Deliverable 5.1

Report on the assessment of crop yield under different CA agricultural practices in Mediterranean countries

Author/s: Carlos Cantero-Martínez, UdL; Jorge Álvaro-Fuentes, CSIC; Michele Rinaldi, CREA); Mathieu Marguerie, ARVALIS; Thomas Gitsopoulos, HAO; Mohamed Annabi, INRAT; Rachid Moussadek, INRA; Mourad Latati, ENSA).

Approved by all Principal Investigators: Carlos Cantero-Martínez, UdL; Jorge Álvaro-Fuentes, CSIC; Michele Rinaldi, CREA; Mathieu Marguerie, ARVALIS; Thomas Gitsopoulos, HAO; Mohamed Annabi, INRAT; Rachid Moussadek, INRA; Mourad Latati, ENSA.

Approved by Leader of Work Package (WP5): Carlos Cantero-Martínez (UdL)

Approved by Project Coordination: Michele Rinaldi (CREA)

Type of deliverable*: R

Dissemination level**: PU

Deliverable date according to Grant Agreement: Month 45

Actual delivery date: Month 48

*Type: **R** = Document, report (excluding the periodic and final reports); **DEM** = Demonstrator, pilot, prototype, plan designs, **DEC**= Websites, patents filing, press & media actions, etc.; **OTHER** = Software, technical diagram, etc…

Dissemination level: **PU= Public, fully open, e.g. web; **CO** = Confidential, restricted under conditions set out in Model Grant Agreement; **CI** = Classified, information as referred to in Commission Decision 2001/844/EC

The CAMA project (Research-based participatory approaches for adopting Conservation Agriculture in the Mediterranean Area, GA, no.1912) is part of the PRIMA program supported by the EU H2020 research and innovation program

How to quote this document: (example)

This page is left intentionally blank

Executive summary 3

1. Introduction 4
1.1 Scope of the document and objectives 4
1.2. Notations, abbreviations and acronyms...4
1.3. Background 4

2. Methodology...5
2.1 Field experiments network...5
2.2. Yield assessment and measurements 5
2.3. Statistical analysis...5

3. Results 6
3.1 CREA Experiments (Italy)...6
3.2. ARVALIS Experiments (France) 8
3.3. HAO Experiment (Greece) 10
3.4. UdL-CSIC Experiment (Spain) 14
3.5. INRA Experiment (Morocco)..15
3.6. INRAT Experiment (Tunisia)...17
3.7. ENSA Experiment (Algeria) 19

4. General conclusions by Partner...22
4.1. CREA Experiments (Italy)..22
4.2. ARVALIS Experiments (France)...22
4.3. HAO-DEMETER Experiments (Greece)...22
4.4. UDL-CSIC Experiments (Spain) 22
4.5. INRA Experiments (Morocco) 22
4.6. INRAT Experiments (Tunisia) 23
4.7. ENSA Experiments (Algeria)..23

5. General Conclusions 25

Annex 1. Main characteristics of the field experimental network. 26
CREA EXPERIMENT: Experimental design 27
Field experiments: Foggia (Italy) 28
ARVALIS EXPERIMENT: Experimental design..30
Fields experiment: Oraison (Provence, France)...31
HAO EXPERIMENT: Experimental design..32
Field experiment in Drimos, Greece 33
UdL-CSIC EXPERIMENT: Experimental design 35
Field experiment in Senés de Alcubierre (Huesca, Spain) 36
INRA EXPERIMENT: Experimental design 38
Field experiment in Merchouch, Morocco 39
INRAT EXPERIMENT: Experimental design 41
Field experiment in Kef Experimental Station of INRAT...42
ENSA EXPERIMENTs: Experimental design 43
Field experiment in Algiers (North Algiers) – S1 45
Field experiment in Mezloug, Algeria - S2:..46

Field experiment in Baida Bordj (Setif, Algeria) – S3 47
Annex 2. Network of field experiments: 48
Methodology for yield and yield component measurements 48

Executive summary

This report summarizes the results obtained in the CAMA WP5 task 5.1 aimed to evaluating the impact of conservation agriculture (CA) on crop yield an biomass

The WP5 of the CAMA project has evaluated the impact of conservation agriculture on crop yield and some related variables as yield component and even grain protein content. The network of experiments with 10 scenarios (different edapho-climatic conditions) gives us a main assessment of the soil management system comparison (effect of reduction of tillage). Other factors as water regime, crop and varieties type, cropping system (crop rotation, intercropping), fertilizer application.

The main conclusions obtained in this WP are:

Soil management options (main factor, tillage options): In general we could conclude that the reduction of the intensity of de tillage produces the same yields or better that intensive soil management options.

Cropping system: Cropping system factor represents the important factor in the definition of Conservation Agriculture (CA). Some scenarios of the network experiment stated and conclude those crop rotations an intercropping option as crop diversification are better to sustainable yield productivity and even protein content.

Plant material: Crops and varieties also showed differences in yield related with soil management and tillage reduction options. Adjusting the variety to tillage option should be taking into account. Also, crop specie and winter cereal are clearly more adapted to a reduction of tillage reduction and no tillage options, possible due to the effect of crop residue production. The crop water regime and summer in irrigated or humid scenarios also influence the response in tillage options. Then, summer crops suffer usually in Med condition a shortage in water availability under rainfed condition. The sometime failure of the crops is expected (Greece scenario). Irrigation could help but then the differences between tillage system reduction is less clear.

Fertilization options: All the scenarios where N fertilization is considered, demonstrate that there is an interactive effect thought the water response. N application produces better response of the reduction of the tillage system. In the experiments that consider the N fertilization, a reduction of the dose is needed. Farmer has the tendency to apply over fertilization and will lead to a better optimized for yield and for environmental sustainability.

1. Introduction

1.1 Scope of the document and objectives

This document presents the main results obtained in the activities performed on WP5 Task 5.1. The main aim of WP5 was to assess the performance of conservation agriculture on crop yields, water conservation and crop water use in Mediterranean condition. This general objective was divided among the next three specific objectives that match with the four tasks of WP5:

- Assess the effect of short- and long-term CA on crop yield in different pedo-climatic conditions. (Task 5.1)
- Assess the effect of short- and long-term CA on water use and water use efficiency in different pedo-climatic conditions. (Task 5.1)
- Determine the effect of CA on water infiltration and available water for the crop. (Task 5.3)
- Predict variability of yields and water use efficiency under different management and climate scenarios in different agroecosystems, especially for small holders using calibrated models. (Task 5.4.)

Therefore, the findings presented in this D 5.1 belongs to the activities performed partly in Task 5.1

1.2. Notations, abbreviations and acronyms

CA	Conservation Agriculture
CAMA	Conservation Agriculture in the Mediterranean Area
CAP	Common Agricultural Policy
CDERP	Communication, dissemination and exploitation of results plan
EC	European Commission
IPR	Intellectual Property Rights
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

1.3. Background

CA was developed in many areas around the world with successful adoption by farmers, however in Mediterranean areas still there is a limited expansion. Despite Mediterranean basin has pedo-climatic conditions and traditional agriculture that makes a very suitable area for the adoption of CA, due to different reasons this adoption is still limited. Crop yield is one main reason for the adoption of whatever crop technology. If the farmer does not obtain the same or higher crop yield, possibly he will not be willing to make a change is its cropping strategy. Mediterranean basin is a diversified cropping area in type of crops and cropping systems. CA could be adopted in all diverse crops (field crops, orchards and even horticultural crops). The cropping system is defined by the integration of different agricultural practices (choosing plant material, sowing characteristics,

fertilization, irrigation, pest, weeds and diseases control, crop diversification strategy, etc.) Then, adoption of CA technology should be adjusted to those agricultural and cropping systems and to assess the productivity in diverse scenarios.
For this reason one of the main objectives of the CAMA project is to assess the crop yield comparing different soil management systems in combination with other practices in different countries of the Mediterranean basin. For that, a limited network of experiments (running since several years or new established for the project) has been used in the frame of the project.

2. Methodology

2.1 Field experiments network

A network of long-term experiments in Italy, France, Morocco, Tunisia and Spain representing several levels of pedo-climatic conditions and with several soil management systems comparing no-till (NT) with reduced-minimum (RT or MT) and intensive conventional tillage systems (CT) has been used to test the adequacy of CA in terms of crop performance and yield. New experiments trials has been setup in Algeria, Greece and Tunisia with soil management treatments comparing CA systems vs. intensive tillage and adapted to local conditions and technological needs. In all those locations cereal-based rotations for grain (soft and durum wheat, barley, triticale, etc.,) with crop legumes as pea, chickpea, lentils and fava bean will be tested for yield. Agricultural practices tested, such as fertilization, sowing date, and overall crop diversification scenarios (crop rotation and intercropping) with legumes and other crops, has been taken into account to develop integrated packages for small farms conditions.
A large description of the experimental network is found in the Annex 1 of this document and that was shown in milestone M5.1 in month 6. In this Annex and through partners, experimental field design, location, main climate and soil characteristics of the area, and the variables that have been measured and controlled are shown.

2.2. Yield assessment and measurements

Crop yield has been obtained by the harvesting of the plots. In some cases, before crop harvest, aboveground crop biomass has been be sampled to determine total biomass and yield components. Also in some cases, during crop harvest, representative grain samples from every plot have been taken to measure grain weight and grain moisture. In some experiments, further determinations as protein content or others were done. In Annex 2 there is the methodology used by each partner for yield assessment.

2.3. Statistical analysis

To analyze the significance of the differences between treatments specially those referring to comparison between tillage systems, different statistical analyses have been done by the research groups and can be seen in the Results section.

3. Results

3.1 CREA Experiments (Italy)

The results of the three growing seasons within the project are shown for this experimental field in Foggia Italy.

Growing season 2020-2021: Sowing of broad bean (*Vicia faba* var. *minor* L.) was done on 23 December 2020**.** At harvest on 25 June 2021: seed yield (t ha^{-1}) and 1000 seeds weight (g) measurements. The final seed yield was not significantly different between the two treatments (1,07 vs. 0,99 t ha^{-1}, respectively for NT and MT). A greater 1000 seed weight was observed in NT and this highlights a more favorable condition in the seed ripening phase in NT than in MT (Table 1).

Table 1. Broad bean seed yield (t ha^{-1}) and 1000 seeds weight (g) in the two treatments. The data were subjected to analysis of variance according to the randomized block design with five replications. The means separation test was the Student-Newman-Keuls at 0.05 probability level. GLM procedure of SAS/STAT program were used in the analysis of variance and mean separation test. Means followed by different letters are significantly different at 0.05 probability level.

	Grain Yield (t ha^{-1})	1000 seeds weight (g)
No Tillage (NT)	**1,07 ± 0,17**	**265,91 ± 8,64 a**
Minimum Tillage (MT)	**0,99 ± 0,05**	**232,92 ± 7,07 b**

Growing season 2021-2022: Sowing of durum wheat (*Triticum durum* Desf.) was done on 21 December 2021. At harvest on 28 June 2022: seed yield (t ha^{-1}), 1000 seeds weight (g), test weight (kg hL^{-1}) and protein (%) measurements. The final seed yield was not significantly different between the two treatments (3,78 vs. 4,32 t ha^{-1}, respectively for NT and MT). A greater 1000 seed weight was observed in NT and this highlights a more favorable condition in the seed ripening phase in NT than in MT (Table 2).

Table 2. Durum wheat grain yield (t ha^{-1}) and 1000 seeds weight (g) in the two treatments. The data were subjected to analysis of variance according to the randomized block design with five replications. The means separation test was the Student-Newman-Keuls at a 0.05 probability level. GLM procedure of the SAS/STAT program was used in the analysis of variance and mean separation test. Means followed by different letters are significantly different at a 0.05 probability level.

	Grain Yield (t ha^{-1})	1000 seeds weight (g)
No Tillage (NT)	**3,78 ± 0,56**	**45,29 ± 0,74 a**
Minimum Tillage (MT)	**4,32 ± 0,58**	**43,25 ± 0,34 b**

The test weight (kg hL^{-1}) was the same in the two treatments (78,62 vs. 78,19 kg hL^{-1} respectively in NT and MT); also the protein content (%) was not significantly different between the two treatments (13,75 vs. 14,05 %, respectively for NT and MT) (Table 3).

Table 3. Durum wheat test weight (kg hL^{-1}) and protein (%) in the two treatments. The data were subjected to analysis of variance according the randomized block design with five replications. The means separation test was the Student-Newman-Keuls at 0.5 probability level. GLM procedure of SAS/STAT program were used in the analysis of variance and mean separation test. Means followed by different letters are significantly different at 0.5 probability level.

