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Deliverable 3.3

Diagchamp field notebook: main interventions, problems and diagnosis aspects of the Diagchamp

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Executive summary

This report summarizes the results obtained in the CAMA WP3 task 3 aimed to evaluate the limiting factors in CA on the yield.

In 7 countries (Greece, France, Italy, Morocco, Portugal, Tunisia, Spain), measurements were realized on farmers ‘fields with the Diagchamp ® method. This method, developed by Arvalis allows to identify the man abiotic (nitrogen, water, climate) and biotic (weeds, diseases…) limiting factors and evaluate their impact on the yield. 80 plots were followed in the WP3 during the CAMA project.

The main conclusions presented in this deliverable are the following.

In general, there is no yield differences between CT and MT, but some more important risks in MT about mainly weed management, particularly in cereals after cereals. The crop rotation is a central way to limit weed problems in CA. The type of problem weeds quoted under CA is manly *Lolium, Raphanus, Avena fatua, Hirschfedlia incana* and *Poa pratensis*.

Concerning nitrogen nutrition, some deficiency were notices in CA due to the degradation of crop residues which could lead to competition with the crop. However, one of the main problems diagnosed is the positioning of fertilization in very dry conditions.

About plant cover, there is only feedback in France where a trial is dedicated to this point with semi-permanent cover strategies. Very few Mediterranean farmers without irrigation sow plant cover in too dry conditions.

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1. Introduction

1.1 Scope of the document and objectives

This document presents the results, country by country, from a network of measurements in farmers' fields. The global results are presented in the Deliverable 3.4.

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
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 Efficiency

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 OM 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 methodology used for Diagchamp field diagnosis was designed by ARVALIS-Institut du végétal in 2013[1]. The methodology used 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), 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.

This diagnosis is based on yield components, in order to highlight the main yield and/or quality limiting factors for bread wheat or durum wheat. Breaking down the yield into its various components (number of ears/m², number of grains/ear, Thousand Kernel Weight) helps to identify the period when the yield was affected and, through observation and measurements at key stages during the season, the factors or environmental conditions that may have been detrimental.

The actual yield is then compared to the potential yield, i.e. the yield expected, considering the type of soil in question, the weather during the season, the variety and the sowing date. This expected potential yield is calculated using Arvalis’s agro-physiological models (Agrobox, Garicc and CHN), while taking into account the type of soil and weather conditions during the season, especially at the different key growth stages of the wheat variety being studied.

- The Agrobox model helps to pinpoint favourable or harmful weather conditions at the key growth stages of the wheat crop, that may have had an impact on the different yield components. For example, cold temperatures during the meiosis period may make the pollen sterile and reduce the number of grains/ear
- Garicc, a yield forecasting model developed in a Mediterranean area subjected to water deficiency-related stress is based on a comfortable water conditions (actual evapotranspiration/maximum evapotranspiration) at the different growth stages and helps to forecast yield penalties by calculating the possible shortfall compared to a maximum yield of around 10 T/ha for current varieties when conditions are not limiting.
- Finally, the CHN (for carbon, water and nitrogen) model calculates, on a daily basis, the growth factors of the wheat’s above-ground parts and its roots., depending on the water and nitrogen resources available (from soil + weather + farmer’s practices). It updates the expected biomass production track in real time in relation to optimum production (without any water or nitrogen deficiency-induced stress), as well as the state of water and nitrogen resources in the soil, and the water flow situation (nitrogen loss from leaching for example).

The information provided by this model is complemented by a few observations made in the field at key growth stages for wheat (must be carried out at flowering and harvest time, but also at the end of winter/beginning of stem elongation if possible). Those help to define more accurately the state of the crop and detect possible limiting factors unrelated to the weather, such as diseases, pests, weeds, nutrient or water deficiencies, etc. They are also a means of checking whether the CHN forecast is still relevant, or if it needs to be adjusted. In that respect, taking a biomass sample at flowering time in

[1] Stéphane Jézéquel and colleagues

order to calculate the nitrogen nutrition index of the wheat is a very reliable diagnostic measure, in every situation.

Those observations and measurements carried out in the field throughout the season, added to the analysis of actual yield components, help to explain the gap between potential and actual yield, which in turn helps to determine key limiting factors for good crop performance, or conversely highlight a better output than expected and therefore identify a “positive agronomic lever”.

In addition to incorporating many cross-checked corroborating pieces of information (modelling, field observations, yield components), the reliability of the diagnosis is further enhanced by a report jointly validated by the experimenter, the Arvalis contact and the farmer.

An Arvalis data input and interpretation software (Silena) is dedicated to receive the field data components of the diagnosis, to help interpreting it, and to semi-automatically prepare a comprehensive diagnostic report.

A major part of the field diagnosis therefore entails carrying out field observations and recording them:

Characterisation of the working environment:

- Cropping techniques used on the field, equipment
- Date and depth of the last ploughing

Characterisation of soil and weather conditions:

- Soil analysis helps to properly characterise soil conditions in the field under study.
- Soil Moisture monitored by installing Watermark ® type tensiometer probes.
- Agronomic and meteorological analysis of the wheat cycle

Monitoring crop behaviour in the field

To monitor performance in the field, a uniform 20x20m area representative of the whole field is chosen in agreement with the farmer. Observations, samples and counting are repeated within this area in order to ensure the reliability of the results.

Throughout the year:

- Record wheat growth stages
- Record pressure from weeds

Indicators at flowering time:

- Residual nitrogen in the soil at flowering time: to measure what is available for the wheat at that key stage before the grain starts filling.
- Above-ground biomass at flowering stage (sampled on)6 quadrats of 2 consecutive rows along one meter, and its nitrogen content. Those samples enable to calculate the Nitrogen Nutrition Index, which gives the quantity of nitrogen consumed by the plant compared with the critical amount of nitrogen it requires. The critical nitrogen level is the required amount for an optimal nutrition level of the plant, according to its biomass. Calculating the nitrogen nutrition index at flowering time therefore helps to detect possible nitrogen deficiencies at that key stage of the plant’s development, and therefore to explain possible low number of grains/m², the Thousand Kernel Weight , or protein content.

Yield components at harvest time:

- Harvest of the aboveground part of the plant on six quadrats of two consecutive rows by 1 linear metre.
- Measurement of straw biomass, number of ears.
- After fixed-line threshing: measurement of grain mass per quadrat, of the number of grains/m², the Thousand Kernel Weight , and protein content as well as evaluation of the loss of vitreous aspect in the case of durum wheat.

Modelling yield gap

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 agricultural season. To facilitate CHN use, well-defined parameters in the three compartments are essential. The model employs 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 of 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.

Yield gap modelization

The potential yield is calculated using Arvalis' agro-physiological models taking into account the meteorological potential. Water and nitrogen flows are also modelled, as well as crop growth (CHN model for carbon, water and nitrogen). In details, the potential biomass at flowering is modelized by CHN:

- **With nitrogen stress observed** in the fields (CHN running with by NNI and nitrogen soil residues measurements)
- **Without nitrogen stress** to have the potential biomass allowed by the climatic conditions.

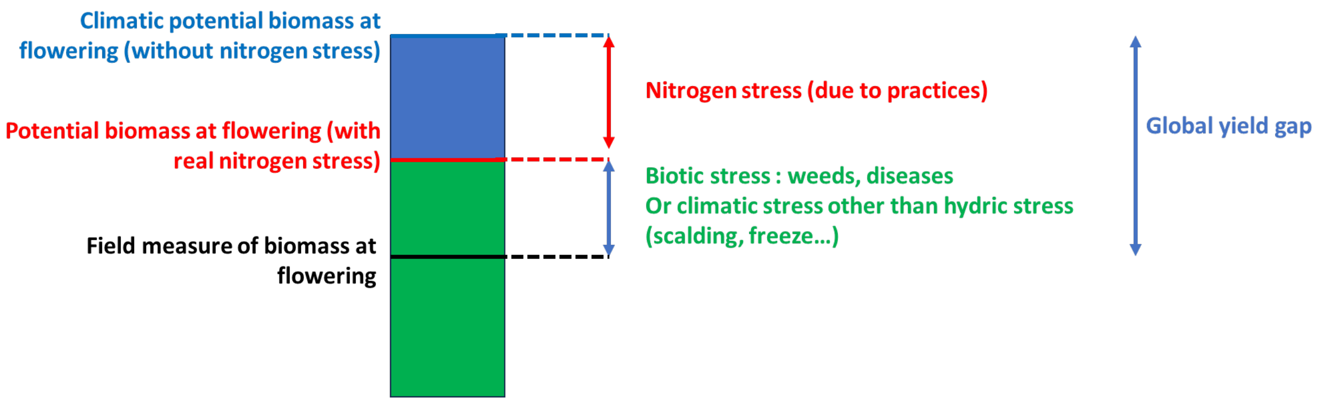


Figure 1: yield gap modelized at flowering with CHN model

The final phase of the diagnosis (**validation, summarisation, and conclusions**) must not be carried out solely by the experimenter, but by the **farmer/experimenter(s)/technical contact trio.**

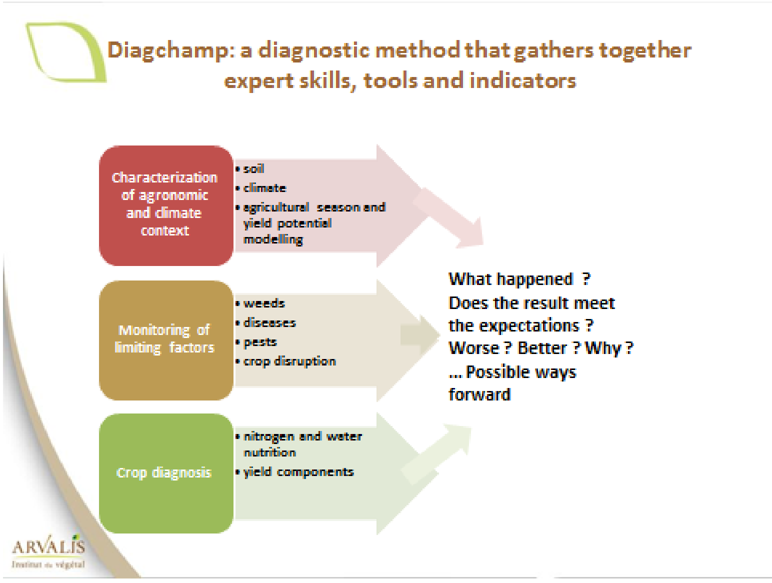


Figure 2: "Diagchamp method" global scheme

Benefits and relevance of the method:

- It helps to monitor the performance of farmers' practices in situ, in varied working, soil and meteorological environments.
- The farmer participates in the diagnostic process and in the production of the summary
- Works regardless of parcel size, and importantly, without any need for "control" or "reference" practices within the same field, since thecomparison is based on the potential yield expected in that specific environment and weather conditions throughout the season.
- Helps to establish group dynamics among the participating farmers.
- Repeating monitoring throughout the years helps to identify trends in practices at a production area level.
- Even with few monitoring events, it still helps to deliver a precise message to the farmer.
- However, this is not a traditional experiment where "everything else is equal" and therefore requires repeated observations and measurements, and to exercise caution when extrapolating from the results (diagnostic concept = cross-checking corroborating pieces of information).
- For a better characterisation of the impact that a specific practice or cropping technique has, farmers can be asked to try simple variations (direct drilling/minimum tillage), and a diagnosis process can be carried out in each field.

2.2 Global dataset

89 plots were followed with the Diagchamp method in the WP3 in all countries repartition of Diagchamp followed in all countries in the WP3Figure 3).

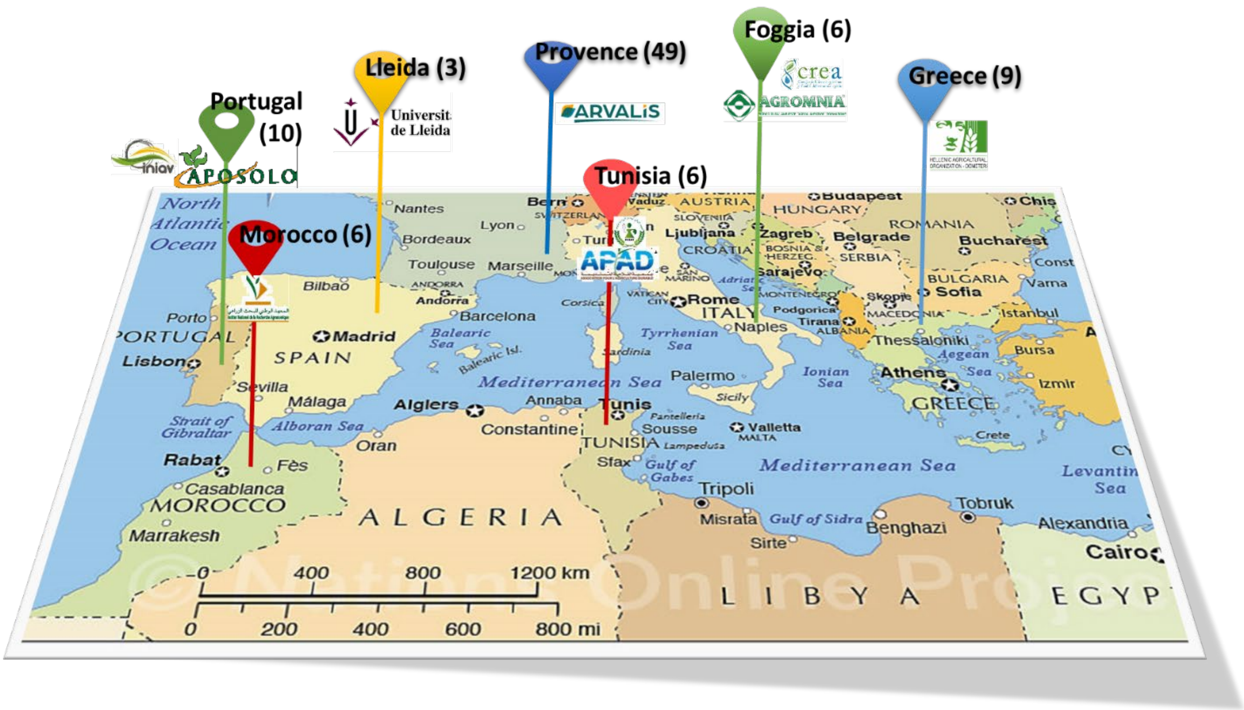


Figure 3: repartition of Diagchamp followed in all countries in the WP3

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

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 4: thematic worked on WP3

3. Results

3.1 France

Pedologic conditions

Field experiments in South-Eastern France are calcareous, mainly limestone clay with an average organic matter rate at 2.57%. Water holding capacity are very different between fields: from 60 to 210 mm.

Climatic conditions

The Figure 5 illustrates the climatic conditions in Gréoux-les-Bains (Arvalis station in Provence) for the wheat seasons 2021, 2022 and 2023. We can notice:

- Rainy autumn and good conditions to sow wheat.
- Drought in winter (February-March) and in consequences, difficulties to have good conditions to apply fertilization.
- Return of rain in April or May, important to "save" the yield potential. In 2023, many symptoms of fusarium have been observed due to a lot of rain in May.

Meteo station	Gréoux-les-Bains									
	Unity	2020-2021			2021-2022			2022-2023		
Rain (01/10 to 30/06)	mm	361.2			360.5			484.4		
Average T° (15/10 to 15/06)	°C	10.38			10.83			11.21		
Average Potential Evapo-Transpiration	mm	544.15			549.29			592.13		
		rain (mm)	Temp (°C)	PET (mm)	rain (mm)	Temp (°C)	PET (mm)	rain (mm)	Temp (°C)	PET (mm)
October		40.4	12.18	46.07	83	12.92	45.06	3.6	16.91	49.98
November		28.4	10.14	16.72	58.4	8.23	15.99	94.4	9.71	23.2
December		40.4	5.04	6.08	80.1	5.50	8.79	90.8	6.93	16.7
January		51.2	4.76	17.29	3.2	4.05	9.69	14.8	4.52	24.7
February		35.6	8.16	27.94	13	7.25	38.24	14.4	5.57	29.1
March		3.8	8.06	65.11	6.2	8.33	62.37	13.6	9.43	69.5
April		72.6	10.15	81.38	32.2	11.16	88.85	28.6	11.56	97.8
May		81.6	14.09	127	76	17.25	115.4	170	15.52	114.38
June		7.2	20.81	156.56	8.4	22.82	164.9	54.2	20.74	166.77

Figure 5: average climatic conditions for South East of France

Dataset

62 fields experiments have been followed in South-Eastern France during the CAMA project in different conditions: with (22) or without irrigation (40 fields) cultivated in bread or durum wheat. 52 plots were in direct sowing, 6 in simplified tillage and 4 in ploughing practices.

Average yields on seasons 2021-2023

Average results by year, according to the regime of irrigation, are presented in the Figure 6. The percentage of the potential yield reached is estimated by a model (Garric©) based on yield penalization due to hydric stress. The yield gap is explained by the diagnosis of limiting factors with the Diagchamp® method. In 2021, the average yield in plots with irrigation was more important than without irrigation due to important limiting factors in some of plots with irrigation (spike freezing). In 2022, the level of yield was better with irrigation and in 2023, only plots in rainfed conditions were followed.

