Deliverable 3.4

Global innovation field analysis, results and lessons learned

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Executive summary

This report proposes a global analysis of results obtained in the CAMA WP3 task 3. In 7 countries (Greece, France, Italy, Morocco, Portugal, Tunisia, Spain), measurements were realized on farmers' fields with the Diagchamp® method. The goal was to identify technical innovations to reduce limiting factors under Conservation Agriculture in Mediterranean Area on the topics defined in the WP3, tasks 3.1 and 3.2: weed control, seeding, crop fertilization and crop rotation.

On weed management, some problems are noticed on Conservation agriculture about *Lolium, Raphanus, Avena fatua*, *Poa pratensis* and *Hirschfedlia incana*. A positive effect of crop rotation was noticed, especially to control *Lolium*, thanks to herbicides rotation. There is also a positive effect of pluriannual legume as previous crops (*onobrychis*, alfalfa) for cereals due to mowing and weeds exportation out of the field, due to inhibiting the weed to reach the generative growth stage. The effect of pluriannual legume as previous crop is maintained if this legume is well managed on the cereal to avoid nitrogen and water competition. About herbicides uses, Glyphosate remains essential in no-till systems and efficient to manage weeds.

On seeding, no significant yield differences have been noticed in general between conventional tillage and minimum tillage or direct sowing even if we could notice more risks on achieving potential yield under conservation agriculture practices. Some data have demonstrated a positive effect of plant cover and crop rotation on soil compaction under conservation agriculture.

On crop fertilization, the experiments have not demonstrated differences on nitrogen efficiency comparing type of fertilizers (ammonium, urea or urea with inhibitor) on wheat, but investigations must be continued. According to French experimentation, there is a negative effect of minimizing nitrogen inputs at tillering in conservation agriculture probably due to dry periods at this time and nitrogen competition with crop residues degradation. Nitrogen stress is first caused by difficulties to have climatic niches for nitrogen positioning and a good valorization in Mediterranean conditions. In any cases, legumes as previous crops seem to improve nitrogen nutrition in situations with low fertilization possibilities due to the climatic or socio-economical context.

On crop rotation, the observation is established of the difficulty of covering the soil in summer in Mediterranean conditions. Semi-permanent cover seems to be an interesting innovation to be tested and adapted in other countries than France. According to Maroc experiments, some genotypes seem to be more adapted to Conservation Agriculture than others (barley).

Furthermore, some data were calculated on nitrogen and water efficiency according to type of tillage or crop rotation, on specific fields. In 6 comparations on 8, conservation agriculture (MT and DS) has a better nitrogen productivity or water efficiency than conventional tillage, even if it's statistically significant only in one case.

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1. Introduction

1.1. Scope of the document and objectives

This document presents global results from a network of measurements in farmers' fields in Conservation Agriculture. The global dataset is presented in the Deliverable 3.3.

If the Deliverable 3.3 presents the results country by country, this deliverable aims to analyze the lessons learned from the WP3 in a synthetic point of view, according to the topics raised in the Deliverables 3.1 and 3.2:

- Weed control;
- Seeding;
- Crop fertilization;
- Crop rotation.

1.2. Notations, abbreviations and acronyms

CA	Conservation Agriculture
AAC or AUC	Area Under the Curve
AET	Actual evapotranspiration
CAMA	Conservation Agriculture in the Mediterranean Area
CAP	Common Agricultural Policy
CDERP	Communication, dissemination and exploitation of results plan
CHN	Carbon, Water and Nitrogen model
CT	Conventional Tillage
DS	Direct Sowing
EC	European Commission
IPR	Intellectual Property Rights
MET	Maximum evapotranspiration
MT	Minimum Tillage
NNI	Nitrogen Nutrition Index
NUE	Nitrogen Use Efficiency
PMT	Project Management Team
RD&I	Research, Development and Innovation
RIA	Research and Innovation Action
TRL	Technological Readiness Level
WP	Work Package
WT	Work Task
WUE	Water Use Efficency

1.3. Background

CA, built upon the principles of minimal soil disturbance, crop residue retention, and strategic crop rotations, not only enhances soil health but also plays a pivotal role in optimizing nutrient and water management for crops like winter wheat. In a technical point of view, we could consider than there could have some differences between CA and CT about:

- **Weed management** because of no tillage, especially with *Lolium*.
- **Nitrogen nutrition**:
  - On one hand:
    - We could have more nitrogen competition between crop and microbial biomass, supposed to be more important under CA.
    - We also could have a more important level of residues to be degraded and, in consequences, more nitrogen immobilization.
  - On the other hand :
    - If we supposed to have a more important Organic Matter rate, we could expect more nitrogen mineralization.
    - Systems with legume as crop or plant cover in rotation can generate more nitrogen mineralization.
- **Seeding** with crop residues management.

2. Methodology

2.1. Diagchamp method

The results come from the use of the "Diagchamp" Method, explained in the D3.3. "Diagchamp" is based on an experimental approach: it is not *analytical* (where the modalities of one or two factors are compared, all other things being equal, with repetitions), but *diagnostic* (considering a whole cropping system with several interacting factors that are not controlled), trying to understand and explain the phenomena that are occurring, as a doctor would with a patient. However, some data come from analytic trials.

2.2. Data description

To realize a global analysis by grouping results from different countries, a precise characterization of the different fields' experiments was realized.

For each field, the following elements of the technical itinerary and environmental characterization are noticed for the three growing seasons of the project (2021, 2022 and 2023).

Type	Theme	Indicator (*used for modelization)
Technical itinerary	Previous crop type*	Legume / No legume
	Type of tillage before crop*	DS/MT/CT
	Irrigation*	Number of irrigation on the studied crop
	Crop*	Bread wheat / Durum Wheat/ Barley
	Variety*	Genotype used
	Sowing date of the crop and sowing density *	Sowing density in grains/m²
	Water inputs (irrigation and rain) *	mm
	Nitrogen Inputs and type of fertilizer *	kg N/ha or kg
	Crop protection	Type and dose of herbicides, fungicides and insecticides
Environmental data	Soil analysis	SOM, texture, depth
	Soil nitrogen content at BBCH 31	kg N/ha
	Soil moisture art BBCH 31	Soil water content (%)
	Weather data	Daily rainfall, minimum and maximum temperature, daily radiation, wind speed

Figure 1: technical itineraries and environmental data collected by famer's field

2.3. Data modelization

2.3.1. Global View of indicators about water and nitrogen stress

As explained in the D3.3, the nitrogen and water stress of cereals were modelized for each field experiment with CHN model. The indicators used to characterize water and nitrogen stress are resumed in the following table.

Theme	Indicator	Explanations
Nitrogen stress	Nitrogen Nutrition Index at flowering	
	Nitrogen stress index biomass	Nitrogen stress index biomass calculated by CHN for each day of crop growing from 0 (maximum water stress level) to 1 (no water stress)
	Global nitrogen stress index biomass	Area Under the Curve (AUC) of nitrogen stress index biomass
	Nitrogen Use Productivity	Kg of N/t
Water stress	MET	Maximum evapotranspiration (mm)
	AET	Actual evapotranspiration (mm)
	sum MET-AET (mm) pre-Flowering	MET-AET (mm)
	Stress pre-flow (AET/MET) pre-Flowering	AET/MET
	Water stress index biomass	Water stress index biomass calculated by CHN for each day of crop growing from 0 (maximal water stress level) to 1 (no water stress)
	Global water stress index biomass	Area Under the Curve (AUC) of water stress index biomass
	Water use productivity	mm (rain + irrigation) / Yield (mm/t)

Figure 2:data collected to calculate nitrogen and water stress.

The Figure 3 explains how AUC is calculated for Nitrogen and Water stress with CHN Model.

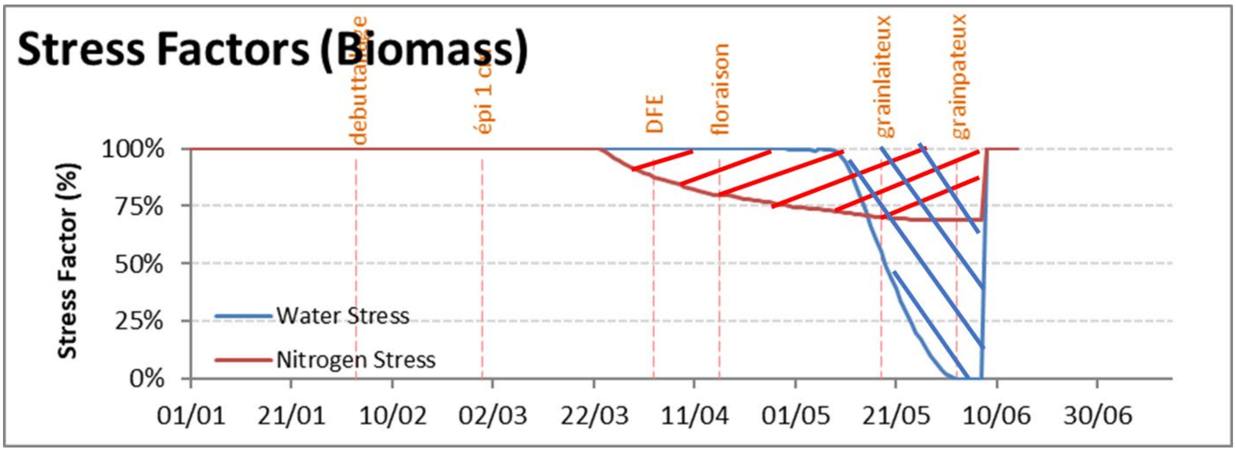


Figure 3: example of Area Under the Curve calculated for nitrogen and water stress with CHN

2.3.2. CHN Model

The Crop Hydro-Nitrogen (CHN) model, developed by ARVALIS - Institut du végétal, operates as a mechanistic crop model designed primarily for real-time decision support during the cropping season. To facilitate CHN use, well-defined parameters in the three compartments are essential. The model uses three modules for calculations and equations, corresponding to carbon (C), water (H), and nitrogen (N) fluxes. CHN assesses water, nitrogen, and carbon fluxes within the soil-plant-atmosphere continuum daily, considering each 1cm layer of soil. Comprising three main compartments—soil, plant, and atmosphere—the model is intricately connected to databases administered by ARVALIS. The soil compartment interfaces with a comprehensive soil database housing approximately 500 records, providing detailed descriptions of various soil horizons. These records are categorized based on characteristics such as limestone content, stoniness, soil texture, depth, and hydromorphy. Pedotransfer functions integrated into the database estimate additional soil characteristics. The atmosphere compartment links to a weather database containing daily data from over 700 weather stations across France, spanning more than 25 years.

