Project no. **INCO – 509107**

Project acronym: **WatNitMed**

Project title: **Management Improvements of WUE and NUE of Mediterranean Strategic Crops (Wheat and Barley)**

Instrument: **Specific Targeted Research Project**

Thematic Priority: **B. Mediterranean Partner Countries**
B.1 ENVIRONMENT – ***Integrated management of limited water resources***

Final Activity Report

Period covered: **from 01.01.2008 to 31.08.2009** Date of preparation: **29.10.2009**

Start date of project: **01.01.2005** Duration: **56 months**

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Revision: **Definitive**

Main achievements in each WP

In this section the main results achieved in each of the 12 WPs of the project are briefly highlighted.

WP1 Target environments

Leader of workpackage: **Partner 2, LARI**

Workpackage Objectives

- To identify, characterize and define a minimum number of representative agro-ecological target environments for wheat and barley production within the Mediterranean region.
- To refine physical and biological definitions of target environments using local knowledge of soils and agronomic practices of wheat and barley growers in the region.

List of Deliverables

- D1.1 A map describing an initial biophysical characterization of target environments for wheat and barley throughout the Mediterranean region (Achieved in 2005).
- D1.2 A revised map describing characterization of target environments using information and expertise provided by local growers (Achieved in 2006).
- D1.3 A final report including statistical analyses of influences of seasonal and long-term variability in weather and climate on the scale and extent of target environments (Achieved in 2009).

List of Milestones

- M1.1 Target environments – initial characterization (Achieved in 2005).
- M1.2 Target environments – r3efined by stakeholders (Achieved in 2005).
- M1.3 Minimum number of target environments defined (Achieved in 2006/7).
- M1.4: Match agronomic strategies against defined target environments (Achieved in 2008/9).
- M1.5: Statistical analysis of influences of seasonal and long-term variability in weather and climate on scale and extent of target environments (Achieved in 2008/9).

Summary of Workpackage main findings

Characterization of target environments

Efforts undertaken during the first year of the project life within the frame activities of WP1 aimed at characterizing the target environments, in terms of physical (weather and soil) and bio-physical (soil) conditions prevailing in the Mediterranean region, and to refine those conditions at the light of information on the dynamics of water and nitrogen for efficient capture and use by wheat and barley in scarce-resource environments. To this scope, a first step of work was planned for the first two years (2005 and 2006) in order to meet the requirements of WP1 first objective. Consequently, an analysis of geographical extent of wheat and barley growing environments was made throughout the Mediterranean region, using already existing information, climate, soils, crops and agronomic practices. Because the Mediterranean region has large climatic and soil variability, it was agreed during the kick off meeting that the environmental characterization for wheat and barley follows through the Mediterranean a downscaling approach for four countries of the South-East Mediterranean (Morocco, Tunisia Lebanon and Jordan), in terms of rainfall pattern, air temperature ranges and soil classes, known to be the most important environmental factors influencing wheat and barley growth and yield. Accordingly, WP1 first deliverable, D1.1 (Map describing an initial biophysical characterization of target environments for wheat and barley throughout the Mediterranean region), the one due time was the end of year 2005, was placed into action against the respective milestones M1.1 (Initial characterization of target environments), the one due time was month 4, and M1.2 (Target environments refined by stakeholders) the one due time was month 11.

In addition, the WP contributed to the integration of information on the soil and climate characteristics of the target regions by the production of the of the retrieval glossary of WP2, as proposed by the Project Coordinator, and promoted online access of retrieved information to all partners. This included:

- Online cataloguing of existing international scientific articles and similar projects, which look relevant for the implementation of WP2;
- Review of the frame activities of WP2;
- Preparation of the country annual report as regarding WP2.

During the third year of the project duration, the 2nd step of work was initiated to match the retrieval information obtained in the 1st work step, in order to meet the requirements of the second objective of WP1 (Refine physical and biological definitions of target environments using local knowledge of soils and agronomic practices of wheat and barley growers in the region). To this scope, published sources on different soil types (structure, texture, depth, soil organic matter) in the Mediterranean region were inquired. Both physical and biological soil information sources were complemented by local information provided by farmer groups in selected cereal production sites. The information on weather characteristics (Rainfall + Temperature) obtained in step I was, beside the information on soil types obtained in step II, were used to define a minimum number of characteristic environments agreed in type and extent between research institutions and farmer groups. This was undertaken in parallel to milestone M1.4 (Matching of agronomic strategies against the already defined target environments) the one due time was set at month 45.

The following retrieval information were then inquired and explicitly described in the annual report with relation to: (i) water dynamics, (ii) nitrogen dynamics, and (iii) drought/N-deficiency indexing for wheat and barley:

1. Water Dynamics in the soil-plant-atmosphere continuum, including:

- Evapotranspiration rate (seasonal and per period of growth);
- Water Use Efficiency (Agronomic);
- Levels and timing of supplemental irrigation (SI);
- Wheat most critical growth stages to water stress;
- Production levels.

2. Nitrogen Dynamics, including:

- Nitrogen in the soil;
- Nitrogen uptake;
- Nitrogen content in shoots and grain;
- N-Fertilization rates;
- N-Fertilization timing;
- N-Fertilization sources;
- Interaction N × Yield;
- NUE.

3. Drought/N-deficiency Indexing included information on:

- Soil color;
- Soil depth;
- Initial N-soil test (kg/ha);
- Nitrogen Balance (Nsoil = Ninitial + Ninput - Nuptake);
- OM content (%);
- Nitrogen uptake with relation to dryness.

Accordingly, WP1 second deliverable, D1.2 (Revised map describing characterization of target environments using information and expertise provided by local growers), the one due time was the end of year 2006, was placed into action against the respective M1.3 milestone (Minimum number of target environments defined), the one due time was month 23.

In this period of the project life, the 3rd step of work started in order to accomplish the requirements of WP1 second objective. The aim of the work plan in the 4th year and in the extension period was to have a final report that included analyses of the influence of seasonal and long-term climatic variability on scale and extent of target environments, in parallel to deliverable D1.3 (a final report including a statistical analysis of the influences of seasonal and long-term variability in weather and climate on scale and extent of target environment) and milestones M1.5.

Moreover, during year 2008 and the 2009 extension period LARI support team contributed to the integration of terms of reference and glossary in the final report as due to deliverable D1.3. To this scope, the retrieval information on climate variability in one hand, and water and nitrogen dynamisms in the other hand, were used to define the effects of seasonal and long-term climate variability on the scale and extent of target environments across the Mediterranean region. One of the major retrieval information was related to drought/N deficiency indexing, by means of thermal and spectral imageries, such the Normalized Difference Vegetation Index (NDVI), the Normalized Difference Red Edge (NDRE) and the Crop Canopy Chlorophyll Index (CCCI). To this scope, online and offline cataloguing of the existing international articles and relevant projects were made, which helped in the execution of D1.3, with respect to the respective M1.5 (Statistical analysis of influences of seasonal and long-term variability in weather and climate on scale and extent of target environments), with regards to the following parameters: Apparent nitrogen recovery; Biomass production efficiency; Radiation interception (%); Green leaf area; Harvest index; Leaf mass ratio; Nitrogen uptake after anthesis; Nitrogen harvest index; Nitrogen remobilization efficiency; Nitrogen use efficiency; Photosynthesis nitrogen use efficiency; Nitrogen uptake efficiency and Nitrogen utilization efficiency.

It was concluded at the issue of the online and offline research activities that the Crop Canopy Chlorophyll Index (CCCI) well correlates under differing watering regimes with Nitrogen Index (NS), the later defined as the shoot N per unit of dry matter per area (N g^{-1} DM^{-1}). NS index involves derivation of upper and lower limits of shoot %N as a function of shoot dry weight. It also provides a measure of crop N status normalized for biomass per area and is defined as the measured N % minus the minimum N % divided by the potential range. Consequently, CCCI was found to be able to differ between low plant N content and high plant N content. However, CCCI was not able to account for early season N. On the other hand, values of NDRE (Normalized Difference Red Edge) ≤ 0.1 were referred to bare soil points while values > 0.1 indicated covered soils.

Field experiments

First year (January – December 2005)

A field trial was conducted during 2004-2005 with the aim to determine the responsiveness of some local durum wheat cultivars (Haurani, Waha and Stork) to different water and nitrogen inputs. A second experiment was conducted during the same period using the same wheat cultivars at the Irrigation Technologies Center in Jabboulé in Northern Bekaa Valley. The scope was to compare the response traits of the cultivars under study to water and nitrogen under different weather and soil conditions. The protocol being applied in both experiments, along with the first sets of results were presented during WatNitMED workshop in the Netherlands in October 2005.

Regardless of cultivar, results showed that supplemental irrigation significantly increased grain number per square meter and grain weight with respect to the rainfed treatment, while nitrogen fertilization was observed to have significant effects only on grain number per square meter. Moreover, results showed that grain yield for cultivar Haurani was in all years less affected by supplemental irrigation and more affected by nitrogen fertilization than cultivars Waha and Stork. However, the effects of cultivar were of lower magnitude compared to those of irrigation and nitrogen. We conclude that optimum yield was produced for all cultivars at 50% of soil water deficit as supplemental irrigation (I-50) and N rate of 150 kg N ha^{-1}. However, Harvest index (HI) and water use efficiency (WUE) in all cultivars were not significantly affected neither by supplemental irrigation nor by nitrogen rate. Evapotranspiration (ET) of rainfed wheat ranged from 300 to 400 mm, while irrigated wheat had seasonal ET ranging from 450 to 650 mm.

Second year (January-December 2006)

During the second year of the project duration, LARI achieved the following activities:

Realization of field experiments during the growing season November 2005-June 2006 at Tal Amara Research Station in the Central Bekaa Valley on wheat and barley responsiveness to water and nitrogen inputs. During these experiments, water levels and nitrogen rates were based on the recommendations and outputs of WatNitMED workshop on modeling, which was held in the Netherlands in October 2005. Likewise, LARI supervised one student from the Faculty of Agriculture and Food Sciences of the Lebanese University to help in the verification of field observations and measurements.

Results of the experiment revealed that wheat (cv Haurani) and barley (cv. Karim) had similar NUE values under the semi-arid environments of the central Bekaa Valley. Moreover, there was a clear relationship between nitrogen utilization efficiency (UTE) and NUE, and the relationship tended to weaken as the dryness index increases from central (semi-arid) to northern (arid) Bekaa Valley. However, UTE was in both sites clearly lower in wheat than in barley. On the basis of obtained results, there appears to be potential and also a need for improvement in NUE in wheat and barley under Mediterranean dry lands.

Third year (January-December 2007)

Field experiments were conducted during the 3rd year at Tal Amara Research Station in the Central Bekaa Valley and at the Centre of Irrigation Technologies in the Northern Bekaa Valley. The experiments were accompanied by field days, which were oriented towards providing cereal growers of the Bekaa Valley of Lebanon technical assistance aiming at improving the production conditions of wheat and barley.

Results showed that supplemental irrigation induced for Waha cultivar increases in grain yield of 18.7%, 26.6% and 29.5% in I-50, I-75 and I-100, respectively, compared to the rainfed treatment (I0), while for Haurani, the increases were 17.2%, 25.8% and 42.7% in the same treatments, respectively, with comparison to the rainfed treatment. For both cultivars, the effects of supplemental irrigation were rather observed on grain weight than on grain number. Concerning N-fertilization, results showed that for Waha grain yield increased by 9.0%, 31.0% and 19.2% in treatments N-100, N-150 and N-200, respectively, in comparison to the treatment with no N supply (N0), while for Haurani cultivar the increases were 24.0%, 35.4% and 28.0% in the same treatments, respectively, when compared to the control (N0). Results showed that for both cultivars, supplemental irrigation had more effects on grain number, while nitrogen fertilization seemed to increase grain weight.

Fourth year and the extension period (January 1st 2008 – August 31st 2009)

Field experiments were conducted in the 4th growing season of the project duration (2005-2006; 2006-2007; 2007-2008 and 2008-2009) at Tal Amara Research Station in the Central Bekaa Valley, as a continuation of previous field trials conducted in other growing seasons, with the aim to study the responsiveness of two durum wheat cultivars (Waha and Haurani) N-fertilization rate and supplemental irrigation level. The scope of the experiments was also to provide practical guidelines to wheat growers on nitrogen and irrigation requirements in the /central Bekaa Valley.

Based on the results of the four-year field experiment, a paper entitled “Yield and water-production functions of two durum wheat cultivars grown under different irrigation and nitrogen regimes” was published in 2009 treating the behaviour of cultivars Waha and Haurani to different water and nitrogen regimes. Besides, a poster entitled “Wheat growth and production under semi arid conditions of the Central Bekaa Valley” was exhibited at different National scientific events, highlighting consistent information on target environments for wheat and barley in the Mediterranean region (see below the plan for using and disseminating knowledge).

At the basis of the obtained results, it was concluded that Haurani, being a lodging-susceptible cultivar, showed less response to N-fertilization than Waha. These results may help understand the underlying physiological differences in NUE and could help to identify alternative production options, such as the different roles that wheat species can play in crop rotations with emphasis to N-fertilization practices. They also may help in accounting for the N losses through leaching, which is greater from the sandy soils typical of the northern Bekaa Valley than the alluvial clayey soils of the central Bekaa Valley. Finally, we concluded that the increase in grain yield potential brought about through high yielding cultivars and supplemental irrigation was possible only with adequate timing and rates of N-fertilizer.

WP2 Farmers benchmarking and socio-economy

Leader of workpackage: **Partner 3, ESHE Tunisia**

Workpackage Objectives

The main objective of the socio-economic study is to make the output of the project scientific parts have a realistic chance of making an impact. The specific objectives are:

- To enable representative farmers groups to test and evaluate the decision aid and package of agronomic strategies.
- To undertake a cost-benefit analysis of the proposed strategies for regional production systems involving wheat.
- To integrate participatory involvement of farmers' groups in project inception, execution and dissemination.

List of Deliverables

All deriverables of this WP are expected towards the end of the fourth year:

- Decision aid produced and disseminated after testing and evaluation by representative farmers groups in contrasting target environments (it has been achieved).
- Package of agronomic strategies produced and disseminated after testing and evaluation by representative farmers groups in contrasting target environments (it has been achieved).
- A final report describing the outputs and learning outcomes from WP2 (it has been achieved).

List of Milestones

- Farmers' groups – benchmark field sites nominated (achieved).
- Farmers' groups – benchmark field sites confirmed (achieved).
- First year of benchmark crops sown (achieved).
- Second year of benchmark crops sown (achieved).
- Stakeholders' final validation sites confirmed (achieved).
- Decision Aid tested and evaluated (achieved).
- Package of agronomic strategies tested and evaluated (achieved).
- Farmers groups' report to final project review and Workshop 2 (achieved).
- Decision Aid disseminated (achieved).
- Package of agronomic strategies disseminated (achieved).

Summary of Workpackage Main Findings

Methodology

To achieve the objectives of the socioeconomic work package, several steps have been followed. The first step was the collection of secondary data about the relevant socio-economic indicators of the target regions with regard to the cereal sector. The second step aims at identifying the technical behaviour of the cereal growers based on data obtained through surveys conducted in Tunisia (44 farmers) and Jordan, Lebanon and Morocco on 30 farmers in each country[1] with the collaboration of partners 2, 10 and 12. The questionnaire aims at describing the production systems and particularly farmers' wheat and barley conventional practices. An emphasis was put on water and nitrogen use (applied quantities, date of application, type of fertilizers and their fractionation). The last part includes open questions allowing farmers to express their opinion regarding the main factors favouring and/or hindering the development of cereal crops (profitability, prices, marketing, etc.). The obtained results combined with the literature review are likely to give a significant picture describing the technical practices and the main socioeconomic parameters of the cereal growers in the south Mediterranean countries. The results of the survey can serve as proxy describing the initial situation which is needed to assess the impacts of the recommended nitrogen strategy.

These steps allowed to respect the first four milestones mentioned previously. However, for the fifth and the rest of milestones and deliverables, a change in the stakeholders' validation sites occurred and Tunisia was selected as the country hosting the pilot study. This decision has been taken by the entire consortium. The reasons are that testing the new strategies in the other three MPC (Morocco, Lebanon and Jordan) needs a permanent contact with farmers to disseminate and monitor the decision aid implementation which implies high additional costs and feasibility problems. Indeed, there is a need to have each of the selected farmers in each country committed to the project by allocating a plot. The latter has to be characterized in terms of soil nitrogen and organic material contents, soil texture and structure, climatic characteristics etc. Furthermore, there is a need for a regular monitoring to be sure that farmers are applying the recommended nitrogen strategy only on these plots. Since that these considerations are not among the attributions of the other partners and particularly: partners 2, 10 and 12 and that partner 3 can not fulfill this task alone, it has been decided to choose Tunisia as a pilot country. However, to overcome this situation, we decided to proceed by simulating the costs and benefits associated to the new management strategies according to the obtained results in Tunisia and the initial surveys results that have been conducted in Morocco, Lebanon and Jordan used as benchmark.

To implement the pilot experience, a meeting with farmers hosted by partner 13 in collaboration with partner 3, 9 and 11 has been organized in order to present the objectives of WatNitMED project and enhance farmers' commitments. Following this meeting, 31 farmers from two regions (15 in Béja and 16 in Siliana) were committed to test WatNitMED nitrogen strategy (eleven farmers have access to irrigation water and the rest operate in rainfed conditions). Another survey before the growing season 2007-2008 has been conducted to collect data on the experimental plots in Tunisia with the objective of getting a full agronomic history of the plots before the implementation of the pilot experience (area, crop, yield, sowing date and rate, fertilization for the last three years,

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[1] A survey was conducted during July-August 2005 period on a sample of 44 Tunisian farmers practicing cereals (wheat and barley) in irrigated and rainfed conditions located in four governorates: Béja, Jendouba Bizerte and Zaghouan. The aim was to analyze the current situation and expectations of new technology adoption by farmers. However, as Tunisia has been selected as the country where the pilot experience will be implemented and after discussions with the scientific coordination, partner 9 and 11, it has been agreed to choose two cereal producing governorates in Tunisia: Béja (humid and sub-humid) and Siliana (semiarid).

estimated or measured yield of the previous year (2006-2007), average obtained yield for the last ten years etc.). Moreover, three soil samples were taken from each plot and were analyzed in terms of texture, nitrogen content, saturation point, field capacity, wilting point etc. This database coupled with weather characterization of these two regions has been provided to Work package 4 for simulation activities.

On the basis of the information gathered on each plot, the experiment was designed as follows:

- Soil preparation is identical to the conventional practices.
- Date and dose of sowing are also the same as the conventional practices.
- In view of the high nitrogen content of the soils revealed by the analysis, it was recommended to both groups of farmers (irrigation and rainfed) to apply 240 kg/ha of Diammonium Phosphate (DAP) two to three days before sowing.
- Then, a single visit of the scientific coordination of WatNitMED project (partner 9) took place during mid-January 2008[2] in order to observe the state of the plant growth and to recommend to each farmer the amount of nitrogen to be applied[3].

Based on the potential yield of each plot, the state of plant growth and nitrogen soil content, it has been decided for each farmer the application of a specific amount of nitrogen in one time and no later than the week following the three-leaf stage.

During June-July 2008 and just before harvesting, several field visits to each farmer took place. We took a sample of durum wheat of two square meters (that is 4 diagonal samples of 0.5 m^2 each one if the vegetation is homogeneous and 8 samples in cases where it was deemed heterogeneous) from each plot (experimental and conventional) in order to estimate grain and straw yields[4].

The results of the pilot experience, compared to those obtained using conventional practices by the farmer's sample allowed conducting a cost-benefit analysis in order to evaluate the profitableness of the recommended nitrogen strategy and to fulfil partly the deliverables committed by WP2 (D21 and D22) and almost of the milestones.

The final step was to identify factors favouring and constraining adoption of WatNitMED nitrogen strategy. To do so, after getting the results of the pilot experiment, visits have been organized to farmers in order to present for them the obtained results and to ask them to respond to a structured questionnaire. The questions are intended to evaluate farmer's willingness to adopt WatNitMED recommendation: if a farmer replies by yes, he has to classify a list of reasons based on a certain criteria by order of importance and if he replies by no, he has also to rank the reasons by order of importance.

Results of the initial survey conducted at the beginning of the campaign coupled with those of the adoption survey have been used to develop a Probit econometric model, which is used to analyze the factors that affect farmers' willingness to adopt WatNitMED recommendation.

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[2] At this period, plants were at three leaves stage.

[3] Unfortunately twelve farmers withdrew from the project for various reasons

[4] We took also soil samples after harvesting in order to estimate the soil nitrogen content. Grain and straw samples were also analyzed in the laboratory of partner 9 in terms of nitrogen content allowing the completion of the nitrogen balance diagram.

The econometric model is presented as follows:

$$P(Yi=1) = F(BiXi)$$

where:
- P is the probability of adopting WatNitMED recommendation,
- F is a cumulative density function,
- Xi represents a vector of the explanatory variables,
- Bi are parameters coefficients.

A positive value of the estimated coefficient parameter of a particular variable means that higher value of this variable result in higher probability of adoption. A lower value implies a lower probability of adoption. In the empirical application, the dependent variable is a dichotomous variable with a value of 1 for adopters of WatNitMED recommendation and 0 for non adopters. The explanatory variables are:

- Farmer's age (**AGE**): Number of years.
- Educational level (**EDUC**): 1 illiterate, 2 koutteb[5], 3 primary education, 4 secondary education and 5 university level.
- Farm size (**SIZE**): Number of hectares.
- Tested (**TES**): 1 if a farmer has participated in the demonstration trial, 0 otherwise.
- Experience of growing wheat (**EXP**): Number of years.
- Activity (**ACTIV**): 1 if the main source of farmer's income is cropping, 0 otherwise.
- Land tenure (**TENURE**): percentage of owned land.
- Extension visits (**Ext**): Number of visits of extension agents during the previous year.
- Membership in a farmers' association (**FAS**): 1 if the farmer is a member and 0 otherwise.

Garrett's ranking technique is used to analyse the constraints against adoption of WatNitMED recommendation. The tested farmers are asked to rank the factors that are limiting their adoption (Lack of experience, Low straw yield difference, Lack of incentives to grain quality improvement, Lack of extension services, High cost of soil analysis, High production cost and Low grain yield difference). The orders of merit assigned by the respondents the calculation of the percent position of each rank using the following formula:

Percentage position of each rank = $100(R_{ij} - 0{,}5) / N_j$

R_{ij} =Rank given for i_{th} factor by j_{th} individual

N_j = Number of factors ranked by j_{th} individual

The percentage position of each rank is then converted into scores referring to a table given by Garret and Woodworth (1977). For each factor, the scores of individual respondents were added together and divided by the total of respondents for whom scores were added. These mean scores for all factors were arranged in descending order, ranks were given and the most limiting factors were identified.

Results and discussion

This section is divided into three parts. The first is devoted to the main obtained results of the survey conducted in Tunisia, Morocco, Lebanon and Jordan. The second part presents the cost-

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[5] Koutteb is a Koranic education

benefit results based on the pilot experience and the estimated and simulated gains at sectoral level in Tunisia, Morocco, Lebanon and Jordan. The last part presents the main factors favouring and constraining technology adoption.

Survey results

The survey results allowed the understanding of the current situation in terms of technical practices, economic performances as well as water and nitrogen valuations by the cereal growers. Generally, the revealed yields obtained by farmers are low, compared to the technical potential, as determined by the project, which confirms the existence of possible substantial improvements through more effective use of water and nitrogen. The results revealed also a great disparity between farms. The latter can be explained mainly by natural endowments variabilities and farmers know how.

Table 1 summarizes the main socioeconomic characteristics of farmers' samples.

Table 1. Socioeconomic characteristics

	Tunisia	**Morocco**	**Jordan**	**Lebanon**
Farm size (less than 50 ha) (%)	35	91	73	96
Average farmers' age	48	53	60	49
Educational level	Sec-univ	Illetr-prim	Prim-sec	Prim-sec
No agricultural training	67	84	90	73

The percentage of farms having a size higher than 50 ha is the highest in Lebanon and Morocco (96% and 91%) whereas it is the lowest in Tunisia. The average age of the surveyed farmers is 48 years in Tunisia, 53 in Morocco, 60 in Jordan and 49 in Lebanon. Farmers more than 60 years old represent about 10%, 18%, 43% and 3% in Tunisia, Morocco, Jordan and Lebanon, respectively. The surveyed farmers had mostly secondary and university educational level in Tunisia, primary and secondary respectively in Jordan and Lebanon and the lowest level is observed in Morocco, where no formal school educational and illiteracy predominates. Table 1 shows also that the majority of the surveyed farmers in all countries didn't benefit from an agricultural training. These characteristics play a role in technology adoption behaviour, with the younger and more educated farmers more likely to adopt new technologies.

Table 2 presents a synthesis of farmer's behaviour in terms of water and nitrogen management in the 4 Mediterranean countries.

Table 2. Amounts and frequencies of consumed water and nitrogen by Durum wheat

		Tunisia	**Morocco**	**Jordan***	**Lebanon**
Water	Amount (m^3/ha)	832	2039	-	N.a
	Frequency	2-3	3-4	-	3-4
Nitrogen in irrigated conditions	Amount (kg/ha)	119	123	-	111
	Frequency	3-4	3	-	2-1
Nitrogen in rainfed conditions	Amount (kg/ha)	88	42	31	98
	Frequency	3	2	0-1	2-1

*No irrigated durum wheat in the sample of farmers in Jordan.

The examination of this table reveals that Moroccan farmers applied water more than the double of the Tunisian which is mainly related to the favourable rainfall in Tunisia during 2006-2007. In terms of applied nitrogen in rainfed conditions, Table 2 shows that Tunisian and Lebanon farmers apply the highest amounts compared to Morocco and Jordan with respectively 88 and 98 kg/ha against 42 and 31 kg/ha. In terms of frequency, Tunisian farmers tend to fractionate much more nitrogen application (3 times) whereas, Jordanian farmers apply it only once or don't apply at all.

Table 3 presents shares of water and nitrogen costs in total variable costs of durum wheat.

Table 3. Share of water and N costs in total variable costs of Durum wheat (%)

	Tunisia		**Morocco**		**Jordan**		**Lebanon**	
	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed
Water cost	16	-	9	-	-	-	Na	Na
N cost	19	24	20	18	-	10	20	21

Even though Tunisian farmers applied less water per ha during the year 2006-2007, the share of water cost in total variable cost is higher than in the case of Moroccan farmers. This can be explained by the higher price paid by Tunisian farmers compared to the Moroccan. Nitrogen cost represents approximately 20% of the total variable cost in Tunisia, Morocco and Lebanon and only 10% in Jordan where farmers tend to use the lowest amounts.

Table 4 illustrates the performances indicators obtained by durum wheat growers during the season 2006-2007. Average yields in irrigated conditions are quite similar in Tunisia and Morocco and higher in Lebanon. However, in terms of cost price per quintal of durum wheat in rainfed conditions, the lowest is obtained by Tunisian farmers with 13 €/q whereas the highest is observed in Lebanon with (26 €/q). Regarding the gross margin which is calculated as the difference between the production value and variable costs, Table 4 shows that the highest is obtained by the Tunisian farmers. Deviations of the gross margins between Morocco, Jordan and Lebanon are weak. This is mainly due to the high durum wheat price fixed by Tunisian government in order to encourage wheat production. Durum wheat prices have increased in Tunisia by more than 80% from season 2005-2006 to the season 2006-2007 following the increase of cereal world prices.

Table 4. Performances indicators of durum wheat growers

		Tunisia	**Morocco**	**Jordan**	**Lebanon**
Average yields (q/ha)	Irrigated	41	42	-	52
	Rainfed	30	20	16	31
Cost price (€/q)	Irrigated	15	21	-	19*
	Rainfed	13	19	24	26
Gross margin (€/ha)	Irrigated	670	461	-	590
	Rainfed	561	270	294	221

Cost-benefit results

To evaluate the efficiency of the tested technological package, *ceteris paribus*, we proceed by a descriptive, cost-benefit analysis and a Student's *t* test on two samples associated in pairs in order to check the hypothesis that the average difference between the two alternatives is zero. This statistical test is appropriate when the samples are dependent; that is, a single sample is tested twice (before and after the experiment) or when there are two samples that have been paired (Dagnelie, 1998). Hence, we calculate a Student *t*-test to compare the average difference between two treatments when the observations have been obtained in pairs. So, if $\overline{D}$ represents the mean difference between two treatments, the hypotheses are:

- Null hypothesis H_0: The average difference between two treatments is zero $\overline{D} = 0$
- Alternative hypothesis Ha: The average difference between two treatments is different from zero $\overline{D} \neq 0$

The difference between the paired values is assumed to be normally distributed, and the null hypothesis that the expectation of the difference is zero is tested by Student *t*-test. If the calculated t is higher (lower) than critical t with n-1 degrees of freedom at the chosen significance level, there is evidence to reject (accept) the null hypothesis.

Comparison of yields

In this subsection we compare, *ceteris paribus*, the obtained yields with and without applying the technological package. Table 5 synthesizes grain and straw average yields and shows that farmers' yields are variable according to the management method. The average durum wheat yield in rainfed conditions is about 37 q[6]/ha, against 32 q/ha, in irrigated conditions, and 31 q/ha, against 29 q/ha in rain fed conditions, in experimental and conventional plots, respectively. Average yields in the experimental as well as conventional plots are higher in Béja than in Siliana in view of the respective sub-humid and semi-arid nature of the climate. Indeed, in irrigated conditions, the average yield is 44 q/ha in Béja against 29 q/ha in Siliana, whereas in rainfed conditions, the average yield is about 38 q/ha in Béja compared to 27 q/ha in Siliana.

On the other hand, average straw yields obtained in the experimental plots are estimated at 223 bales/ha and 196 bales/ha, respectively in irrigated and rainfed conditions. These yields are much higher than those obtained by cereal growers with their conventional practices. On average, straw yields are higher by approximately 28% and 44% respectively in irrigated and rainfed conditions.

Table 5. Durum wheat grain and straw average yields in Béja and Siliana

	Grain yields (q/ha)				**Straw yields (bale/ha)**			
	Irrigated		**Rainfed**		**Irrigated**		**Rainfed**	
	Exp*	**Conv***	**Exp***	**Conv***	**Exp***	**Conv***	**Exp***	**Conv***
Béja	44.17	40.90	38.43	35.09	293	245	321	201
Siliana	28.9	28.23	27.35	22.41	154	107	134	103
Region average	36.51	31.65	31.04	28.58	223	176	196	136

*Exp and Conv refer to experimental and conventional plots.

Comparison test of average yields

The average of grain yield differences between the two samples (experimental versus conventional) is about 4.9 q/ha and 2.5 q/ha respectively in irrigated and rainfed conditions (cf. Table 6).

Table 6. Durum wheat grain yields

Yield averages	Experimental (A)	Conventional (B)	Difference (D=A-B)
Irrigated average yield **(q/ha)**	36.51	31.65	4.87
Not statistical significance			*Tcal=1.74*
Rainfed average yield **(q/ha)**	31.04	28.58	2.46
Not statistical significance			*Tcal=0.75*

*The critical value of Student's *t* test at the 5% significance level is *2.3*

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[6] q/ha means quintals per hectare

The application of the Student *t* test on the observed grain yields (two paired samples) led to the non rejection of the null assumption H_0 at the 5% significance level. In other terms, the average difference between the two alternatives in irrigated and rainfed conditions is not statistically significant from 0. That is grain yields obtained with the proposed nitrogen management package are not statistically different from those generated by farmer's conventional practices. Indeed, the calculated student *t*-test is lower than its critical value both in irrigated and rainfed areas (cf. Table 6).

With regard to straw, the average of the difference between the two sample's is about 47 bales/ha and 60 bales/ha respectively in irrigated and rainfed conditions (cf. Table 7). Moreover, these differences are statistically different from zero at threshold significance of 5% allowing the rejection of the null hypothesis H_0. Hence the recommended strategy generates higher straw yields than the farmer's conventional practices.

Table 7. Durum wheat straw yields

Yield averages	Experience (A)	Conventional (B)	Difference (D=A-B)
Irrigated average yield (bale/ha)	223.6	176.44	47.15
Statistical significance			*Tcal=2.4*
Rainfed average yield (bale/ha)	196.66	136.56	60.10
Statistical significance			*Tcal=2.95*

*The critical value of Student's *t* test at the 5% significance level is *2.3*

Comparison test of average gross margins

In addition to testing the significance of physical results, a profitability analysis is needed to examine whether the recommended strategy is beneficial to farmers or not. The gross margin (GM) expressed as the difference between the gross product value, including straw, and variable costs[7] for the experimental and conventional plots and the difference is tested using Student *t* test. The GM indicator is appropriate since that only variable costs change according to the management practice. The average gross margin is evaluated at 1859 TND[8]/ha and 1624 TND/ha respectively in irrigated and rainfed conditions (cf. Table 8). These values are higher than those obtained using conventional practices which are estimated at 1467 TND/ha and 1226 TND/ha, respectively in irrigated and rainfed areas.

Table 8. Durum wheat gross margins

Gross margins	Experiment (A)	Conventional (B)	Difference (D=A-B)
Irrigated average GM (TND/ha) **Statistical significance**	1859.07	1467.28	381.78 *Tcal=3.11*
Rainfed average GM (TND/ha) **Statistical significance**	1624.62	1225.91	398.71 *Tcal=2.47*

*The critical value of Student's *t* test at the 5% significance level is *2.3*

The average of GM differences between the two samples is approximately 382 TND/ha and 399 (TND/ha) respectively in irrigated and rainfed areas. Based on Student's *t* test values (Table 4), we reject the null hypothesis H_0 in the case of irrigated and rainfed conditions at the 5% significance level which means that the GM average difference between the two alternatives is significantly different from zero at 5% level. Hence the recommended strategy is likely to increase GM and

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[7] To calculate the gross margin, we used the current output and input prices

[8] TND : 1 Tunisian dinar equals approximately 0.8 USD

consequently farmers' profits. We also point out that the impacts on GM are more pronounced in rainfed than in irrigated conditions. This can be explained by the fact that in conventional practices farmers tend to apply usually few quantities of nitrogen depending on rainfall. However, the recommended nitrogen quantities on the experimental plots were much higher than those applied by farmers on the rest of their land.

Estimated and simulated gains at sectoral level

Since that the whole experiment has proven to be beneficial and farmers' incomes have significantly increased, the aim of this subsection is to show the net gain that would occur at sectoral level if the recommended nitrogen strategy will be adopted by farmers in the four selected countries: Tunisia, Morocco, Jordan and Lebanon. Nevertheless, we make a strong assumption of a proportional increase in nitrogen use and durum wheat output as observed in the pilot experience conducted in Tunisia. Hence, the results can be interpreted as lower bounds for all countries because of the following reasons:

- For Tunisia, the physical advantage in terms of grain yield was not very large, but this might be due to the fact that farmers would have fertilized their field in the pilot experience more heavily than if they would have not been involved in the study. There are several reasons to sustain this statement, the main one being the farmers were questioned before entering into the experience on which was their fertilization schemes and most of them replied that they applied at least 20 Kg N ha^{-1} less than what they have applied this time (Thabet *et al.*, 2006). Due to the fact that the farmers themselves applied the doses suggested from our project they learnt that information before applying their dose, and probably felt influenced and raised their doses to get closer to that "recommended" from the model. Thus the general view of the relative advantage of the recommendation process used compared to that actually used by the farmers was minimized. Furthermore, based on the Tunisian Ministry of Agriculture statistics, the average level of nitrogen use at the sectoral level is much below the one applied by farmers from Béja and Siliana.
- For Morocco, Jordan and Lebanon, all the surveyed farmers apply lower amounts of nitrogen than in Tunisia.

Table 9 presents the total durum wheat surface in each country and the estimated and simulated gross margins per country. Results show that the highest gains would be obtained by Tunisian farmers because of the interesting durum wheat price offered by the government.

Table 9. Estimated and simulated gross margins at country level

	Tunisia		**Morocco**		**Jordan**		**Lebanon**	
	Irrigated	**Rainfed**	**Irrigated**	**Rainfed**	**Irrigated**	**Rainfed**	**Irrigated**	**Rainfed**
Surface (ha)	41000	608000	64145	755801	-	55000	22834	23766
GM (Millions €)	6	60	11	31	-	4	3.5	1.4

Technology adoption evaluation. Factors affecting adoption

Table 10 summarizes the Probit regression results for WatNitMED recommendation adoption among farmers. The model has a goodness of fit. The likelihood ratio test shows that the hypothesis that all regressors are zero is rejected at 1% significance level. The main results obtained from Probit estimation are:

- Education level, experience, land tenure and principal activity do not significantly influence willingness to adopt WatNitMED recommendation.
- A negative relationship between farmers' age and adoption is found.
- Participants in demonstrations trials, extension services, farm size and membership in a farmers' associations influence willingness to adopt WatNitMED recommendation.
- The most significant variables for the adoption of WatNitMED recommendation are the participants in demonstration trials and farm size.

Table 10. Estimation results of Probit model

Variables	Coefficients	t-statistic	Significance level
C	-2.342	-0.853	
TES	2.348	2.601	***
AGE	-0.094	-2.426	**
EDUC	0.284	0.851	
SIZE	0.012	2.220	**
EXP	0.014	0.294	
TENURE	0.016	1.479	
ACTIV	-0.121	-0.130	
EXT	0.301	1.878	*
FAS	1.553	1.905	*
$LogL_r$	-29.07		
$LogL_u$	-14.18		
LR	29.76		***

$LogL_u$: Log-likelihood function
$LogL_r$: Restricted log-likelihood
LR: Likelihood ratio test
* Significant at the 10% level
** Significant at the 5% level
*** Significant at the 1% level

Constraints ranking

The ranking results of the constraints in WatNitMED recommendation adoption by farmers are illustrated by Table 11. The score variation was high varying from 38 to 70. High cost of soil analysis received rank I, lacks of incentives to grain quality improvement received rank II, low grain yield difference received rank III and lack of extension services received rank IV.

Table 11. Garrett's ranking and constraints in WatNitMed recommendation adoption

Constraints	Garrett's mean scores	Rank
High cost of soil analysis	70	1*
Lack of incentives to grain quality improvement	64	2*
Low grain yield difference	59	3*
Lack of extension services	48	4*
Low straw yield difference	45	5
Lack of experience	40	6
High production cost	38	7

*The most important problems

Socio-economic factors such as farmer's advanced age, land fragmentation, low educational level, and financial problems are the most important factors hindering the adoption of new technologies aiming at optimizing WNUE. Following the survey, farmers believe that productivity growth is possible through better nitrogen fertilization or irrigation. However, the frequently mentioned constraints deal with financial difficulties, increasing factor costs and the inefficiency of the institutional organization of the cereal sector which is characterized by the Cereal Office monopoly at all the value chain levels.

Policy recommendations

We draw two general implications from this study. First, the current nitrogen management by Mediterranean farmers is not optimal and there is a need to adjust the amount and the appropriate application periods in order to improve the output and consequently water productivity. Second, the positive outcome of the project cannot be implemented without a strong implication of the Tunisian Ministry of Agriculture in one hand and the Ministries of Agriculture of the other considered Mediterranean countries in the other hand and particularly their extension departments, which have to disseminate these results at the farmer level. The need to change the nitrogen management practices highlights the importance of farmer training and extension services in order to improve the competitiveness of the cereal sector.

The study recommends the following to raise the adoption rate such as:

- Dissemination by providing farmers with guidelines defining clearly nitrogen management to be followed.
- Farmer-led extension approaches where tested farmers who possess certain experience regarding technology should constitute the initial group for disseminating information.
- Ministries of Agriculture have to play a major role. Indeed, the need to facilitate the replacement of one set of conventional N practices by another highlights the importance of farmer training and extension services required to convince farmers to change their N management and to fertilize.
- The Tunisian Ministry of Agriculture can subsidize soil analysis at least for some years, encourage farmers to be membership of farmers' association and establishes incentives to grain quality improvement.

WP3 Modelling

Leader of workpackage: **Partner 4, WUR**

Workpackage Objectives

- Construct a physiological model for wheat to quantify responses of yield formation to a wide range of simulated environments differing in timing and intensity of water and N stresses

List of Deliverables

- D3.1 A subroutine that describes quantitatively drought effects on the regulation of photosynthesis and transpiration processes in wheat during the developmental stages from booting, flowering till maturity and senescence.

- D3.2 A subroutine to carry out sensitivity analyses on genotypic traits that have been evaluated in the experimental working packages.

- D3.3 A subroutine that describes the impact of different acclimation strategies, either through short-term physiological control or long-term storage patterns, will be evaluated to shed new light on the emerging consequences of these underlying strategies for drought tolerance and yield stability of wheat.

- D3.4 A final report summarising scientific findings of WP3.

List of Milestones

- M3.1 Make a standardised protocol to assure that the model will be able to use the data from the experiments in other working packages. Discuss with the researchers in the other WP's how data will become available for the validation of the model. (Month 2).

- M3.2 First draft of a preliminary wheat model and description of agronomic implications for N and water shortage (Month 12). Test the application with respect to experimental input from other working packages.

- M3.4 Subroutine that describes the effect of nitrogen on wheat growth in three different developmental stages: stem elongation, flowering ripening. (Month 24).

- M3.5 Subroutine that describes interaction with water supply. Further refinement of the nitrogen subroutine, including effects on sink-source interaction. (Month 30).

- M3.5 Gather data and run the sensitivity analyses for the range of physiological properties that has been observed in the experiments.

- M3.6 Submit report summarizing scientific findings of WP3 (Month 47).

Summary of WorkPackage Main Findings

Background: the GECROS model

To meet overall objectives of WP3, we first examined all existing available Wageningen crop growth models. It was concluded from an initial evaluation analysis in the first year of the project implementation that a relatively new Wageningen model GECROS, as described in the book "Crop Systems Dynamics; an ecophysiological simulation model for genotype-by-environment interactions" (Wageningen Academic Publishers, ISBN 9076998558), could serve as a basic model for further progress. The model introduces new concepts describing carbon and nitrogen accumulation in the different parts of the crop and their interactions. The interrelationships between different processes describing direct and indirect effects of environmental conditions and management decisions makes the model robust and reduces the triviality compared to other models using many correction factors and coefficients. The model performance was evaluated using a dataset from Spain, which included different agroecological environments, water regimes and genotypes. This resulted in a protocol for acquisition of data and applying the model for wheat and barley in Mediterranean conditions. The evaluation was discussed at several occasions with experts. A summary information of the GECROS model is given as below:

"The model incorporates the Farquhar type of algorithms for calculating potential leaf photosynthesis. When water stress occurs, leaf photosynthesis is reduced according to stomatal regulation based on the actual transpiration. The concept of the two-leaf model is adopted, in which the canopy is divided into sunlit and shaded fractions to calculate canopy photosynthesis and transpiration. For both fractions, the photosynthetically active nitrogen is calculated by a base value of leaf nitrogen, below which photosynthesis is zero and a leaf nitrogen extinction coefficient for describing an exponential profile in the canopy for vertical decline in nitrogen. GECROS includes several types of respiration: a. growth respiration, b. respiration for ammonium and nitrate uptake and nitrate reduction; uptake of other ions, phloem loading, and c. residual maintenance respiration. Nitrogen demand is the maximum of the deficiency driven and the growth-activity driven demand. The deficiency driven demand is the amount of nitrogen required to restore the nitrogen concentration in the plant to a critical minimum concentration. The growth-activity driven demand is based on the optimum nitrogen/carbon ratio for maximising the relative carbon gain. The actual nitrogen uptake is limited by the maximum nitrogen uptake rate, which is an input parameter.

Root-shoot partitioning for carbon and nitrogen responds to environmental conditions, based on the root-shoot functional balance theory. Intrashoot carbon partitioning to the stems (including sheaths) and grains are determined according to expected their daily C demands, which are described by the differential form of a sigmoid function for asymmetric determinate growth. The remaining shoot-carbon goes to the leaves, or when the leaf area index (LAI) becomes nitrogen limited, it goes to the carbon reserve pool in the stems. The LAI is calculated according to the principles that either the carbon or the nitrogen limited leaf area index. The carbon reserves, if any, become available to the grains, when current photosynthesis does not satisfy the carbon demand.

The intra-shoot nitrogen partitioning is based on a pre-defined maximum grain of a genotype nitrogen concentration and a minimum nitrogen concentration in the stems. If the nitrogen requirements for the grains and stems are met, the remaining shoot nitrogen goes to the leaves, which include the photosynthetically active part of the stems, sheaths and ears. If the requirements for the grains are not met, remobilization of nitrogen in the reserves, and in the leaves and the roots takes place, until the reserves are depleted and the nitrogen concentrations in the leaves and roots reach their minimum values. This remobilisation stimulates leaf and root senescence. If the grain nitrogen requirements are not met by new shoot nitrogen and remobilisation, the grain nitrogen concentration declines.

In GECROS, development stages are defined as 0 at seedling emergence, 1 at start of grain filling and 2 at physiological grain maturity. The intervals from stage 0 to 1 and 1 to 2 depend on the genotype specific number of days at optimum daily average temperature. A flexible bell-shaped non-linear function is used to describe temperature response of development rate, which has a value of zero when the daily average temperature is below the base temperature or above the ceiling temperature and one when it is equal to the optimum temperature. In case of photoperiod-sensitive genotypes, development rate is also affected by daylength during the photoperiod sensitive phase of the interval from stage 0 to 1."

Development of new sub-routines within GECROS

With respect to deliverable D3.1, the subroutines in the GECROS model describing quantitatively drought effects in wheat and barley were tested. It was concluded that these subroutines were suitable for the application of the model in the WatNitMED project. The simulation of drought itself could be improved by describing soil water flows and root growth including the relation between root biomass or length and potential water uptake. However, to use GECROS for accurate prediction of canopy photosynthesis and transpiration, an accurate estimation of photosynthesis parameters of its underlying biochemical leaf-photosynthesis model is essential. We therefore went a step further to develop a robust procedure to estimate these parameters, and found that many of these parameters were quantitatively associated with regulation of photosynthesis in response to plant developmental status. This work was published in *Plant, Cell & Environment*. The abstract of this paper is:

"*We appraise the literature and describe an approach to estimate parameters of the Farquhar, von Caemmerer & Berry model using measured CO_2 assimilation rate (A) and photosystem II (PSII) electron transport efficiency (Φ_2). The approach uses curve-fitting to data of A and Φ_2 at various levels of incident irradiance (I_{inc}), intercellular CO_2 (C_i) and O_2. Estimated parameters include day respiration (R_d), conversion efficiency of I_{inc} into linear electron transport of PSII under limiting light ($\kappa_{2(LL)}$), electron transport capacity (J_{max}), curvature factor (θ) for the nonrectangular hyperbolic response of electron flux to I_{inc}, Rubisco CO_2/O_2 specificity ($S_{c/o}$), Rubisco carboxylation capacity (V_{cmax}), rate of triose phosphate utilization (T_p), and mesophyll conductance (g_m). The method is used to analyze combined gas exchange and chlorophyll fluorescence measurements on leaves of various ages and positions in wheat plants grown at two nitrogen levels. Estimated $S_{c/o}$ (25°C) was 3.13 mbar μbar^{-1}; R_d was lower than respiration in the dark; J_{max} was lower and θ was higher at 2% than at 21% O_2; $\kappa_{2(LL)}$, V_{cmax}, J_{max} and T_p correlated to leaf nitrogen content; and g_m decreased with increasing C_i and with decreasing I_{inc}. Based on the parameter estimates, we surmise that there was some alternative electron transport.*"

With respect to delivery D3.2, methods for parameterisation and sensitivity analysis were developed for different types of parameters representing genotypic traits. In particular, also in relation to Milestone 4 on source and sink interaction, we developed a quantitative method to characterise sink-source relationships during grain filling in contrasting wheat genotypes. This work has resulted in a paper published in *Field Crops Research*. The abstract of the paper is as follows:

"*We present a simple generic framework to quantify source-sink relationships during grain filling, by using a determinate growth function which has a unique property, namely being able of explicitly describing the time for the end of a growth process. This model framework was applied to analyze these relationships in plants of six wheat (Triticum aestivum* L.*) genotypes grown in pots in climate-controlled greenhouses under two temperature regimes (day/night: 20/15 and 25/20°C). The function accurately described the sigmoid pattern of grain growth (sink activity), as its* *modified form did for the reversed sigmoid shape of flag-leaf area (source capacity), during grain filling. The six genotypes differed significantly in grain number as well as in grain yield, ranging from 54 to 81 grains and from 2.67 to 4.52 g DM per culm, respectively, when grown at 20/15°C. Biomass and grain yield were significantly reduced by a rise of 5°C. Grain nitrogen contents raised from 2.1 to 2.6% as a consequence of less carbon accumulation resulting in lower grain weights at the high temperature. On average, a rise of 5°C in temperature reduced the duration of grain growth by 12 days (>30%), and increased the growth rate from 1.32 to 1.67 mg grain^{-1} d^{-1} (20%). Genotypic differences in grain-filling duration were also larger than in rate of grain growth. The genetic variation in the flag-leaf area duration (a proxy for the capacity for intercepting radiation and photosynthesis) was positively associated with sink size. Model analysis showed that whether or not the timing for the cessation of grain filling and for the end of post-anthesis source activity was synchronized depended on temperature. The quantitative approach yielded parameters that characterize genotypic differences of post-anthesis source and sink capacity in responding to environmental variables.*"

Subroutines, relations and methods were developed in relation to the objective and deliverables and in particular milestones and expected results 3 (month 24) and 4 (month 30). For example, a subroutine was implemented that describes nitrogen partitioning and relocation among the plant organs between crop emergence and physiological maturity (milestones and expected results 3, month 24). Similarly, an alternative method for calculating the number of grains per m^2 was implemented for determining the grain sink capacity. Also, subroutines were implemented in the model that describe water and nitrogen flows in the soil and root length distribution over the profile. Subsequently, a relation between potential daily water and nitrogen uptake and root length per soil horizon that corresponds with the work by the partner 5 (Nottingham, England) was implemented. This work resulted in a paper that was presented in the Nottingham Resource Capture symposium. Its summary information is given below:

"Root growth and its distribution across the soil profile determine the ability of a crop to capture water and nitrogen (N). We developed algorithms to model root growth, flows of water and N in the soil and capture of water and N by the roots in wheat and barley. These algorithms were then incorporated into the crop simulation model GECROS to simulate the dynamics of root length density profiles. We used an empirical equation from literature to describe the relation between the volumetric root length density in 0.1 m horizons and the ability to capture the available resources. The fraction of incremental root length allocated daily to each horizon was partly based on a negative exponential profile related to the depth of the root front, and partly based on the distribution of water and N in the soil. Experimental data from a site in the Netherlands (wheat, cv. Arminda) and a site in Australia (barley, cv. Beecher) were used to estimate parameter values. The performance of the extended GECROS model in predicting root length density profiles in relation to crop biomass accumulation and root-shoot partitioning was evaluated using data sets from two other sites in the Netherlands, two sites in Syria and data in literature for different cultivars. The estimates of the maximum root front velocity were similar for all wheat and barley cultivars, whereas the estimates of the parameter determining the curvature of the negative exponential incremental root length allocation were different. Genotypic differences were also found when analysing a wider range of data sets, suggesting the need for genotype-specific values for this parameter. Effects of soil water and N on the allocation of root length were relatively small but statistically significant ($P < 0.05$). Simulations resulted in high accuracy for most sites and treatments. Despite the large variation in the observed root biomass and root length, our model was able to predict root length density profiles accurately under diverse field conditions."