	2021		2022		2023	
	rainfed	irrigated	rainfed	irrigated	rainfed	irrigated
Nb of field experiments	**12**	**4**	**13**	**15**	**15**	**0**
Average biologic yield at moisture 15% (T/ha)	**6.3**	**5.25**	**4.9**	**6.0**	**4.53**	**-**
% of potential yield reached	**73%**	**64%**	**87%**	**70%**	**83%**	**-**
Spikes/m²	**503**	**502**	**360**	**510**	**371**	**-**
Grains/spike	**26.7**	**25.9**	**19.8**	**28.6**	**25.1**	**-**
Dry Thousand Kernel Weight (g)	**46.2**	**37.6**	**48.8**	**45.3**	**48.1**	**-**
Proteins (%)	**13.5**	**15**	**15.2**	**15**	**15.7**	**-**
NNI at flowering	**0.92**	**0.96**	**0.82**	**0.85**	**0.72**	**-**
Total nitrogen inputs (kg N/ha)	**178**	**221**	**162**	**143**	**140**	**-**
Nitrogen/Yield (kg N/T)	**30.8**	**49.7**	**43.3**	**22.4**	**35.5**	**-**

Figure 6: average yield of the French experiments (2021-2023)

Yield component building up

A PCA analysis on yield components realized on all plots from 2021 to 2023. The variable number of grains/m² is highly correlated to the biomass at flowering and the final yield measured in the field and related to the NNI at flowering. The correlation level between NNI at flowering and the percentage of potential yield reached is low because of the limiting factors observed.

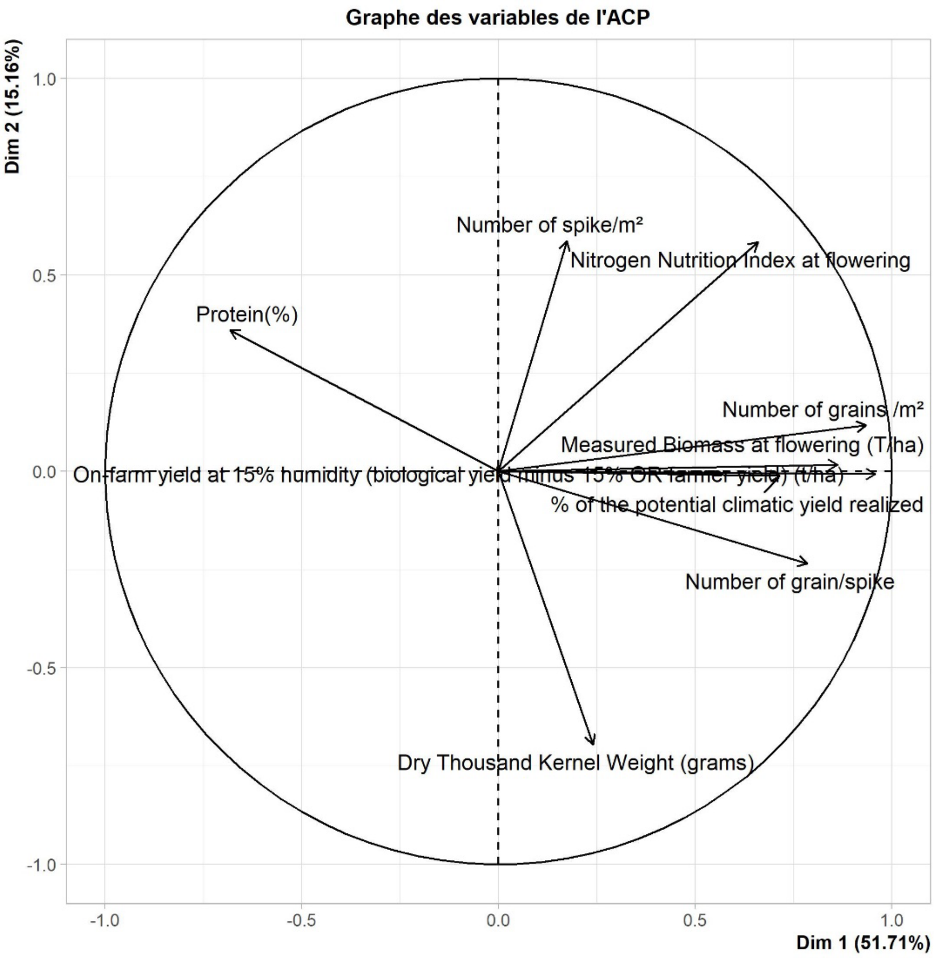


Figure 7: PCA on yield components of French plots 2021-2023

Hierarchization of limiting factors under conservation agriculture practices

In a first analysis, we can notice that we have not measured an impact of conservation agriculture practices on the yield or a very small effect (less than 10 %) in 27% of cases (Figure 8). At the opposite we have measured an important and very important impact in 44% of the cases, even if we must notice than all these yield penalties are not exclusively due to conservation agriculture practices.

Yield impact	Value class of yield potential realization	number of plots	% of the samples
Null or very low	>=90%	17	27%
Moderate	[70-90%[	18	29%
Important	[50-70%[	17	27%
Very important	<50%	10	16%

Figure 8: yield impact classes measured on French plots

The repartition of the plots followed according to the percentage of climatic potential yield reached and nitrogen nutrition index at flowering is presented on Figure 9. The previous crop is materialized by different colours. In orange, an envelope curve represents the percentage of yield reachable according to the nitrogen nutrition index at flowering without any other limiting factors than hydric stress (percentile 0.9). If a plot is significantly under this curve, it's due to other limiting factors than hydric stress (diseases, pests, agronomic accident, other climatic accident than hydric stress) quantified by a scoring (0: no limiting factors identified, 3: very high level of limiting factors on yield). The different limiting factors are separated in different categories:

- Weeds: biomass of weeds measured at flowering.
- Diseases: diseases noticed all along wheat cycle.
- Pest noticed all along cereal cycle.
- Seeding: problem of the emergence of the cereal
- Climate: climatic accident except hydric stress (frozen, scalding…)
- Nitrogen fertilization: nitrogen stress (modelized by CHN) due to the strategy of nitrogen inputs applied by the farmer.

We can notice that **the climatic potential yield is more often reached with pluriannual legumes** (alfalfa or *Onobrychis*) as previous crop. It's a way to insure nitrogen nutrition and weed control (less *Lolium* pressure). With such a previous crop, yield penalties can be explained by a bad control of the pluriannual legume development in the cereal.

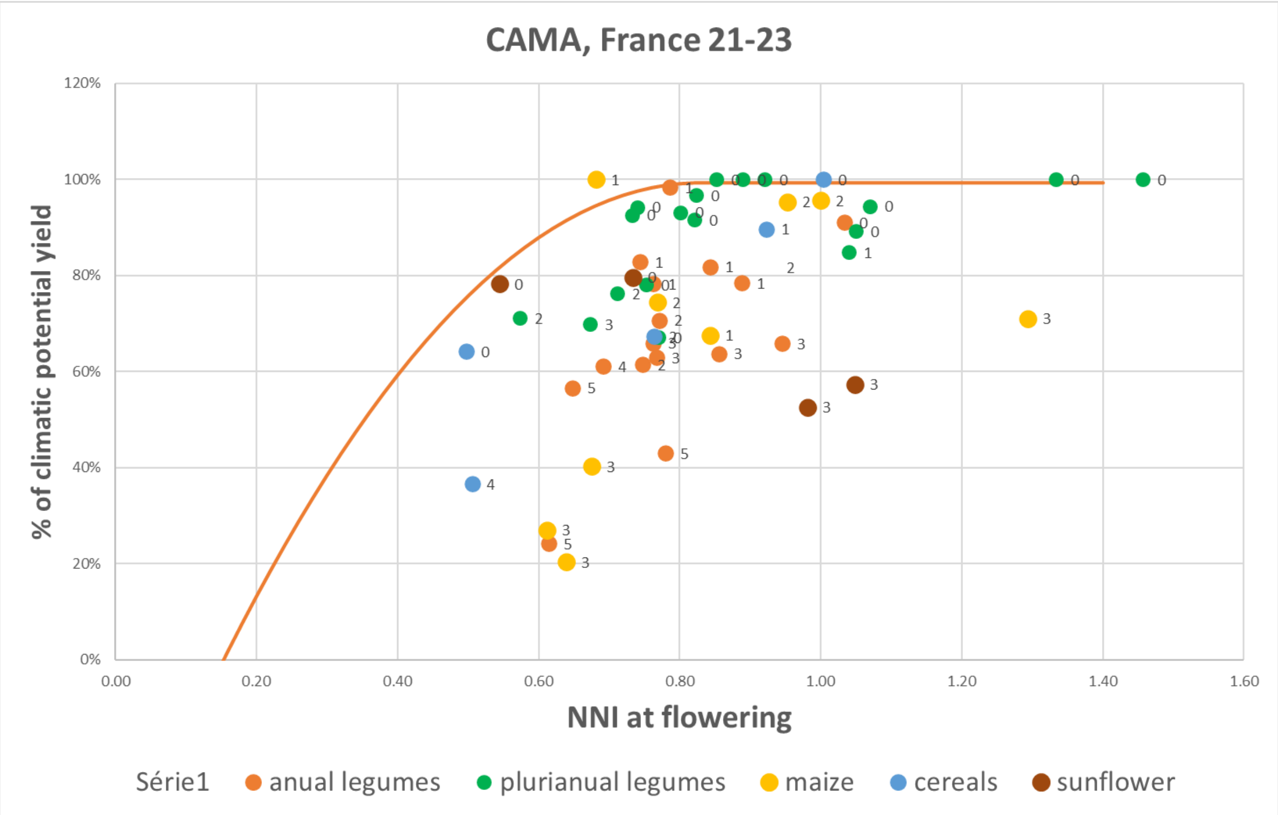


Figure 9: yield gap depending on the nitrogen nutrition index at flowering. The limiting factors scoring is mentioned for each plot.

The importance and the type of limiting factors could be in relation (direct or indirect) with the previous crop (Figure 10), especially for weeds, diseases, pest and seeding. this index is reported in "scoring limiting factors in relation with crop rotation". Weed issues are more important after cereals because of *Lolium* management without tillage in fields with problem of herbicides resistance (prosulfocarb). *Lolium* could be also an important yield limiting factor after annual legume if it was not enough controlled inside with herbicides with no problem of resistance (propyzamide for example). With maize as previous crop, the main problem is due to the quality of the direct sowing in very important residue biomass to manage. Problems of nitrogen fertilization are mainly due to the difficulties of good climate positioning because of very long periods without rain.

Previous crop	weeds	diseases	pest	seeding	scoring limiting factors in relation with crop rotation	*climate (expept 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 10: 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. Climate and nitrogen fertilization are not directly related with the type of previous crop.

The yield Impact of the different types of limiting factors when they have been observed is estimated is the Figure 11. These limiting factors could be:

- Very specific of CA practices: restart of semi-permanent cover like sainfoin (*Onobrychis sp*.) or alfalfa, residues management in direct sowing;
- Moderately specific: *Lolium* management is more difficult with no tillage but we observed also problems on fields with conventional tillage due to herbicides resistance.
- Low specific: problems of dicotyledons or very long drought period which complicate nitrogen inputs valorisation.

Type of limiting factor identified	Description	CA specitcity	Meduim yield inpact measured	Yield inpact variations measured	Explanations
weeds	Loluim	Meduim	30%	from 18 to 43 %	Important risks in no-tillage systems with resistant ray grass With no use of seeds herbicide
weeds	Restart of permanent cover	High	54%	from 24 to 76 %	No use of glyphosate to control permanent plant cover before wheat sowing Difficulties to control onobrychis
weeds	Dicotyledone	Low	38%	from 37 to 38 %	Difficulties to herbicides application
sowing	Residues management and wheat emergence after maize	High	20%	from 4 to 33 %	Dificulties to sow in maize residues and nitrogen consumption due to maize residues
sowing	Residues management after legume	Meduim	31%		Seeding material not adapted
nitrogen fertilization	Early fertilization in one time	High	34%	from 34 to 56 %	Important risks to have a deficit of nitrogen nutrition in situations with too early inputs
nitrogen fertilization	Adaptation of fertilization to climate	Low	49%	from 39 to 64 %	Difficulties in positionning nitrogen inputs in long periods without rain

Figure 11: Yield impact of limiting factors in relation with the specificity of CA practices

Yield fertilization in conservation agriculture

In 2022, an on-farm trial have been realized in Vinon-sur-Verdon, to test different fertilization strategies in conservation agriculture on a field managed in Conservation Agriculture during 10 years. The goals were to test (Figure 12):

- **Different modalities of splitted fertilization**:
    - classical splitting (fertilization in three times);
    - a reduction of the splitting justified by the hypothesis of an important level of microbial biomass in Conservation Agriculture which could be in competition with crop for nitrogen and be the cause of early deficiency (observed in famers' fields).
    - A monitoring of fertilization by CHN (without satellite resetting).

- **Different type of fertilizers:** urea vs ammonium.

In south-eastern France, one of the main issues for nitrogen inputs is the frequent lack of rain between January and April. An experimentation have been realized to test different fertilization strategies (Figure 12) to test the effect on yield and protein to bring most of the Nitrogen early before BBCH 25 (tillering). On this field, mixture of different durum wheat varieties was sown on the 22nd of October, 2021, and irrigated during spring. The micro-plots with 4 duplication were clipped by Arvalis after the wheat emergence. The amount of total nitrogen input was determined by the "nitrogen balance method" in vigor in France.

Inputs dates and stages			BBCH 25 09/02/2022	BBCH 31 22/03/2022	BBCH 45 29/04/2022	Total Niutrogen Input (kg N/ha)
Station météo : 8330	Pluie 15	(mm) dans les jours après l'apport	14.2	5	68.6	Irrigation : mm
mm inputs + 15 days				26 *27/03/2022*	26 *01/05/2022*	130 *(3 autres tours d'eau de 26 mm également le 15/04, 23/05 et 30/05)*
Somme pluie + irrigation dans les 15 jours			14.2	31	94.6	
Module	n°	Stratégie de ferti N				
Ammonuim CA	T0	Untreated control				0
	T04	Splitting	40	130	40	210
	T07	All before BBCH 25	210	-	-	210
	T08	All before BBCH 25 and 40 kgN for "quality"	170	-	40	210
	T09	BBCH 25 +	80	90	40	210
	T10	BBCH 25 0	-	170	40	210
	T11	BBCH 45+	40	90	80	210
	T12	CHN Monitoring	50	40	80	170
Urea CA	T13	Splitting Urea	40	130	40	210
	T14	All before BBCH 25	210	-	-	210
	T15	All before BBCH 25 and 40 kgN for "quality"	170	-	40	210

Figure 12: fertilization modalities (France, 2021)

The results are presented in Figure 13 and show:

- An effect of any kind of fertilizers in comparison to untreated control.
- no yield differences between splitting strategies and others with early inputs.
- On the opposite, the yield was significantly lower with a lack of fertilization at tillering (BBCH 25).

	N Dosis (Kg N/ha)	Yield (T/Ha)	HG Yield	Yield standard deviation	Protein	HG protein	Protein standard deviation
T04 Splitting	210	6.1	ab	2.9	16.3	a	1.63
T 10 No inputs at BBCH 25	210	5.3	b	3.1	17.0	a	0.69
T07 All inputs before BBCH 31	210	5.9	ab	1.3	16.2	a	1.10
T08 All inputs before BBCH 31 - 40 kgN BBCH 3	210	5.9	ab	4.6	16.6	a	0.29
T 09 BBCH 25+	210	6.0	ab	2.9	15.0	ab	0.46
Untreated control	0	3.4	c	2.9	12.6	b	3.11

Figure 13: results of fertilization experiment in conservation agriculture

About type of fertilizer, we don't observe any difference between ammonium and urea (Figure 14).

	UREE vs ammo	N dosis (kg N/ha)	Yield	GH Rdmt	Standard deviation	Protein	GH Protéines
Splitting	Ammo	210	6.10	ab	2.9	16.3	a
	Urea	210	5.87	ab	3.2	17.2	a
All before BBCH 25	Ammo	210	5.86	ab	4.4	16.4	a
	Urea	210	5.96	ab	1.8	16.2	ab
All inputs before BBCH 31 - 40 kgN BBCH 39	Ammo	210	5.86	ab	1.5	16.2	ab
	Urea	210	6.14	ab	1.3	16.2	a

Figure 14: effect of the type of fertilizer on the yield and the protein content

In conclusion about fertilization experiment in South-East of France realized in 2022, we observe:

- **No difference between Urea and Ammonium on yield and protein.**
- **No advantage to reduce splitting fertilization, but a risk to put too light inputs around tillering.**

Plant cover in dry conditions

A trial in Oraison is dedicated since 14 years to work out technical itineraries in conservation agriculture in Mediterranean conditions in rainfed and irrigated systems. The main limiting factor to succeed plant cover development during intercropping in Mediterranean conditions is the permanent negative water balance (Rain-0.35*Potential Evapotranspiration) during summer (Figure 15). In those conditions, it's too hazardous to succeed plant cover sowing and development in summer.