	Test weight (kg hL^{-1})	Protein (%)
No Tillage (NT)	**78,62 ± 1,44**	**13,75 ± 0,62**
Minimum Tillage (MT)	**78,19 ± 1,18**	**14,05 ± 0,64**

Growing season 2022-2023: Sowing of chickpea (*Cicer arietinum* L.) was done on 14 February 2023 and harvest on 4 August 2023; At maturity: seed yield (t ha^{-1}), 1000 seeds weight (g). A greater final seed yield was observed in MT treatment; the rainy spring induced a large weed growth in NT treatment that negatively impacted con chickpea growth. The 1000 seeds weight was not significantly different between the two treatments (33,49 vs. 33,31 g, respectively for NT and MT) (Table 4).

Table 4. Chickpea seed yield (t ha^{-1}) and 1000 seeds weight (g) in the two treatments. The data were subjected to analysis of variance according the randomized block design with five replications. The means separation test was the Student-Newman-Keuls at 0.5 probability level. GLM procedure of SAS/STAT program were used in the analysis of variance and mean separation test. Means followed by different letters are significantly different at 0.5 probability level.

	Grain Yield (t ha^{-1})	1000 seeds weight (g)
No Tillage (NT)	**0,73 ± 0,21 b**	**33,49 ± 1,07**
Minimum Tillage (MT)	**1,73 ± 0,23 a**	**33,31 ± 0,85**

3.2. ARVALIS Experiments (France)

Pluriannual analysis: The results of the three growing season within the project are shown for this experimental fields in Oraison (France).

The yield results are very different depending on the year. The potential climatic yield is calculated by a model (Garric ®), which simulates the yield according to the useful reserve of soil water and N, the earliness of the variety and the level of hydric stress on wheat. It could be interpreted like the potential yield without any other limiting factor than the hydric stress (Table 5).

Table 5. Yield and yield component on Oraison platform in 2021, 2022, 2023 in rainfed conditions. NNI = Nitrogen Nutrition Index at Flowering. The potential yield is estimated by the model Garric ®.

Year	Potential climatic Yield (T/ha)	Biologic Yield (T/ha)	% of potential climatic yield realized	Spike_m²	Grains_spike	Grains_m²	Dry Thousand Kernel Weight (g)	Protein_content (%)	Flowering biomass (T/ha)	N concentration in above ground biomass at flowerinf (%)	NNI at flowering	N abs at flowering in above-ground biomass (kg/ha)	Total Nitrogen inputs (kg N/ha)	Rainfall between sowing and maurity (mm)	Water productivity (kg/m3)
2021	8.0	5.0	63%	412.8	26.3	11339.3	37.7	14.3	10.0	0.82	158.7	170.0	35.8	555.0	0.9
2022	2.9	2.8	91%	320.2	23.3	7286.8	32.6	17.5	7.1	0.81	130.2	160.0	67.7	211.7	1.4
2023	4.3	4.6	107%	411.8	25.5	10428.9	38.6	16.7	7.3	0.78	127.0	140.0	32.0	532.0	0.9

Growing season 2022-2023. Sowing of durum and bread wheat was done on two dates October 20 (B4 to B16) and November 20 (B17, B18). The very rainy spring had an important negative impact on yield, particularly with the impact of Fusarium (Table 6). All wheat was sown sowed after legumes (annual or pluriannual).

Table 6. Yield and yield component on Oraison platform in 2023. NNI = Nitrogen Nutrition Index at Flowering. The potential yield is estimated by the model Garric ®. Tukey test at a confidence interval of 95%.

Plot	irrigation	Crop n-1	Crop	Genotypes	Biologic Yield (T/ha)	Tukey	% Potential yield realized	Spike/m²	Grain/spike	Grains/m²	Dry Thousand Kernel Weight (g)	Protein content (%)	Flowering biomass (T/ha)	NNI at flowering	N abs at flowering in above-ground biomass (kg/ha)	Nitrogen input / Yield (kgN/T)	Water productivity (kg/m3)
B14	no	Alfalfa	Bread wheat	Forcali	4.6	a	112%	434.4	23.3	10104.9	38.9	16.2	7.9	0.78	132.9	31.1	0.9
B13	no	Alfalfa	Bread wheat	Forcali	3.7	ab	89%	334.9	25.7	8296.8	37.7	17.2	8.4	0.76	133.3	39.5	0.7
B18	no	Onobrychis	Durum whea	Portuguese genetic	5.1	b	112%	461.5	28.5	13155.1	33.1	17.0	7.5	0.82	136.0	28.8	1.0
B4	no	Fababean	Durum whea	Mixture	6.5	b	142%	603.6	27.2	16563.9	33.4	16.4	8.4	0.89	156.0	22.0	1.2
B16	no	Alfalfa	Durum whea	Mixture	4.4	b	106%	388.0	23.1	8952.1	41.4	16.3	7.1	0.73	117.0	32.7	0.8
B15	no	Alfalfa	Durum whea	Mixture	4.4	b	108%	334.4	25.3	8588.9	43.9	16.6	6.2	0.74	109.3	35.0	0.8
B17	no	Onobrychis	Durum whea	Portuguese	4.0	b	90%	316.1	29.1	9054.4	37.8	16.4	7.1	0.77	122.7	35.3	0.8
B5	no	Fababean	Durum whea	Mixture	4.7	b	105%	421.9	22.4	9430.8	42.3	17.1	6.0	0.75	109.3	30.6	0.9

Growing season 2021-2022. For the season 2021-2022, 13 plots have been sowed:

- On October 15 in irrigated (I1-I2; I3-I4) or in rainfed conditions (B23, B22, B25, B26). One modality was conducted without fertilization (I3-I4 0N).
- On January 16 in irrigated (I5, I6) or in rainfed conditions (B21, B22). Two modalities were conducted without fertilization (I5 0N, I6 0N).

The effect of fertilization in the different modalities was not statically significant due to the Onobrychis as previous crop (Table 7). The effect of irrigation was very important due to very drought spring: it mainly preserves the number of spikes/m².

Table 7. Yield and yield component on Oraison platform in 2022. NNI = Nitrogen Nutrition Index at Flowering. The potential yield is estimated by the model Garric ®. Tukey test at confidence interval of 95%.

Year	Plot	irrigation	Crop n-1	Crop	Genotypes	Biologic Yield (T/ha)	Tukey test	% Potential yield realized	Spike/m²	Grain/spike	Grains/m²	Dry Thousand Kernel Weight (g)	Protein content (%)	NNI at flowering	Nitrogen input / Yield (kgN/T)	Water productivity (kg/m3)
2022	I1-I2	yes	Onobrychis	Bread wheat	Forcali	10.3	a	145%	847	31.1	26149	33.6	13.2	0.9	18.0	2.2
2022	I3-I4	yes	Onobrychis	Durum whea	Mixture	9.0	ab	125%	668	30.6	20592	37.3	13.9	1.0	21.3	2.0
2022	I3-I4 0N	yes	Onobrychis	Durum whea	Mixture	7.2	b	100%	496	31.9	14724	41.6	10.4	0.6	0.0	1.6
2022	I5	yes	Onobrychis	Durum whea	Portuguese genetic	4.6	c	73%	530	19.7	10443	37.3	17.6		36.6	1.5
2022	B23	no	Maize	Durum whea	Mixture	3.8	c	121%	428	19.2	8131	39.9	17.9	0.7	52.7	1.5
2022	B26	no	Maize	Bread wheat	Forcali	3.7	c	112%	425	24.6	10545	29.9	16.3	1.0	55.1	1.4
2022	I6	yes	Onobrychis	Durum whea	Portuguese genetic	3.6	cd	57%	506	17.2	8721	35.2	17.8		51.5	1.2
2022	I6 0N	yes	Onobrychis	Durum whea	Portuguese genetic	3.6	cd	57%	379	23.0	8832	34.4	16.7		0.0	1.1
2022	B24	no	Maize	Durum whea	Mixture	2.8	cd	87%	316	20.4	6544	35.7	17.5	0.8	79.3	1.1
2022	I5 0N	yes	Onobrychis	Durum whea	Portuguese genetic	2.7	cd	42%	358	18.5	6818	33.1	18.3		0.0	0.8
2022	B25	no	Maize	Bread wheat	Forcali	2.6	cd	71%	316	25.0	8040	31.7	15.8	0.8	83.6	1.0
2022	B21	no	Maize	Durum whea	Fado	1.8	d	78%	206	26.3	5289	29.0	18.3		68.3	1.6
2022	B22	no	Maize	Durum whea	Vadio	1.8	d	77%	219	24.3	5172	29.1	19.0		68.9	1.6

Growing season 2020-2021. For the growing season 2020-2021, 7 plots have been sowed in rainfed situation.

Table 8. **Yield and yield component on Oraison platform in 2021**. NNI = Nitrogen Nutrition Index at Flowering. The potential yield is estimated by the model Garric ®. Tukey test at a confidence interval of 95%.

3.3. HAO Experiment (Greece)

The results of the three growing seasons within the project are shown for this experimental field in Drimos (Greece).

Growing season 2020-2021: *Panicum milliaceum was grow between* June 2020 and October 2020. *Panicum milliaceaum* was the first crop in crop rotation; it was sown on 25/6/2020 after barley harvest under both CT and MT tillage in two adjacent field units described above. CT included deep ploughing followed by disc arrow/cultivator followed by harrowing at seeding. MT included a soil loosener (Michel-tine) before sowing and harrowing at seeding. No fertilization was applied in this trial. Extreme dry weather conditions and the absence of irrigation (rain-fed conditions) resulted in very low soil water content that affected negatively *P. milliaceum* emergence till August 2020. The occurrence of extreme rainfalls in August 2020 resulted in crop emergence, however, with poor crop establishment growth and development. Plant height was recorded on 20.8.2020 and the results indicated no different effect of MT and CT (Table 9). Harvest of *P. miliaceum* took place at the beginning of October 2020 and crop biomass (g/m^2), crop yield (g/m^2) and thousand kernel weight (TKW) (g) were calculated. The results revealed no significant differences between the two tillage systems, although more pronounced values in the variables measured were observed in CT compared to MT (Table 9). Due to poor crop establishment, all assessments were performed in places of the field units with as many as possible *P. milliaceum* plants present.

Table 9: **Plant height, crop biomass, crop yield and TKW of *P. milliaceam* plants under MT and CT.** The data were subjected to analysis of variance according to the randomized block design. The means separation test was the Student-Newman-Keuls at 0.05 probability level. GLM procedure of SAS/STAT program were used in the analysis of variance and mean separation test. (*) Means followed by different letters are significantly different at 0.05 probability level.

Tillage system	Plant height (cm)	Crop biomass (g/m^2)	Crop yield (g/m^2)	TKW (g)
MT	18.1a*	53a	2.7a	0.563a
CT	19.4a	82a	3.6a	0.525a

From December 2020 to June 2021 *Lathyrus sativus* was planted in both CT and MT. This crop was sown (120 kg/ha) on 1st December 2020. One day before sowing, the field unit of CT was ploughed, whereas on the day of sowing both field units were power-harrowed as described above. Although *L. sativus* was a legume crop, basic fertilization was applied on the day of sowing in both MT and CT systems with a 14-22-7 fertilizer (200 kg/ha). Due to high weed infestation, the low half part of both field units was excluded from the assessments. Plant height was recorded twice, once on 25.2.2021 and the other on 18.3.2021. The first assessment revealed a slight but significant difference between the plants grown under MT and those under CT, with taller plants observed under MT. However, the second assessment showed no significant difference in height (Table 10). Four Leaf Area Index (LAI) assessments were performed (on 27/4, 7/5, 18/5 and 27/5, year 2021) on *L. sativus* plants in both MT and CT systems. The results revealed no effect of the tillage system in LAI values, whereas, *L. sativus* biomass (g/m^2), yield (g/m^2) and thousand seed weight (gr) were higher under MT compared to CT (Table 10). It should be pointed out that the difference observed between the MT and CT in yield might be attributed to the higher weed infestation observed in CT compared to

MT. The limited number of registered herbicides for use in *L. sativus* and the non-application of any mechanical weed control in order not to interfere with the aim of the study resulted in a high weed population. Other weed species observed in the field were *Avena sterilis* and *Anthemis* spp. The weed population and weed density of the weed species were more pronounced under CT in the upper half of the field (Table 11).

Table 10. Assessments for height (cm), LAI, crop biomass (g), crop yield (g/m²) and TKW (g). The data were subjected to analysis of variance according to the randomized block design. The means separation test was the Student-Newman-Keuls at 0.5 probability level. GLM procedure of SAS/STAT program were used in the analysis of variance and mean separation test. (*) Means followed by different letters are significantly different.