Evaluation of new subroutines

Deliverable 3.3 requires the evaluation of a subroutine that describes the impact of different acclimation strategies. The algorithms in GECROS for photosynthesis, transpiration and partitioning biomass described in Yin and Van Laar (2005) include mechanisms that simulate the effect of these strategies. However, very recently it has been recognised that mesophyll conductance for CO_2 diffusion from intercellular airspaces to chloroplasts is a key limitation to photosynthesis in C_3 plants like wheat and barley, and the nature and environmental responses of this conductance play a key role in plant photosynthesis under environmental stresses like drought. As such mesophyll conductance has major implications for photosynthesis and crop modelling. These important consequences highlight the need to explore differences in response of this conductance to the environmental variables. To improve model predictability and assess photosynthetic acclimation mechanisms, we paid particular attention to modelling mesophyll conductance (g_m). This work was published in *Plant, Cell & Environment*. The abstract of this paper is:

"*Existing methods to estimate the mesophyll conductance to CO_2 diffusion (g_m) are often based on combined gas exchange (GE) and chlorophyll fluorescence (CF) measurements. However, estimation of average g_m by these methods is often unreliable either because the range of usable data is too narrow or because the estimations are very sensitive to measurement errors. We describe three method variants to estimate g_m, for which a wider range of data are usable. They use curve-fitting techniques, which minimize the sum of squared model deviations from the data for A (CO_2 assimilation rate) or for J (linear electron transport rate). Like the existing approaches, they are all based on common physiological principles assuming that electron transport limits A. The proposed variants were far less sensitive than the existing approaches to 'measurement noise' either created randomly in the generated data set or inevitably existing in real data sets. Yet, the estimates of g_m from the three variants differed by ca. 15%. Moreover, for each variant, a stoichiometric uncertainty in linear electron transport-limited photosynthesis can cause another 15% difference. Any estimation of g_m using GE and CF measurements should be considered with caution, especially when g_m is high.*"

As mentioned in the 2007 annual report, data sets from various sources including those from WatNitMed partners were collected. These collected data were used to evaluate the improved GECROS model, which incorporated newly upgraded subroutines on the basis of the original version of GECROS. Such an evaluation analysis resulted in a paper that is still under review for a journal publication. Its abstract is given below:

"*Modelling grain yield, incorporating genetic traits, physiological processes and environmental conditions, can support decision making in crop management and give guidance to research on improving crop productivity. The relatively new Wageningen model GECROS (**G**enotype-by-**E**nvironment interaction on **CRO**P growth **S**imulator) uses concepts based on mechanisms for the balance, interaction and feedback among various contrasting components of crop growth, such as carbon and nitrogen, source and sink and roots and shoots.*

The objective of this study was to evaluate the performance of GECROS in modelling growth and yield of barley and wheat under a wide range of environmental conditions: from temperate to Mediterranean and subtropical environments. It was hypothesized that GECROS would show adequate performance under abiotic stress (drought, N-shortage and heat) conditions. To validate GECROS, four datasets derived from field experiments conducted with various water and nitrogen regimes under contrasting conditions were used. One dataset was derived from winter-wheat experiments carried out under temperate conditions (the Netherlands) with different N regimes. The other datasets concerned barley genotypes grown in a sub-tropical environment (Queensland, Australia), durum-wheat genotypes grown in a Mediterranean environment (Northern and Southern

Spain) and wheat genotypes grown in a semi-arid environment (Obregon, Mexico) under different water and N regimes. Species- and genotype-specific model parameters were based on subsets of the data and the model was evaluated for the complete datasets.

Various parameters, such as: biomass, grain number, grain weight and grain N concentration, were used to evaluate the performance of the model. The root mean squared deviation (RMSD) for grain yield was used as the main indicator of model performance. Overall, GECROS performed well in predicting parameters for winter wheat (RMSD = 77 g m^{-2}*) and spring wheat grown under temperate and semi-arid conditions (RMSD =100 g* m^{-2}*), respectively, with no or only mild water stress. Model performance was less convincing for assessing yields, when abiotic stresses – mainly drought - were prevailing during the growth cycle, as was the case for durum wheat in Spain (RMSD = 114 g* m^{-2}*) and barley in Queensland, Australia (RMSD = 143 g* m^{-2}*). The performance of the model under those conditions was also affected by incomplete soil data, underpinning the importance of reliable input data. Under highly variable stress conditions, simulating actual yields accurately will require spatially and temporally detailed input data."*

"The results of the model evaluation were discussed. The strength of GECROS is that actual yields can be simulated quite accurately when heat, drought or N deficiency do not affect crop growth processes strongly. However, also under stress conditions the use of GECROS to explore relative yield improvements combined with expert knowledge can support management decisions and guide trait selection in breeding programs."

WP4 Strategy Design

Leader of workpackage: **Partner 12, INRA Moroccco**

Workpackage Objectives

- To review and link scientific and farmers' knowledge on the capture and use of water and nutrients of different wheat and barley genotypes in the Mediterranean Basin.

- To design and evaluate agronomic and water management strategies for the Mediterranean Basin that optimise nitrogen and water use efficiency of different wheat and barley genotypes, in cooperation with research partners and farmers.

- To provide recommendations and guidelines for the use of a cropping systems model as decision aid for the design and evaluation of management strategies for different wheat and barley genotypes in Mediterranean environments.

List of Deliverables

- D4.1 Review of scientific and farmers' knowledge on the capture and use of water and nutrients of different wheat and barley genotypes in the Mediterranean Basin (Achieved in 2006).

- D4.2 Guidelines and recommendations for the use of a simulation model as decision aid to evaluate water and nutrient use efficiency of different wheat and barley genotypes in Mediterranean environments (Achieved in 2008).

- D4.3 Report with agronomic strategies for optimal use of nitrogen and water in the Mediterranean Basin (Achieved in 2008).

- D4.4 A final report describing the outputs and learning outcomes from WP4 (Achieved in 2009).

List of Milestones

- M4.1 Review of local and scientific knowledge on NUE and WUE of different genotypes of barley and wheat (Achieved in 2006).

- M4.2 Workshop to discuss agronomic strategies and design evaluation methodology (Achieved in 2006).

- M4.3 Workshop to evaluate and adapt research trials and discuss model application (Achieved in 2007).

- M4.4. Working paper in crop system modelling recommendations (Achieved in 2008).

- M4.5 Agronomic strategies evaluated for selected target environments and clime scenarios (Achieved in 2008).

Summary of WorkPackage Main Findings

Introduction

Many factors limit crop production in the Mediterranean region, but the most limiting factors are the supply of water and nitrogen. These resources are scares; therefore it is of big interest to use them efficiently. WatNitMED project aims to improve the understanding on the determinants of the crop capacity to both capture more water and nitrogen and use these limiting resources more efficiently. In this context, the understanding of the physiological bases of crop responses to different management strategies is crucial. For this purpose, many workpackages were linked and gathered the efforts to design more consistent management practices to increase the efficiency of water and nitrogen. The work we describe below fit in the one of the two modelling WPs proposed in the WatNitMED, particularly on designing management strategies using a model for both the present prevalent conditions and for those expected in the near future (WP4). The inclusion of modelling development/adaptation and simulation exercise in the WatNitMED Project provides not only a powerful tool to design management strategies, but also, a framework in which the physiological-crop science-agronomic information produced as innovation of the specific WPs will be integrated to produce reliable outputs in form of management alternatives, as the main outreach activity of the proposed work of this consortium. In this context, the project addresses a subject that is of high relevance for unlocking new developments in agriculture.

Description of work

The aim of this workpackage is to complement the development objectives and outputs of the crop simulation model and decision aid (WP3). The workpackage also links closely with the resource capture and conversion objectives of WP8, WP9, WP10 and WP11 and the farmer benchmarking activities in WP2. INRA Morocco is responsible for collating evidence from farmers and scientists to design rational strategies for water and nutrient management that optimise yield whilst minimising losses to the environment.

Review of scientific and farmers' knowledge on the capture and use of water and nutrients of different wheat and barley genotypes in the Mediterranean Basin

The first deliverable then was a review of available information on agronomic and water management practices and morphological and physiological traits that affect nitrogen and water use efficiency (WUE) of barley and wheat in Mediterranean environments. Data and knowledge from research trials, farmer participatory research and breeding programs have been used and critical missing knowledge has been identified. The review document is available in the second annual report (annex I).

As planned, workshops with stakeholders were organized in Morocco in two major producing areas of barley and wheat production. Key INRA Morocco and other research and development institutions attended these workshops. Emphasis was given to identifying and filling of critical knowledge gaps. Two workshops were held to review and adjust the strategies and design a research plan for their evaluation, to discuss agronomic strategies and design evaluation methodology, and to evaluate and adapt research trials and discuss model application. These workshops were attended by farmers, extension people and scientists. Qualitative and quantitative information provided by farmers groups has been collated and analyzed. Similarly, information from farmers and scientists to design rational strategies for water and nutrient management that optimize yield whilst minimizing losses to the environment was collated. These workshops took place in two major producing areas of wheat and barley in the arid and semi-arid regions of Morocco. During these workshops, the objectives of the Project and the workshop were presented in order to involve all stakeholders and targeted communities in the description of actual management strategies and identify ways for improvement. A description of management practices used by farmers with regard to rotations, cultivars used, soil preparation, fertilization, sowing, weed and disease control, and harvesting was made. With regard to fertilizers use and nitrogen, farmers in the Chaouia region use 100 kg of 14N-28P-14K prior to planting and 50 kg of urea at tillering-stem elongation for bread and durum wheat, while for barley, in general, no fertilizer is applied. Farmers in Zaers region, a more favorable region, use 200 kg of 19N-38P-0K or 18N-46P-0K prior to planting and 100 kg of urea during crop growth depending on the seasonal rainfall.

Guidelines and recommendations for the use of a simulation model as decision aid to evaluate water and nutrient use efficiency of different wheat and barley genotypes in Mediterranean environments

To fulfill the second objective aiming at designing and evaluating agronomic and water management strategies for the Mediterranean Basin that optimise nitrogen and water use efficiency of different wheat and barley genotypes, in cooperation with research partners and farmers, several activities have been conducted.

A WatNitMED workshop on Modelling was organized during October 2005 at Wageningen, the Netherlands. The workshop aimed at becoming more familiar with the GECROS model and to discuss common research activities to study Genotype × Environment × Management interactions for cereal crops in a Mediterranean environment. The program consisted of on systems analyses and modelling, the concept and applications of GECROS model, the evaluation of GECROS for a Mediterranean environment, besides an interactive training on modules GECROS. Afterwards, modelling G×E×M interactions in a Mediterranean environment (Workpackage WP3) were discussed and reports on planning of G×E×M experiments and data acquisition by WatNitMED partners in the 2005/2006 growing season were agreed upon.

It was hypothesized that GECROS would show adequate performance under abiotic stress, such as drought, heat and N shortage conditions which prevail in the southern Mediterranean regions. To evaluate then the performance of GECROS in modelling growth and yield of wheat and barley under such conditions, detailed datasets were needed. Thus, detailed field experiments for model testing and validation were conducted for two growing seasons. These experiments were necessary to complement the development objectives and outputs of the crop simulation model and decision aid (WP3). These experiments consisted of testing durum wheat genotypes that are largely used in the North Africa (cv. Karim) and the Middle East (cv. Hourani) under three nitrogen management strategies both under rainfed and irrigated water regimes Sidi El Aidi, Morocco. The dataset provided helped to parameterize GECROS. All the required management data, daily weather data and soil characteristics were collected. The model's specific parameters of species were determined by interpreting measured values or by optimising model performance by changing the values within ranges found in the literature. Genotype specific parameters were measured plant characteristics.

The model evaluation was performed by calculating the root mean square error (RMSE) of the observed and simulated grain yield, grain number per m^2, grain weight, shoot N at anthesis and maturity. The RMSE is a common indicator for crop model evaluations. The slope b and R^2 of linear regression between observed and simulated values were used as quantitative indicators of bias and scatter, respectively. Low b values indicate that there is a tendency for overestimation at low observed values and/or underestimation at high observed values. High b values indicate the opposite.

Model evaluation is important in providing the opportunity for possible improvements in the model in order to have even more accurate predictions. This will result in strong recommendations and research guidance towards further analyses of NUE and WUE, selection of plant traits for breeding, crop management options and regional farming policies.

Once the first dataset was available, collaborators in both WP4 and WP3 exchange visits to run the model with the dataset generated through field experiments and evaluate GECROS for Mediterranean environment and to agree on steps to go forward with model application and strategy design.

Collaboration also with project partners (WP10, WP11, and WP12) on the evaluation of research results and the application of a cropping system's model took place. The available and newly generated experimental data was used to calibrate and evaluate crop parameters for different barley and wheat genotypes. Model development issues have been discussed with WP3. Guidelines and recommendations for model use were prepared and presented to the partners.

With regard to the GECROS model version July 2007, in collaboration with WP3, the model was parameterised using datasets from Moroccan field experiments 2005/06 and 2006/07. The model output turned out to be satisfactory for estimating grain yield and aboveground biomass at maturity; however, estimates of yield components need further development (Figure 1).

For the demonstration of the GECROS model user interface for validation and use by other partners: an excel spreadsheet was presented for organising model input data and parameterisation, so partners can easily use the model for validation using experimental data. The spreadsheet is well structured, but still needs some guidelines and recommendations for the use of the model.

A workshop with partner 4 was organized to discuss methods for decision support tools: how the model can be used a tool for designing strategies in the WatNitMED project. It was suggested to use either one of the following two options: (1) use average, dry and wet year of long term weather data for running the model; or (2) run the model for 30 consecutive years and then do frequency analysis. This of course depends on availability of data from other workpackages and on the availability of long term daily weather data and soil data from WP2 (farmers benchmarking and socioeconomic).

During Marrakech meeting, WP4 and WP3 in cooperation with project partners (WP2, WP10, WP11, and WP12) worked out on the evaluation of research results and the application of a cropping system's model. The available and newly generated experimental data were used to calibrate and evaluate crop parameters for different wheat genotypes, and for proposing a strategy to be compared with "*normal practise*" for WP2.

A final meeting with partner 4 took place in Wageningen, NL to finalize the guidelines and recommendations for the use of the simulation model (GECROS) for Mediterranean environment. A working paper is annexed to the last annual report. During this meeting between partners from WP4 and WP3, it was decided to use the model in its original form using FORTRAN (TSP Windows, version 1.08), programmed in FST (FORTRAN Simulation Translator, van Kraalingen *et al.*, 2003) since it was no more possible to prepare the model GECROS on a simple interface using a spreadsheet of Excel after the departure of the research assistant from the Netherlands' team.

Many of the model parameters were already fixed, however some others needed a new parameterization, and for this new dataset from field experiments of Sidi El Aidi-Settat (Morocco) as used to calibrate the new model parameters, namely soil parameters, species specific and genotype parameters, also the crop management parameters such as fertilization and irrigation. The new parameters were defined and described in detail in the working paper on cropping system modelling recommendations.

Agronomic strategies for optimal use of nitrogen and water in the Mediterranean Basin

An independent data set for durum wheat and barley was used for validation of the model. For durum wheat, three cultivars (Karim, Nassira and Ourgh) were considered. These cultivars were subjected to 10 management strategies (a combination of nitrogen rates and time of application). The nitrogen fertilizer treatments were applied as ammonium nitrate at the rates: 0; 40; 80; 120 and 160 kg/ha. Timing of application was: at sowing date, tillering and at stem elongation. This gave rise to the following managements strategies: 0-0-0 (control); 0-40-0; 0-40-40; 0-80-0; 0-80-40; 40-0-0; 40-40-0; 40-40-40; 40-80-0; and 40-80-40 kg N ha^{-1}. A detailed description of the experimental site, crop management and weather conditions are reported on a previous scientific report (2006). For the cultivars which were not included in the calibration study, we did not have the correspondent genotype parameters such as phenology MTDV and MTDR, SEEDW, SEEDNC, BLD, HTMX, PNPRE, and then we used the data from a DB of INRA on previous experiments to estimate these parameters.

For barley, the cultivar included in this study was Tissa which is a common variety used in our region, for this case we modified the species parameters according to the values described by Yin and Van Laar (2005) and we also estimated the genotypes parameters from existing experiments and literature. The last version of GECROS model calibrated to Mediterranean region is available along with the guidelines for use (deliverable D4.2).

The results showed that the comparison of simulated and observed variables of three durum wheat cultivars was accurate for grain yield (RMSD= 83 g/m^2, r^2=0.80); inaccurate for the number of grain yield per area (NG/m^2) (RMSD= 4018 $grains/m^2$, r^2=0.01) and for grain weight (r^2=0.20), acceptable but slightly overestimated the shoot dry weight at both anthesis (RMSD= 521 g/m^2, r^2=0.79) and maturity (RMSD= 286 g/m^2, r^2=0.72) (Figure 2). These results are encouraging, especially those estimating the grain yield. The results are comparable with the values found in the literature for several models. However, the inaccuracy in estimating the yield components such as the NG/m^2 needs further development of the model algorithm especially when using it in the Mediterranean conditions. In GECROS model, the NG/m^2 is calculated based on nitrogen accumulation and the genotype specific parameter NPRE (proportion of seed N expected from relocation of N taken up before seed number determining phase), this represents an advantage, unfortunately the estimation of this variable is not accurate, other methods taking into account the biomass accumulation from flag leaf could help enhancing this issue (Wang *et al.*, 2003).

The model validation slightly overestimated the grain yield (RMSD= 159 g/m^2, r^2=0.79); especially in the irrigated site. However data for grain weight showed opposite results, an overestimation in the rainfed site and a good estimation in the irrigated conditions. Considering both sites the model underestimated the grain weight by 36.1% (RMSD=3 g, r^2=0.32). The shoot dry weight at maturity was overestimated by the model by up to 50% (RMSD=6 g/m^2, r^2=0.58). Due to some irregularity in experimental data the results for validation of the model were not shown for the growing season 2005/06. The GECROS model developed initially for the conditions of the Netherlands showed good performances. The model is based on individual physiological crop processes with interaction of climatic factors and availability of resources such as nitrogen and water (Yin and Van Laar, 2005). In areas with arid and semi-arid conditions, the climate is irregular and subjected to big fluctuations which influence strongly the soil water availability and nitrogen content (Garabet *et al.*, 1998). Under field conditions the crops are also subjected to biotic stress; pest and diseases can significantly influence the yield and its components (Duveiller *et al.*, 2007).

To test and evaluate the decision aid and package of agronomic strategies developed by the project and through the model (Figure 3 and 4), on-farm trials were conducted in a major producing area of wheat and barley in the arid and semiarid regions of Morocco. For this purpose eight selected farmer's sites with large plots of at least 1 hectare each: 4 with barley cv. Tissa and 4 with durum wheat cv. Tomouh. The farmer's strategy (FS) consisted in application of common practice of nitrogen fertilization. The proposed strategy (PS) in the WatNitMED project from model output consisted in three applications of ammonium nitrate: at sowing date, tillering and at stem elongation stage. For each application 40 kg/ha of ammonium nitrate was added. For each trial a total of 120 kg/ha of N fertilizer was applied. The objectives of this experiment were to test and evaluate the decision aid and package of agronomic strategies developed by the project and also, to evaluate the prediction of grain yield and total biomass by GECROS model for all trials (deliverable D4.3). The climatic data was obtained from the nearest weather station (Sidi El Aidi (Settat)).

For durum wheat trials the results showed that grain yields were considerably different among farmers, being slightly similar for total biomass yields (except farmer 4 with less grain and total biomass production) (Figure 5 and 6). The FS and PS identified in WatNitMED project were significantly different. The PS showed an increase in grain yield ranging from 20 (Farmer 2) to 400% (Farmer 1), also, an increase for total biomass ranging from 27 (Farmer 2) to 175% (Farmer 1). This increase in grain and total biomass yields is mainly due to nitrogen fertilization, since all farmers sowed on the same date and no one had supplement irrigation. The differences among farmers are probably due to local conditions. The GECROS model predicted well the grain and total biomass yields. There were not significant differences in simulated data among farmers, due to almost similar crop managements. Considering all data, the regression coefficient r^2 was 0.62 between observed and simulated data.

For barley trials, the difference among farmers was mainly due to irrigation. Applications of supplemental irrigations were translated into high grain and total biomass yields. The PS (40+40+40 kg/ha N) generated significant grain yield increases up to 300%, and up to 160% for total biomass yield. The simulated data by GECROS model showed significant differences among farmers, due to crop managements, especially irrigation and sowing dates, while timing of nitrogen application was to some extent similar (Figure 7 and 8). The model overestimated yield and above ground biomass especially in irrigated conditions (Farmers 2 and 3), while the prediction in rainfed conditions was more convincing.

Conclusions

Genotype × Environment × Management interactions obviously determine yield and quality of cereals. To minimise the input of water and nutrients (especially nitrogen) and maximise yield and quality require deep knowledge of ecophysiological bases. In this WP a detailed review of the literature in Mediterranean region was developed, in conjunction many experiments were conducted to design, evaluate agronomic and water management strategies and also develop and adapt the GECROS cropping model to Mediterranean environment. In this context, the GECROS model performance was quite accurate for grain yield and total biomass. The strength of GECROS is that actual yields can be simulated quite accurately when drought and N deficiency do not affect crop growth process strongly. The model however was less convincing for yield components. Under Mediterranean conditions, the interaction genotype by environment (biotic and abiotic stress) is quite complex which can affect considerably the performance of the model. For a better evaluation of the GECROS, more experiments are needed and a good control of pest and diseases is required.

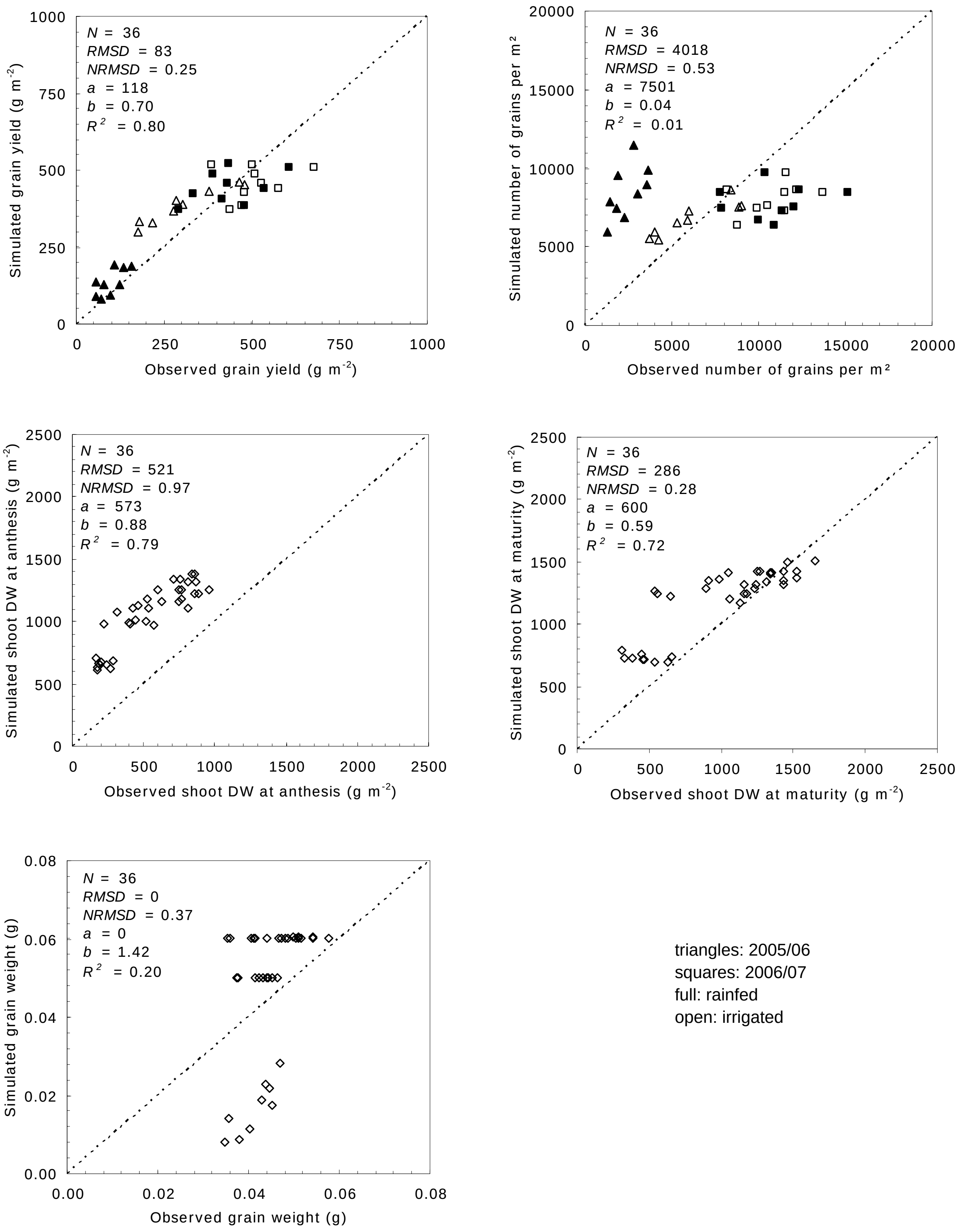


Figure 1. Model calibration; simulated versus observed data for three genotypes (Karim, Donta and Hourani) under three Nitrogen treatments (N0, N60 and N120 kg/ha) and two contrasting water regimes (rainfed and irrigated) during two years in Sidi El Aidi experimental station (Morocco).

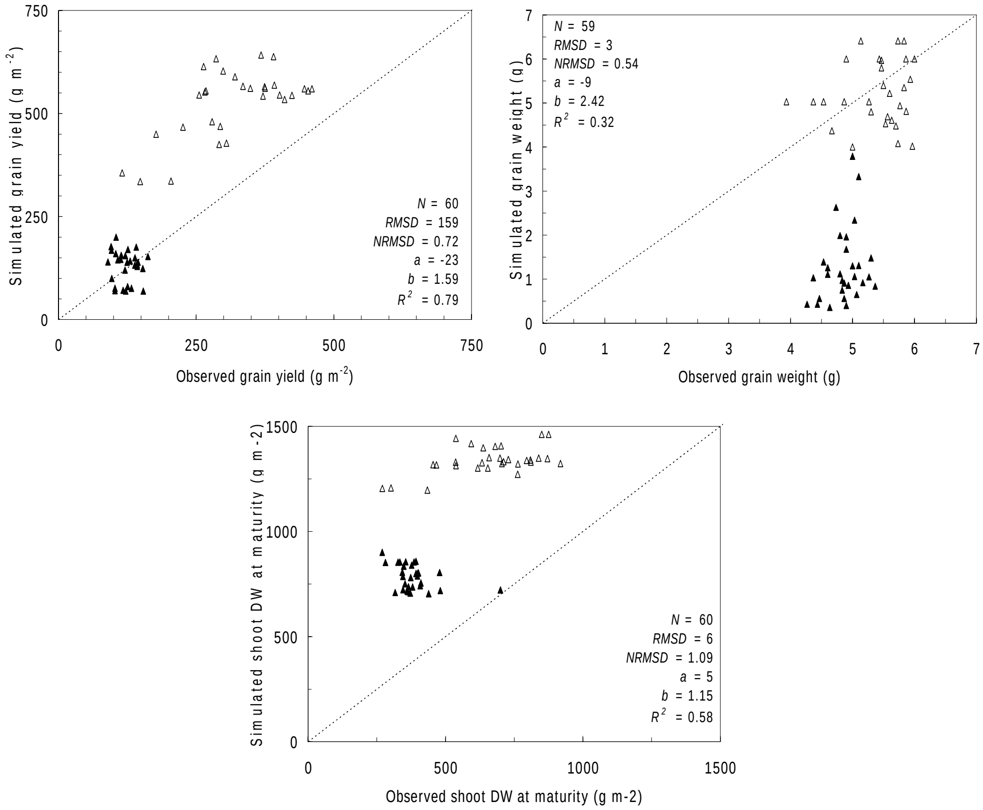


Figure 2. Model evaluation; simulated versus observed data for three genotypes (Karim, Nassira and Ourgh) under 10 N treatments (a combination of nitrogen rates and time of application) during the growing season 2006-07 in Sidi El Aidi experimental station (Morocco), full triangles: rainfed, open triangles: irrigated conditions.

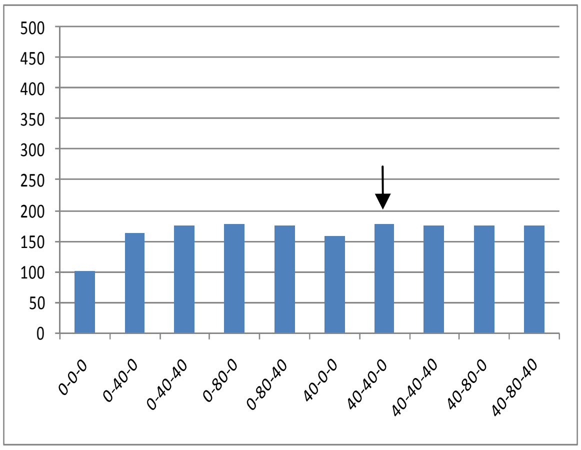


Figure 3. Scenario of simulated grain yield using different nitrogen strategies under rainfed conditions of Morocco using GECROS model.

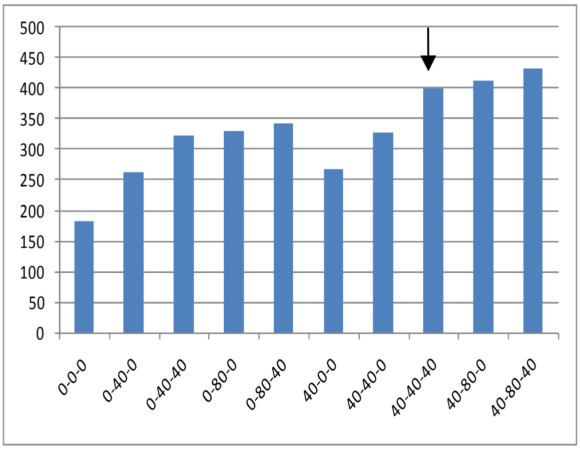


Figure 4. Scenario of simulated grain yield using different nitrogen s strategies under irrigated conditions of Morocco using GECROS model.

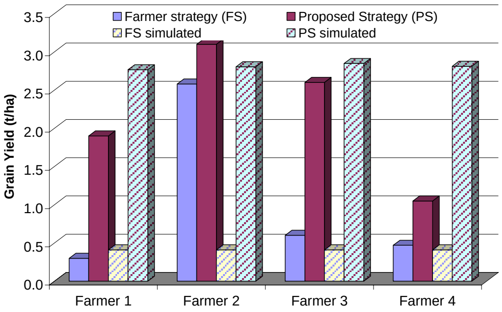


Figure 5. On-farm demonstration: Grain Yield (GY) of durum wheat *vs*. GY simulated by GECROS model.

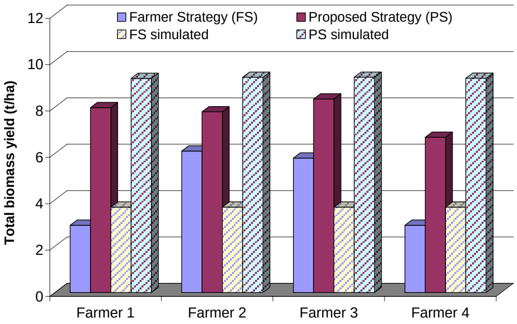


Figure 6. On-farm demonstration: Total Biomass Yield (TBY) of durum wheat *vs.* TBY simulated by GECROS model.

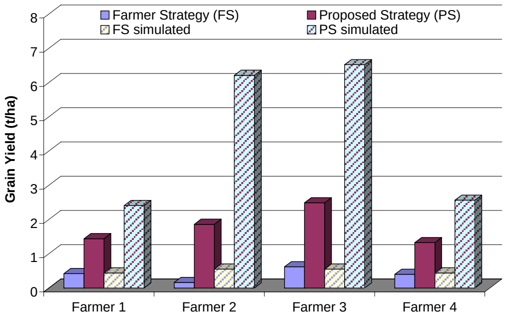


Figure 7. On-farm demonstration: Grain Yield (GY) of barley *vs*. GY simulated by GECROS model.

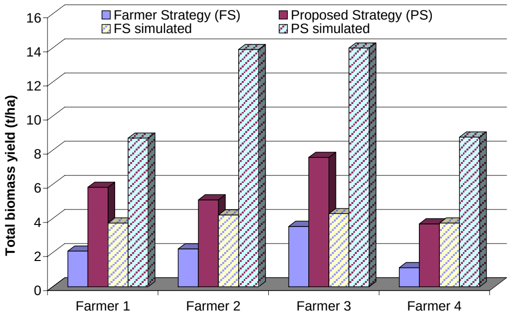


Figure 8. On-farm demonstration: Total Biomass Yield (TBY) of barley *vs*. TBY simulated by GECROS model.

WP5 Root Capture

Leader of workpackage: **Partner 5, UNOTT UK**

Workpackage Objectives

- Identify single root traits or combinations of traits for improved resource capture under different timing and intensity of water and/or N stress.
- Quantify responses of root growth, root: shoot partitioning and water and N capture to a wide range of simulated environments differing in timing and intensity of water and N stresses, using controlled environment conditions.

List of Deliverables

- D5.1 Datasets describing responses of rooting traits and water and N capture to a range of water and/or N stresses; appropriate treatment combinations of water and N identified for further evaluation in the field (Achieved in 2007/8).
- D5.2 A list of rooting traits and combinations of traits tested for physiological relationships with water and N resource capture (Achieved in 2007/8).
- D5.3 A list of candidate traits for further evaluation in WP3 and WP4 (Achieved in 2007).
- D5.4 A final report summarizing scientific findings of WP5 (Achieved in 2009).

List of Milestones

- M5.1 A Preliminary controlled environment studies - initiated (Achieved in 2005).
- M5.2 Preliminary controlled environment studies – analysed (Achieved in 2006).
- M5.3 First detailed controlled environment experiments – initiated (Achieved in 2006).
- M5.4 First controlled environment experiments – analysed (Achieved in 2007).
- M5.5 Second year of detailed controlled environment experiments – initiated (Achieved in 2007).
- M5.6 Second year of controlled environment experiments – analysed (Achieved in 2008).
- M5.7 Submit report summarising scientific findings of WP5 (Achieved in 2009).

Summary of WorkPackage Main Findings

Material and methods

Three controlled-environment experiments were carried out in 2006, 2007, and 2008 at the University of Nottingham, School of Biosciences, Sutton Bonington Campus, UK (52.5° N, 1.3° W) to test the responses of root growth, below-ground resource capture and above-ground growth to water and N stresses in Mediterranean barley and durum wheat. The treatments in each experiment are summarized in Table 1.

Table 1. Experimental treatments (species, irrigation, nitrogen) for the experiments carried out in 2006, 2007 and 2008

Experiments Year	**Species**	**Treatments**		**Reps.**	**Sampling points**
		Irrigation	**N (equivalent)**		
2006	Barley cv Rum Wheat cv Hourani	Irrigated (90% FC) Drought (50% to 25% FC)	0 Kg ha^{-1} 50 Kg ha^{-1} 100 Kg ha^{-1}	3	5
2007	Barley cv Rum Wheat cv Karim Wheat cv Hourani	Irrigated (90% FC) Drought (50% to 25% FC)	0 Kg ha^{-1} 50 Kg ha^{-1} 100 Kg ha^{-1}	5	3 *(1 for wheat cv Hourani)*
2008	Barley cv Rum	Irrigated (90% FC) Drought (50% to 25% FC)	50 Kg ha^{-1}	5	3

Three South Mediterranean cereals genotypes were used: one spring barley (*Hordeum vulgare* L.) variety, cv. Rum (in 2006, 2007 and 2008), and two durum wheat (*Triticum durum* L.) varieties, cvs Hourani (in 2006 and 2007) and Karim (in 2007). Both barley cv. Rum and wheat cv. Hourani are commonly grown in Jordan. The durum wheat cv. Karim is a modern variety currently grown in Tunisia and Morocco. The 2006 and 2007 experiments used a factorial randomised block design and the 2008 experiment a completely randomized block design.

Single seeds of genotypes were sown in plastic pots with 7 cm diameter, 8.5 cm depth (Fig. 1), at a depth of 2 cm. The soil used was sandy loam of low N availability in 2006 and a mixture of 80 or 60% washed sand with sandy loam in 2007 and 2008, respectively. After vernalization, the plants were transplanted into PVC columns (one plant per column), 15 cm diameter, filled to a depth of 100 or 150 cm (Fig. 1). The 100 cm columns were used on the first two samplings and the 150 cm one for the final sampling.

For all the sampling points in each year the developmental stage according to Zadoks' system was recorded, according to the stage on the main stem. The shoots were separated into four categories: main stem, fertile tiller 1-3 (T1-3), fertile tiller 4+ (T4+), and non-fertile shoots. Each of the categories was separately analysed. For the fertile shoot categories, the number of leaves and ears as well as: (i) flag-leaf green and dead areas, (ii) remaining leaf lamina green and dead areas, (iii) stem plus sheath green and non-green areas, and (iv) green ear area was recorded using a leaf area meter

(Licor 3100, Lexicon instruments, Lincoln, Nebraska). The dry weight of all green and non-green plant components was recorded after drying for 48 h at 80ºC.

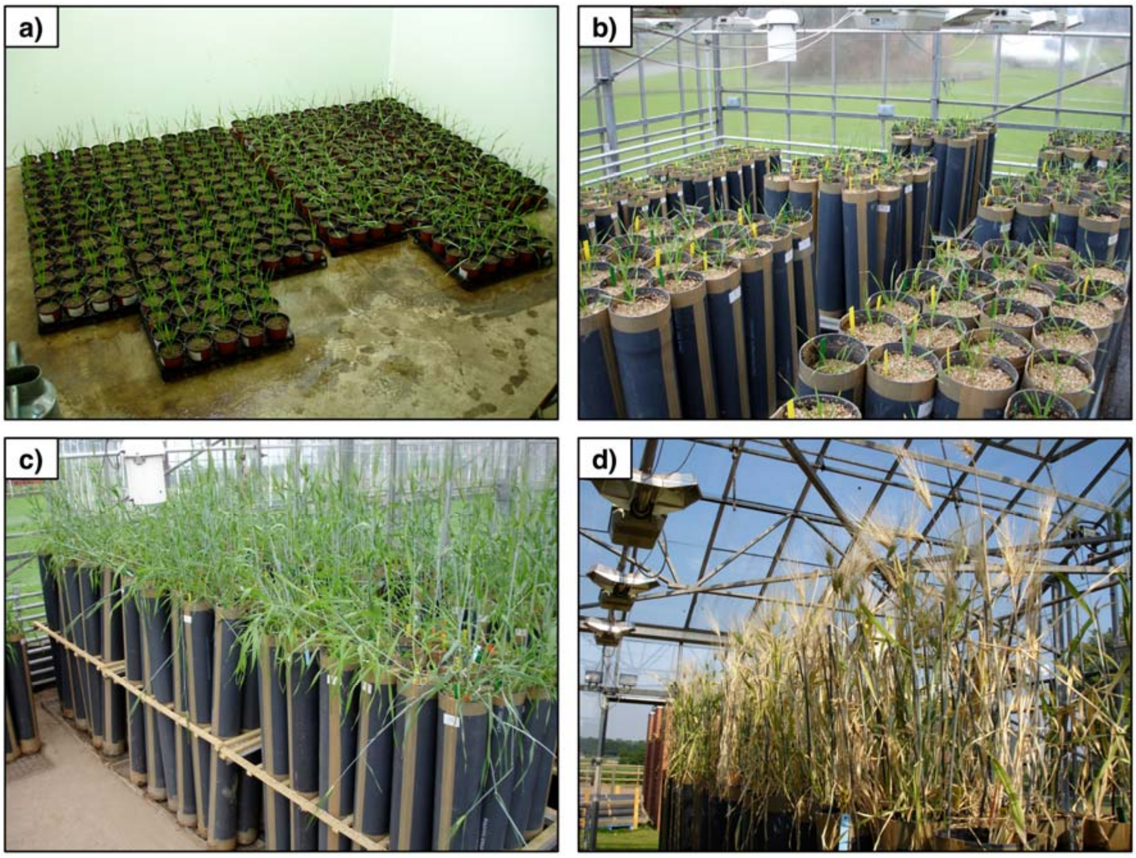


Figure 1. The 2006 experiment: a) wheat cv. Hourani and barley cv. Rum in growth room during vernalization, b) after transplantation into soil columns, c) general view of the plants and d) plants near to maturity.

After sampling plants, the roots were extracted from the soil using a Delta-T root washer (RWC-UM-2, Delta-T Devices LTD, Cambridge, UK; 8) in 20 cm soil layers to 100 cm; and in 25 cm soil layers from 100 to 150 cm. Cleaned root samples were digitalized (at 400 dpi resolution and 256 greys contrast, Tiff file format) with a scanner with a transparency adapter (WinRHIZO STD 1600+, Regent Instruments Inc., Quebec, Canada). On the scanned images of the root systems the total length, mean diameter, total area and volume were measured, using the WinRHIZO regular V.2002c software (Regent Instruments Inc., Quebec, Canada). Subsequent to scanning the root system, dry weight was recorded after drying for 48 h at 80ºC.

Plant water use (WU) in 2006 was gravimetrically measured weekly. In 2007 and 2008 the WU was calculated weekly using the soil moisture per layer data measured with the ThetaProbe MLX2 in access holes in the column at each soil layer depth.

Estimation of critical root length and root volume densities

The root length density (RLD; cm cm^{-3}) and root volume density (RVD; cm dm^{-3}) were analysed for three soil-depths (0 -20, 60-80 and > 125 cm). The proportional resource (water) capture (ϕ) was calculated as the percentage of available water (water in the soil – water at permanent wilting point) captured from: (i) anthesis to harvest for the drought treatment, and (ii) during the last 3 weeks of grain growth for the irrigated treatment, for each soil-depth. These values of ϕ were then used to estimate a resource capture coefficient (k) from the RLD and RVD data according to the equations 1 and 2:

$$\phi = 1 - e^{-k_{RLD} \times RLD},\ \text{for RLD} \qquad \text{Eqn 1}$$

$$\phi = 1 - e^{-k_{RVD} \times RVD},\ \text{for RVD} \qquad \text{Eqn 2}$$

Critical RLD (C_{RLD}) and critical RVD (C_{RVD}) are defined as the values of RLD and RVD required for the plants to extract 90% ($\phi = 0.9$) of the water available in the soil. Calculations of C_{RLD} and C_{RVD} were made solving equations 1 and 2 for RLD and RVD, respectively, for a $\phi = 0.9$. The β parameter describing the shape of the proportional distribution of root weight (β_W), length (β_L) and volume (β_V) with soil depth was calculated fitting the Eqn 3 to the cumulative distribution of the relevant traits in the soil layers analysed.

$$Y = 1 - \beta_w^{\,d} \qquad \text{Eqn 3}$$

The R:S ratio is calculated as the ratio between the above-ground dry mass and the total root weight. Since in the experiment the complete root system was not analysed, the total root weight was estimated by interpolation between the three measured soil layers.

Main Results

The data collected allow us to consider the physiological basis of the differences in water and N capture in the different irrigation and/ or N treatments in spring barley and durum wheat.

Root: shoot partitioning

The most common effect of water and/ or N deficits on biomass partitioning is an increase in the relative biomass allocated to the roots (Brouwer, 1983). In pot glasshouse experiments, Karrou & Maranville (1994) using Moroccan bread wheat varieties found R:S values in the range of 0.186 – 0.369 at anthesis. In the present study all R:S values were much lower than the above-mentioned findings. Overall R:S average for barley cv. Rum at anthesis and harvest across experiments was 0.040 and 0.037 respectively, while for durum wheat at harvest it was 0.096 and 0.031 for cv. Hourani and cv. Karim 0.037 and 0.029. For all genotypes R:S increased with drought at anthesis and harvest (except for barley cv. Rum in 2008); and this response was higher for wheat cvs Hourani and Karim than for barley cv. Rum. N application did not change the biomass allocation pattern (Fig. 2).

Distribution of RLD with depth (β)

In 2006, at anthesis for all the three soil layers (0 – 20, 60 – 80 and >125 cm) barley cv. Rum had higher RLD than wheat cv. Hourani ($p < 0.01$ (Fig. 3). At harvest at 0 – 20 cm, there was an effect of irrigation ($p \leq 0.01$), and an interaction between irrigation and species ($p \leq 0.01$), with drought decreasing RLD by 0.614 cm cm^{-3} for barley cv. Rum, but with no effect for wheat cv. Hourani. There was also a nitrogen ($p = 0.053$) and an irrigation x nitrogen effect ($p \leq 0.01$), with nitrogen application decreasing the RLD for both species under irrigation, although not under drought.

In 2007 at harvest, for barley cv Rum drought increased RLD of all soil layers, by 30% ($p \leq 0.05$) at 0 – 20 cm, 181% ($p \leq 0.001$) at 40 – 60 cm and 205% ($p \leq 0.05$) at 80 – 100 cm. At harvest the overall RLD was 62% higher for barley cv. Rum than for wheat cv. Karim. For barley cv. Rum at harvest in 2008 a decrease of the RLD with depth was found for the drought treatment, but not for the irrigated treatment. Drought decreased RLD at all soil layers in study but only significantly at the soil depth > 125 cm.

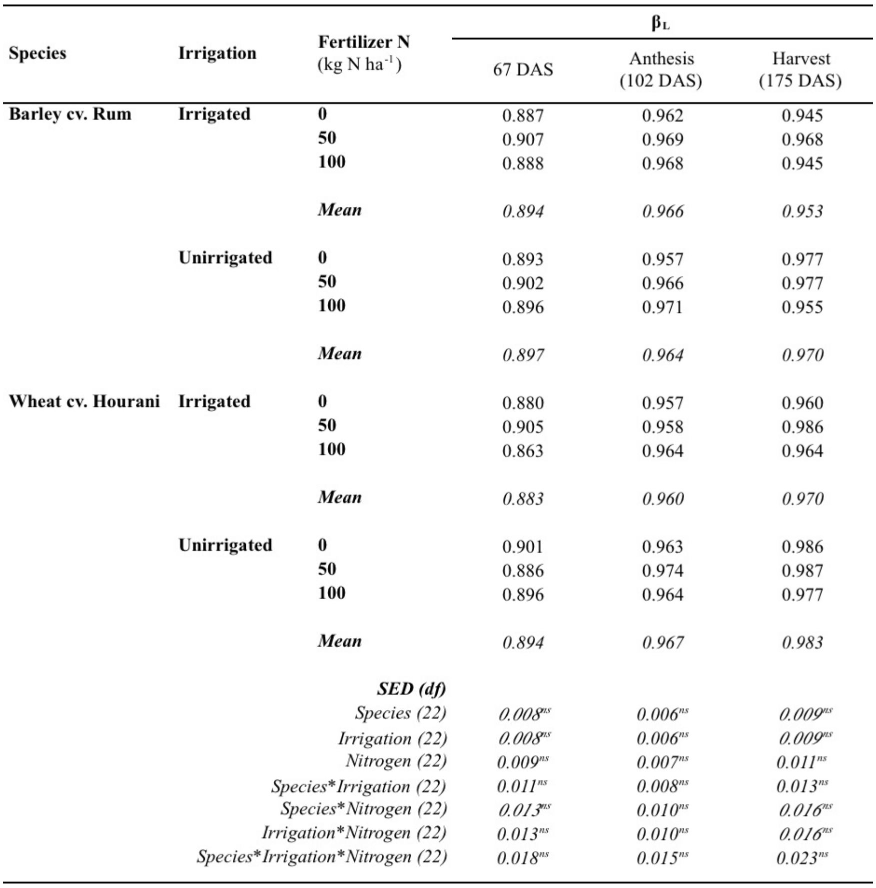
The β_L estimated from the soil-depth layers analysed generally increased (rlelatively deeper roots) with time for both barley cv. Rum and wheat cv. Hourani in 2006 (Table 2). Representing a decrease from 89% of proportion root length in the top 20 cm at 67 DAS to only 55% at harvest for barley cv. Rum; and 91% cf. to 38% respectively for wheat cv. Hourani

In 2007 for barley cv. Rum, β_L increased with time from an overall value of 0.940 at 75 DAS to 0.981 at harvest, representing a decrease of the proportion of root length in the soil-depth 0 – 20 cm from 71% to 31% (Table 2). For wheat cv. Karim, β_L also increased with time but only to anthesis. Deeper root distribution (higher β_L) was found under drought: at anthesis for barley cv. Rum ($p \leq 0.05$) and harvest for wheat cv. Karim ($p \leq 0.001$) and wheat cv. Hourani ($p = 0.068$; Table 2). Nitrogen application slightly decreased ($p \leq 0.05$) from a β_L of 0.974 with nil N applied to 0.970 with 50 kg N ha^{-1} and 0.968 with 100 kg N ha^{-1} (Table 2). Overall wheat cv. Karim ($\beta_L = 0.965$) at harvest had lower proportion of root length deeper in the profile when compared to barley cv. Rum ($\beta_L = 0.981$) and wheat cv. Hourani ($\beta_L = 0.979$); with only 5% wheat cv. Karim root length being below 100 cm soil-depth comparing to 12 – 15% for wheat cv. Hourani and barley cv. Rum.

For barley cv. Rum at harvest in contrast to 2008 irrigation increased ($p \leq 0.05$) the βL. This means that under irrigation 15% of root length was distributed bellow 100 cm comparing to only 5% under drought.