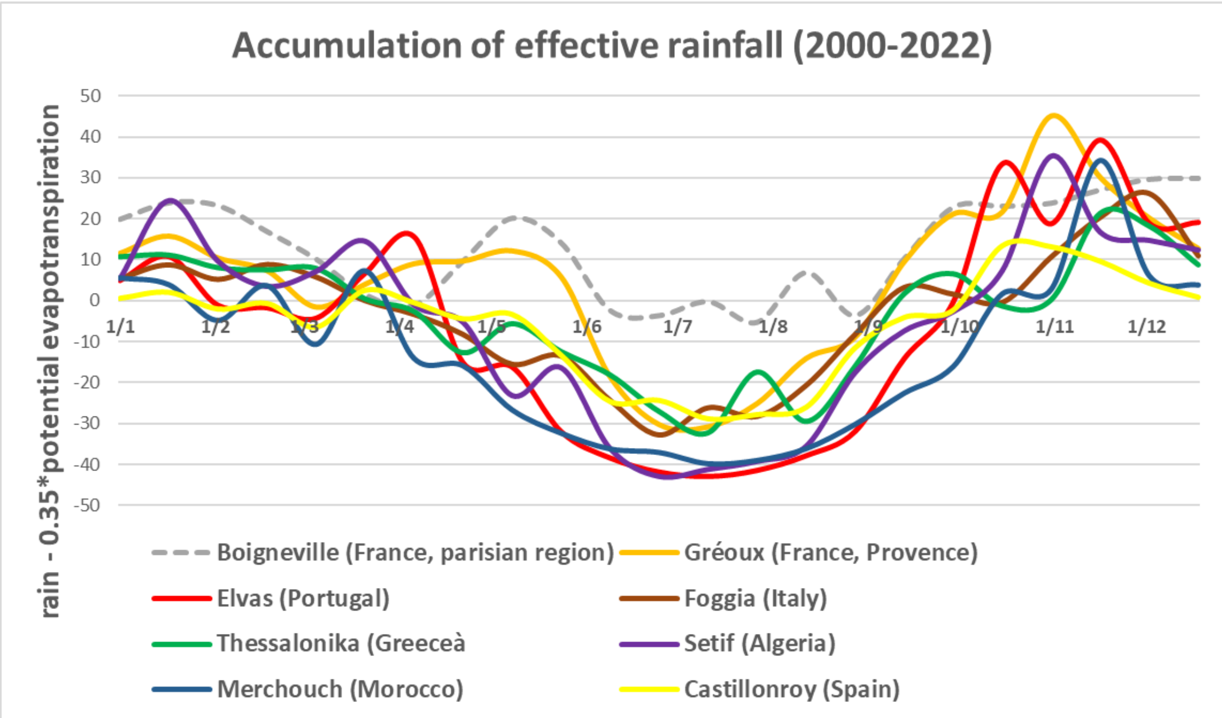


Figure 15: accumulation of effective rainfall (2000-2022)

The Figure 16 presents the results of association of semi-permanent cover (alfalfa, onobrychis) with crops in South-East of France according to :

- Ease of installation: does the association allow for a good start in the development of the plant cover?
- Sustainability: does the association allow for a good development of the plant cover ?
- Management in crop : does the association is adapted to a management of plant cover development with herbicides ?

What	How	When (SE France)	implantation	Sustainability	Management in crop
Alfafla or sainfoin	Alone fodder	August	4	4	2
Alfafla	Alone seed production	August	4	4	3
Alfafla	In rapeseed	August	4	4	4
Alfafla or sainfoin	Under maize mulch	September	3	3	5
Alfafla or sainfoin	Before wheat	September	4	2	2
Sainfoin	With fababean	September - October	3	4	2
Alfafla	With fababean	September - October	2	4	2
Alfafla or sainfoin	With wheat	October	1	1	1
Alfafla or sainfoin	Under chickpea	March	3	4	3
Alfafla or sainfoin	With sunflower	March	3	4	3
Alfafla	In maize	April	4	1	2
Alfafla or sainfoin	In field pea	March/April	4	1	2

1	2	3	4	5
Complicated				Easy

Figure 16: semi-permanent plant cover implantation with different crops (Oraison, France)

Semi-permanent competition with crop

One of the problems of semi-permanent cover could be the competition with associated crop, particularly about nitrogen and water. In many situations before autumn cereal the semi-permanent cover is destroyed. But in some cases, farmers keep the semi-permanent cover alive in the wheat and regulate it with crop herbicides (hormones most of the time). In the French data from 2021 to 2023, the permanent plant cover left alive in the wheat does not affect the realization of the climatic potential yield simulated by the model Garric ® (Figure 17). The realization of potential yield is even better, probably due to the nitrogen inputs from to the semi-permanent plant cover regulation before sowing and during wheat cycle. In some cases, if the semi-permanent plant cover is not sufficient, we can measure a strong competition.

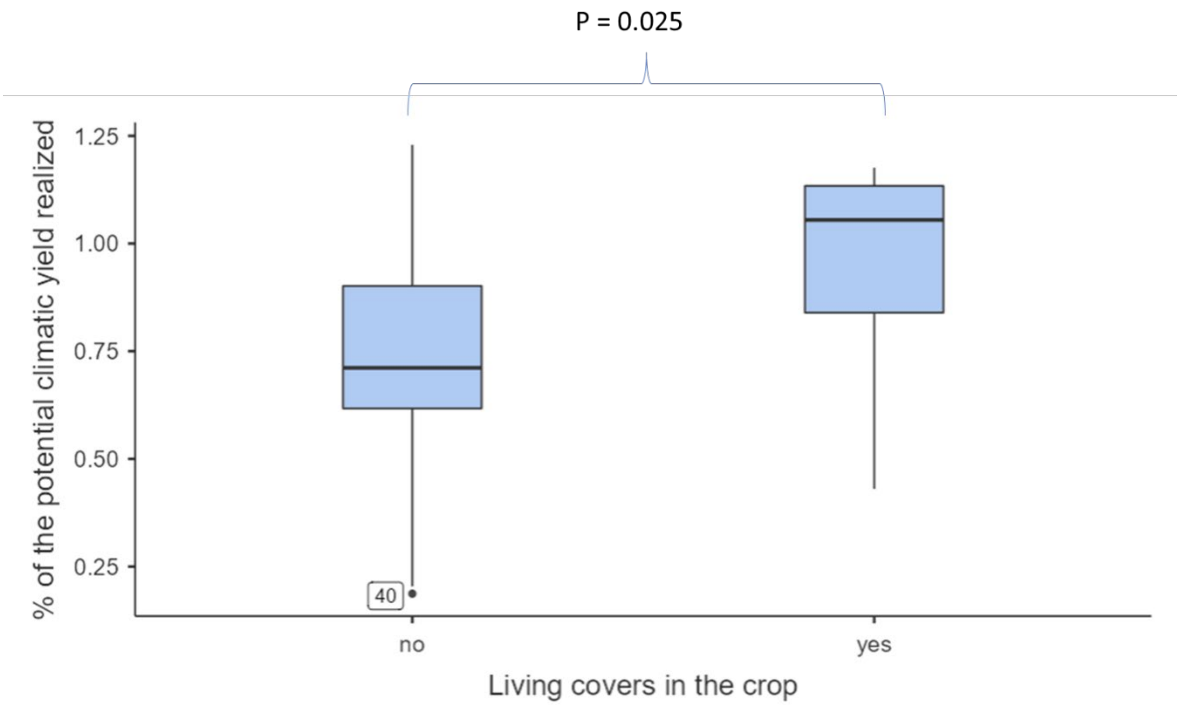


Figure 17: effect of living cover in wheat on percentage of realization of potential yield. Yes : n=7; no : n=55.

Soil compaction management by crop rotation under CA

Due to the impossibility of tillage, there is a risk of soil compaction in DS systems, especially in silt or clay soil in regions frost free in winter. A analysis with penetrometer was realized in the French trial in Oraison to compare :

- Conventional agriculture (CT) and CA
- Under CA, durum wheat with different previous crop.
- Under CA, onobrychis as cover associated with oat, or alone.

The results are presented on Figure 18. It shows :

- a more important level of compaction under CA upper than 40 cm of depth.
- Under CA, less compaction in wheat with onobrychis as previous crop than maize. We can explicate this results by risks of compaction in maize harvest and roots effect of onobrychis.
- A positive effect on compaction by associating oat (superficial roots) with onobrychis (deep roots).

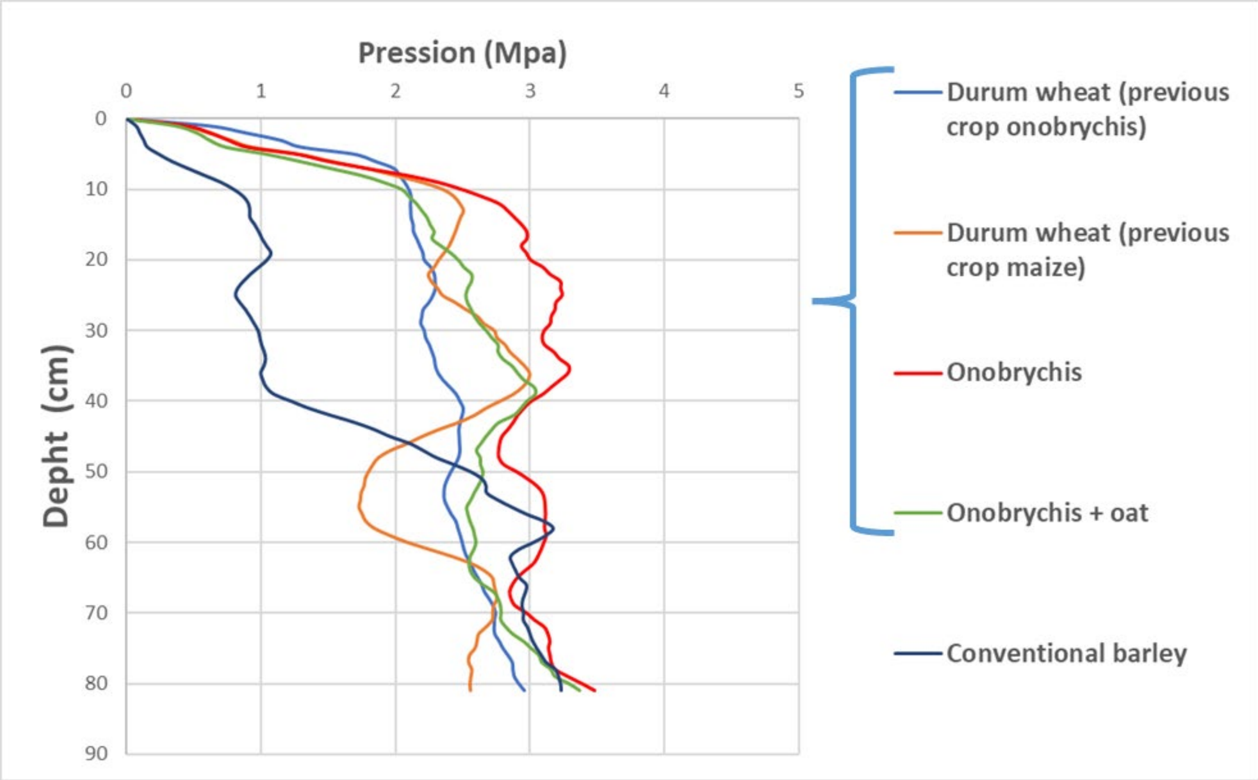


Figure 18: effect of crop rotation on soil compaction under CA

Main conclusions– France

The main conclusions of limiting factors under Conservation Agriculture in France are presented in Figure 19. We can notice a **specific problem of *Lolium* in no tillage systems**, with resistances to herbicides with sulfonylurea. Diagchamp have demonstrated than *Lolium* could be well managed thanks to crop rotation with legumes, perennial (meadow mowing) or annual (possibility to use herbicides with no problem of resistance, like propyzamide).

For seeding technics, the main problem observed is the sowing quality after maize caused by an insufficient management of the residues in direct sowing and nitrogen consumption by maize residues degradation.

For crop fertilization, many farmers without irrigation have many difficulties in positioning correctly nitrogen inputs in dry climate. Some tests have been realized to increase early inputs (for South East of France before the end of January) to anticipate the risk of very long drought period.

For **crop rotation**, it was noticed frequently yield penalties in case of wheat in succession with a first autumn cereals due mainly to *Lolium* management.

Semi-permanent plant cover is a good way to cover the soil during summer in Mediterranean conditions, if the competition with crops is minimized or avoided thanks to efficient chemical regulation.

Farmers needs and technical problems (D3.1)	Diagchamp lessons	Conservation Agriculture specificity
Weed control and crop residues	• More level of weeds control with legumes (perennial or annual) as previous crop, especially for *Lolium*.	**HIGH**
Seeding	• Problems of sowing quality on wheat after maize: residues management and nitrogen consumption by residues degradation.	**HIGH**
Crop fertilization	• Difficulties in positioning nitrogen inputs in dry climate. • Important risks to have a nitrogen nutrition deficit in situation with too early inputs	**LOW**
Crop rotation	• Difficulties to succeed wheat with cereals as previous crop (weeds management).	**MEDUIM**

Figure 19 : main conclusions on limiting factors (France)

3.2 Portugal

Pedologic conditions

Field experiments in Portugal were placed in calcareous soils, mainly with clay texture with an average organic matter rate at 0.63%. Water holding capacities are very different between fields: from 63 to 210 mm/m.

Climatic conditions

The Figure 20 illustrates the climatic conditions in Elvas for the wheat seasons 2021, 2022 and 2023. We can notice:

- Rainy autumn, and in some cases (December 22), too much rain to sow.
- Drought in winter (February-March) and in consequences, difficulties to have good conditions to apply fertilization in 2022 and 2023.
- Uncertain return of rain in April or May, important to "maintain" the yield potential.

Meteo station	Elvas									
	Unity	2020-2021			2021-2022			2022-2023		
Rain (01/10 to 30/06)	mm	589.2			224.4			500.2		
Average T° (01/10 to 30/06)	°C	14.91			15.12			16.03		
Average Potential Evapo-Transpiration	mm	785.6			828.3			780.9		
		rain (mm)	Temp (°C)	PET (mm)	rain (mm)	Temp (°C)	PET (mm)	rain (mm)	Temp (°C)	PET (mm)
October		60.0	17.42	89.4	41.8	19.42	92.6	75.8	20.32	78.2
November		148.8	14.68	33.5	13.2	11.91	47.1	60.4	14.25	37.1
December		53.5	10.60	32.5	36.8	11.50	33.7	253.6	13.43	28.8
January		56.6	8.76	30	2.2	9.89	38.1	37	9.25	34.8
February		117.3	12.23	40.2	1.3	11.83	54.3	2.6	10.02	47.8
March		18.7	13.64	93.7	87.4	12.50	62.1	19.6	13.93	84.9
April		83.0	16.59	93.7	34.3	14.33	114.8	4.8	18.28	138.1
May		9.9	18.13	175.9	3.4	21.48	185.3	36.4	19.95	155
June		41.4	22.16	196.7	4	23.25	200.3	10	24.88	176.2

Figure 20 : average climatic conditions for Elvas

Dataset

Ten plots have been followed in Portugal during CAMA project, 5 with irrigation. Crops were durum wheat, bread wheat and spring barley. All plots were in direct sowing.

Average yields on seasons 2021-2023

Average results by year, according to the regime of irrigation, are presented in the Figure 21. In addition to a strong irrigation effect (2021 and 2022), we can notice a very important variation of yields between the three years of the program. For the season 2022-23, the potential yield was very low because of very important drought in winter and spring. For this season, 2 fields were not harvested due to lack of yield because of dry conditions.

	2021		2022		2023	
	rainfed	irrigated	rainfed	irrigated	rainfed	irrigated
N. of field experiments	**1**	**3**	**3**	**1**	**1**	**1**
Average biologic yield at moisture 15% (T/ha)	**5.4**	**6.5**	**3.7**	**8.3**	**1.3**	**1.7**
Spikes/m²	**304**	**434**	**370**	**483**	**165**	**159**
Grains/spike	**36**	**34**	**25.1**	**37.5**	**27**	**31**
Thousand Kernel Weight at moisture 0% (g)	**41.5**	**38.1**	**40.7**	**45.6**	**30.2**	**34.8**
Proteins (%)	**10.3**	**10.5**	**12.5**	**12.1**	**14**	**14.9**
NNI at flowering	**0.49**	**0.70**			**0.62**	**0.43**
Total nitrogen inputs (kg N/ha)	**77**	**135**	**30**	**180**	**78**	**108**
Nitrogen/Yield (kg N/T)	**14.3**	**20.5**	**8.1**	**21.7**	**49**	**130**

Figure 21 : average yield of wheat experiments in Portugal

Limiting factors analysis

The Figure 22 illustrates, field by field, the biologic yield realized, the Nitrogen Nutrition Index at Flowering and the percentage realized of the modelized biomass at flowering. Except the hydric stress, the main limiting factors identified in CA are :

- **Nitrogen nutrition**, especially due to lack of sufficient rain to position fertilization (essentially ammonium nitrate). According to CHN simulation, the average level of nitrogen stress at flowering is around 32 kg N/ha in comparison with the optimal nutrition in function of the climatic potential biomass. The Figure 23 illustrates a common situation in a trial in Melinho in 2021.
- **Weed control** : Raphanus, Avena fatua and Poa pratensis are the main weeds observed in CA fields. The weed control is particularly difficult due to climatic conditions and especially lake of rain, in particularly in total direct sowing which could represent an additional risk (for Poa pratensis for example).
- **Difficulties to sow wheat in dry conditions** in places with no irrigation due to superficial soil compaction and residues management (for example with sorghum as previous crop). In tillage systems, farmers can prepare soils just after harvest.