Tillage system	Height (cm) 25.2.21	Height 18.3.21	LAI 27.4.21	LAI 7.5.2021	LAI 18.5.2021	LAI 27.5.21	Crop biomass (g)	Yield (g/m²)	TKW (g)
MT	9.53 a*	15.58 a	2.60a	2.98a	4.81a	3.13a	779a	279a	97a
CT	8.31 b	15.91 a	2.57a	2.98a	4.82a	3.11a	496b	189b	87b

Table 11: Weed density (plants/m²) recorded in MT and CT of *L. sativus* cultivation. The data were subjected to analysis of variance according the randomized block design. The means separation test was the Student-Newman-Keuls at 0.5 probability level. GLM procedure of SAS/STAT program were used in the analysis of variance and mean separation test. Means followed by different letters are significantly different.

Tillage system	weed species (plants/m²)		
	H. incana	*A. sterilis*	*Anthemis spp.*
MT	6.2 a*	0.13 a	0.13 a
CT	10.8 b	0.50 b	0.45 b

Growing season 2021-2022: The third crop in crop rotation was *Sorghum bicolor* and it was sown in both MT and CT field units in June 2021. Unfortunately the extreme drought environmental conditions occurred in summer 2021 led to failure of crop emergence. For this reason no yield data was collected for this crop. That demonstrated the water limitations that could occur in such as conditions and failure of the crop could be happen in this Med areas for summer crops. In November 2021 ***Hordeum vulgare*** **(cv. *Triptolemos*) was planted until June 2022 .** Barley was the fourth crop in crop rotation. It was sown on 17 November 2021 both under CT and MT at 12.5 cm distance between rows. CT included ploughing that was applied with moldboard plow some days before sowing and harrowing the date of sowing. MT included harrowing the date of crop sowing. Before barley sowing, both field units (CT & MT) were already infested by *Hirschfeldia incana* L. the dominant weed species of the field. Glyphosate was applied to control this weed species followed by ploughing and harrowing in CT and by harrowing for MT; this resulted in effective weed management and no weed issues occurred during the growing season. In June 2022 harvest of barley was done).

There was a significant difference in spike number, grains/spike, grain yield; and thousand kernel weight (TKW) between MT and CT (Tables 12 and 13). Only the % of proteins in the seed was higher in CT (Table 13).

Table 12. Effect of CT and MT on barley height (cm) and dry biomass at flowering. The data were subjected to analysis of variance according the randomized block design. The means separation test was the Student-Newman-Keuls at 0.5 probability level. GLM procedure of SAS/STAT program were used in the analysis of variance and mean separation test. Means followed by different letters are significantly different.

Tillage system	Plant height (cm) on 14.1.22	Plant height (cm) on 16.2.22	Dry biomass (t/ha) at flowering
CT	8.97 a	11.5 a	9.11 a
MT	8.01 a	9.5 b	7.15 a

Table 13. Effect of CT and MT tillage on barley yield and yield components. The data were subjected to analysis of variance according the randomized block design. The means separation test was the Student-Newman-Keuls at 0.5 probability level. GLM procedure of SAS/STAT program were used in the analysis of variance and mean separation test. (*) Means followed by different letters are significantly different.

Tillage system	Spikes/m^2	Grains/spike	Grain yield (t/ha)	TKW (g)	Seed protein %
CT	553 a*	21.4 a	4,05 a	39.9 a	13.3 a
MT	604 a	21.6 a	4,35 a	39.0 a	12.6 b

Growing season 2022-2023. In November 2022, Barley (cv. Nure) was planted and was the fifth crop in the three-year crop rotation. It was sown on 30 November 2022 both under CT and MT at 12.5 cm distance between crop rows as described for the last year barley sowing. Basic fertilization was applied on the crop sowing date (30.11.2022) with 36 kg N/ha of 18-23-0 + 23 SO_3 (Ωmega fert Hellagrolip, 16.6% NH_4, 1.4% NO_3) whereas topdressing fertilization of 52 KgN/ha of Ammonium Sulphate Nitrate (26-0-0 +29 SO3 Fertamon, 18.7% NH_4, 7.3% NO_3) was applied on 3.3.2023. The dates for different BBCH growth stages, plant height, Leaf Area Index (LAI), crop yield, yield components; weed counts and weed dry weight were assessed in both CT and MT field units. Although there was no difference in the number of plant emergence between CT and MT, barley plants under CT were ahead compared to MT plants regarding growth and development, reaching BBCH growth stages earlier than those in MT (Table 14). That was evident also in the previous year trial with barely grown in CT and MT.

Table 14: **Effect of CT and MT on barley height (cm), LAI (four recording) and dry biomass at flowering.** The data were subjected to analysis of variance according the randomized block design. The means separation test was the Student-Newman-Keuls at 0.5 probability level. GLM procedure of SAS/STAT program were used in the analysis of variance and mean separation test. Means followed by different letters are significantly different.

Tillage system	Height 10.2.23	LAI 12.4.23	LAI 21.4.23	LAI 19.5.23	LAI 7.6.23	Dry biomass (t/ha) at flowering (21.4.23)
CT	13.1 a*	2.423 a	4.686 a	4.214 a	2.483 a	4.27 a
MT	10.1 b	1.873 a	3.223 b	3.600 b	2.214 a	3.18 b

Moreover, differences were observed in the number of spikes/m^2, the number of grains/spike and the grain yield, whereas TKW and % of seed protein revealed similar for barley crop in MT and CT (Table 15).

Table 15: **Effect of CT and MT on number of spikes, number of grains/spike, grain yield, TSW and % seed protein**. The data were subjected to analysis of variance according the randomized block design. The means separation test was the Student-Newman-Keuls at 0.5 probability level. GLM procedure of SAS/STAT program were used in the analysis of variance and mean separation test. Means followed by different letters are significantly different.

Tillage system	Spikes/m^2	Grains/spike	Grain yield (t/ha)	TKW (g)	Seed proteins %
CT	469 a*	17 a	3.90 a	45.2 a	11.9 a
MT	340 b	18 a	3.02 b	44.3 a	11.68 a

The conclusions for yields under CT and MT are that Similar yields for *Panicum miliaceum*, *Lathyrus sativus* and *Hordeum vulgare* in crop rotation were recorded under CT and MT. Higher yield under CT for *Hordeum vulgare* yield after *Hordeum vulgare* was recorded the last year of the crop rotation.

Table 16: Summary table for yield of each crop cultivated in crop rotation from 2020 to 2023 under MT and CT in Drimos Greece. Grain yield for *P. miliaceum*, *L. sativus*, *H.vulgare* and *H. vulgare* in crop rotation under MT and CT. **means followed by the same number in the same column are not statistically different.*

Tillage system	*Panicum miliaceum*	*Lathyrus sativus*	*Sorghum bicolor*	*Hordeum vulgare*	*Hordeum vulgare*
	June 2020-October 2020	**December 2020-June 2021**	**June 2021**	**November 2021-June 2022**	**November 2022-June 2023**
	gr/m^2		**Crop failure due to limited rainfall occurred**	**t/ha**	
MT	2.7a*	279a		4.35 a	3.02 b
CT	3.6a	189b		4.05 a	3.90 a

3.4. UdL-CSIC Experiment (Spain)

The results of the three growing season within the project are showed for this experimental field in Senés de Alcubierre (Spain). Table 17 shows the results of the three growing season studied in the CAMA project in the rotation Wheat - Pea Crop - Barley. Differences of crop yield between the years are consistent with the climate recorded in the three growing seasons. In 2020-21 and 2021-22 received the normal rainfall for the area (300-400 mm) and with a regular distribution. However, 2022-23 was the driest growing season registered in the last 40 years (less than 250 mm). The yields in the normal rainfall years ranged for wheat crop between 1 and 3 t/ha in 2020-21 and 1 and 4,7 t/ha in Pea crop in 2021-22, depending treatments. However ranged between less than 0,2 and 1 t/ha of barley grain in the driest growing season of 22-23. Clearly differences in tillage system were obtained of the growing seasons and in all crops. NT showed higher yield than CT in the three growing seasons. The effect of N fertilization dose was positive in the 2 of the 3-growing seasons with average rainfall and no differences in N dose in the last 2022-23. No interaction was observed between Tillage system and N fertilization dose. In all cases, higher yields were obtained in NT. These results are consistent with the lack/availability of water. Crops response to N fertilization depends on water available in these Mediterranean systems. Combinations of treatments dose and type and fertilizer product (mineral vs. organic) showed the positive response to organic fertilizer more than in mineral fertilizer.

Table 17. Grain yield (kg/ha) in wheat, pea crop and barley under different tillage, fertilization N dose and type of fertilizer products from 2020 to 2023 growing seasons in Senes de Alcubierre (Huesca, Spain). The data were subjected to analysis of variance according the randomized block design. The means separation test was the Student-Newman-Keuls at 0.5 probability level. GLM procedure of JMP program was used in the analysis of variance and mean separation test. Mean values labeled with the same letter were not significantly different at $p < 0.05$ in the ANOVA and t-student test.

Growing season	2020-21		2021-22		2022-23	
Crop	**Wheat Crop**		**Pea crop**		**Barley crop**	
Tillage system						
CT	1845,93	b	1969,41	b	224,06	b
NT	2697,58	a	4116,72	a	814,57	a
N fertilization dose						
0	*1821,54*	*b*	*1374,40*	*b*	*517,80*	*a*
75	*2481,24*	*a*	*3090,58*	*a*	*521,95*	*a*
150	*2287,38*	*a*	*3829,88*	*a*	*519,32*	*a*
Treatment combination						
0	1821,54	b	1374,40	c	517,80	a
Medium N (75) -Mineral	2011,63	b	2646,73	bc	468,10	a
Medium N (75) -Organic	2950,85	a	3534,42	ab	575,81	a
High N -MIN (150)- Mineral	2050,02	ab	3026,29	ab	400,21	a
High N -ORG (150)-Organic	2524,75	ab	4633,48	a	638,42	a

3.5. INRA Experiment (Morocco)

The CAMA project included field trials in Morocco spanning three consecutive cropping seasons (2020-21, 2021-22, and 2022-23). Evaluation of Durum wheat yield took place during the 2020-21 and 2021-22 cropping seasons. Due to a severe drought in the third cropping season in 2022-23, the crops were failure in Central Morocco in this last season specifically at the Merchouch site. During the two cropping seasons (2020-21 and 2021-22), the total rainfall recorded at the Merchouch experimental station was 347 mm and 251 mm, respectively. However, the 2022-23 season, the rainfall recorded was less than 171 mm.

Growing season 2020-21: In this cropping season, five durum wheat varieties tested under two tillage systems (NT vs. CT) and three doses of N fertilization (35N, 55N and 75N). The table 18 below shows the analysis of variance that highlighted the effect of tillage systems on grain yield indicators.

Table 18. Durum Wheat grain yield (t ha^{-1}), measured at the end of the experiment during the cropping season 2020-2021, for tillage types, nitrogen doses (kg N ha^{-1}), and varieties. Means (n=3), with (standard deviations), followed by the same letter are not statistically different at the 0.05 significance level using the Duncan post-hoc test. NT= No tillage, CT= Conventional tillage.

Nitrogen (kg N ha^{-1})	Tillage / Variety	Faraj	I.C	Louiza	M.G	Nachit	Mean	Mean
35	**NT**	4.31 (0.34)	4.74 (0.42)	3.42 (0.49)	4.52 (0.96)	4.47 (0.83)	4.29 (0.73)	4.09 (0.75) A
	CT	4.46 (0.34)	3.87 (0.70)	3.21 (0.55)	3.40 (0.41)	4.52 (0.74)	3.89 (0.73)	
55	**NT**	4.32 (0.17)	3.88 (0.66)	2.93 (0.66)	3.97 (0.48)	5.14 (1.03)	4.05 (0.93)	3.92 (0.81) A
	CT	3.77 (0.35)	4.24 (0.19)	3.34 (0.55)	3.05 (0.13)	4.48 (0.76)	3.78 (0.67)	
75	**NT**	4.04 (0.59)	3.93 (0.44)	3.17 (0.47)	3.95 (0.13)	4.24 (0.03)	3.86 (0.51)	3.72 (0.56) A
	CT	3.86 (0.20)	3.63 (0.89)	3.01 (0.15)	3.43 (0.73)	3.90 (0.50)	3.57 (0.59)	
Mean	**NT**	4.22 (0.38)	4.18 (0.61)	3.17 (0.52)	4.15 (0.61)	4.62 (0.78)	4.07 (0.75)	
	CT	4.03 (0.42)	3.91 (0.63)	3.19 (0.42)	3.29 (0.46)	4.30 (0.66)	3.75 (0.67)	
Mean		4.13 (0.40) a	4.05 (0.62) b	3.18 (0.46) c	3.72 (0.68) b	4.46 (0.72) a	3.91 (0.72)	

A slightly higher grain yield was attained under NT (4.07 t ha^{-1}) compared to CT (3.75 t ha^{-1}). The tillage type effect on yield was not significant even though there were significant differences between soil properties (especially Organic Carbone) corresponding to the two tillage types. This may be explained, as above, by the water stress that impacted the crop yield. For nitrogen doses, mean grain yields were 4.09, 3.92, and 3.72 t ha^{-1} under 20, 40, and 60 kg N ha^{-1}, respectively. The water stress is likely behind the absence of nitrogen dose effect on crop yield.