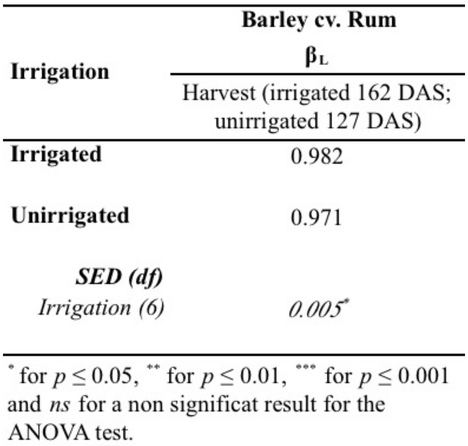
Table 2. The cumulative length distribution with depth (β_L) estimated from three soil depths: 0 – 20 cm, 20 – 40 cm and 40 – 60 cm at 67 DAS; 0 – 20 cm, 60 – 80 cm, > 125 cm for barley cv. Rum and durum wheat cvs Hourani and Karm in irrigated and unirrigated treatments at three levels of N fertilizer (0, 50 and 100 kg N ha^{-1}), at 67 DAS, anthesis and harvest in a) 2006, b) 2008 and c) 2007

a) 2006



Species	Irrigation	Fertilizer N (kg N ha^{-1})	β_L 67 DAS	β_L Anthesis (102 DAS)	β_L Harvest (175 DAS)
Barley cv. Rum	**Irrigated**	**0**	0.887	0.962	0.945
		50	0.907	0.969	0.968
		100	0.888	0.968	0.945
		Mean	*0.894*	*0.966*	*0.953*
	Unirrigated	**0**	0.893	0.957	0.977
		50	0.902	0.966	0.977
		100	0.896	0.971	0.955
		Mean	*0.897*	*0.964*	*0.970*
Wheat cv. Hourani	**Irrigated**	**0**	0.880	0.957	0.960
		50	0.905	0.958	0.986
		100	0.863	0.964	0.964
		Mean	*0.883*	*0.960*	*0.970*
	Unirrigated	**0**	0.901	0.963	0.986
		50	0.886	0.974	0.987
		100	0.896	0.964	0.977
		Mean	*0.894*	*0.967*	*0.983*
		SED (df)			
		Species (22)	*0.008^{ns}*	*0.006^{ns}*	*0.009^{ns}*
		Irrigation (22)	*0.008^{ns}*	*0.006^{ns}*	*0.009^{ns}*
		Nitrogen (22)	*0.009^{ns}*	*0.007^{ns}*	*0.011^{ns}*
		*Species*Irrigation (22)*	*0.011^{ns}*	*0.008^{ns}*	*0.013^{ns}*
		*Species*Nitrogen (22)*	*0.013^{ns}*	*0.010^{ns}*	*0.016^{ns}*
		*Irrigation*Nitrogen (22)*	*0.013^{ns}*	*0.010^{ns}*	*0.016^{ns}*
		*Species*Irrigation*Nitrogen (22)*	*0.018^{ns}*	*0.015^{ns}*	*0.023^{ns}*

b) 2008

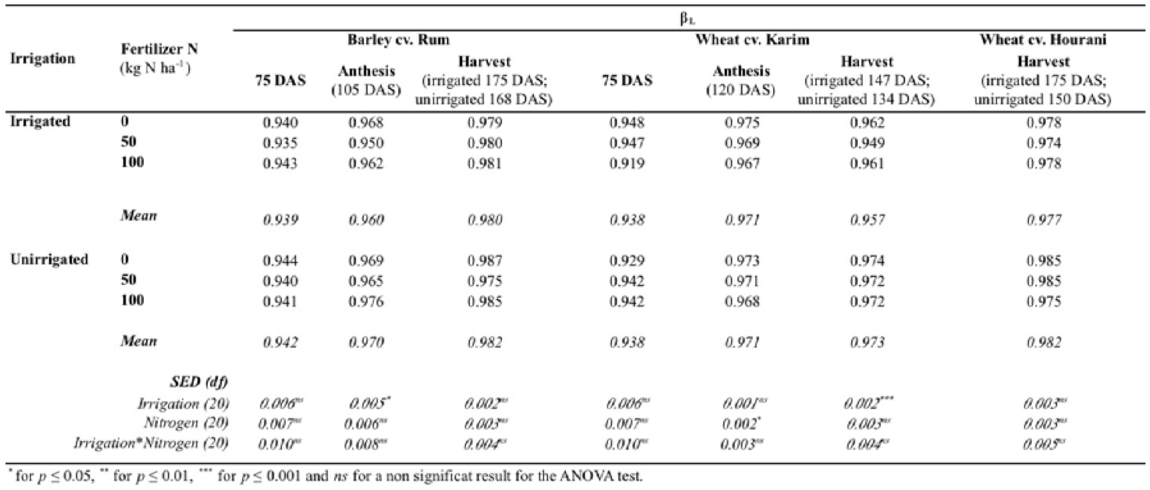


Irrigation	Barley cv. Rum β_L Harvest (irrigated 162 DAS; unirrigated 127 DAS)
Irrigated	0.982
Unirrigated	0.971
SED (df)	
Irrigation (6)	*0.005**

* for $p \leq 0.05$, ** for $p \leq 0.01$, *** for $p \leq 0.001$ and *ns* for a non significat result for the ANOVA test.

Table 2. (cont.)

c) 2007



Irrigation	Fertilizer N (kg N ha^{-1})	β_L						
		Barley cv. Rum			Wheat cv. Karim			Wheat cv. Hourani
		75 DAS	Anthesis (105 DAS)	Harvest (irrigated 175 DAS; unirrigated 168 DAS)	75 DAS	Anthesis (120 DAS)	Harvest (irrigated 147 DAS; unirrigated 134 DAS)	Harvest (irrigated 175 DAS; unirrigated 150 DAS)
Irrigated	**0**	0.940	0.968	0.979	0.948	0.975	0.962	0.978
	50	0.935	0.950	0.980	0.947	0.969	0.949	0.974
	100	0.943	0.962	0.981	0.919	0.967	0.961	0.978
	Mean	*0.939*	*0.960*	*0.980*	*0.938*	*0.971*	*0.957*	*0.977*
Unirrigated	**0**	0.944	0.969	0.987	0.929	0.973	0.974	0.985
	50	0.940	0.965	0.975	0.942	0.971	0.972	0.985
	100	0.941	0.976	0.985	0.942	0.968	0.972	0.975
	Mean	*0.942*	*0.970*	*0.982*	*0.938*	*0.971*	*0.973*	*0.982*
	SED (df)							
	Irrigation (20)	0.006^{ns}	0.005^{*}	0.002^{ns}	0.006^{ns}	0.001^{ns}	0.002^{***}	0.003^{ns}
	Nitrogen (20)	0.007^{ns}	0.006^{ns}	0.003^{ns}	0.007^{ns}	0.002^{*}	0.003^{ns}	0.003^{ns}
	*Irrigation*Nitrogen (20)*	0.010^{ns}	0.008^{ns}	0.004^{ns}	0.010^{ns}	0.003^{ns}	0.004^{ns}	0.005^{ns}

* for $p \leq 0.05$, ** for $p \leq 0.01$, *** for $p \leq 0.001$ and *ns* for a non significat result for the ANOVA test.

Relationship between proportional water capture and rooting traits

For barley cv Rum, the regressions obtained for ϕ and rooting traits, particularly RVD in 2007, gave successful fits and hence estimates of the critical values of root size for water capture. Unfortunately the RLD and RVD values in the 2007 experiment were generally low and the critical values equivalent to 90% potential resource capture were therefore extrapolated beyond the points of the observed values. Thus, one of the main objectives of the 2008 experiment was to examine the relationship between ϕ and water capture across a wider range of RLD and consequently to obtain a more reliable estimate of the C_{RLD} and C_{RVD} values. In 2008 for the fully irrigated treatment, the regression between ϕ and both RLD and RVD was not significant. However, under drought both regressions were statistically significant. The regression was also significant when pooling the data across 2007 and 2008 for the N50 data. The k_{RLD} value for in 2008 was 2.42 cm^2 corresponding to C_{RLD} of 0.95 cm cm^{-3} (Fig 3; Table 3) When using the pooled 2007 and 2008 data the k_{RLD} value slightly decreased to 2.40 cm^2 increasing the C_{RLD} to 0.96 cm cm^{-3}, whilst R^2 substantially increased from 0.77 to 0.91. The regression between ϕ and RVD for 2008 resulted in a k_{RVD} value of 6.41 ($R^2 = 0.89$, $p \leq 0.01$) and a C_{RVD} of 0.36 cm^{-3}, but when using the pooled 2007 and 2008 data the k_{RVD} value was 5.21 ($R^2 = 0.94$, $p \leq 0.01$) and the critical C_{RVD} 0.44 cm^3cm^{-3}.

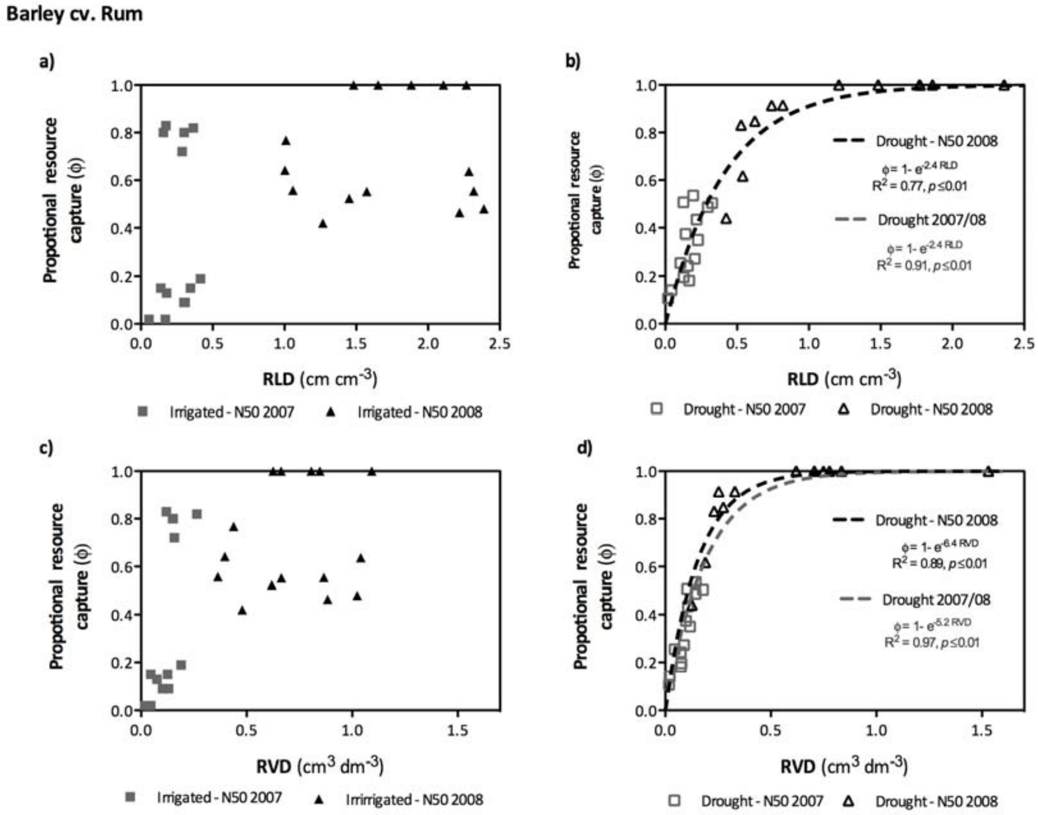


Figure 3. Regression of proportion of available water captured (ϕ) on root length density (RLD) in 2007 and 2008 under (a) full irrigation and (b) drought; and on root volume density (RVD) in 2007 and 2008 under (c) irrigation and (d) drought,. $\phi = 1 - e^{-k\ RLD}$ and $\phi = 1 - e^{k\ RVD}$ barley cv. Rum with an application of 50 Kg N ha^{-1} in fully irrigated (closed symbols) and droughted treatments (open symbols), only significant regressions are shown (df = 12 for 2008 and df = 26 for 2007/2008).

With regard to effects in durum wheat, the main findings were K_{RLD} was approximately 2.4 for barley (cv Rum) under drought, but 3.5 for durum wheat (cv Karim). Also overall K_{RLD} had a slightly higher value under drought than irrigation. Similar effects were observed for RVD. Although the growth of the durum wheat was apparently sub optimal in the glasshouse conditions in the UK, the function of the root in terms of the relationship between root traits and uptake should be unaffected by the intrinsic range of root density. Thus. the comparison of the wheat versus barley for root morphology traits may have been affected slightly by the low tillering for durum wheat experienced in the UK glasshouse conditions. Nevertheless the comparison root function as described the relationship between RLD and potential resource capture should not have been affected by differences in the overall range of RLD between the two species.

Table 3. Summary of effects for K (resource capture coefficient) for a) root length density (RLD) and b) root volume density (RVD) and critical root densities in 2007 and 2008

a)	2007		2008	
Genotype	K_{RLD}	C_{RLD} (cm cm^{-3})	K_{RLD}	C_{RLD} (cm cm^{-3})
Wheat cv Hourani	-	-		
Wheat cv Kari	Irr = 5.6	Irr = 0.41		
	Unirr = 3.7	Unirr = 0.63		
Barley cv Rum	Unirr = 2.7	Unirr = 0.85	Unirr = 2.4	Unirr = 0.95

b)	2007		2008	
Genotype	K_{RLD}	C_{RVD} (cm cm^{-3})	K_{RLD}	C_{RVD} (cm dm^{-3})
Wheat cv Hourani	Irr = 5.0	Irr = 0.46		
	Unirr = 4.4	Unirr = 0.52		
Wheat cv Kari	Irr = 10.0	Irr = 0.23		
	Unirr = 6.1	Unirr = 0.38		
Barley cv Rum	Irr = 5.2	Irr = 0.45		
	Unirr = 4.7	Unirr = 0.49	Unirr = 6.4	Unirr = 0.36

Conclusions

The N treatment only had a statistically significant effect in increasing N uptake and above-ground growth in 2006, probably associated with high mineralization of soil N during the growing season. So most emphasis on the interpretation of the present results is placed on the relationship between rooting traits and water capture. The main root parameters investigated were:

- Root: shoot dry weight ratio
- β (cumulative DW ratio with depth)
- Specific root length (cm root cm^{-3} soil volume)
- K (resource capture coefficeinct; describes curvature of exponential relations between increasing RLD (K_{RLD}) or RVD (K_{RVD}) and proportional water capture

For wheat and barley crops grown in Mediterranean environments, the interactions between fertilizer N applications, yield and water use are imperfectly understood, but since roots are the agents of both water and nutrient uptake their activity is crucial. To be in a position to manage more effectively, an improved quantitative understanding of relationships between root traits and capture of water and nitrogen is required. The results of WP5 have increased our understanding of root activity during grain filling, and the factors that influence it. Our results indicate the weight of the shoot and root systems do not provide the best measure of their ability to capture resources. A more appropriate measure is the relation between potential water uptake and root length density (cm root length per unit soil volume, RLD). The relationship between RLD and below-ground resource capture in cereal root systems may be described in a quantitative model, linking the size and distribution of the root system to the capture of water during grain filling. Our results demonstrate that a larger investment in fine roots at depth in the soil and less proliferation of roots in surface layers would improve yields in rain-fed Mediterranean environments with moderate to high winter rainfall, by accessing extra resources. The results of the WP were used to assist in the development of the GECROS model in WP3 'Modelling' coordinated by University of Wageningen and to develop protocols for measuring roots and identify target root traits for investigation in field experiments in WP 10 'Crop root capture' co-ordinated by University of Jordan.

In summary, the main findings were:

- Relative cumulative distribution of roots with depth β generally was similar for barley (cv Rum) and wheat (cvs Hournai and Karim) at ca. 0.97-0.98
- There was generally a tendency for drought to increase β (relatively deeper roots), particularly for durum wheat cv. in Karim in 2007
- No effect of N was observed on β values
- KRLD was ca. 2.4 for barley (cv Rum) under drought, but KRLD was slightly higher for durum wheat than barley at ca. 3.5. Therefore the critical root length density (= 90% available water capture) was greater in barley (0.96 cm-2) than in durum wheat (0.63 cm-2)
- The critical root length density we report for spring barley is generally similar to values reported for spring barley in the literature of ca. 1 cm cm-3 (Gregory and Brown,), whereas that for durum wheat is lower than previous reports of crtical root length density of ca. 1-2 cm for winter bread wheat (Barraclough et al, 1989).
- For cv Rum barley one unique relationship explained the variation between RLD and proportional available resource capture (ϕ) in all three experiments: $\phi = 1 - e^{-2.4.RLD}$
- The resource capture coefficient KRLD tended to be slightly higher under irrigation than drought
- Generally similar treatment effects observed for RVD and RLD in the present experiments

References

Barraclough, P.B., Kuhlmann, H. & Weir, A.H. (1989). The effects of prolonged drought and nitrogen-fertilizer on root and shoot growth and water-uptake by winter-wheat. Journal of Agronomy and Crop Science **163**: 352-360.

Brouwer, R. (1983). Functional equilibrium: sense or nonsense? *Netherlands Journal of Agricultural Science* **31**, 335-348.

Gregory, P.J. & Brown, S.C. (1989). Root growth, water use and yield of crops in dry environments: what characteristics are desirable? Aspects of Applied Biology **22**: 235–243.

Karrou, M. & Maranville, J.W. (1994). Response of wheat cultivars to different soil nitrogen and moisture regimes: I. Dry matter partitioning and root growth. *Journal of Plant Nutrition* **17**: 729-744.

WP6 Plant growth/Yield

Leader of workpackage: **Partner 6, UB Spain**

Workpackage Objectives

- Identify single root traits or combinations of traits for improved resource capture under different timing and intensity of water and/or N stress.
- Quantify responses of root growth, root: shoot partitioning and water and N capture to a wide range of simulated environments differing in timing and intensity of water and N stresses, using controlled environment conditions.

List of Deliverables

- D6.1 Photosynthetic productivity of crops under two growing environments at two nitrogen levels (Achieved in 2007).
- D6.2 Water and nitrogen use efficiency of crops under two growing environments at two nitrogen levels (Achieved in 2006).
- D6.3 A final report summarising scientific findings of WP6 (Achieved in 2009).

List of milestones and progress

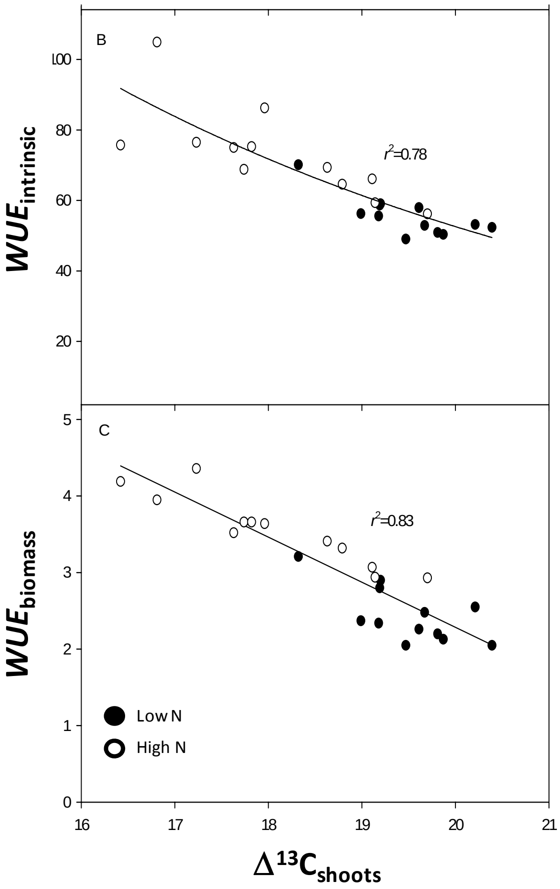
- M6.1 Ecophysiological performance of crops under contrasting environments at different nitrogen levels (Achieved in 2006).
- M6.2 Relationship between physiological parameters and agronomic parameters measured in the field conditions. (Achieved in 2007).
- M6.3 Description of crops with the best water and nitrogen use efficiency. (Achieved in 2008).
- M6.4 Submit report summarising scientific findings of WP6 (Achieved in 2009).

Summary of Workpackage Main Findings

In order to achieve the objectives of WP6, the following experiments were carried out:

The combined effect of constant water deficit and nitrogen supply on WUE, NUE and $\Delta^{13}C$ in durum wheat potted plants

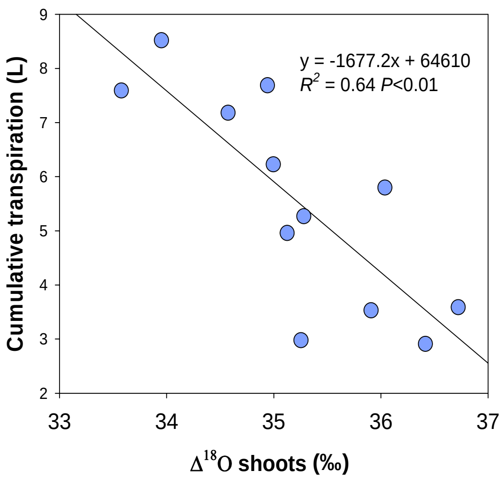
Water scarcity and nitrogen shortage are the main constraints on durum wheat productivity. This study examines the combined effects of a constant water deficit and nitrogen supply on growth, photosynthesis, stomatal conductance and transpiration, instantaneous and time-integrated water-use efficiency (WUE) and nitrogen-use efficiency (NUE) and carbon isotope discrimination ($\Delta^{13}C$) in durum wheat genotypes grown in pots under greenhouse conditions. Three water levels (40, 70 and 100% container capacity), two nitrogen doses (high and low N) and four genotypes were assayed in a total of 24 experimental treatments. Water and nitrogen treatments were imposed two weeks after plant emergence. The growth, nitrogen content and $\Delta^{13}C$ of the shoot and the gas exchange in the flag leaf were determined about two weeks after anthesis. As expected, both water and nitrogen supply had a strong positive effect on growth. However a reduction in water supply had low effect decreasing photosynthesis and transpiration, $\Delta^{13}C$ and NUE and increasing WUE. On the other hand, increasing the level of nitrogen supplied had a significant negative effect on stomatal conductance, which decreased significantly the ratio of intercellular to ambient CO_2 concentrations and $\Delta^{13}C$, and increased both instantaneous and time-integrated WUE. In addition, a higher N level also negatively affected the instantaneous and time-integrated NUE. The $\Delta^{13}C$ of shoots correlated significantly and negatively with either instantaneous or time-integrated measurements of WUE. Moreover, within each nitrogen supply, $\Delta^{13}C$ also correlated negatively with the integrated NUE. We concluded that under our experimental conditions, $\Delta^{13}C$ gives information about the efficiency with which not just water but also nitrogen are used by the plant. In addition this study illustrates that a steady water limitation may strongly affect biomass without consistent changes in WUE. The lack of effect of the different water regimes on gas exchange, WUE and $\Delta^{13}C$ illustrate the importance of how stress is imposed during growth.

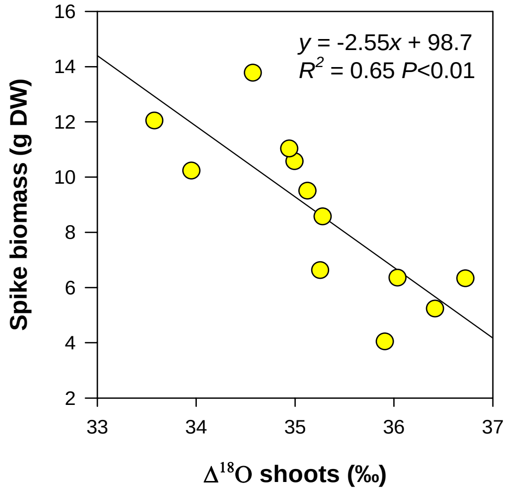


	Low Nitrogen			High Nitrogen		
	40%	**70%**	**100%**	**40%**	**70%**	**100%**
Shoot DM	$7{,}8^{c}$	$11{,}6^{b}$	$32{,}2^{a}$	$14{,}8^{c}$	$25{,}5^{b}$	$38{,}3^{a}$
A_{sat}	$16{,}2^{b}$	$18{,}6^{a}$	$17{,}4^{a}$	$14{,}1^{b}$	$15{,}6^{b}$	$18{,}1^{a}$
g_s	$0{,}32^{ab}$	$0{,}37^{a}$	$0{,}30^{b}$	$0{,}20^{b}$	$0{,}23^{b}$	$0{,}29^{a}$
T	$3{,}1^{ab}$	$3{,}7^{a}$	$3{,}0^{b}$	$2{,}1^{b}$	$2{,}3^{b}$	$3{,}0^{a}$
C_i/C_a	$0{,}72^{a}$	$0{,}72^{a}$	$0{,}68^{a}$	$0{,}62^{a}$	$0{,}64^{a}$	$0{,}66^{a}$
Leaf N	$3{,}6^{b}$	$4{,}1^{a}$	$4{,}1^{a}$	$4{,}3^{a}$	$4{,}4^{a}$	$4{,}5^{a}$
Δ^{13}C Shoots	$19{,}6^{a}$	$19{,}7^{a}$	$19{,}2^{b}$	$17{,}8^{b}$	$17{,}8^{b}$	$18{,}6^{a}$
$WUE_{biomass}$	$2{,}2^{b}$	$2{,}2^{b}$	$2{,}9^{a}$	$3{,}5^{a}$	$3{,}5^{a}$	$3{,}6^{a}$
$WUE_{instantaneous}$	$5{,}3^{a}$	$5{,}3^{a}$	$5{,}9^{a}$	$6{,}9^{a}$	$6{,}9^{a}$	$6{,}5^{a}$

Water and nitrogen conditions affect the relationships of Δ^{13}C and Δ^{18}O with gas exchange and growth in durum wheat

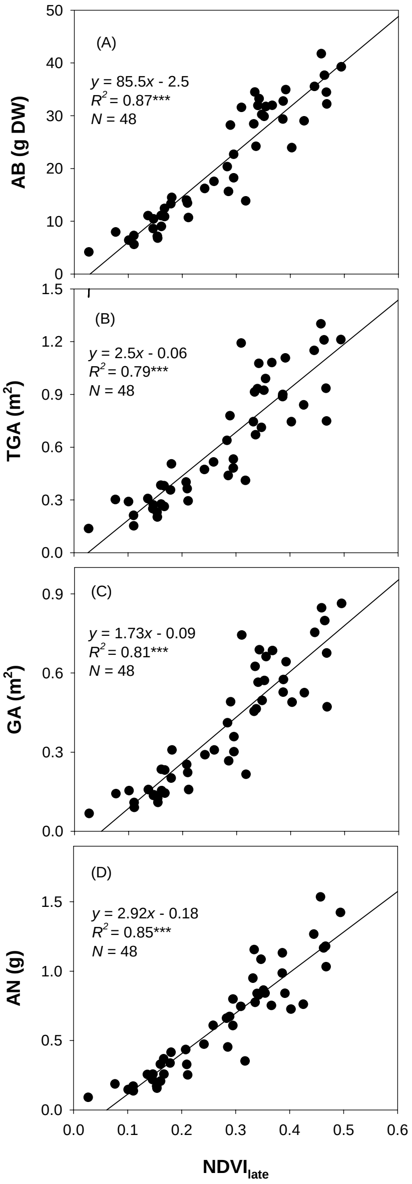
Whereas the effects of water and nitrogen on plant Δ^{13}C have been previously reported, these factors have scarcely been studied for Δ^{18}O. In this study, we investigated the combined effect of different water and nitrogen (N) regimes on Δ^{13}C, Δ^{18}O, gas exchange, water-use efficiency (*WUE*) and growth of four genotypes of durum wheat (*Triticum turgidum* L. ssp. *durum* (Desf.) Husn.) cultiv in pots. Water and nitrogen supply significantly increased plant growth. However, a reduction in water supply did not lead to a significant decrease in gas-exchange parameters, and consequently Δ^{13}C was only slightly modified by water input. Conversely, N fertilizer significantly decreased Δ^{13}C. On the other hand, water supply decreased Δ^{18}O values, whereas N did not affect this parameter. Δ^{18}O variation was mainly determined by the amount of transpired water throughout plant growth (T_{cum}), whereas Δ^{13}C variation was explained in part by a combination of leaf N and stomatal conductance (g_s). Even though the four genotypes showed significant differences in cumulative transpiration rates and biomass this was not translated into significant differences in $\Delta^{18}O_S$. However, genotypic differences in Δ^{13}C were observed. Moreover, around 80% of the variation in biomass across growing conditions and genotypes was explained by a combination of both isotopes, with Δ^{18}O alone accounting for about 50%. This illustrates the usefulness of combining Δ^{18}O and Δ^{13}C in order to assess differences in plant growth and total transpiration, and also to provide a time-integrated record of the photosynthetic and evaporative performance of the plant during the course of crop growth.





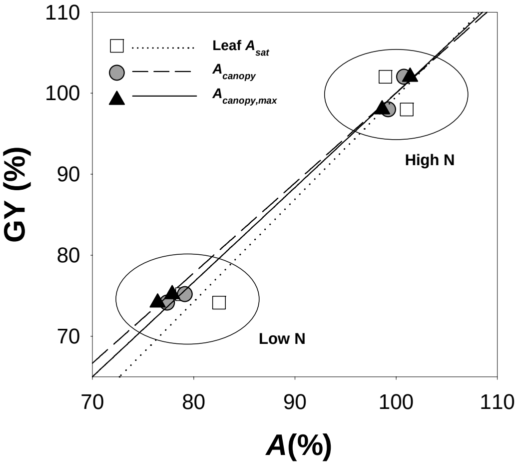
NDVI as a potential tool for predicting biomass, nitrogen content and growth in potted wheat genotypes.

The application of spectroradiometric indices such as the Normalized Difference Vegetation Index (NDVI) to assess green biomass or total nitrogen content has focused on the plant canopy in, for example, precision agriculture or breeding programs. However, little is known about the usefulness of these techniques in isolated plants. The few reports available propose the use of a spectroradiometer in combination with special adaptors that improve signal acquisition from plants, but this makes measurements relatively slow and unsuitable. Here we studied the direct use (i.e. without adaptors) of a commercial low-cost spectroradiometer (GreenSeeker^{TM}) provided with an active sensor (i.e. equipped with its own source of radiation) for measuring NDVI in four genotypes of durum wheat (*Triticum turgidum* L. var. durum) grown in pots under a range of water and nitrogen regimes. Strong correlations were found between NDVI measurements and dry aboveground biomass (AB), total green area (TGA), total green area without spikes (GA) and aboveground nitrogen content (AN). To prove the predictive ability of NDVI measured under potted conditions, linear regression models for each growth trait and for nitrogen content were built with the data of two genotypes. These then predicted, on the basis of NDVI measurements, the response of the two outstanding genotypes, which differed greatly in plant growth and nitrogen accumulation. The models accurately predicted growth traits and nitrogen content, particularly in relation to AB, confirming the direct relationship between total plant biomass and spectroradiometric readings. In addition, the instruments and methodological procedure, used to measure NDVI from wheat plants grown in pots, proved to be easier and faster than with previous approaches.



Photosynthetic capacity of field-grown durum wheat under different N availabilities: a comparative study from leaf to canopy

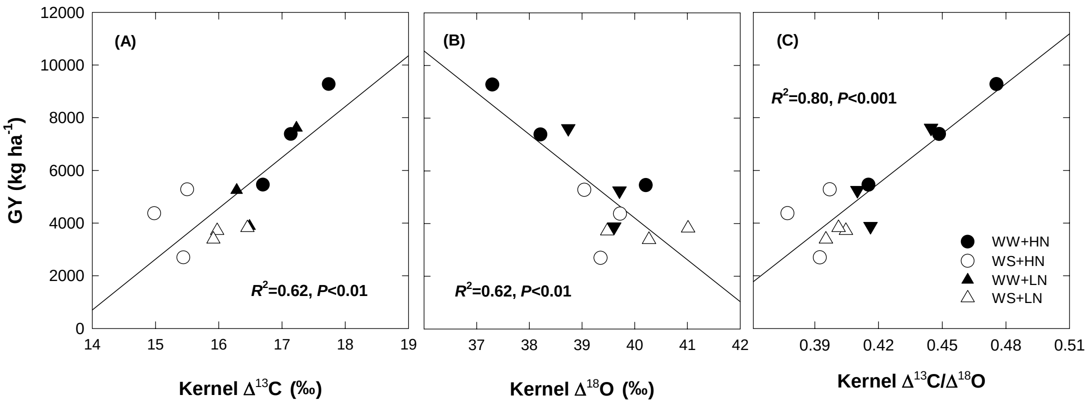
The effect of N availability on photosynthetic capacity, growth parameters and yield was studied in field-grown durum-wheat plants at both the leaf and canopy levels. Two contrasting nitrogen levels (120 and 0 kg ha$^{-1)}$ were assayed in a randomised block design with 9 replicates each. Total biomass was measured at anthesis and yield and its agronomical components at maturity. Photosynthetic measurements were performed two weeks after anthesis in two plots of each N treatment. Flag leaves were measured, using a LI-COR 6400 combined with the chlorophyll fluorescence meter, and the whole canopy by measuring CO_2 and H_2O fluxes in an innovative canopy-chamber system. We showed a clear increase in photosynthetic gas-exchange and chlorophyll contents with N fertilisation at both canopy and leaf levels. As a consequence the increase in yield as response to N fertilisation seems the result of a larger green leaf area combined with a higher photosynthetic capacity of the leaves attributable to an increase in the maximum carboxylation velocity of Rubisco. Moreover gas exchange measurements of the flag leaf during grain filling seem to provide a realistic characterisation, not just of the photosynthetic performance of the crop, but also about the impact of N availability on yield. Thus, measurements performed on the flag leaf matched those at the canopy level, with proportional increases in terms of gas exchange and chlorophyll content, providing a fast, cheap and reliable estimation of canopy photosynthesis and the grain yield attained by the crop.



	Low N			High N		
GY **(Mg ha^{-1})**	4.0	±	0.5	5.8	±	0.3*
HI	0.45	±	0.02	0.48	±	0.02
TKW **(g)**	56.6	±	0.9	57.3	±	1.0
KWP **(g)**	3.2	±	0.4	5.2	±	0.5*
Grains spike^{-1}	30.2	±	2.2	37.5	±	3.0*
Spikes plant^{-1}	1.9	±	0.2	2.5	±	0.2*
AB **(Kg m^{-2})**	1.0	±	0.1	1.3	±	0.1*
LAI **(m^{2} m^{-2})**	0.6	±	0.3	2.2	±	0.4*
SPAD	30.2	±	1.8	51.3	±	1.8*
NDVI	0.51	±	0.05	0.74	±	0.02*
Ψ_p (MPa)	-0.38	±	0.05	-0.48	±	0.08
Ψ_m (MPa)	-1.85	±	0.11	-1.88	±	0.11

Dual Δ^{13}C/Δ^{18}O response to water and nitrogen availability and its relationship with yield in durum wheat and barley

Wheat and barley are commonly grown under rain-fed production systems where water limitation, which is frequently accompanied by low nitrogen (N) availability, is the main constraint limiting yield. However despite its importance, few reports comparing wheat and barley performance under different water and N conditions are available. Leaf and kernel Δ^{13}C values were significantly affected by water regime, with higher values under WW conditions. Regardless of the water and nitrogen conditions, lower Δ^{13}C values were found in kernels than leaves. This may reflect changes in soil water availability, as well as an increase in evaporative demand occurring during the final stages of crop growth, however, the lower g_s of the spike compared with that of leaves may also be involved. In addition higher kernel Δ^{13}C values were observed in barley. On the other hand, kernel δ^{18}O values decreased with water supply and also as a result of nitrogen fertilization. Lower kernel δ^{18}O values were also found in barley. The lower δ^{18}O values in plants grown under WW conditions are in accordance with the current theory of Barbour & Farquhar. The higher Δ^{13}C and the lower δ^{18}O values in barley could be related with the higher *E* values found when compared with wheat. In addition kernel Δ^{13}C and δ^{18}O correlated positively and negatively with the GY in wheat. However such correlations were not found in barley. In conclusion, the combined measurement of Δ^{13}C and δ^{18}O in plant matter seems to be interesting for plant breeding as may help separate the independent effects of carbon fixation and stomatal conductance. Thus, the simultaneous measurement of Δ^{13}C and δ^{18}O can be used to understand how water and nitrogen may affect variation in water-use efficiency and yield.



WP7 Plant Sink Strength

Leader of workpackage: **Partner 7, MTT Finland**

Workpackage Objectives

- To identify the effects of water deficit, occurring at growth stages typical to Mediterranean climate, on nitrogen (N) and carbon (C) dynamics of barley and wheat, in controlled environment experiments.

- To link the drought induced changes in nitrogen and carbon dynamics to growth, source versus sink limitation and yield determination, and to quantify the recorded effects in response to timing of drought.

- To understand the underlying physiological processes (enzymes, hormones) responsible for recorded responses to water deficit. (This was dropped due to cutting in research funding).

List of Deliverables

- D7.1 Datasets describing relationships between N and C economy as well as formation and realisation of yield in response to water x N availability. (Achieved in 2006/7).

- D7.2 A list of traits and trait combinations dominating crop response to drought in terms of grain setting and establishment of sink strength. (Achieved in 2006/7).

- D7.3 A list of most critical (vulnerable) growth stages of barley and wheat to water x N deficit. (Achieved in 2006/7).

- D7.4 A final report summarising scientific findings of WP7. (Achieved in 2009).

List of Milestones

- M7.1 First year of controlled environment experiments – initiated (Achieved in 2005).

- M7.2 First year of controlled environment experiments – data available (Achieved in 2005).

- M7.3 First year of controlled environment experiments – data analyzed (Achieved in 2006).

- M7.4 Second year of controlled environment experiments – initiated (Achieved in 2006).

- M7.5 Third year of controlled environment experiments – initiated (Achieved in 2007).

- M7.6 Third year of controlled environment experiments – data analyzed (Achieved in 2008).

- M7.7 Fourth year of controlled environment experiment – initiated (Achieved in 2008)

- M7.8 Fourth year of controlled environment experiment – data analysed (Achieved in 2009).

- M7.9 Scientific report summarizing findings of WP7 submitted (Achieved in 2009).

Summary of Workpackage Main Findings

Material and methods

Wheat (cv. Amaretto) and barley (cv. Clyde) were studied by organising their experiments for different years due to the high number of treatments and replications and the need for large sampling areas in each treatment. Controlled environment experiments were arranged in a greenhouse (20 x 30 m) with automatic control of day length, temperature and watering. Day length (with automatic blackout curtains) and temperature were set to correspond with the mean values typical for Mediterranean climate. Sowings were carried out with standard, experimental field machinery.

Experiment was arranged in randomised block design with control watering and drought treatments imposed either prior or post pollination. Each main plot had individually controllable watering system. Watering treatments were CONT (control watering), DR1 (drought prior pollination) and DR2 (drought at grain filling). Fertiliser (NPK 20-3-8) was supplied prior to sowing by placing into soil at the rate of N 120 kg ha^{-1} (2005, wheat), 60 and 120 kg ha^{-1} (2006, wheat) and 0 and 120 kg ha^{-1} (2007, barley). An additional pot experiment with barley and wheat was arranged in 2008. Plants were grown in open-sided greenhouse. Barley (cv. Clyde) and wheat (cv. Amaretto) were grown under controlled conditions in plastic pots containing 9 kg of nutrient poor quartz sand (92% with grain diameter <0.5 mm). Pots were fertilised with NPK (20-2-12) at rate of 3 g of N per pot. Micronutrients were supplemented separately. Twenty-five seeds were sown per pot and after sprouting plant stands were thinned to 20 seedlings. Pots were placed outdoors in a greenhouse with net walls and a glass roof in a completely randomised design with 12 pots per treatment. Watering treatments were control (CONT, full watering), early drought induced at 4-leaf stage (DR1, drought prior pollination) and terminal drought (DR2, drought at grain filling). Drought prior pollination (DR1) was onset at four-leaf stage withholding watering. At pollination watering was resumed in DR1 and withheld in DR2. Aphids were controlled with deltamethrin spray.

Photosynthesis and stomatal conductance of wheat flag leaves, or before flag leaf emergence, the youngest fully developed leaves, were measured with portable CO_2 exchange measuring equipment (LCA-3, ADC Ltd, Hoddesdon, UK), combined with Parkinson Leaf Cuvette for narrow leaves. Leaf water potential measurement: the uppermost fully expanded leaf was detached and the water potential measured using a pressure chamber (PMS Instrument Co., Corvallis, OR, USA). To measure osmotic potential on the same material, leaves were frozen in liquid N and stored at –80ºC until analysis. The sap was squeezed out from thawed leaf and then the osmolality was measured by a freezing point depression osmometer (Micro-Osmometer 3M, Advanced Instruments Inc., USA). Physiological measurements were started on onset of DR1 and carried out 7-14 days interval until yellow ripeness.

Ovary starvation and abortion were studied close to pollination for control and DR2 treatments by feeding five wheat plants per plot with carboxyfluorescein diacetate (CFDA), which was injected to peduncle (halfway from flag leaf stipule to head). Each plant was fed with about 2-3 ml of prepared CFDA stain (50 µl CFDA per 10 ml KOH with pH 6.13 and diluted with H_20 to end up in 200 ml of solution). Day after injection, stained samples were collected and stored at –80 ºC until sectioned and viewed under microscope.

Spike samples were collected for determination of endosperm cell number development and starch, sucrose and invertase localization. Date of pollination was determined for each plot. After that spikes were collected at two to four day intervals. Samples for starch, sucrose and invertase localization were stored at –80 ºC or fixed in FAA until sectioned, stained and viewed under microscope.

Biomass and N accumulation measurements were conducted from early stem elongation to yellow ripeness 7 to 14 day interval. 20 randomly sampled, up-rooted plants per plot were divided to main shoot and tillers and then to leaves, stems and at later stages to spikes to monitor drought effects on biomass accumulation to different plant parts. N content was measured using a modified version of the Kjeldahl procedure with a Kjeltec Auto 1030 Analyzer (Tecator Ab, Höganäs, Sweden).

Grain yield was combine harvested and yield components were measured on plant samples randomly up-rooted when yellow ripened.

Main results

According to the repeated physiological measurements, drought treatments were successfully organised. Stomatal conductance and photosynthetic rate decreased together with decreasing water content of the soil in DR1 treatment. When watering was resumed, both stomatal conductance and photosynthetic rate expressed clear recovery from the drought. In the course of the terminal drought (DR2), both stomatal conductance and photosynthetic rates decreased steadily. Similar steady decrease was observed also in control treatment, most likely due to leaf aging and beginning of senescence (Figure 1). Also leaf water potential and osmotic potential clearly responded to the water availability in the early drought treatment (DR1). Leaf water potential decreased and osmotic potential increased until the watering was resumed. Also terminal drought (DR2) caused similar results but to a lesser extent.

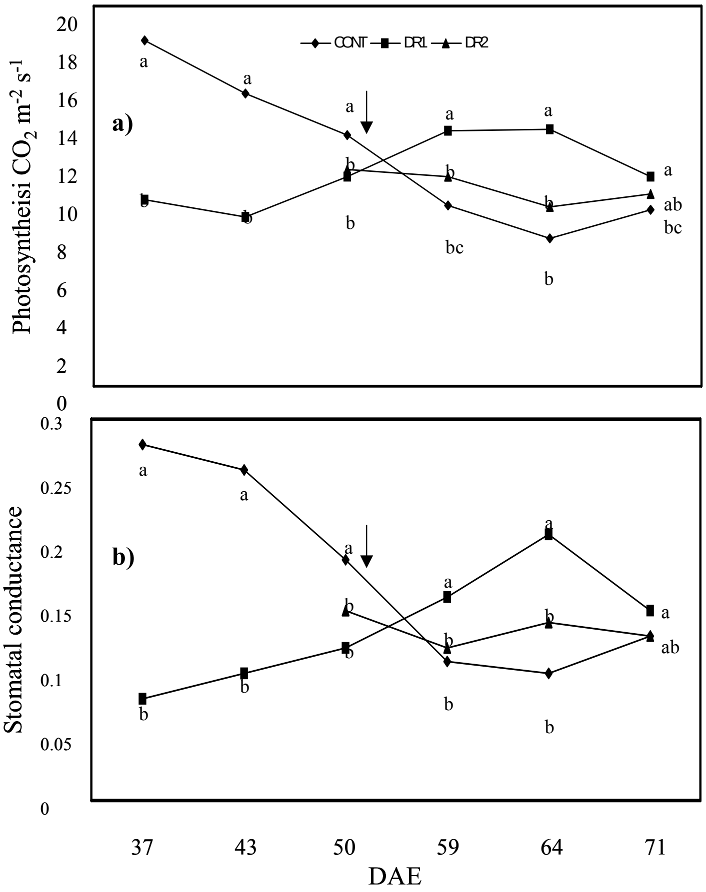


Figure 1. Watering effect on leaf photosynthesis (a) and stomatal conductance (b) during growing period in wheat (2006 trial). CONT, contol watering; DR1, drought prior pollination; DR2, drought during grain filling; DAE, days after pollination. The same lowercase letter indicates no statistical difference at P=0.05. Arrow indicates the time of pollination.Limited water and N availability reduced growth and biomass accumulation during the growth cycle (Table 1).

Table 1. Biomass accumulation (g plant^{-1}) in barley (2007 trial). Presented over N and water regimes. The same lowercase letter within N rate and watering indicates no statistical difference at P=0.05CONT, contol watering; DR1, drought prior pollination; DR2, drought during grain filling

	DAE							
Treatment	33		46		60		maturity	
N 0	0.29	a	0.78	b	1.37	b	2.33	b
N 120	0.36	a	1.20	a	2.01	a	3.09	a
CONT	0.33	a	1.17	a	2.29	a	3.65	a
DR1	0.30	a	0.68	b	1.09	c	1.90	c
DR2	0.34	a	1.13	a	1.66	b	2.59	b

N 0, N fertilisation rate 0 kg N ha^{-1}; N 120, N fertilisation rate 120 kg N ha^{-1}

The timing of drought affected different components of the yield. Early drought (DR1) reduced strongly fertile floret number in wheat and potential grain number in barley. DR1 reduced strongly grain number, but it did not have a negative effect on single grain weight. Terminal drought (DR2) reduced both grain number and single grain weight (Table 2). Also low N availability reduced both of these yield components, but to a lesser degree. Early drought (DR1) reduced both source and sink capacity, whereas DR2 reduced only source capacity. When watering was resumed at pollination in DR1, favourable water availability during grain filling enhanced assimilate distribution to fewer grains resulting in similar or higher single grain weight than in CONT. Both drought and low N resulted in yield reductions at individual plant and plot level (Table 2).

Table 2. Yield and yield components of barley (2007 trial). The same lowercase letter within N rate and watering indicates no statistical difference at P=0.05sgw, single grain weight; HI, harvest index; N 0, N

	grain potential no		grains plant^{-1} no		sgw mg		HI %		yield plant^{-1} mg		plot yield kg ha^{-1}		tiller yield %	
N 0	45.9	a	26	b	32.9	a	33.8	a	832	b	1605	b	3.4	b
N 120	49.0	a	32.2	a	33.8	a	34.4	a	1111	a	2337	a	7.2	a
CONT	55.3	a	39.4	a	39.5	a	43.0	a	1563	a	2885	a	2.9	b
DR1	34.5	b	15.3	c	36	a	28.6	b	546	c	1423	b	11.4	a
DR2	52.5	a	32.5	b	24.6	b	30.8	b	805	b	1605	b	1.7	b

fertilisation rate 0 kg N ha^{-1}; N 120, N fertilisation rate 120 kg N ha^{-1}; CONT, contol watering; DR1, drought prior pollination; DR2, drought during grain filling

When yield formation was examined within the spike at spikelet level, DR1 and in DR2 reduced grain number more evidently in two most apical spikelets and in spikelets situated below the fourth/fifth spikelet from the apex, phenomenon being similar for barley and wheat (Figure 2ab). The spikelets at the mid-section of the spike dominated yield formation. In those spikelets the grain number and SGW, as well as grain yield were the highest in both species (Figures 2cd). High N increased spikelet yield particularly below the fourth spikelet from the apex. Both species responded to nitrogen rather similarly (Figure 2ef).

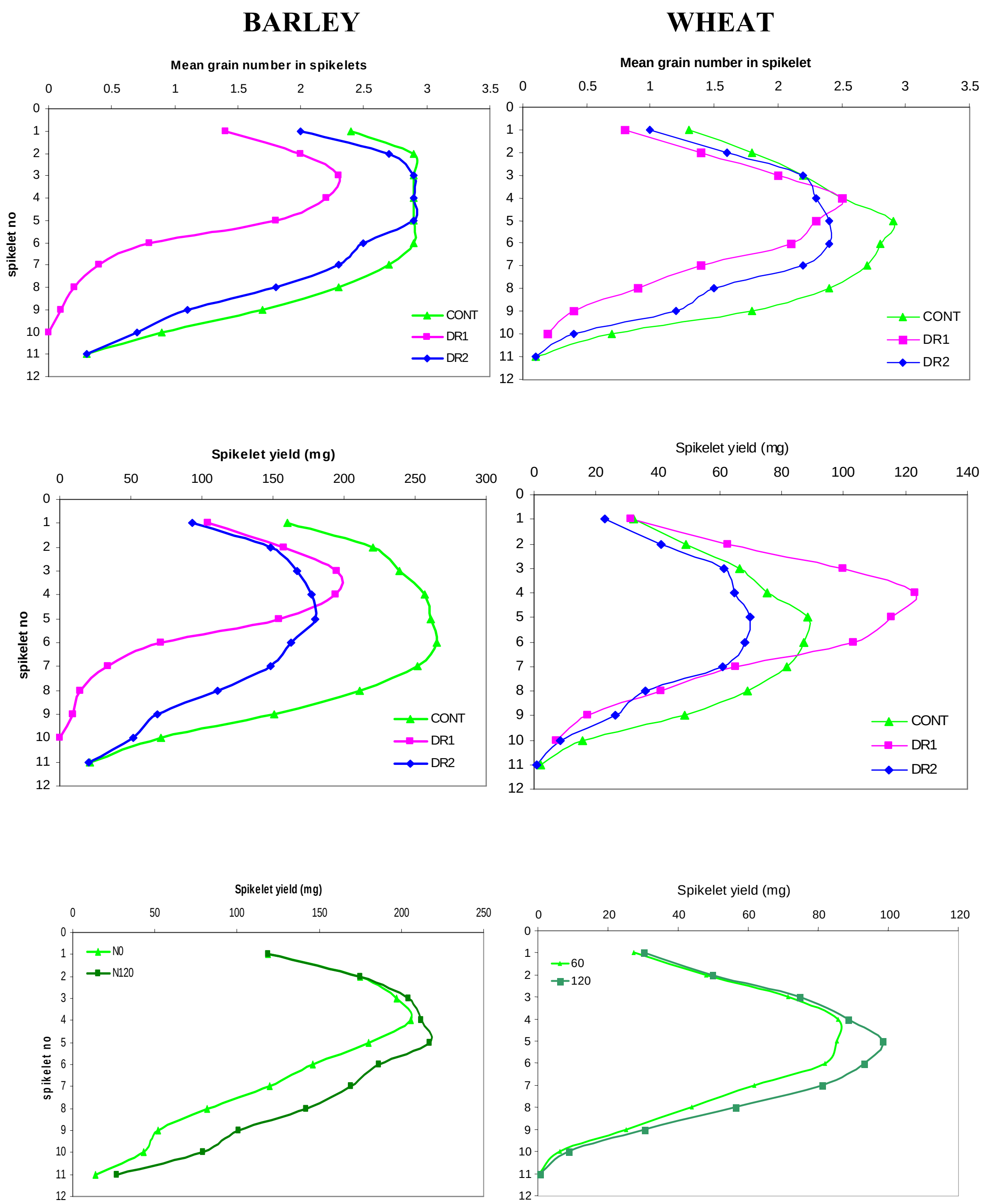


Figure 2. Watering effect on grain number in spikelets of barley (a) and wheat (b), and spikelet yield (mg) of barley (c) and wheat (d). Nitrogen rate effect on spikelet yield (mg) of barley (e) and wheat (f). CONT contol watering; DR1, drought prior pollination; DR2, drought during grain filling. N 0, N fertilisation rate 0 kg N ha^{-1}; N 60, N fertilisation rate 60 kg N ha^{-1}; N 120, N fertilisation rate 120 kg N ha^{-1}

Grain position within the spikelet had marked effect on single grain weight and thus yield production potential. In wheat proximal grains were heavier compared to distal grains (Table 3). Early drought (DR1) enhanced single grain weight of proximal grains over the distal grains, whereas in terminal drought (DR2) SGW of proximal grains was only slightly higher than distal grains (Table 3). Majority of the grains formed in the wheat spike were proximal (75 to 80%). Terminal drought and N rate of 60 kg N increased the proportion of proximal grain number and grain yield (Table 3). In barley, likewise than in wheat, central grains of barley outweighed lateral grains in all treatments by 20%.