Utilizing the Monteith principle for the plant compartment (Monteih et al., 1977), CHN models foliar growth and biomass production in response to intercepted solar radiation. Root growth is also modeled, contributing to estimates available nitrogen and water. Stresses related to hydric and nitrogenous availability impact foliar and biomass growth, incorporating response functions inspired by Sinclair's work (Sinclair, 1986). Crop development is simulated using ARVALIS phenological models connected to a variety database comprising over 400 maize, 350 bread wheat, and 50 durum wheat varieties, updated annually.

The carbon fluxes module incorporates the AMG model (Andriulo et al., 1999), allowing for the simulation of long-term organic carbon stock evolution in the soil. For nitrogen fluxes, CHN utilizes a nitrogen balance derived from standard formalisms, Comifer references, bibliography (Mary et al., 1999, Justes et al., 2009), and ARVALIS research. CHN manages nitrogen forms daily, considering potential inputs and losses: organic nitrogen, urea, ammoniac and nitrate. Each day, CHN updates each step of the nitrogen balance calculation by taking into account potential inputs and losses from the soil compartment: soil supplies (humus mineralization, crop residues mineralization, catch crop residues mineralization, organic waste products mineralization, and mineralization due to ploughing up grassland), mineral fertilizer inputs, atmospheric nitrogen inputs, symbiotic nitrogen inputs, eventual nitrogen inputs in irrigation water, nitrogen losses by run-off, by leaching, by volatilization, nitrogen organization, and finally nitrogen uptakes by the plant.

The water fluxes module employs a water balance model distinguishing topsoil evaporation and plant transpiration. Inspired by Lecoeur's work (Lecoeur, 2000, Lecoeur et al., 2004) and other models like PILOTE, the model calculates daily in a sequence that includes estimating plant transpiration, evaluating effective rain, simulating evaporation and transpiration, and determining soil moisture levels and water stocks.

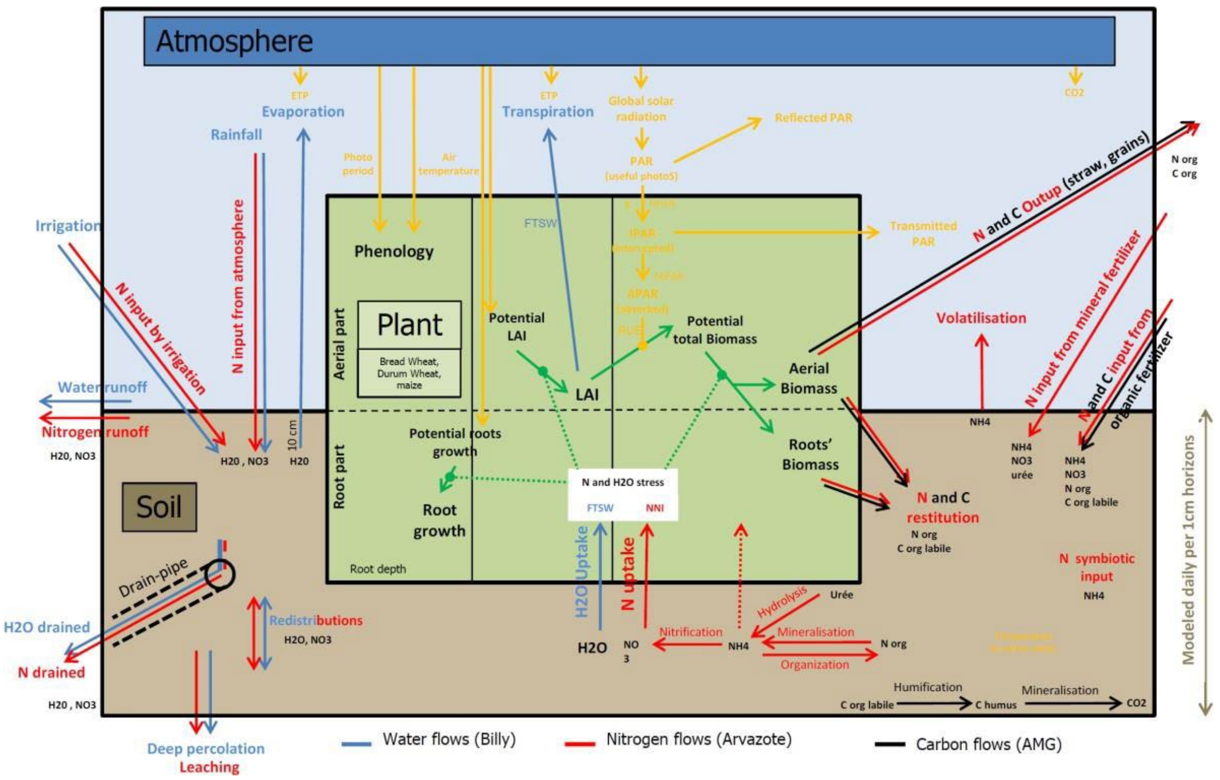


Figure 4: synoptic of CHN crop model

2.3.3. CHN resetting with fields' measurements

In the Diagchamp® method, CHN is used to precise the agronomic diagnosis, especially on nitrogen and water stress. CHN is resetting by fields measurements on:

- Crop stages.
- Soil nitrogen residues and moisture at BBCH 31.
- Biomass and nitrogen absorbed at flowering.
- LAI and chlorophyll all along the campaign with satellite measures.

2.3.4. Modelization of potential biomass at flowering

A modelization of potential biomass at flowering was realized with CHN. It represents the biomass allowed by the level of hydric and water stress simulated in each monitored plot. The quantification of nitrogen and water stress depends on the parametrization of CHN: technical itinerary (Figure 3), resetting with fields measurements (soil nitrogen residues) and satellite. Differences observed between the biomass simulated at flowering and measured in the field could be due to:

- Limiting factors cannot be simulated by CHN: biotic (pests, weeds, diseases) or climatic (frozen, scalding…); these limiting factors are identified by technicians' observations with Diagchamp.
- Persistent problems to parametrize the model: atypic genotypes, impact of very early water stress (not well considered before BBCH31), soil correspondences with French database…

The identification of model deviation (limiting factors or model parametrization) will be studied in this deliverable.

2.3.5. Modelization of potential yield

A modelization of potential yield was also realized by Garric ® a model from Arvalis. This model, parametrized for French Mediterranean conditions estimate a potential yield based on:

- Soil useful reserve/soil water capacity (mm);
- Sowing date;
- Principle stages (BBCH 31, BBCH 65);
- Estimation of water balance based on AET/MET according to climatic data.
- Estimation of yield losses due to AET/MET based on Mediterranean French data. For each simulation, a potential yield without water stress serves as the basis for modelization. This potential was estimated by each partner in CAMA (Figure 6). With GARRIC the potential is degraded according to the level of AET/MET.

	Potential yield without water stress (t/ha)
Spain	9
Morocco	7
Greece	7
Algeria Algier	6
Algeria setiff	4
Tunisia semiarid	4
Tunisia subhumid	6
France	12
Portugal	10
Italy	10

Figure 5: estimation of potential yield without water stress for each country

2.4. Global dataset

89 plots were monitored using the Diagchamp method in the WP3.

The different themes worked with the Diagchamp method are illustrated in the following table, according to WP3.1 & 3.2 conclusions.

89 plots were monitored used the Diagchamp method in the WP3 in all countries (Figure 6, Figure 7).