Trial	Crop	Previous crop	Biological yield (t/ha) at 15% of humidity (and protein content of the grain)	NNI at flowering (Total N input kg/ha)	% realized of the modelised biomass at flowering (potential biomass according to the hydric stress)	Biotic limiting factors	Abotic stress
2021 – Melinho (irrigated)	Spring Bread Wheat	Spring wheat	4.4 (11)	0.65 (70)	83%	Presence of weeds (Raphanus, Avena Fatua, poa pratensis) - no herbicides used due to rain Yellow rust and septoriose	Insufficient fertilization due to rain. Too late irrigation.
2021 - Murtaes	Spring Bread Wheat	Pumpkin	5.4 (10)	0.49 (77)	90%		Nitrogen stress due to insufficient fertilization regarding to rain
2021 - Romeiras (irrigated)	Winter Bread Wheat	Sunflower	6.4 (10)	0.79 (171)	100%		
2021 - Figueiras (irrigated)	Winter Bread Wheat	OSR	8.9 (11)	0.67 (165)	59%		Nitrogen stress due to insufficient fertilization regarding to rain
2022 - Comenda	Triticale	Triticale	2.8 (14)	(101)			
2022 - Melinho	Spring Barley	Spring Wheat	4.1 (9)	(52)	88%	Weed infestation (Raphanus, Avena Fatua, poa pratensis) fungi diseases at tillering (Yellow rust)	Insufficient fertilization due to severe dry condition.
2022 - Murtaes	Winter Bread Wheat	Fallow	3.7 (13)	(30)	100%		
2022 – Figueiras (irrigated)	Winter Bread Wheat	Sorghum	8.3 (12)	(180)	100%		
2023 - Figueiras (irrigated)	Winter Bread Wheat	OSR	0.8 (15)	0.43 (108)	41%		Nitrogen stress due to insufficient fertilization regarding to rain
2023 - Comenda	Winter Bread Wheat	Cereals	1.6 (14)	0.62 (78)	100%	Previous crop was sorghum	

Figure 22: limiting factors identified in Portuguese fields experiment.

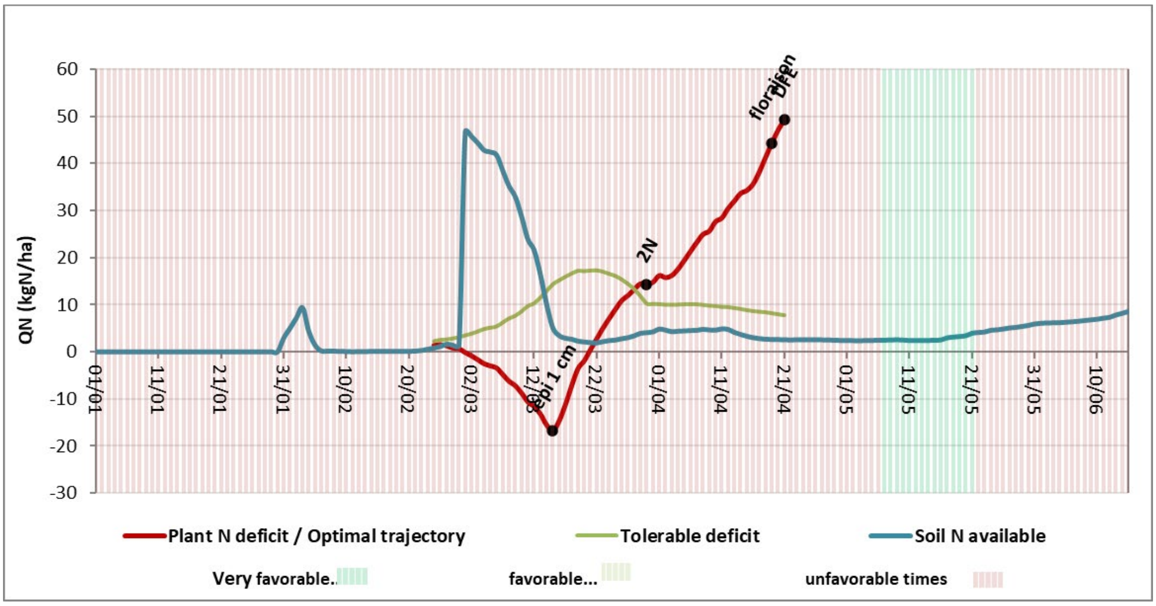


Figure 23: nitrogen dynamics in soil and plant modelized by CHN (Portugal, Melhino, 2021)

Main conclusions– Portugal

For Portugal, the main conclusion about **weed control** was the difficulty to put herbicides due to the lack of rain during long periods, so a non-efficient conditions.

About sowing, one of the main problems diagnosed was the difficulty of direct sowing in dry conditions (soil compaction after summer season) while minimum tillage could be practiced just after previous crop harvest in conventional systems.

About fertilization, the main problem observed is the difficulty of positioning nitrogen inputs in dry conditions.

Farmers needs and technical problems (D3.1)	Diagchamp lessons	Conservation Agriculture specificity
Weed control and crop residues	• Difficult due to lack of rain	**MEDIUM**
Seeding	• Problems of sowing quality in dry conditions with no tillage	**HIGH**
Crop fertilization	• Difficulties in positioning nitrogen inputs in dry climate.	**LOW**

Figure 24: main conclusions on limiting factors (Portugal)

3.3 Greece

Pedologic conditions

There are two situations in field experiments in Greece:

- Thessaloniki: non calcareous, no stoniness, entisol; loam, 90cm deep allowing a maximum root growth of 80cm, 1.3% of OM, water holding capacity = 38mm;
- Drimos: non calcareous, no stoniness, vertisol; clay, 30cm deep allowing a 25cm deep root growth, 3% of OM, water holding capacity = 21mm.

Climatic conditions

Meteo station	Thesaloniki									
	Unity	2020-2021			2021-2022			2022-2023		
Rain (01/10 to 30/06)	mm	242.2			380.4			594.9		
Average T° (01/10 to 30/06)	°C	13.71			13.68			13.91		
Average Potential Evapo-Transpiration	mm	616.3			655.5			604.2		
		rain (mm)	Temp (°C)	PET (mm)	rain (mm)	Temp (°C)	PET (mm)	rain (mm)	Temp (°C)	PET (mm)
October		1.0	17.83	73.4	116.8	15.77	49.5	13.1	17.80	79.1
November		9.6	11.01	32.5	19.8	13.37	37.6	36.8	14.10	40.9
December		67.5	9.74	22	44.2	8.40	42.3	38.6	10.60	21.3
January		96.2	8.57	21.8	30	6.37	35	59.4	9.20	25.1
February		7.7	9.29	34.9	29.6	8.96	40.7	21.4	7.50	39.4
March		22.2	9.80	63.6	46.6	8.02	59.6	61.6	11.20	64.8
April		23.1	12.76	84.9	24.2	14.94	91.7	103.6	13.80	83.4
May		2.3	19.72	145.5	20.6	21.21	141.7	132	18.00	106.1
June		12.6	24.70	137.7	48.6	26.11	157.4	128.4	23.00	144.1

Figure 25: average climatic conditions in Thessalonika

The Figure 25 illustrates the climatic conditions in Thessaloniki. It shows a correct level of rain, in comparison with other Mediterranean countries involved in the project. We can notice a very strong variation in precipitation from one year to the next, especially during spring (March to May).

Dataset

Ten fields have been followed for the CAMA project in Greece in durum wheat, bread wheat or barley in two locations, Drimos and Thessaloniki. For 2022-23 in Drimos and Thessalonika, a comparison between conventional tillage (ploughing at 25 cm) and minimum tillage (disks at 5 cm) was realized. In 2020-21 and in 2021-22 a comparison between five types of nitrogen (two Controlled Released Fertilisers, one double Urease inhibitor, one fertiliser with MPPA DUO technology and a Conventional fertiliser) was performed in Conventional tillage. All plots were conducted without irrigation. In 2023, a comparation between two types of nitrogen fertilizers (ammonium nitrate and a double Urease Inhibitor Fertilization) was done in Minimum Tillage.

Average yields on seasons 2021-2023

	2021	2022		2023	
	Winter Bread Wheat	Barley	Durum Wheat	Barley	Winter Bread Wheat
N. of field experiments	2	3	1	2	2
Average biologic yield at moisture 15% (T/ha)	2.8	5.7	4.1	3.7	4.6
Spikes/m²	347	570	458	404	436
Grains/spike	22.5	23.4	15	17.6	25.7
Thousand Kernel Weight at moisture 0% (g)	30	43.6	60	44.8	34.2
Proteins (%)	14.2	12.3	13	11.8	11.3
NNI at flowering	0.66	0.57	0.63	0.51	0.66
Total nitrogen inputs (kg N/ha)	118	61	136	88	120
Nitrogen/Yield (kg N/T)	46.8	10.6	33	24.4	27.3

Figure 26 : average yield of experiments in Greece

Limiting factors analysis

Minimum tillage effect on yield and nitrogen stress

In 2022 and 2023, field experiments have consisted to compare, as the same place, technical itineraries Minimum Tillage (MT) with Conventional Tillage (CT). The comparison between MT and CT started in 2020:

- For harvest 2022, barley (Cultivar: Triptolemos) was sowed on 2021 November 17th after pea crop.
- For harvest 2023, barley (Cultivar: Nure) was sowed on 2022, November 11th after barley.

CT consists of a plow at 25 cm, whereas for MT the use of “power harrow” at 5-8 cm. The global yield of two years of experiment showed that there is no significant difference between MT and CT. In 2023, the yield was lower in Minimum Tillage (“23_Drimos_MT”) in comparation to Conventional Tillage in 2023 (“23_Drimos_CT”) (barley after barley as previous crop) because a **higher level of nitrogen stress** (materialized by NNI at flowering and levels of soil nitrogen residues in January: 16 kg N/ha in MT ; 24 in CT). A slower residues degradation in MT, and weed development (*H. incana*) could also explain this results. In 2022 (barley after lathyrus crop), the yields between the two modalities were equal.

Between MT and NT, there is no significant differences on 2 years experiment on yield component and nitrogen stress (Figure 27).

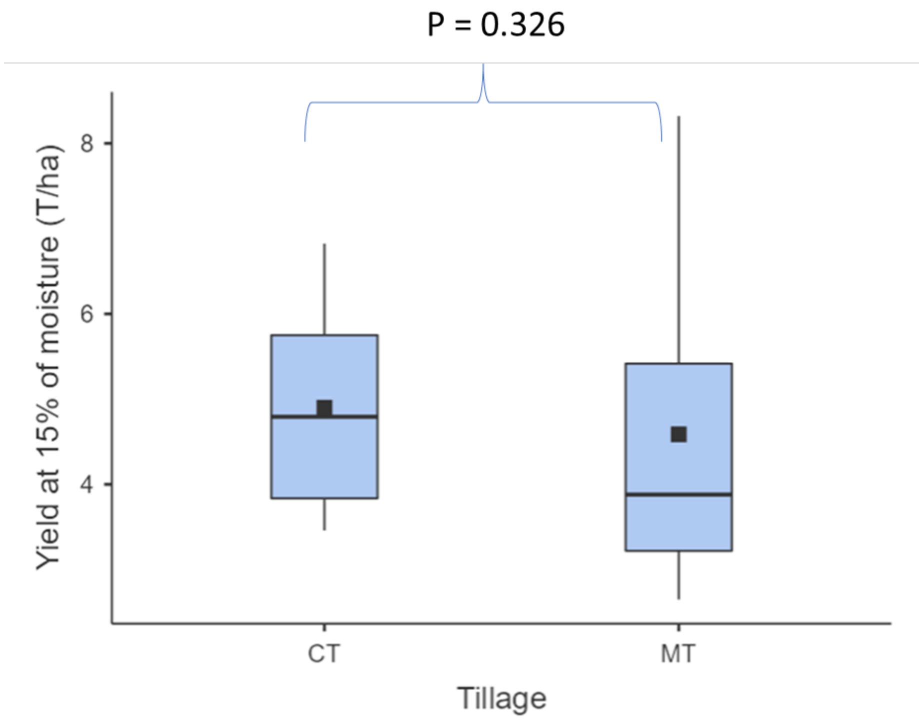


Figure 27: average yield in MT and CT (Greece, 2022 to 2023)

Kruskal-Wallis

	χ²	ddl	p
WHEAT Dry matter at flowering (T/ha)	1.613	1	0.204
N absorbed at flowering in above ground biomass (Kg/ha)	3.413	1	0.065
Nitrogen Nutrition Index	5.070	1	0.024
Dry matter straw (T/ha)	0.600	1	0.439
Yield at 15% of moisture (T/ha)	0.963	1	0.326
Dry Thousand Kernel Weight (grams)	0.368	1	0.544
Number of spike by m²	0.702	1	0.402
Number of grains /m²	0.480	1	0.488
Number of grain/spike	0.120	1	0.729

Figure 28: yield component in NT and MT experiments (Greece 2022 to 23)

Type of fertilizer in minimum tillage systems

In Greece, two experiments were developed about type of fertilizer adapted to Mediterranean conditions:

- Under conventional tillage in 2022.
- Under minimum tillage in 2023.

2020-2021 and 2021-2022 years

A trial was set up under conventional tillage in 2021 and repeated in 2022 in an adjacent field to compare the effect of conventional fertilizer with **four non-conventional types of fertilizers compared to conventional type of fertilization**. The non-conventional fertilizers included: a) **a controlled release fertilizer (CRF) 31-21-0 (2)** with a polymer coated urea set for **2 months longevity**, b) **a controlled release fertilizer (CRF) 31-21-0 (4)** with a polymer coated urea set for **4 months longevity**, c) a fertilizer with **dual urease inhibitors (NPPT and NBPT) 20-20-0 (12 SO_3)**, and d) a fertilizer **(10-24-0 + 24%SO_3+ 0.1%Zn+ 0.1%B) with MPPA DUO technology** (that protects the nutrients contained in the fertilizer throughout the growing season, stimulates sand mobilizes the absorption of the soil-bound elements, stimulates the growth of the plant's metabolism and development of the root system and promotes the rapid growth of crops). **The conventional fertilizer** used as **base fertilizer** was a **36-16-0** fertilizer with nitrogen in the form of **urea and ammonium nitrate (50:50)**. All the base fertilizers were hand-broadcast and afterwards were mechanically soil-incorporated before crop sowing. The **fertilizer 33.5-0-0 (ΕΛΛΑΓΡΟΛΙΠ) ammonium nitrate** (½ ammonium and ½ nitrate forms) was used as a **top-dressing nitrogen fertilizer** that accompanied the base fertilizers of the three of the five base fertilizers and more specifically the dual urease inhibitor, the fertilizer with MPPA DUO technology and the conventional fertilizer (Figure 29). No top-dressing fertilization was applied in plots where CRF fertilizers were applied as base fertilizers; these plots received only a single application of fertilizers (base fertilization). The top-dressing fertilizer was broadcast by hand at the tillering growth stage. The total amount of nitrogen application was 120 kg N ha^{-1} for all treatments. Details of nitrogen application for each treatment is provided **in** Figure 30.

Bread wheat (cv. *Oropos*) was seeded with a seeding machine at 200 kg ha^{-1} on **1.12.2020** (year 2020) in a field of the experimental farm of Institute of Plant Breeding and Genetic Resources at Thessaloniki, Greece. Next year, on the same cultivar was seeded on **20.11.2021** and the experiment was conducted in a adjacent field in the same way as in 2020 year. The experimental design was that a Randomized complete block design with four replication per treatment. Experimental plots were 6m x 5m=30 m^2 of size.

Fertilizer used	Trade name of fertilizer	Type of fertilizer	Company	Time of application
31-21-0 (2*)	**CoteN mix Booster (2*)**	**Controlled release fertilizer (CRF)**	**Haifa**	**Base**
31-21-0 (4)**	**CoteN mix Booster (4**)**	**Controlled release fertilizer (CRF)**	**Haifa**	**Base**
20-20-0 (12 SO_3)	**ΑδΑΜΑΣ**	**Dual inhibitors of Urease (NPPT[#] + NBPT[##])**	**ADAMA**	**Base**
10-24-0 + 24% SO_3 +0.1% Zn+0.1% B	**Eurocereal**	**MPPA DUO technology**	**Timac Agro- ΛΥΔΑ**	**Base**
36-16-0	**Win-Win**	**Conventional fertilizer**	**ZIKO**	**Base**
33.5-0-0	**Nutramon**	**Conventional fertilizer**	**ΕΛΛΑΓΡΟΛΙΠ**	**Top-dressing**

Figure 29: Fertilizer applied, trade name, type of fertilizer and company name.