Table 3. The difference (+ %) of proximal grain over distal grain, proximal grain yield proportion (%) and grain number proportion (%) of the total in wheat (2006 trial). The same lowercase letter within N rate and watering indicates no statistical difference at P=0.05

	Proximal/distal SGW %		Proximal grain yield proportion %		Proximal grain number proportion %	
N 60	22	a	83	a	80	a
N 120	20	a	77	b	73	b
CONT	23	b	79	b	75	b
DR1	32	a	80	b	75	b
DR2	4	c	82	ab	81	a

N 60, N fertilisation rate 60 kg N ha^{-1}; N 120, N fertilisation rate 120 kg N ha^{-1};
CONT, contol watering; DR1, drought prior pollination; DR2, drought during grain filling

Similar results were recorded also in a pot trial (2008), though central grain (barley) and proximal grain (wheat) domination in yield formation seemed to be slightly higher in stressed plants (Table 4) when compared to field conditions.

Table 4. Watering effect on central (barley) and proximal (wheat) grain weight (mg). Lateral (barley) and distal (wheat) grain weight (mg) and yield proportion (%) produced by central (barley) and proximal (wheat) grains. The same lowercase letter within species indicates no statistical difference at P=0.05

Species	Treatm	central grain mg		lateral grain mg		central grain yield proportion %	
Barley	CONT	39.5	a	31.3	a	39.0	b
Barley	DR1	40.0	a	32.4	a	46.4	ab
Barley	DR2	12.1	b	10.3	b	52.3	a
		proximal grain mg		distal grain mg		proximal grain yield proportion %	
Wheat	CONT	45.3	a	35	b	72.4	b
Wheat	DR1	46.7	a	37.2	a	88.3	a
Wheat	DR2	6.2	b	4.9	c	88.0	a

CONT, contol watering; DR1, drought prior pollination; DR2, drought during grain filling

Post-pollination cell number accumulation was determined in wheat. There are some indications that grain cell number would regulate filling potential of the grain. Indeed, both droughts tend to decrease number of formed grain cells. However, lower cell number in DR1 did not apparently associate with filling potential of the grain, as SGW in DR1 was similar or higher than in CONT. On the other hand, when the filling potential of the grain was studied/viewed at the grain position level, proximal grains exceeded distal grains in grain cell number and SGW.

Terminal drought increased the number of aborting ovaries, which could be observed visually under microscope. However, the starch, sucrose and invertase staining revealed that there were no differences in grain filling between treatments in remaining grains. This suggest that the plants were able to control the number of filling grains probably based on the carbon flux and that the flux was maintained nearly similar into filling grains regardless of treatment. CFDA could not be detected in the endosperm tissue, even though it was localised in the stem and leaves indicating that there exist mechanisms preventing it to be loaded into endosperm.

Concluding remarks

Drought had marked effect on plant growth and yield formation: drought prior pollination (DR1) reduced fertile floret and grain number and terminal drought (DR2) reduced grain number and single grain weight. Even drastic drought prior pollination seemingly does not reduce the filling potential of the grain, as the single grain weight in DR1 plants was equal with the CONT plants for both species. Evidently, when water and nutrients are available for the plant after drought, even reduced source capacity provides adequate assimilates for filling of the fewer grains. Low N rate reduced growth and yield performance (decreased grain number and grain weight), but in general N rate effect was much milder than drought effect. Higher N rate improved growth and grain yield independent of water availability.

When yield formation was examined within the spike at spikelet level, the mid-section of the spike dominated yield formation, as the grain number and SGW were the highest in these spikelets in both species. DR1 and in DR2 reduced grain number and grain yield more evidently in two most apical spikelets and in spikelets situated below the fourth/fifth spikelet from the apex, phenomenon being alike for both species. Low N induced yield reduction seemed to be prominent in spikelets situating below the mid-spike.

Within the spikelet, proximal grains in wheat and central grains in barley outweighed distal/lateral grains and dominated yield formation. Both droughts and low N increased proportion of yield produced by these grains. Grains situating in distal/lateral positions in the spikelet seemed to be more vulnerable for non-optimum growing conditions.

Both droughts tend to decrease grain cell number in wheat. However, lower cell number in DR1 did not associate with filling potential of the grain, as SGW in DR1 was similar or higher than in CONT. On the other hand, when the filling potential of the grain was viewed at the grain position level, grain cell number and SGW correlated positively indicating potential connection between grain cell number and SGW.

No marked differences in starch and sucrose localisation in CONT and DR2 was found in this study indicating that the number of filling grains was controlled by the drought effect and the carbon flux into remaining developing grains was maintained regardless of treatment.

WP8 Water Use Efficiency

Leader of workpackage: **Partner 8, IAMB Italy**

Workpackage Objectives

- To quantify, at canopy scale, carbon dioxide and water vapour gas-exchanges responses and crop growth at two N levels in field experiments.
- To verify the validity of specific management crop strategies to improve water use efficiency.
- To test the conservative expressions of WUE, under two N levels.

List of Deliverables

- D8.1 Assess the quantitative relationship between above ground biomass and evapotranspiration under two N levels (It has been achieved).
- D8.2 Test the robustness of the biomass-transpiration relationship for predicting crop growth (It has been achieved).
- D8.3 Feed the model (WP3) supplying widespread values for wheat and barley under several N treatments (It has been achieved).
- D8.4 A final report summarising scientific findings of WP8 (It has been achieved).

List of Milestones

- M8.1 Preliminary field studies - initiated (achieved).
- M8.2 First detailed field experiments – initiated (achieved).
- M8.3 First field experiments – analysed (achieved).
- M8.4 Second year of detailed field experiments – initiated (achieved).
- M8.5 Second year of field experiments – analysed (achieved).
- M8.6 Final report summarising scientific findings of WP8 (achieved).

Summary of Workpackage Main Findings

The main results achieved during the whole period of execution of WatNitMED are presented for the major focuses of the WP

Comparing the interactive effects of water and nitrogen on durum wheat and barley grown in a Mediterranean environment

Introduction

Wheat and barley are the two major cereals cultivated in the Mediterranean region and represent strategic crops for food security across the whole area (FAOSTAT, http://faostat.fao.org). In high yielding environments, durum wheat is usually favoured over barley (Josephides, 1993), because of its superior grain nutritional value for human food production (Wahbi and Sinclair, 2005).

In the dry areas barley is considered to provide better yield potential than wheat, because of its superior adaptation to drought conditions, while in the areas characterized by annual rainfall ≥ 400 mm wheat is preferred. Jamieson *et al.* (1995), indeed, observed that the critical potential soil moisture deficit was much lower for barley than wheat. In general, water deficit during the growth period (from double ridge to anthesis) and around anthesis causes yield losses due to reductions in potential grain number per unit area (Fisher, 1985; Savin and Slafer, 1991; Giunta *et al.*, 1993; Cossani *et al.*, 2009), while drought stress and high temperatures during grain filling period, as it often occurs in Mediterranean conditions, reduce mean grain weight (Oweis *et al.*, 2000; Acevedo *et al.*, 2002).

Similarly, the nitrogen nutrition has been found responsible for cereal yield loss in actual farming of the Mediterranean environment (Anderson, 1985; Passioura, 2002). Crop responses to N fertilization depend on soil water availability, rainfall amount and distribution during the crop cycle, further than amount and timing of N applications (Pala *et al.*, 1996; Latiri-Souki *et al.*, 1998). It is largely proved that the early developmental processes, such as tiller proliferation, occurring during early growth, depend on the availability of water and N in both durum wheat (Simane *et al.*, 1993) and barley (Garcia del Moral *et al.*, 1991). Moreover, combined water and N shortages around anthesis are known to induce flower abortion resulting in a reduced grain number per unit area (McMaster, 1997; Jeuffroy *et al.*, 1999; Acevedo *et al.*, 2002). Therefore, the understanding of the interactive effects of water and N availability, along with the crop ability to efficiently use these resources is of crucial importance for stabilizing the cereal production in the Mediterranean areas.

Although under low yielding conditions the higher yield potential of barley compared with wheat is generally accepted, a systematic comparison of the two species, particularly in relation to modern varieties grown under Mediterranean conditions, has not been fully investigated. In particular, the special traits distinguishing the two species when grown under various water and N availability have not been yet quantitatively resolved (Wahbi and Sinclair, 2005). In the literature there is large evidence of works separately performed on wheat and barley grown under different water and N conditions (Garabet *et al.*, 1998; Latiri-Souki *et al.*, 1998; Li *et al.*, 2004; Tavakkoli and Oweis, 2004; Kibe *et al.*, 2006; Karam *et al.*, 2009), or of studies carried out on both crops and considering only one of the two factors (Jamieson *et al.*, 1995; Delogu *et al.*, 1998; Sieling *et al.*, 1998). On the contrary, side by side experimental comparisons of wheat and barley performance and of their efficiency in using resources (WUE and NUE) under different combinations of water and N availability are quite scarce in the Mediterranean area (Cossani *et al.*, 2007; Cossani *et al.*, 2009).

Moreover, some studies comparing the response of the two species to different water and N input, analyse only data collected from different experimental sites (Lopez-Castañeda and Richards, 1994), while others are based on simulation analysis by crop models (Wahbi and Sinclair, 2005). Consequently, the aim of this work was to compare the relative performance of wheat and barley under different water regimes and nitrogen levels in a typical Mediterranean area of Southern Italy, in order to identify the outstanding features of these species that contribute to higher grain yield and better resource use efficiency. The understanding of the specific traits leading the response to various combination of water and N would allow designing more consistent and environmentally sustainable management practices in Mediterranean conditions.

Materials and Methods

Experimental site and climate

The field experiments were carried out in Valenzano (Bari) (41°03' N, 16°52' E, and altitude 72 m) at the experimental field of the Mediterranean Agronomic Institute (IAMB) in three years 2006, 2007 and 2008. The climate is typically Mediterranean, characterized by 35-year average annual rainfall of 528 mm mostly concentrated in autumn and winter months, with maximum air temperature of 30-35 °C in summer.

Treatments and agronomic management

Durum wheat (Triticum durum Desf.) 'Quadrato' and barley (Hordeum vulgare L.) 'Ponente'- a six-rowed cultivar for both malting and feeding - were sown in rows 0.18 m apart. Both cultivars are largely cultivated in Southern Italy and well adapted to Mediterranean climate.

Wheat and barley response was assessed under three water supply regimes (I100, I50, I0 corresponding to full irrigation, 50% of full irrigation and rainfed, Table 1) coupled with two N fertilizer levels (high N, HN: 120 kg ha^{-1} and low N, LN: not fertilized).

In order to evaluate the yield response of barley under lower doses of N fertilizer, following the cropping techniques usually adopted in most of the Mediterranean countries, 60 kg (N) ha^{-1} were used in 2006. The nitrogen fertilizer as ammonium sulphate (21% of N) was applied at the beginning of tillering, while as ammonium nitrate (26-27%) at the beginning of stem elongation.

Irrigation was managed using an Excel-based irrigation tool (Todorovic, 2006) that employs meteorological, soil and crop data for a day-by-day estimation of the soil water balance in the effective root zone. Reference evapotranspiration was calculated on a daily basis from measured weather data using the FAO Penman-Monteith equation (Allen *et al.*, 1998). The Kc values were determined on the basis of in-field observations of crop phenological stages and using the FAO 56 data (Allen *et al.*, 1998), adjusted for the local conditions (Tarantino and Caliandro, 1984). Runoff and capillary rise were assumed to be negligible due to karstic soil features and very deep soil water table, while deep percolation was calculated as the surplus of water over field capacity in the root zone caused by excessive precipitation and/or irrigation.

In all years, due to abundant rainfalls in mid of December, the soil water content was reset at field capacity for all treatments. The gravimetric method, based on the conventional oven-dry weight and multiplied by the bulk density (Qiu *et al.*, 2001), was used 3-4 times during the growing season to measure the soil water content in the root zone and to make any required adjustments of soil water content estimated by the model. Soil samples were taken at three points of the central zone of each plot at two soil depths (0-20, 20-60 m).

To ensure uniform water distribution, a drip irrigation method was used with one emitter line per two crop rows and drippers with 1.5 L h^{-1} flow rate, 0.2 m apart. A flow-meter, one for each irrigation treatment, was placed on the main lines of the experimental field to accurately measure the amount of water supplied at each irrigation event. Irrigation was stopped at dough maturity stage.

Treatments were arranged in a split–strip plot design with three replicates. Water regime was the main plot factor, while nitrogen and crop were the subplot factors, arranged inside each main factor unit in a strip plot design as horizontal and vertical factor, respectively. Each experimental plot was 10 m x 14 m. The main details of the experiments are reported in Table 1.

Biomass and yield

Phenology was recorded according to Zadoks *et al.* (1974). Aboveground biomass during the whole crop cycle was measured on 0.25 m2 (0.5m x 0.5m) surface samples for each plot. Plant sampling was performed, almost regularly during the season on a two weeks basis. The above-ground biomass was determined by oven drying samples at 70°C until constant weight was reached. At physiological maturity, yield and its main components (grain number per m2 and mean grain weight) were measured by harvesting a sample area of 9.0 m2 at the centre of each plot. Harvest index (HI) was calculated as grain to above ground dry biomass ratio.

Plant water status and N measurements

Pre-dawn leaf water potential were measured on two leaves per plot by a Scholander pressure chamber (Mod. 3000, Soil Moisture Equipment Corp., Santa Barbara, CA, USA), before irrigation water supply.

Total tissue nitrogen concentration was measured by the Dumas dry combustion method, using a Nitrogen analyzer (Perkin Elmer, Mod. 2410 Ser. II, Norwalk, CT, USA), on oven dried samples of grain and straw, collected at physiological maturity. Each sample was derived from three plants randomly chosen in each plot. N uptake by the whole plant and by the different organs was obtained by multiplying the aboveground dry matter by the respective N percentage.

At the beginning of the experiments and before fertilizer application, soil samples were collected at a depth of 0.40 m, in order to evaluate the N available in the soil for crop growth. NO3-N and NH4-N were determined on field moist samples and quantified through distillation, after extraction with a 1 M KCl solution.

Water and nitrogen use efficiencies

Water use efficiency (expressed in kg m-3) was calculated as the ratio of dry above ground biomass to the seasonal water lost by evapotranspiration (biomass water use efficiency – WUEb) and as the ratio of dry grain yield to the seasonal water lost by evapotranspiration (yield water use efficiency – WUEy).

The crop ability to use N derived from soil and from fertilizer application was investigated. Nitrogen use, nitrogen uptake and nitrogen utilization efficiencies were determined in relation both to the fertilizer applied, using the difference method, and to the total amount available for the crop.

The following efficiency terms were examined (Janssen, 1998; Delogu *et al.*, 1998): (i) nitrogen use efficiency - RYS - (kg kg^{-1}), as the ratio of yield to available N, (ii) nitrogen uptake efficiency - RUS - (%), as the ratio of uptaken to available nitrogen, and (iii) N utilization efficiency - RYU - (kg kg^{-1}), as the ratio of yield to N uptaken. Finally, nitrogen harvest index (NHI) was computed as the ratio of total N in grain to total aboveground plant N at maturity.

Available nitrogen was defined as the mineral N (NO3-N and NH4-N) in the 0-0.40 m soil layer at sowing plus the N supplied through fertilization .

Statistical analysis

Three factors (water regime, nitrogen and crop) were analysed together, according to a split-strip plot experimental design. Each dependent variable was preliminary evaluated for normal distribution according to Shapiro-Wilk test.

Separate analyses of variances were carried out on 2006 data, due to the different amount of N supplied to the crops (Table 1). Combined analyses were instead run over 2007 and 2008, after verifying the homogeneity of error variances using Bartlett's chi-square test. Year was considered as a random effect.

Statistical analyses were performed through the GLM procedure of SAS/STAT by using the correct error term to evaluate each factor and interaction. Least significant difference (LSD) at 0.05 probability level was used as mean separation test. For significant interactions, the proper standard errors were computed according to Gomez and Gomez (1984).

Results

Weather conditions and crop phenology

The weather regime, in terms of maximum (Tmax) and minimum air temperature (Tmin), incoming solar radiation (Rs) and rainfall, during the three experimental years is shown in Figure 1. Overall average air temperature during the growing cycle in 2005-06 was very similar to the 35-year average value, whereas in 2006-07 and 2007-08 it was 1.1°C greater. The trial carried out in 2005-06 was characterized by much colder winter season (December-February) than two other experiments: it was specially evident in January 2006 (tillering stage) when mean air temperature was about 2.5-3°C lower than in the same month in 2007 and 2008. In March 2008 (stem elongation stage), maximum air temperature was about 1.5°C greater than in the same month of two other years. In the period April-May (flowering and grain filling), mean air temperatures were similar for all three years, whereas June 2006 was colder than the same month of two other years: mean air temperature was 2.2 and 1.3°C lower than in 2007 and 2008, respectively.

Overall average solar radiation during the whole growing cycle was very similar in three years under study, although substantial differences were evident on a monthly basis.

In 2005-06, the rainfall over the growing season was 480 mm, 47% greater than the 35-year average; this large difference occurred in all months except May. In 2006-07, although rainfall (347 mm) was similar to the 35-year average values, it was regularly distributed during the whole season with March and April (from stem elongation to flowering) receiving more precipitation than both 2005-06 and 2007-08 and than long-term averages. In 2007-08, the seasonal rainfall was 395 mm, about 19% greater than long-term average, but its pattern was more similar to the trend usually observed for this environment: precipitation was concentrated in December and March. The rainfall distribution during the growing season greatly affected the behaviour and the response of the two crops. Indeed, the more favourable rainfall pattern, observed in 2006-07, has resulted in the lower irrigation requirements recorded during this year (Table 1).

Because of late sowing in 2005-06, the phenological stages of both crops along the whole crop cycle were postponed, as compared to both 2006-07 and 2007-08 (Table 1). As consequence of the described rainfall regime, water treatments of both crops did not differentiate during most of the season in 2006 and 2007 and they showed a very similar water status in terms of predawn leaf water potential (LWP) at flowering. On the contrary, in 2008 both rainfed and I50 treatments had a significantly lower LWP (-0.69 and -0.62 MPa), as compared to I100 (-0.45 MPa) (Fig. 2).

Biomass, yield and yield components

Tables 2 and 3 report the analysis of variance results for the main examined dependent variables. The higher order significant sources of variation were mainly discussed. The results obtained over the two years period (2007-2008) were first described; 2006 data were used principally to compare wheat and barley response under different N fertilizer rates.

Over the 2007-2008 period, total aboveground biomass and grain yield of both crops were highly influenced by the amount of nitrogen applied (Table 2). Wheat produced a significantly higher biomass than barley and a greater, although not significant, grain yield (Tables 2 and 4).

Grain yield of both crops varied significantly in relation to the amount of available water (average increments, as compared to the rainfed condition, were of 5 and 23%, for I50 and I100, respectively) and a trend (P=0.0537) was observed for biomass (average increments of 3 and 19.6% with water supply increase). In 2006 only the N effect was evident on biomass and grain yield.

Number of grains per square meter was highly related to grain yield (Fig. 3) and, consequently, strongly affected by N fertilization in all the three years (Tables 2 and 3).

Grain weight accounted for a lower proportion of grain yield and it was affected by water regime and weather conditions (significant Y x WR interaction). In the year characterized by the most uniform rainfall pattern (2007), similar grain weights were recorded for both crops under the different water regimes; in the year characterized by limited rainfall availability from heading to physiological maturity (2008), the irrigation supply determined a significantly higher weight (crop average increments were of 7.6 and 12.2%, for I50 and I100, respectively). In 2006, despite the high total rainfall regime, a significant positive effect of irrigation was observed (Tables 3 and 6). This behaviour can be attributed to the uneven rainfall distribution compared to 2007, and particularly to lower rainfall in May, which caused water deficiency during the grain filling stage (Fig. 1).

The two crops exhibited a different sensitivity of the main yield components to the increase in water and N availability. Over 2007-2008, barley responded to N fertilization mainly by increasing the number of grains per square meter (7883 grains and 47.1 mg per grain for LN and 11876 grains and 47.0 mg per grain for HN treatment, respectively), while durum wheat by improving both yield components (8001 grains and 53.6 mg per grain for LN and 10685 grains and 54.7 mg per grain for HN treatment, respectively). A similar trend was observed in 2006.

This behaviour is clearly shown in Figure 3. Comparing the two crops across the three experimental years, there was a strict relationship between number of grains produced and yield, but with a higher response in wheat (slope of 0.622 vs. 0.465 for barley) related to a greater increment of grain weight.

Across all the experimental years, on average barley had lower grain yields than wheat under unfertilised conditions, but a higher response to N fertilization. Although only two fertilizer rates per year were compared, barley showed a saturation of its response to N fertilization. In fact, the crop gave similar yield values with 60 and 120 kg N ha^{-1} (5.28 Mg ha^{-1} in 2006 vs. 5.38 Mg ha^{-1} in 2007-2008) under years having analogous average productivity, as shown by wheat grain yields (5.37 Mg ha^{-1} in 2006 vs. 5.85 Mg ha^{-1} in 2007-2008). The higher barley response to N fertilization and its saturation at a low N rate is confirmed by the analysis of the yield components. The lower barley grain yield under unfertilized conditions was related to a lower grain weight and not to a smaller number of grains per square meter and therefore tillering rate. N fertilization induced an average increase in number of grains per unit ground area in barley higher than that observed in wheat, while grain weight increased only for wheat, remaining constant for barley and showing even a slight reduction in 2008. As in barley the increment in number of grains per square meter was equal when applying 60 kg N ha^{-1} (49%) and 120 kg N ha^{-1} (50.5 and 50.8% in 2007 and 2008, respectively), greater N availability for this crop would not induce further increments in grain number and therefore in yield under similar environmental conditions. Finally, under fertilized conditions, wheat showed an increase in both yield components, although the number of grains per square meter was lower than in barley. It indicates higher yield potentiality of wheat at higher N rates.

Harvest index (HI) was not affected by the compared treatments over the three experimental years. A trend was observed between year and crop, with HI values of barley higher than wheat in 2007. In both crops HI reduced over years; this behaviour, more evident for barley than for wheat, may be ascribed to the ‘haying effect’ which can occur in cereals when grown in monoculture (Karam *et al.*, 2009).

Water use efficiency

Grain yield water use efficiency (WUEy) was strongly affected by N fertilization in both crops (Table 2). Under N fertilization, WUEy, as average of the two crops, was 44.6% higher than the values obtained under unfertilised conditions over 2007-2008.

As compared to the rainfed conditions, the mean WUEy decrement was of 14.2% for I50 and 11.7% for I100. Over 2007-2008, wheat showed a higher WUEy than barley, although it was not significantly different.

Nitrogen concentration, uptake and use efficiency

Nitrogen concentration in the grain was affected by nitrogen fertilization and water regime, but with a different trend as a function of climatic conditions and crops (significant Y x WR x C interaction, Table 2). On average, N concentrations were higher in 2007 and wheat showed significantly higher values than barley (Table 5).

As regards water regime, in 2007 similar N concentrations were observed under different water supply, although the lowest values were observed for full irrigated conditions (15.9 g kg^{-1} DM against an average of 16.7 g kg^{-1} DM for I50 and I0); in 2008, significantly lower N concentrations were observed under rainfed conditions (13.4 g kg^{-1} DM in 2008 against 16.8 g kg^{-1} DM in 2007) and irrigation enhanced plant N uptake and its accumulation in the grain (an average increment of 15% was recorded passing from I0 to I100; Fig. 4). Moreover, in both years the variations in grain N concentrations were more evident for wheat than for barley (Table 2).

Higher water availability increased total N absorption, but determined a different element partitioning in the two crops: especially in 2008, straw N concentration was not affected by water supply in wheat (average values of 3.15 g kg^{-1} DM were recorded), while it increased in barley passing from rainfed to irrigated conditions (2.70, 3.77, 4.15 g kg^{-1} DM, for I0, I50 and I100, respectively; Table 2); an opposite behaviour was, instead, observed for grain N concentration (Figs. 4 and 5a).

For unfertilized and fertilized treatments, grain N uptake at maturity, averaged over the two years period, was 47.2 and 80.4 kg N ha^{-1} in barley and 66.6 and 105.5 kg N ha^{-1} in wheat. Whole plant N uptake was 62.9 and 108.0 kg N ha^{-1} in barley and 83.7 and 133.2 kg N ha^{-1} in wheat.

Nitrogen harvest index (NHI), which represents the crop ability in partitioning the total N uptaken between the different plant organs, synthesized the previously observed results. Although average values were similar across the three experimental years, they were significantly affected by crop (Table 2). Across the two year period (2007-2008), with the increase in irrigation water supply a decrease in NHI was observed for barley (Fig. 5b), while more constant values were recorded for wheat. This behaviour was more evident in 2008. In barley NHI was 77.5, 76.9, and 71.6% in 2006, 2007 and 2008, respectively. An average reduction of NHI, significant only in 2006, was observed as consequence of N fertilization (Tables 5 and 7).

Nitrogen use efficiency (RYS), the grain yield (kg) produced per unit of available N (kg), was on average significantly higher for both crops in 2007, because of the lower initial soil mineral N content (92.7 vs. 128.4 kg N ha^{-1} in the 0-0.40 m layer) and the similar yield response. RYS decreased as consequence of N fertilization, but the decrement was less marked in 2008 (34.4 vs. 27.3% in 2007 and 2008, respectively), as shown by the trend in the Y x N interaction.

In 2006, barley was less efficient than wheat in the absence of N fertilization, but more efficient under fertilised conditions: similar yields were obtained with a lower N fertilizer rate – 60 kg N ha^{-1} – (Fig. 6a). The same behaviour, though less marked (Fig. 6b), was observed for nitrogen uptake efficiency (RUS).

RYS showed a trend to increase in 2008 under irrigated conditions (compared to the rainfed conditions, average increments were of 10.8 and 43% for I50 and I100, respectively). The overall RYS mean value recorded in this study was of 30.2 kg of grain yield per kg of available N.

The nitrogen utilization efficiency (RYU) reflects the ability of the crop to transform the N uptaken (kg) into economic yield (grains, kg). Although not significant, an interaction was observed between WR and N levels: the RYU was not affected by the increase in irrigation water supply in fertilized conditions, while it decreased in unfertilized treatments. The increment in tissue N concentration induced by higher water availability was greater than the increment in grain yield.

Nitrogen uptake efficiency was higher in wheat in 2007-2008, while N utilization efficiency was higher in barley in all the three experimental years (Tables 2 and 3).

Discussion

Biomass, yield and yield components

Water regime and nitrogen fertilization affected wheat and barley growth and yield throughout the experimental period, but N supply was the predominant limiting factor in this study. Irrigation water supply influenced grain weight more than grain number per square meter, contrary to the trend frequently observed for winter cereals in semiarid environments (García del Moral *et al.*, 2003; Karam *et al.*, 2009). These results can be explained by the non limited water availability conditions occurred during the most sensitive stages to drought stress for winter cereals with respect to grain yield, i.e. the early growth period and from double ridge to anthesis (Shpiler and Blum, 1991; Giunta *et al.*, 1993; Acevedo *et al.*, 2002). Water deficit during these stages sharply reduces the number of grains per square meter. Instead, water stress from anthesis to maturity, especially if accompanied by high temperatures, hastens leaf senescence, reduces the duration and rate of grain filling, decreasing the time for translocating carbohydrate reserves to the grain (Oweis *et al.*, 2000), and reduces mean kernel weight (Acevedo *et al.*, 2002).

In 2006 and 2007, the irrigated treatments of both crops did not differentiate from the rainfed one during most of the season, as shown by the similar water status until the flowering stage. In 2008, rainfed and I50 treatments had significantly lower pre-dawn leaf water potentials (LWP) at flowering as compared to I100. However, the quite consistent rainfall events, occurred in March (during stem elongation and booting stages) and in the first 5 days of April, kept the soil water depletion in the root zone within allowable limits that attenuated plant drought stress. Consequently, under our experimental conditions, the number of grains per square meter was never significantly influenced by irrigation water supply, neither in 2008. On the contrary, in both 2008 and 2006, the high temperatures and the low precipitation after flowering induced mild water deficit in I0 and I50, as confirmed by the LWPs recorded at maturity (data not shown). Therefore, the effect of water availability was evident on kernel weight.

The effect of nitrogen fertilization was instead always marked. The applied N amount, split in two times, induced differences in N availability between treatments since the early growth stages, when N deficiency affects tillers appearance and growth of developing tillers (Jeuffroy *et al.*, 1999), until anthesis, when N shortage may induce flower abortion (McMaster, 1997; Jeuffroy *et al.*, 1999). The constant N availability throughout the growing cycle for the fertilised crops seems confirmed by the lack of differences in harvest index between fertilized and unfertilized treatments, indicating a similar dry matter partitioning. The decline of HI with the increase in N rate, observed under some experimental conditions (Delogu *et al.*, 1998; Garabet *et al.*, 1998), may be related to high N availability at the beginning of the cropping cycle. In this case, the number of tillers and ears per square meter increases, but the additional ears, derived from higher shoot categories, yield less than the main stem, causing a reduction of the yield to total aboveground biomass ratio (Sieling *et al.*, 1998).

Differences in yield were mostly due to differences in grain number per square meter rather than to grain weight across all the experimental years. The strict relationship between the number of grains and yield has been observed by several authors in many species (Fischer, 1985; Demotes-Mainard *et al.*, 1999; Cossani *et al.*, 2007 and 2009) and it is common in winter cereals (Jamieson *et al.*, 1995). The effect of N fertilization mainly on the number of grains per square meter has been observed also in other studies (Karam *et al.*, 2009).

Because only mild water stress did occur during the experimental period, different crop traits mainly emerged in response to nitrogen fertilization.

The lower average yield response of barley compared to wheat under unfertilised conditions was observed also in other studies (Sieling *et al.*, 1998; Cossani *et al.*, 2007). Sieling *et al.* (1998), comparing the two crops under the same experimental conditions, found a saturation of barley response to a lower rate than wheat (120 against 160 kg N ha^{-1}), while Cossani *et al.* (2007)

observed the maximum crop response at a rate (200 kg N ha^{-1}) higher than that found for wheat (120 kg N ha^{-1}).

Barley response to N fertilization consisted in a higher number of grains per unit surface and thus in a higher tillering rate compared to wheat; hence differences between the crops occurred mainly during the early growth stages. This behaviour can be explained with the greater availability of N deriving from fertilizer during the initial growth period, as demonstrated by Garabet *et al.* (1998).

As concerns the higher yield potentiality of wheat at higher N rates, Karam *et al.* (2009) observed that the supply of 150 and 200 kg N ha^{-1}, compared to 100 kg ha^{-1}, increased the number of grains per unit ground area by 11 and 17% and 24 and 39%, as average of three years in two durum wheat cultivars.

Nitrogen concentration, uptake and use efficiency: year, water regime and N fertilization effect

Water availability enhanced nitrogen uptake and the irrigation effect was amplified in years characterised by low rainfall during April and May (2006 and 2008), in agreement with the results obtained in several previous studies (Campbell *et al.*, 1993; Pala *et al.*, 1996; Garabet *et al.*, 1998; Tavakkoli and Oweis, 2004).

The response of both crops to N fertilization in terms of N absorbed and grain N concentration was averagely higher in 2007, the year with higher water availability during the most sensitive crop stages to drought stress. Indeed, crop response to nitrogen fertilization is heavily reliant on water availability and rainfall distribution (Pala *et al.*, 1996; Tilling *et al.*, 2007) and it is reduced during years of low rainfall (Rasmussen and Rohde, 1991). In addition, the availability, uptake and utilization of N by plants increase with the increase in soil moisture supply (Kibe *et al.*, 2006).

Crop response to weather conditions, with variation in N concentration and uptake both in grain and straw, is in agreement with the behaviour observed by Delogu *et al.* (1998) who found significant "Y x N" interactions for the same parameters.

NHI values averaged over the two crops (76.5%) were similar to those found in other studies, but in this experiment they were not significantly affected by N fertilization, except a slight trend observed in 2006 (Delogu *et al.*, 1998; Garabet *et al.*, 1998; Sticksel *et al.*, 1999). These authors observed that NHI decreased, as total N fertilizer dose increased, mainly because of a more than proportional increase in straw N uptake. In our study, N fertilization on average did not significantly affect either dry matter partitioning (HI) or N partitioning in dry matter (NHI). A slight effect of water regime on NHI values was instead observed in barley.

The decrease in nitrogen use efficiency (RYS) as consequence of N fertilization is in agreement with results reported by other authors (Latiri-Souki *et al.*, 1998; Raun and Johnson, 1999) and it is attributed to the fact that grain yield rises less than the N supply in soil and fertilizer (López-Bellido and López-Bellido, 2001). The other parameters related to the efficiency of N use (RUS, RYU) also declined as consequence of N fertilization (Huggins and Pan, 1993; Delogu *et al.*, 1998; López-Bellido and López-Bellido, 2001). Finally, the trend of RYS to increase in 2008 under irrigated conditions confirms that low water availability reduces the capability of plants to uptake and efficiently use the soil nitrogen.

Nitrogen concentration, uptake and use efficiency: different crop characteristics

By increasing water availability, a rise in straw N concentration, not followed by a straw dry matter increment, was observed for barley in 2007 and 2008. In barley, grain N concentration was always lower than in wheat, while straw N concentration was lower in 2006 and higher in 2007 and 2008. By increasing N rate from 60 to 120 kg N ha^{-1}, straw N increased more markedly than grain N concentration in both 2007 and 2008. This result, not followed by a different dry biomass partitioning especially in 2007, could be explained by greater tillering induced by the higher N rate. Sticksel *et al.* (1999) found that, under different fertilizer strategies tested, tillers had higher straw N concentration than main stems. Therefore, above certain levels, N fertilization favoured higher tillering in barley than in wheat and higher N partitioning to straw.

These findings were reflected by the NHI. Except for 2006, NHI decreased passing from wheat to barley, mainly because of a more than proportional increase in straw N concentrations and uptake. NHI of tillers is, in fact, lower than that of main stems, which is also the reason for the decrease in N utilization in dense cereals canopies. The inadequate sink capacity developed by the ears of tillers in wheat has to be considered as a limiting factor for N use efficiency (Sticksel *et al.*, 1999).

N uptake efficiency was higher in wheat in 2007-2008, while N utilization efficiency was higher in barley in all three experimental years. Comparing the two crops, barley produced a similar yield of wheat with a lower total N uptake, while wheat had greater uptake capacity compared to barley with the same total N availability. Similarly, Muurinen *et al.* (2006) found higher N use and N uptake efficiency and lower N utilization efficiency in wheat than in barley.

The lower barley grain N concentration, observed in this study and reported by several authors (Delogu *et al.*, 1998; Sieling *et al.*, 1998; Arregui and Quemada, 2008), probably derives from breeding barley for malting that involves consistent selection for low-protein cultivars (Muurinen *et al.*, 2006).

Due to the lower N utilization efficiency, wheat would require higher N rates to optimise yields, while barley, due to the lower N amount needed to achieve higher yields, could better perform under low-input conditions (Delogu *et al.*, 1998). However, the higher N utilization efficiency of barley compared to wheat, recorded at the same yield level and total N availability in this study, was due to a lower N concentration in the grain more than to a greater ability in using N of soil for producing higher yields.

Conclusions

This study confirms that under mild water stress, at least during the initial growth stages and from double ridge to flowering, nitrogen is the factor that primarily affects cereal yield. In addition, the increase in water availability enhances N uptake and this is primarily reflected in a higher tissue N concentration more than in dry biomass accumulation, especially if differences in water status occur late in the season.

As consequence of the abundant rainfall occurred during the experimental period, durum wheat and barley response differentiated mainly in relation to nitrogen fertilization.

Under unfertilised conditions, a similar response in terms of number of grains produced per unit ground area was observed between the two compared crops, and the higher grain yield of wheat was due to higher seed weight.

Under N fertilization, barley appeared to be more responsive than wheat, showing a higher increase in the number of grains per unit ground surface, but wheat compensated for the lower number of grains with a higher seed weight that induced similar yields.

By increasing irrigation water supply, a similar average yield response was observed for the two crops, but a higher N partition in straw was recorded for barley, as confirmed by the lower NHI values over 2007-2008.

Finally, comparing similar N availability in the soil and considering the same yield level between the two crops, barley reached higher N utilization efficiency than wheat, mainly because of a lower N concentration in the grain rather than higher efficiency in using the available N. This is confirmed by the evidence that, above certain levels of total N supply and water availability, barley tends to partition absorbed N to straw, instead of using it to further increase yield. For this reason, wheat was able to use the total N supply similarly to barley.

References

Acevedo, E., Silva, P., Silva, H., 2002. Wheat growth and physiology. In: Curtis, B.C., Rajaram, S. and Gómez Macpherson, H. (Eds.), Bread Wheat, Improvement and Production. FAO Plant Production and Protection Series, 30.

Allen, R.G., L.S. Pereira, D. Raes, M. Smith, 1998. Crop evapotranspiration. Guidelines for computing crop water requirements (Irrigation and drainage paper 56). Food and Agriculture Organization, Rome.

Anderson, W.K., 1985. Grain yield responses of barley and durum wheat to split nitrogen applications under rainfed conditions in a Mediterranean environment. Field Crops Res., 12, 191-202.

Arregui, L.M. and Quemada, M., 2008. Strategies to improve nitrogen use efficiency in winter cereal crops under rainfed conditions. Agron. J., 100, 277-284.

Campbell, C.A., Selles, F., Zentner, R.P., McConkey, B.G., 1993. Available water and nitrogen effects on yield components and grain nitrogen of zero-till spring wheat. Agron. J., 85, 114–120.

Cossani, C.M., Savin, R., Slafer, G.A., 2007. Contrasting performance of barley and wheat in a wide range of conditions in Mediterranean Catatonia (Spain). Ann Appl. Biol., 151, 167-173.

Cossani, C.M., Slafer, G.A., Savin, R., 2009. Yield and biomass in wheat and barley under a range of conditions in a Mediterranean site. Field Crops Res., 112, 205-213.

Delogu, G., Cattivelli, L., Pecchioni, N., De Falcis, D., Maggiore, T., Stanca, A.M., 1998. Uptake and agronomic efficiency of nitrogen in winter barley and winter wheat. Eur. J. Agron., 9, 11-20.

Demotes-Mainard, S., Jeuffroy, M.H., Robin, S., 1999. Spike dry matter and nitrogen accumulation before anthesis in wheat as affected by nitrogen fertilizer: relationship to kernels per spike. Field Crops Res., 64, 249-259.

Demotes-Mainard, S. and Jeuffroy, M.H., 2001. Incorporating radiation and nitrogen nutrition into a model of kernel number in wheat. Crop Sci., 41, 415-423.

Fischer, R.A., 1985. Number of kernels in wheat crops and the influence of solar radiation and temperature. J. Agric. Sci., 105, 447-461.

Garabet, S., Wood, M., Ryan, J., 1998. Nitrogen and water effects on wheat yield in a Mediterranean-type climate 1. Growth, water-use and nitrogen accumulation. Field Crops Res., 57, 309-318.

García del Moral, L.F., Ramos, J.M., García del Moral, M.B., Jimenez-Tejada, P., 1991. Ontogenic approach to grain production in spring barley based on path-coefficient analysis. Crop Sci., 31, 1179-1185.

García del Moral, L.F., Rharrabti, Y., Villegas, D., Royo, C., 2003. Evaluation of grain yield and its components in durum wheat under Mediterranean conditions: an ontogenic approach. Agron. J., 95, 266-274.

Giunta, F., Motzo, R., Deidda, M., 1993. Effect of drought on yield and yield components of durum wheat and triticale in a Mediterranean environment. Field Crops Res., 33, 399–409

Gomez, K.A. and Gomez, A.A., 1984. Statistical procedures for agricultural research. Second edition. An International Rice Research Institute Book. John-Wiley & Sons, New York.

Huggins, D.R. and Pan, W.L., 1993. Nitrogen efficiency component analysis: an evaluation of cropping system differences in productivity. Agron. J., 85, 898-905.

Jamieson, P.D., Martin, R.J., Francis, G.S., 1995. Drought influences on grain yield of barley, wheat, and maize. New Zealand J. Crop Hortic. Sci., 23, 55-66.

Janssen, B.H., 1998. Efficient use of nutrients: an art of balancing. Field Crops Res., 56, 197-201.

Jeuffroy, M.H. and Bouchard, C., 1999. Intensity and duration of nitrogen deficiency on wheat grain number. Crop Sci., 39, 1385-1393.

Josephides, C.M., 1993. Analysis of adaptation of barley, triticale, durum and bread wheat under Mediterranean conditions. Euphytica, 65, 1-8.

Karam, F., Kabalan, R., Breidi, J., Rouphael, Y., Oweis, T., 2009. Yield and water-production functions of two durum wheat cultivars grown under different irrigation and nitrogen regimes. Agric. Water Manage., 96, 603-615.

Kibe, A.M., Singh, S., Kalra, N., 2006. Water-nitrogen relationships for wheat growth and productivity in late sown conditions. Agric. Water Manage., 84, 221-228.

Latiri-Souki, K., Nortcliff, S., Lawlor, D.W., 1998. Nitrogen fertilizer can increase dry matter, grain production and radiation and water use efficiencies for durum wheat under semi-arid conditions. Eur. J. Agron., 9, 21-34.

Li, W., Li, W., Li, Z., 2004. Irrigation and fertilizer effects on water use and yield of spring wheat in semi-arid regions. Agric. Water Manage., 67, 35-46.

López-Bellido, R.J. and López-Bellido, L., 2001. Efficiency of nitrogen in wheat under Mediterranean conditions: effect of tillage, crop rotation and nitrogen fertilization. Field Crops Res., 71, 31-46.

López-Castañeda, C. and Richards, R.A., 1994. Variation in temperate cereals in rainfed environments. I. Grain yield, biomass and agronomic characteristics. Field Crops Res., 37, 51-62.

McMaster, G.S., 1997. Phenology, development, and growth of the wheat (Triticum aestivum L.) shoot apex: A review. Adv. Agron., 59, 63-118.

Muurinen, S., Slafer, G.A., Peltonen-Sainio, P., 2006. Breeding effects on nitrogen use efficiency of spring cereals under northern conditions. Crop Sci., 46, 561-568.

Oweis, T., Zhang, H., Pala, M., 2000. Water use efficiency of rainfed and irrigated bread wheat in a Mediterranean environment. Agron. J., 92, 231-238.

Qiu, Y., Fu, B., Wang, J., Chen, L., 2001. Soil moisture variation in relation to topography and land use in a hillslope catchment of the Loess Plateau, China. J. Hydrol., 240, 243-263.

Pala, M., Matar, A., Mazid, A., 1996. Assessment of the effects of environmental factors on the response of wheat to fertilizer in on-farm trials in a Mediterranean type environment. Exp. Agric., 32, 339-349.

Passioura, J.B., 2002. Environmental biology and crop improvement. Functional Plant Biol., 29, 537-546.

Raun, W.R. and Johnson, G.V., 1999. Improving nitrogen use efficiency for cereal production. Agron. J., 91, 357-363.

Rasmussen, P.E. and Rohde, C.R., 1991. Tillage, soil depth, and precipitation effects on wheat response to nitrogen. Soil Sci. Soc. Am. J., 55, 121-124.

Savin, R. and Slafer, G.A., 1991. Shading effects on the yield of an Argentinian wheat cultivar. J. Agric. Sci., 116, 1-7.

Sieling, K., Schröder, H., Finck, M., Hanus, H., 1998. Yield, N uptake and apparent N-use efficiency of winter wheat and winter barley grown in different cropping systems. J. Agric. Sci., 131, 375-387.

Simane, B., Struik, P.C., Nachit, M.M., Peacock, J.M., 1993. Ontogenic analysis of field components and yield stability of durum wheat in water-limited environments. Euphytica, 71, 211-219.

Shpiler, L. and Blum, A., 1991. Heat tolerance to yield and its components in different wheat cultivars. Euphytica, 51, 257-263.

Sticksel, E., Maidl, F.X., Retzer, F., Fischbeck, G., 1999. Nitrogen uptake and utilization in winter wheat under different fertilization regimes, with particular reference to main stems and tillers. J. Agron. Crop Sci., 183, 47-52.

Tarantino, E. and Caliandro, A., 1984. Water requirements and crop coefficients of different crops in Italy as related to the climatic characteristics and the growth stage. Proc. Int. Conf. ‘Crop Water Requirements’, Paris 11-14 Sept., 291-304.

Tavakkoli, A.R. and Oweis, T., 2004. The role of supplemental irrigation and nitrogen in producing bread wheat in the highlands of Iran. Agric. Water Manage., 65, 225-236.

Tilling, A.K., O’Leary, G.J., Ferwerda, J.G., Jones, S.D., Fitzgerald, G.J., Rodriguez, D., Belford, R., 2007. Remote sensing of nitrogen and water stress in wheat. Field Crops Res., 104, 77-85.

Todorovic, M., 2006. An Excel-based tool for real time irrigation management at field scale. Proceedings of International Symposium on “Water and Land Management for Sustainable Irrigated Agriculture”, Çukurova Univ., Adana, Turkey, 4-8 April 2006.

Wahbi, A., Sinclair, T.R., 2005. Simulation analysis of relative yield advantage of barley and wheat in an eastern Mediterranean climate. Field Crops Res., 91, 287-296.

Zadoks, J.C., Chang, T.T., Konzak, C.F., 1974. A decimal code for the growth stages of cereals. Weed Res., 14, 415-421.