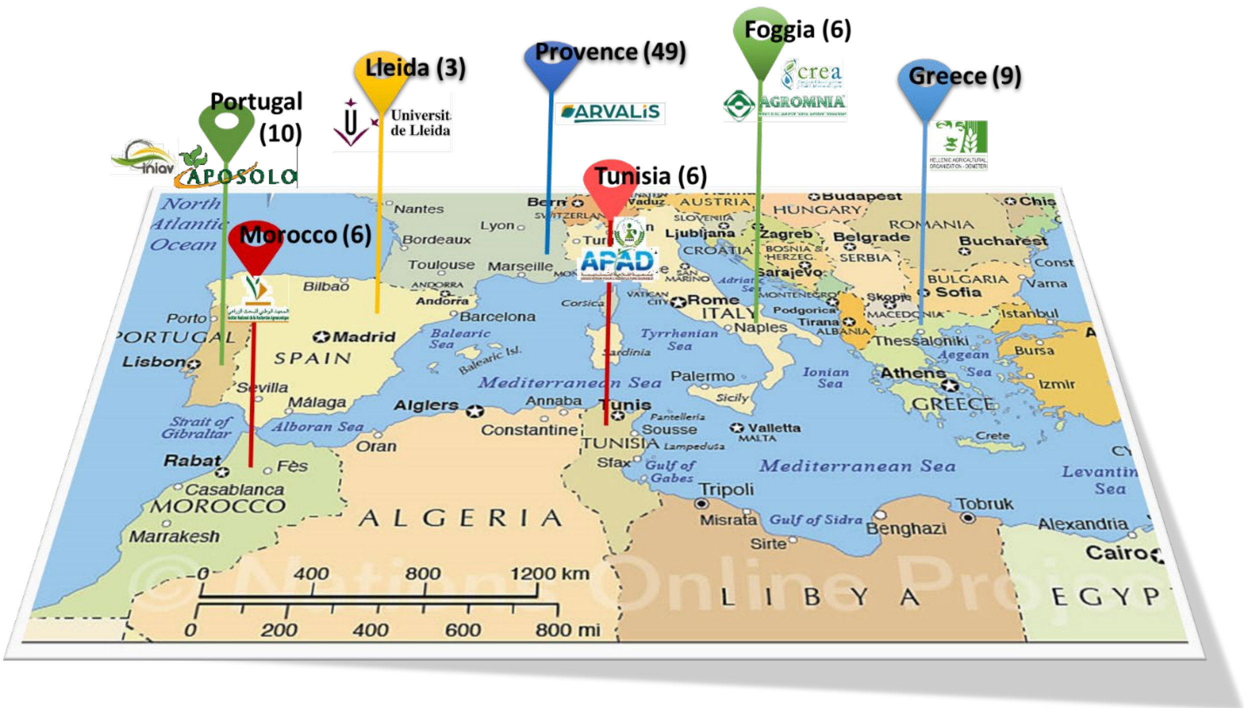


Figure 6: repartition of Diagchamp fields monitored in all countries in the WP3

WP 3.1 & 3.2 themes	France	Italy	Spain	Portugal	Greece	Morocco	Tunisia
Weed control	- Crop rotation effect on weeds management			- weeds problems	- Crop rotation effect on weeds management		
Seeding		- Minimum tillage effect on yield			- Minimum tillage effect on yield	- Minimum tillage effect on yield	- Minimum tillage effect on yield
Crop fertilization	- Splitting strategies - type of fertilizers			- Nitrogen stress caracterisation	-Type of fertilizers effect (inhibitor urease)		
Crop rotation	- Plant cover in dry conditions -Effect of semi-permanent plant cover on yield		-crop rotation effect			-genotypes adapted	

Figure 7: thematic worked on WP3

2.5. Data analysis

All statistical analyses were performed with R software version 4.1.2 (R Come Team 2021). The required packages are: “ggpubr”, “KableExtra”, “dplyr”, “ggpmisc”, “FactoMineR”.

3. Results

3.1. Global yield and yield components

The deliverable 3.3 details the results by country. The Figure 8 shows the average performance of bread and durum wheat in the different countries. The performances are very different due to huge variations in the conditions of production (irrigation, rain, genotypes…).

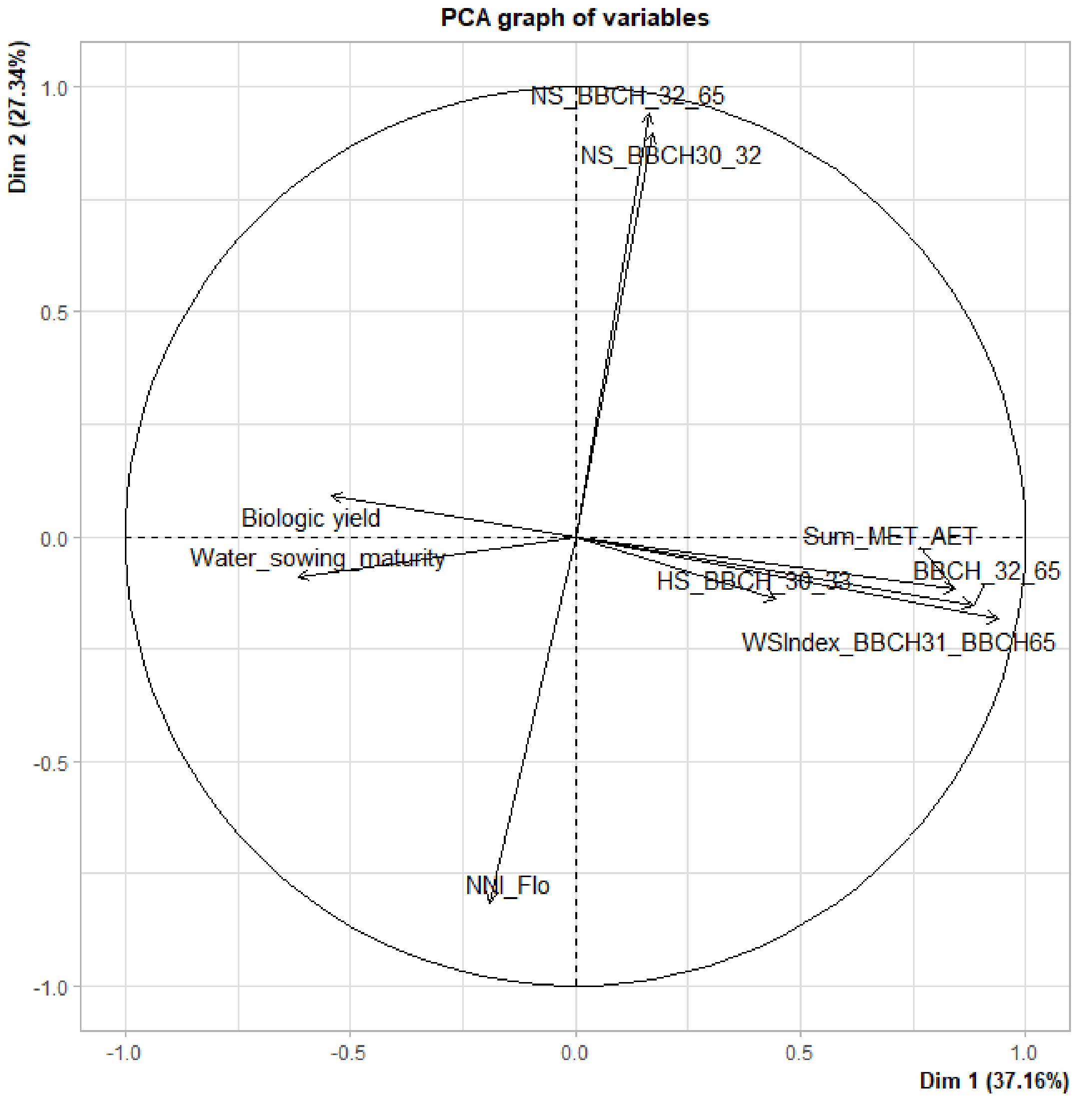
	Grain Yield		Nitrogen inputs		Nitrogen productivity		Water productivity	
Country	**Mean (T/ha)**	**SD**	**Mean (kg N/ha)**	**SD**	**Mean (kgN/T)**	**SD**	**Mean (mm/T)**	**SD**
France	5.57	2.16	175.31	47.1	39.03	24.22	75.39	75.39
Greece	4.42	1.31	95.89	32.32	25.66	16.63	58.81	58.81
Italy	2.94	0.58	73.75	8.5	25.63	5	98.17	98.17
Morocco	4	0.81	87	0	22.56	4.7	68.03	68.03
Portugal	4.63	2.66	103.3	52.41	33.51	36.34	56.16	56.16
Spain	4	NA	75	NA	18.75	NA	45.38	45.38
Tunisia	3.46	0.38	83	0	24.21	2.72	80.13	80.13

Figure 8: average performances of durum and bread wheat production by country

3.2. Correlation between water and nitrogen stress

The Figure 9 presents the results of a PCA according to water and nitrogen stress indicators. It demonstrates:

- A high positive correlation between water stress indicators calculated with CHN and weather data ("Sum_MET_AET").
- A high negative correlation between nitrogen stress indicators calculated and NNI at flowering.
- No correlation between Nitrogen stress and Water stress, probably due to other limiting factors in many cases.
- For biologic yield, a moderate negative correlation with water stress and no correlation with nitrogen stress. It demonstrates that Water stress deleterious than nitrogen stress in the dataset.



variables

	Dim.1	ctr	cos2	Dim.2	ctr	cos2	Dim.3	ctr	cos2
HS_BBCH_30_33	0.445	5.915	0.198	-0.138	0.779	0.019	0.033	0.088	0.001
BBCH_32_65	0.885	23.436	0.784	-0.152	0.945	0.023	0.253	5.031	0.064
WSIndex_BBCH31_BBCH65	0.939	26.381	0.882	-0.184	1.377	0.034	0.235	4.326	0.055
Sum_MET_AET	0.846	21.392	0.715	-0.118	0.566	0.014	0.353	9.744	0.124
NS_BBCH30_32	0.171	0.877	0.029	0.898	32.755	0.806	0.212	3.532	0.045
NS_BBCH_32_65	0.163	0.795	0.027	0.941	35.972	0.885	0.161	2.028	0.026
Water_sowing_maturity	-0.617	11.373	0.380	-0.089	0.323	0.008	0.646	32.750	0.418
NNI_Flo	-0.191	1.092	0.037	-0.814	26.955	0.663	0.267	5.602	0.071
Biologic yield	-0.541	8.738	0.292	0.090	0.328	0.008	0.686	36.898	0.471

Figure 9: PCA on water and nitrogen stress indicators

In 58% of the plots monitored in the WP3, the impact of water stress on biomass was more important than nitrogen stress (Figure 10).