**= set for 2 months longevity (at 21 °C), **= set for 4 months longevity (at 21 °C), #= N-(n-propyl) thiophosphoric triamide, ##= N-(n-butyl) thiophosphoric triamide*

Treatments (base + top dressing)		Kg N ha^{-1} (base fertilization)	Kg N ha^{-1} (top dressing fertilization)	Total Kg N ha^{-1} (base + top dressing)
1	31-21-0 (2) + no top dressing	120	0	120
2	31-21-0 (4) + no top dressing	120	0	120
3	20-20-0 (12 SO_3) + 33.5-0-0	60	60	120
4	10-24-0 (24% SO_3 plus 0.1% Zn plus 0.1% B) + 33.5-0-0	60	60	120
5	36-16-0 + 33.5-0-0	60	60	120
6	Untreated control	0	0	0

Figure 30: Treatments of fertilization (base + top dressing application) and relevant rates (Kg N ha^{-1})

Results of year 2020-2021

- *Nutrient soil analyses*:

Two soil-nutrient analyses were performed: one before the base fertilization (Figure 31) and the other before the application of the top-dressing fertilizer.

Nitrate Ppm	P ppm	K ppm	Mg ppm	Ca ppm	Fe ppm	Zn ppm	Mn ppm	Cu ppm	B ppm
10.3	**10.6**	**421**	**600**	**>2000**	**6.23**	**0.33**	**5.58**	**1.34**	**0.88**

Figure 31: Soil nutrient analysis before fertilization

Treatment (base +top dressing)		Nitrates ppm
1	31-21-0 (2) + no top dressing	10.1a*
2	31-21-0 (4) + no top dressing	7.4a
3	20-20-0 (12 SO_3) + 33.5-0-0	16.6a
4	10-24-0 (24% SO_3 plus 0.1% Zn plus 0.1% B) + 33.5-0-0	9.5a
5	36-16-0 + 33.5-0-0	15.0a
6	Untreated control	7.9a

**Numbers followed by the same latter do not statistically differ (a=0.05)*

Figure 32: Soil-nitrates before the top-dressing fertilization (March 2021) as influenced by the base fertilization.

- *Leaf-nutrient analyses:*

Three leaf-nutrient analyses were performed: one before the top-dressing fertilization (February 2021, at tillering, Figure 33), one two weeks after the topdressing fertilization (end of March 2021, stem elongation, Figure 34) and one two months (May 2021, Figure 35) after top-dressing fertilization.

Treatment	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	% D.W.					mg kg^{-1} D.W.				
1	5.41a*	0.38a	2.97a	0.58a	0.28a	253ab	82a	19a	8.0a	5.5a
2	5.25a	0.38a	3.03a	0.58a	0.28a	205b	81a	19a	8.0a	5.0a
3	5.17a	0.39a	3.44a	0.66a	0.27a	197b	75a	25a	9.5a	5.5a
4	5.37a	0.39a	3.11a	0.70a	0.27a	192b	80a	21a	8.0a	6.0a
5	5.20a	0.38a	3.06a	0.57a	0.26a	198b	70a	23a	7.0a	5.0a
6	5.01a	0.36a	3.01a	0.59a	0.27a	312a	82a	23a	8.5a	5.0a

**Numbers followed by the same latter do not statistically differ (a=0.05)*

Figure 33: Leaf-nutrient analysis at tillering (before top-dressing application)

Treatment	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	% D.W.					mg kg^{-1} D.W.				
1	4.99a*	0.36a	2.74a	0.54a	0.24a	72a	76a	21a	10a	10b
2	4.94a	0.37a	2.79a	0.54a	0.24a	69a	76a	20a	10a	11ab
3	5.30a	0.37a	3.23a	0.58a	0.24a	69a	94a	28a	11a	11ab
4	5.33a	0.37a	2.93a	0.64a	0.26a	72a	86a	23a	9a	15a
5	5.04a	0.33a	2.90a	0.51a	0.23a	68a	74a	25a	10a	10b
6	5.22a	0.34a	2.98a	0.54a	0.25a	75a	74a	25a	8a	12ab

**Numbers followed by the same latter do not statistically differ (a=0.05)*

Figure 34: Leaf-nutrient analysis at stem elongation (2 weeks after top-dressing application)

Treatment	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	% D.W.					mg kg^{-1} D.W.				
1	1.23a*	0.14ab	0.94a	0.59a	0.33a	75a	169a	15a	6a	10a
2	1.25a	0.13ab	0.79a	0.50a	0.28a	63ab	149ab	12a	5a	9a
3	1.25a	0.14ab	0.83a	0.54a	0.31a	66ab	151ab	14a	5a	9a
4	1.25a	0.18a	1.08a	0.75a	0.42a	66ab	157ab	16a	5a	11a
5	1.21a	0.14ab	1.01a	0.59a	0.34a	71a	168a	15a	5a	10a
6	1.25a	0.12b	0.83a	0.54a	0.31a	51b	122b	12a	4a	11a

**Numbers followed by the same latter do not statistically differ (a=0.05)*

Figure 35: Leaf-nutrient analysis 2 months after top-dressing application.

- *Yield components and yield*

At harvest the number of spikes m^{-2}, spike length and the yield (gr m^{-2}) was estimated after harvesting one square meter from the centre of each plot (Figure 36).

The results showed that greater yield compared to the control was achieved only in the application of the CRF 31-21-0 (4) + no top dressing.

Treatment (base + top-dressing)		Number of spikes/m^2	Spike length (cm)	Yield gr/m^2
1	31-21-0 (2) + no top dressing	441a*	8.3a	411ab
2	31-21-0 (4) + no top dressing	483a	8.5a	497a
3	20-20-0 (12 SO_3) + 33.5-0-0	415ab	8.9a	416ab
4	10-24-0 (24% SO_3 plus 0.1% Zn plus 0.1% B) + 33.5-0-0	421ab	8.5a	368b
5	36-16-0 + 33.5-0-0	469a	8.9a	410ab
6	Untreated control	362b	8.5a	333b

**Numbers followed by the same latter do not statistically differ (a=0.05)*

Figure 36: Yield components and yield as affected by fertilization.

Results of year 2021-2022

- *Nutrient soil analysis*:

Two soil-nutrient analyses were performed: one before the base fertilization (Figure 37) and the other before the application of top-dressing fertilizer (Figure 38).

Nitrates ppm	P ppm	K ppm	Mg ppm	Ca ppm	Fe ppm	Zn ppm	Mn ppm	Cu ppm	B ppm
13.0	**8.70**	**113**	**338**	**>2000**	**4.30**	**0.51**	**4.84**	**1.01**	**0.26**

Figure 37: Soil nutrient analysis before fertilization

Treatment (base +top-dressing)		Nitrates ppm
1	31-21-0 (2) + no topdressing	4.2a*
2	31-21-0 (4) + no topdressing	4.3a
3	20-20-0 (SO_3) + 33.5-0-0	3.9a
4	10-24-0 (24% SO_3 plus 0.1% Zn plus 0.1% B) + 33.5-0-0	3.9a
5	36-16-0 + 33.5-0-0	3.5a
6	Untreated control	3.4a

**Numbers followed by the same latter do not statistically differ (a=0.05)*

Figure 38: Soil nutrient analysis before the application of top-dressing fertilizer

- *Leaf-nutrient analysis:*

Three leaf-nutrient analyses were performed: one before the top-dressing fertilization (February 2021, tillering, Figure 39), one two weeks after the top dressing fertilization (end of March 2021, stem elongation, Figure 40) and one two months (May 2021, Figure 41) after top dressing fertilization.

Treatment	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
1	4.14ab*	0.38a	3.57a	0.47a	0.21a	281ab	82a	28a	9.5a	4.0a
2	4.23ab	0.38a	3.35ab	0.51a	0.20a	195b	77ab	28a	9.0ab	4.5a
3	4.60a	0.34a	3.50ab	0.58a	0.24a	217b	68ab	30a	10.0a	4.3a
4	4.41ab	0.41a	3.46ab	0.52a	0.21a	182b	78ab	29a	9.0ab	5.0a
5	4.45a	0.34a	3.52ab	0.51a	0.20a	185b	66b	28a	9.5a	4.5a
6	3.78b	0.33a	2.89b	0.54a	0.23a	374a	83a	24a	7.0b	4.5a

**Numbers followed by the same latter do not statistically differ (a=0.05)*

Figure 39: Leaf-nutrient analysis at tillering (before top dressing application)

Treatment	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	% D.W.					mg kg^{-1} D.W.				
1	4.10a*	0.32a	2.80ab	0.34a	0.17a	88a	54a	31a	11.0a	15.0a
2	4.01a	0.31a	2.67b	0.33a	0.16a	97a	48a	27a	11.0a	13.0ab
3	4.23a	0.30a	2.94ab	0.36a	0.15a	89a	61a	32a	11.5a	12.0ab
4	3.95a	0.33a	2.93ab	0.40a	0.16a	83a	59a	29a	11.0a	11.0b
5	4.11a	0.33a	3.17a	0.37a	0.16a	89a	54a	32a	12.0a	14.5a
6	3.58a	0.30a	2.78ab	0.34a	0.15a	87a	47a	26a	10.0a	14.0ab

**Numbers followed by the same latter do not statistically differ (a=0.05)*

Figure 40: Leaf-nutrient analysis at stem elongation (2 weeks after top dressing application)

Treatment	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
	% D.W.					mg kg^{-1} D.W.				
1	1.82ab*	0.09a	1.07ab	0.71ab	0.42a	9a	123ab	57a	5.0a	9a
2	1.97ab	0.09a	1.05ab	0.68ab	0.39a	9a	110ab	58a	5.5a	9a
3	2.08a	0.11a	1.23a	0.75a	0.44a	10a	117ab	57a	6.0a	9a
4	2.13a	0.10a	0.83b	0.78a	0.45a	10a	146a	75a	5.5a	10a
5	2.14a	0.10a	1.08ab	0.72ab	0.46a	9a	121ab	72a	5.0a	11a
6	1.77b	0.10a	0.95ab	0.60b	0.35a	9a	95b	56a	5.0a	10a

**Numbers followed by the same latter do not statistically differ (a=0.05)*

Figure 401: Leaf-nutrient analysis 2 months after top dressing application.

- *Yield components and yield*

At harvest the number of spikes m^{-2}, the number of seeds/spike, the spike length and the yield (g m^{-2}) was estimated after harvesting one square meter from the centre of each plot (Figure 42).

Yield (g m^{-2}) and number of spikes m^{-2} were greater for each fertilizer compared to the untreated control, whereas there was no significant difference in other yield components. No significant difference was observed among fertilization treatments.

	Treatment (base +top-dressing)	Number of spikes/m^2	Number of seeds/spike	Spike length (cm)	Yield gr/m^2
1	31-21-0 (2) + no top dressing	576 a*	32 a	6,95 a	596 a
2	31-21-0 (4) + no top dressing	572 a	31 a	6,92 a	617 a
3	20-20-0 (12 SO_3) + 33.5-0-0	491 a	35 a	7,05 a	536 a
4	10-24-0 (24% SO_3 plus 0.1% Zn plus 0.1% B) + 33.5-0-0	542 a	33 a	7,20 a	544 a
5	36-16-0 + 33.5-0-0	538a	33 a	7,20 a	580 a
6	Untreated control	369b	29 a	6,75 a	390 b

**Numbers followed by the same latter do not statistically differ (a=0.05)*

Figure 41: Yield components and yield as affected by fertilization.

Year 2023 - Comparison of Conventional fertilizers with Dual Urease Inhibitors

In 2023, a comparison was made between Conventional Fertilization (cf) and Urease Inhibitor Fertilization (UIF) in winter bread wheat (cultivar VERGINA). The trial took place at the Institute of Plant Breeding and Genetic Resources of HAO-DEMETER, Greece. Vergina was seeded on 18.11.2022. The cf included the Eurochem fertilizer 20-20-0 (14S) (ammonium nitrate) as base fertiliser and the top-dressing fertiliser ΕΛΛΑΓΡΟΛΙΠ (Hellagrolip) 40-0-0 (14 SO_3) at 60+60 kg N ha^{-1}, respectively. The Urease inhibitor included the ΑδΑΜΑΣ 20-20-0 (21S) as base fertilizer and the ΑδΑΜΑΣ 40-0-0 (14 SO_3) as top-dressing fertilizer at at 60+60 kg N ha^{-1}, respectively. All fertilizers were applied by hand. Top dressing was applied at tillering stage. The protocol of the DiagChamp Method was followed to compare the yields.

Type of fertilization	Base fertilization 60 Kg N/ha (18.11.2022)	Top-dressing fertilization 60 Kg/ha (28.2.2023)
Conventional fertilization	Eurochem 20-20-0 (14S) 19.2% $N\text{-}NH_4$	ΕΛΛΑΓΡΟΛΙΠ 40-0-0 (14 SO_3) Urea S 40N
Urease inhibitor	20-20-0 (12 SO_3) ($NPPT^{\#}$ + $NBPT^{\#\#}$) ΑδΑΜΑΣ Dual inhibitors of Urease 11% urea, 9% ammonium nitrate	40-0-0 (14 S03) ($NPPT^{\#}$ + $NBPT^{\#\#}$) ΑδΑΜΑΣ Dual inhibitors of Urease 35% urea, 5% $N\text{-}NH_4$

#= N-(n-propyl) thiophosphoric triamide, ##= N-(n-butyl) thiophosphoric triamide

The results show a lower yield with Urease Inhibitor Fertilization, even if it's not statistically significant (Fig. 43). Regarding to the yield component, the number of spikes/m² and grains/spike are impacted with UIF. At flowering, the biomass was the same between the two treatments, but the level of nitrogen absorbed by the wheat was higher in UIF treatment. At the opposite, the number of grains/spike and Dry Thousand Kernel Weight were more important in CF. We can suppose that nitrogen availability was higher in conventional fertilization, however this point required further investigation.

	WHEAT Dry matter at flowering (T/ha)	Ncritical (%)	N concentration in above-ground biomass at flowering (%)	NNI_flowering	N_absorbed_flowering (kg/ha)	Dry matter grain yield (T/ha)	Dry Thousand Kernel Weight (grams)	Number of spike by m²	Number of grains /m²	Number of grain/spike	Proteines (%)
UIF	6.3	2.4	1.6	0.67	101.2	3.2	33.9	428.7	10048.2	23.5	11.9
CF	6.4	2.4	1.3	0.55	82.9	4.4	34.4	443.3	12951.5	28.9	10.8
p value (Kruskall Wallis)	0.19			0.83	0.17	0.16	0.41	0.20	0.18	0.69	0.54

Figure 42: yield and yield component in a trial with two types of fertilizer (Greece, 2023)

In conclusion about type of fertilization in Greece, we observed :

- **Same yield with conventional fertilizer and Control Release Fertiliser, double Urease inhibitor and the fertiliser with MPPA DUO technology and conventional fertilization under conventional tillage.**
- **Control Release Fertilizer may be a good practise to avoid expenses and time for applying top-dressing fertilizer.**
- **Lower yield (but not statistically significant) in conservation agriculture with fertilizers with the double urease inhibitor.**
- **The trials must be continued because they were not realized the same year.**

Weeds management

About weeds management, difficulties on *Hirschfedlia incana* (also known as Mediterranean mustard) management were noticed but weeds were controlled with the false seed-bed technique in 2021-2022 barley crop (cv. Triptolemos) and with post-emergence herbicides in barley 2022-2023 barley crop (cv. Nure). Diagchamp highlighted the H. incana infestation in minimum tillage (MT) for a barley crop in 2022-2023 seeded after barley 2021-2022 , where although the weed density was much lower in Minimum tillage compared to Conventional tillage, the weed growth was higher in the former (MT) due to lower growth of barley in under NT that year. Any other weed species such as L. rigidum in other fields where Diagchamp method was applied were well managed by pre- or post-herbicides.

	Crop	Previous crop	Biological yield (t/ha) at 15% of humidity (and protein content of the grain)	NNI at flowering (Total N input kg/ha)	% of the modelised biomass at flowering (potential biomass according to the hydric stress)	Biotic limiting factors	Abotic stress
21_Greece_Drimos	Winter Bread Wheat	Winter Oat	3.5 (12)	0.62 (110)	100%	lolium, but well managed	
21_Greece_Thessaloniki	Winter Bread Wheat	Fallow	2.1 (16)	0.71 (130)	92%		
22_Greece_Thessaloniki_CT	Spring Barley	Winter Bread Wheat	5.7 (11)	0.48 (40)	47%		nitrogen stress
22_Greece_Drimos_CT	Spring Barley	Spring pea	5.6 (13)	0.59 (70)	100%		
22_Greece_Drimos_MT	Spring Barley	Spring pea	5.9 (13)	0.51 (70)	100%		
22_Greece_Drimos_DW	Winter Durum Wheat	OSR	4.1 (13)	0.63 (135)	100%		
23_Drimos_MT	Spring Barley	Spring Barley	3.2 (12)	0.51 (90)	34%	L.Sativus	nitrogen stress
23_Drimos_CT	Spring Barley	Spring Barley	4.2 (12)	0.59 (90)	47%		nitrogen stress
23_Thessaloniki_CF	Winter Bread Wheat	Winter Bread Wheat	5.2 (11)	0.65 (120)	67%		
23_Thessaloniki_UIF	Winter Bread Wheat	Winter Bread Wheat	3.8 (12)	0.67 (120)	66%		

Figure 43: limiting factors identified in Greek fields experiment (CT = conventional tillage ; MT = Minimum Tillage).

Main conclusions– Greece

For Greece, it was noticed a **risk more of more weed (H. incana) density on wheat in direct sowing** with cereal as previous crop.