Table 1. Experimental details and dates of the main phenological stages for wheat and barley during the three years of experiment. In brackets the days after sowing (DAS) are reported

	2005-06		**2006-07**		**2007-08**	
	Wheat	**Barley**	**Wheat**	**Barley**	**Wheat**	**Barley**
Sowing	8 Dec 05	7 Dec 05	28 Nov 06	27 Nov 06	23Nov07	24 Nov 07
Emergence	30 Dec (22)	26 Dec (19)	13 Dec (15)	10 Dec (13)	3 Dec (10)	3 Dec (9)
Booting	19 Apr (132)	17 Apr (131)	3 Apr (126)	9 Apr (133)	24 Mar (122)	4 Apr (132)
Flowering	1 May (144)	24 Apr (138)	11 Apr (134)	20 Apr (144)	20 Apr (149)	22 Apr (150)
Harvesting	22 Jun (196)	22 Jun (197)	16 Jun (200)	17 Jun (202)	16 Jun (206)	17 Jun (206)
Length of crop cycle (days)	196	197	200	202	206	206
Nitrogen fertilization for HN (kg ha^{-1})	120	60	120	120	120	120
Seasonal irrigation supply for I_{100} and I_{50} (mm)	142, 70	142, 70	108, 54	106, 53	150, 75	146, 73
Soil mineral N content at sowing in the 0-0.40 m layer (kg N ha^{-1})	60	60	92.3	92.3	128.4	128.4

Table 2. Significance levels of analysis of variance combined over 2007 and 2008; ***, ** and * indicate, respectively, significance at 0.001, 0.01 and 0.05 probability level. In this table and in the following ones, WUE_b, WUE_y, N_{HI}, RYS, RUS and RYU represent respectively: biomass and yield water use efficiency, nitrogen harvest index, N use, uptake and utilization efficiencies

Source of variation	d.f.	Biomass yield	Grain yield	Number of grains	Grain weight	WUE_y	Grain N (‰ DM)	Straw N (‰ DM)	Whole plant N uptake	N_{HI}	RYS	RUS	RYU
Year (Y)	1						*				*	*	
Rep	2												
E_A	2												
Water regime (WR)	2		*		***				*				
Y x WR	2				***		*						
EB	8												
Nitrogen (N)	1	***	***	***		***	***	**	***		***	***	***
WR x N	2												
Y x N	1								*				
Y x WR x N	2												
EC	12												
Crop (C)	1	*			***		***	*	***	*		***	***
WR x C	2							*					
Y x C	1												
Y x WR x C	2						*						
ED	12												
N x C	1												
WR x N x C	2												
Y x N x C	1				*			**					
Y x WR x N x C	2							*					
EE	12												

Table 3. Significance levels of analysis of variance on data collected in 2006; ***, ** and * indicate, respectively, significance at 0.001, 0.01 and 0.05 probability level

Source of variation	d.f.	Biomass yield	Grain yield	Number of grains	Grain weight	WUE_y	Grain N (‰ DM)	Straw N (‰ DM)	Whole plant N uptake	N_{HI}	RYS	RUS	RYU
Water regime (WR)	2				*								
Rep	2												
E_A	4												
Nitrogen (N)	1	***	***	***		***	**	**	***		***	***	**
WR x N	2									*			
E_B	6												
Crop (C)	1				***		*	**	**	*			**
WR x C	2												
E_C	6												
N x C	1			*							**	**	
WR x N x C	2												
E_D	6												

Table 4. Yield parameters as affected by year (2007-2008), water regime, nitrogen fertilization and crop

Source of variation	**Biomass yield ($Mg\ ha^{-1}$)**	**Grain yield ($Mg\ ha^{-1}$)**	**Number of grains ($n\ m^{-2}$)**	**Grain weight (mg)**	**Harvest Index**
Year					
2007	10.74	4.83	9340	51.76	0.45
2008	11.24	4.65	9883	49.40	0.41
LSD $_{(0.05)}$	*2.03*	*1.39*	*1560*	*3.41*	*0.05*
Water regime					
I_0	10.24	4.34	9273	40.77	0.42
I_{50}	10.52	4.55	9095	50.9	0.43
I_{100}	12.21	5.33	10466	52.08	0.44
LSD $_{(0.05)}$	*1.67*	*0.79*	*1556*	*0.72*	*0.03*
Nitrogen					
Low N	9.06	3.87	7942	50.32	0.42
High N	12.92	5.62	11281	50.85	0.44
LSD $_{(0.05)}$	*0.86*	*0.50*	*907*	*1.19*	*0.03*
Crop					
Barley	10.12	4.45	9880	47.06	0.44
Wheat	11.86	5.03	9343	54.11	0.42
LSD $_{(0.05)}$	*1.36*	*0.66*	*1051*	*1.18*	*0.03*

Table 5. Water use efficiency, N uptake and N use efficiency as affected by year (2007-2008), water regime, nitrogen fertilization and crop

Source of variation	**WUE_y (kg m^{-3})**	**Grain N (g kg^{-1} DM)**	**Straw N (g kg^{-1}DM)**	**Grain N uptake (kg ha^{-1})**	**Straw N uptake (kg ha^{-1})**	**Whole plant N uptake (kg ha^{-1})**	**N_{HI} (%)**	**RYS (kg kg^{-1})**	**RUS (%)**	**RYU (kg kg^{-1})**
Year										
2007	1.48	16.44	3.67	80.71	21.70	102.42	78.58	34.43	70.86	48.71
2008	1.48	14.54	3.34	69.14	22.35	91.50	74.74	25.99	50.36	52.11
LSD $_{(0.05)}$	*0.43*	*1.645*	*1.36*	*27.85*	*5.18*	*28.54*	*9.05*	*7.40*	*15.71*	*7.39*
Water regime										
I_0	1.62	15.07	3.10	67.15	18.69	85.88	77.83	28.27	54.46	53.37
I_{50}	1.39	15.75	3.68	73.00	21.95	94.96	75.83	28.70	58.99	48.67
I_{100}	1.43	15.66	3.74	84.63	25.44	110.00	76.33	33.66	68.38	49.19
LSD $_{(0.05)}$	*0.25*	*1.1*	*0.73*	*14.47*	*6.22*	*17.99*	*4.75*	*5.03*	*11.54*	*4.86*
Nitrogen										
Low N	1.21	14.58	3.21	56.91	16.41	73.32	77.03	35.84	68.29	53.60
High N	1.75	16.40	3.80	92.94	27.65	120.6	76.29	24.57	52.93	47.22
LSD $_{(0.05)}$	*0.17*	*0.60*	*0.40*	*7.48*	*2.77*	*7.77*	*3.06*	*3.17*	*4.65*	*2.47*
Crop										
Barley	1.41	14.12	3.78	63.78	21.65	85.44	74.24	28.28	53.30	53.30
Wheat	1.55	16.87	3.23	86.70	22.40	108.48	79.08	32.13	67.92	47.52
LSD $_{(0.05)}$	*0.20*	*0.45*	*0.40*	*10.1*	*3.44*	*11.33*	*3.63*	*4.33*	*7.21*	*2.87*

Table 6. Yield parameters as affected by water regime, nitrogen fertilization and crop in 2006

Source of variation	Biomass yield (Mg ha^{-1})	Grain yield (Mg ha^{-1})	Number of grains (n m^{-2})	Grain weight (mg)	Harvest Index
Water regime					
I_0	9.72	4.28	8858	48.4	0.44
I_{50}	10.30	4.46	8803	50.6	0.44
I_{100}	11.21	4.84	9345	51.8	0.43
LSD $_{(0.05)}$	*3.23*	*1.53*	*2885.3*	*2.02*	*0.07*
Nitrogen					
Low N	8.53	3.73	7492	49.8	0.44
High N	12.28	5.32	10512	50.8	0.43
LSD $_{(0.05)}$	*1.11*	*0.48*	*886.44*	*1.73*	*0.02*
Crop					
Barley	9.90	4.39	9369	46.8	0.44
Wheat	10.91	4.66	8635	53.7	0.43
LSD $_{(0.05)}$	*1.25*	*0.54*	*947.78*	*1.26*	*0.03*

Table 7. Water use efficiency, N uptake and N use efficiency as affected by water regime, nitrogen fertilization and crop in 2006

Source of variation	**WUE_y (kg m^{-3})**	**Grain N (g kg^{-1} DM)**	**Straw N (g kg^{-1} DM)**	**Grain N uptake (kg ha^{-1})**	**Straw N uptake (kg ha^{-1})**	**Whole plant N uptake (kg ha^{-1})**	**N_{HI}**	**RYS (kg kg^{-1})**	**RUS (%)**	**RYU (kg kg^{-1})**
Water regime										
I_0	1.58	11.93	2.73	51.25	15.34	66.59	77.40	49.12	72.44	68.82
I_{50}	1.31	12.02	3.03	54.72	18.21	72.93	75.37	51.01	77.69	65.56
I_{100}	1.28	13.50	3.24	66.87	21.38	88.26	76.03	54.31	94.81	57.64
LSD $_{(0.05)}$	*0.55*	*1.33*	*0.52*	*21.65*	*10.16*	*30.40*	*5.21*	*17.25*	*31.97*	*10.79*
Nitrogen										
Low N	1.15	11.28	2.65	42.24	12.96	55.20	76.81	65.30	96.64	70.55
High N	1.63	13.69	3.34	72.99	23.67	96.65	75.72	37.66	66.65	57.46
LSD $_{(0.05)}$	*0.14*	*1.48*	*0.30*	*9.88*	*3.55*	*13.10*	*1.17*	*5.33*	*8.48*	*7.40*
Crop										
Barley	1.36	11.12	2.58	49.99	14.68	64.67	77.46	53.26	75.75	71.88
Wheat	1.43	13.84	3.42	65.24	21.95	87.18	75.08	49.70	87.54	56.13
LSD $_{(0.05)}$	*0.16*	*1.85*	*0.45*	*11.87*	*3.51*	*14.81*	*2.22*	*7.23*	*16.90*	*9.50*

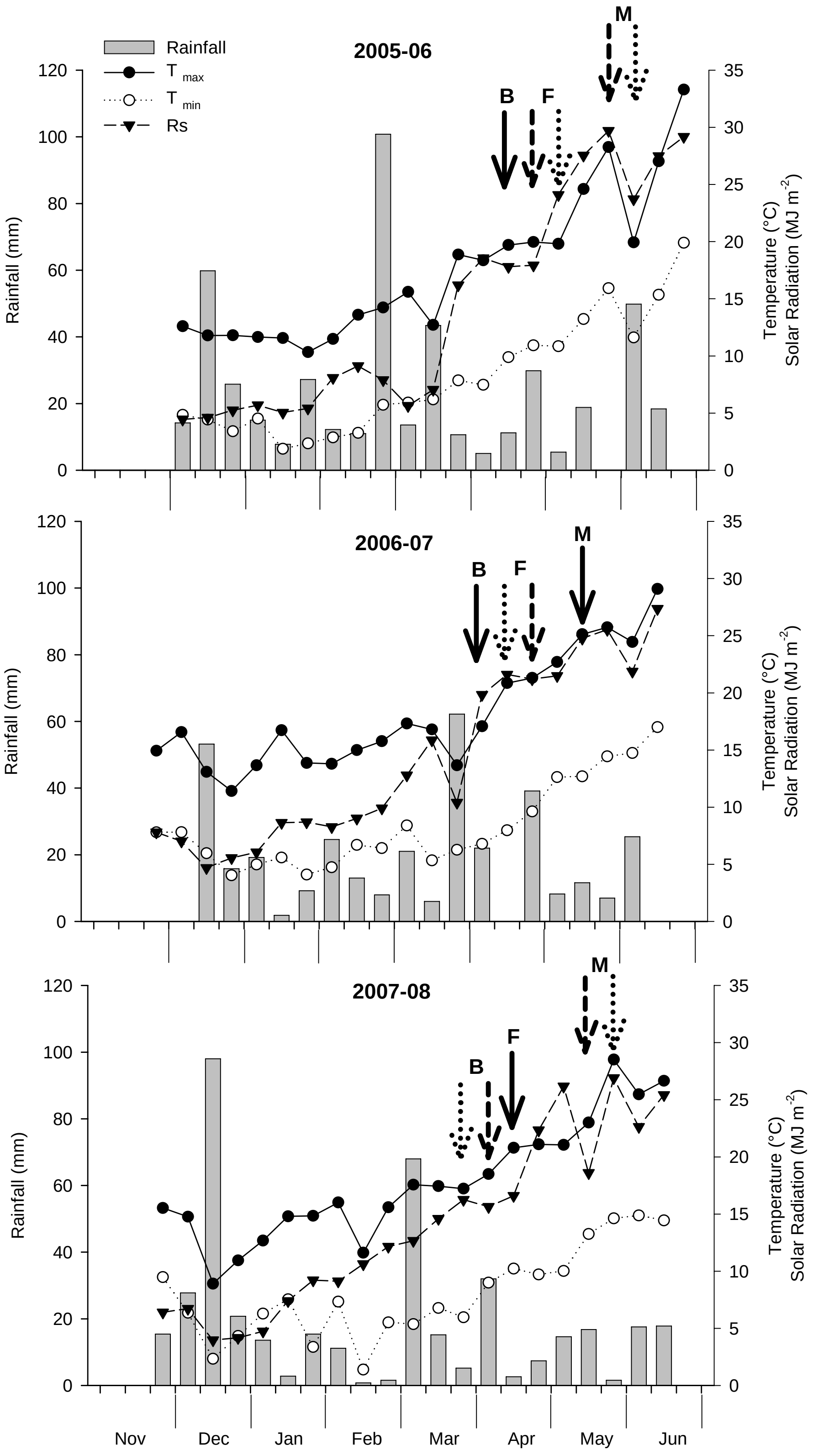


Figure 1. Rainfall, air temperature (T_{min} and T_{max}) and solar radiation distribution during the three experimental years. Main phenological stages are indicated by arrows. Plain arrows are used for both wheat and barley when phenological stages occurred concurrently; dotted and dashed arrows are used for wheat and barley, respectively. Letters indicate the main phenological stages: B = booting; F = flowering; M = maturity.

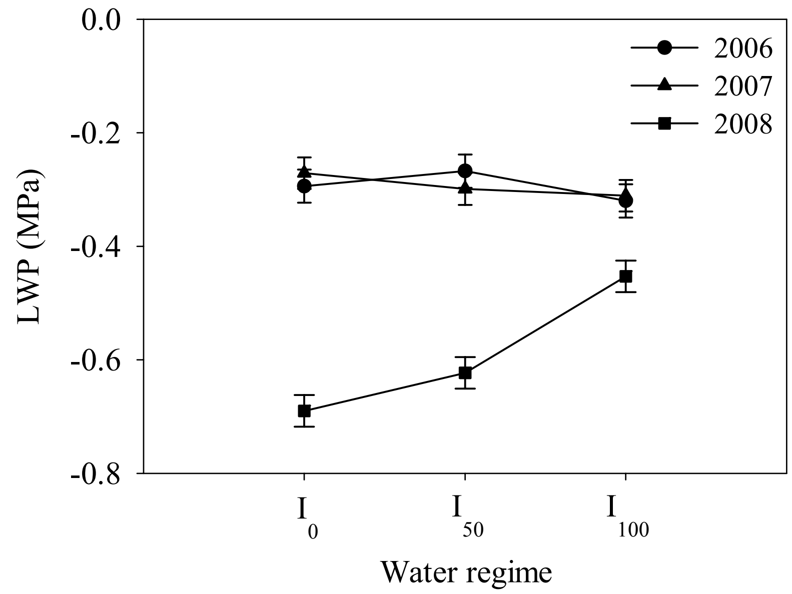


Figure 2. Pre-dawn leaf water potential at flowering stage under different water regimes, during the three experimental years. Bars stand for standard error of the mean difference.

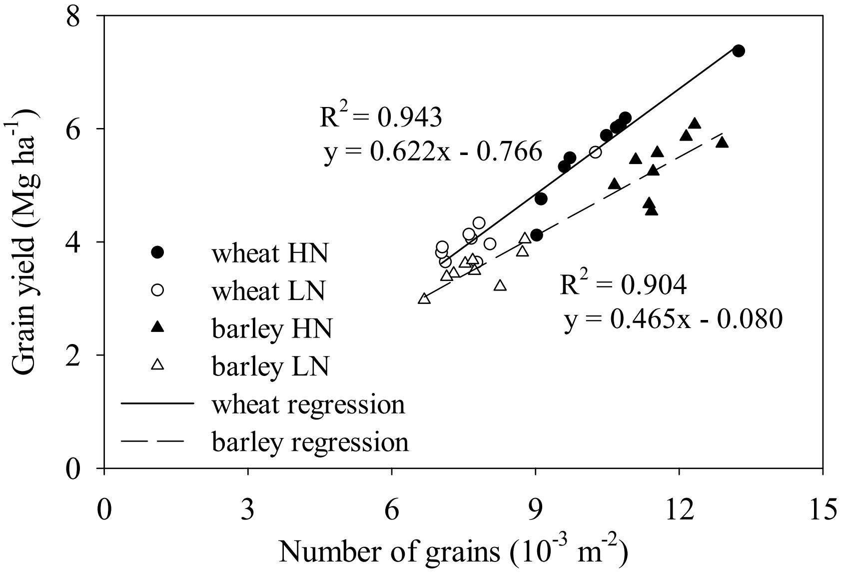


Figure 3. Relationship between grain yield and number of grains per m^2 for wheat (circle) and barley (triangle), as a function of N supply, during the three experimental years.

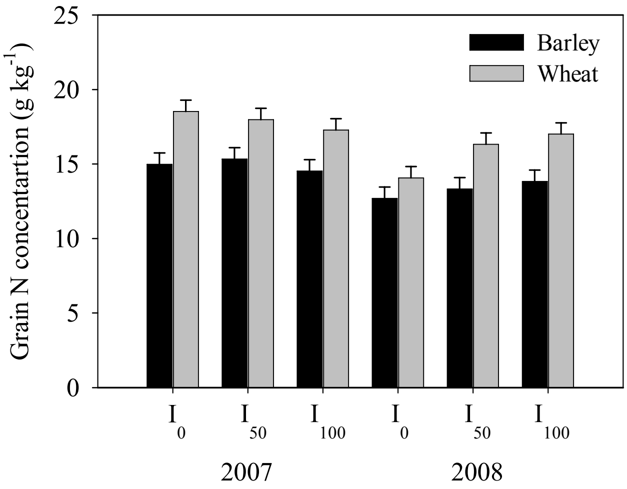


Figure 4. Grain nitrogen concentration for wheat and barley under different water regimes in 2007 and 2008. Bars stand for standard error of the mean difference.

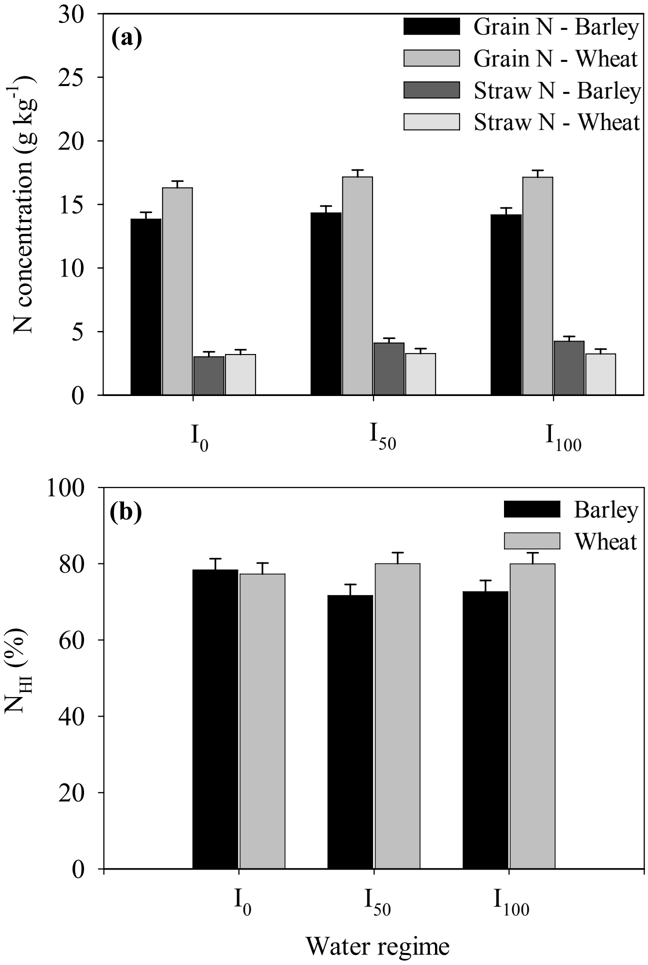


Figure 5. Nitrogen concentration in grain and straw (a) and nitrogen harvest index - N_{HI} - (b) for wheat and barley under different water regimes, as average of 2007-2008 period. Bars stand for standard error of the mean difference.

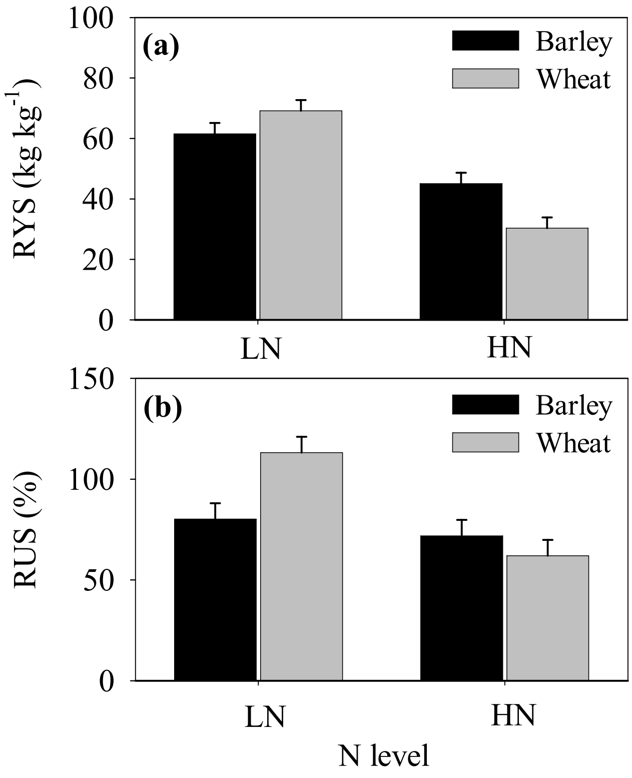


Figure 6. Nitrogen use (a) and nitrogen uptake (b) efficiency for wheat and barley under fertilized and unfertilized conditions in 2006. Bars stand for standard error of the mean difference.

WP9 Nitrogen Use Efficiency

Leader of workpackage: **Partner 9, UdL Spain**

Workpackage Objectives

- To quantify, at a canopy scale, responses of carbon and nitrogen assimilation to a range of N availabilities under contrasting water regimes in field experiements.
- To verify the validity of specific management crop strategies to improve nitrogen use efficiency and the dependence of these management strategies on the water availability.
- To test the conservative expression of NUE under two water regimes.

List of Deliverables

- D9.1 Assess the quantitative relationship between crop growth (and partitioning) and N absorption under a range of N levels in factorial arrangements with two water regimes representing extreme cases of the region under study (It has been achieved).
- D9.2 Test the robustness of the growth-nitrogen relationship for a range of GxE interactions and at different levels of organization within the crop (It has been achieved).
- D9.3 Feed the model (WP3) supplying widespread values for wheat and barley under several N treatments (It has been achieved).
- D9.4 A final report summarising scientific findings of WP8 (It has been achieved).

List of Milestones

- M9.1 Preliminary field studies - initiated (achieved).
- M9.2 First detailed field experiments – initiated (achieved).
- M9.3 First field experiments – analysed (achieved).
- M9.4 Second year of detailed field experiments – initiated (achieved).
- M9.5 Second year of field experiments – analysed (achieved).
- M9.6 Final report summarising scientific findings of WP9 (achieved).

Summary of Workpackage Main Findings

In order to reach the deliverables (i) and (ii) 7 field experiments were conducted at typical cereal crops regions of Catalonia: Agramunt (seasons 2004/05, 2005/06, 2006/07, 2007/08), Tudela de Segre (season 2007/08), and Gimenells (season 2007/08). Furthermore, two additional experiments were conducted under semi-controlled conditions at the campus of the University of Lleida (2006/07 and 2007/08 growing seasons).

Regarding deliverable (iii), information from the mentioned experiments was sent to partners involved in WP3 from the field data corresponding to the seasons 2004/05, 2005/06 and 2006/07.

Methodology

Field experiments

The experimental site from 2004/05 to 2006/07 was Agramunt (lat. 41º 47´17´´ N, long. 1º 5´59´´ E, altitude 337 m), province of Lleida (Catalonia, north-eastern Spain) on a Fluvisol calcari soil (FAO, 1990). Four experiments were sown with wheat and barley (experiment I: barley and bread wheat; experiment II, III, and IV: barley, bread wheat and durum wheat) were a factorial combination of N and water availabilities was tested. Previous crop was bread wheat in all the experiments.

Cultivars for barley (cv. Sunrise), bread wheat (cv. Soisson) and durum wheat (cv. Claudio) were the same in the four experiments and were chosen to represent successful and well adapted modern cultivars sown in the region. In addition, the cultivars were used as standard controls in the last 5 years by the GENVCE evaluation group (Group for the Evaluation of the New Cereals Varieties in Spain; Anonymous, 1999-2004).

In experiment I, bread wheat and barley were sown on November 16, 2004, combined with two water regimes (rainfed and irrigated) and with two N fertilizer rates (0 and 200 Kg N ha^{-1}). The irrigated treatment consisted of a weekly (twice weekly on few occasion) frequency, starting at the beginning of stem elongation (DC 3.1, Zadoks *et al.*, 1974). Crops received 17 mm of water in each irrigation time. It was carried out with a drip irrigation system with drip lines separated at 25 cm at right angle to the crops rows. N was applied splitting the dose in two, in order to minimize possible losses, at DC 1.2 and DC 3.1 as ammonium nitrate (34.4-0-0). Flowering date was recorded on May 3 and May 10, 2005 for barley and bread wheat respectively. Harvest date for wheat and barley was similar under rainfed conditions (June 20, 2005) while under irrigated conditions wheat was harvested a week later than barley (June 28, 2005).

Experiment II consisted of a factorial combination of the three species (barley, bread wheat and durum wheat) with two water regimes (rainfed and irrigated), and four levels of N fertilization (0, 50, 100, and 150 kg N ha^{-1}) sown on November 28, 2005. N was applied splitting the dose as in experiment I. Irrigated treatment was achieved through a drip irrigation system with a weekly (twice weekly on few occasion) as in the experiment I, but this time with the drip tube's lines placed in between crop rows (only due to facilitate the irrigation). Irrigation treatment started one week before of the beginning of stem elongation. The amount of water supplied in each irrigation was c. 7 mm. Flowering dates were recorded on May 03, 09 and 16, 2006 for barley, durum wheat, and bread wheat respectively. Harvest date was on June 06, 2006 for barley, and June 13 (rainfed) and 20 (irrigated) June for bread wheat and durum wheat.

Experiments III and IV were both carried out during the last growing season (2006/07). Experiment III consisted of a factorial combination of the three species (barley, bread wheat and durum wheat) with two water regimes (rain-fed and irrigated), and three levels of N fertilization (0, 75, and 150 kg N ha^{-1}) sown on November 06, 2006. Irrigated treatments consisted of a similar system as in the previous experiments, with the drip lines placed in the same way to experiment II. Weekly amount of water irrigated was c. 18 mm. Total irrigated water amount is given in Table 1 for experiments I, II and III. As the field was rather flat and precipitations were never strong, it was assumed that any amount of water lost by runoff or deeper drainage was negligible. Flowering date in experiment III were recorded on April 30, May 07 and 15, 2007 for barley, durum wheat, and bread wheat respectively. Harvest date was on June 18, 2007 for barley, and June 25 for bread wheat and durum wheat in experiment III.

Experiment IV was sown far later than what is recommended in the region only to expose the cultivars to more extreme stresses (February 22, 2007), and treatments were the combination of the three species with the two most contrasting N conditions (0 and 150 kg N ha^{-1}) under rainfed conditions. Bread wheat (cv. Soissons) in exp. IV did not reach anthesis (probably because its vernalisation requirements would have been not satisfied) and so data is not available for this trait. A delayed flowering respect experiment III, was observed for barley and durum wheat in experiment IV (May 21 and May 27 respectively). Harvest date was only delayed a few days in experiment IV (June 28, 2007).

Size of each plot for experiment I, II, and III was 3 x 5 m and treatments were arranged in a split block split plot design, while in experiment IV treatments were arranged in a randomized complete block design, with each experimental unit of 3 x 1.5 m. Prior to sowing of each experiment combining formula of P and K (0-7-14) was applied at a rate of 1000 kg ha-1 in all experiments. During the three growing seasons control of weeds and pest were used following the typical practices of farmers of the region.

Table 1. Experimental details for the three growing seasons

Exp.	Species	Sowing date	Plant density (plants m^{-2})	Initial water content (mm)**	Initial N-NO$_3^-$ content (kg N ha^{-1})**	Irrigation volumes (mm)	Precipitations (sowing - maturity) (mm)	Nitrogen treatment (kg N ha^{-1})
I	Ba / Bw *	16-Nov-04	195	83	34	222.1	163	0 and 200
II	Ba / Dw / Bw	28-Nov-05	180	240	115	75.8 / 95.1 / 95.1	93.5	0-50-100 and 150
III	Ba / Dw / Bw	06-Nov-06	245	201	150	318.6 / 336.3 / 336.3	331	0-75 and 150
IV	Ba / Dw / Bw	22-Feb-07	340	153	143	0	281	0 and 150

* Ba = Barley, Dw = Durum wheat, Bw = Bread wheat.
** Availability measured for the whole profile up to 1 m depth.

During 2007/08 growing season, field experiments were conducted in different locations within the province of Lleida, Catalonia (NE Spain). Experiment V was located at Agramunt (a typical rainfed agricultural area); experiment VI at Tudela de Segre (another typical rainfed area of Catalonia but with lower minimum and maximum temperatures than Agramunt location); and experiment VII was located at Gimenells location within an irrigated agricultural area of Catalonia.

Soil types were Fluvisol calcari (experiment V and VI) following the classification of FAO (1990), and experiment VII was a Petrocalcic Calcixerept following Soil Survey Staff (1998) classification.

Treatments in each experiment consisted in a different factorial combination of: species (durum wheat and barley), sowing density (0-720 plants m^{-2}) for all the three experiments and only for experiment V, N availabilities (0-150 kg N ha^{-1} supplied as N fertilizer) were contrasted in the same location. Water and N availabilities differed for the three experimental sites. The same cultivar of each species (cv. Claudio for durum wheat and cv. Sunrise for barley) was sown to the three experiments. Two irrigations of 90 mm and 100 mm were applied on April 8, and 30 respectively at Gimenells. Experimental details including the specific treatments for each experiment are summarized in Table 2.

Table 2. Experimental details for the three experiments conducted during 2007/2008 growing season

Experiment	**Location**	**Species**	**Nitrogen condition**	**Plant density (plants m^{-2})**	**Initial soil water content (mm)***	**Initial N content (Kg N ha^{-1})***
V	Agramunt	Barley Durum wheat	Un-fertilized	60-120-180-360-720	143	203
		Barley Durum wheat	Fertilized (150 Kg N ha^{-1})	60-120-180-360-720	143	203
VI	Tudela de Segre	Barley Durum wheat	High availability	60-120-180-240	313	517
VII	Gimenells	Barley Durum wheat	High availability	60-180-540	232	439

* Water and NO_3^- availability at 1 m soil depth.

Semi-controlled experiments

Two experiments were carried out in two consecutive growing seasons (2006-2007, exp. 1 and 2007-2008, exp. 2). Malting barley (*cv.* Sunrise) and Durum wheat (*cv.* Claudio) were sown in large rectangular containers (1 m height and 1 m^2) located outdoors in the experimental field of ETSEA, University of Lleida, Spain (41° 37' 50.23" N, 0° 35 ' 27" E). These cultivars were the same used in the field expewriments. In order to ensure a low availability of nitrogen, the containers were filled with a sand:soil mix (3:1 by volume). In each of the two studies, N-nitrate in the soil mixture at the beginning of the experiment was 70 and 30 kg $_{N}$ ha^{-1} in exp. VIII and IX, respectively.

Treatments consisted of the factorial combination of: (i) two species, (ii) two levels of nitrogen, and (iii) two levels of water availability. The nitrogen treatments were a control without fertilization (N_0) and a fertilized treatment (N_{100} or N_{250}, 100 (exp. VIII) and 250 (exp. IX) kg $_{N}$ ha^{-1}). N fertilizer (urea) was applied together with the earliest irrigations, splitting the dose in two (DC 2.1 and 3.1 in exp. VIII) or three (DC 2.1, 2.3 and 3.1 in exp. 2) to avoid leaching. The two water treatments consisted in a rain-fed (RF, watered at sowing and when N was applied) and an irrigated (IR, maintained at or near field capacity throughout the growing cycle). Due to the excessive rainfall during pre-anthesis in exp. VIII, this treatment was only analysed in exp. IX. Treatments were arranged, within each experiment, in a complete randomized design with three replicates.

Microcrops were sown in November 24 2006 (exp. VIII) and November 14 2007 (exp. IX), within each container crops were sown in rows, 10 cm apart. To warrant uniformity within each microcrop, seeds were placed manually on a masking tape (1 m linear strips) and covered with tissue paper. These strips were placed in the rows and covered with the soil mixture. The density was 500 plants (exp.VIII) and 300 plants m^{-2} (exp. IX). P fertilizer (triple superphosphate) was uniformly mixed within the upper 20 cm of the soil mixture before sowing in each experiment. Weeds were removed by hand. Diseases and insects were prevented by spraying typical products of the region.

Main conclusions

From field experimental results

The wide range of water and nitrogen availabilities explored across the 7 experiments resulted in a grain yield range from 0.8 Mg ha^{-1} to 10 Mg ha^{-1}. In all the three species grain number per unit land area was the main sub-component explaining grain yield (Fig 1a). Grain weight did not present a clear relationship with grain yield of barley, bread wheat or durum wheat (Fig 1b).

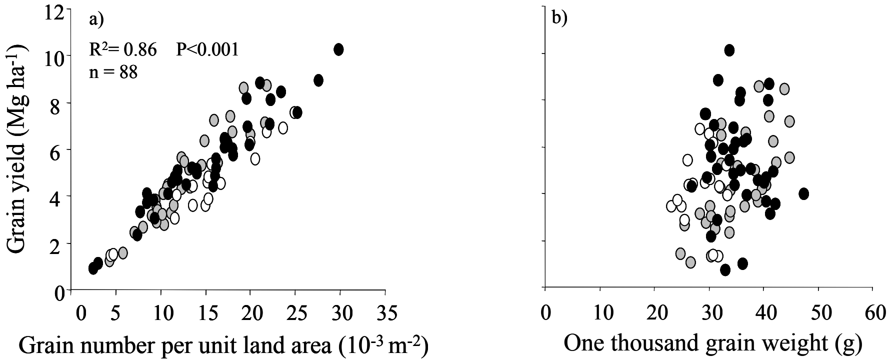


Figure 1. Grain yield of the 7 field experiments as a function of (a) grain number per unit land area and (b) one thousand grain weight for barley (black symbols), bread wheat (white symbols) and durum wheat (grey symbols).

Across the wide range of N and water availability conditions explored during the project, grain yield of the three species was positively and robustly related to N uptake at maturity by the crops (Fig. 2). The relationship observed for the experimental data between grain yield of the three species evaluated and N uptake at maturity, fits inside the boundary defined by Savin *et al.* (2006) for the bibliographic data reported in Mediterranean conditions. Total dry matter at maturity as well as grain number per unit land area for the three species presented a similar tendency to grain yield with N uptake at maturity.

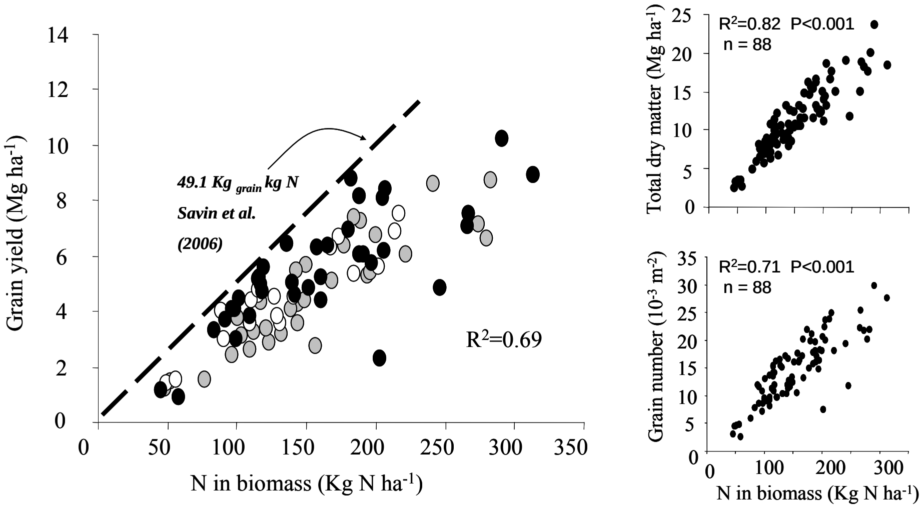


Figure 2. Grain yield as a function of the N in biomass at maturity for barley (black symbols), bread wheat (white symbols) and durum wheat (grey symbols). Small figures correspond to the relationship observed for total DM at maturity (upper-right figure) and grain number per unit land area (bottom-right figure) of the three species.

Nitrogen use efficiency (NUE) of the three species was positively related to N uptake efficiency (U_pE) and to N utilization efficiency (U_TE), although the relationship was closer for U_pE and NUE than for U_TE (Fig. 3). The range of variability observed in U_pE across the 7 experiments was higher than in U_TE. This variability was the consequence of the wide range of water availability during the whole growing season among the experiments.

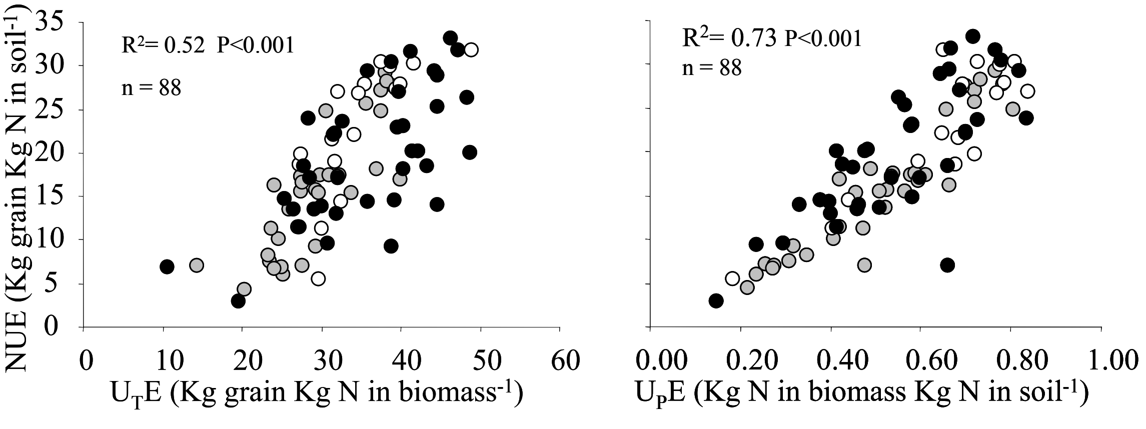


Figure 3. Nitrogen use efficiency as a function of nitrogen utilization efficiency (U_TE) and N uptake efficiency (U_pE) for barley (black symbols), bread wheat (white symbols) and durum wheat (grey symbols).

N uptake by the crops differed between experimental conditions, and it could be defined a boundary of N uptake per mm of water used (evapotranspirated) equal to 1 Kg N ha^{-1} mm^{-1} (Fig. 4).

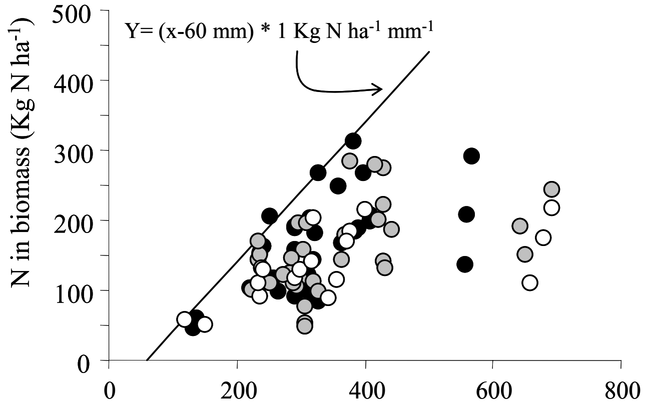


Figure 4. Nitrogen in biomass at maturity as a function of water used by the species from emergence to maturity for barley (black symbols), bread wheat (white symbols) and durum wheat (grey symbols).

From semi-controlled experiments

As expected, increasing N availability resulted in higher aboveground biomass and grain yield at maturity in both experimental years and both species (Table 1). Increasing water availability in exp. IX also resulted in higher biomass and yield (Table 3). Grain yield was higher in exp. VIII than in exp. IX (average 5.3 *vs.* 4.1 Mg ha^{-1} for exps. VIII and IX, respectively) mainly due to N availability at sowing as differences in temperature, incident radiation and rainfall were minimal between experimental years (data not shown). Barley had higher yields than wheat in exp. VIII but negligible differences between species were found in the second year (Table 3).

Differences in grain yield were better explained by differences in the number of grains m^{-2} (R^2= 0.95, P< 0.05 and R^2= 0.94 P< 0.05, for wheat and barley, respectively), than by grain weight (R^2= 0.01 and 0.06 for wheat and barley, respectively), as also found in the field experiments. The increased number of fertile florets at anthesis produced by N in all experiments (Fig. 5) was related to an effect of this factor on the rate of floret development, particularly for the floret positions in which the final number of fertile florets was defined in each of the spikelets considered (Table 4).

Floret development in wheat was modified by treatments. In exp. VIII (Fig. 5) increased N availability resulted in an increased of fertile floret (mainly floret 3) in the apical and basal spikelets while no differences were found in florets 1 and 2 (data shown in 4th year report). In exp. IX, under N+ W+ the three most proximal floret (F1, F2 and F3) reached W10 in apical, central and basal spikelets, while under N+ W-, the same proximal floret reached W10 only in the central spikelet (data shown in 4th year report) and in apical and basal spikelets reached W9. Increasing water and N availabilities resulted in greater impact on the development in floret 4 as only reached W10 in the central spikelet and c. W9.5 in the basal spikelet. The distal florets on the rachis (greater than F4) did not achieve the status floret fertile regardless of treatment.

Table 3. Grain yield, grain weight and total aboveground biomass for the two semi-controlled experiments (2006-2007 and 2007-2008) at Lleida (Spain)

Durum Wheat		Yield (g m^{-2})	Weight grain (mg)	Biomass total (g m^{-2})
2006-2007	N_{0}	360.42	39.20	857.83
	N_{100}	511.78	40.42	1171.67
2007-2008 $_{Irrigated}$	N_{0}	306.88	44.81	588.94
	N_{250}	726.83	40.63	1527.89
2007-2008 $_{Ranifed}$	N_{0}	234.48	34.59	663.50
	N_{250}	517.98	47.03	1062.98
Barley				
2006-2007	N_{0}	535.30	33.71	1099.88
	N_{100}	708.04	32.68	1463.11
2007-2008 $_{Irrigated}$	N_{0}	286.21	35.55	570.60
	N_{250}	722.50	41.42	1389.65
2007-2008 $_{Rainfed}$	N_{0}	209.71	35.63	433.13
	N_{250}	306.52	36.40	642.08
LSD $_{(2006-2007)}$		119.49	3.05	230.93
LSD $_{(2007-2008)}$		68.33	2.60	117.67

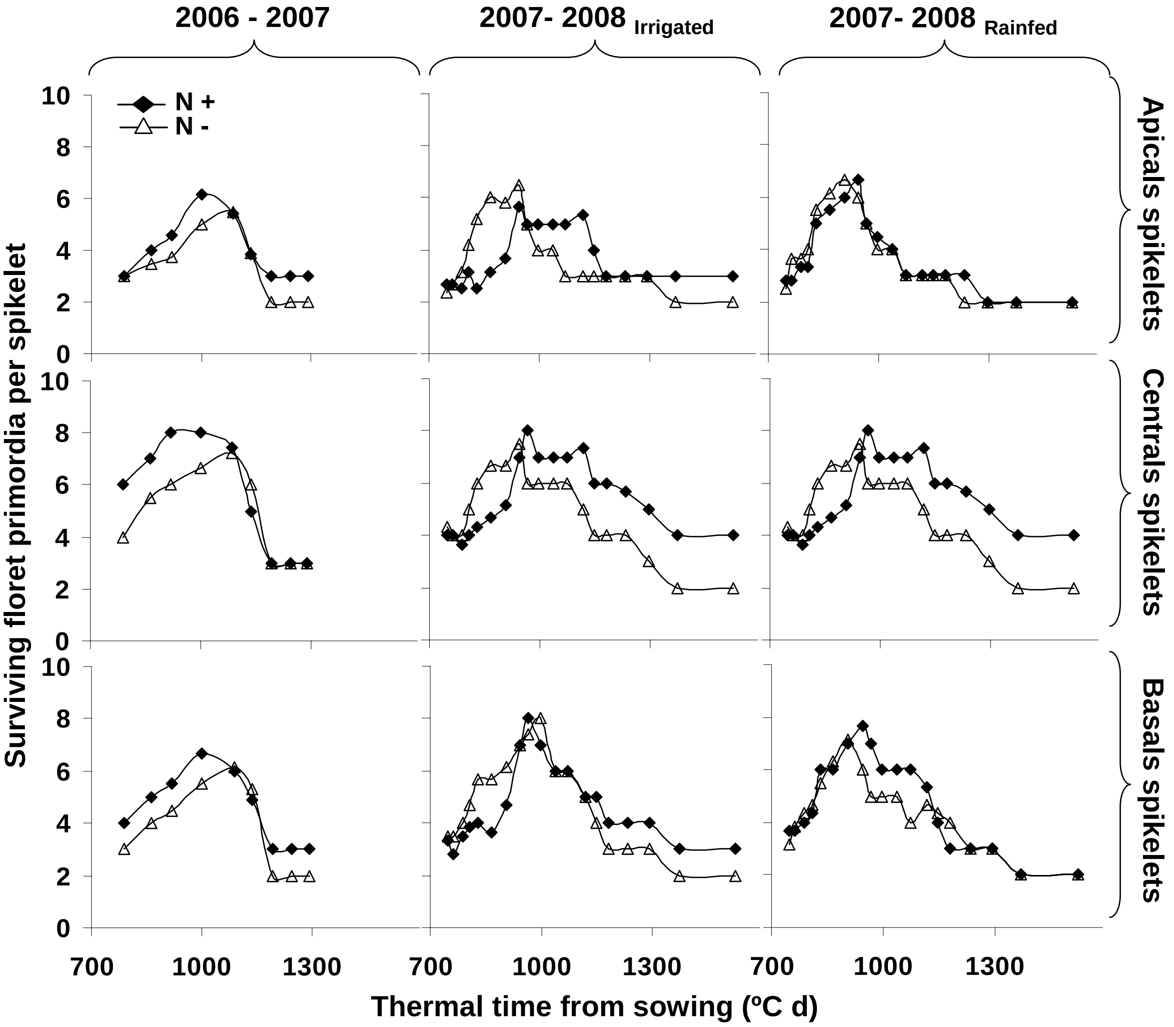


Figure 5. Relationship between surviving floret primordia (closed symbols: N+ and open symbols N-) and thermal time from sowing (ºCd) for 2 basal, 2 central and 2 apical spikelets on main-shoot spike in durum wheat. The N treatments were a control without fertilization (N-) and a fertilized treatment (N_{100} or N_{250}, for exps. VIII and IX, respectively).

Table 4. Nitrogen effect on the developmental rate towards W_{10} (10^{-2} ºCd^{-1}; calculated as the slope between floret score from $W_{3.5}$ to W_{10} and thermal time from sowing) of selected florets of wheat and barley in each of the three conditions and for each of the three spikelet categories considered (basals, centrals and apicals). The nitrogen treatments were a control without fertilization (N_0) and a fertilized treatment (N_{100} or N_{250}, 100 (exp. VIII) and 250 (exp. IX) kg N ha^{-1})

		Durum wheat				**Barley**
		Floret 1	**Floret 2**	**Floret 3**	**Floret 4**	
Apicals						
2006-2007	N_0	1.64 ± 0.09	1.44 ± 0.07	1.27 ± 0.08		1.75 ± 0.12
	N_{100}	1.69 ± 0.07	1.55 ± 0.09	1.39 ± 0.15		1.74 ± 0.13
2007-2008 *Irrigated*	N_0	1.64 ± 0.06	1.51 ± 0.07	1.26 ± 0.06	0.89 ± 0.12	1.78 ± 0.15
	N_{250}	1.55 ± 0.06	1.45 ± 0.06	0.83 ± 0.10	0.56 ± 0.09	1.60 ± 0.10
2007-2008 *Rainfed*	N_0	1.95 ± 0.11	1.81 ± 0.08	1.38 ± 0.09	1.28 ± 0.22	1.96 ± 0.10
	N_{250}	1.74 ± 0.05	1.83 ± 0.06	1.19 ± 0.06	1.17 ± 0.23	1.79 ± 0.10
Centrals						
2006-2007	N_0	1.61 ± 0.10	1.51 ± 0.07	1.46 ± 0.05	1.10 ± 0.18	1.72 ± 0.11
	N_{100}	1.79 ± 0.10	1.61 ± 0.09	1.58 ± 0.08	1.41 ± 0.09	1.78 ± 0.14
2007-2008 *Irrigated*	N_0	1.44 ± 0.06	1.61 ± 0.08	1.56 ± 0.06	1.12 ± 0.05	1.70 ± 0.09
	N_{250}	1.53 ± 0.09	1.65 ± 0.07	1.62 ± 0.07	1.33 ± 0.07	1.54 ± 0.06
2007-2008 *Rainfed*	N_0	1.81 ± 0.08	1.90 ± 0.10	1.77 ± 0.07	1.36 ± 0.09	1.86 ± 0.10
	N_{250}	1.63 ± 0.05	1.85 ± 0.06	1.80 ± 0.06	1.51 ± 0.08	1.66 ± 0.08
Basals						
2006-2007	N_0	1.63 ± 0.05	1.59 ±0.08	1.46 ± 0.12		1.83 ± 0.19
	N_{100}	1.62 ± 0.07	1.53 ±0.10	1.58 ± 0.12		1.79 ± 0.09
2007-2008 *Irrigated*	N_0	1.59 ± 0.06	1.61 ± 0.06	1.42 ± 0.07	0.82 ± 0.07	1.65 ± 0.10
	N_{250}	1.48 ± 0.07	1.62 ± 0.07	1.48 ± 0.06	1.17 ± 0.06	1.52 ± 0.07
2007-2008 *Rainfed*	N_0	2.05 ± 0.12	1.86 ± 0.09	1.57 ± 0.06	1.04 ± 0.08	1.81 ± 0.08
	N_{250}	1.75 ± 0.07	1.80 ± 0.06	1.73 ± 0.08	1.10 ± 0.07	1.64 ± 0.07

Regarding barley, the effect of increasing N availability in the unique floret, resulted in a reduced rate of development compared to the control in all spikelets positions (Table 4).

Thus, Increasing N and water availabilities in wheat increased the rate of development of the florets mainly at the distal positions, and thus increased the establishment of additional fertile florets in those spikelets. In barley the dynamics of tillering might be more relevant than in wheat as determinant of the responses to N and water.

References

Anonymous (Group for the Evaluation of New Cereals Varieties in Spain). (1999-2004). Report of new varieties of wheat and barley evaluated during the growing season 1999-2000, 2000-2001, 2001-2002, 2002-2003 and 2003-2004.

Savin, R., Sadras, V.O., Slafer, G.A. (2006). Do Mediterranean environments set up an upper limit in wheat nitrogen use efficiency?. In: Bibliotheca fragmenta Agronomica. Vol.11. Books of proceedings, part I. European Society for Agronomy, Polish Society for Agronomy. IX ESA Congress, 4-7 September 2006. Warsaw, Poland. 439pp.

Zadoks, J.C., Chang, T.T., Konzak, C.F. (1974). A decimal code for the growth stage of cereals. *Weed Research*, 14, 415-421.

WP10 Crop Root Capture

Leader of workpackage: **Partner 10, UJ Jordan**

Workpackage Objectives

- To quantify responses of root growth, root: shoot partitioning and water and N capture to a range of environments differing in timing and intensity of water and N stresses in field experiments.
- To test for crop traits and management interventions to improve crop water and N capture.
- To evaluate the impact of rooting traits on above-ground growth and grain productivity under a range of water and N regimes to identify combinations of water and N stresses in which agronomic manipulation of rooting systems is likely to most beneficial.

List of Deliverables

- Datasets describing responses of rooting traits and water and N capture to a range of water and N stresses (it has been achieved).
- Nominated candidate agronomic intervention strategies for evaluation at the field scale in WP11 and WP12 (it has been achieved).
- List of rooting traits and combinations of traits tested for physiological relationships with water and N resource capture at the whole crop level (It has been achieved).
- List of potential impacts of rooting traits for enhanced resource capture on utilization efficiency. (it has been achieved).
- A final report summarizing scientific findings of WP10. (it has been achieved).

List of Milestones

- Preliminary field studies - initiated (achieved).
- First detailed field experiments – initiated (achieved).
- First field experiments – analyzed (achieved).
- Second year of detailed field experiments – initiated (achieved).
- Second year of field experiments – analyzed (achieved).
- Third year of field experiments – initiated (achieved).
- Analysis of third year of field experiments and final report summarizing scientific findings of WP10 (achieved).

Summary of Workpackage Main Findings

Materials and Methods

Preliminary field study was conducted based on two different ongoing field experiments for wheat (*Triticum turgidum* L. var *durum*) and for barley (*Hordeum vulgare* L.) under rainfed conditions. Wheat experiment included well adapted variety of durum wheat (Hourani) at Maru Experimental Station (31.85^o N latitude and 32.55^o E longitude with an elevation of 620 m). Nitrogen treatments were restricted to two levels only; N0 and N50 with no fertilizers and 50 kg N.ha^{-1}, respectively. Second ongoing field experiment was for Barley, sown with a well adapted local variety Rum at Ramtha Experimental Station (32^o 46$^\backslash$ N latitude and 33^o 45$^\backslash$ E longitude with an elevation of 590 m). Barley was sown at two separate dates; November 2, 2004 and November 17, 2004.

Three detailed field studies were conducted during 2006, 2007, and 20008 growing seasons to fulfill the objectives of this workpackage. The field experiments was sown at the University of Jordan Agriculture Research Station at Jubeiha (32.02^o N, 35.87^o E, 980 m altitude) during 2006 and 2007 growing seasons and at Mushaqqar Research Station during 2006 and 2008 growing seasons (31.8° N 35.78° E, 790 m above sea level). These two stations have a Mediterranean climate of mild rainy winters and hot dry summers with average seasonal precipitation of 490 mm and 360 mm at both Jubeiha and Mushaqqar, respectively.

One wheat and one barley vars (Hourani and Rum) were use at Jubeiha during 2006 growing season while two wheat vars (Hourani and Om Qais) and two barley vars (Rum and Acsad 176) were used at 2007 growing season. In the second field at Mushaqqar, two wheat vars (Hourani and Dairalla) were used during 2006 growing season and three wheat vars (Hourani, ACSAD 68, and OmQaise) were used during 2008 growing season.