Table 19 shows the effects of factors (Tillage system, Nitrogen and Variety) and their interactions. The analysis showed that the only Variety effect was significant on the grain yield (Table 19).

Table 19. ANOVA results for wheat grain and straw yield (t ha^{-1}), measured at the end of the experiment during the cropping season 2020-2021. ns: not significant; *, **, and ***: significant at the 0.05, 0.01, and 0.001 levels, respectively.

	Grain yield		Straw yield	
Source of variation	**F value**	**p-value**	**F value**	**p-value**
Tillage (T)	4.40	0.171 ns	1.20	0.388 ns
Nitrogen (N)	3.95	0.064 ns	2.06	0.190 ns
Variety (V)	14.62	<0.001 ***	6.41	<0.001 ***
T*N	0.14	0.876 ns	0.13	0.880 ns
T*V	1.60	0.189 ns	2.12	0.093 ns
N*V	0.76	0.637 ns	0.16	0.996 ns
T*N*V	1.07	0.398 ns	0.70	0.690 ns

Growing season 2020-21: In this cropping season and due to drier conditions (rainfall less than 257 mm), it was difficult to effect the nitrogen fertilization. Four durum wheat varieties were tested under 2 tillage system (NT vs. CT). The table 20 below shows the analysis of variance that highlighted the effect of tillage system on wheat yield.

Table 20. ANOVA results for wheat grain and straw yield (t ha^{-1}). Effect of tillage system (T), genotype (G) and their interaction (T*G) on grain yields (GY) and straw yields (SY) of durum wheat at the Merchouch experimental field in 2021-2022. DL: degree of freedom; MS: mean square; P significance level: * (<0.05), ** (<0.01), ***(<0.001), ns: not significant.

Factor	DF	GY		SY	
		MS	**P**	**MS**	**P**
T	**1**	**43,422**	***	**60,173**	**
G	**3**	**11,152**	**	**30,764**	**
T x G	**3**	**11,074**	**	**22,829**	*
Residual	**16**	**1,727**		**5,558**	
Total	**23**	**5,989**		**13,473**	

3.6. INRAT Experiment (Tunisia)

Field trials in Tunisia conducted as part of the CAMA project were carried out over three consecutive cropping seasons, from 2020-21 to 2022-23. The average durum wheat yield varied according to climatic conditions. Indeed, for the first two crop seasons (2020-21 and 2021-22), the average durum wheat yield was 1979 kg ha^{-1} and 1794 kg ha^{-1}, respectively. However, for the last crop season 2022-23, no yield was recorded due to a severe drought observed throughout Tunisia, including the Kef region. Total rainfall recorded at El Kef experimental station was 292 mm, 246 mm for the 2020-21 and 2021-22 cropping seasons respectively, and only 156 mm for the 2022-23 cropping season.
Table 21 summarizes the effects of Rotation (R) and Tillage (T) factors and their interactions on durum wheat grain yield (GY), Harvest Index (HI), and thousand kernel weight (TKW) for the 2020-21 and 2021-22 cropping seasons. In the 2020-21 season, no significant effect was observed except for the interaction R × T on HI ($P \leq 0.05$) (Table 21 & 22). However, for the 2021-22 season, the Rotation factor has a statistically significant impact on Grain Yield (GY) at $P \leq 0.01$. Moreover, Tillage is statistically significant for GY and Harvest Index (HI) at $P \leq 0.05$, but not for TKW. The interaction between Rotation (R) and Tillage (T) is statistically significant for GY and HI at $P \leq 0.05$, while not significant for TKW (Table 21). As compared to the 2020-21 season, significant effects observed within the 2021-22 season might be attributed to differences in precipitation and distribution during the cropping season. Precipitation was notably 17% lower in the 2021-22 season compared to the 2020-21 season. This decline was particularly evident in the spring period, with spring precipitation measuring 127 mm for the 2020-21 season and only 43 mm for the 2021-22 season. Additionally, this resulted in a 78-day free rainfall for the 2021-22 season. Such climatic conditions during the 2021-22 season may provide a favorable environment for better understanding and evaluating the potential of conservation agriculture practices. Indeed, a comparison of mean grain yield (GY) demonstrates that No-till (NT) significantly outperforms the Conventional Tillage (CT) practices in both Biennial (+84%) and Triennial (+17%) rotations (Table 23). The lack of significant differences between NT and CT practices within durum wheat monoculture emphasizes the importance of rotation practices. Moreover, for the Harvest Index (HI), the highest value (29.4%) was obtained with the NT practice under the triennial rotation. These results underscore the importance of considering both tillage and rotation practices in optimizing durum wheat production, especially in varying climatic conditions.
The results indicate that both experimental factors do not affect the durum wheat TKW (Table 22). The average TKW was 43 g for the 2020-21 cropping season and 37 g for the 2021-22 cropping season (Table 22 & 23). The notable difference in mean TKW between the two seasons might be attributed to the greater spring precipitation of 127 mm in the 2020-21 season, as opposed to only 43 mm in the 2021-22 season. This difference in spring precipitation has led to a more favorable grain-filling phase in the 2020-21 season, thus contributing to the variations observed in TKW.

Table 21. Analysis of variance (F values) for the effect of the Rotation (R), Tillage (T) and their interactions on grain yield (GY), Harvest Index (HI) and Thousand kernel weight (TKW) of durum wheat for the 2020-2021 cropping season. ”°” represents statistical significance at P ≤ 0.1, ”*” represents statistical significance at P ≤ 0.05 and “**” represents statistical significance at P≤ 0.01.

Cropping season	Source of variance	Grain Yield (GY)	Harvest Index (HI)	Thousand kernel weight (TKW)
2020-21	Rotation (R)	1.481	1.055	2.1
	Tillage (T)	0.347	0.713	0.583
	R*T	2.38	3.433 *	0.228
2021-22	Rotation (R)	13.657**	3.139	1.867
	Tillage (T)	5.375*	2.693°	1.977
	R*T	2.996*	2.548°	0.705

Table 22. Effect of the interactions between rotation and tillage on durum wheat grain yield (GY), Harvest Index (HI) and Thousand kernel weight (TKW) for the 2020-2021 cropping season. Column numbers displaying '±' represent the standard deviations, and column letters indicate the Tukey HSD (P ≤ 0.05) statistical output. Different letters within a column indicate significant differences within treatments. Rotations are Monoculture (M), Biennial (B) and Triennial (T). Tillage practices are No-till (NT), Minimum Tillage (MT) and Conventional Tillage (CT).

Rotation	Tillage	GY (kg ha^{-1})			HI (%)			TKW (g)		
M	NT	2123	±550	a	32.33	±9.77	a	42.13	±3.06	a
	MT	1387	±658	a	26.37	±9.78	a	42.13	±1.05	a
	CT	1323	±572	a	25.29	±9.66	a	41.93	±1.21	a
B	NT	2073	±267	a	31.47	±1.4	a	42.12	±2.26	a
	MT	2057	±120	a	33.77	±5.24	a	41.14	±2.47	a
	CT	2243	±315	a	37.71	±0.44	a	42.51	±1.79	a
T	NT	1993	±640	a	23.11	±4.78	a	44.73	±3.29	a
	MT	2423	±534	a	28.73	±6.11	a	42.57	±0.88	a
	CT	2183	±170	a	30.36	±3.87	a	44.9	±1.32	a

Table 23. Effect of the interactions between rotation and tillage on durum wheat grain yield (GY), Harvest Index (HI) and Thousand kernel weight (TKW) for the 2021-2022 cropping season. Column numbers displaying '±' represent the standard deviations, and column letters indicate the Tukey HSD (P ≤ 0.05) statistical output. Different letters within a column indicate significant differences within treatments. Rotations are Monoculture (M), Biennial (B) and Triennial (T). Tillage practices are No-till (NT), Minimum Tillage (MT) and Conventional Tillage (CT).

Rotation	Tillage	GY (kg ha^{-1})			HI (%)			TKW (g)		
M	NT	1365	±277	bc	22.06	±5.62	ab	35.47	±1.29	a
	MT	1113	±306	c	21.23	±1.82	ab	37.79	±2.46	a
	CT	1363	±444	bc	23.66	±5.49	ab	37.6	±1.43	a
B	NT	2390	±221	a	27.74	±0.54	ab	36.85	±1.1	a
	MT	2087	±247	ab	26.44	±2.52	ab	37.73	±1.89	a
	CT	1297	±128	bc	18.66	±1.33	b	35.98	±2.71	a
T	NT	2403	±478	a	29.4	±4.75	a	37.72	±1.83	a
	MT	2083	±265	ab	27.48	±1.18	ab	39.13	±1.1	a
	CT	2043	±472	ab	26.15	±5.78	ab	39.03	±0.52	a

3.7. ENSA Experiment (Algeria)

Field trials in Algeria conducted as part of the CAMA project were carried out over three consecutive cropping seasons, from 2020-21 to 2022-23. However here are shown results from 2018-2019 and not in 2022-2023. This last growing season due to extreme drought there was a failure of the crop. Grain yield durum wheat, was significantly ($p \leq 0.001$) affected by crop-syst during all cropping seasons, while they were affected ($p \leq 0.05$) by N-level treatment during 2022 and 2020 years, (Table 24). In terms of grain yield (GY), crop-syst and N-level affected significantly ($p \leq 0.001$) GY of durum wheat, except in 2021 and 2019 where we observed no significant effect of N-application. The greater GY was noted in durum wheat monoculture which was significantly increased by increasing N-application, particularly in the 2022 and 2020 growing seasons. Results in table 24 show also that N-application increased gradually GY of mixed crop between N-30 and N-60 dose. Thus, raising from N-30 to N-60 dose resulted in the increase of the grain yield of mixed chickpea-durum wheat by +0.81, +0.24, +0.22 and +0.74 t ha^{-1}, respectively in 2022, 2021, 2020 and 2019 growing season. However, when considering the difference in grain yield between N-30 and N-100 doses, it was significantly increased only in the 2020 (+1.71 t ha^{-1}) cropping season. The same trend was observed for chickpea monoculture where GY was significantly increased when passing from N-30 to N-60 dose, except in the 2021 growing season. In the case of durum wheat monoculture, N-application increased gradually GY among the three N-application doses during all experiment years, this increase was more pronounced (+1.97 t ha^{-1} passing from N-30 to N-100 dose) in the 2020 growing season when crop-syst × N-level interaction affect significantly GY (Table 24).

According to Table 25, they was significantly ($p \leq 0.001$) affected by crop-syst during all cropping seasons, while they were affected ($p \leq 0.05$) by N-level treatment during 2022 and 2020 year and by crop-syst × N-level interaction ($p \leq 0.05$) in both 2021 and 2020 growing season. Durum wheat monoculture had the highest protein yield as compared to both chickpea monoculture and intercropping systems. Increasing N-application leads to enhance gradually protein production when increasing N dose from N-30 to N-100 dose. This increase in protein yield was only significant in the GY of mixed crops and during the 2022 and 2020 growing seasons. Hence, protein yield was increased by 57 and 133 kg ha^{-1} when passing from N-30 to N-100, respectively in the 2022 and 2020 growing seasons.

Table 24. Grain yield (GY) in chickpea, durum wheat and crop mixture under different crop-N level treatments from 2019 to 2022 growing seasons in the Site of MEZLOUGH at Setif region. Data are means ± standard error of 4 replicates. Mean values labelled with the same letter were not significantly different at $p < 0.05$.