Although higher density of H. incana was observed in CT than in MT, the weed growth was higher in MT due to retardation of growth of barley (after barely) in MT (possibly due to immobilization of nitrogen in the soil due to crop residues)

In comparison to Conventional Tillage, yields in Minimum Tillage were lower for one year and equal for another year.

The percentage of wheat potential biomass realization is, in average, better with legume as previous crop than with other crops.

For fertilization, a negative effect of Urease Inhibitor Fertilization was noticed in a trial in 2023.

Farmers needs and technical problems (D3.1)	Diagchamp lessons	Conservation Agriculture specificity
Weed control and crop residues	• More weeds in wheat with cereals as previous crop in no tillage (*L. sativus)*	**MEDIUM**
Crop fertilization	• Nitrogen stress due to cereals residues degradation	**MEDIUM**
Crop rotation	• Better yields for wheat in Conservation Agriculture with legumes as previous crop	**MEDIUM**

Figure 44: main conclusions on limiting factors (Greece)

3.4 Morocco

Pedologic conditions

Field experiments were in clay soil (vertisoil), superficial stony limestone on alluvium. The average rate of Organic Matter is 1.9% and the water holding capacity around 130 mm.

Climatic conditions

The Figure 46 illustrates the climatic conditions in Merchouch. If the season 2020-2022 is within the expected range in terms of rainfall, 2022-2023 has a very low level of rain, especially in January and February.

Meteo station	Merchouch						
	Unity	2020-2021			2021-2022		
Rain (01/10 to 30/06)	mm	363.2			246.6		
Average T° (01/10 to 30/06)	°C	15.78			16.50		
Average Potential Evapo-Transpiration	mm	542.1			778.3		
		rain (mm)	Temp (°C)	PET (mm)	rain (mm)	Temp (°C)	PET (mm)
October		4.5	18.38	62.7	3	20.91	98.1
November		31.4	17.22	44.6	45.6	13.81	49.5
December		32.8	12.59	24.6	60.8	13.69	47
January		152.4	10.74	24.3	5	12.13	53.2
February		40.8	13.11	38	10.2	14.43	68.9
March		47.1	13.53	58.2	62.2	13.27	72.4
April		23.5	16.19	75.2	32.2	15.31	105
May		29.7	19.37	101.6	24.4	21.46	168
June		1.0	20.92	112.9	3.2	23.50	116.2

Figure 45: average climatic conditions in Merchouch (Morocco)

Dataset

Two years of experiments in Merchouch to test the effect of genotypes on conservation agriculture practices on yield with comparison between direct sowing and ploughing (18 cm).

Genotypes adapted to Conservation Agriculture

2021

In 2021, the trial consisted of testing interaction between genotypes and soil management (conservation agriculture in direct sowing or conventional agriculture with ploughing). For that, three genotypes of durum wheat (Faraj, Louiza, Nachit) were sowed in Merchouch on December 15th in direct sowing or tillage. It was in rainfed conditions and 87 kg N/Ha were applied. The previous crop was winter barley. The results are presented in the Figure 47. The statistical analysis (Anova with p value 0.05) shows a significant effect of genotype but not of type of tillage.

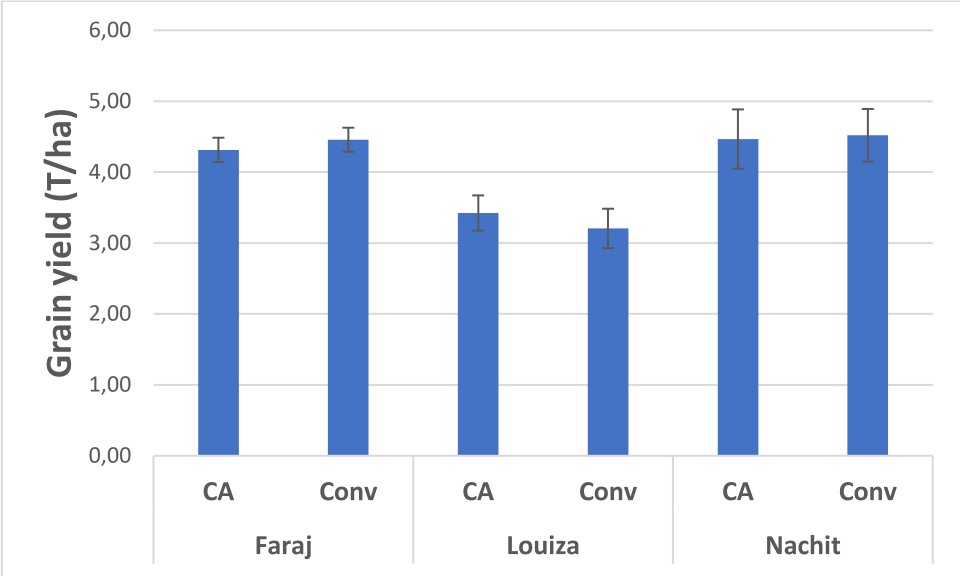


Figure 46: yields under Conservation and Conventional Agriculture in Morocco for the season 2020-2021

2022

In 2022, the same kind of experiment was tested with for genotypes of barley : Firdaws, Adrar, Aglou and Azilal (Figure 48). 87 kg N/ha were applied on the crop. If the average global yield was superior under CA practices (0.93T/ha in CA and 0.85 in conventional), the effect was not significant (p value =0.432).

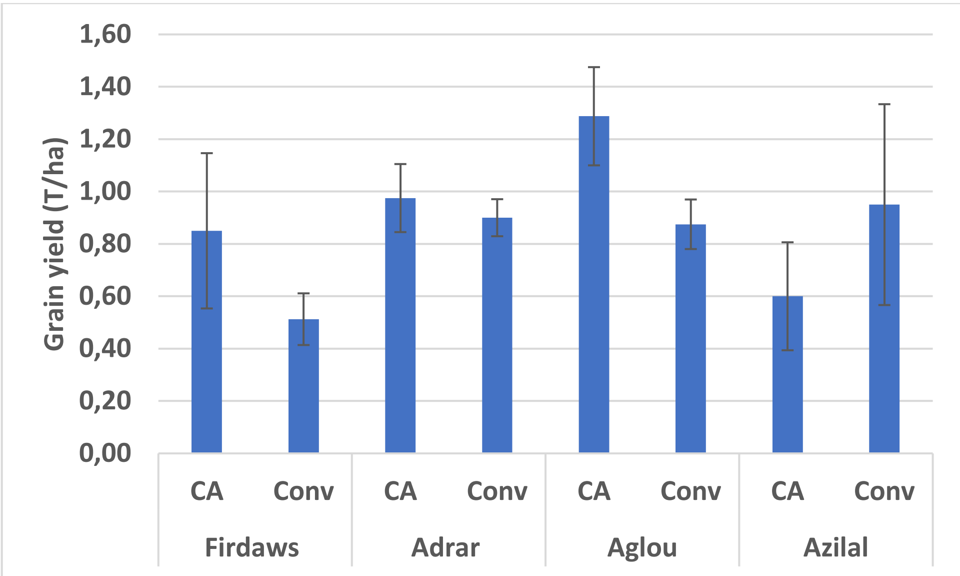


Figure 478: yields under Conservation and Conventional Agriculture in Morocco for the season 2021-2022

Global conclusion

These two years of experiments show:

- **Yields under Conservation Agriculture were statistically equal to Conventional Agriculture under two different climatic years.**
- **Some barley varieties seem to be more adapted to Conservation Agriculture (for example Aglou).**

- **Weeds could be well controlled in Conservation Agriculture thanks to Glyphosate and pre-emergence herbicide.**

Main conclusions– Morocco

Farmers needs and technical problems (D3.1)	Diagchamp lessons	Conservation Agriculture specificity
Weed control and crop residues	• Problems related to crop residues and livestock	**MEDIUM**
Seeding	• Weeds control (*Lolium*) in direct sowing	**HIGH**
Crop rotation	• Problems related to crop residues and livestock	**MEDIUM**

Figure 48: main conclusions on limiting factors (Morocco)

3.5 Italy

Pedologic conditions

Field experiment in Italy (Foggia) is located in a calcareous soil, mainly limestone clay with an average organic matter rate at 2.3%. Soil depth is around 60 cm and water holding capacity 138 mm.

Climatic conditions

The climatic conditions for Italy from 2021 to 2023 are presented in the following table.

Meteo station	Foggia									
	Unity	2020-2021			2021-2022			2022-2023		
Rain (01/10 to 30/06)	mm	417.2			512			608.4		
Average T° (01/10 to 30/06)	°C	13.24			13.22			13.39		
Average Potential Evapo-Transpiration	mm	785.9			701.6			644.1		
		rain (mm)	Temp (°C)	PET (mm)	rain (mm)	Temp (°C)	PET (mm)	rain (mm)	Temp (°C)	PET (mm)
October		48.8	15.98	75.1	48.3	16.38	58.6	12.3	19.14	75.5
November		90.8	12.63	30.2	120.5	13.33	34.1	101.2	12.98	37.5
December		63.7	9.76	22.8	54.2	9.05	37.9	39.8	10.65	23.7
January		60.9	7.15	28.7	27	7.08	40.4	99	8.06	18.9
February		34.1	9.23	43	79.6	8.71	48.7	15.7	7.56	31
March		72.6	9.29	120.5	40.1	7.63	59.7	86	11.18	76.5
April		36.2	11.82	86	17.5	12.56	97.1	77.4	12.12	89.2
May		9.8	18.60	160.8	62.1	19.54	139.9	77.5	16.66	108.7
June		0.3	24.70	218.8	62.7	24.74	185.2	99.5	22.17	183.1

Figure50: average climatic conditions in Foggia

Dataset

Seven field experiments were followed in 2021 and 2022 to test the performances of different genotypes of durum wheat according to the Diagchamp method. Fields were sown after ploughing (at 35 cm deep) in rainfed conditions. In 2023, an experiment of chickpea was realized with minimum and conventional tillage.

Average yields on seasons 2021-2023

The average yield and yield component for durum wheat are presented in the following table.

	2021	2022
	rainfed	rainfed
Nb of field experiment	**4**	**3**
Average biologic yield at moisture 15% (T/ha)	**2.9**	**4.2**
Spikes/m²	**-**	**153**
Grains/spike	**-**	**48**
Thousand Kernel Weight at moisture 0% (g)	**45.6**	**49.9**
Proteins (%)	**-**	**14**
NNI at flowering	**-**	
Total nitrogen inputs (kg N/ha)	**74**	**85**
Nitrogen/Yield (kg N/T)	**25.6**	**21.5**

Figure 49: average yield of the experiments in Italy (durum wheat)

Limiting factors analysis

2021 analysis

The results for 2021 are presented in the following table.

Three genotypes of durum wheat were sown in Foggia (28 November 2020) in order to calibrate CHN model for Italian conditions. Ploughing was applied and previous crops are different according to the modalities. 27 kg N/ha were applied on 18 November 2021 (18_46) and 51 kg N/Ha on the 3rd of March, 2023 (Ammonium nitrate). We can notice (Figure 52) an important effect of previous crop on the percentage of realization of biomass at flowering, illustrated by the differences between durum wheat after tomato or fallow and durum wheat. The nitrogen use efficiency is better after tomato than after durum wheat, probably due to a better level of soil nitrogen content. We can also notice a genotype effect between Cappelli and Sfinge.

Trial (varieties)	Previous crop	Tillage	Biological yield (t/ha) at 15% of humidity (and protein content of the grain)	N ferti (kg N/ha)	N ferti/yield (kg/T)	% realized of the modelised biomass at maturity (potential biomass according to the hydric stress)
Natal	fallow	plough	3.4	78	22.9	86%
Cappelli	tomato	plough	2.53	61	24.1	86%
Sfinge1	tomato	plough	3.48	78	22.4	97%
Sfinge2	durum wheat	plough	2.36	78	33.1	53%

Figure 50 : yield results of the Italian trials for 2021

2022 analysis

In 2022, three genotypes have been tested on the same field in Foggia, with regular biomass and LAI measurements in order to:

- Compare dynamic of genotype growing (Figure 54).
- Evaluate the performances of CHN in Italian genotypes (Figure 55).

The durum wheat was sown on 23 December 2021 after ploughing; 85 kg N/ha of ammonium nitrate were applied on 6 April 2022.

The yields are presented in Figure 53. We can notice:

- A better yield for Sfinge in comparison to Cappelli and Inizio which could be explained by a better biomass potential a maturity, due to a higher LAI before flowering (to fill the grains).
- The biomass simulated by CHN (with LAI resetting) is compliant to field measurements for final biomass at maturity for Capelli and Inizio. For Sfinge, the model under-estimates the final biomass at maturity. For stages before maturity, the biomass estimation seems to be compliant until the middle of May (around flowering), and then under-estimated (during the grain filling).

Trial (varieties)	Previous crop	Tillage	Biological yield (t/ha) at 15% of humidity (and protein content of the grain)	N ferti (kg N/ha)	N ferti/yield (kg/T)	% realized of the modelised biomass at maturity (potential biomass according to the hydric stress)
Cappelli	Tomato	Conventional	3.58	85	23.7	110%
Sfinge	Tomato	Conventional	5.25	85	16.2	151%
Inizio	Tomato	Conventional	3.68	85	23.1	124%

Figure 513: yield results in Italy (2022)

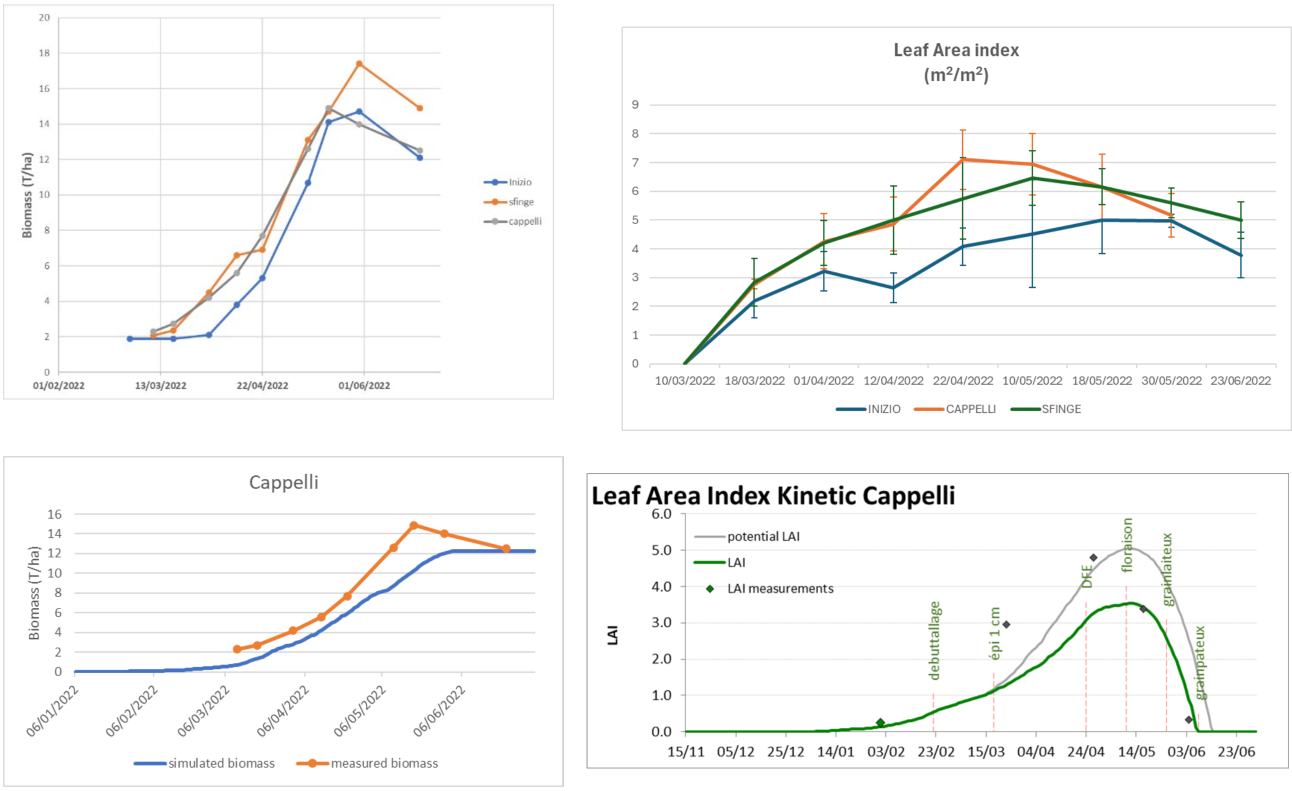
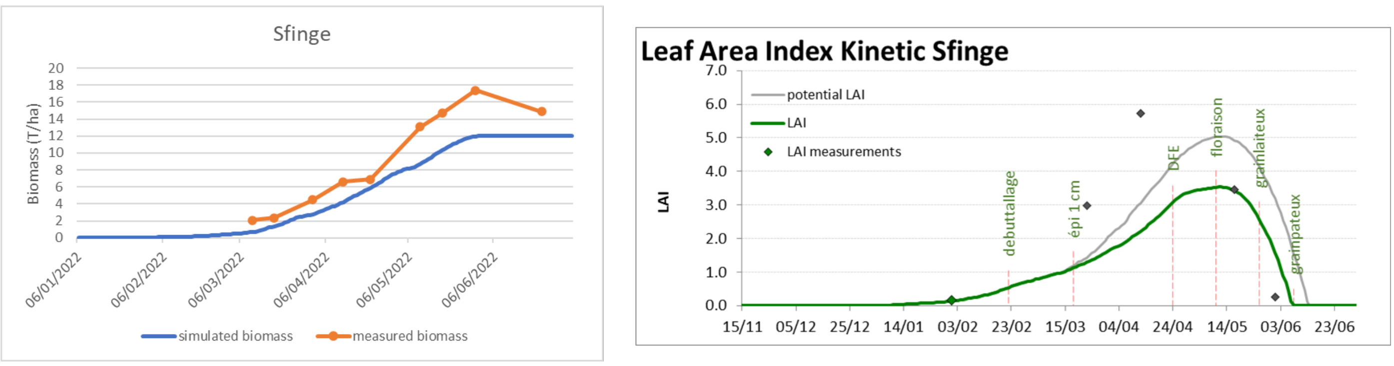
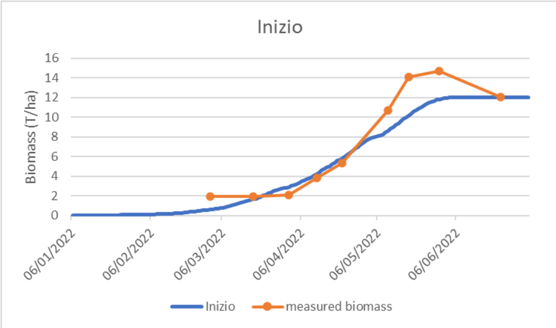