With the exception in the preliminary study, three nitrogen (N0, N50, N150) treatments, unfertilized, fertilized with 100 kg and 150 kg N/ha, respectively were studied in 2006, 2007 and 2008. Water availability was manipulated by supplemental irrigation as compared to rainfall only. The water regimes were precipitation and precipitation plus supplementary irrigation to maintain soil moisture deficit to < 50% available water (AW) up to GS83 and < 75% AW thereafter up to full canopy senescence. The treatments imposed were complementary with treatments used in the parallel controlled-environment work in WP5.

Developmental stages of wheat and barley under different treatments was recorded according to Zadoks scale (GS). Plots were sampled at jointing (GS31), Anthesis (GS61), physiological maturity (GS89), and at maturity harvest during 2006 and at GS61, GS89 and maturity during 2007 and 2008 growing seasons for above ground growth measurements; yield and yield components. Environmental parameters including Max TºC, Min T ºC, precipitation, and relative humidity, was recorded from weather station on nearby the experimental field during the growing season. Soil samples was also taken before planting for some soil analysis.

Roots were sampled GS 61 in 2006 and at GS 89 at 2007 growing season. Two roots samples were taken from between and within the crop rows by soil corers (10 cm diameter) and separated into five horizons (0-20, 20-40, 40-60, 60-80 and 80-100 cm depth. The roots were extracted from the soil by washing samples using a root washer (Delta-T Devices Ltd., Cambridge, UK) and stored in refrigerator (-10 oC) for root analysis. Roots samples were scanned to estimate the root length and root length density using a root scanner (Regent STD 1600+ using a WinRhizo Pro 2005b software program) and then weighed after drying at 70°C for 48h for dry matter determination and nitrogen analysis.

Gravimetric soil moisture measurements were made before sowing and at GS 61, and harvest stage. Soil samples have been taken in 0.2 m depth horizons to 1m depth from each plot. Crop water use was calculated for all treatments at harvest stage as initial soil water + precipitation + irrigation – final soil moisture. Crop water use efficiency was also calculated as the ratio between total biomass yield and grain yield (g m^{-2}) to the total crop water use (m^3) during the growing season.

Samples of various plant parts (leaves, stems, spikes, straw, grain, roots) that has been taken at GS61, GS89, and maturity was prepared for Nitrogen analysis by micro-Kjeldahl procedure. On the other hand soil samples have been taken at harvest time for soil residual nitrogen determination.

Results

Weather and crop development

Seasonal precipitation was variable during the 4 last growing seasons at both locations where field experiments were conducted. Total rainfall was 433 mm and 512 mm at Jubeiha during and 2006 and 2007 growing seasons, respectively. Mushaqqar station has a less precipitation with about 312 mm and 173 mm during 2006 and 2008, respectively. The long term average annual precipitation for Jubeiha and Mushaqqar is 490 and 360 mm. respectively. The variability in precipitation amounts and duration resulted in a variable growth measures that is summarized in the next presented data.

Crop growth, yield and its components

Green area of plants is very important in growing cereal, especially during early developmental phases. It affects the ability of the crop canopy to intercept solar radiation and biomass accumulation and partitioning. A significant effect of both genotypes and nitrogen treatments on green area index at anthesis (GS61) was observed. The effect of irrigation was only significant in dry years such as 2008 season. Barley shows higher GAI as compared to wheat especially under high nitrogen levels. Similar effect of nitrogen on GAI of wheat genotypes grown at Mushaqqar were observed. However, No obvious differences were observed between wheat genotypes during 2006 and 2008 seasons at Mushaqqar station..

Yield and yield components of both wheat and barley genotypes varied between seasons. However, barley produced higher grain yield than wheat genotypes and this was consistent over 2006 and 2007 growing season (Figure 1 and 2). Effect of irrigation on yield and yield components was more distinct in dry years such as 2008 growing season. Nitrogen affected positively yield of both wheat and barley genotypes, especially under irrigation during 2006-2008 growing seasons.

On the other hand, straw yield was similar for both wheat and barley under rainfed and irrigated conditions (Figure 1 and 2). The use of nitrogen between 50 and 100 kg ha^{-1} resulted in increasing straw yield between 27 and 39% of the two treatments over the non fertilized one.

There was an interaction between irrigation x genotype x var and between irrigation x genotype x nitrogen. These effects were associated with differences in number of grains per square meter and with number of spikes (ears) per square meter as well as number of grains per spike. Irrigation overall increased number of spikes and number of grains per square meter and the effect was higher for wheat varieties than for barley. The effect of nitrogen was also significant.

During the last growing seasons, total wheat biomass and grain yield was almost doubled in all genotypes in response to irrigation (Figure 3). Grain yield increased from about 160% for OmQais to about 260% in Hourani. Nitrogen application has resulted in increasing grain yield over al genotypes by 112 to 118% of that non fertilized vars. The effect of nitrogen interacted with irrigation resulted in 17-21% increase in grain yield as compared to rainfed (1-12%)

Root length density and root dry weight

Averaging overall irrigation and nitrogen treatments, genotypic differences were observed at various soil depths and between seasons. During 2006 growing season, wheat had a higher RLD than barley (Figure 4) while in the second year (2007, wettest year), the two barley varieties had higher RLD than wheat vars (Figure 5). The variation between genotypes and varieties was not significant over all soil depths. The effect of nitrogen application (N50 and N100) significantly increased RLD of both species with the exception of the deepest soil horizon (80-100 cm) where no effect of nitrogen was observed. The effect of nitrogen on RLD was higher under irrigation than under rainfed treatments. The effect of nitrogen and irrigation was almost consistent in all wheat and barley vars. Rainfed treatments increased RLD through different soil horizons of all wheat and barley varieties and this was higher for barley genotypes (Figure 5). Nitrogen treatments also increased RLD of various genotypes.

During the driest year of 2008, supplemental irrigation resulted in higher wheat RLD than rainfed and the magnitude of increase varied among genotypes (Figure 6). The percentage increase in RLD in response to irrigation ranged from 15-81% for ACSAD and from 37-144% for hourani and from 39-101% for Om Qais.

Average of specific root length was significantly affected by nitrogen application where SRL increased from 84.63 to 99.09 mm mg^{-1} when plants fertilized with N50 (Figure 7). Under irrigated conditions, the application of nitrogen significantly increased SRL of barley but not of wheat whereas under rain-fed conditions, the application of nitrogen significantly increased SRL of wheat but not of barley. No significant effect of irrigation, species or other interactions among treatments was observed. In the present study, distribution of fine roots differed with depth. Specific root length in the top 40 cm layer of the soil was 32% of its total specific root length whereas that at lower soil depths was 68%.

Crop water use and root water capture rate

Barley had a higher water use efficiency for both grain yield and total biomass as compared to wheat in both 2006 and 2007 seasons, especially under rainfed conditions (Figures 8-10).

Nitrogen treatments also resulted in significantly higher water use efficiency. Water use efficiency was higher for rainfed treatments as compared to irrigated.

There was appositive reponse of WUE to nitrogen fertilizers and this was higher under irrigation treatments. These tendencies were more noticeable in barley than in durum wheat vars. Barley BY

WUE GY WUE reached the highest values in N100, and in the rainfed treatments showed a slight trend to decrease with N supply, although it did not differ significantly.

Water use efficiency for grain yield ranged between 0.9 and 3.1 Kg m^{-3} and water and between 2.7 and 7.4 Kg m^{-3} for total biomass during 2006. The higher values of BY WUE were obtained for barley (Acsad) with a mean of 3 Kg m^{-3}, and the lowest for wheat (Om Qais) with mean of 1.8 $kg.m^{-3}$.

During the last driest year compared to 2006 and 2007 seasons, wheat GY WUE and BY WUE tended to increase with supplemental irrigation with the exception of OmQaise var. (Figure 10). There was no effect of nitrogen fertilizers on WUE for all geotypes. BY WUE was low for this year with values ranging from 1.6 kg/m^3 for OmQais var to 2.9 kg/m^3 for ACSAD. Similar trend were observed for GY WUE with values ranging from 0.46 kg/m^{3for} Hourani to 1.22 kg/m^3 for ACSAD var.

The relationship between total RLD (km m^{-3}) and water used by the crop (mm at harvest) for irrigated and rain-fed wheat and barley plants is shown in figure 13. A higher slope was found for barley under irrigation and rain-fed conditions (R^2=0.94 and 0.52) as compared to wheat (R^2=0.22 and 0.76).

Negative relationship was found under rain-fed conditions between RLD and residual soil moisture content with higher slope also found for barley (-0.003; R^2= 0.92) as compared to wheat (-0.001; R^2= 0.81). That means barley plants depleted less soil moisture than wheat. Furthermore, nitrogen application resulted in increased soil moisture depletion.

The high slope of water capture per unit total root length (RWCR) of barley is probably because of the root systems of this genotype which consist of very fine roots. This appears to allow water absorption more efficiently.

Crop Nitrogen use and root nitrogen uptake

Nitrogen uptake g m^{-2} was affected significantly by irrigation, genotype and nitrogen level at anthesis (Figure 11). The highest leaf nitrogen uptake was for irrigated wheat with 100 kg N ha^{-1}. Stem nitrogen uptake was higher than that of leaves and spikes for most of treatments. Stem nitrogen uptake was only affected by nitrogen level. Spike nitrogen uptake was also affected by nitrogen level. However there were a trend for the effect of irrigation and genotype on spike nitrogen uptake, where irrigated barley had the highest uptake levels. Total nitrogen uptake at anthesis was only affected by nitrogen level with 30-48% increase over the non fertilized treatments.

At maturity harvest, straw nitrogen uptake was only affected by nitrogen level (Figure 12) while grain nitrogen uptake was affected by both genotype and nitrogen. Barley grains showed about 35% higher nitrogen uptake than wheat grains. Nitrogen uptake by various plant parts was affected by genotype and nitrogen level. Nitrogen harvest index (NHI) is an indication of nitrogen portioning to grains at maturity harvest stage and into spike at anthesis stage. NHI at anthesis was only affected by genotype while at maturity harvest, the effect of nitrogen was only significant. NHI was significantly reduced at maturity harvest stage by the addition of nitrogen fertilizers with no difference between N50 and N100. Considerable amounts of nitrogen in the vegetative parts are present in the roots and since roots were the last vegetative part to senesce, the roots might play a major part in the redistribution of nitrogen in the plant. Redistribution of nitrogen from the root to the nitrogen amount in grain at maturity for both wheat and barley cultivars should be taken into consideration in future work.

Root length is the most obvious attribute to relate to the rate of nutrient uptake as it has a clear functional significance and closely related to the volume of soil explored. A strong relationship between RLD and shoots N uptake was observed (Figure 14). A higher slope was found under rain-fed conditions for both wheat and barley (0.81; R^2=0.91 and 0.29; Fig.5.27) as compared to irrigation conditions (0.5; R^2=0.89 and 0.35). The rate of N uptake per unit total root length (RNUR) increased with increasing root length density and the magnitude of increase was higher for plants that have higher values of specific root length (plants grown under rain-fed conditions).

A positive relationship between RLD and residual soil mineral nitrogen was found under rain-fed conditions with higher slope found for barley (1.41; R^2= 0.998) as compared to wheat (1.002; R^2=0.47). In contrast a negative relationship was found under irrigated conditions with higher slope also found for barley (-5.6; R^2= 0.92) as compared to wheat (-1.49; R^2= 0.89).

Discussion

Maintenance of root growth during water deficits is an obvious benefit to maintain an adequate plant water supply, and it is under genetic control (O'Toole and Bland, 1987; Sponchiado *et al.*, 1989). An important feature of the root system response to soil drying is the ability of some roots to continue elongation at water potentials that are low enough to inhibit shoot growth completely (Sharp *et al.*, 2004). Lascanor and Van bavel (1984) showed that the water uptake by the root system is proportional to the rooting density in a particular layer and the difference between the water potential of that layer and the overall mean leaf water potential.

A wide range of literature on varietals differences in rooting depth of wheat in response to moisture stress is available. Improvement in rooting aspects can be brought by increasing the rooting depth and root distribution with depth which are associated with an increase in the duration of the vegetative period (Brown *et al.*, 1987; Wahbi and Gregory, 1995, Siddique *et al.,* 1990; Miralles *et al.*, 1997).

Specific root length defined as the root length produced by a unit of root biomass (m g^{-1}), an indication of how much biomass plants invest in a given root length and how efficiently plants invest carbon to acquire soil resources (Barber and Silberbush 1984, Fitter 1985). Wright and Westoby (1999) found that species typical of low rainfall environments had both lower SRL and lower potential than species typical of higher rainfall environments. The decreases in SRL resulted from larger root diameter, most likely reflecting anatomical modifications to enhance ability to conduct water in arid conditions, or ability to penetrate dry soil.

Passioura (1983) suggested that the root systems of some crops appear to be too large and reducing their size may not have negative consequences on the resource capture and productivity of such crops. Calculation by McCoy *et al*., (1984) and Passioura (1983) for theoretical situations in which RLD, initial water status and root diameter were varied suggesting that RLD values <0.1 cm cm^{-3} would require between 12 and 20 days to deplete various soils of available water. In another study on barley, it was reported that a RLD of about 1 cm cm^{-3} is required for extraction of 90% of the available water, and about 2 cm cm^{-3} for complete extraction of field based estimate (Gregory and Brown, 1989). Theoretically, the mean RLD (0.5-1.0 cm cm^{-3}) of cereals in top layers of most soils are adequate to access most of the available water and that densities more than 1.0 cm cm^{-3} are associated with only small increase in the total amount of water taken up during yield forming period (Gregory *et al.*, 1978; King *et al.*, 2003).

The size of the absorbing surface, as well as the ability to explore undepleted soil horizons are important factors for mineral nutrient acquisition (Silverbusit, and Barber, 1983). It has been demonstrated both theoretically and experimentally that such factors are of special importance when explaining genotypic differences in the growth and yield under conditions of low soil fertility (Sattelmacner and Thoms, 1991). It was found for cereal crops that, on average, 33 % of the total nitrogen taken up by the crop can come from the subsoil (25% from 30 to 90 cm soil depth and 8 % from 90 to 150 cm depth) (Kuhlmann *et al.*, 1989).

One of the main responses to nitrogen deficiency is a shift in dry matter partitioning in favor of the roots, producing an increase in root to shoot ratio (Clarkson, 1985; Jeschke an Hartung, 2000; Doncheva *et al.*, 2001). Several mechanisms have been proposed to explain this response, including the fact that roots are near to the nutrient supply and can therefore preferentially access it (Clarkson, 1985); roots may also retain a higher proportion of N during N deficiency, so reducing the quantity transported to the shoot (Cooper and Clarkson, 1989).

Alternative views have been suggested. For example, Hunt (1975) showed that nitrogen deficiency slowed root growth to lesser extent than shoot growth, thus leading to a decrease in root to shoot ratio, while Brewitz *et al.* (1995) reported that phytohormones may influence root: shoot ratio under condition of N deficiency. Liang (1996) found that increasing nitrogen supply increased root to shoot ratio due to increase of root dry weight and the number of seminal roots.

Changes in soil water status directly impact root-nutrient relationships. Vegh (1991) showed that, under adequate soil water conditions, changes in nutrient supply had little effect on root length of barley plants. However, when water was limiting, increasing the nutrient supply increased the total root surface area.

There is also some evidence that different genotypes respond differently to soil nutrient status. Hackett (1968) reported that the root systems of different barley varieties showed different morphological characteristics as a result of differences in nutrient levels, particularly phosphorus and potassium deficiencies

The uptake rate of N changes during the life cycle. A large percent of this nutrient is taken up during vegetative stage, and much of it is translocated to the grain during the grain filling period (Karrou and Maranville, 1994). Nitrogen uptake is also influenced by root growth. High density rooting system usually explores more soil volume, and hence the uptake per plant may be increased (Cure *et al.*, 1988). However, N uptake per unit of root mass can be decreased (Cure *et al.*, 1988). Robinson (1986) and Burns (1980) suggested that approximately 20% of the root mass is all that is needed to supply enough N if the inflow rate is as high as10 µmole cm^{-1} sec^{-1}, and soil supply is sufficient.

Delogu *et al.,* (1998) suggested that nitrogen uptake and partition being largely determined by supply and demand during the various stages of plant growth. They found that at heading barley N uptake was 70, 77 and 86% of total N uptake for zero N, 80 kg N ha^{-1} and 140 kg N ha^{-1}, respectively. At the post-heading stages, N assimilation appeared no longer to be linked to the different N rates, whereas in wheat the post-heading N uptake increased by about 50% with the addition of 20 kg N ha^{-1}.

Karrou and Maranville (1994) found that under mild water stress or non stressed conditions, N uptake by the shoot increased with increased soil N in all cultivars. They further reported that severe water stress masked the effect of N supply, and decreased N uptake and root N uptake was not affected by water stress but increased when N was supplied.

Nitrogen utilization efficiency (N_{UTE}; as the ratio of grain yield to total nitrogen uptake) reflects the ability of the plant to translate the N up taken into economic yield (grains). This parameter has been extensively used to compare different species or cultivars at different levels of N fertility (Ortiz-Monasterio *et al*., 1997). Delogu *et al.,* (1998) compared the N_{UTE} values of wheat and barley and they found that barley outperformed wheat with 32% and 8% N_{UTE} increase over wheat at the zero N and 140 kg N ha^{-1}, respectively suggesting a higher ability of barley to generate yield, particularly at low N input. This finding is connected to barley's higher nitrogen harvest index (N_{HI}) than wheat. These results can be linked to better translocation ability, indicating that barley removed more nitrogen from the straw to the grain (Delogu *et al*., 1998). Oweis (2000) examined the effects of various levels of supplemental irrigation, N levels, and sowing time on ET and WUE of wheat and he found that on average, the application of 5, 10, and 15 g N m^2 significantly increased WUE_{GY} for grain yield from less than 0.6 kg m^3 to between 0.80 and 0.99 kg m^3 in the November and December sowings. A similar trend occurred in WUE_{GY} for total dry matter, and no difference in mean WUE_{GY} for grain yield and total dry matter occurred between 10 and 15 g N m^2.

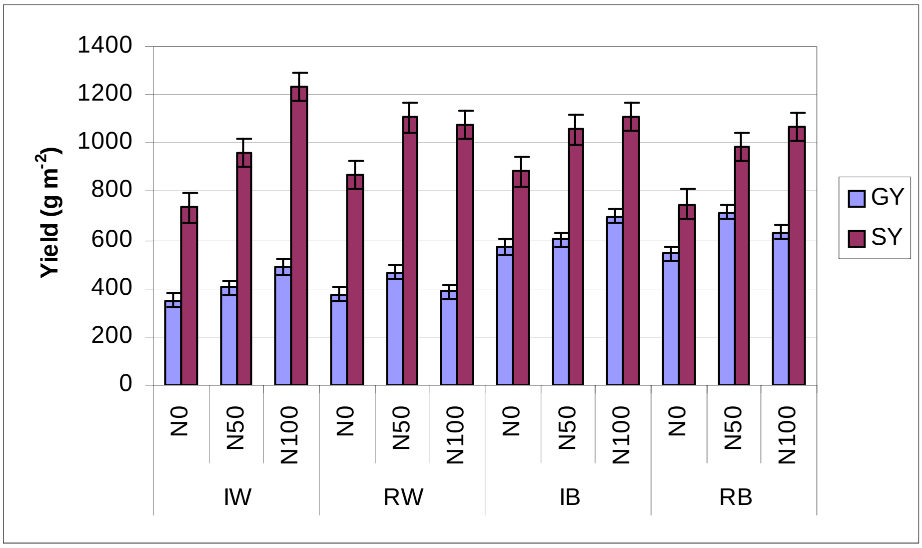


Figure 1. Grain yield (GY) and straw yield (SY) of wheat (W) and barley (B) under both rainfed R and irrigated (I) conditions using 3 nitrogen levels at Jubeiha during 2006 growing season.

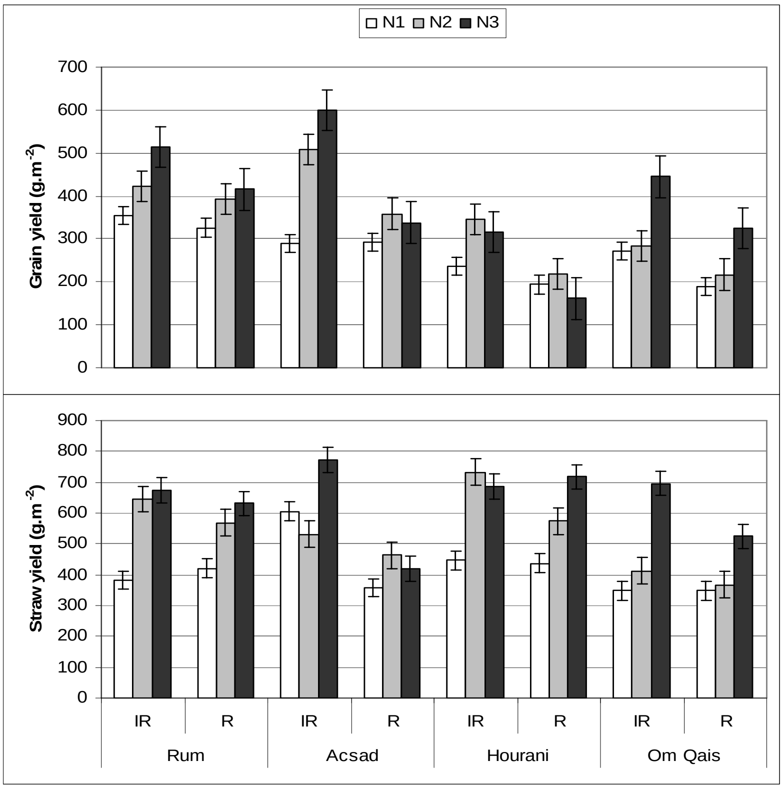


Figure 2. Effect of irrigation (R vs IR) and N on grain and straw yield of 2 barley (Acsad and Rum) and wheat vars (Hourani and Om Qais) during 2007 at GS6

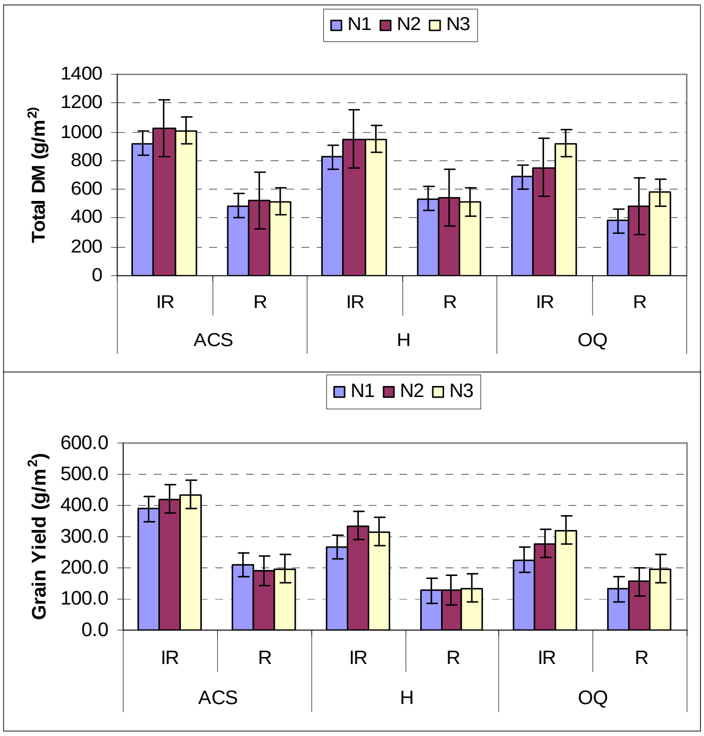


Figure 3. Effect of nitrogen and irrigation on total dry matter and grain yield of 3 wheat genotypes (Acsad, Hurani and OmQasise).

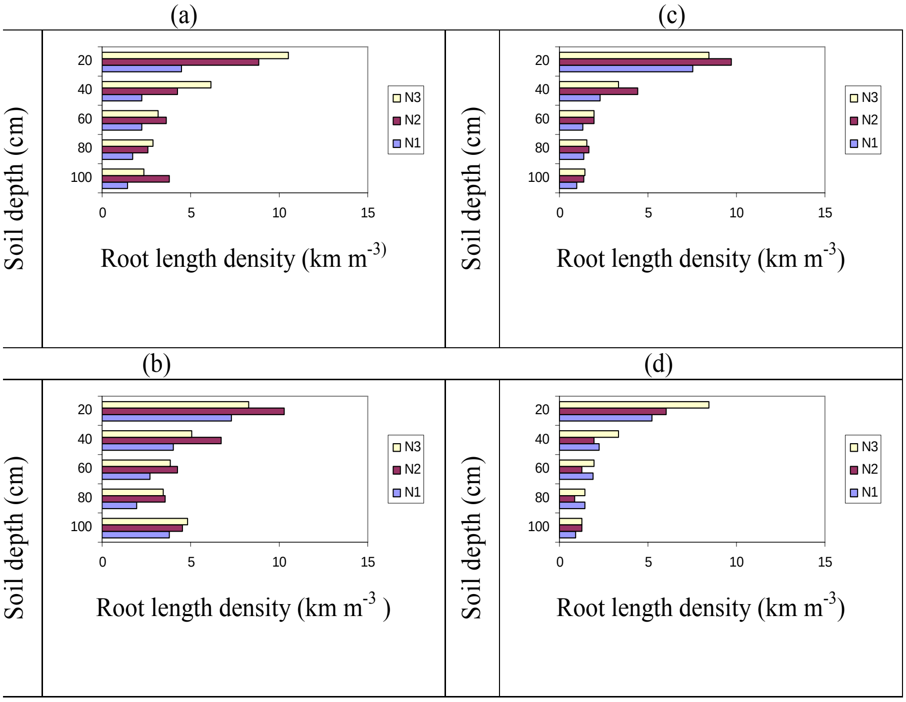


Figure 4. Effect of nitrogen fertilizers and water on root length densities (km m^{-3}) at GS 61 for (a) irrigated wheat (b) rain-fed wheat (c) irrigated barley and (d) rain-fed barley measured in 0-20, 40-60, 60-80 and 80-100 cm depth soil.

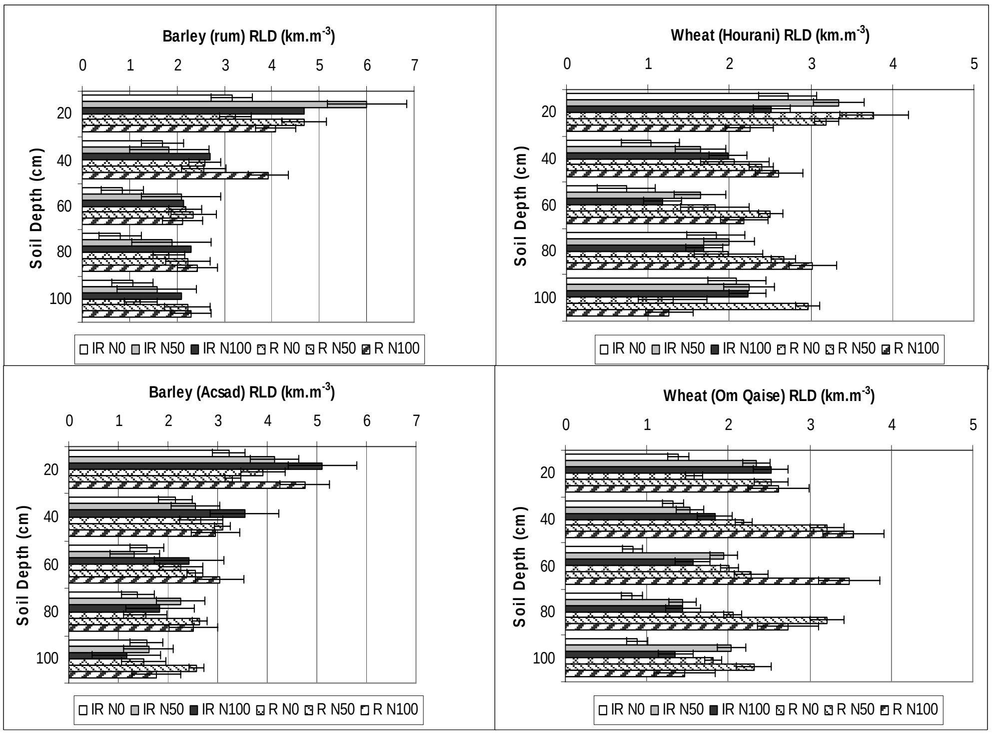


Figure 5. Effect of irrigation (R vs IR) and nitrogen on RLD wheat and barley vars at different soil depths (0-20, 20-40, 40-60, 60-80, 80-100 cm) during 2007 growing season.

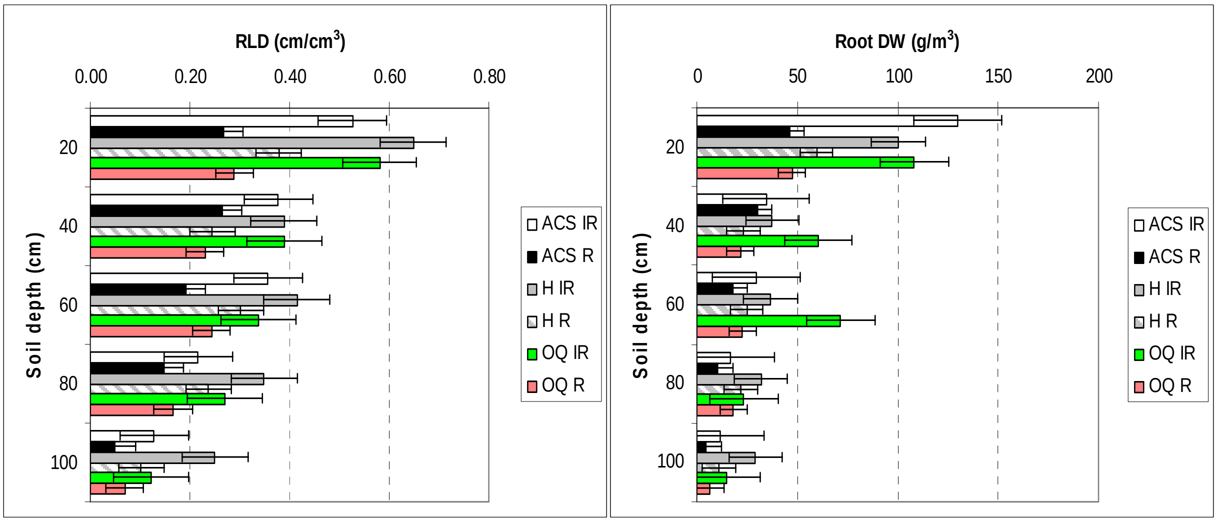


Figure 6. Effect of nitrogen and irrigation on RLD and RWD of 3 wheat genotypes (Acsad, Hurani and OmQasise) at Mushaqqar during 2008 growing season.

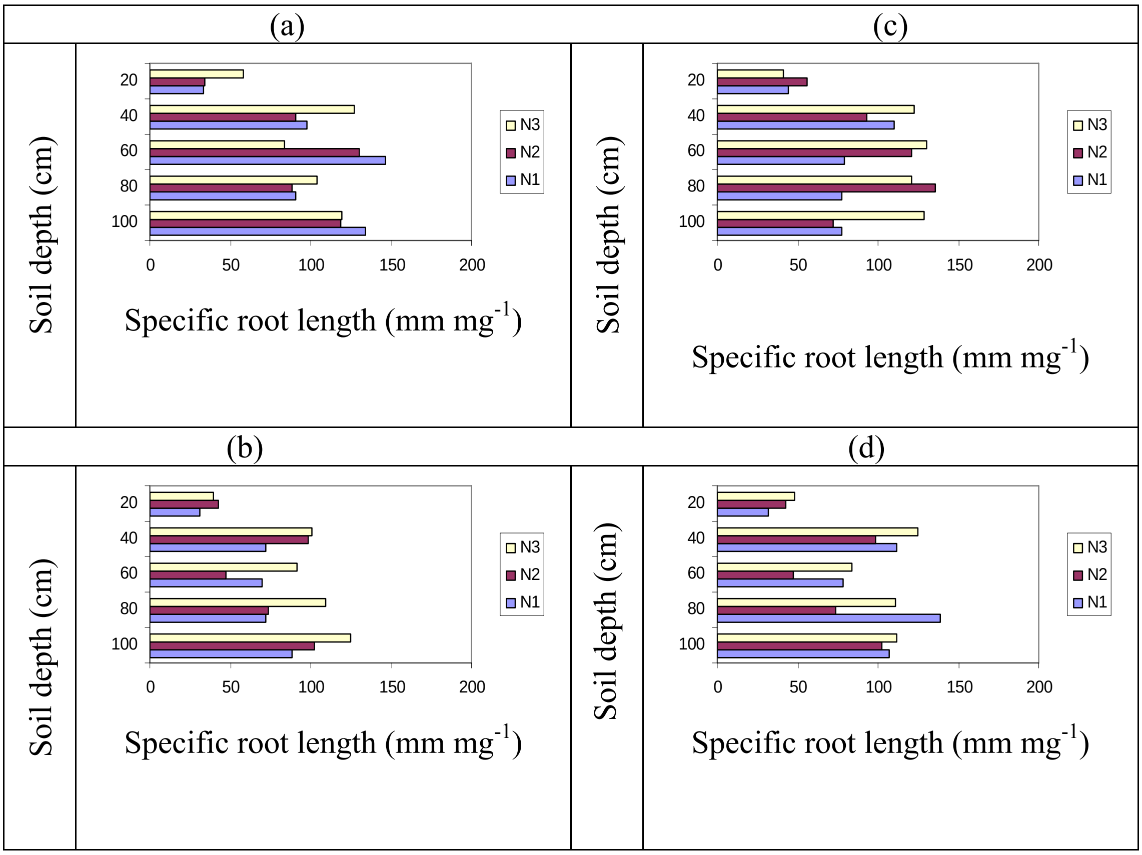


Figure 7. Effect of nitrogen fertilizers and water on specific root length (mm mg^{-1}) at GS 61 for irrigated wheat (b) rain-fed wheat (c) irrigated barley and (d) rain-fed barley measured at various soil depths.

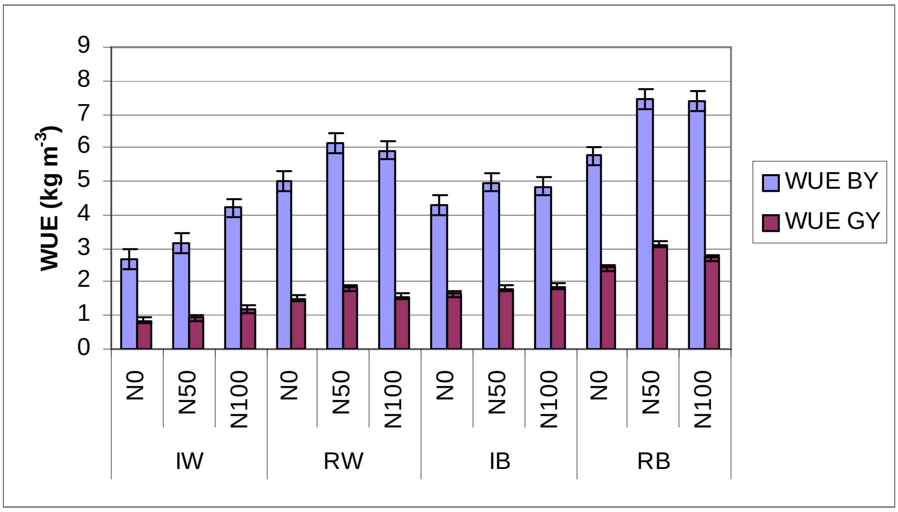


Figure 8. Water use efficiency (WUE, Kg m^{-3}) of wheat (W) and barley (B) under both rainfed R and irrigated (I) conditions using 3 nitrogen levels at Jubeiha during 2006 growing season.

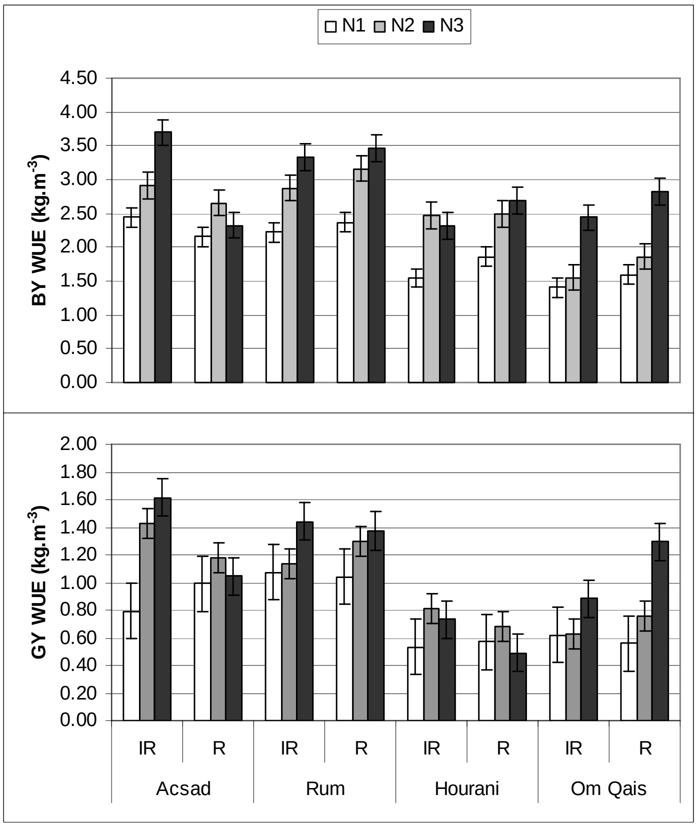


Figure 9. Effect of irrigation (R vs IR) and N on biological yield WUE (BY WUE) and grain yield WUE (GY WUE) of two barley (Rum, Acsad) and wheat vars (Hourani, Om Qais) at during 2007 growing season.

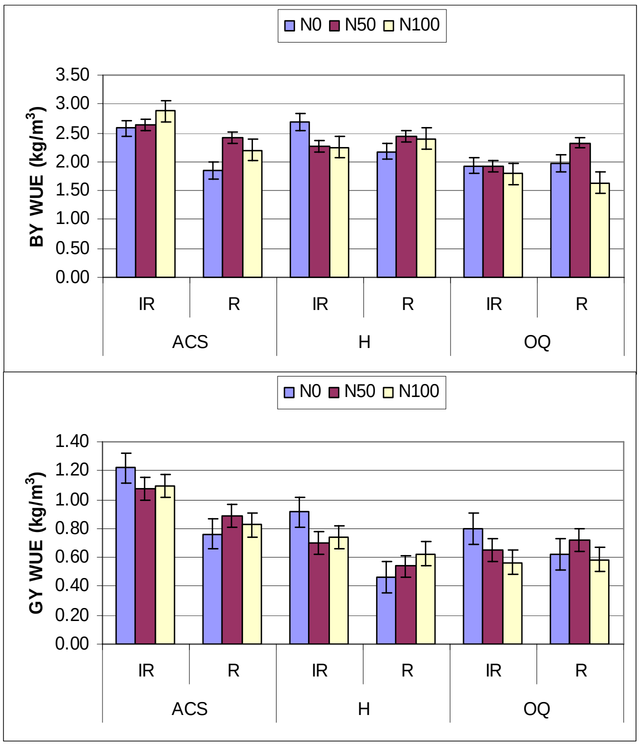
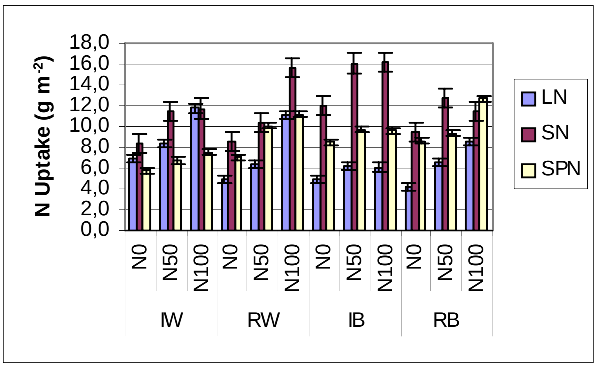


Figure 10. Effect of N and irrigation on biological yield WUE (BY WUE) and grain yield WUE (GY WUE) of 3 wheat vars (Acsad, Hurani and OmQasise) at Mushaqqar during 2008 growing season.



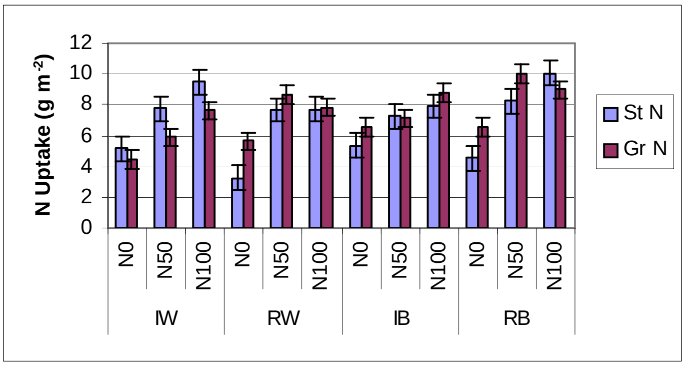


Figure 11. N uptake of leaves (LN), stem (SN), and spikes (SPN) of wheat (W) and barley (B) at GS61 under rainfed R and irrigated (I) conditions at 3 N levels at Jubeiha during 2006 growing season.

Figure 12. N uptake of straw (St N) and grains (Gr N) of wheat (W) and barley (B) at anthesis (GS61) under rainfed R and irrigated (I) conditions at 3 N levels at Jubeiha in 2006 growing season.

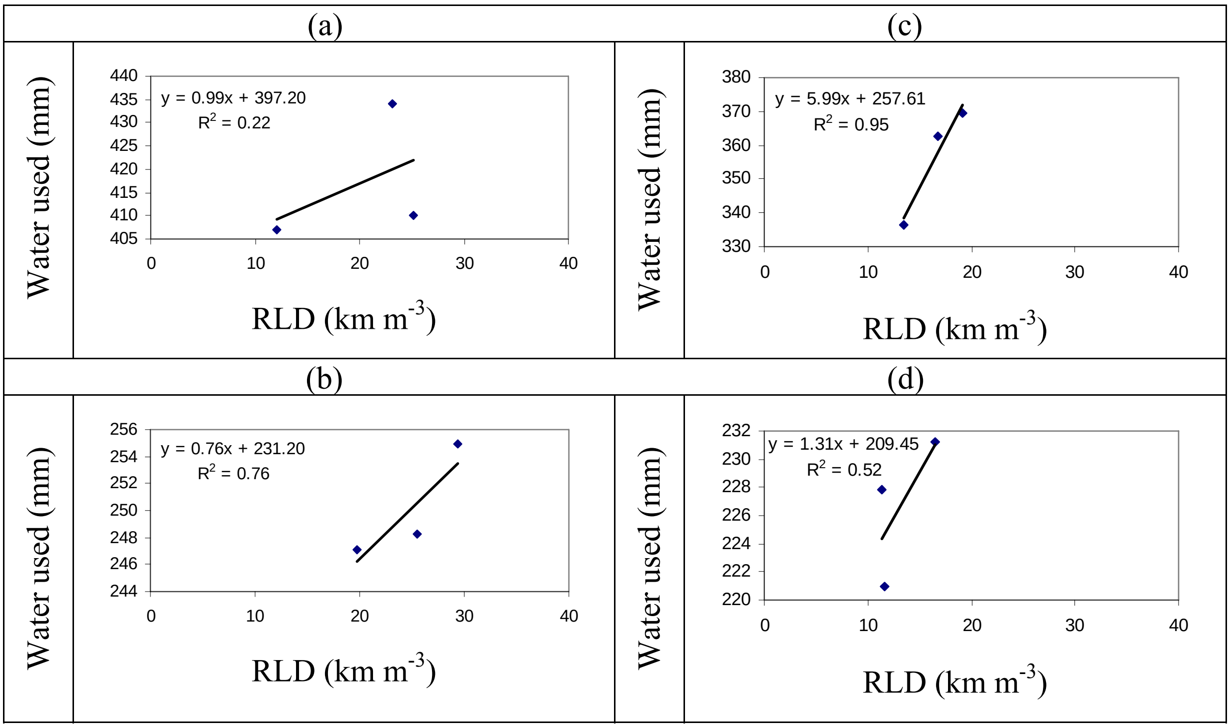


Figure 13. Regression of RLD (km m^{-3}) against water used by the crop (mm) for (a) irrigated wheat (b) rain-fed wheat (c) irrigated barley and (d) rain-fed barley.

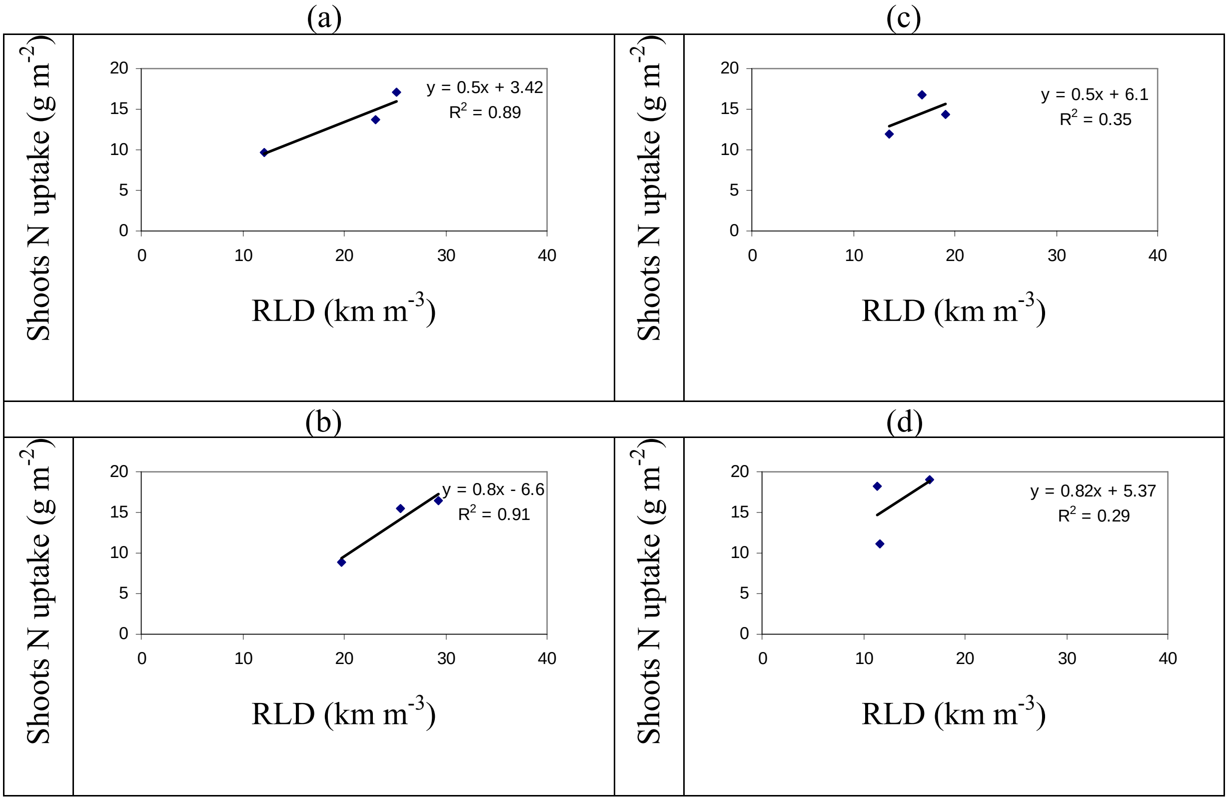


Figure 14. Regression of RLD (km m^{-3}) against shoots N uptake (g m^{-2}) for (a) irrigated wheat (b) rain-fed wheat (c) irrigated barley and (d) rain-fed barley.

References

Barber, S.A. and Silberbush, M. (1984). Plant root morphology and nutrient uptake, p. 65-87. In: S.A. Barber and D.R. Bouldin (eds.), Roots, nutrient and water influx, and plant growth. Amer. Sot. Apron.

Brewitz, E., Larsson, C.M and Larsson, M. (1995). Influence of nitrate supply on concentrations and translocation of abscisic acid in barley (Hordeum vulgare). Physiologia Plantrum, 95, 499-506.

Brown, S.C., Keatinge, J.D.H., Gregory, P.J., and Cooper, P.J.M. (987). Effects of fertilizer, variety and location on barley production under rainfed conditions in north Syria 1. root and shoot growth. Field crop research, 16, 53-66.

Burns, I.G. (1980). Influence of the spatial distribution of nitrate on the uptake of N by plants. A review and model for rooting depth. Journal of Soil Science, 31, 155-173.

Clarkson, D.T. (1985). Factors affecting nutrient acquisition by plants. Annual Review of Plant Physiology, 36, 77-115.

Cooper, H.D. and Clarkson, D.T. (1989). Cycling of amino-nitrogen and other nutrients between shoots and roots in cereals: A possible mechanism integrating shoot and root in the regulation of nutrient uptake. Journal of Experimental Botany, 40, 753-762.

Cure, I.D., Israel, D.W., and Rufty, T.W. (1988). Nitrogen stress effects on growth and seed yield of nonnodulated soybean exposed to elevated carbon dioxide. Crop Science. 28, 671-677.

Delogu, G., Cattivelli, L., Pecchioni, N., Defalcis, D., Maggiore, T., and Stanca., A.M. (1998). Uptake and agronomic efficiency of nitrogen in winter barley and winter wheat. European Journal of Agronomy, 9, 11-20.

Doncheva, S., Vassileva, V., Ignatov, G., Pandev, S., Dris, R. and Niskanen, R. (2001). Influence of nitrogen deficiency on photosynthesis and chloroplast structure of pepper plants. Agricultural and Food Science in Finland, 10, 59-64.

Fitter, A.H. (1985). Functional significance of root morphology and root system architecture, p. 87-106. In: A.H. Fitter, D. Atkinson, D.J. Read, and M.B. Usher (eds.), Ecological interactions in soil: Plant, microbes and animals. Blackwell Scientific Pub., London.

Gregory, J.P., Mcgowan, M., Biscoe, P.V., and Hunter, B. (1978b). Water relation of winter wheat. 2. Soil water relations. Journal of Agricultural Science, Cambridge, 91, 113-116.

Hunt, R.C. (1975). Further observation on root-shoot equilibria in perennial rye-grass (Lolium perenne). Annals of Botany, 39, 745-755.

Jeschke, W.D. and Hartung, W. (2000). Root to shoot interaction in mineral nutrition. Plant and Soil, 226, 57-69.

Karrou, M., and Maranville, J.W. (1994). Response of wheat cultivars to different soil nitrogen and moisture regimes: I. Dry matter partitioning and root growth. Journal of Plant Nutrition, 17(5), 729-744.

King, J., Gay, A., Sylvester-Bradley, R., Bingham, I.J., Foulkes, M.J., Gregory, P.J. and Robinson, D. (2003). Modelling cereal root systems for water and nitrogen capture: Towards an economic optimum. Annals of Botany, 91, 383-390.

Kuhlmann, H., Barraclough, P.B. and Weir, A.H. (1989). Utilization of mineral nitrogen in the subsoil by winter wheat. Z. Pflanzenernähr. Bodenk, 152, 291-295.