		Grain yield (t ha^{-1})			
Cropping system	N-level	20021/2022	2020/2021	2019/2020	2018/2019
Chickpea	N-30	0.12^{c}	1.84^{a}	0.70^{d}	0.39^{d}
Chickpea	N-60	0.17^{bc}	1.64^{ab}	1.27^{c}	0.99^{c}
Chickpea	N-100	0.18^{bc}	1.60^{ab}	0.34^{d}	1.42^{c}
Wheat	N-30	2.68^{b}	0.89^{bc}	3.05^{b}	3.30^{b}
Wheat	N-60	4.64^{a}	1.04^{b}	4.62^{a}	3.42^{b}
Wheat	N-100	4.25^{a}	1.37^{b}	5.02^{a}	4.21^{a}
Mixed crop	N-30	1.04^{c}	0.59^{c}	1.03^{c}	0.88^{c}
Mixed crop	N-60	1.85^{bc}	0.83^{bc}	1.25^{c}	1.62^{c}
Mixed crop	N-100	2.08^{bc}	0.50^{c}	2.74^{bc}	1.16^{c}
p-value	Cropping	≤0.001	≤0.001	≤0.001	≤0.01
	N-level	0.03	0.99	≤0.01	0.51
	Crop*N-level	0.16	0.26	≤0.001	0.96

Table 25. Protein contents in chickpea, durum wheat and crop mixture under different crop-N level treatments from 2019 to 2022 growing seasons in the Site of MEZLOUGH at Setif region. Data are means ± standard error of 4 replicates. Mean values labelled with the same letter were not significantly different at $p < 0.05$.

		Protein yield (kg ha^{-1})			
Cropping system	N-level	2021/2022	2020/2021	2019/2020	2018/2019
Chickpea	N-30	15.12^{c}	438.47^{a}	120.85^{cd}	68.05^{a}
Chickpea	N-60	28.83^{c}	276.25^{ab}	267.90^{c}	133.84^{a}
Chickpea	N-100	17.94^{c}	359.94^{a}	67.20^{d}	253.13^{a}
Wheat	N-30	243.49^{ab}	138.2^{bc}	408.85^{b}	619.54^{a}
Wheat	N-60	340.62^{a}	181.61^{b}	495.34^{b}	630.26^{a}
Wheat	N-100	338.80^{a}	256.18^{b}	610.50^{a}	731.31^{a}
Mixed crop	N-30	104.6^{bc}	144.66^{bc}	155.04^{cd}	164.16^{a}
Mixed crop	N-60	141.22^{b}	128.70^{bc}	169.18^{cd}	308.76^{a}
Mixed crop	N-100	161.65^{b}	91.04^{c}	288.05^{c}	221.90^{a}
p-value	Cropping	≤0.001	≤0.001	≤0.001	≤0.001
	N-level	0.02	≤0.001	≤0.001	≤0.001
	Crop*N-level	≤0.01	≤0.001	≤0.001	≤0.001

Table 26 shows all calculated values of LER in terms of biomass (TB), grain yield (GY) and N uptake by either biomass (NB) or yield (NY). The ANOVA analysis showed a significant effect ($p \leq 0.05$) of all studied factors on LER values, except for the N-level effect on LER_{GY}. According to the data reported in Table 26, the highest values of LER were observed in the 2019 (1.22) and 2020 (0.80) growing season under respectively moderate and high N-application, but they were greater than 1 only under moderate N-application during 2019 growing season. In terms of N accumulation by grain yield (LERNY), the intercropping advantage was only observed in the 2019 growing season and under moderate N-application, which allows more than 65% of the advantage as compared to the sole crop (Table 26). For biomass production, intercropping showed an advantage over the 2019, 2021 and 2022 cropping seasons. This advantage was observed only under both low and moderate N-application in 2019 (20 and 44%, respectively in N-30 and N-60 dose) and 2022 (5% in N-30 dose) seasons. However, it was confirmed among all applied N doses (19, 1 and 12%, respectively in N-30, N-60 and N-100 doses) in the 2021 growing season. The same trend was found for LER_{NB}, in which low and moderate N-application leads to a greater advantage of intercropping, in particular in 2019 (91% in N-30 dose) and 2021 (71% in N-60 dose).

Table 26. Land equivalent ratio (LER) values for grain yield (LER_{GY}). nitrogen uptake by grain yield (LER_{NY}). total biomass (LER_{TB}) and LER for nitrogen uptake by biomass (LER_{NB}) calculated from 2019 to 2022 cropping seasons under the three nitrogen fertilizer doses. Data are means ± standard error of 4 replicates. Mean values labelled with the same letter were not significantly different at $p < 0.05$.

Cropping season	N-level	LER_{GY}	LER_{NY}	LER_{TB}	LER_{NB}
Season:2018/2019	N-30	0.88[ab]	1.01[b]	1.20[b]	1.56[ab]
	N-60	1.22[a]	1.65[a]	1.44[a]	1.91[a]
	N-100	0.45[c]	0.50[cd]	0.86[b]	0.78[c]
Season:2019/2020	N-30	0.48[c]	0.49[cd]	0.48[d]	0.44[d]
	N-60	0.36[c]	0.39[d]	0.26[d]	0.22[d]
	N-100	0.80[b]	0.75[bc]	0.31[d]	0.28[d]
Season:2020/2021	N-30	0.57[bc]	0.60[cd]	1.19[b]	1.71[ab]
	N-60	0.57[bc]	0.51[cd]	1.01[b]	1.25[b]
	N-100	0.35[c]	0.31[d]	1.12[b]	1.39[b]
Season:2021/2022	N-30	0.55[bc]	0.55[cd]	1.05[b]	1.02[c]
	N-60	0.62[bc]	0.67[c]	0.69[c]	0.59[c]
	N-100	0.62[bc]	0.65[c]	0.69[c]	0.61[c]
p-value	Season	≤0.001	≤0.001	≤0.001	≤0.001
	N-level	0.10	≤0.001	0.04	0.01
	S*N-level	≤0.001	≤0.001	0.05	0.01

4. General conclusions by Partner

4.1. CREA Experiments (Italy)

The final seed yield was not significantly different between NT and MT for broad bean and for durum wheat. For chickpea, it was greater in MT than in NT treatment, but it has been mainly due to a not optimal weed control in NT. The seed weight was greater in NT for broad bean and durum wheat, showing a better soil water condition during seed ripening; while for chickpea, it was not different between the two treatments. For durum wheat the values of protein and test weight were not different between the two treatments.

4.2. ARVALIS Experiments (France)

No clear differences were observed between the different soil management systems. Higher importance were (in this edaphoclimatic situation) due to crops, precedent crops and water regime. The France situation is highest humid scenario between all the studied in the network experiments. For this reason the advantages from No tillage and reduce tillage are less marked than in other Med conditions. However the importance of this scenario come from the extreme situation that represents the France experiments.

4.3. HAO-DEMETER Experiments (Greece)

The effect of Conventional and Minimum tillage in crop rotation revealed similar yields for both *Lathyrus sativus* grown after cereals and *Hordeum vulgare* after *Lathyrus sativus. Hordeum vulgare* yield after *Hordeum vulgare* in crop rotation was lower in MT. Nitrogen fertilization/availability might have been the critical point for this. Barley crop residues might have caused less soil nitrogen availability. Rotation with a legume after or/and before winter cereal cultivation is suggested in MT. Nitrogen nitrate levels after *Lathyrus sativus* were greater in autumn under MT. The emergence and density of the weed species *Hirschfeldia incana* was lower in MT with *Hordeum vulgare* crop residues.

4.4. UDL-CSIC Experiments (Spain)

The results suggest after these three growing seasons, that reduction of till and No-tillage are adequate strategies for this Mediterranean area to maintain and increase the yield. N fertilization could be adapted to the growing season and a higher dose of N fertilization did not increment the yields. Best results are obtained under NT. In this study, the use of organic fertilizer obtained better yields making suitable this option to reduce the use of synthetic fertilizers.

4.5. INRA Experiments (Morocco)

Under semi-arid conditions, the 3 consecutive cropping seasons show how climate variation affects the crop production in the study region. The average durum wheat yield varied due to different weather conditions (mainly rainfall distribution and total amount). The third season had no yield due to a severe drought. The impact of genetic factors on yield properties, especially in the 2021-22 season, emphasizes the importance of using adequate varieties tolerant to water stress. No-Till practices were found to be superior to Conventional Tillage, especially in semi-arid conditions, showing the benefits of combining (No Tillage x Nitrogen Management). In conclusion, the results demonstrate that by using a suitable agronomy package which include CA practices with strategic fertilization adapted to the drought tolerant variety can optimize durum wheat production, aligning with conservation agriculture principles and promoting sustainable and climate-smart agricultural practices in semi-arid Mediterranean zones.

4.6. INRAT Experiments (Tunisia)

The three consecutive field trials demonstrate the significance of climate variation in the study region. The average durum wheat yield exhibited fluctuations, influenced by varying climatic conditions, with the third season marked by a severe drought resulting in no recorded yield.

The observed significant impact of Rotation on grain yield (GY), particularly in the 2021-22 season, highlights the importance of diversifying crop sequences. Additionally, the superiority of No-Till over Conventional Tillage practices, especially in Biennial and Triennial rotations, emphasizes the synergistic benefits derived from incorporating both no-tillage and rotation practices.

In conclusion, the results of the field trials demonstrate the potential of combining No-Till (NT) practices with strategic crop rotation for optimizing durum wheat production. This combination aligns with the principles of conservation agriculture, providing a pathway toward sustainable and climate-smart agricultural practices for the studied region.

4.7. ENSA Experiments (Algeria)

Under semi-arid conditions of the Mezlough site, for durum wheat monoculture, yields and protein yield were increased by increasing N-application from low to high-level overall rain-fed conditions. Regarding the intercropping system, similar results were found only under high rainfall conditions which correspond to the 2022 and 2020 growing seasons, while grain yield and protein accumulation were boosted only under low and moderate N-application in response to an increasing drought during the crop growth period (i.e. from tillering to inflorescence emergence stage). Application of N-synthetic fertilizers may stimulate growth and development but it can also lead to early exhaustion of soil water in dry-land areas. Consequently, a higher N-fertilizer input may lead to a decrease in grain yield as compared to the grain yield obtained with low and moderate application of N-fertilizer. For the three studied sites, results show also that N-application gradually increased both grain and protein yield only in the grain yield of mixed crops where protein production was increased (e.g. MEZLOUGH site) by 16 and 41 kg ha^{-1} (passing from N-30 to N-60 and fromN-60 to N-100, respectively), 139 and 210 kg ha^{-1} (OUED SMAR site) and 165 and 26 kg ha^{-1} (BAIDA BORDJ site). In the case of the durum wheat monoculture, there was also a gradual increase with N application, particularly under high rainfed conditions (OUED SMAR site), while we observed that the highest protein yield was obtained with N-60 level for sole-cropped chickpea. This improvement of protein and grain yield components was globally observed under low and moderate N-soil inputs (available from natural soil N and added fertilizer) and in either sub-humid (OUED SMAR site) or semi-arid (MEZLOUGH site) climate. Chickpea-durum wheat intercropping was supported as a beneficial practice to improve aboveground protein accumulation and grain yield of intercropped durum wheat.

Our study, therefore, highlights an increase of N-fertilizer use by chickpea-durum wheat intercropping among the different pedo-climatic conditions, owing to higher NUE as compared to both sole cropped chickpea and durum wheat. Moreover, NUE improvement was demonstrated under either moderate or low N-application in semi-arid climate, while it was shown under all N-application doses under sub-humid conditions (OUED SMAR site). Overall, a greater effect of intercropping on improving NUE was underlined under sub-humid climate as compared to that observed in semi-arid sites. This was probably due to much water availability in OUED SMAR site, by which excessive N-fertilizer was efficiently optimized during growth and yield development.

5. General Conclusions

The WP5 of the CAMA project has evaluated the impact of conservation agriculture on crop yield and some related variables as yield component and even grain protein content. The network of experiments with 10 scenarios (different edapho-climatic conditions) gives us a main assessment of the soil management system comparison (effect of reduction of tillage). Other factors as water regime, crop and varieties type, cropping system (crop rotation, intercropping), fertilizer application.

The main conclusions obtained in this WP based on the evaluation of the results are:

Soil management options (main factor, tillage options): In general we could conclude that the reduction of the tillage intensity produces the same yields or better that intensive soil management options. Dependence of the edaphoclimatic conditions makes more effective the reduction of the tillage systems. The more humid situations as France, Italy or Greece, gives less differences to the reduction of the soil management. Dryer scenarios as in Spain or Northern African countries have given more clear advantages for the reduction of the tillage intensity.

Cropping system: Cropping system factor represents the important factor in the definition of Conservation Agriculture (CA). The principle for CA stated crop diversification is needed for the efficient performance of the CA. It is case some scenarios of the network experiment stated and conclude that crop rotation and intercropping option as crop diversification are better to sustainable yield productivity and even protein content.