Figure 52: biomass and LAI dynamic of italian genotypes (2022). Based on field measurements





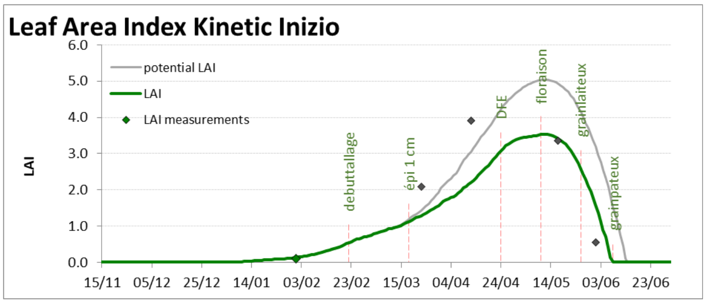


Figure 535: simulated and measured biomass and LAI on 3 Italian durum wheat genotypes (2022)

2023 analysis

In 2023, a trial was realized to compare chickpea (RITA cultivar) yield with two tillage treatment : Minimum Tillage (MT) and No Tillage (NT). The trail was sown on 14 February 2023 after durum wheat as previous crop.

The results are presented in Figure 56 and show a strong negative impact of no tillage on chickpea yield and development, because of weed (Lolium spp) development.

	Flowering_biomass (T/ha)	Dry matter grain yield (kg/ha)	Dry_thousand_kernel_weight (g)	Grains_m^2
MT	4.575	508.225	33.05	15381.45
NT	2.107	207.575	32.90	6293.82
P value	**0.043**	**0.043**	0.56	**0.021**

Figure 54: yield and yield component of chickpea experiment (Italy, 2023)

Main conclusions– Italy

For Italy, the main conclusions from WP3 are:

- Difficulties to succeed chickpea in no tillage systems due to weed management.
- A good final biomass estimated by the CHN model on Italian genotypes thanks to LAI, chlorophyll and stages resetting.

3.6 Spain

Pedologic conditions

In Spain, trials were realized in Senes de Alcubierre in loamy-limestone soil with water holding capacity around 90 mm (soil depth 50 cm).

Climatic conditions

The climatic data for Spain for 2020-2021 are presented in the following table.

Meteo station	Spain									
	Unity	2020-2021			2021-2022			2022-2023		
Rain (01/10 to 30/06)	mm	376.2			238.9			266		
Average T° (01/10 to 30/06)	°C	11.19			11.93			12.41		
Average Potential Evapo-Transpiration	mm	537.8			725.8			728.2		
		rain (mm)	Temp (°C)	PET (mm)	rain (mm)	Temp (°C)	PET (mm)	rain (mm)	Temp (°C)	PET (mm)
October		17.5	15.19	80	33.7	14.05	62.7	32.6	17.88	64
November		39.6	11.34	30.4	48.3	8.37	43.6	45.9	10.78	35.2
December		20.8	6.87	29.2	18.7	6.74	22.5	45.1	7.55	16
January		72.1	2.55	16.1	5.2	4.68	29.8	32.1	4.70	32.6
February		52.5	8.67	28.2	4.0	8.57	55.1	25.4	5.25	37
March		12.4	9.59	61.3	38.9	9.39	57.1	0.5	11.32	91.7
April		88.9	10.72	63.4	42.3	12.16	102.5	1.4	14.44	131.9
May		42.3	15.16	106.9	15.1	19.17	160.6	12	17.44	163.1
June		30.1	20.58	122.3	32.7	24.24	191.9	71	22.35	156.7

Figure 55: Climatic data for Spain (2021)

Dataset

For Spain, one crop rotation was studied in direct sowing :

- 2021: bread wheat in direct sowing after spring barley.
- 2022: pea crop in direct sowing.
- 2023: barley in direct sowing.

Results

2021

In 2021, bread wheat (Cultivar Chambo) was sown in direct sowing at 450 grains/m² on the 16th of October, 2020 after barley as previous crop. 75 kg N/ha were applied with N Solution on the 3rd of March, 2021 and weeds were managed with different applications of herbicides according to the following table.

Date	Type of treatment & Name	Active substance	Dose	Unit
14/10/2020	**Herbicide Roundup**	**Glyphosate**	**1,5 L/ha**	**360 gr/L**
19/02/2021	**Herbicide Pacifica Plus**	**1% de iodosulfuron-metil-sodio, 5% de amidosulfurón y 3% de mesosulfuron-metil**	**300 g/ha**	**gr/ha**
19/02/2021	**Herbicide&Estaca WG**	**Diflufenican 40%, Florasulam 2%, Iodosulfuron 5%**	**150 gr/ha**	**gr/ha**

Figure 56: herbicides applications in barley in direct sowing (Spain, 2021)

The yield results are presented in the following table.

YEAR	DATE	POINT	Til	EARS/m2	PMG (g)	Harvest Index	YIELD (kg/ha)	STRAW (kg/ha)	GRAIN/STRAW	Specific Weight (kg/100L)
2020-21	23/06/2021	1	DD	294.1	35.8	0.4	2614.1	3512.7	0.7	75.4
2020-21	23/06/2021	2	DD	294.1	37.6	0.5	2634.1	2855.3	0.9	72.7
2020-21	23/06/2021	3	DD	458.8	45.5	0.4	3182.4	5845.9	0.5	74.5
2020-21	23/06/2021	4	DD	729.4	23.0	0.4	3454.1	5431.3	0.6	72.4
2020-21	23/06/2021	5	DD	411.8	37.9	0.5	4143.5	4950.6	0.8	73.1
2020-21	23/06/2021	6	DD	517.6	36.4	0.4	4829.4	7403.5	0.7	75.0
2020-21	23/06/2021	7	DD	435.3	28.4	0.3	2642.4	5367.1	0.5	74.5
2020-21	23/06/2021	8	DD	458.8	35.2	0.4	3490.6	5308.2	0.7	73.7
				450	34.98	0.40	3373.82	5084.33	0.69	73.91

Figure 57: Yield results of wheat in direct sowing (Spain, 2021)

An analysis of CHN modelization, resetting with fields measurements, shows:

- **A nitrogen stress from BBCH 39** (last leaf spread) to maturity which could impact the Thousand Kernel Weight and protein content (measured at 11.7%). The nitrogen stress is materialized by the red curve (Figure 60). The green curve materializes the nitrogen stress tolerable by the wheat without biomass penalty. The blue curve indicates the nitrogen soil available. We consider a harmful nitrogen stress when the red curve is higher than the green one: at BBCH 39 in this case. It could give us some indications for advices for nitrogen monitoring, according to the rain.
- **An important water stress level**, which has an important impact on yield, much more than the nitrogen stress (Figure 61).

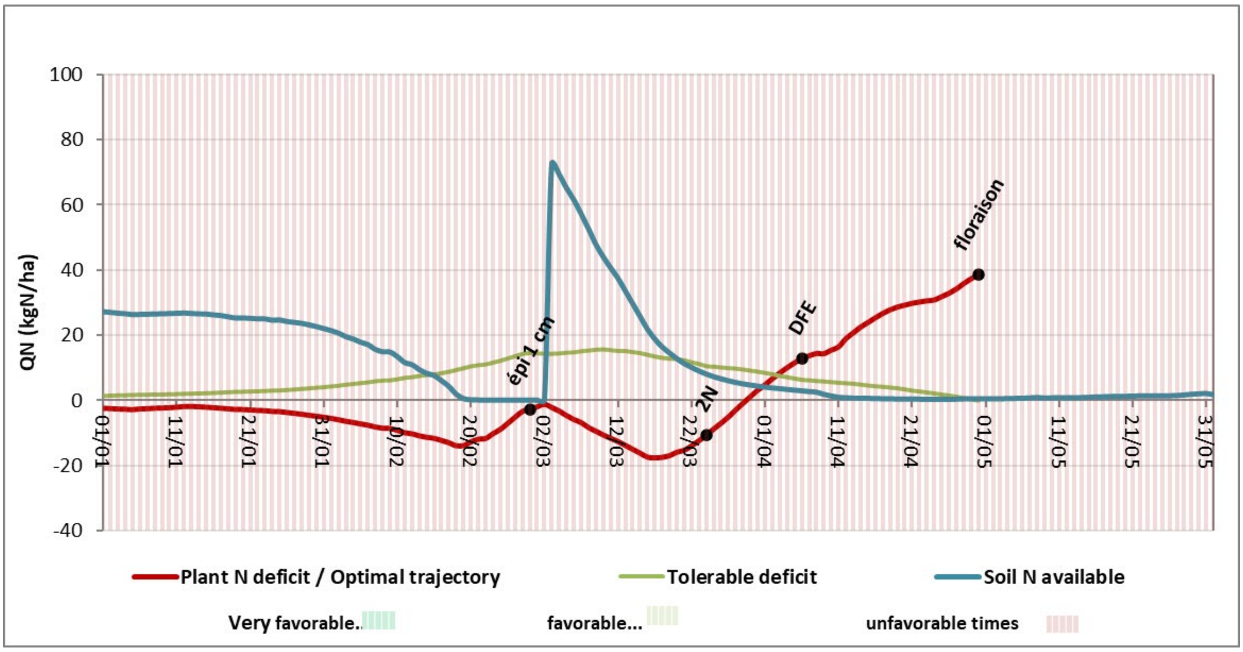


Figure 58: nitrogen dynamics in soil and plant modelized by CHN (Spain, 2021)

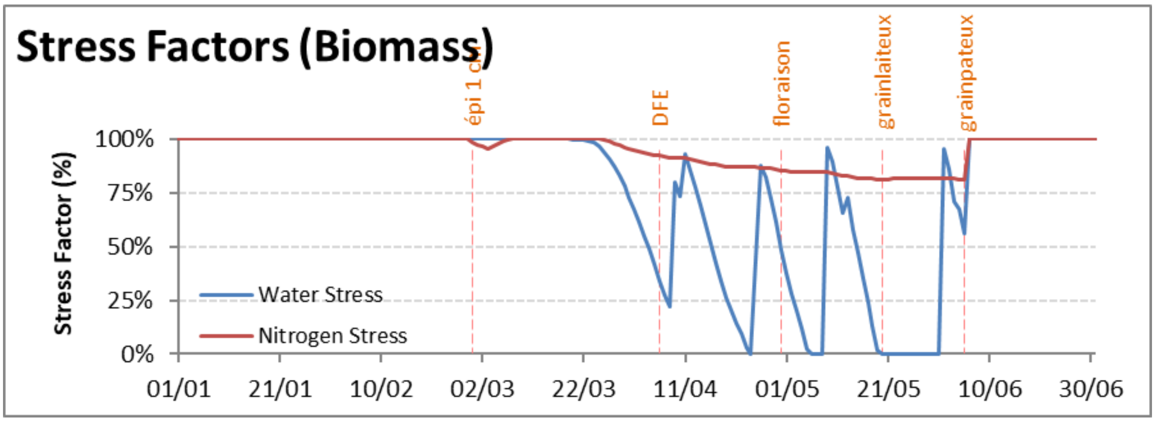


Figure 59: hydric and water stress on potential biomass modelized by CHN (Spain, 2021). A value of 100% corresponds to an absence of stress

No limiting factors apart from the normal limited rainfall was observed. The wheat crop yield could be considered the average for the area under no tillage

2022

On the 31st of November, 2021 a pea crop (Cultivar: Aviron) was sown in direct sowing after bread wheat in direct sowing too. The program of herbicides is presented on the following table.

Date	Type of treatment & Name	Active substance	Dose	Unit
20/11/2021	**Herbicide&Roundup**	**Glyphosate**	**1,5 L/ha**	**360 gr/L**
25/11/2021	**Herbicide AUROS**	**800 g/l (78,40% p/p) Prosulfocarb**	**3 L /ha**	**800 g/L**
25/11/2021	**Herbicide CINDER**	**40% p/v (400 g/l) Pemdimetalina**	**2,5 L/ha**	**400 g/L**

Figure 602: herbicides applications in pea crop in direct sowing (Spain, 2022)

Yield results are presented in the following table.

DATE	POINT	Til	EARS/m2	PMG (g)	HI	YIELD (kg/ha)	STRAW (kg/ha)	GRAIN/STRAW
31/05/2022	1	DD	882.35	122.62	0.46	3635.29	3756.47	0.97
31/05/2022	2	DD	1411.76	83.69	0.34	4351.76	7643.53	0.57
31/05/2022	3	DD	2152.94	86.19	0.35	8111.76	13692.94	0.59
31/05/2022	4	DD	1317.65	102.19	0.44	5001.18	5422.35	0.92
31/05/2022	5	DD	847.06	90.14	0.14	3128.24	18065.88	0.17
31/05/2022	6	DD	1976.47	88.74	0.40	8090.59	10872.94	0.74
31/05/2022	7	DD	1764.71	99.34	0.45	7584.71	8165.88	0.93
31/05/2022	8	DD	2564.71	86.31	0.41	9037.65	11327.06	0.80
			1614.71	94.90	0.37	6117.65	9868.38	0.71

Figure 61: Yield results of pea in direct sowing (Spain, 2021)

No limiting factors apart from the normal limited rainfall was observed. The pea crop yield could be considered higher than normal for the area under no tillage

2023

On 15 November 2022, a spring barley was sowed in direct sowing after pea in direct sowing. An application of N solution was realized on 21 February 2023 (75 kg N/ha) and weeds managed with herbicides.

Date	Type of treatment & Name	Active substance	Dose	Unit
10/11/2022	**Herbicide & Roundup**	**Glyphosate**	**1,5 L/ha**	**360 gr/L**
28/02/2023	**Herbicide - Mustang**	**2,4 D Ácido (ester etilhexil) 300 g ea/L (30% p/v) + Florasulam 6,25 g/L (0,62% p/v)**	**0,5 L/ha**	**g/L**

Figure 624: herbicides applications in barley in direct sowing (Spain, 2022)

Yield results are presented in the following table.

DATE	POINT	Til	EARS/m2	PMG (g)	HI	YIELD (kg/ha)	STRAW (kg/ha)	GRAIN/STRAW	Specific Weight (kg/100L)
07/06/2023	1	DD	152.94	24.92	0.14	804.6	1134.1	0.71	62.4
07/06/2023	2	DD	541.18	26.01	0.18	834.2	4047.1	0.21	60.0
07/06/2023	3	DD	800.00	27.67	0.40	1223.6	6032.9	0.20	58.3
07/06/2023	4	DD	647.06	34.17	0.41	367.1	4881.2	0.08	62.0
07/06/2023	5	DD	1164.71	29.35	0.41	283.6	9585.9	0.03	62.9
07/06/2023	6	DD	1623.53	22.53	0.37	1238.4	9301.2	0.13	60.5
07/06/2023	7	DD	505.88	28.28	0.41	448.7	3412.9	0.13	60.4
07/06/2023	8	DD	517.65	16.66	0.11	1440.5	4663.5	0.31	59.6
			744.12	26.20	0.30	830.08	5382.35	0.22	60.76

Figure 635: Yield results of barley in direct sowing (Spain, 2023)

An analysis of CHN simulation shows:

- **No nitrogen stress on barley**, due to high level of nitrogen residues, probably explained by an effect of the previous crop (pea). (Figure 66);
- **An important level of water stress.** (Figure 67).