Lascanor, J. and Van bavel, C. H. M. (1984). Root water uptake and soil water distribution: Test of an availability concept. Soil Science Society of America, 48, 233-237.

Liang, Y.L. (1996). Adjustment of physiological characters of root systems of wheat by soil moisture, nitrogen and phosphorus, Acta Phytoecol. Sin, 20, 255-262.

McCoy, E.l., Boersma, L., Ungs, M.L., and Akratanakul, S. (1984). Towards understanding soil water uptake by plant roots. Soil Science, 137, 69-77.

Miralles, D. J. and Salfer, G.A. (1997). Radiation interception and radiation use efficiency of near-isogenic wheat lines with different height. Euphytica, 97, 201-208.

Ortiz-Monasterio, J.I., Sayre, k.D., Rajaram, S., and McMahom, M. (1997). Genetic progress in wheat yield and nitrogen use efficiency under four nitrogen rates. Crop Science, 37, 898-904.

OToole, J.C, and Bland, W.L. (1987). Genotypic variation in crop plant root systems. Advances in Agronomy, 41, 91–145.

Oweis, T., Zhang, H., Pala, M. (2000). Water use efficiency of rain-fed and irrigated bread wheat in a Mediterranean environment. Agronomy Journal, 92, 231-238.

Passioura, J.B. (1983). Roots and drought resistance. Agriculture Water Management, 7, 265-280.

Robinson, D. (1986). Compensatory changes in the partitioning of dry matter in relation to nitrogen uptake and optimal variations in growth. Annals of Botany, 58, 841-848.

Silverbusit, M. and Barber, S. A. (1983) Sensitivity analysis of parameters used in simulating K uptake with a mechanistic mathematical model. Agronomy Journal, 75, 851- 854.

Sponchiado, B.N., White, J.W,, Castillo, J.A. and Jones, P.G. (1989). Root growth of four common bean cultivars in relation to drought tolerance in environments with contrasting soil types. Experimental Agriculture, 25, 249–257.

Vegh, K. R. (1991). Effect of soil water and nutrient supply on root characteristics and nutrient uptake of plants. Pages 143-148 in B. L. McMICHAEL and H. Persson, (eds.) Plant roots and their environment. Elsevier, Amsterdam.

Wahbi, A., and Gregory, P.J. (1995) Growth and development of young roots of barley (Hordeum vulgare L.) genotypes. Annals of Botany, 75, 533-539.

Wright, I.J, Westoby, M. (1999). Differences in seedling growth behavior among species: Trait correlations across species, and trait shifts along nutrient compared to rainfall gradients. Journal of Ecology, 87, 85–97.

WP11 Agronomy WUE

Leader of workpackage: **Partner 11, INRAT Tunisia**

Workpackage Objectives

- To test, in field experiments at farm level, the management strategies, coming from model simulation and experimental outputs, to improve growth and water use efficiency of wheat and barley under four Water regimes and four N levels.

- To test, in the field, management strategies interventions to improve water use efficiency for different genotypes-traits.

List of Deliverables

- Datasets describing responses of rooting traits and water and N capture to a range of water and N stresses (it has been achieved).

- Nominated candidate agronomic intervention strategies for evaluation at the field scale in WP11 and WP12 (it has been achieved).

- List of rooting traits and combinations of traits tested for physiological relationships with water and N resource capture at the whole crop level (It has been achieved).

- List of potential impacts of rooting traits for enhanced resource capture on utilization efficiency. (it has been achieved).

- A final report summarizing scientific findings of WP10. (it has been achieved).

List of Milestones

- Preliminary field studies - initiated (achieved).
- First detailed field experiments – initiated (achieved).
- First field experiments – analyzed (achieved).
- Second year of detailed field experiments – initiated (achieved).
- Second year of field experiments – analyzed (achieved).
- Third year of field experiments – initiated (achieved).
- Analysis of third year of field experiments and final report summarizing scientific findings of WP10 (achieved).

Summary of Workpackage Main Findings

Introduction

In Tunisia, irrigated agriculture consumes around 80% of water supply. Regarding the demographic evolution and the economic expansion, the competition between users becomes more and more important. Consequently, *integrated management of limited water resources* occupies the head of the decider preoccupation and it's a national priority. WatNitMED has an ambition to contribute in the process of the water resources management by testing and proposing innovative strategies for a better use of water in the field in the case of cereal. Since, the experiment will be conducted with different irrigation regimes and as well as with rainfed conditions as a control treatment, the major force task of the WP 11 will be consequently achieving an Efficient water Use (EWU), that it means saving water, its valorization and in the extreme situation, coping with its scarcity.

In other side, generally Mediterranean, soils are characterized by their relatively low and variable fertility, particularly their nitrogen content deficiency. Nitrogen supply, particularly for the strategic crops (Wheat and barley), remains in this region subjected to a deficient management.

If crop breeding, is well advanced in the Mediterranean region, improved management of the environmental factors would be the challenge in order to monitor the soil moisture or water and nitrogen that affect strongly cereal crop grain yields. This, since, It's recognized that when a cultivars or varieties are made available with agronomic and physiologic proficiency, agricultural practices represent the major problem to be solved in order to reach the real potential of the cultivars and achieving the best water and nitrogen capture and or use efficiency.

The WP 11 is target on the testing of a different alternatives exploring the interaction Genotypes X Environment X Water X Nitrogen in order to establish a new and innovative approach based on an improved Water Use Efficiency that would allow reaching the real potential of the cultivars. Consequently, increasing productivity in a sustainable way is a general objective whenever management strategies are designed in wheat and other crops.

The WP 11 is based also in looking for water and nitrogen under scarcity. By exploring the rainfed condition as well as the low rate of nitrogen the impact of such shortage could be identified. Strategies based on tools decision, which would be given in hand of farmers when they would have to cope with water and nitrogen deficiency and scarcity, as well as when they have to manage available water and fertilizers, namely the nitrogen.

Finally, WatNitMED project played an important by *confirming the international role of community research* by the establishment and the reinforcement of multilateral research involving regional and across-regional Mediterranean economies. It contributed significantly to key scientific and technological issues of the programme formulating improvements in management strategies for water and nitrogen use efficiency under rainfed and irrigated Mediterranean environments for wheat and barley, the strategic crops of the region.

The main general objective of WatNitMED Project is target on identifying and transferring improvements in management of wheat and barley (two strategic crops for farmers across the whole Mediterranean region) through increasing the capture and/or the use efficiency of the most limiting factors determining their productivity, the water and the nitrogen. This would include a mix of several considerations as natural conditions (e.g. climate impact on ecosystems); variety and efficiency of uses (water and nitrogen); and agronomy management practices for efficient water and nutrient use, etc.).

The objectives of WP11, are subscribed within the main general objectives of WatNitMED Project. To increase the productivity of the cereal, the Mediterranean strategic crops, in a sustainable way, the WP11 has to test different management strategies. The WP 11 is more focused in water management while in the WP12 in N issues, but in both the interactions is considered. The main objectives of the WP11 are namely:

- To test, in field experiments at farm scale, the management strategies, coming from model simulation and experimental outputs, to improve growth and water use efficiency of wheat and barley under four Water regimes and four N levels.
- To test in the field management strategies interventions to improve water use efficiency for different genotypes-traits.

In the primary proposition only 2 water regimes and 2 nitrogen levels have to be explored. Never less, as result of the discussion with the scientific coordinators, and the partners in the project, it was decided to enhance the output of the WP11 by adding 2 others levels for both water and nitrogen. Such decision was highly important, since it allowed to INRAT partner to insure an extended Datasets with the most appropriate agronomic strategies in order to improve water efficiency at farm scale**.**

General description of work

This work package links closely with the analytical approach of WP8 (Crop WUE). The WP11 also integrates with the experimental approach of WP12 and data-processing of the modeling (WP3) and strategy design (WP4).

Different crop management strategies to improve growth and yield water use efficiency will be explored in field experiments under 4 water regimes and 4 levels of N fertilization. The experimental trials of this work package differ from the ones of WP8 for a higher hierarchical scale (mainly biomass and yield) and for the management boundary conditions closer to those of farmers.

Progress towards the objectives

The first year was consecrated to conduct preliminary activities related to sites identification and characterization by using the agricultural map of Tunisia and as well as by in situ soil sampling. In addition, Purchasing equipments and other requirements for starting 2005/2006 experimentations in time. In other hand a preliminary experiment was conducted during 2004/2005 at MHAMDIA EL KHIR STATION by testing by using KARIM variety with two nitrogen levels namely 110 and 150 kg/ha and by comparing the 40 and 70 % ETM with the rainfed condition.

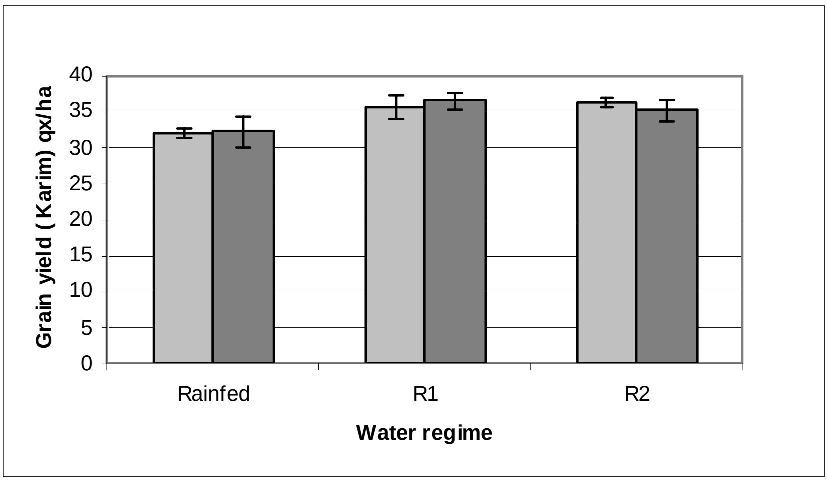


Figure 1. KARIM variety Grain yield (qx/ha) versus water regimes and nitrogen levels at MHAMDIA EL KHIR STATION during 2004/2005.

The regime 1 (40% ETM) and 2 (70% ETM) received one irrigation respectively 25 and 50 mm. Regarding the well rainfall during this preliminary experiment, no difference between R1 and R2 witch are slightly similar to rainfed conditions. But this results showed that 110 Kg N/ha would be the optimal for the durum wheat Karim variety. So why, we decided to apply 4 levels of nitrogen ranging from no supply until 150 kg N/ha in order to detect the optimum doses during the experiments of WatNitMED project, on which INRAT was committed to achieve.

The work on which INRAT was committed was achieved in two sites. The first, at M'HAMDIA "EL KHIR Private Company" (36° 37' N Lat, 10° 08' 25" E Long, 60 m asl), is located 30 km from Tunis, and characterized by a semi-arid climate with annual average rainfall of 400 mm. The second is located, around 200 km from Tunis (36° 27' N Lat, 8° 26' E Long, 200 m asl), at OUED MLIZ INRAT Experimental Station, and characterized by a sub humid climate with 500 mm as annual average rainfall. On the first site experimentations was conducted during three subsequent years from 2005/2006, 2006/2007 and 2007/2008 while on the second one experimentation was conducted during 2005/2006 year in order to confirm previous results obtained. During the project period including the extension one, MHAMDIA and OUED MLIZ sites were qualified as pilot and demonstrative sites. Open doors and field days were the key of the dissemination activities of WatNitMED tasks.

Material and Methods

To sound water management strategies under different nitrogen regimes, the field experiments were conducted at the two sites previously cited. Treatments included Tunisian widespread cultivars (varieties) of wheat and barley, namely durum wheat *(Triticum durum Desf) "KARIM"* and barley *(Hordeum vulgare L.) "MANEL"*. Karim represents the 50% of durum wheat field in Tunisia, while MANEL is adopted in 40% of barley growing area. During 2006/2007 experiment we did added KHIAR durum wheat variety (cultivated by an important number of farmer). In both the two sites, N treatments consisted of four rates, namely 150, 100, 50, 0 Kg N/ha for wheat whilst barley received 100, 50, 25, 0 kg/ha as rates of Nitrogen. Nitrogen application was dispatched on 3 amounts (25% at emergence, 50% at tillering phase, and 25% at the stage of stem elongation) 4 water regimes was monitored in MHAMDIA EL KHIR (full irrigated with 100% ETM, 2 deficit irrigation based on 70 and 40% of ETM, and a rainfed plots as a control). Regarding the rainfall conditions of OUED MLIZ STATION located in sub humid area, water regimes were limited to the Full Irrigated and Rainfed condition, while Nitrogen levels were maintained as whose monitored at MHAMDIA EL KHIR Site.

Irrigation scheduling was based on weather data from Meteorological plants in both the tow sites. At Oued Mliz, relevant to National Meteorological Institute weather plant is already nested at INRAT Station, nearby the project trials. At M'HAMDIA EL KHIR, meteorological station, purchased within the project, supplied continuously the weather data and allowed crop water requirements calculation. Water Mark Tensiometers at 35 cm depth were used to confirm the watering moments in the different treatments. In addition, twin tensiometers were set up at 85 and 105 cm in order to monitor water flux through 1 m soil level. A set of 3 tensiometers was connected to M'HAMDIA EL KHIR plant, which registered data continuously and could be consulted directly or via GSM.

The experimental design was Split Plot with 3 repetitions, resulting on 96 and 48 elementary plots, of water and nitrogen combination, respectively at M'HAMDIA EL KHIR and OUED MLIZ. 4 m interval band was maintained between the water regimes treatments and 2 m in the case of the nitrogen fertilization elementary plots. The elementary plots covered 25m² each, were soil water balance was measured to calculate Crop evapotranspiration (water consumption) and the several non destructive (Phenological development, Number of plant per m², on leaf SPAD measurements) and destructive (plant sampling in order to identify the biomass and the leaf area evolution) measurements were achieved on the plant material. Finally, in each elementary plot 3 separated samples of 1 m² area were harvested. Grain and biomass yields were determined. Required measurements related to yield components (number of grain per m², number of grain per m², number of spikes/m², weight of 1000 grains) were cared. Non- destructed harvested plant Samples are conserved in order to measure the grain and straw nitrogen content as well as the grain quality parameters.

STATITCF – V was used in the Statistical analysis of the results. Two factors variance analysis were applied on whole measurements by using Fisher Test in order to verify the means equality hypothesis with 95% of confidence (5% of risk level). These analyses were completed by a multiple comparison of the means values based on Newman and Keuls test when equality hypothesis is rejected.

Results and Discussion

Soil characterization

The agricultural map of Tunisia was used to establish a preliminary characterization of the sites during 2005. Since, the agricultural map gives information in the scale of whole the region, and in order to have a precise soil characterization in the local situation of the experimental sites, 4 remote spots were ploughed at MHAMDIA EL KHIR whilst at OUED MLIZ 3 profiles were realized. Soil samples were taken by horizon until 1 m depth for texture and physical and chemical analysis (Tables 1a & 1b). The soils are alluvial and deep. Their textures are a Silt Loam and Clay loam respectively at MHAMDIA EL KHIR and OUED MLIZ. The first one has slightly higher fine particle (Clay + Silt) content than the second. Undisturbed samples were taken in order to determine the bulk density and soil moisture curves (pF curves). By using van Genuchten Model for soil desorption characteristic, a simulated pF curves were obtained with a high correlation coefficients. The observed and simulated points were closely (Fig 1a and 1b).

Table 1a. Physical and Chemical characteristics of the soil at MHAMDIA EL KHIR (Means of 4 profiles)

Horizon (cm)	0-30	30-60	60-100
Clay (%)	21	28	27
Silt (%)	54	55	55
Sand (%)	25	17	18
Texture	Silt Loam	Silt Loam/Silty Clay Loam	
Bulk density(g/cm^3)	1,375	1,55	1,56
Volumetric Water Content at (FC) Field Capacity (vol/vol)	0,401	0,421	0,450
Volumetric Water Content at (WP) Wilting Point (vol/vol)	0,282	0,273	0,295
Water Stock at FC (mm/m)		426	
Water Stock at WP (mm/m)		284	
Available Water Capacity (mm/m)		142	
Electrical Conductivity (mS/cm)	1,35	1,33	1,42
Total $CaCO_3$ (%)	35,0	35,8	34,5
Active $CaCO_3$ (%)	11,0	12,5	10,8
pH	8,3	8,6	8,5
Available P2O5 (mg/kg) – OLSEN	69,5	22,8	20,3
Available K2O (mg/kg)	870	405	295
Organic Matter Content (%)	2,9	1,5	1,4
C (%)	1,7	0,8	0,8

Table 1b. Physical and Chemical characteristics of the soil at OUED MLIZ STATION (Means of 3 profiles)

Horizon (cm)	0-20	20-40	40-60	60-100
Clay (%)	29	30	30	37
Silt (%)	42	42	37	36
Sand (%)	29	28	33	27
Texture	Clay Loam			
Bulk density(g/cm^3)	1,35	1,40	1,45	1,45
Volumetric Water Content at (FC) Field Capacity (vol/vol)	0,359	0,351	0,384	0,372
Volumetric Water Content at (WP) Wilting Point (vol/vol)	0,233	0,220	0,234	0,217
Water Stock at FC (mm/m)	370			
Water Stock at WP (mm/m)	220			
Available Water Capacity (mm/m)	150			
Electrical Conductivity (mS/cm)	1,17	0,67	0,80	0,97
Total $CaCO_3$ (%)	26	31	30	31
Active $CaCO_3$ (%)	4,8	4,3	6,7	5,0
pH	8,4	8,6	8,7	8,9
Available P2O5 (mg/kg) – OLSEN	47,7	30,6	26,7	22,7
Available K2O (mg/kg)	550	410	190	360
Organic Matter Content (%)	2,03	1,40	1,10	0,77,
C (%)	1,17	0,80	0,63	0,43

According to the measured soil water characteristics, calculation showed that the soils are characterized by high water retention. The Available Water Capacities of the two sites are closely similar being 142 and 150 mm/m (Tables 1a & 1b).

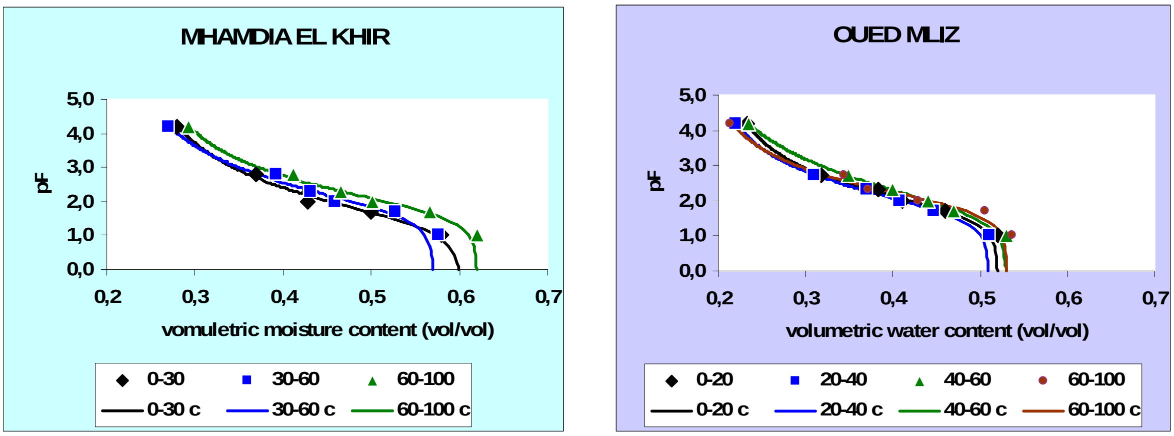


Figure 1. Measured and Simulated Soil Moisture Characteristic (pF = |h|) Curves of the different horizons of the experimental sites soil.

Initial soil nitrogen content

Tables 2a and 2b summarize the initial soil nitrogen content. Such condition allowed around 50 kg N/ha at the beginning of the experiment. Levels of Nitrogen to be applied were chosen according to thus amounts which are typical of the Mediterranean soils.

Table 2a. Soil Initial Nitrogen content at Mhamdia El Khir

Horizon (cm)	0-30	30-60	60-100
N-NO_3^- (mg/kg) : 2005/2006	0,89	14,97	20,22
N-NH_4^+ (mg/kg) : 2005/2006	7,96	8,78	8,56
N-NO_3^- (mg/kg) : 2006/2007	7.7	6.0	7.10
N-NH_4^+ (mg/kg) : 2006/2007	8.9	8.5	8.57
N-NO_3^- (mg/kg) : 2007/2008	5.3	7.0	8.8
N-NH_4^+ (mg/kg) : 2007/2008	7.1	8.8	8.8

Table 2b. Soil Initial Nitrogen content at Oued Mliz Station

Horizon (cm)	0-20	20-40	40-60	60-100
N-NO_3^- (mg/kg) : 2005/2006	0	5,08	0	0
N-NH_4^+ (mg/kg) : 2005/2006	7,71	9,26	9,26	5,65

Rainfall

Figure 2 summarize rainfall data recorded during 2005/2006 growing season at OUED MLIZ and during the period of 2005/2006, 2006/2007 and 2007/2008. Irrigation was realized, depending on the soil water storage, when rainfall inconvenient temporal distribution and deficit occurred and according to the crop water requirement.

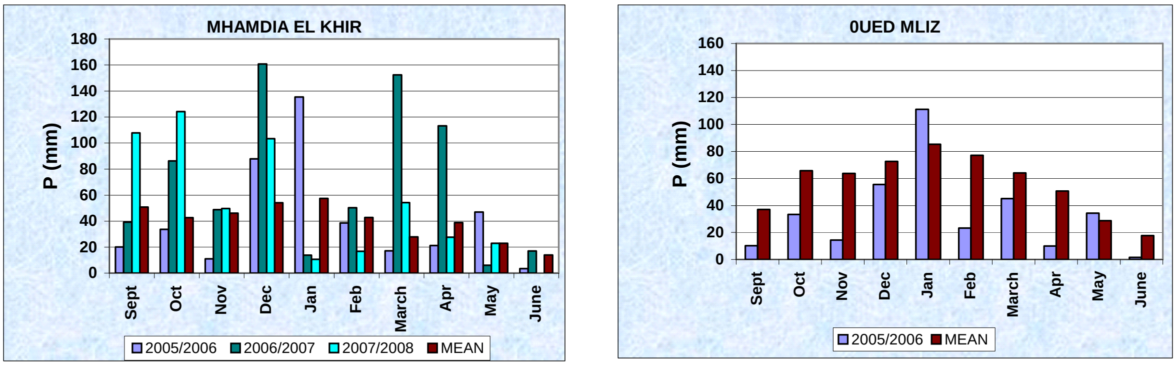


Figure 2. Rainfall during experiment years at Mhamdia and Oued Mliz sites.

Results

Results 2005/2006 of the yield components of wheat crop, in the case of MHAMDIA EL KHIR STATION, showed no significant difference among nitrogen rates wile the water regimes showed significantly the better situation when 100 and 70% ETM were applied. At OUED MLIZ, Water & Nitrogen strategies did not affect the number of spike/m² and the mean weigh of grain. In other hand, the numbers of grains per spike and of grains/m² were basically significantly higher in the case of the higher rate of nitrogen undependably of the water regime. No Nitrogen effect did recorded on the Grain, Straw and total biological yields at MHAMDIA EL KHIR STATION. Never less, the best water regime would be situated on 70 and 100% ETM water regimes. The water regimes significant effect did not appeared on the yields obtained at OUED MLIZ STATION, whilst the two higher Nitrogen rates give the best yields.

Water Use Efficiency was calculated on Grain and total biological yield basis. At MHAMDIA EL KHIR STATION (Semi arid), no significant differences obtained among the water regimes and among N management strategies. In other hand, Water Use Efficiency was significantly higher in rainfed conditions at OUED MLIZ STATION (Sub humid). The nitrogen rates of 100 kg/ha and 50 Kg/ha would be optimal respectively for wheat and barley.

The 2006/2007 year was runny; rainfall deficit was registered only during January and May. Particularly for January irrigation was very important for crop emergence. Precipitation deficit on May did no have a significant effect, since the soil was well humidified by April excess of rainfall. No significant interaction did act between Water regime and Nitrogen rate. Water regime appeared as critical factor acting on barley and with less amplitude on wheat. Generally, the Nitrogen did not affect the yield parameters and WUE, this is resulting from Nitrogen lixiviation due to high soil moisture content resulting from the rainfall events with relatively an important amounts and received continuously, particularly during March and April. No significant difference among nitrogen rates was obtained regarding yield components and grain, straw and biological results. The water regimes showed significantly the better situation when 100 and 70% ETM were applied. Similar results were obtained during the previous experimentation year (2005/2006). Water Use Efficiency was calculated on Grain and total biological yield basis. No significant differences among the Nitrogen strategies but irrigated conditions were significantly better than the rainfed one, although the rainy conditions. It seems that the 2 irrigations given during relatively dry period had positive effect on the crops. From the results of this year, the most important lesson was in the case of a runny year, the nitrogen should be supplied on 4 times instead in 3 fractions in order to minimize the lixiviation.

Results 2007/2008 confirmed the results of 2005/2006 and gave precise information on the differences between water regimes. It appeared that two significant similar situations. Rainfed and 40% ETM are similar in one side and 70 and 100% ETM together in other side. Among nitrogen rates the two highest levels are the significant better than two remainder one.

Conclusion

Watering strategies are important in the semi-arid area, were rainfall deficit occur basically during the critical stages of cereals. Irrigation should be target on the supply of around 70% of the water requirements. The sub humid environment is characterized by a relatively a sufficient rainfall, and the soil is already with a good water holding capacity. So why, cereal irrigation in this area became urgent only when drought is upon. Results showed the importance of Nitrogen strategies in this area, while in the semi arid zone, fallow live an important content of nitrogen in the soil, around 50 kg N (N-NO_3^- and N-NH_4^+)/ha on the top soil layer. Such initial nitrogen soil content was mentioned in the previous research on similar environment and conducted by INRAT since 1956 and 1981.

Having in count the initial N content on the soil, particularly in the first 50 cm depth, 100 to 120 kg N/ha could be maintained as optimal strategy for wheat and 50 to 70 kg N/ha in the case of barley. Since no significant difference on the water regimes 70 and 100% ETM, 70% ETM could be advised as optimal watering process to be conducted. Thus results were disseminated on workshops, round tables with farmers, field days and field open doors organized in collaboration with UTAP.

WP12 Agronomy NUE

Leader of workpackage: **Partner 12, INRA Morocco**

Workpackage Objectives

- To test, at the farm level and on experimental station, nitrogen management strategies to optimize yield and nitrogen use efficiency under different water situations.
- To validate simulation models for crop growth and nitrogen management strategies under different water situations.
- To identify and validate genotypic traits to optimise nitrogen and water use efficiencies under different water regimes.
- To evaluate the impact of rooting traits on above-ground growth and grain productivity under a range of water and N regimes to identify combinations of water and N stresses in which agronomic manipulation of rooting systems is likely to most beneficial.

List of Deliverables

- Characterize the genotypes in terms of nitrogen use efficiency under different nitrogen levels and water regimes (has been achieved).
- Identify potential morphological and physiological traits associated with nitrogen use efficiency and yield (has been achieved).
- Test and validate the models developed in WP3 (it has been achieved).
- Final report summarising scientific findings of WP12 (has been achieved).

List of Milestones

- Preliminary field studies initiated (achieved).
- First detailed field experiments initiated (achieved).
- First field experiments analysed (achieved).
- Second detailed field experiments initiated (achieved).
- Second field experiments analysed (achieved).
- Final report summarising scientific findings of WP12 (achieved).

Summary of Workpackage Main Findings

Introduction

Barley and wheat are the strategic crops determining the fate of many farmers in the driest agricultural land areas throughout the Mediterranean. The grain yields of these crops are particularly affected by drought, which is a problem of major importance, as most Mediterranean countries are characterised by strong water deficits and often suffer from strong drought episodes.

In the context of Mediterranean, these main crops are being predominantly limited by water but also by nitrogen (N) deficiencies. In WP12 (Agronomy-NUE) we aim to improve the understanding on the determinants of the crop ability to capture more N and/or to use N more efficiently in a range of water availability conditions. It is intended to significantly contribute to key scientific and technological issues of the programme formulating improvements in management strategies for resource use efficiency under rainfed Mediterranean environments for wheat and barley.

The purpose is to design adequate management strategies by direct agronomic experimentation to improve our understanding on the way in which cereals do acquire their abilities to use more, and use more efficiently the water and N and to produce their growth and partitioning and to what degree management may influence in the production of fertile spikelet and florets per unit of dry matter allocated to reproductive growth.

In order to identify N management strategy to achieve high and stable grain yields, and to understand the effect of water and nitrogen interaction on crop responses to drought and nitrogen availability, and genetic diversity in traits indicating improved water and nitrogen use and use efficiency, detailed experimentations were carried out in three environments selected to represent a rainfall gradient (300-450 mm), with and without irrigation. These experimentations consisted of studying three genotypes of barley and three of durum wheat and 10 nitrogen management strategies, a combination of rates and time of application of nitrogen.

Materials and Methods

Experimental sites

Two Experimental Stations in the main cereal producing areas of Morocco: One is Sidi El Aydi station in the Chaouia region and the other one is Merchouch station in the Zaers region; and one farmer site in Skhirat region. These sites were selected to represent different agro-ecological settings. The experiments were conducted during 2005-06 and 2006-2007 growing season in all sites and in 2007-2008 only at Merchouch station.

Sidi El Aydi experiment station is located near Settat- Morocco (31° 15’ N, 7° 30’ W). The soil is a vertic calcixeroll and has a depth of 90 to 120 cm. The rainfall pattern at this location is erratic in nature. The long term average annual precipitation is 360 mm.
Merchouch is located in the central plateau at 68 km North-east of Rabat and 16 km North-West of Rommani, Morocco (33° 60’ N, 6° 71’ W). The soils are vertisoils. The long term average annual precipitation is 407 mm.

Crop management

Both barley and durum wheat were planted around mid-November at a seeding rate of 160 kg ha^{-1} in 20 cm row spacing. The nitrogen fertilizer treatments were applied as ammonium nitrate either incorporated prior to seeding or top dressed at tillering or stem elongation stage depending on the strategy being tested. The plots were also supplied with P and K fertilizers before sowing at a rate of 40 kg P_2O_5 and 40 kg K_2O ha^{-1}, respectively; both were incorporated in the soil. To prevent any damage by Hessian fly, 25 kg ha^{-1} of Furadan were also incorporated into the soil prior to sowing. The wheat was managed using standard pesticide practices when required to prevent the development of any disease or pest. Weed control was accomplished with 12.5 mg ha^{-1} Granstar and 0.75 l ha^{-1} Topic at three leaves stage. Two fungicides were sprayed: Tilt (1 l ha^{-1} for barley) and Opus (1 l ha^{-1} for durum wheat). The crops were usually harvested around mid-may.

Meteorological data were recorded and obtained from the weather station situated few meters away from the experiment.

N management strategies, water regimes and cultivars

Three barley cultivars and three durum wheat cultivars were tested under a combination of ten nitrogen management strategies (a combination of rates and time of application of N) and under both rainfed and irrigated regime. The cultivars used for barley were Massine, Tissa and Amira and for durum wheat, Karim, Ourgh and Nassira were used. The nitrogen rates being tested were 0; 40; 80; 120; and 160 kg N ha^{-1}. The following management strategies: 0-0-0 (control), 0-40-0, 0-40-40, 0-80-0, 0-80-40, 40-0-0, 40-40-0, 40-40-40, 40-80-0, and 40-80-40 kg N ha^{-1} were used. The times of application of N were, prior to sowing, at tillering, and at stem elongation, respectively.

Observations and measurements

Soil samples were collected before planting of the crops and from each sub-sub-plot after harvesting to a soil depth of 40 cm. Soil were analyzed for N content.

During crop growth, date of emergence (50%), date of anthesis (50% flowering) or Zadoks 65 for wheat and heading for barley, and date of physiological maturity (peduncle or spike turn yellow) were recorded.

Plant height at anthesis (average height in cm to tip of the ear) was also measured. Dry weights of leaves, stems and ears at early stem elongation ("double ridge" stage), anthesis (50% flowering) and physiological maturity (max. 15% grain moisture content) were measured through sampling a portion of 0.25 m² from each sub-sub-plot.

In addition to growth and development data, physiological measurements were taken. These include spectral reflectance indices (using the spectroradiometer), chlorophyll concentration of flag leaves using SPAD meter, and chlorophyll fluorescence parameters (Fo, Fm, Fv, and Fv/Fm) using a Hand Held fluorometer. From the spectroradiometer measurements vegetation indices, estimation of pigments contents and radiation use efficiency and assessment of plant water status (water index) were derived. The chlorophyll meter helped us determine chlorophyll content and senescence of leaves. These parameters are affected by nitrogen and genotype. Consequently, they are very useful to understand how the tested genetic material responds to the variation of nitrogen management strategies and identify potential traits involved. All the physiological measurements were taken 3 weeks after anthesis.

At harvest, a 1 m² portion at the centre of each sub-sub-plot was sampled. From this sample, the biomass, grain yield, number of heads per m², thousand seed weight, harvest index, and N content of the straw and the grain were measured or determined.

Statistical analysis

Experimental design was a split-split-plot design with three replications. The main plots were assigned to cultivars. The split plots to N at sowing, and the split-split-plots to N split between tillering and stem elongation. The data for each parameter were subjected to analysis of variance procedure of SAS (SAS Inst., 1995). Mean separation analyses were conducted using Fisher's protected least significant difference LSD test at $P \leq 0.05$. The LSDs for different main effect and interaction comparisons were calculated using appropriate standard error terms.

Results

Weather conditions

Figure 1 summarizes climate data recorded during 2005-2006 growing season at the experimental site of Sidi el Aydi. Total seasonal rainfall was 332.4 mm. The rainfall distribution pattern was balanced, with about 27% in the fall, 53% in winter and 20% in spring. The temperatures were quite optimal for cereal crop growth and development. Below normal temperatures (below 0°c) were recorded only in December but with no consequences on the crop. During the grain filling period, there were no sub-normal temperatures recorded.

These data illustrate the good season comparatively to previous ones. An irrigation of 70 mm water was supplied to irrigated treatment in early April.

Figure 2 summarizes weather data recorded during 2006-07 growing season at Sidi el Aydi, morocco. It shows a 31% rainfall deficit compared with the long term average rainfall. In fact, total seasonal rainfall was about 156 mm, far below the long term average rainfall of 360 mm. Besides, 59% of the rainfall was received early in the season, between October and December 2006. The rainfall distributions worsen the rainfall scarcity. There was an almost 90 day drought during critical stages of growth and development of cereal crops. The season was then very dry. The temperatures were also sub- optimal for the crops.

The season being dry, an amount of 162 mm was given to dry treatment, whereas, the irrigated treatment received 360mm of irrigation water.

Merchouch experimental station was also much affected by the drought during 2006/07 season. Total annual rainfall did not exceed 180mm.

Characterization of genotypes in terms of resource use efficiency under different nitrogen levels and water regimes

a) Barley: Yield components, yields and water use efficiency

Under rainfed conditions, in general significant differences were found among barley genotypes and N management strategies for spike density and seed weight. The cultivar Tissa showed higher number of spikes per land area, and higher seed weight, comparatively, to Massine and Amira. The N management strategies showing the highest spike density were: 40-40-40 and 40-80-40, while for seed weight, the highest weight was recorded within the control and 0-40-0 treatments.

Under well watered conditions, significant differences also exist among cultivars and N management strategies for both spike density and seed weight. The cultivar Tissa again showed significantly both higher spike density and seed weight than Massine and Amira which are not significantly different. For N management, the strategies 40-80-40 and 0-80-40, while showing the highest spike number per land area, have the lowest seed weight. Inversely, the control, 0-40-0 and 40-0-0, have lower spike density and higher seed weight. There is a negative correlation between spike density and seed weight. The higher the spike density the lower is the seed weight.

For total biological yields under rainfed conditionsthere were highly significant differences among cultivars and N management strategies for both yields and water use efficiencies. The cultivar Tissa showed significantly higher yields and WUE, comparatively, to Amira, and to Massine. Applying N prior to sowing significantly improved total biological yields and biomass WUE. For N management strategies, an additional application of 40 or 80 kg N/ha at tillering (GS25) significantly improved yields and WUE's. The best N management strategy appeared to be application of 80 to 120 kg N/ha split as either 40-80-0 or 40-40-0 under rainfed dry season conditions. But when the rainfall amount and distribution are appropriate, an additional application of N at stem elongation (GS30) proved to be beneficial; the strategy 40-40-40 gave highest yields.

Under well watered irrigated conditions, significant differences exist among cultivars and N management strategies for both yields and WUE's. The cultivar Tissa showed significantly superior yields and WUE's than Amira or Massine. Applying 40 kg N/ha at sowing significantly improved the parameters studied. For N management, the strategies consisting of additional application of N at tillering (GS25) and stem elongation (GS30) significantly improved the yields and WUE's. The best N management strategy under adequate moisture appears to be 40-40-40 or 40-80-40 kg N/ha respectively at sowing, tillering and stem elongation for higher yields, biomass WUE and grain WUE.

Figure 3a and 3b shows the response of the barley varieties in terms of biomass and grain yields, respectively, to N rates when averaged over different management strategies under both water conditions at Sidi El Aydi. In general, all cultivars showed positive response to applied N. The response is up to 120 kg applied N ha^{-1} before it starts levelling off. The variety Tissa is superior to the others in terms of both biomass yields and grain yield. Massine is superior to Amira for biomass production whereas Amira is superior for grain yield at lower N rates.

In general, N application under both dry rainfed and irrigated conditions significantly improves the yields and water use efficiencies in comparison with the control. It also appears from these results that application of 80 to 120 kg N ha^{-1} split either 40-40-0 or 40-80-0 kg N ha^{-1} under rainfed conditions or 120-160 kg N ha^{-1} split either 40-40-40 or 40-80-40 kg N ha^{-1} under irrigated conditions, respectively, at sowing, tillering (GS25) and beginning of stem elongation (GS30) are the best N management strategies. Adding N did improve yields comparatively to the control (no nitrogen). This suggests the importance of N even under water limiting conditions.

b) Wheat: Yield components, yields and water use efficiency

Under rainfed conditions, spike density and seed weight were cultivar and N management strategy dependent. Cultivar Karim had higher spike density and seed weight compared to Ourgh and Nassira at lower rates of N.

In terms of yields and WUE significant differences among the cultivars and N management strategies were found. The cultivar Karim showed significantly higher yields and water use efficiencies compared to Ourgh and to Nassira. The application of 40 kg N/ha at sowing improved both the yields and the WUE's. Similarly, application of N at tillering and stem elongation gave better yields and water use efficiencies. It appears that even under dry rainfed conditions, N application significantly improves yields and water use efficiencies of durum wheat.

For well watered irrigated conditions, the interaction cultivar*N management strategy was significant for yield components, except for seed weight for which differences exist only among the cultivars. The cultivar Karim had significantly higher spike number per unit area and higher seed weight, comparatively, to Ourgh and Nassira cultivars. For N management, the strategies 40-40-40 and 40-0-0 for cultivar Karim; and 40-40-0 for cultivar Nassira; and 0-80-40 and 40-40-40 for cultivar Ourgh give the highest yields and spike density. For seed weight, in general, the N management strategy 40-40-40 gives the best weights.

In fact, highly significant differences among cultivars and N management strategies for the yields and water use efficiencies were found. The cultivar Karim had significantly higher yields and WUE's, comparatively, to Ourgh and to Nassira cultivars. For N application prior to sowing, it also improved significantly these components. The application of 40 or 80 kg N/ha at tillering and 40 kg N/ha at stem elongation improved the yields and WUE's significantly.

Figure 4a and 4b shows the response of the durum wheat varieties in terms of biomass and grain yields respectively, to N rates averaged over different management strategies under both water conditions at Sidi El Aydi. In general, all cultivars show positive response to applied N. The response is up to 120 kg applied N ha^{-1} before it starts levelling off. The variety Karim is superior to the others in terms of both biomass yields and grain yield. Nassira is superior to Ourgh for biomass production whereas the latter is superior for grain yield and comparable to Karim.

Discussion

Proper N application timing and rates are critical for meeting plant needs and improving resource use efficiency. Moreover, the growth stage of plants at the time of fertilizer application also determines resource use efficiency, with significant genotypic variations. There was an increased barley and wheat yield when N fertilizer was applied between end of tillering and stem elongation. This suggests that N applications should occur immediately before the period of peak N demand, i.e., the onset of stem elongation.

Nitrogen application rate strongly affects dry-matter production, increasing total dry-matter yield proportionally to the amount of N applied; and the timing of N application is associated with the magnitude of the response. Application early in the growing season (up to the on-set of stem elongation) induces a larger production of dry-matter compared to late N application. Similarly, early application of N had a positive effect on spikelet number per spike, and spike fertility was increased by N application at the on-set of stem elongation. In the other hand, early application had a negative effect on kernel weight. Little or no N applied early in the growing season resulted in fewer grains per unit area and, thus, less competition for assimilates among kernels. Late N application, however, significantly increased kernel size over that of early application.

The improvement of resource use efficiency in barley and wheat has also been achieved through use of efficient cultivars and appropriate N management strategy. Results show that response to N is cultivar dependent. Cultivar Tissa for barley and Karim for durum wheat were more responsive to N application than other cultivars tested.

Wheat and barley growing environments overlap, but of the two crops, barley tends to be the more drought tolerant, so it is usually grown in drier environments than wheat. In comparison with other small-grain cereals, barley has higher adaptability to water stress because of a more extensive root system and its early development that permits drought escape (Fischer and Maurer, 1978; Lopez-Castaneda and Richards, 1994). (Ref. NUE biblio. Barley WUE)

Morphological and physiological traits associated with resource use efficiency and yield

a) Barley

Spectral reflectance indices were used to characterize morphological and physiological traits associated with resource use efficiency and yield. Plant reflectance is determined by leaf surface properties, internal structure, and the concentration and distribution of biochemical components; therefore, remote analysis of reflected light can be used to assess plant biomass and the physiological status of a plant. Spectral reflectances in the visible and near-infrared regions were used to estimate a range of physiological characteristics. The spectral reflectance indices are based on simple operations between reflectance at given wavelengths. The indices calculated in our study are widely used to quantitatively relate changes in reflectance spectra to changes in physiological variable. These indices are: For vegetation indices, normalized difference vegetation index (NDVI) and single ratio (SR) were used; for leaf pigments, RAR_Sa, RAR_Sb and RAR-Sc indices were used, at both rainfed and irrigated experiments, for the estimation of chlorophyll a, chlorophyll b, and carotenoid, respectively; the photochemical index (PRI) was used for assessing radiation use efficiency; and water index (WI) to assess plant water status.

Assessing the photosynthetic size of the canopies

The analysis of variance revealed highly significant differences among cultivars and N management strategies for rainfed and for irrigated experiments for SR and NDVI. These vegetation indices measure the photosynthetic size of the canopy (green biomass, leaf area index, green area index, PAR absorbed by the canopy…). Application of N significantly improved both indices. The cultivar Tissa showed significantly higher values than Amira and Massine which were comparable under irrigated conditions but under water stressed conditions Massine performed better than Amira. Under both water conditions the application of 120 to 160 kg N/ha split between sowing, tillering and/or stem elongation showed the highest values of SR and NDVI.

Estimating chlorophyll concentration

The amount of chlorophyll is adversely affected by stresses involving nitrogen. Remotely sensed measurements of this parameter using remote sensing of pigments provide information about the status of the plant. Differences among genotypes and N management strategies, respectively, for rainfed and irrigated experiments exist. In fact, there were highly significant differences among cultivars and among N management strategies. The cultivar Tissa showed, comparatively, lower Chla, similar Chlb and higher carotenoid content than Massine and Amira under well-watered conditions, whereas, under water limiting conditions, Tissa and Massine had lower PARSa, higher PARSb, and higher PARSc than Amira. For N management strategies, the control had the highest RAR_Sa, the lowest RAR-Sb and RAR-Sc in comparison with other strategies in opposite with strategy where N was applied at sowing, tillering and stem elongation under both rainfed and irrigated experiments. These indices are useful in assessing the nutritional state of the crop.

Radiation use efficiency and plant water status

The PRI and WI, respectively, give good estimates of photosynthetic radiation use efficiency (PRUE) and water status of the plants. However, no significant differences among cultivars for PRI were observed which indicate comparative radiation use efficiencies. PRI has been shown to track changes in PRUE induced by different factors such as nutritional state and drought stress. PRI values under water limitation are much higher than the values obtained under irrigation. PRI increases with N application and differ among strategies. The higher values were obtained with N management strategies where N was applied at tillering and stem elongation.

For WI, significant differences among cultivars and N management strategies were found in the rainfed and in the irrigated experiment. Cultivar Tissa had lower values than Massine and than Amira. For N management strategies, N application reduces WI significantly under both regimes. However, although WI closely matches to relative water content, it is not only affected by drought stress but also by N stress under well watered conditions.

b) Wheat

For the spectral reflectances in the visible and near-infrared regions used to estimate the physiological characteristics in response to water and nitrogen, significant differences were observed only for N management strategies under the water limiting experiment. The application of N improved all the physiological parameters compared to the control. Strategies consisting of splitting N between tillering and stem elongation also favoured the response of the crop to water deficits.

Under well-watered conditions, there highly significant differences among cultivars for WI, SR, NDVI, PAR_Sa and PAR_Sc and among N strategies for all the physiological characteristics studied. The variety Karim showed higher performances compared to Ourgh and to Nassira. These performances consist of better vegetation indices (NDVI and SR) that assess the photosynthetic size of the canopy; leaf pigments that estimate chlorophyll a, chlorophyll b, and carotenoid (PAR_Sa, PAR_Sb and PAR-Sc indices); and the photochemical index (PRI) that assesses radiation use efficiency; and water index (WI) that assesses plant water status. Similarly, application of N significantly improves the photosynthetic size of the canopy, radiation use efficiency and plant water status, and the nutritional state of the crop. However, these performances are altered under no N application despite non water limiting conditions. The best N strategies consist of application of 120 to 160 kg N/ha split between sowing, tillering and stem elongation.

Testing and validation of simulation models for crop growth and nitrogen management strategies under different water situations

The data set for durum wheat and Barley developed in WP12 was used for validation of the GECROS model developed by WP3 and tested with WP4 for strategy design. For the cultivars which were not included in the calibration study, we did not have the correspondent genotype parameters such as phenology MTDV and MTDR, SEEDW, SEEDNC, BLD, HTMX, PNPRE, so data from INRA Morocco database on previous experiments to estimate these parameters was used.

For barley, the cultivar included in this study was Tissa which is a common variety used in the region, For this case the species parameters according to the values described by Yin and Van Laar (2005) were modified and the genotypes parameters from existing experiments and literature were also estimated.

Simulated versus observed data for validation of the model are shown in Figure 5. The model slightly overestimated the grain yield (RMSD= 159 g/m^2, r^2=0.79); especially in the irrigated site. However data for grain weight showed the opposite results, an overestimation in the rainfed site and a good estimation in the irrigated conditions. Considering both sites the model underestimated the grain weight by 36.1% (RMSD=3 g, r^2=0.32). The shoot dry weight at maturity was overestimated by the model by up to 50% (RMSD=6 g/m^2, r^2=0.58). Due to some irregularity in experimental data the results for validation of the model were not shown for the growing season 2005/06.

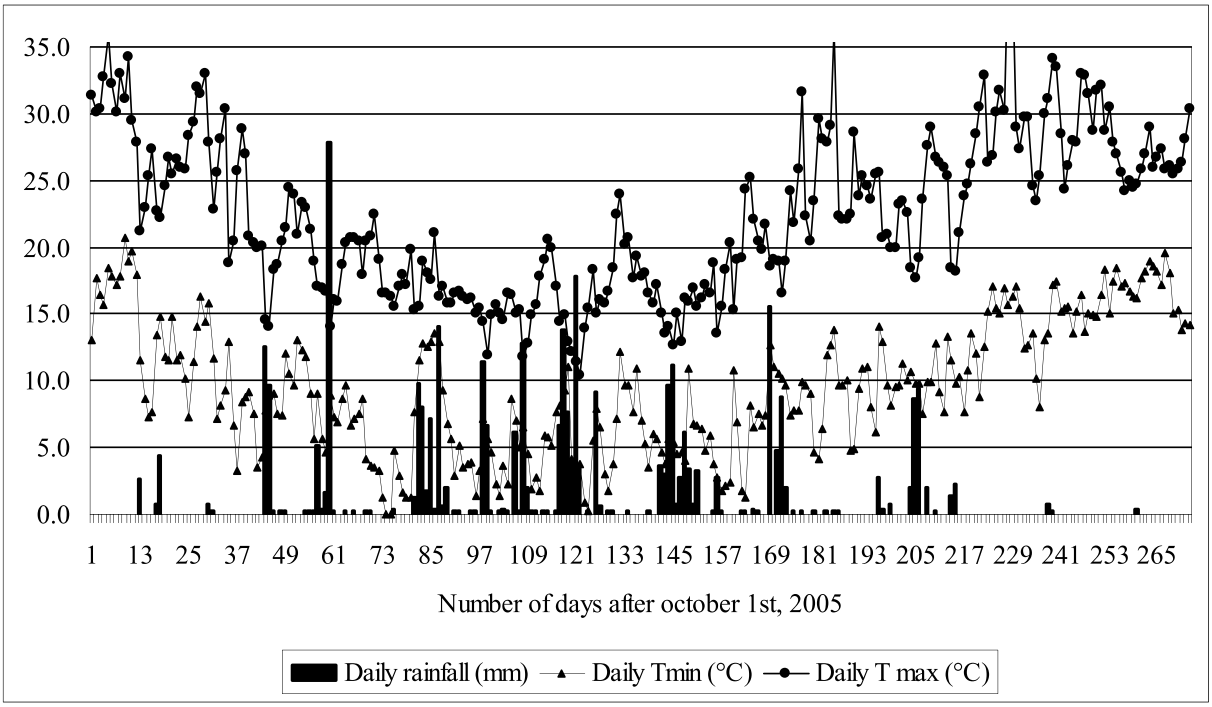


Figure 1. Daily rainfall (mm), maximum and minimum temperatures (°C) at the experimental site, Sidi El Aydi, 2005-2006.