Plant material: Crops and varieties also stated differences in yield related with soil management and tillage reduction options. The crop (depending of if winter cereals, legume crops or summer or winter species) gives differences of the performance of reduction of tillage. Variety type it looks has some effect on the performance in yield of tillage reduction. Adjusting the variety to tillage option should be taking into account. Also, crop specie and winter cereal are clearly more adapted to a reduction of tillage reduction and no tillage options, possible due to the effect of crop residue production. However legume crops, less resilient and less productive in crop residues are more critical in the advantages in crop yield. The crop water regime and summer in irrigated or humid scenarios also influence the response in tillage options. Then, summer crops suffer usually in Med condition a shortage in water availability under rainfed condition. The sometime failure of the crops is expected (Greece scenario). Irrigation could help but then the differences between tillage system reduction is less clear.

Fertilization options: All the scenarios where N fertilization is considered, demonstrate that there is an interactive effect thought the water response. N application produces better response of the reduction of the tillage system. Also is detected that adjustment to N dose and type of fertilizer is needed. In the experiments that consider the N fertilization, a reduction of the dose is needed. Farmer has the tendency to apply over fertilization and will lead to a better optimized for yield and for environmental sustainability.

Annex 1. Main characteristics of the field experimental network.

The CAMA project (Research-based participatory approaches for adopting Conservation Agriculture in the Mediterranean Area, GA, no.1912) is part of the PRIMA program supported by the EU H2020 research and innovation program

CREA EXPERIMENT: Experimental design

PARTNER Country	Tasks involvedin CAMA project	Location experiments	Year beginning exp./Crop rotation / Water regime	Main Treatments - Replications	Main Variables	MODELLING Model used
CREA Italy	5.1; 5.2; 5.3; 5.4	Foggia	2013 DurumWheat-Legumes Rainfed	No-Till vs. Minimum Tillage 5 replications	Grain yield Crop/plant biomass LAI Soil water content Soil compaction Hydraulic conductivity	AQUACROP BEST-K2
			2002 Monoculture of durum wheat and wheat-legumes from 2021 onwards Rainfed	No-Till vs. Minimum Tillage 3 replications	Grain yield Crop/plant biomass LAI Soil water content Soil compaction Hydraulic conductivity	AQUACROP BEST-K2

Field experiments: Foggia (Italy)

Location	The field experiment 1 was established in 2013 in Foggia (South of Italy, 41◦ 27.741' N; 15◦ 30.389' E) in a rainfed area. The field experiment 2 was established in 2002 in Foggia (South of Italy, 41◦ 27.050' N; 15◦ 30.104' E) in a rainfed area. The two experiments are at 1400 m far each other.
General Climate	Temperate Continental Mediterranean Climate.
General Soil description	Soil and climatic characteristics of the site are: General and soil (0–30 cm) characteristics of the field site. Soil properties were measured at the beginning of the experiment (October 2010). Elevation (masl) 80; Annual precipitation (mm) 550; Mean annual air temperature (◦C) 13.4; Annual PET (mm) 1197 Soil classification. Vertisol Typic Haploxerert, According to the USDA classification (Soil Survey Staff, 2014). pH (H2O, 1:2.5) 8.1, EC1.5 (dS m−1) 0.21, Organic C (g kg−1) 19.0, Organic N (g kg−1) 1.23 Particle size distribution (%): Sand (2000–50 m) 19; Silt (50–2 m) 41; Clay (<2 m) 40
General description of experimental design, factor and levels of the factor.	**Experiment 1 started in 2013:** *The experimental design* consisted in the combination of two tillage practices (MT, minimum tillage; NT, no-tillage) in a randomized block design with five replications. *The cropping system:* The cropping system during the experiment consisted of broad bean (2013) followed by 5 years of continuous durum wheat, one year of fallow (2019), durum wheat (2020), broad bean (2021). Elementary plot size was 120 m × 80 m; 30 subplots of 30 m2 each. *Tillage systems:* The MT treatment consisted of 2-3 passes of field disk cultivator (15 cm depth). A nonselective herbicide (1.5 L 36% glyphosate per hectare) was applied before sowing in the NT treatment. *Sowing:* Sowing was carried out with a no-till seeder (Gaspardo Directa 300) equipped with disk type furrow openers set to 2–4 cm depth. *Fertilization:* It was applied at the beginning of durum wheat tillering with Entec 25-15 (400 kg ha-1). *Harvesting:* Harvest of each elementary plot was carried out with a commercial medium-sized combine that chopped and spread over the soil surface the crop residues. *Crop residue management:* Crop residues were removed in MT and chopped and left on soil surface in NT treatment. *Other operations, variables and observations:* Daily air temperature and rainfall data were recorded with the use of an automated weather station located in the site. **Experiment 2 started in 2002:** *The experimental design* was a completely randomized block design with three replicates and elementary plots of 500 m^2. *The cropping system*: The cropping system during the experiment consisted of continuous durum wheat. From the season 2020-2021, an alternation with leguminous species has been implemented. *Tillage systems:* A two-layer tillage (deep subsoiling cultivator with rotary tiller) was carried out in MT plots. For NT

	plot, a chemical weed control as well as fertilization and sowing, were made in November (first week). *Sowing:* The sowing of durum wheat (both on MT and NT) was carried out with a seeder for direct sowing (Lasemina sodo), equipped with appropriately shaped blades for direct sowing. The chickpea was sown with a “Gaspardo No-Till 1040” seeder. *Crop residue management:* Straw was chopped into 10-15 cm in length and spread back on the plot in September (first week); this results in about 40-50 q/ha of organic matter returned to the soil. *Fertilization:* For both soil management (MT and NT), it was applied i) diammonium phosphate (18-46) 2 q ha-1 at the beginning of durum wheat tillering (basal dressing), and ii) ammonium nitrate at rate of (34,2%) 200 kg ha-1 (top dressing). *Harvesting:* it will be carried out with the “Classic Plus Plot combine – Wintersteiger”, equipped with a continuous weighing system. *Other operations, variables and observations:* The chemical weeding was carried out on the wheat for weed control, while on the chickpea it was carried out the pre-emergency weeding. Daily air temperature and rainfall data were recorded with the use of an automated weather station located in the site.

ARVALIS EXPERIMENT: Experimental design

PARTNER	Tasks involved	Location experiments	Year beginning exp./Crop rotation/ Water regime	Main Treatments - Replications	Main Variables	MODELLING Model used
ARVALIS France	5.4	Oraison (Provence, Mediterranean region of France)	2013 Durum Wheat- Legumes (drought part) Rainfeed plots Durum wheat- Maize or soybean –legumes Irrigation plots	Living cover-crops (30 stripes of 900 m² without replications) No replications but experimental data produced via the *Diagchamp method.*	Grain yield Crop/plant biomass Soil water content Soil properties	CHN

Fields experiment: Oraison (Provence, France)

Location	This field experiment was established in 2013 at Oraison (SE France, 43º 55' 51" N; 5º 55'25" E) in the Mediterranean part of France
General Climate	Temperate continental Mediterranean climate.
General Climate and Soil description	Soil and climatic characteristics of the site are: General and soil (0–30 cm) characteristics of the field site. Soil properties were measured at the beginning of the experiment (October 2010). Elevation (masl) 377; Annual precipitation (mm). 650; Mean annual air temperature (◦C). 13.6°C; Annual PET (mm): 1343 Soil classification. Cambisol colluvic calcaric to the USDA classification (Soil Survey Staff, 2014) pH (H2O, 1:2.5) 8.6; Organic C (g kg−1) 30; Organic N (g kg−1) 1.9 Particle size distribution (%): Sand (2000–50 m) 14; Silt (50–2 m) 62; Clay (<2 m) 23
General description of experimental design, factor and levels of the factor.	This trial is dedicated to the development of the Conservation Agriculture in Mediterranean conditions, in cereal cropping rotations (with or without irrigation) by the use of living legume semi-permanent cover-crops (like trifolium or alfalfa or sula/ sainfoin). This way you only have to get the seed in the ground once for several years (it's easier to find a good climatic period), and you don't have to destroy the cover before the next crop: you will let it "under" the crop, with a chemical (herbicides) regulation. As long as you do not destroy the cover, you are less dependent on glyphosate (very important point in France in this time) *The experimental design:* consists of 30 farming-size stripes (6m x 150 m = 900 m²), 20 in drought conditions and 10 irrigated and with his own rotation and combination crops/ covers. *The cropping system: Without irrigation:* crop rotation with faba bean, chickpea, durum wheat; dead and alive cover (alfalfa, sainfoin). *With irrigation*: crop rotation with durum wheat, maize, soya, dead and alive cover. *Tillage systems:* There is no comparison with a "standard" practice. The goal is to explore the potential of the system (and compare it to a climatic potential yield estimated by models) *Sowing:* each one cultivated with the farmer's machinery (3 m Semeato) direct seeder. *Fertilization:* mineral fertilization applied in January on wheat (in once time) *Harvesting:* manual plot (6 repetitions by stripe with wheat) *Crop residue management:* left on the ground surface *Other operations, variables and observations:* The aim is, using Diagchamp method, to assess each year how far and why each wheat stripe is or isn't different from an expected yield (this climatic year in these field conditions), and thus to contribute to an optimal CA management, minimizing the yield gaps.

HAO EXPERIMENT: Experimental design

PARTNER Country	Tasks involved	Location experiments	Year beginning exp./Crop rotation/ Water regime	Main Treatments - Replications	Main Variables	MODELLING Model used
HAO Greece	5.1; 5.2	Thessaloniki region	2019 2-year crop rotations Barley-Panicum miliaceum (winter) Lathyrous-Sorghum bicolor (summer) Rainfed	Intensive Tillage vs. Minimum Tillage Crop rotation 4 replications	Grain yield Crop plant/biomass Soil water content Nutrient soil analysis Weed species and weed density	NO

Field experiment in Drimos, Greece

Location	This field experiment was established in 2019 in Drimos (40°47'11, 22°57'53), close of Thessaloniki, north Greece.
General Climate	Temperate continental Mediterranean climate.
General Climate and Soil description	Soil and climatic characteristics of the site are: Heavy soil with high clay content (48%), and neutral pH (7.4 both at 0-20 and 20-40 cm), rich in $CaCO_3$ (8.8% at 0-20cm, 11% at 20-40cm) and Organic matter content (3.0%) with normal level of salt (0.443 mS/cm at 0-20cm and 0.433 at 20-40cm). General and soil (0–30 cm) characteristics of the field site. Soil properties were measured at June 2021 before *Panicum miliaceum* seeding. Elevation (masl) 180 m; Annual precipitation (mm). 450 mm; Mean annual air temperature (◦C). 15.1 °C Soil classification. Entisols. According to the USDA classification (Soil Survey Staff, 2014) pH (H2O, 1:2.5) 7.35; EC1.5 (dS m−1) 0.443; Organic C (g kg−1) 2.96; Organic N (g kg−1) 10.08 Particle size distribution (%): Sand (2000–50 m) 30; Silt (50–2 m) 22; Clay (<2 m) 48
General description of experimental design, factor and levels of the factor.	A field of 0.4 ha at Drimos Thessaloniki, Greece was used for field experimentation in cooperation with a local farmer. Before setting up the experiments (June 2020) *Hordeum vulgare* was cultivated in the field by the farmer under Conventional tillage was applied in all the previous years. The aim of the study was to evaluate the effect of conventional (CT) and minimum tillage (MT) on successive crops in a 3-year rainfed crop rotation and study their effect on crop yield. For this reason the 0.4ha field was split in two adjacent field units each one of 0.2 ha, one for CT and the other for MT. CT mainly included ploughing and harrowing, whereas, MT mainly included soil harrowing. Seeding time and all the other field practices (eg. fertilization, herbicides) were applied at the same time and at the same rate in both CT and MT field units. Crop species in crop rotation included winter-sown crops such legumes (*Lathyrus sativus*) and winter cereals (*Hordeum vulgare*) and also summer-sown crops such as *Panicum mileaceum* and *Sorghum bicolor*. <u>*The experimental design*</u>: The experimental field was vertically divided in two equal field units of the size 0.2 ha; one for CT and one for MT throughout the 3-year crop rotation. Both CT and MT field units were divided into four plots that used as experimental blocks to assess the variance of the means resembling a randomized complete block design. Each plot of the CT was located next to the adjacent MT plot. However, due the separate spatial arrangement of the plots (blocks) of each tillage system and due to small (2) number of factors studied (Ct vs MT), data were analyzed with the t-test instead of ANOVA to check differences between conventional and minimum tillage. <u>*The cropping system*</u>*:* rainfed crop rotation, starting with *P. miliaceum* (June 2020)*,* followed by *Lathyrus sativus (December 2020),* followed by *Sorghum bicolor* (June 2021), followed by *Hordeum vulgare* (November 2021) and ending with *Hordeum vulgare* (December 2022) in CT and MT adjacent field units. <u>*Tillage systems*</u>*:* Conventional Tillage (CT) (moldboard plow at 25 cm and power harrow at 5cm) vs Minimum Tillage (MT) (power harrow at less than 5 cm) in adjacent field units. In some cases, disc harrowing was also applied in CT, whereas for MT a soil loosener (Michel-tine) was also used occasionally.