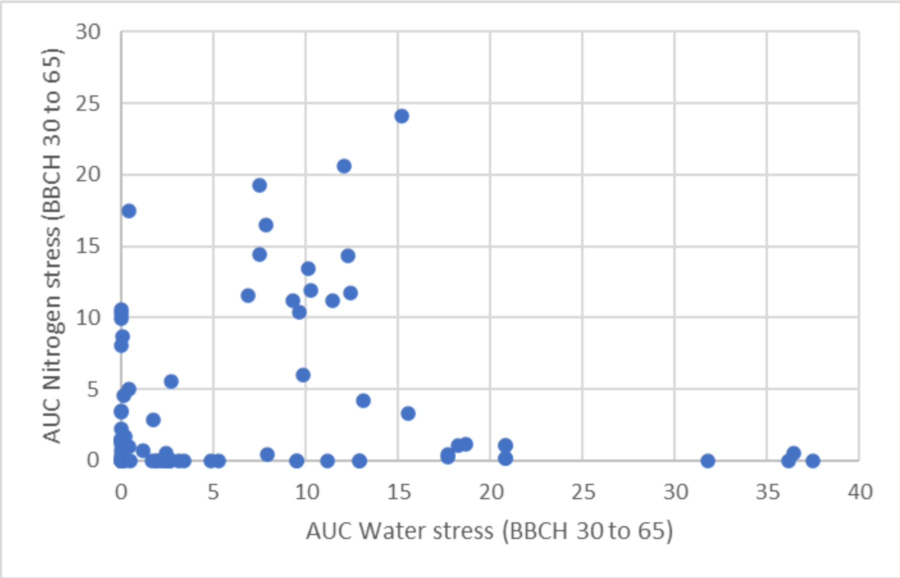


Figure 10: plots repartition according to water and nitrogen stress.

3.3. Impact of water stress on yield

3.3.1. Relation between water available and yield

The biologic yield of durum wheat is very related to water (rain+irrigation) between sowing and maturity, especially without limiting factors identified (LF=0). The correlations are presented in Figure 11. Limiting factors have a significant impact on yield, according to the level of water received by the crop from sowing to maturity. This figure shows the modelized potential yield limited by water.

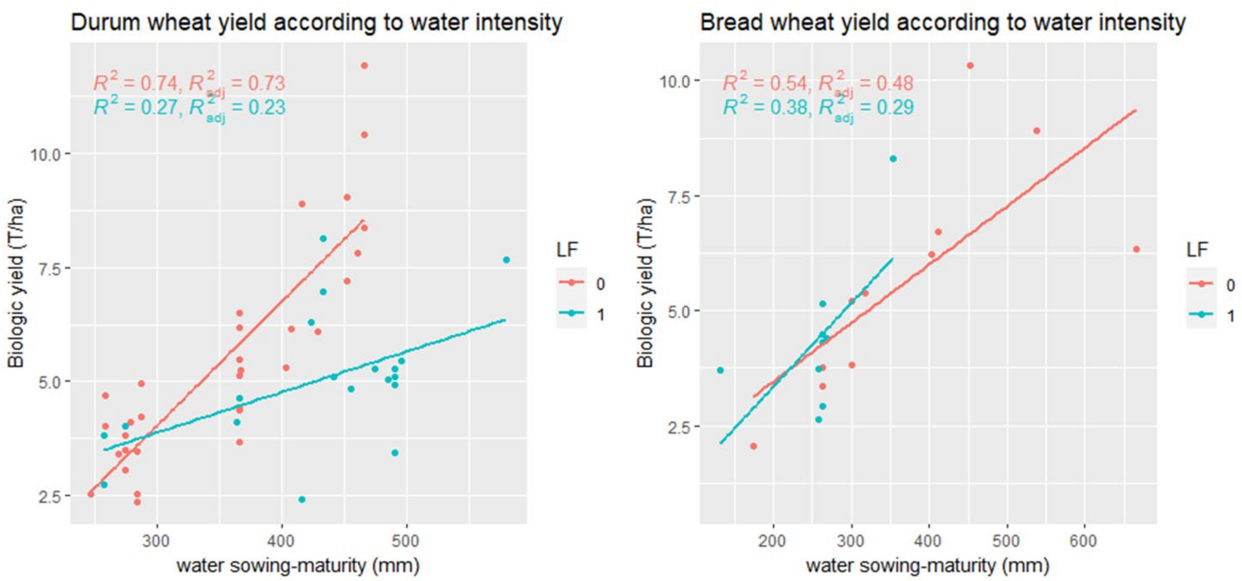


Figure 11: biologic yield (bread and durum wheat) according to water from sowing to maturity

3.4. Conservation agriculture effect on nitrogen nutrition

3.4.1. Relation between NNI and biomass at flowering

The levels of nitrogen inputs could be divided in three groups with equal distribution of effectives:

- Group 1 ("F1"): <85.5 kg N/ha
- Group 2 ("F2"): 85.5-140 kg N/ha
- Group 3 ("F3"): >= 140 kg N/ha

This groups of intensity of fertilization could be crossed with presence of legume as previous crop (L1 = legume as previous crop; L0= other crop).

The Figure 12 shows a strong correlation between measured biomass at flowering and NNI at flowering (R^2=0.92) in cases with legume as previous crop and an important level of fertilization, that's to say in situations with few risks of limiting factors, in a nitrogen point of view. We also can observe that the level of NNI at flowering is strongly conditioned by fertilization and, to a lesser extent by previous crop.

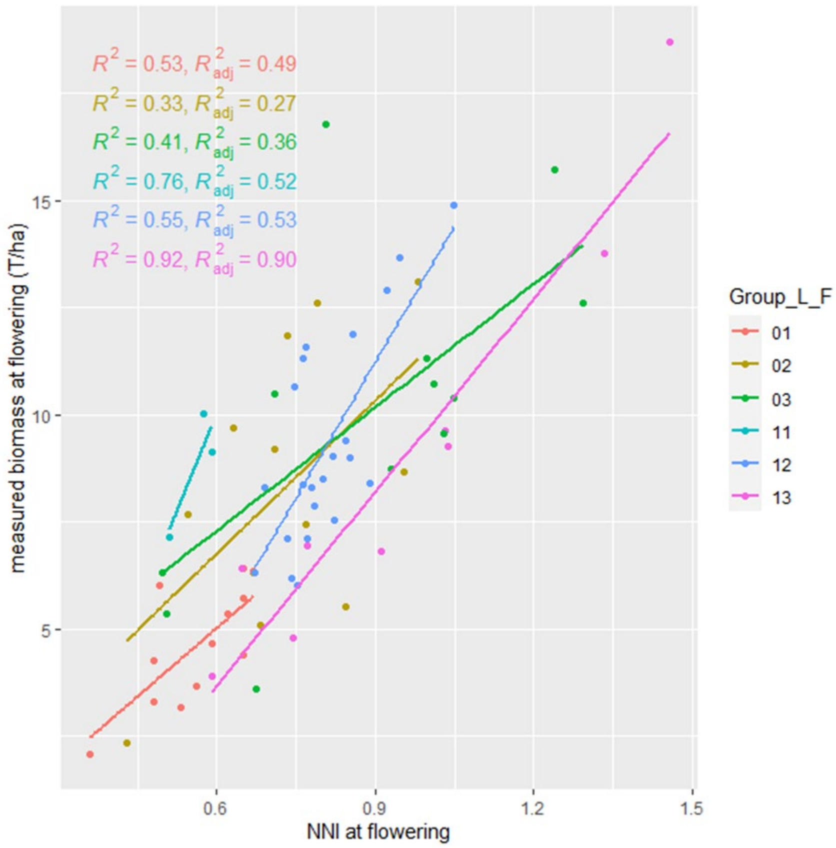


Figure 12: measured biomass at flowering according to NNI at flowering

3.4.2. Effect of fertilization and crop rotation on NNI

The results of the Diagchamp shows:

- **A significant effect of fertilization on NNI at flowering** for the same previous crop (01 vs 02, 11 vs 12) for plots with nitrogen stress measured (NNI<0.9) and moderate level of nitrogen inputs (group “F1” and “F2”).
- No significant effect for fertilization in situations with no nitrogen stress at flowering (NNI>0.9).
- **A significant effect of legume as previous crop** on nitrogen nutrition **only in situation with nitrogen stress** (02 vs 12).

