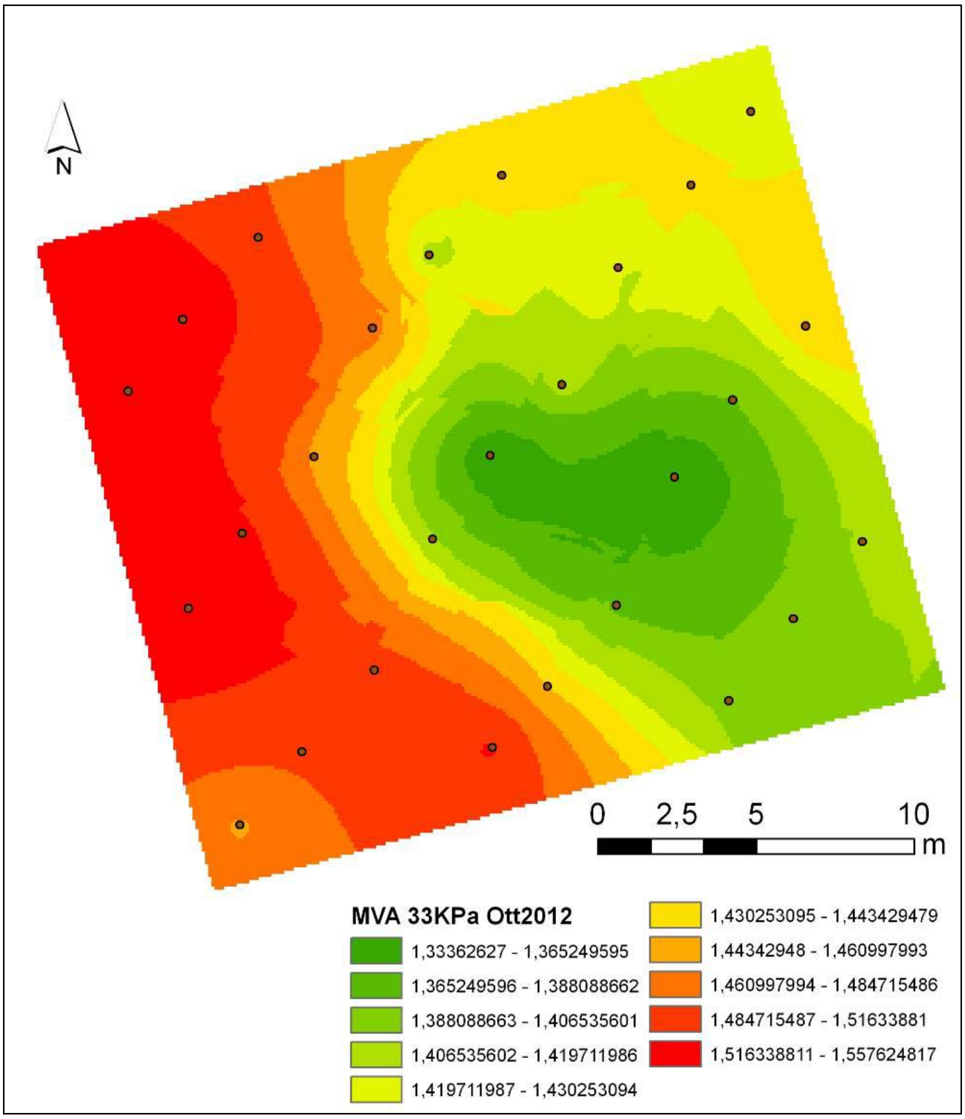


Figure 15. Example of spatialization of Field Capacity soil bulk density (MVA) at plot scale (pixel=2m) performed with Empirical Bayesian Kriging (EBK); sampling points are showed with dots.

1.4.1.3 Indicator Kriging (IK)

Indicator Kriging (IK) methodology provides information on the spatial distribution of specific classes of values, estimating the probability to exceed threshold values (Goovaerts, 1997; Cullmann and Saborowski, 2005; Grunwald et al., 2006; Zhang and Yao, 2008). IK has been widely used for probabilistic analysis, spatial prediction and risk assessment in many fields of investigation, where a probability map allows a better knowledge of the studied phenomena (Alli et al., 1990; Tarboton et al., 1995; Demir et al., 2009; Odeh and Onus, 2008). Many authors adopted this non-parametric geostatistical approach to assess the risk of soil and groundwater pollution (Lin et al., 2002; Diodato and Ceccarelli, 2005; Reis et al., 2005; Adhikary et al., 2010; Zhang et al., 2009).

IK was already applied successfully for mapping the groundwater nitrate vulnerability by CRA-RPS at a semi-detailed scale in the area of the Fucino Plain (Abruzzo, Central Italy), which is characterised by a profitable intensive agriculture, mainly irrigated horticultural and short rotation crops (Piccini et alii, 2012).

All that kind of geostatistical methods could be applied with R Opensource software tools (R Core team, 2014).

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