	Sowing: All crops in crop rotation were direct-seeded with a mounted seed drill for power harrows (*Kvenerland Accord DA*). *Fertilization:* the fertilizers applied are reported separately for each crop; fertilization was similar for CT and MT *Harvesting:* All crops were hand-harvested by sampling *Crop residue management:* crop residues were soil incorporated under CT by ploughing at 25cm applied some days before sowing of the next crop followed by harrowing on seeding time with a power harrow. Crop residues under MT are left on soil surface and harrowing was performed at shallow depth (less than 5 cm) *Other operations, variables and observations:* Plant height, Leaf Area Index, crop biomass, N/P content, soil nutrient values, number of spikes, seed thousand weight and % seed protein content were measured. Other operations included recordings of dates for certain growth stages based on the BBCH scale. Weed counts and weed biomass were recorded in cases a weed management was necessary. 1-4 times per month depending on weather conditions soil samples from 0-20cm and 20-40cm depth were collected from both CT and MT fields to calculate the soil water content for the two soil depths. Weather data were collected from a weather stations nearby.

UdL-CSIC EXPERIMENT: Experimental design

PARTNER Country	Tasks involved	Location experiments	Year beginning exp./Crop rotation/Water regime	Main Treatments - Replications	Main Variables	MODELLING Model used
UdL- EEAD Spain	5.1; 5.2; 5.3; 5.4	Senes (Ebro Valley Region)	2010 Barley-Wheat-Pea. Rainfed	Tillage systems (2): No-til vs. Intensive tillage N fertilization (3) dose : 0, medium and high (2) type: mineral, organic. 3 replications	Grain yield Crop/plant biomass Soil water content Soil properties according Task 5.3	NO

Field experiment in Senés de Alcubierre (Huesca, Spain)

Location	The field experiment was established in 2010 in Senés de Alcubierre (NE Spain, 41◦54’12” N; 0◦30’ 15” W) in a rainfed area
General Climate	Temperate continental Mediterranean climate.
General Soil description	Soil and climatic characteristics of the site are: General and soil (0–30 cm) characteristics of the field site. Soil properties were measured at the beginning of the experiment (October 2010). Elevation (masl) 395; Annual precipitation (mm) 327; Mean annual air temperature (◦C) 13.4; Annual PET (mm) 1197 Soil classification. Typic calcixerept. According to the USDA classification (Soil Survey Staff, 2014). pH (H2O, 1:2.5) 8.0; EC1.5 (dS m−1) 1.04; Organic C (g kg−1) 15.6; Organic N (g kg−1) 1.4 Particle size distribution (%): Sand (2000–50 m) 6.2; Silt (50–2 m) 63.3; Clay (<2 m) 30.5
General description of experimental design, factor and levels of the factor.	*The experimental design*: consisted of the combination of two tillage practices (CT, conventional tillage; NT, no-tillage) and three N fertilization rates (0, 75 and 150 kg N ha−1) based on two different types of fertilizer (mineral N and organic N with pig slurry) in a randomized block design with three replications. Plot size was 40 m × 12 m in the organic fertilization treatments and 40 m × 6 m in the mineral N fertilization and control treatments. *The cropping system* during the experiment consisted of a barley (Hordeum vulgare L., cv. Meseta) monocropping. The first four growing seasons. From 2014-15 growing season a Pea-Barley-Wheat-Barley crop rotation has been following until date. *Tillage systems:* The CT treatment consisted of one pass of disk plow (15 cm depth) followed by a cultivator. However, due to the dry conditions of soil in 2011 two passes of chisel were used. A non-selective herbicide (1.5 L 36% glyphosate per hectare) was applied before sowing in the NT treatment. *Sowing:* Sowing was carried out with a no-till seeder equipped with disk type furrow openers set to 2–4 cm depth. *Fertilization:* The combination of fertilizer types and N rates led to five fertilization treatments: 0, control,75 Min and 75 Org, 75 kg N ha−1with mineral and organic N at the beginning of tillering, respectively, and 150 Min and 150 Org,150 kg N ha−1with mineral and organic N applied at equal rates before sowing and at the beginning of tillering. For the mineral N treatments ammonium sulphate (21% N) and ammonium nitrate (33.5% N) were used before sowing and at the beginning of tiller-ing, respectively. Mineral N applications were performed manually. The organic fertilization treatment consisted on the application of slurry from fattening pigs of a commercial farm close to the site. The application was carried out spreading the slurry with a commercial vacuum tanker fitted with a splashplate (Beguer mod. 12500, Barbastro, Spain) as it is common in the area. Previously to each application pig slurry was analyzed for its N content and the tanker was calibrated accordingly to apply the precise N rate. *Harvesting:* Harvest of the plots was carried out with a commercial medium-sized combine. *Crop residue management:* Combine chopped and spread over the soil surface the crop residues.

	Other operations, variables and observations: Since the 1970s soil management at the site was based on the use of a subsoiler and a chisel. Four years before the establishment of the experiment (i.e. 2006) soil management was switched to NT. Daily air temperature and rainfall data were recorded with the use of an automated weather station located in the site and equipped with a data-logger.

INRA EXPERIMENT: Experimental design

PARTNER Country	Tasks involved	Location experiments	Year beginning exp./Crop rotation/Water regime	Main Treatments - Replications	Main Variables	MODELLING Model used
INRA Morocco	5.1; 5.2; 5.3; 5.4	Merchouch	In 2020-21 Wheat (Durum wheat) Rainfed regime in semi arid conditions In 2021-22 Wheat (Durum wheat) Rainfed regime in semi arid conditions	Three factors tested Variety (5 Durum Wheat) Tillage: No-til vs. conventionnel tillage N Fertilisation dose: 35 N, 55 N, 75 N kg/ha) 3 replications Two factors tested Variety (4 Durum Wheat) Tillage: No-til vs. conventional tillage 3 replications	Grain yield Straw Yield WUE Soil parameters	AQUACROP/APSIM

Field experiment in Merchouch, Morocco

Location	The site is located at the Merchouch experimental station of the National Institute of Agronomic Research in Zaer, 60 km South of Rabat at 33°37 ’N ; 6°43 ’O
General Climate	Mediterranean climate with oceanic influence, with an average temperature of 28 ° C and an average rainfall equal to 350 mm.
General Soil description	Soil and climatic characteristics of the site are: The soil at the site is of the Vertisol type with a clay texture, a weakly developed structure and a relatively high OM content over the first ten centimeters of depth. General and soil (0–30 cm) characteristics of the field site. Elevation (masl) : 402 m; Annual precipitation (mm) 300; Mean annual air temperature (◦C). 19; Annual PET (mm): 1300 Soil classification. Vertisol. According to the USDA classification (Soil Survey Staff, 2014) pH (H_2O, 1:2.5) 7,5; EC1.5 (dS m−1) 1,2; Organic C (g kg−1) 15,3; Organic N (g kg−1) 1,16 Particle size distribution (%): Sand (2000–50 m) 11,5; Silt (50–2 m) 23,3; Clay (<2 m) 55,2
General description of experimental design, factor and levels of the factor.	***The experimental design*:** **In 2020-21.** The experimental setup includes either ten treatments (two tillage types x three nitrogen doses x five durum wheat varieties). The experimental design was a randomized complete block with three replications. The two tillage types were conventional tillage (CT) and no tillage (NT). The three nitrogen doses were 20, 40, and 60 kg. ha^{-1}. The five varieties of durum wheat (Triticum durum Desf.) were Louiza (INRA-Morocco, 2011), Faraj (INRA-Morocco, 2007), and Nachit variety (INRA-Morocco 2017), as well as two new germplasms (M.G and I.C). *The cropping system:* Cereal/ food legume rotation: As the experimentation was under a long term comparative trial under cereal based system with two adjunct big plots (1Ha of plot under NT vs 1Ha of plot under CT). The 2 big plots had the same rotation (cereal-food legume). This year, we adopt the durum wheat (DW) as crop to be studied. With 5 DW germplasm with different Nitrogen dose. *Tillage systems: Conventional tillage was completed using a disc harrow at 10 to 15 cm depth to prepare seedbeds and bury residues followed by a chisel plow. In no-tillage, the soil was loosened by 2 to 3 cm to plant the seeds at a depth of 5 cm, using a special no-tillage drill.* *Sowing:* late-November. Using NT direct seeder and CT seeder. *Fertilization:* 3 different Nitrogen fertilization doses (15+20 N, 15+40 N and 15+60 N). In fact, in sowing period, the base fertilizer NPK 10-20-20 was applied at 150 kg ha−1 for all treatment. , and 2 months later , ammonium-nitrate 33.5% was supplied at small plot to add extra N dose of the selected doses (20, 40, and 60 kg. ha−1). The first fertilization occurs on tillering stage with a rate of 35 N for all treatment and the second one occurs on the beginning of stem elongation where we add respectively, 20 N and 40 U for the 2 treatments. The 1st treatment did not receive any N fertilization (O N). *Harvesting:* at end-June using an experimental harvester. The Harsvet machine under NT was adapted to keep at least 30% of crop residue in the plot in opposite to CT (No crop residues left on top soil as farmers practices).

	Crop residue management: Keeping 30 % of residues under NT and residues burial by tillage for CT *Other operations:* weed control; glyphosate before sowing and selective herbicide during the wheat cycle. **In 2021-22.** The experimental setup includes either ten treatments (two tillage types x four durum wheat varieties). The experimental design was a randomized complete block with three replications. The two tillage types were conventional tillage (CT) and no tillage (NT). The 4 varieties of durum wheat (Triticum durum Desf.) were Louiza (INRA-Morocco, 2011), Faraj (INRA-Morocco, 2007), as well as two new germplasms (M.G and I.C). *The cropping system:* Cereal/ food legume rotation: As the experimentation was under a long term comparative trial under cereal based system with two adjunct big plots (1Ha of plot under NT vs. 1 ha of plot under CT). *Tillage systems: Conventional tillage was completed using a disc harrow at 10 to 15 cm depth to prepare seedbeds and bury residues followed by a chisel plow. In no-tillage, the soil was loosened by 2 to 3 cm to plant the seeds at a depth of 5 cm, using a special no-tillage drill.* *Sowing:* late-Novembre. Using NT direct seeder and CT seeder. *Fertilization:* in sowing period, the base fertilizer NPK 10-20-20 was applied at 150 kg ha−1 for all treatment. , and 2 months later , ammonium-nitrate 33.5% was supplied (to reach 60 kg. Nha−1). *Harvesting:* at end-June using an experimental harvester. The harvest machine under NT was adapted to keep at least 30% of crop residue in the plot in opposite to CT (No crop residues left on top soil as farmers practices). *Crop residue management:* Keeping 30 % of residues under NT and residues burial by tillage for CT *Other operations:* weed control; glyphosate before sowing and selective herbicide during the wheat cycle.