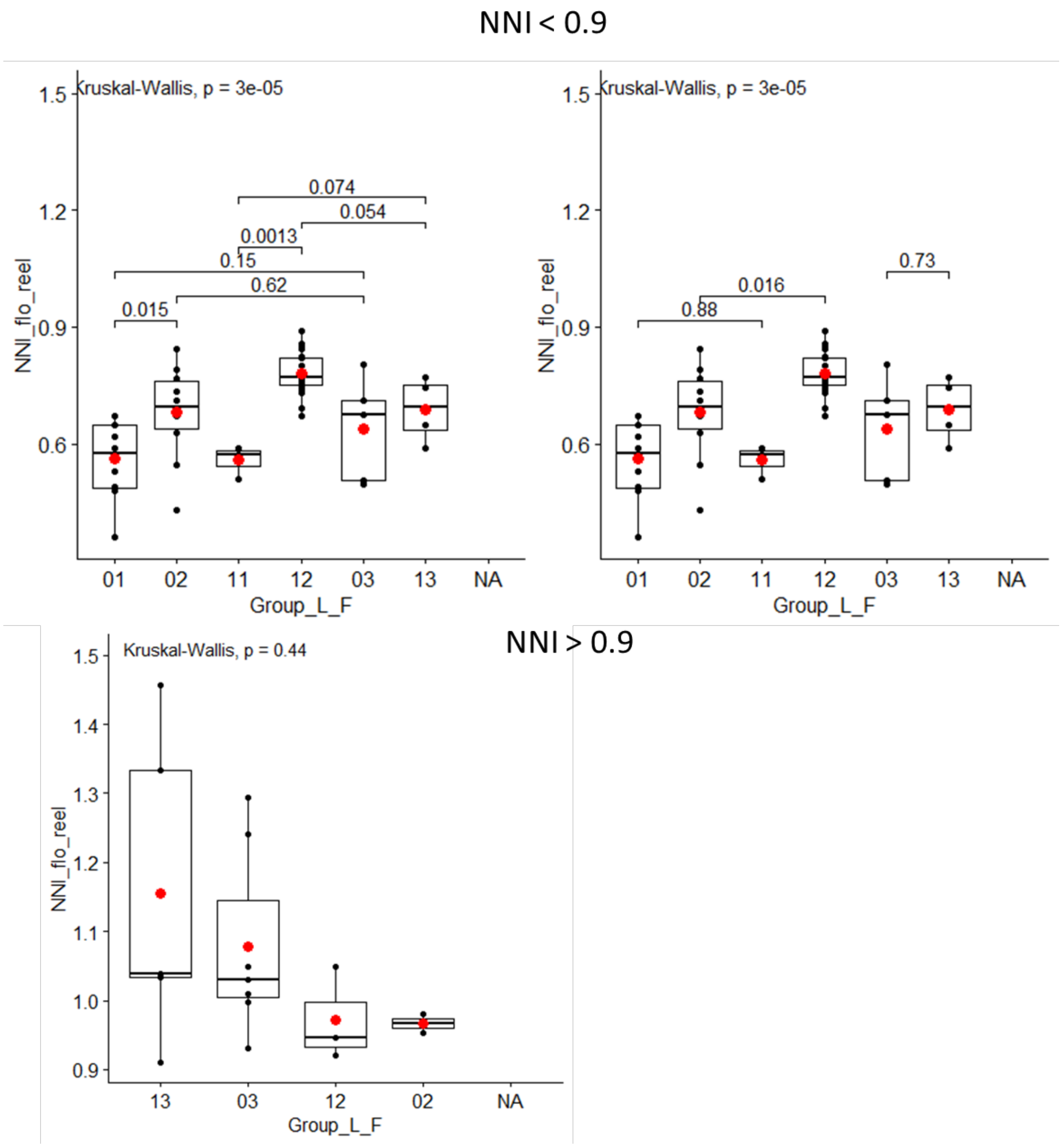


Figure 13: effect of previous crop and fertilization on nitrogen nutrition index at flowering

3.4.3. Effect of tillage intensity on nitrogen nutrition

If we compare situations with plots with comparisons at the same place between CT and MT or DS, we don’t observe significant differences (p Value = 0.8) on NNI at flowering between tillage (W_sol = yes) and direct sowing (W_sol = no). Results are shown on Figure 14.

With all plots, there is also no effect of tillage intensity on NNI at flowering (p Value = 0.76).

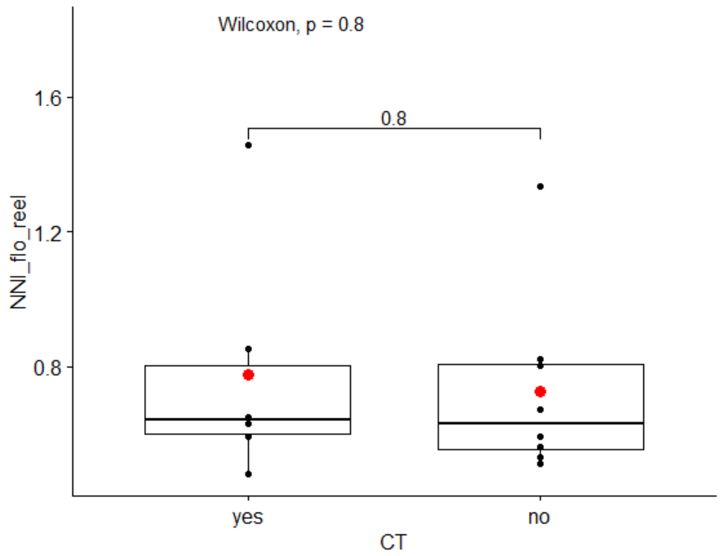


Figure 14: effect of tillage intensity on NNI at flowering (in situations with comparison of tillage intensity at the same place)