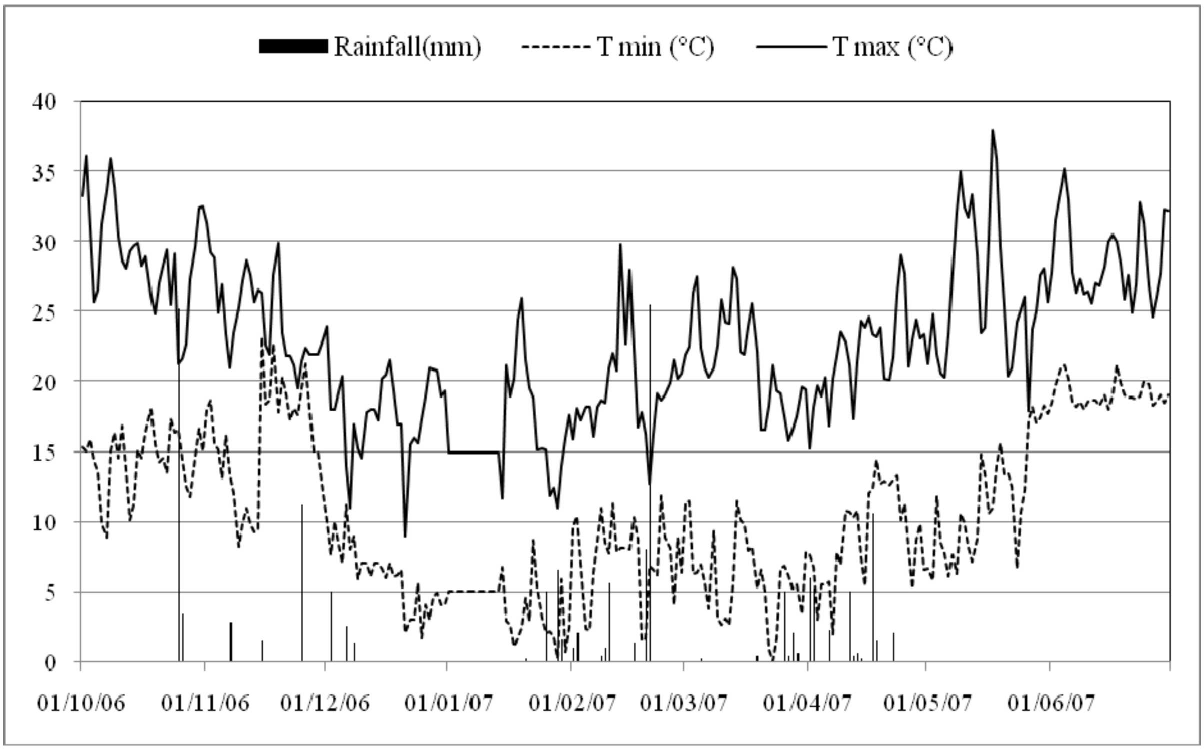


Figure 2. Daily rainfall, maximum and minimum temperatures at Sidi El Aydi during 2006-2007 growing season.

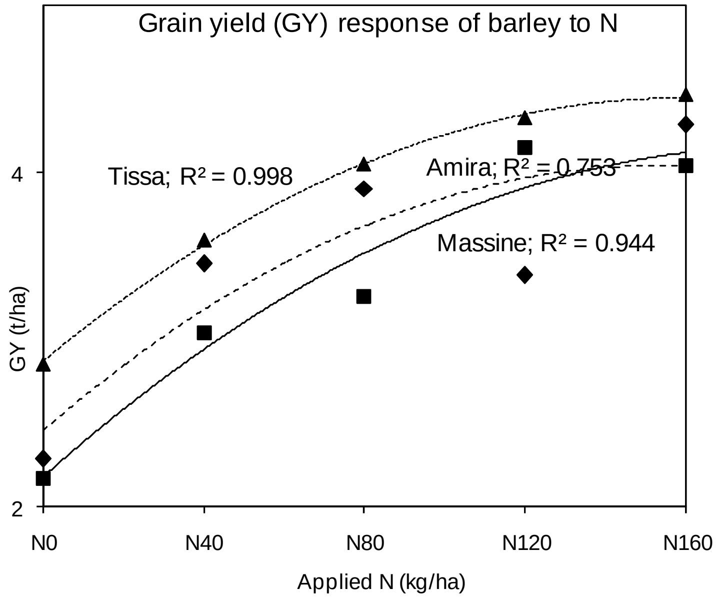


Figure 3a. Response of barley cultivars, in term of grain yield, to N at Sidi El Aydi, Morocco.

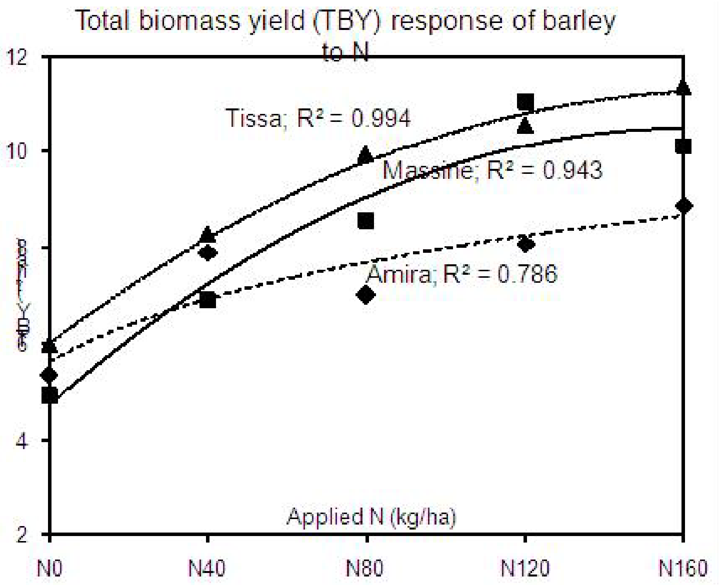


Figure 3b. Response of barley cultivars, in term of total biological yield, to N at Sidi El Aydi, Morocco.

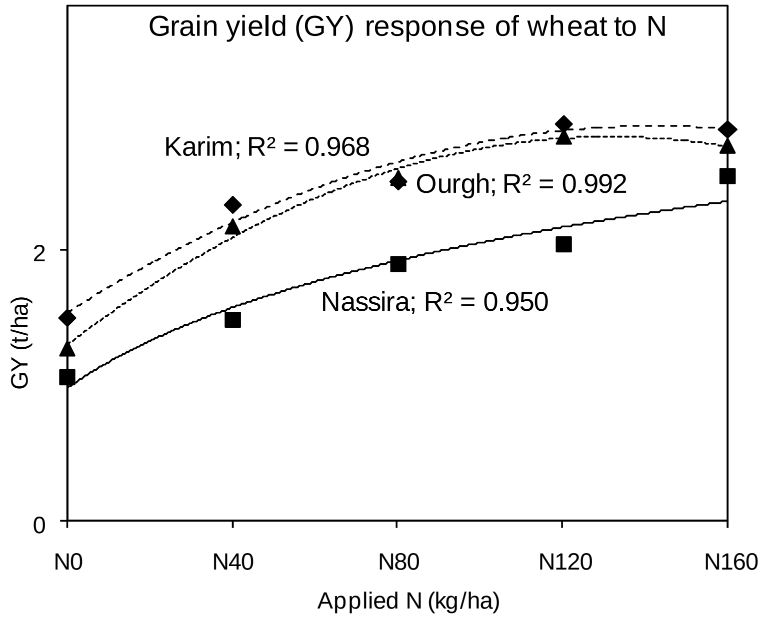


Figure 4a. Response of durum wheat cultivars, in term of grain yield to N at Sidi ElAydi, Morocco.

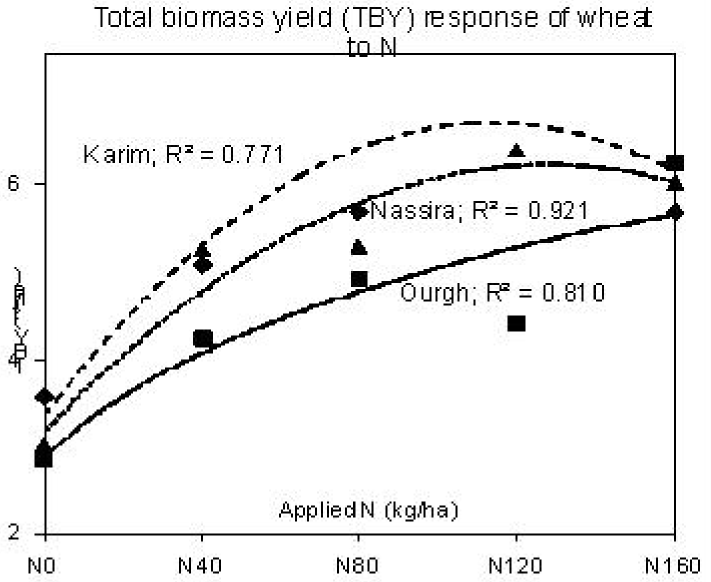


Figure 4b. Response of durum wheat cultivars, in term of total biological yield to N at Sidi ElAydi experimental site, Morocco.

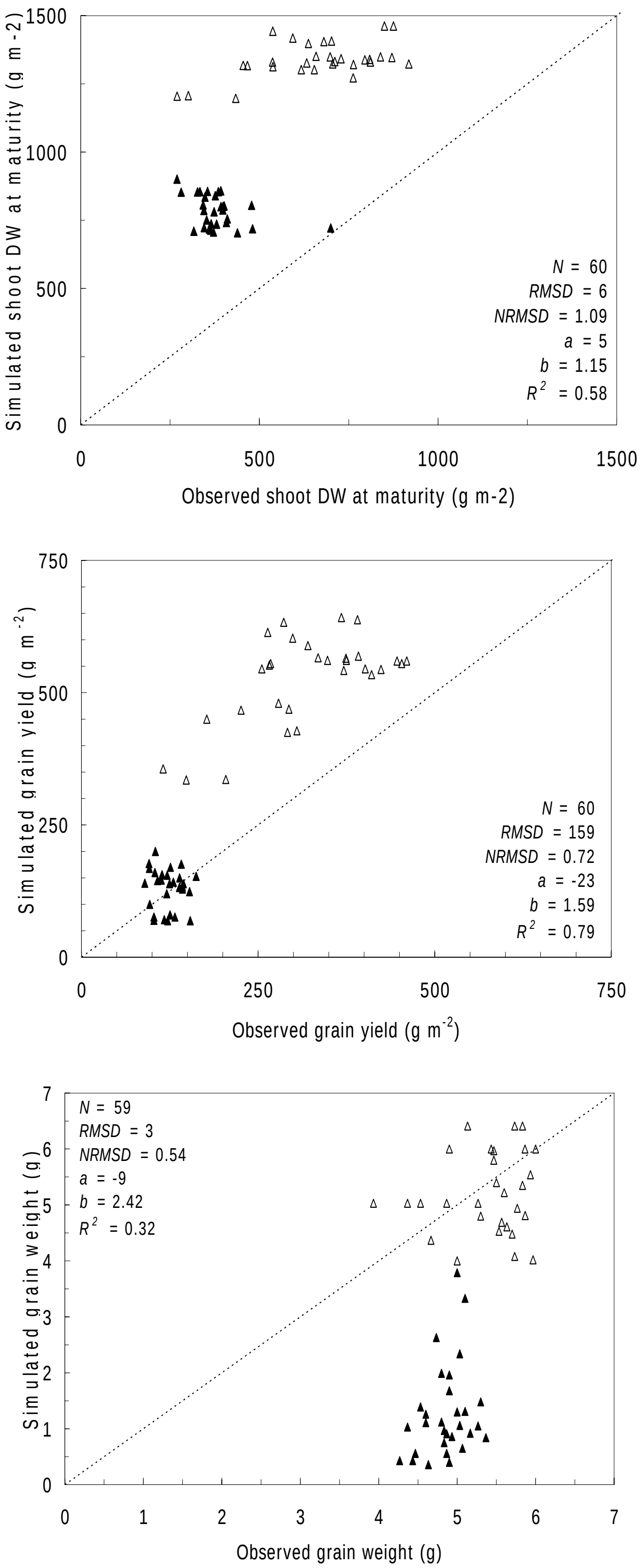


Figure 5. Model evaluation; simulated versus observed data for three genotypes (Karim, Nassira and Ourgh) under 10 N treatments (a combination of nitrogen rates and time of application) during the growing season 2006-07 in Sidi El Aidi experimental station (Morocco), full triangles: rainfed, open triangles: irrigated conditions.

BRIEF INTRODUCTION

The content of the whole Final Report is described.

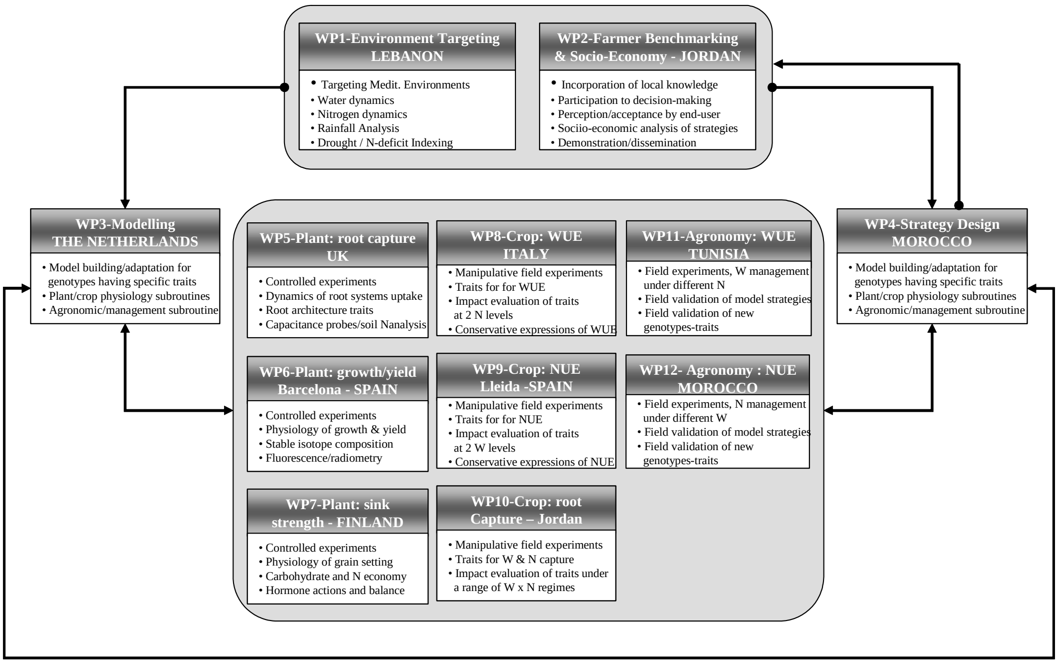
The main, general objective of WatNitMED was to identify and transfer improvements in management of wheat and barley (two strategic crops for farmers across the whole Mediterranean region) through increasing the capture and/or the use efficiency of the most limiting factors determining their productivity. This objective was fulfilled by identifying opportunities for management improvement and the latter related to the analyses of translation actual improvements to the farmers in the Region including outreach activities to make the output of the scientific deliverables to have a realistic impact.

Achieving actual management improvements in capture and use efficiency of limited resources is critical not only in its own but also to power any likely genetic improvement in these attributes that may be achieved. Therefore, the likely impact of the output of these breeding projects may well depend upon parallel advances achieved in management strategies contributing to improve the same characteristics.

The whole project was based on the premise that understanding the physiological bases of the responses to water x nitrogen shortages would allow the design of more consistent management practices to overcome the deficiencies explored, either by directly using the concepts in such strategic design or by being able to build up (or adapt an existing) robust simulation models based on this knowledge and then allowing the testing of different alternatives exploring a large degree of G x E interactions.

Therefore, in the context of Mediterranean main crops being predominantly limited by water x nitrogen (N) deficiencies, we aimed to improve the understanding on the determinants of the crop ability to capture more water and/or to use water more efficiently (WUE) in a range of nitrogen availability conditions; as well as to capture more N and/or to use N more efficiently (NUE) in a range of water availability conditions. In this case,

- the ranges of both characteristics in the South Mediterranean region were characterized and described within the context of the project (WP1),
- the key plant/crop characteristics underlying root capture (WP5), leaf photosynthesis (WP6) and grain number (WP7) that may confer superior ability to cope with insufficient water and nitrogen resources will be determined,
- the information achieved was used to adapt a crop simulation model GECROS (WP3) to provide a mechanistic basis to contribute in the design of management strategies (WP4),
- strategies in realistic field conditions of the Mediterranean region to improve capture (WP10) and/or use efficiency of water (WP8) and/or N (WP9) were evaluated,
- finally we tested agronomic hypothetical management strategies for improving the performance of cereals in these environments (Jordan, WP10; Tunisia, WP11 and Morocco; WP12), and evaluated the socio-economic impact of the adoption of the improved strategies identified in a pilot study in Tunisia (WP2), involving actually transferring the outcomes to the producers (for which we count with invaluable contribution of Farmers Associations in our partnership).



The core of the present report consists of an overview of the main highlights from each Workpackage against the original objectives and deliverables

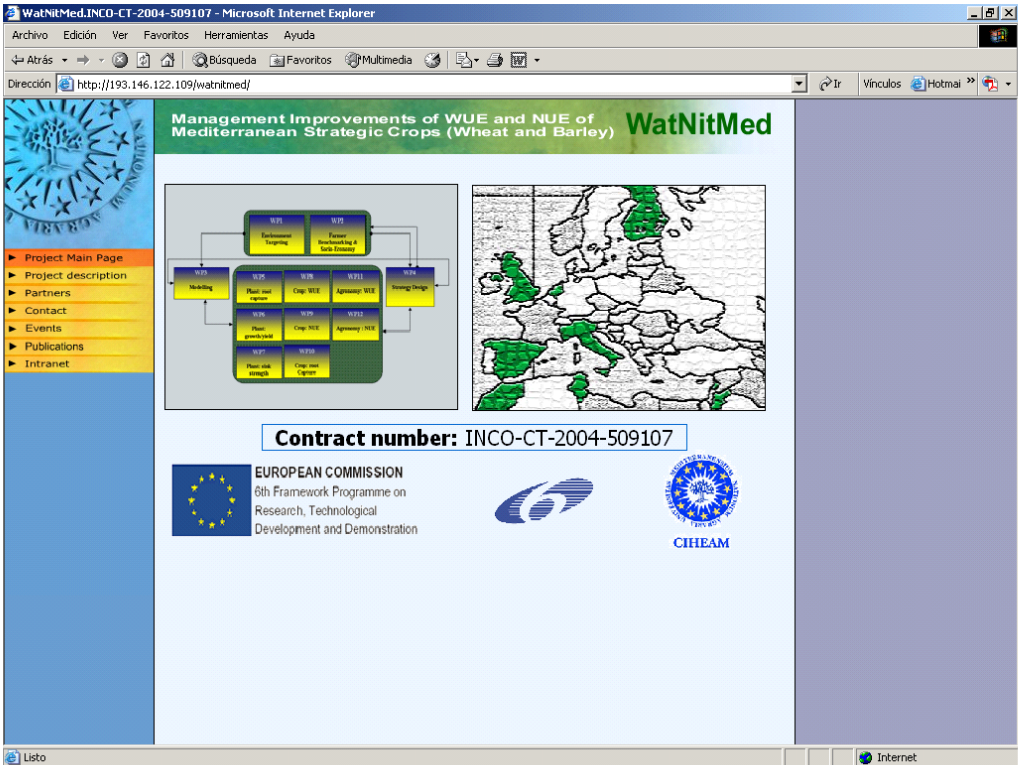
Finally, we provided a summary of the WatNitMED dissemination activities throughout the whole of the project duration (Appendix 1 of this Final Report).

Main actions for dissemination of knowledge

In this appendix we accounted briefly the main actions towards disseminating the knowledge produced in WatNitMED to the potential users in practical agronomy and to the scientific community.

1. Website

We generated a Project's Website with a public and an intranet area. The former with information about the project (and the field of knowledge) of public access, the latter (password-protected) used by partners to interchange information.
The project website has been lodged within the main site of Partner 1 (http://www.iamz.ciheam.org/watnitmed/).


WatNitMed.INCO-CT-2004-509107 - Microsoft Internet Explorer

http://193.146.122.109/watnitmed/

Management Improvements of WUE and NUE of Mediterranean Strategic Crops (Wheat and Barley) WatNitMed

Contract number: INCO-CT-2004-509107

EUROPEAN COMMISSION
6th Framework Programme on Research, Technological Development and Demonstration

CIHEAM

The website offers
(i) a general description of the Project,
(ii) information of each individual partner and a link to contact that partner,
(iii) information with some more detail on the work-packages and deliverables of the project.

In addition it informs on activities (meetings, workshops, field days, etc) done by members of the consortium in the context of the project.

2. Meetings and workshops

- There were Four General meetings of the project: the "kick-off and the Final meetings were held at the premises of the coordinator (Partner 1 in IAM, Zaragoza). The other meetings were held in two of the MPCs of the consortium: Jordan and Morocco.

- WP3 organised a mini workshop on modelling. This workshop was held to allow partners involved in WP3 and other partners interested to become acquainted with the model GECROS and exchange views how to implement the model in WP3. Concepts and preliminary results were also discussed and participants were trained hands-on to use the model. Finally it was discussed and agreed on experimentation and measurements to be done by some partners to contribute with WP3
- A WatNitMed Mini-workshop on 28-30 January 2007 at University of Nottingham, UK attended by P4, P5, P6, P7, P8, P9 and P10 was organized by Partner 5.
- Partner 5 organized the AAB Conference, Resource Capture by Crops, University of Nottingham, UK 10-12 September 2008. (Partner 10, UJ - Jordan). This conference was attended by P3, P5, P7, P8, P9 and P10 (see section 4 for oral and poster papers presented at the conference on WatNitMed results).

3. Dissemination of scientific results outside the consortium

3.1 Publication of International Articles (*copies of documents are in Appendix 2*)

- Ponsioen, T.C., Yin, X., Spiertz, J.H.J. and Royo, C. 2007. Effects of abiotic stress on sink and source affecting grain yield and quality of durum wheat: a model evaluation. In: "*Wheat Production in Stressed Environments*" (H. Buck, Ed.), Springer, Dordrecht, The Netherlands, pp. 633-639.

- Slafer, G.A. 2007. Physiology of determination of major wheat yield components. In: "*Wheat Production in Stressed Environments*" (H. Buck, Ed.), Springer, Dordrecht, The Netherlands, pp. 557-565.

- Cabrera-Bosquet L, Molero G, Bort J, Nogués S, Araus JL. 2007. The combined effect of constant water deficit and nitrogen supply on WUE, NUE and $\Delta^{13}C$ in durum wheat potted plants. *Annals of Applied Biology* **151**: 277–289.

- Cossani, C.M., Savin, R., and Slafer, G.A. 2007. Contrasting performance of barley and wheat in a wide range of conditions in Mediterranean Catalonia (Spain). *Annals of Applied Biology* **151**: 167–173.

- Cabrera-Bosquet L, Albrizio R, Araus JL, Nogués S. 2009. Photosynthetic capacity of field-grown durum wheat under different N availabilities: a comparative study from leaf to canopy. *Environmental and Experimental Botany* **67**: 145-152.

- Cabrera-Bosquet L, Molero G, Nogués S, Araus JL. 2009. Water and nitrogen conditions affect the relationships of□^{13}C and□^{18}O to gas exchange and growth in durum wheat. *Journal of Experimental Botany* **60**: 1633-1644.

- Karam, F, Kabalan, R., Breidi, J, Rouphael, Y, Oweis, T. 2009.Yield and water-production functions of two durum wheat cultivars grown under different irrigation and nitrogen regimes. Journal and year of publication: *Agricultural Water Management* **96**: 603-615.

- Cossani, C.M. Slafer, G.A. and Savin, R.. 2009. Yield and biomass in wheat and barley under a range of conditions in a Mediterranean. *Field Crops Research*, **112**, 205-213.

- Yin, X. and Struik, P.C., 2009. Theoretical reconsiderations when estimating the mesophyll conductance to CO$_2$ diffusion in leaves of C$_3$ plants by analysis of combined gas exchange and chlorophyll fluorescence measurements. *Plant, Cell and Environment*: in press (DOI: 10.1111/j.1365-3040.2009.02016.x).

- Yin, X., Struik, P.C., Romero, P., Harbinson, J., Evers, J.B., van der Putten, P.E.L. and Vos, J. 2009. Using combined measurements of gas exchange and chlorophyll fluorescence to estimate parameters of a biochemical C$_3$ photosynthesis model: a critical appraisal and a new integrated approach applied to leaves in a wheat (*Triticum aestivum*) canopy. *Plant, Cell and Environment* **32**: 448-464.

- Yin, X., Guo, W. and Spiertz, J.H.J., 2009. A quantitative approach to characterize sink-source relationships during grain filling in contrasting wheat genotypes. *Field Crops Research* **114**: 119-126.

- Rajala, A., Hakala, K., Mäkelä, P., Muurinen, S. and Peltonen-Sainio, P. Spring wheat response to timing of water deficit through sink and grain filling capacity. Field Crops Research. (in press).

3.2 Presentations of results in Conferences/Workshops

- Slafer, G.A., Karrou, M., Karam, F., Thabet, C., Spiertz, H.J., Dahan, R, Foulkes, J., Nogues, S., Peltonen-Sainio, P., Albrizio, R., Ayad, J.Y. & Mellouli, H.J. WatNitMED - Management Improvements of WUE and NUE of Mediterranean Strategic Crops (Wheat and Barley). In: International Conference on Water Saving in Mediterranean Agriculture & Future Research Needs, CIHEAM, Mediterranean Agronomic Institute of Bari, Italy, 14-17 February 2007.

- H. J. Mellouli, M. Ben Naceur, M. El Felah, M. S. El Gharbi, M. Kaabia, H. Nahdi, G. A. Slafer and M. Karrou. Efficience de l'utilisation de l'eau chez le ble et l'orge sous differents regimes hydriques et de fertilisation azotee dans des conditions subhumides de tunisie. In: International Conference on Water Saving in Mediterranean Agriculture & Future Research Needs, CIHEAM, Mediterranean Agronomic Institute of Bari, Italy, 14-17 February 2007.

- Savin R., Sadras V.O. and Slafer G.A. Wheat Nitrogen Use Efficiency under Mediterranean and non-Mediterranean environments. In: 15th International Nitrogen Workshop: Towards a better efficiency in N use, University of Lleida, Spain, 28-30 May 2007.

- Cossani, C.M., Savin R. and Slafer G.A. Wheat and barley grain yield performance in relation with Nitrogen and water use efficiency under Mediterranean environments. In: 15th International Nitrogen Workshop: Towards a better efficiency in N use, University of Lleida, Spain, 28-30 May 2007.

- Ferrante A., Savin R. and Slafer G.A. Fate of wheat and barley floret primordia in response to nitrogen. In: XVII Meeting of the Spanish Society of Plant Physiology & X Partuguese-Spanish Congress of Plant Physiology, University of Alcalá, Alcalá de Henares, Spain, 18 -21 September 2007.

- Mäkelä, Pirjo S. A., Ari A. Rajala, Susanna K. Muurinen, Kaija-Liisa Hakala, and Pirjo H. Peltonen-Sainio. Drought occurring at the grain filling period of wheat. In: ASA-CSSA-SSSA Annual International Meetings, A Century of Integrating Crops, Soils & Environment. New Orleans, Louisiana, USA, 4-8 November 2007.

- Todorovic, M., Albrizio, R., Steduto, P., Abi Saab, M. And Zivotic Lj. Simulation of durum wheat and barley growth by AquaCrop and CropSyst models: a comparative analysis in a Mediterranean environment. International Symposium on Crop Modeling and Decision Support, Nanjing Agricultural University, Nanjing, China, 19-22 April 2008.

- Cabrera-Bosquet, L., Molero, G., Sánchez, C., Nogués, S. & Araus. JL Δ18O as integrative physiological criterion associated with growth and yield in cereals. XVIII Reunión de la Sociedad Española de Fisiología Vegetal (SEFV)/XI Congreso Hispano-Luso de Fisiología Vegetal, Zaragoza, September 2009. (Partner 6, UB - Spain). This was also presented earlier by the senior author at the The Rank Prize Funds-Mini-Symposium on High Sustainable Cereal Yields Under Drought, Grasmere, UK, 18-20 November 2008

- Carvalho, P., Foulkes, M.J. and Azam-Ali, S.N. Rooting traits for imporved water capture in barley and durum wheat. AAB Conference, Resource Capture by Crops, University of Nottingham, UK10-12 September 2008. (Partner 5, UNOTT - UK)

- Carvalho, P., Foulkes, M.J. and Azam-Ali, S.N. Optimizing rooting traits for improved water capture in barley and durum wheat. Rank Mini Symposium on "High sustainable cereal yields under Drought". Grasmere, UK 18-20 November 2008 (Partner 5, UNOTT - UK)

- Cossani, CM, Slafer, GA and Savin, R. Nitrogen and water co-limitation in wheat and barley under a Mediterranean environment. 16th Nitrogen Workshop, Turin, Italy 28 June-1 July, 2009 (Partner 9, UL - Spain).

- Cossani, Roxana Savin and Gustavo A. Slafer. Resource capture by crops: Integrated approaches (10-12 Sept 2008). University of Nottingham. Nitrogen and water use efficiency in wheat and barley under Mediterranean environments. (Partner 9, UL - Spain).

- Ebrahim, N., Ayad, J., Shatanawi, M., and Badarneh D. Root growth and water capture of durum wheat (Ttritcum turgidum L. var durum) and barley (Hordeum vulgare L.) in response to nitrogen and irrigation water. AAB Conference, Resource Capture by Crops, University of Nottingham, UK 10-12 September 2008. (Partner 10, UJ - Jordan)

- Ferrante, A, Savin, R and Slafer, GA. Wheat and barley floret development in response to nitrogen and water availability. X Congress of the European Society for Agronomy. 15-19 September 2008. University of Bologna, Italy (Partner 9, UL – Spain).

- Foulkes, Carvalho, P., Azan-Ali, S., Weightman, R. and Snape, J Identifying physiological traits associated with improved performance of rainfed wheat in dry environments. Interdrought-III Conference Shanghai, China 11-16 October 2009. (Partner 5, UNOTT - UK)

- Todorovic M., Albrizio R., Steduto P., Abi Saab M.T., Zivotic Lj. 2008. Simulation of durum wheat and barley growth by AquaCrop and CropSyst models: a comparative analysis in a Mediterranean environment. “International symposium on crop modeling and decision support”, April 18-22, 2008, Nanjing, China. (Partner 8, IAMB - Italy)

- Ponsioen, T.C. Yin, X. Vos, J. Spiertz J.H.J., Struik, P.C. Modelling root growth and resource capture in wheat and barley” AAB Conference, Resource capture by crops: Integrated approaches (Nottingham University, UK, 10-12 September 2008. (Partner 4, Wageningen-UR - NL)

- Ayad, J, Ebrahim, N and Badarneh, D. Crop root and shoot capture for nitrogen by durum wheat (Triticum turgidum L. var. durum) and barley (Hordeum vulgare L.) in Mediterranean climate. AAB Conference, Resource Capture by Crops, University of Nottingham, UK10-12 September 2008. (Partner 10, UJ - Jordan).

- Cossani, CM, Savin, R and Slafer, GA. Do Cereals Differ in Grain Weight Stability? 8th International Oat Conference (Minneapolis, MN, U.S.A., Jun 28 - Jul 2, 2008). (Partner 9, UL - Spain)

- Cabrera-Bosquet, L, Albrizio, R, Araus, JL and S Nogués. On the photosynthetic capacity of field-grown durum wheat under different N availabilities: a comparative study from leaf to canopy. From Seed to Pasta: The Durum Wheat Chain congress held in Bologna, Italy 30 June-3 July 2008) Partner 6, UB-Spain).

- Karam, F. Wheat Growth and Production under Semi Arid Conditions of the Central Bekaa Malley (Management Improvements of WUE and NUE of Mediterranean Strategic Crops – Wheat and Barley) (WatNitMED INCO-CT-2004-509107) was in April 2009 in Beirut during the Francophone Scientific Days. (Partner 2, LARI – Lebanon).

3.3 Papers submitted to International Journals

- Albrizio R., Todorovic M., Matic T. and Stellacci A.M. Comparing the interactive effects of water and nitrogen on durum wheat and barley grown in a Mediterranean environment. Field Crops Research (paper submitted May 2009).

- Cabrera-Bosquet L, Molero G, Stellacci AM, Bort J, Nogués S, JL Araus. NDVI as a potential tool for predicting biomass, nitrogen content and growth in potted wheat genotypes. Precision Agriculture (paper submitted May 2009).

- Cossani, C.M., Slafer, G.A and Savin, R. Nitrogen and water use efficiencies in cereal crops under the Mediterranean environment. Annals of Applied Biology (paper under revision).

- Cossani, C.M., Slafer, G.A. and Savin, R. Nitrogen and water co-limitation reduces yield gap in small grain cereal crops under Mediterranean environments. European Journal of Agronomy (paper submitted).

- Cossani, C.M., Thabet, CH, Hafedh, JM and Slafer, GA. Improving wheat yields through N fertilization in Mediterranean Tunisia. European Journal of Agronomy (paper submitted).

- Ponsioen, T.C., J.H.J. Spiertz, C.J. Birch, C. Royo, and J. Vos. Modelling growth and yield of barley and wheat under diverse stress conditions: An evaluation of GECROS. Agricultural Systems (paper submitted).

- Thabet, C. Improving nitrogen and water use efficiency by wheat farmers in Mediterranean countries: Case of Tunisia. New Mediterranean Review (paper accepted).

4. Dissemination to potential users

During the second reporting period:

1) During this year, workshops with stakeholders were organized in Morocco in two major producing areas of barley and wheat by partner 12 (INRA-Morocco). Key INRA Morocco and other research and development institutions attended these workshops. Emphasis was given to identifying and filling of critical knowledge gaps. The workshops were held to review and adjust the strategies and design a research plan for their evaluation, to discuss agronomic strategies and design evaluation methodology, and to evaluate and adapt research trials and discuss model application. These workshops were attended by farmers, extension people and scientists. Qualitative and quantitative information provided by farmers groups has been collated and analyzed. Similarly, information from farmers and scientists to design rational strategies for water and nutrient management that optimize yield whilst minimizing losses to the environment was collated. These workshops took place in two major producing areas of wheat and barley in the arid and semi-arid regions of Morocco. During these workshops, the objectives of the Project and the workshop were presented in order to involve all stakeholders and targeted communities in the description of actual management strategies and identify ways for improvement. A description of management practices used by farmers with regard to rotations, cultivars used, soil preparation, fertilization, sowing, weed and disease control, and harvesting was made;

2) During 2005/2006 growing season, Partner 11 (INRAT-Tunisia) has been conducting its experiments in a private field owned by El KHIR Company which is an association of a very high number of farmers. The project site was useful for this company since it took advantage from the irrigation scheduling program of WatNitMED experiments, and it was supplied by weather data when needed. This continuous disseminating of the knowledge will be performed as well during the experiment of 2006/2007;

3) In 2006, a workshop with the Tunisian farmers was organized by the project coordination and was hosted by UTAP (Tunisian Union of farmers). In addition to the farmers, partners 3 and 11 participated in this meeting. During the workshop, a short presentation of the project was made and a group of farmers committed themselves to be partners in the testing of the technologies developed by the project during 2007/2008 growing season. Moreover, the coordinators discussed with partner 3 the details of field choice and characterization (see Annex 4).

During the third reporting period

- During the third year of the project, Partner 11 (INRAT-Tunisia) has conducted its experiments in a private field owned by El KHIR Company which is an association of a very high number of farmers. Open doors were achieved by continuous visit of farmers and vulgarisation staff in order to observe, discuss and obtain recommendation related to cereal management, particularly N management. Visits to the project by invited experts and farmers of different regions (Beja, Jendouba, Kef, and Bizerte) were organized in collaboration with UTAP (Partner 13).

- Experiments conducted by Partner 9 were carried out in actual farms, away from experimental stations. Although no formal outreaching activities were organised many farmers of the region visited the field in different occasions and informal discussions on extrapolation of results to other farms were maintained.

- Field trials were demonstrated to local farmer's groups in field visits organized by Partner 10 in Jordan on 6-9 May 2007.

- A field day was organized at MHAMDIA field experiment by Partner 11 on May 28, 2007. Around 50 farmers attended. Discussion was focused on the best strategy in order to enhance the yield and the productivity. Farmers, expressed their interest in maintaining a continuous contact with the project team and some agreed to test alternatives on their own fields.

Ministry of Agriculture and Water Resources of Tunisia

The INCO Project
Management Improved of WUE and NUE of Mediterranean Strategic Crops (Wheat and Barley) : WatNitMED
Contract N° INCO-CT-2004-509107

The National Agricultural Research Institute of Tunisia

Organizes

A FIELD INFORMATION DAY

On the project experimental site SDA EL KHIR Bourbia

Monday May 28, 2007

Programme

09:00 Inscription

09:30 Welcome adress : General Director of SDA EL KHIR (Private Farm Land)

09:50 Introduction : General Director of INRAT

10:10 Opening : President of Institution of Agricultural Research and high Education

10:30 Presentation of WatNitMED project, its objectives, the research conducted in Tunisia within the project activities : Team Leader of the project at INRAT

10:50 Coffee break

11:10 Visit of the experimental site and presentation of the approach and the obtained results / Discussion with the guest farmers, technicians and researchers from different areas of the country (more than 50 participants)

13:00 Lunch

The Project

Water is recognized as the most important factor limiting the cereal production in the Mediterranean region. However, to reach a high yield it's important to be able to manage water as well as the soil tillage and fertilization and other factor linked to on farm practical operations. Since Water Use Efficiency is highly linked to the rational use of Nitrogen, the project **"Management Improved of WUE and NUE of Mediterranean Strategic Crops (Wheat and Barley) : WatNitMED"** financed by COMMISSION OF THE EUROPEAN COMMUNINITIES within the Sixth Framework Programme, aims to identify improvements in management of wheat and barley through increasing a better use and use efficiency of water and nitrogen. By mean harmonized experimental work and advanced modeling, 8 countries presenting 14 partners are involved in the establishment of strategies for enhancing cereal production in the Mediterranean region. Technology Transfer and Dissemination represent an important component of WatNitMED Project. This Field Day is subscribed within this component and has as objective to show the importance of the Water and Nitrogen management in the cereal field. INRAT, as partner in the project is entrusted with experimental work were 4 Water regimes and 4 Nitrogen levels are tested at farm scale in order to identify the best way to improve water use efficiency of wheat and barley under rational nitrogen fertilization.

Contact :
Dr. Hafedh Jamil MELLOULI
mellouli.hafedhjamil@iresa.agrinet.tn

- For dissemination, on-farm trials are being conducted by Partner 12 in the present growing season (sown in late 2007) in a major producing area of wheat and barley in the arid and arid regions of Morocco to test and evaluate the decision aid and package of agronomic strategies developed by the project. For this purpose, 10 selected farmers' sites were sown: 4 with barley and 6 with wheat to compare their current management practices with management strategies identified in the project.

- Partner 3, seconded by partners 1, 9 and 11, started the Pilot Experience in several farms of two regions in Tunisia. This pilot experience will serve, besides of testing some preliminary suggestions from the project, as a perfect framework to develop outreaching activities by either informally discussing with neighbouring farmers to the farms where the alternatives are tested as well as formally organising activities such as field days when a number of WatNitMED scientists may openly discuss with farmers and advisors interested in the outcomes of the project.

- Partner 7 (MTT-Finland) published an article in an extension magazine explaining the activities they developed in WatNitMED.

MTT

-Joulukuun- Koelypsy - 2006 -

Viivytystaisteluun kuivuutta vastaan

Ilmastonmuutoksen arvioidaan kuivattavan laajat alat Etelä-Eurooppaa tämän vuosisadan kuluessa. MTT on mukana EU-hankkeessa, joka etsii keinoja pitkittää viljanviljelyä Välimeren ympäristössä. Suomalaiset selvittävät veden ja typen merkitystä jyvän kehittymisessä.

Professori **Pirjo Peltonen-Sainio** MTT:stä tarkastelee Ilmatieteen laitoksen laatimia Euroopan karttoja, jotka kuvaavat mantereen ilmastoluokkien ennustettua muuttumista tulevien vuosikymmenten aikana. Kuumia, kuivia kesiä koodaava punainen väri valtaa kartta kartalta enemmän alaa Välimeren ympäristössä, niin että vuonna 2080 se peittää alleen esimerkiksi koko Pyreneiden niemimaan.

- On selvää, että kuivumisen myötä maataloustuotannon painopiste siirtyy Euroopassa nykyistä pohjoisemmaksi. Etelä-Euroopan sulkee pois tuotannosta jo se, että maa suolaantuu ja viljelyalueet aavikoituvat, Peltonen-Sainio pohtii.

Hän toteaa EU:n rahoittaman nelivuotisen tutkimushankkeen olevan eräänlaista viivytystaistelua sen puolesta, että Etelä-Eurooppa voitaisiin säilyttää mahdollisimman pitkään viljanviljelyssä. Viime vuonna alkaneen hankkeen kokonaisbudjetti on noin 1,8 miljoonaa euroa, ja siinä on mukana 14 tutkimuslaitosta yhdeksästä eri maasta.

Etusivulle

MTT keskittyy jyvään

Hankkeen tavoitteena on täsmätä viljelytoimia niin, että vehnän ja ohran veden- ja typenkäytön tehokkuutta saadaan parannettua Välimeren oloissa. Käytännössä tämä tarkoittaa esimerkiksi kastelun ajoittamista tarkalleen oikein.

- Vesi ja typpi ovat avaintekijöitä viljan satopotentiaalin rakentumisessa ja toteutumisessa. Ne vaikuttavat paljon esimerkiksi tähkälletulon yhteydessä tapahtuvaan jyvien abortoitumiseen. Typpi on kasvin tarvitsemista ravinteista merkittävin, ja on kallista ja vahingollista, jos se ei päädykään kasvin käyttöön. Myös muiden ravinteiden saatavuus heikkenee vedenpuutteen myötä, professori Peltonen-Sainio taustoittaa.

MTT:n tehtävänä hankkeessa on tutkia, miten kuivuus ja ravinteiden saanti vaikuttavat tähkän jyvien kehittymiseen. Tärkeä yhteistyökumppani on Helsingin yliopistossa työskentelevä professori Pirjo Mäkelä, jonka erikoisosaaminen abortoitumisen syistä tukee hyvin tutkimusta.

Peltonen-Sainio pitää erityisen kiinnostavana sen selvittämistä, miten vehnän ja ohran ohjelmoitu solukuolema eli apoptoosi toteutuu. Geneettisesti ohjautuva solukuolema on osa eliöiden normaalia kehitystä, ja sen tehtävänä on poistaa eliöstä vaurioituneet, vanhentuneet ja turhat solut.

- Onpa jyvä saavuttanut täyttymispotentiaalinsa tai ei, niin apoptoosi päättää sen täyttymisprosessit, hän sanoo.

Välimeren olot Jokioisiin

Yksi MTT:n Jokioisten kasvihuoneista on kunnostettu tutkimusta varten Välimeri-huoneeksi, jonka olosuhteet simuloivat sikäläistä kasvukautta. Kasvihuoneessa hankitaan syventävää tietoa tapahtumaketjuista, jotka vaikuttavat mikrotasolla viljojen sadonmuodostukseen Välimeren seudulla.

Välimeri-huoneen lämpötila pidetään kasvukauden ajan läkähdyttävässä 30 asteen tuntumassa riippumatta Suomen suven säävaihteluista, ja automaattiset pimennysverhot kätkevät tutkimustähkät yöttömältä yöltä keskimäärin kymmeneksi tunniksi vuorokaudessa.

Huoneessa viljeltiin viime ja tänä vuonna vehnää, kahtena seuraavana kesänä on ohran vuoro.

Viime kesänä koeruuduilla testattiin erilaisia lannoitetasoja ja kuivuuskäsittelyjä. Kasvien yhteyttämistä ja vesitaloutta mitattiin jatkuvasti, ja tähkänäytteitä kerättiin myöhempää analyysia varten.

- Tarkkailimme koko ajan, miten kastelu ja ravinteet vaikuttavat jyvien kehittymiseen tai abortoitumiseen. Kasveihin injektoitiin fluoresoivaa merkkiainetta, jotta pystyimme seuraamaan yhteyttämistuotteiden kulkeutumista niissä, Peltonen-Sainio kertoo.

Mailla selkeä työnjako

Espanjan koordinoimaan tutkimushankkeeseen osallistuu Suomen lisäksi Hollanti, Iso-Britannia ja Italia sekä neljä unionin ulkopuolista maata: Libanon, Tunisia, Jordania ja Marokko.

- Tulevaisuudessa Etelä-Euroopassa vallitseva tilanne on jo nyt muutamien tutkimushankkeessa mukana olevien maiden todellisuutta, Peltonen-Sainio huomauttaa.

Hankkeessa on selkeä työnjako: Välimeren maat tekevät kenttäkokeet ja Suomi ja Iso-Britannia tutkivat sadonmuodostusta erilaisissa kuivuusoloissa - britit selvittävät juuriston kehittymistä. Hollanti laatii kaiken hankkeessa kertyvän aineiston perusteella malleja, joiden avulla laajennetaan tulosten sovellettavuutta.

Peltonen-Sainio toteaa, että tutkimuksen tuottamaa perustietoa kuivuuden vaikutuksesta kasveille voidaan hyödyntää myös Suomessa, esimerkiksi erilaisten ennustemallien tekemisessä.

- Meillä kuivuus ajoittuu yleensä alkukesään ja rajoittaa satopotentiaalia, mutta ajoittumisen vuotuinen vaihtelu on suurta. Etelä-Euroopassa satopotentiaali voi olla hyvä, mutta kasvukauden päättävä kuivuus estää sen täysmittaisen tai edes kohtuullisen toteutumisen.

Lisätietoja: Pirjo Peltonen-Sainio, puh. (03) 4188 2451

Tulevaisuutta kartoittamassa

Ilmatieteen laitoksen laatimat skenaariokartat havainnollistavat ilmastonmuutoksen vaikutuksia Euroopan ilmastoon ja kasvillisuuteen.

Tutkija **Heikki Tuomenvirta** Ilmatieteen laitokselta kertoo, että skenaarioiden laatiminen lähtee ilmastomallista, joka simuloi energian ja aineen kiertoa maapallon merissä, jäässä, ilmassa, kasvillisuudessa ja maaperässä. Malli tuottaa koko maapallon kattavan ilmastojärjestelmän fysikaalisen kuvauksen, joka sisältää miljoonia muuttujia. Silti paraskin malli on yksinkertaistettu kuvaus järjestelmästä

"Ilmastoennuste" syntyy, kun malliin syötetään arvio kasvihuonekaasujen

During the last reporting period

− A working report was produced by Partner 4 (INRA - Morocco) on “Guidelines and recommendations for the use of a simulation model as a decision aide to evaluate water and nitrogen use efficiency of different wheat and barley genotypes in Mediterranean environments”**.** *A copy of the Guideline is in Appendix 2*)

- Farmers Field Day at Ajloun area, Jordan. Partner 10 (UJ - Jordan) organized a *Dissemination and demonstration meeting with farmers* on June, 18 2009 and introduced WatNitMED activities and extension to local farmers. Twenty three farmers in addition to team members participated in this meeting. Oral talks of the major findings and recommended agricultural practices in rainfed agriculture were demonstrated in the field including visual evaluation of field plots.

Farmers partcipated in the field day organized by Partner 10 (University of Jordan) at Ajloun farmer field. June 18 2009 Dissimination Activity

- Two field days were organized by Partner 4 (INRA - Morocco) in two main regions for cereal production (Chaouia and Zaers) in May 2009 to show the main outcomes of the project with regard to nitrogen management strategy. The management improvements produced in the project were demonstrated to the farmers with focus on the best strategy that would enhance the yield and the productivity of cereal crops. Around 50 farmers and extension agents attended. Two field days were organized at Chaouia and Zaers region in 2009. Around 50 farmers and extension agents attended.

Demonstration to the farmers and extension agents of the WatNitMed strategies tested, at Zaers region, May 15, 2009 organised by Partner 4 (INRA Morocco)

Filed plots as part of the demonstration platform organised by Partner 4 (INRA Morocco) of the WatNitMed strategies tested, at Zaers region, May 15, 2009.

The demonstration platform at Zaers region, Morocco May 15, 2009

Field day at Zaers region, Morocco May 15, 2009

- During the last experiment year (2008/2009), the project site of Partner 11 (INRAT-Tunisia) was converted as pilot site were soil water and nitrogen fertilisation were monitored. In addition to the outcomes of the research*, the site had open door for farmers to obtain information's on how to evaluate and decide on N-fertilization recommendations from the project. In addition, three important events were organized by INRAT partner: (i) "Listening to the farmers" (ii) "Building capacities to improve wheat, barley and livestock production in North Africa: Case of Tunisia and Libya" and (iii) "The Use of agro meteorological Plants and recent instrumentation to monitor irrigation, fertilization and disease control".

*which is now one of the manuscripts submitted for publication (see in this Appendix 1 within the list of papers submitted that of Cossani, Thabet, Hafedh and Slafer. *Improving wheat yields through N fertilization in Mediterranean Tunisia* submitted to the *European Journal of Agronomy*; and find attached to Appendix 2 a copy of that submission).

Two pictures illustrating the activity developed by WatNitMED in Beja, one of the sites in Tunisia where the “open door for farmers” was conducted to discuss on how to use the knowledge developed by the project on N-fertilization recommendations

- LARI’s team (Partner 2) in the project organized a series of field days at both Tal Amara Research Station (Central Bekaa Valley) and the Irrigation Technology Center (Northern Bekaa Valley). The objective was to gather a certain number of target farmers and cereal growers in field workshops to transfer knowledge and to set up for a series of management/production techniques.

Set of pictures illustrating the training activities developed by WatNitMED at the Center of Irrigation Technologies in Northern Bekaa Valley

- The GECROS model is open-source, and has been uploaded by Partner 4 (Wageningen-UR - NL) on their website for any broad application of the model even by colleagues other than the WatNitMed community.

5. Plans for future use and dissemination of knowledge

- A publication of a paper on technology adoption in the frame of WatNitMED project titled: Adoption of new technologies by cereal growers in Mediterranean Tunisia: lessons from WatNitMED project is planned by Partner 3 (Tunisia).

- WatNitMED results will be presented by Partner 11 (INRAT – Tunisia) with the collaboration of Partner 13 (UTAP) to the Salon d’Agriculture (Agriculture show) during next November which is yearly organised and offers opportunity to present.

- The list of papers published and manuscripts already submitted for publication will be complemented in the near future by the publication of other papers derived from the information most recently achieved in the project in International Journals (some of them are actually under preparation at the moment)

6. PhD Theses

- PhD Thesis: results from WP10 were included in the PhD Thesis by Mr. Najy Ebrahim “Responses of root and shoot of durum wheat (T. turgidum L. var. durum) and barley (H. vulgare L.) plants to different water and nitrogen levels. Which was submitted and defended (July 2008).

- PhD Thesis: results from WP5 will be included in the PhD Thesis of Pedro De Carvalho to be submitted University of Nottingham (expected viva December 2009).

- PhD Thesis: results from WP6 will be included in the PhD Thesis of Llorenç Cabrera-Bosquet to be submitted to University of Barcelona (expected viva March 2010).

- PhD Thesis: results from WP9 will be included in the PhD Thesis of Mariano Cossani to be submitted to University of Lleida (expected viva March 2010).

- PhD Thesis: results from WP6 will be included in the PhD Thesis of Gemma Molero Milan to be submitted to Univ Barcelona (expected viva June 2010).

- PhD Thesis: part of the results from WP9 will be included in the PhD Thesis of Ariel Ferrante to be submitted to University of Lleida (expected viva 2011).