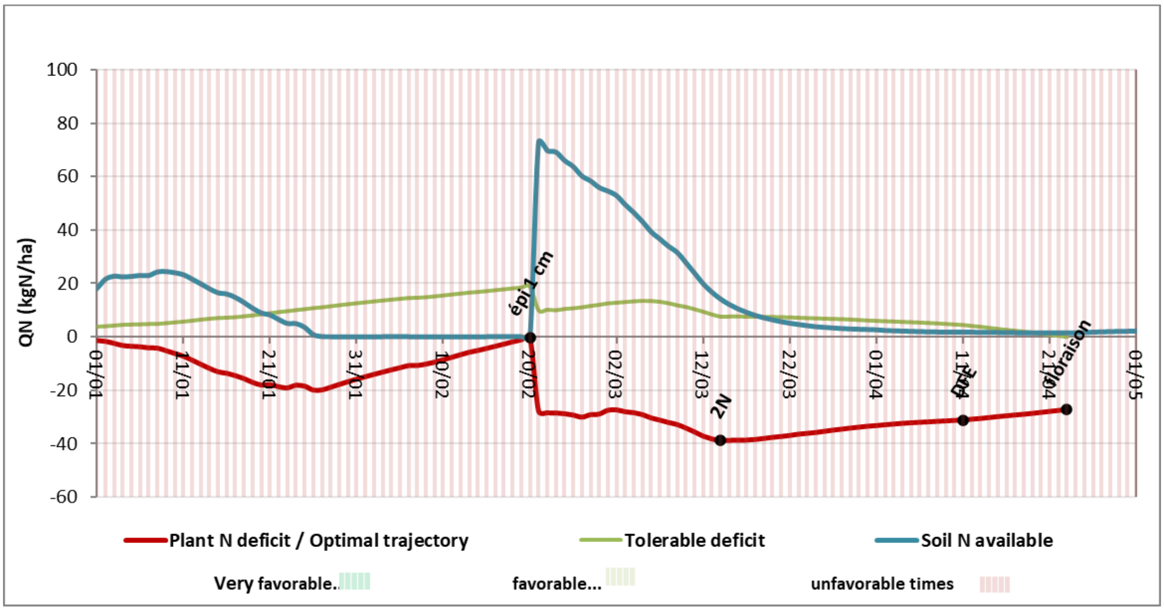


Figure 646: nitrogen dynamics in soil and plant modelized by CHN (Spain, 2023)

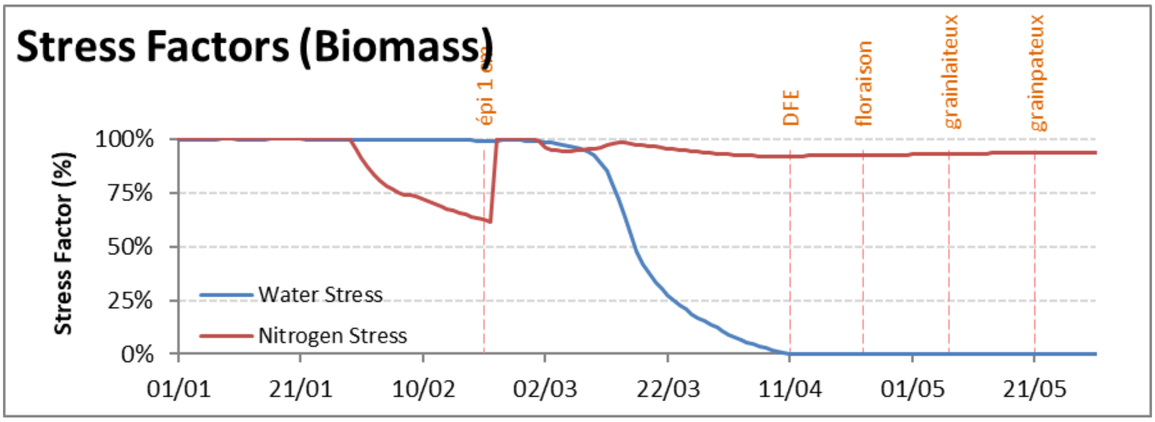


Figure 65: hydric and water stress on potential biomass modelized by CHN (Spain, 2021). A value of 100% corresponds to an absence of stress

The main limiting factor this growing season has been the extreme drought that is not normal in the area. The barley crop yield could be considered very lower than normal for the area under no tillage.

Main conclusions - Spain

The results observed in the commercial field demonstrates the good performance of the no tillage system that was adopted in the field since 7 years ago.

The crop rotation with winter cereals and pea crop performed well and reduced the impact of weeds allowing a better chemical control with less use of herbicides.

Clearly the main limiting factor in the area is the water availability. That could be mitigate on the normal and with some limitations, but cannot save the yield under extreme drought.

3.7 Tunisia

Pedologic conditions

In Tunisa, trials were realized in Mateur in a calcisol silty clay, in Salah Lamouchi 's farm (APAD association). The field was in conventional tillage before the experiment.

Climatic conditions

The climatic data for Tunisia are presented in the following table.

Meteo station	Tunisia			
	Unity	2020-2021		
Rain (01/10 to 30/06)	mm	376.2		
Average T° (01/10 to 30/06)	°C	11.19		
Average Potential Evapo-Transpiration	mm	537.8		
		rain (mm)	Temp (°C)	PET (mm)
October		48.0	19.42	73.2
November		112.0	17.53	42.6
December		171.5	12.73	28.9
January		62.0	12.13	36.7
February		36.2	12.86	45.8
March		64.5	12.73	73.2
April		40.0	15.28	95.6
May		23.2	19.48	133
June		0.2	25.47	152.2

Figure 66: climatic data for Mateur in Tunisia (2021)

Dataset

A trial was realized in Mateur in order to compare Conventional Tillage (CT), Minimum Tillage (MT) and Direct Sowing (ST) in 2020-21 and 2021-22. The technical itineraries are resumed in the following table.

		Direct Sowing (DS)	Minimum Tillage	Conventional tillage
	Sowing	Sowing with a disk seeder (SEMEATO)	1 passage with disk cultivator before sowing	3 passages with disk cultivator before sowing
2020-2021	Previous crop	Fallow (weeds)		
	Cultivar	Durum wheat DHAHBI		
	Date of sowing	12/12/2020		
	weed managment	Glyphosate (2l/ha) + 2-4D (0.5l/ha)		
		- Tolurex 50/Chlototoluron : 3l/ha + 0.15 l DFF (BBCH 12) - Nikoss/Aminopryralides +5:6Florasulam +2-4D : 0.4l/ha (BBCH 25)		
	N fertilization Ammonium nitrate (33.5% N)	-50 kgN/ha (BBCH 25) - 33.5 kg N/ha (BBCH 31)		

2021-2022	Previous crop	Chickpea
	Cultivar	Durum wheat DHAHBI
	Date of sowing	12/12/2020
	weeds managment	Glyphosate (2l/ha) + 2-4D (0.5l/ha)
		- Tolurex 50/Chlotoluron : 3l/ha + 0.15 l DFF (BBCH 12) - Nikoss/Aminopryralides +5:6Florasulam +2-4D : 0.4l/ha (BBCH 25)
	N fertilization Ammonium nitrate (33.5% N)	-60 kgN/ha (BBCH 21) - 70 kg N/ha (BBCH 25) - 50 kg N/Ha (BBCH41)

Figure 67: technical itineraries in Tunisia

Results

Soil moisture

The following graphs (Figure 70) present the results of soil moisture at 0-15 cm, 15-30 cm and 30-45 cm of depth. It shows:

- In 2020-2021 a better soil moisture for Minimum Tillage at 0-15 cm in comparison to Conventional Tillage and Direct Sowing. It could be due to a lower level of weed infestation and a lower competition for water. At 15-30 cm the soil moisture is significantly higher for CT and DS.
- No significant differences between 2021-2022.

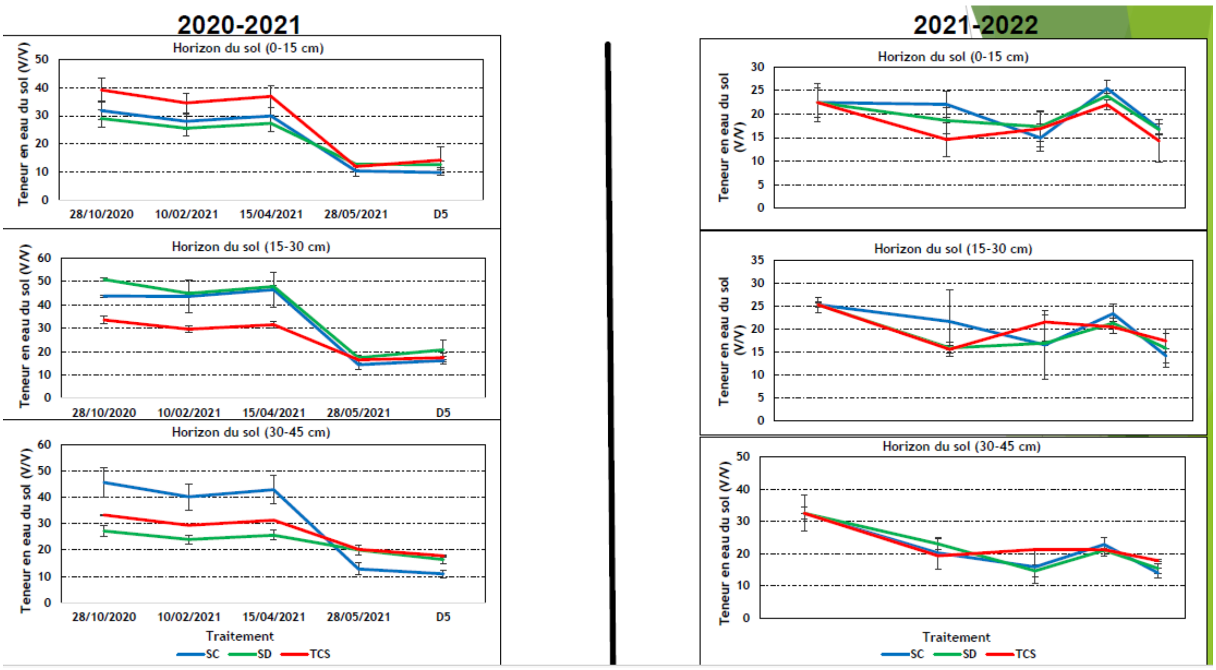


Figure 70: soil moisture according to the tillage management (Tunisia, 2021-22)

Weed development

The abundance and the biomass of weeds were measured for the two years of the experiment (Figure 71), in a context of resistance at sulfonylureas. It shows a better weed management on Minimum Tillage. In DS, the density of *Lolium* was important, probably due to the combination of resistance and not possibility to use tillage to manage it.

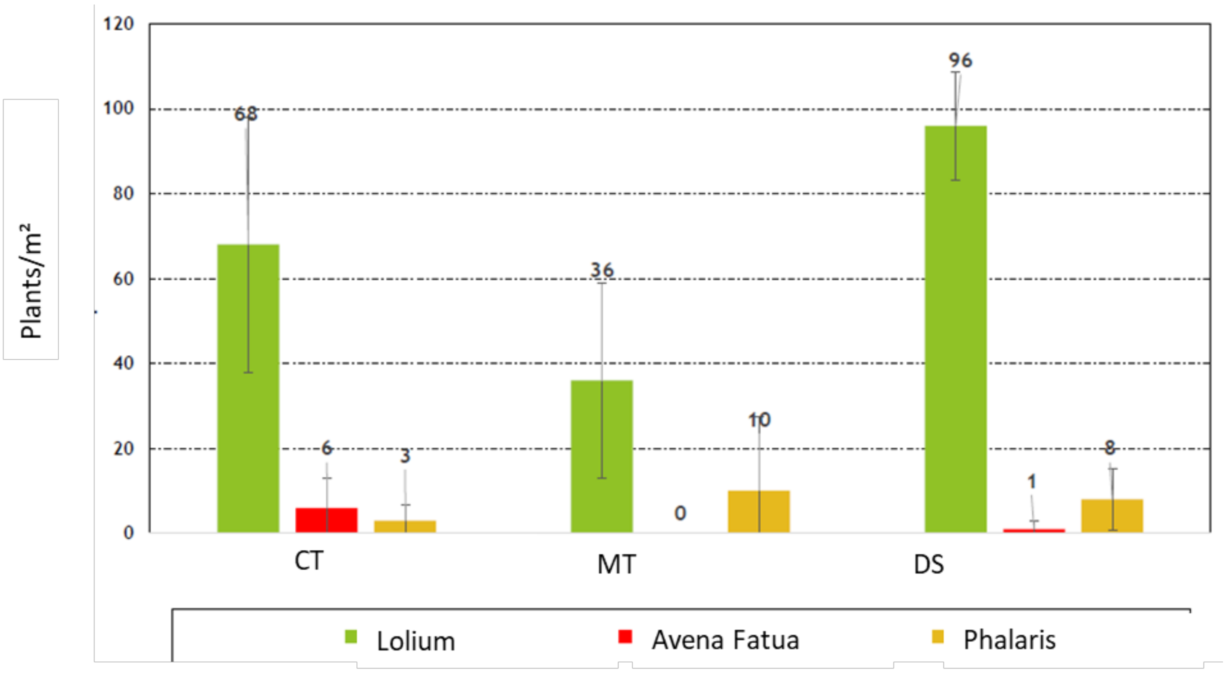


Figure 68: weeds development according to the strategy of tillage (Tunisia, 2021 and 2022)

Yield results

The yield results of two years of experiment are presented in Figure 72. It shows:

- In 2021, a statistically lower yield on Minimum Tillage, probably due to a higher development of weeds in MT.
- A better yield in Minimum Tillage in 2022 which could be explained by a better weed control due to the effect of chickpea as previous crop.

2020-2021				
	Aboveground dry biomass at maturity (T/ha)	Spikes/m²	Yield (T/ha)	Thousand Kernel Weight (g)
Conventional tillage	6.32 (a)	195 (a)	1.6 (ab)	39.14 (b)
Minimum Tillage	5.69 (a)	170 (a)	1.53 (b)	41.43 (a)
Direct Sowing	5.82 (a)	188 (a)	1.84 (a)	40.26 (ab)

2021-2022				
	Aboveground dry biomass at maturity (T/ha)	Spikes/m²	Yield (T/ha)	Thousand Kernel Weight (g)
Conventional tillage	9.22 (b)	263 (b)	3.7 (c)	48.1 (b)
Minimum Tillage	12.46 (a)	312 (a)	4.4 (a)	52.1 (a)
Direct Sowing	10.16 (b)	286 (ab)	4.0 (b)	48.6 (b)

Figure 69: Yield results of tillage management (Tunisia, 2021-22)

Main conclusions - Tunisia

For Tunisia, the two years of experiment have shown that the Direct Sowing could be more performant than Conventional and Minimum Tillage after a legume as previous crop.

The risks of weed infestation could be more important in Direct Sowing, especially in a context of resistances to herbicides.

4. General conclusions

In **France** experiments, the results have demonstrated than *Lolium* could be well managed thanks to crop rotation with legumes, perennial (meadow mowing) or annual (possibility to use herbicides with no problem of resistance, like propyzamide). **For seeding technics**, the main problem observed is the sowing quality after maize caused by an insufficient management of the residues in direct sowing and nitrogen consumption by maize residues degradation. **For crop fertilization**, many farmers without irrigation have many difficulties in positioning correctly nitrogen inputs in dry climate. Some tests have been realized to increase early inputs (for South East of France before the end of January) to anticipate the risk of very long drought period. For **crop rotation**, it was noticed frequently yield penalties in case of wheat in succession with a first autumn cereals due mainly to *Lolium* management. **Semi-permanent plant cover** is a good way to cover the soil during summer in Mediterranean conditions, if the competition with crops is minimized or avoided thanks to efficient chemical regulation.

In **Portuguese** experiments, the main conclusions about **weed control** was the difficulty to put herbicides due to the lack of rain during long periods, so a non-efficient conditions. **About sowing**, one of the main problems diagnosed was the difficulty of direct sowing in dry conditions (soil compaction after summer season) while minimum tillage could be practiced just after previous crop harvest in conventional systems. **About fertilization**, the main problem observed is the difficulty of positioning nitrogen inputs in dry conditions.

In **Spanish** experiments, the results observed in the commercial field demonstrates the good performance of the no tillage system that was adopted in the field since 7 years ago. The crop rotation with winter cereals and pea crop performed well and reduced the impact of weeds allowing a better chemical control with less use of herbicides. Clearly the main limiting factor in the area is the water availability. That could be mitigate on the normal and with some limitations, but cannot save the yield under extreme drought.

In **Tunisia** experiments, the two years of experiment have shown that wheat in Direct Sowing could be more performant than Conventional and Minimum Tillage **after a legume as previous crop**. The risks of weed infestation could be more important in Direct Sowing, especially in a context of resistances to herbicides.

In **Greece**, it was noticed a **risk more of more weed (Hirschfedlia incana) density on wheat in direct sowing** with cereal as previous crop. Although higher density of H. incana was observed in CT than in MT, the weed growth was higher in MT due to retardation of growth of barley (after barely) in MT (possibly due to immobilization of nitrogen in the soil due to crop residues). In comparison to Conventional Tillage, yields in Minimum Tillage were lower for one year and equal for another year. The percentage of wheat potential biomass realization is, in average, better with legume as previous crop than with other crops. For fertilization, a negative effect of Urease Inhibitor Fertilization was noticed in a trial in 2023.

In **Morocco**, the results show that yields under Conservation Agriculture were statistically equal to Conventional Agriculture under two different climatic years. Some barley varieties seem to be more adapted to Conservation Agriculture (for example Aglou). Weeds could be well controlled in Conservation Agriculture thanks to Glyphosate and pre-emergence herbicide.

In **Italy**, the main conclusions from WP3 are the difficulties to succeed chickpea in no tillage systems due to weed management.