3.4.4. Effect of technical itinerary on nitrogen nutrition

The NNI at flowering is mainly positively correlated to the level of nitrogen input ("N_input_group"), and, at a lower level to legume as previous crop (Figure 15). The intensity of tillage ("CT") does not explain the level of nitrogen nutrition at flowering.

```
Coefficients:
                     Estimate Std. Error t value Pr(>|t|)    
(Intercept)         0.4118078  0.0643040   6.404 1.93e-08 ***
N_input_group       0.1805907  0.0278333   6.488 1.38e-08 ***
Previous_crop_leg1  0.1004534  0.0407773   2.463  0.01642 *  
Sum_MET_AET        -0.0015741  0.0004864  -3.236  0.00191 ** 
CTyes               0.0101584  0.0546372   0.186  0.85308    
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 15: effect of technical itinerary on nitrogen nutrition (linear model)

If we compare situation with plots with comparisons at the same place between Direct Sowing and Tillage (MT or CT), we don't observe significant differences.

3.5. Conservation agriculture effect on yield

3.5.1. Intensity tillage effect on yield

The Figure 16 compares grain yield in situation with plots with comparisons at the same place between CT and MT or DS. It doesn't show significant differences.

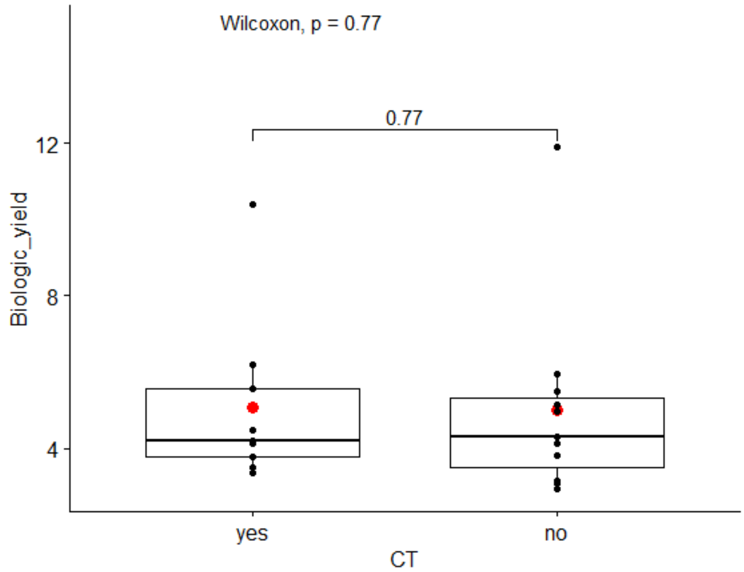


Figure 16: effect of tillage on biologic yield (plots with side by side tillage intensity; Wsol = tillage)

Regarding all the plots (Figure 17), the level of realization of potential yield is not statistically different between CT and MT-DS. However, we can observe a better average of realization or potential yield under MT and DS.

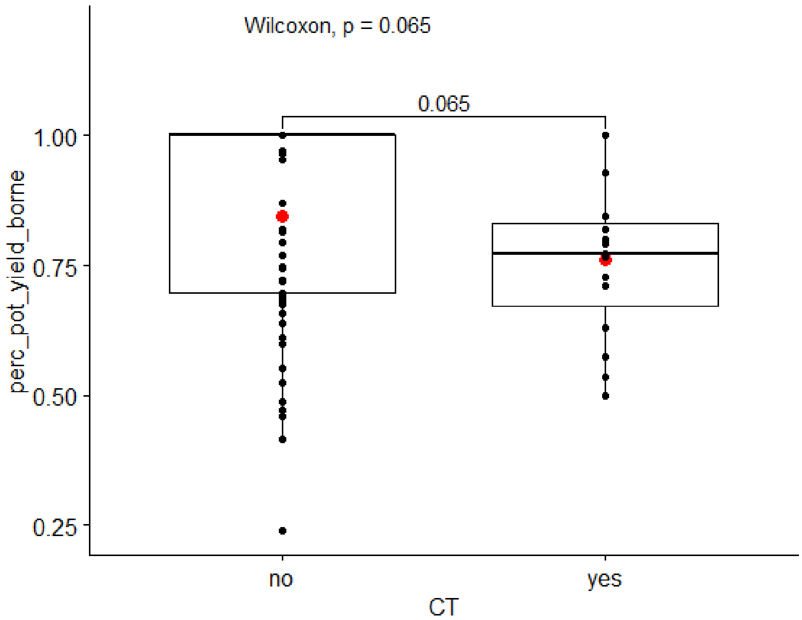


Figure 17: effect of tillage on realization of potential yield.

3.5.2. Crop rotation effect on yield

Regarding all the plots, we can observe a significant effect of legume as previous crop on the percentage of realization of potential yield (Figure 18).

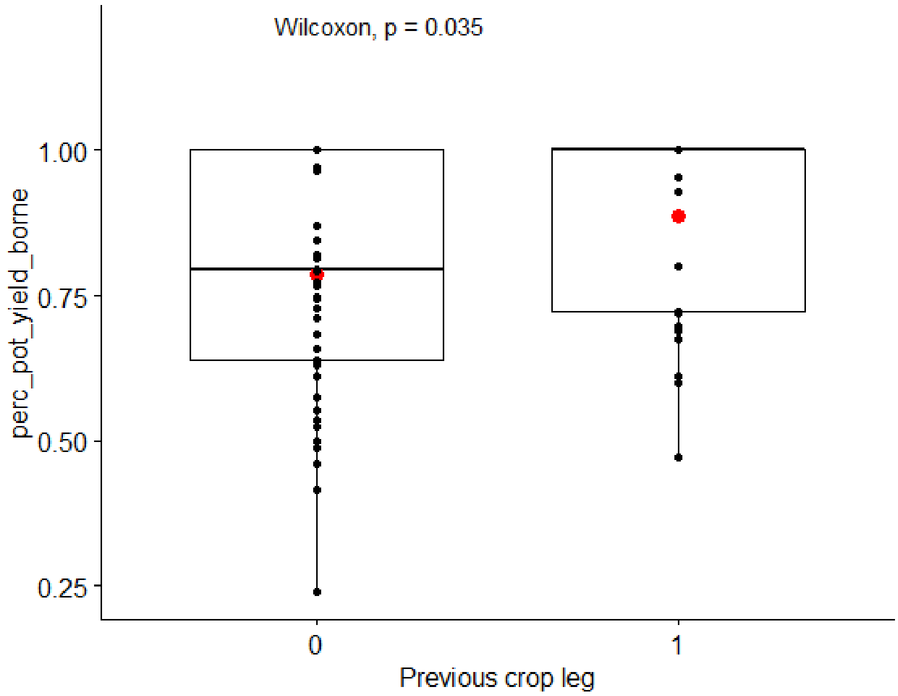


Figure 18: effect of legume as previous crop on achieving potential yield

More details of the effect of previous crop type on the realization of the potential yield are summarized in the Figure 19. A significant effect (P Value <0.05 with a Kruskall Wallis test) shows a significant effect for perennial legume vs annual legume, OSR, cereals, vegetable, annual, beetroot and fallow.

		realized	
Prevous crop type	**Effective**	**Mean (ù)**	**SD**
annual legume	16	76%	0.17
Beetroot	3	73%	0.06
cereals	23	77%	0.17
fallow	3	76%	0.25
maize	7	85%	0.29
OSR	4	86%	0.26
perennial legume	16	100%	0.02
sunflower	6	71%	0.23
vegetable	3	79%	0.21

Figure 19: effect of previous crop type on the realization of potential yield

3.5.3. Effect of technical itinerary on yield

The Figure 20 presents the effect of tillage intensity and crop rotation ("No leg"= no legume as previous crop; "leg"= legume as previous crop) on wheat yield (% of GARRIC modelized realized, specific to each plot). In that case, all plots are considered, contrary to Figure 16:

- There is **no significant effect of tillage intensity** on the percentage of potential yield realized, whatever the previous crop.
- **The effect of legume as previous crop on the realization of potential yield** is not for CT or MT-DS. In fact, in some cases, if the legume - especially pluriannual - is not well managed without tillage, it could lead to yield losses (cfr. Deliverable 3.1).

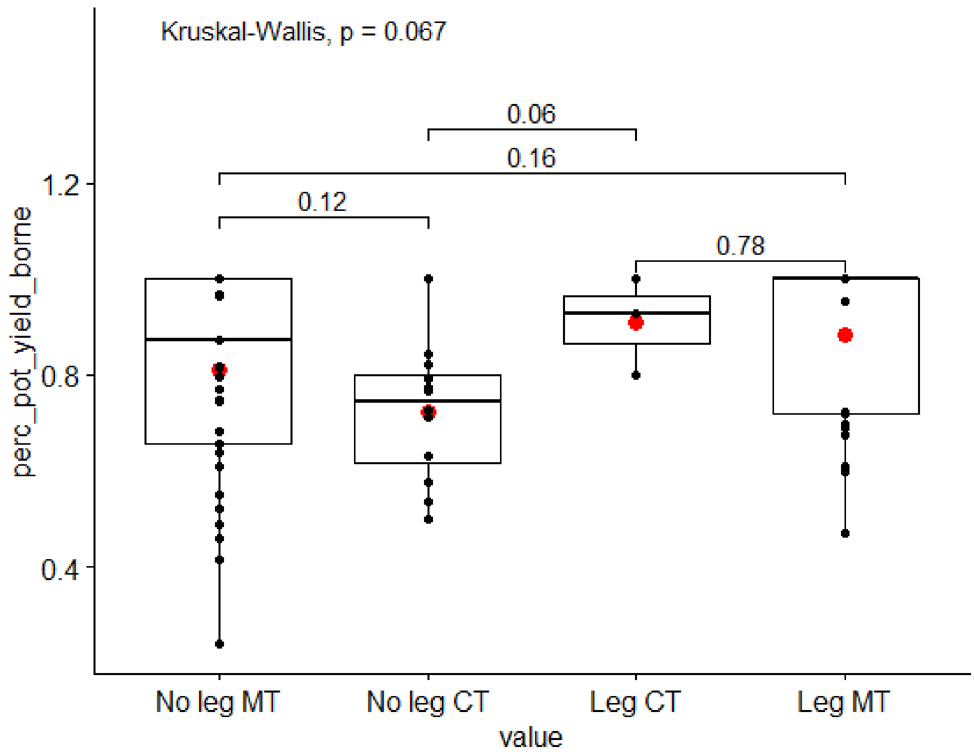


Figure 20 : effect of crop rotation and intensity of tillage on yield

3.6. Effects of conservation agriculture on water and nitrogen efficiency

The effects of limiting factors are well characterized on NNI at flowering (P value=0.06), percentage of potential biomass realized (P value=0.097) and percentage of potential yield (P value=0.35), as illustrated on Figure 21.

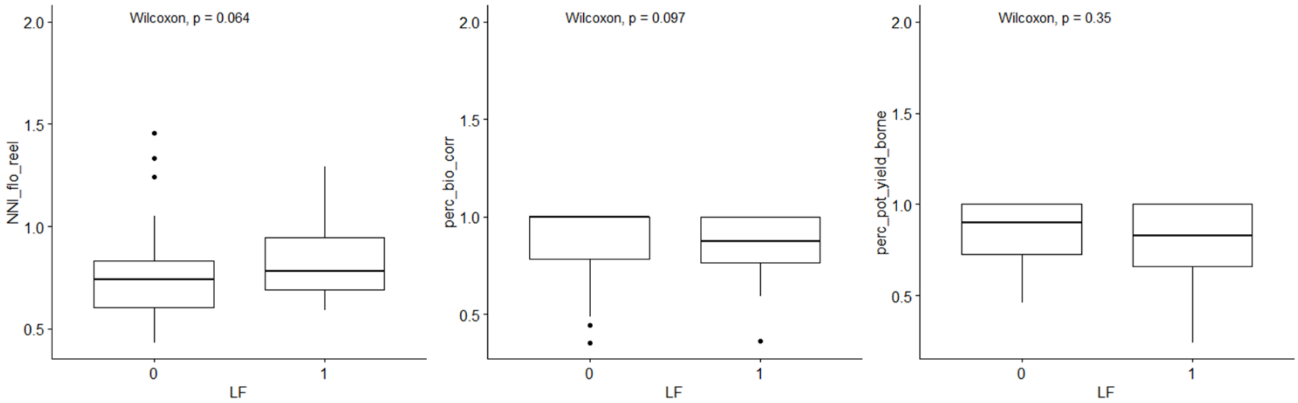


Figure 21: impact of limiting factors on Nitrogen nutrition and potential yield and biomass

An analysis of water (mm/T) and nitrogen (kg N/T) productivity is shown on Figure 22. This analysis is concentrated on plots with comparisons side by side between CT and MT-DS. It does not show significant differences on nitrogen efficiency and on water efficiency.

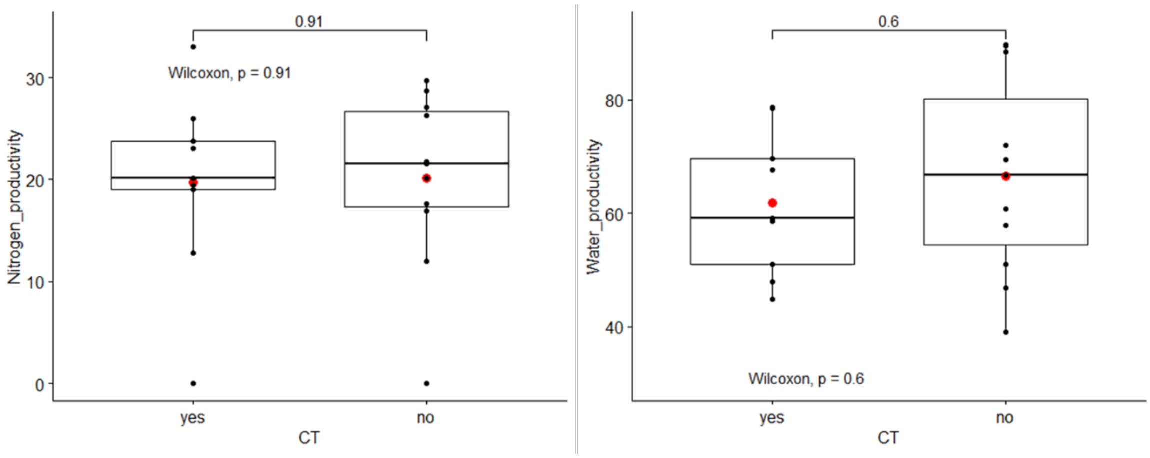


Figure 22: effect of previous tillage intensity on water (mm/T) and nitrogen (kg N/T) productivity (Wsol = yes: MT or CT)

The Figure 23 details the effect of minimum tillage or direct sowing on yields as well as nitrogen and water efficiency. In 6 comparations out of 8, conservation agriculture (MT and DS) has a better nitrogen productivity or water efficiency than conventional tillage, even if it's statistically significant only in one case. In two cases, conservation agriculture was less performant than conventional, due to previous crop management in direct sowing ("23_France") or residues degradation of previous crop ("23_Drimos"). We can conclude that conservation tillage could be an opportunity to improve water and nitrogen efficiency in Mediterranean area, if possible limiting factors (weeds for ex.) are well managed.

			Yield (t/ha)			Nitrogen efficency			Water efficency			
	Previous crop	Crop	CT	MT	DS	CT	MT	DS	CT	MT	DS	Explanations
22_Drimos	anual legume	barley	5.56 (a)	5.94 (a)		12.7 (a)	12 (a)		50.1 (a)	46.9 (a)		
23_drimos	cereal	barley	4.2 (a)	3.2 (b)					52.7 (a)	70.1 (b)		Higher level of nitrogen stress in MT due to a slower residues degradation
21_Morocco	cereal	durum wheat	3.9 (a)	4.13 (a)		22.3 (a)		21.9 (a)	68.2 (a)		66.5 (a)	
22_Morocco	anual legume	barley	0.85 (a)	0.93 (a)		102.3 (a)		93.5 (a)	212 (a)		232 (a)	
21_Tunisia	fallow	durum wheat	1.6 (a)	1.53 (a)	1.84 (a)	23.8 (a)	21.8 (a)	27.1 (a)	83.3 (a)	76.1 (a)	95 (a)	
22_Tunisia	anual legume	durum wheat	3.7 (c)	4.4 (a)	4 (ab)	34.1 (c)	28.7 (a)	31.5 (ab)				