INRAT EXPERIMENT: Experimental design

PARTNER Country	Tasks involved	Location experiments	Year beginning exp./Crop rotation/Wateer regime	Main Treatments - Replications	Main Variables	MODELLING Model used
INRAT Tunisia	5.1; 5.2; 5.4	Kef site	2010 Three rotations - Monoculture: Durum Wheat - Biennial: Fava beans / Durum wheat; - Triennial: Fava beans / Durum wheat/Barley. Rainfed	Two factors experiment: Tillage: - CA: Conservation Agriculture. - CH: Chisel. - CO: Conventional tillage Rotation: - M: Monocroping. - Bi: Biannual rotation (Faba bean / Durum Wheat) - Tri: Triennal rotation: (Faba bean / / / Durum What) Three replications	Grain yield TKW Harvest Index (HI) Crop/plant biomass Soil water content WUE. Soil properties	APSIM

Field experiment in Kef Experimental Station of INRAT

Location	This field experiment was established in 2010 at Kef experimental Station of INRAT (Western Tunisia) , (Long 36°07'58.01" N Lat 8°42'57.82"E, altitude= 520m)
General Climate	The Kef site, 5 km south of the Kef City, is characterized by a medium semi-arid climate with a cold winter, an average annual rainfall of 450 mm and an annual mean temperature of 15,5°C
General Soil description	Soil and climatic characteristics of the site are: General and soil (0–30 cm) characteristics of the field site. Soil properties were measured at the beginning of trial implementation in 2010 Elevation (masl): 520 m; Annual precipitation (mm): 450 mm; Mean annual air temperature (◦C): 15.5 °C; Annual PET (mm): 950 mm Soil classification. Entisol pH (H2O, 1:2.5): 8.1; EC1.5 (dS m−1): 0.2; Organic C (g kg−1): 10; Organic N (g kg−1): 0.3 Particle size distribution (%): Sand (2000–50 m): 20%; Silt (50–2 m): 30%; Clay (<2 m): 50%
General description of experimental design, factor and levels of the factor.	*The experimental design*: This long-term trial combine three modes of soil tillage (main plot) and three rotation types (subplot) within a split-plot design. Three replications for each treatment are set up. *The cropping system:* Three rotation (monocropping, bi and trianual) . (i) monoculture :Durum Wheat (ii) biennial: Fava beans / Durum wheat; (iii) triennial: Faba beans/Durum wheat/Barley *Tillage systems:* (1) Conventional Tillage (CT) : plowing carried out by two plow coulters and mouldboard followed by an off-set sprayer , harrow and seed drill. (2) Minimum Tillage (MT): Working the soil with a chisel with rigid teeth followed by a Canadian cultivator with vibrating tines, a harrow and a seeder. (3) No-till (NT): Direct drilling in un-tilled soil with a disc drill without the previous removal of residues. *Sowing:* late-Novembre – early-Decembre. Using direct seeder *Fertilization:* DAP before sowing (100 kg.ha-1)+ ammonium nitrate (300 kg.ha-1) *Harvesting:* at maturity mid-June using an experimental harvester *Crop residue management*: according the treatments (retention of residues NT and residues burial by tillage for CT and MT) *Other operations, variables and observations*: weed control; glyphosate before sowing and selective herbicide during the wheat cycle. Variables to be measure: Yield and yield component, WUE, physiological; biomass evolution, N soil and plant content.

ENSA EXPERIMENTs: Experimental design

PARTNER Country	Tasks involved	Location experiments	Year beginning exp./Crop rotation	Main Treatments	Main Variables	MODELLING Model used
ENSA Algeria	5.1; 5.2; 5.4	Experiment S1: Algiers (North Algiers)	2018 Intercropping Chickpea/wheat vs. monocropping Rainfed	*Minimum Tillage* Under N fertilization Factors: 1)Cropping system (mono vs. intercropping) 2) N fertilizers (30, 60 and 100 kg N ha^{-1}) Rainfed conditions	Grain yield. Plant biomass. LAI. Soil water content. Plant water content. N uptake. Root depth and width Weed biomass Soil NO3 and NH4	These data will be used to run CHN model or STICS
		Experiment S2: MEZLOUG (SETIF Center)	2018 Intercropping Chickpea/wheat vs. monocropping Rainfed	Conventional tillage under N fertilization Factors: 1)Cropping system (mono vs. intercropping) 2) N fertilizers (30, 60 and 100 kg N ha^{-1}) Rainfed conditions	Grain yield. Plant biomass. LAI. Soil water content. Plant water content. N uptake. Root depth and width Weed biomass Soil NO3 and NH4	These data will be used to run CHN model or STICS

		Experiment S3: BAIDA BORDJ (South SETIF)	2018 Intercropping Chickpea/wheat vs. monocropping Rainfed	Conventional tillage under N fertilization Factors: 1)Cropping system (mono vs. intercropping) 2) N fertilizers (30, 60 and 100 kg N ha^{-1}) Rainfed conditions	Grain yield. Plant biomass. LAI. Soil water content. Plant water content. N uptake. Root depth and width Weed biomass Soil NO3 and NH4	These data will be used to run CHN model or STICS

Field experiment in Algiers (North Algiers) – S1

Location	The experiment. is situated in the North of Algiers región (36°42′ N, 3°09′ E)
General Climate	Sub-humid climate
General Soil description	Soil and climatic characteristics of the site are: General and soil (0–30 cm) characteristics of the field site. Soil properties were measured at sowing stage of each year experiment Elevation (masl): 40 m; Annual precipitation (mm). 450-500 mm; Mean annual air temperature (◦C). 19.55; Annual PET (mm): 1411 mm Soil classification. VERTISOLS pH (H2O, 1:2.5) 7.9; EC1.5 (dS m−1) 0.3 (dS cm); Organic C (g kg−1) 18; Organic N (g kg−1) 14 Particle size distribution (%): Sand (2000–50 m) 8; Silt (50–2 m) 35; Clay (<2 m) 57
General description of experimental design, factor and levels of the factor.	*The experimental design*: TWO FACTORS. Split plot with 3 replicates 1) Cropping system (mono vs intercropping) 2) N fertilizers (30, 60 and 100 U). Growing seasons: 2018/2019, 2019/2020 and 2020/2021 *Tillage system:* Minimum Tillage, working the soil with a cover crop followed by a harrow then a roller after the seed-drill *Sowing:* Sowing with a seed drill and intercrop chickpeas manually. Sowing was done in late November for the 2020/2021 season and mid-December for the 2018/2019 and 2019/2020 growing season *Fertilization:* 3 different fertilization doses (N-30 U, 60U and 100U). We used Urea spited in two times. The first fertilization occurs on the tillering stage with a rate of 30 U for all modalities and the second one occurs on the beginning of stem elongation where we add respectively 0 U, 30 U and 70 U for the three modalities. *Harvest:* At maturity on late May up to mid-June. *Crop residue management:* Crop residue was incorporate with tillage *Other operations, variables and observations:* Manual weeding without any treatment, cropping under rainfed conditions. Variables to be measured: Grain yield, Plant biomass. LAI. Soil water content. Plant water content. N uptake, Root depth and width, Weed biomass, Soil NO_3 and NH_4, STICS or CHN mode

Field experiment in Mezloug, Algeria - S2:

Location	The experiment is situated in Setif at MEZLOUGH región (center) at (36°06′ N, 5°20′ E).
General Climate	SEMI-ARID
General Soil description	Soil and climatic characteristics of the site are: General and soil (0–30 cm) characteristics of the field site. Soil properties were measured at sowing stage in 2019 Elevation (masl) 951; Annual precipitation (mm). 280-300; Mean annual air temperature (◦C). 14.29 ; Annual PET (mm): 1524 Soil classification. VERTISOLS pH (H2O, 1:2.5) 8.38; EC1.5 (dS m−1) 0.26 dS cm; Organic C (g kg−1) 12; Organic N (g kg−1) 1.4 Particle size distribution (%): Sand (2000–50 m) 21; Silt (50–2 m) 36; Clay (<2 m) 43
General description of experimental design, factor and levels of the factor.	*The experimental design*: TWO FACTORS. Split plot with 3 replicates 1) Cropping system (mono vs intercropping). 2) N fertilizers (30, 60 and 100 U) Growing seasons: 2018/2019, 2019/2020 and 2020/2021 *Tillage system:* Minimum Tillage, working the soil with a cover crop followed by a harrow then a roller after the seed-drill *Sowing:* Sowing with a seed-drill and intercrop chickpea manually. Sowing was done in late November for 2020/2021 season and mid-December for 2018/2019 and 2019/2020 growing season *Fertilization:* 3 different fertilization doses (N-30 U, 60U and 100U). We used Urea spited in two times. The first fertilization occurs on tillering stage with a rate of 30 U for all modalities and the second one occurs on the beginning of stem elongation where we add respectively 0 U, 30 U and 70 U for the three modalities. *Harvest:* At maturity on late may up to mid June. *Crop residue management:* Crop residue was incorporate with tillage *Other operations, variables and observations:* Manual weeding without any treatment, cropping under rainfed conditions. Variables to be measured: Grain yield, Plant biomass. LAI. Soil water content. Plant water content. N uptake, Root depth and width, Weed biomass, Soil NO3 and NH4, STICS or CHN model

Field experiment in Baida Bordj (Setif, Algeria) – S3

Location	The Baida Bordj experiment (955 m) (35°53′ N, 5°39′ E) is located in the South of the Setif region.
General Climate	SEMIARID CLIMATE
General Soil description	Soil and climatic characteristics of the site are: General and soil (0–30 cm) characteristics of the field site. Soil properties were measured at sowing stage 2019 Elevation (masl) 1000 m; Annual precipitation (mm). 180-220 mm; Mean annual air temperature (◦C). 15.11; Annual PET (mm): 1719 Soil classification. VERTISOLS pH (H2O, 1:2.5) 8.30; EC1.5 (dS m−1) :0.27; Organic C (g kg−1) 19 g Kg; Organic N (g kg−1) 2.4 g Kg Particle size distribution (%): Sand (2000–50 m) 16; Silt (50–2 m) 34; Clay (<2 m) 50
General description of experimental design, factor and levels of the factor.	*The experimental design*: TWO FACTORS. Split plot with 3 replicates 1) Cropping system (mono vs intercropping) 2) N fertilizers (30, 60 and 100 U) Growing seasons: 2018/2019, 2019/2020 and 2020/2021 *Tillage system:* Minimum Tillage, working the soil with a cover crop followed by a harrow then a roller after the seed-drill *Sowing:* Sowing with a seed-drill and intercrop chickpea manually. Sowing was done in late November for 2020/2021 season and mid-December for the 2018/2019 and 2019/2020 growing season *Fertilization:* 3 different fertilization doses (N-30 U, 60U and 100U). We used Urea spited in two times. The first fertilization occurs on the tillering stage with a rate of 30 U for all modalities and the second one occurs on the beginning of stem elongation where we add respectively 0 U, 30 U and 70 U for the three modalities. *Harvest:* At maturity in late May up to mid-June. *Crop residue management:* Crop residue was incorporated with tillage *Other operations, variables and observations:* Manual weeding without any treatment, cropping under rainfed conditions. Variables to be measured: Grain yield, Plant biomass. LAI. Soil water content. Plant water content. N uptake, Root depth and width, Weed biomass, Soil NO3 and NH4, STICS or CHN model

Annex 2. Network of field experiments:

Methodology for yield and yield component measurements

Variable	Methodology
CREA: Grain yield and Yield Components	Grain yield: grain harvested with a 1,5 m wide Wintersteiger plot combine (1,5 x 20 = 30 m^2) and grain yield (t ha^{-1}) was determined and expressed at 13% moisture content. Yield components: Samples were taken and grain weight, grain humidity, test weight, protein content, gluten index were determined.
ARVALIS: Grain yield and Yield Components	Grain yield from yield components: 6 microplots of 2 rows of wheat x 1 m are cut in each experimental 900 m^2 stripe. Yield components: Samples were taken and number of spikes/m^2, number of grain/spike, and TKW were determined.
HAO: Grain yield and Yield Components	Grain yield and yield components were measured by harvesting plants within a square meter frame 1m x 1m (4 replicates). Yield components: spikes/m^2, dry crop biomass, thousand seed weight, seed protein content were calculated after harvesting plants from 6 two-meter long crop rows within the field. Some occasional measurements of LAI, weed density, weed species, N/P for plant nutrient analysis have been recorded up to now.
UDL-CSIC: Grain yield and Yield Components	Grain yield. Each plot was harvested by a commercial combine and weight was measured by a weighting machine mounted in a trolley. Grain moisture and density were measured in the lab. Yield components: (heads/plant, seeds/plant, seeds/head, seed weight/plant, seed weight /head), TKW, Grain weight per unit volume. Protein content was measured in lab by biomass partitioning. Protein content was determined by determination of N total content of the grain and biomass by DUMAS method and protein content was calculated by the transformation of N into protein.

INRAT: Grain yield and Yield Components	Grain yield and yield components were evaluated.
INRA: Grain yield and Yield Components	Grain yield from yield components: 3 microplots of wheat x 1 m are cut, in order to measure number of spikes/m², number of grain/spike, and TKW.
ENSA: Grain yield and Yield Components	Grain yield and it components were sampled and estimated by harvesting all aboveground biomass (i.e. chickpea and durum wheat) from the quadrat of 1 m2 in each treatment (four replicate for each treatment). The protein content was calculated (in percent) by converting N content (in percent) in grain yield by using the conversion constant k (k=6.25 and 5.7, respectively for chickpea and durum wheat). However, to assess the performance of chickpea-durum wheat intercrops in terms of growth, yield and N acquisition, we calculated the Land Equivalent Ratio (LER), which is considered as the main competitive index for evaluating intercropping advantage. The LER was calculated at similar unit area between both monoculture and intercropping system under the different N-fertilizer levels (Eq. 1) $LER_{ab} = Y_{ab}/Y_{aa} + Y_{ba}/Y_{bb}$ (1) Where: Y_{aa} and Y_{bb} are the interest variables (i.e. biomass, yield and N uptake by biomass and yield) measured for the sole crop for the species a and b. While, Y_{ab} and Y_{ba} are the yields in intercropping for the species a and b, respectively.