21_France	alfalfa	durum wheat	10.4 (a)		11.9 (a)	24.1 (a)		20.9 (a)	36.4 (a)		31.7 (a)	
23_France	alfalfa	durum wheat	6.2 (a)	5.5 (ab)	4.1 (c)	18.9 (a)	21.5 (ab)	28.7 (b)	57.2 (a)	64.5 (ab)	85.5 (b)	Alfalfa restart on wheat in DS

Figure 23: effect of minimum tillage on yield, nitrogen and water efficiency

4. General conclusions

4.1. Global results of innovation tested in WP3

4.1.1. Weed control

4.1.1.1. Status report

Weed control is one of the most important issue under CA, because of abolition of plowing. The problem is particularly important with Lolium with herbicide resistance in some Mediterranean regions. Other weeds, noticed in the Diagchamp, could cause competition: *Raphanus spp*, *Avena fatua* and *Poa pratensis* and *Hirschfeldia incana.*

The problem of *Lolium* is particularly important in crop rotations in rainfed conditions with a high frequency of winter cereals. Measurements in France in Diagchamp under CA have shown that Lolium absorb 18 kg N/ton of DM. The yield impact of weeds on biomass at flowering could be until 60% (Figure 24).

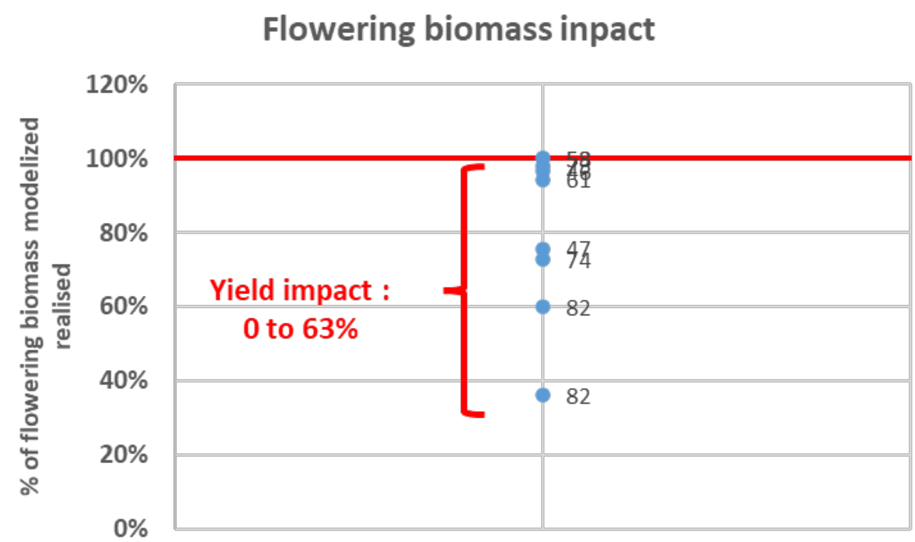


Figure 24: biomass impact of weeds as limiting factor (potential biomass – measured biomass)

4.1.1.2. Innovations tested

One of the main lessons of CAMA WP3 about weeds management is in relation to crop rotation. French data have demonstrated a positive effect of annual legume as previous crop to control *Lolium* thanks to herbicides rotation. Indeed, active substances presenting no problem of resistance to *Lolium* can be used on legume. We can note the use of Propyzamide (pre-emergence herbicide) in France, but the optimal climatic conditions rarely occur in the other countries, according to legislation and temperatures (Propyzamide is efficient under 10-12 °C).

In rainfed systems, the use of fodder (alfalfa, *Onobrychis*) is another efficient means to control weeds, especially *Lolium*. Repetitive mowing allow to export *Lolium* out of the fields, resulted in eliminating Lolium abundance due to inhibiting the weed to reach the generative growth stage: Figure 25.

Previous crop	weeds	diseases	pest	seeding	scoring limiting factors in relation with crop rotation	*climate (except hydric stress)**	*nitrogen fertilization**	Total scoring limiting factors
perennial legume	0.25	0.00	0.00	0.25	0.50	*0.04*	0.33	0.88
annual legume	0.38	0.15	0.00	0.00	0.54	*1.23*	0.85	2.62
maize	0.09	0.00	0.00	1.18	1.27	*0.91*	0.00	2.18
cereals	0.60	0.00	0.00	0.00	0.60	*0.00*	0.80	1.40
sunflower	0.75	0.00	0.00	0.00	0.75	*0.75*	0.00	1.50

Figure 25: average scoring of limiting factors according to different previous crops (scoring from 0 to 3). Weeds, diseases, pests and seeding are limiting factors which could be put in relation the type of previous crop.

Pre-emergence herbicides are often applied on Wheat to control Lolium but some data are missing about efficiency in no tillage systems (the herbicide intercept with the crop residues and does not get to the soil). An alternative solution may be the Reduced tillage, ie. shallow (3-5 cm) cultivation of soil to make space for the herbicide.

4.1.1.3. Future prospect

The future prospect noticed by CAMA partners about weeds management are:

- Economic market: if the crop rotation is an important lever to manage weeds, it supposes to have economic market for crop diversification, which could be complicated in many countries (administered markets, price paid for legume…).
- To work on Glyphosate alternative, which is, until now, an effective option to control weeds under CA. However, resistance problems are starting to be reported in France, and many public policies want to limit or prohibit its use.
- Work on pre-emergence herbicide efficiency under CA and according to the tillage intensity.

4.1.2. Seeding

4.1.2.1. Statuts reports and innovation tested

About seeding, one of the recurrent problems under no tillage could be soil compaction, especially in sensitive soil and climate. Measurements in France in limestone clay soil have shown that risks of soil compaction are more important in no tillage systems. They could be reduced thanks to crop rotation and association of semi-permanent cover (deep roots) and annual plant with superficial roots.

However, in the WP3 we have not noticed significant yield differences between Conventional and Minimum Tillage. Same results could be noticed on Nitrogen and Water efficiencies.

4.1.2.2. Futur prospects

Many questions have been highlighted in the Deliverables D3.1 and 3.2 about difficulties to manage crop residues in CA. Two prospects could be imagined in consequences:

- Accessibility to machines to succeed direct sowing in residues and distribute evenly crop residues on the field.
- Works on technical itineraries to:
  - Succeed direct sowing after crop with high level of residues (crushing, distribution of straw).
  - Accelerate residues degradation with crop fertilization management.

4.1.3. Crop fertilzation

4.1.3.1. Status report

Under CA, there is many questions about fertilization strategies adaptation (Figure 26) :

- On one hand:
  - We could have more nitrogen competition between crop and microbial biomass, supposed to be more important under CA.
  - We also could have a more important level of residues to be degraded and, in consequences, more nitrogen immobilization.
- On the other hand:
  - If we supposed to have a more important OM rate, we could expect more nitrogen mineralization.
  - Systems with legume as crop or plant cover in rotation can generate more nitrogen mineralization.

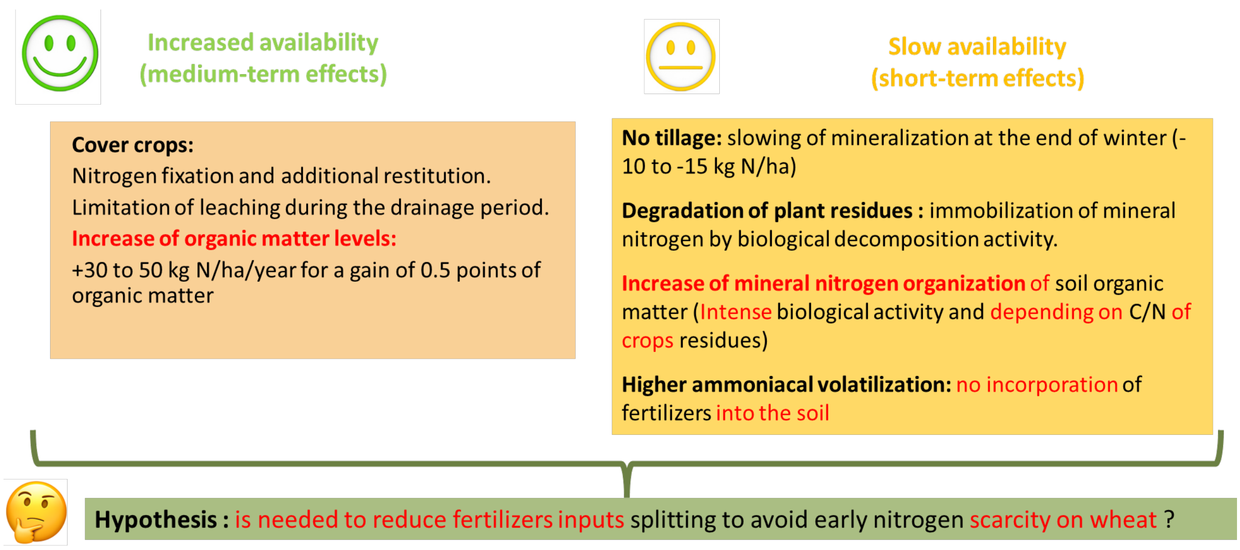


Figure 26: supposed effect of Conservation Agriculture on soil nitrogen residues

In consequences, farmers and technicians have many questions about fertilization strategies under CA.

4.1.3.2. Innovations tested

First, due to the various climatic and socio-economic conditions of the different partners of the project, there is very important differences of fertilization practices in the different countries (Figure 8).

The WP3 has demonstrated the positive effect of legume as previous crop before wheat, especially in situations with nitrogen stress (Figure 13).

Trials in France have demonstrated that it was important to avoid nitrogen stress at the beginning of wheat elongation (tillering). Trials in Greece and France did not highlight differences between the efficiency of fertilizer types (ammonium vs urea or urea vs urea with inhibitors).

4.1.3.3. Future prospects

These first results on nitrogen fertilization management must:

- Be adapted in each country and climatic and socioeconomic conditions.
- Develop Decision Support Tools and work on Mediterranean adaptation. The crop model CHN was used in WP 3 & 5 to complete agronomic diagnosis. Many data were necessary to perform model calibration (wheat stages, soil nitrogen residues, biomass at flowering…). For now, it could not be used to manage fertilization under Mediterranean conditions and conservation agriculture.
- Consider deeply the dynamic of soil nitrogen residues and microbial biomass in CA under Mediterranean conditions.

4.1.4. Crop rotation

4.1.4.1. Status report

Many questions have been identified in D3.1 and D3.2 on strategies to succeed plant cover during summer in Mediterranean conditions, due to permanent water deficit (Figure 27).

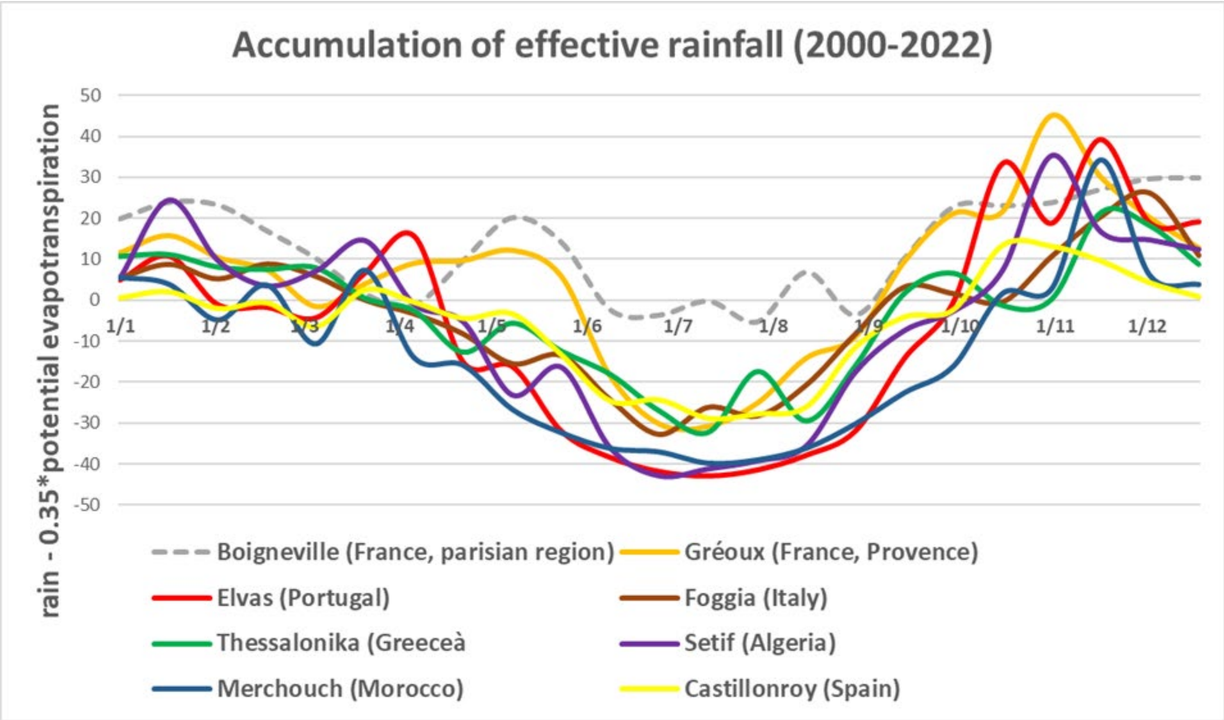


Figure 27: accumulation of effective rainfall (2000-2022)

It’s an important challenge to test strategies and genotypes to maximize plant cover during summer to preserve soil fertility in Mediterranean conditions.

4.1.4.2. Innovations tested

A trial in France has demonstrated some innovations to maximize soil cover during summer by using semi-permanent cover sown into a crop (Figure 28), according to local crop rotation.

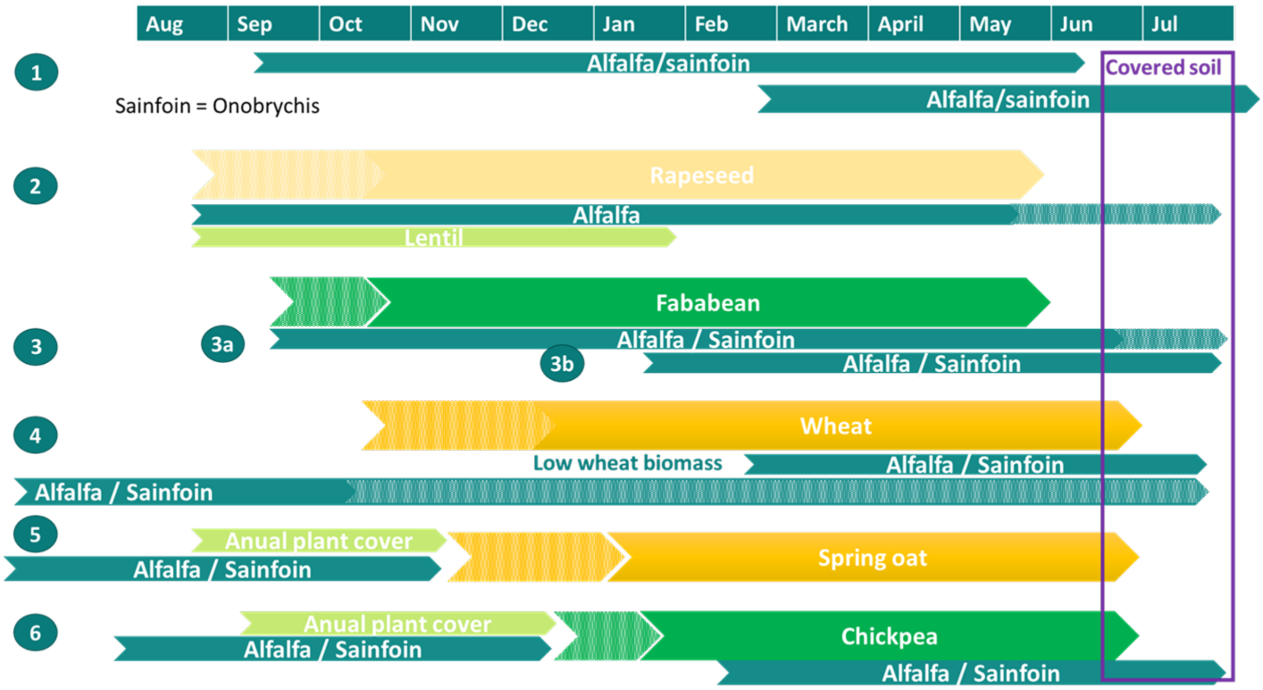


Figure 28: semi-permanent plant cover implantation with different crops (Oraison, France)

The result of this experimentation is developed on D3.3. It's important to notice that semi-permanent cover could lead to a nitrogen and water competition with crop if it's regulation is not sufficient.

Beyond plant cover, Morocco trials have demonstrated that some genotypes (in barley) are more adapted to CA.

4.1.4.3. Future prospects

About crop rotation, the future prospects could be:

- Define genotype characteristics adapted to Conservation Agriculture and identify or select more adapted varieties to CA.
- About semi-permanent plant covers:
    - Identify species and genotypes more adapted to arid conditions (water and temperature stress) in relation with WP4 (alfalfa selection).
    - Identify the least competitive genotypes and an unsynchronized development cycle with the crop (late restart after the winter…).
    - Identify the best combination between plant cover and crops (sowing density…).
    - Integration of semi-permanent cover with breeding, livelihood for many inhabitants of rural areas.
    - In many countries, semi-permanent plant cover could be grazed by animals during periods when the soils are generally bare.

4.2. Global discussion on results

The WP3 allows to identify some important results and innovation with participatory research approach on weeds management, seeding, crop fertilization and crop rotation (Figure 29). To work directly in farmers' fields made it possible to test numerous innovations and open up significant work perspectives, directly in connection with farmers preoccupations. The collaboration between researchers and farmers was very important to identify main limiting factors, private innovation by farmers to reduce it and think about future prospects. Partners are ready to continue to collaborate on prospects presented on 4.1.

The results on CA must be viewed cautiously, because field studies were, for a part of them, recently in CA. Therefore, data about Nitrogen and Water Efficiency, as well as the yields are not representative of the way soils routinely work under conservation agriculture. It's important to continue measurements to study the evolution of agronomic and soil performances. Long term measurements in specific trials (WP5) are very complementary.

Finally, the WP3 demonstrate that technical limiting factors to CA could also be socio-economic. It's important, by working with farmers, to evaluate innovations in climatic and socio-economic contexts.

Theme	CAMA learning	Future prospect
Theme 1 : weed control	• *Positive effect of crop rotation (legume)* • *Glyphosate dependency*	• *Economic market should be more developed for crop diversification* • *Alternatives to glyphosate ?*
Theme 2 : seeding	• *No significant yield differences between No Tillage and Conventionnal Tillage* • *But more risks of limiting factors in No Tillage* • *Reduction of compaction risks with crop rotation and plant cover*	• *Nitrogen mineralization dynamic in No Tillage.* • *Accessibility to machines*
Theme 3 : crop fertilization	• *No very big differences in fertilization strategies in Conservation Agriculture.* • *Positive impact of legumes as previous crop in situations with nitrogen stress.*	• *Decision support tools need to be more better configured for Mediterranean and CA agriculture conditions.* • *Nitrogen residues dynamics in relation to Mediterranean climate and CA specifies*
Theme 4 : crop rotation	• *Semi permanent cover to have soil covered in summer.* • *Genotypes adapted to CA*	• *Genetic selection of semi permanent cover to minimize competition with crop.* • *Define ideotypes adapted to CA*

Figure 29: global results and future prospects of WP3