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Full Length Research Paper

Adaptation of Moroccan durum wheat varieties from different breeding eras

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The continuous technological and environmental changes are reasons for periodical re-evaluation of variety performances and adaptation. The objective of this work was to re-assess the adaptation of the main registered durum wheat (*Triticum turgidum var. L. durum*) varieties in Morocco. Twenty three varieties were tested in six sites and during four consecutive growing seasons 2001 to 2005. The experimental layout was a randomized complete block design trials of three replicates. Two methods of genotype by environment interaction analysis were performed and results were compared: the regression model and the additive main effects and multiplicative interaction model (AMMI). Analysis of variance showed highly significant effects of the experiment sites, the cropping seasons and of the varieties. Significant interactions of these main effects were also shown. Specific adaptation of particular varieties to specific sites was hence demonstrated. The conclusions brought by the two methods were concordant in rating the new Hessian fly resistant varieties as adapted to the dry lands and in rating the remaining high-yielding varieties as adapted to the favorable areas. AMMI analysis first component of variation explained 60.4% of error sum of squares due to genotype by location interaction while the regression model only explained 37.7 % of that same error.

Key words: *Triticum turgidum var. 'durum',* environment, GxE interaction, adaptation, regression, AMMI.

INTRODUCTION

The area planted annually with cereals in Morocco is about 5 million hectares. The national production contribute 43% of total consumption (Bartali, 1995). Durum wheat, *Triticum turgidum var. L. durum* is grown on over 1.0 million hectares, 45% of which are in the arid and semi arid region, 11% in high altitude and 44% in more favorable rainfed areas. The average durum wheat consumption is about 90 kg/person/year. Morocco is ranked third in the Mediterranean region and first in the North Africa and Middle East region in term of durum wheat acreage. Arid and semi arid regions (60% of the cropped Moroccan lands) are characterized mainly by drought and poor rainfall distribution within seasons (El Mourid and Karrou, 1996). Due to these reasons, the average yield is low and variable ranging from 0.5 to 1.2 t/ha (Jouve, 1988).

It is necessary, in a Mediterranean type environment which is characterized by highly diversified agro-ecological zones and by climatic unpredictability, to regularly map and assess the adaptation of the available varieties.

The biotic stresses (major diseases and insect pests) and abiotic stresses (climatic and edaphic) are factors that mainly determine the economic profitability of crops production and that are responsible for the interactions between genotype and environments (Finlay and Wilkinson, 1963). These interactions are a source of concern to breeders since they mask the genotypic effects and slow down genetic progress (Fox et al., 1990). The partition of Genotype-Environment (GxE) interactions remains a significant indicator for the specific and broad adaptation of tested genotypes (Amri, 1992). The yield of the specifically adapted varieties can be increased by exploiting the effects of Genotype by Location (GxL) interactions under the assumption that these effects are repeatable in time. This will help

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Table 1. Characteristics of the experiment sites

Site name	Acronym.	Agro-ecological zones	Site characteristics.
Marchouch	MCH	Mid favorable rainfed mid season length	Central region, heat, drought, leaf rust, root rot, tan spot, medium infestation by Hessian fly.
Sidi El Aydi	SEA	Dryland, short season Irrigable	West dryland, supplemental irrigation, Drought, heat, root rot, leaf rust, tan spot, high infestation by Hessian fly.
Jemaa Shaim	JSH	Dryland, very short season	West and southern dryland , extreme drought, heat, leaf rust, extreme infestation Hessian fly.
Khmis Zemamra	KHZ	Irrigated dryland	West and southern dryland , drought, heat, leaf rust, medium infestation by Hessian fly.
Afourer	AFR	Fully irrigated dryland southern. Short season.	Central south, continental Hot season, Leaf rust, tan spot, Low infestation by Hessian fly.
Tassaout	TST	Fully irrigated south. Short season	South central, dryland, heat, leaf stem and stripe rusts, tan spot, lodging, medium infestation by Hessian fly.

determine groups of varieties adapted to specific sites (Gauch and Zobel, 1997; Annicchiarico, 2002b). If it is the case, the localities having similar average yield can be grouped into sub regions or environments of recommendation (also called even area of recommendations (Annicchiarico et al., 2006).

Since its start in the early years of the twentieth century, durum wheat breeding has undergone many stages with changing constraints and results. In the 1920s, the main objective was to increase production thru adaptability, in the 1940s, grain quality was added to the objectives. In the 1970s, the objectives were to increase yield potential and stability; Starting from the 1980s, tolerance and resistance to biotic and abiotic stresses became a priority. The reason for these changes was climate change: drought and Hessian fly atacks became paramount since the mid 1970s. The collaboration with international institutions such as CIMMYT and ICARDA (1970s), helped release high yielding and diseases resistant varieties. Hessian fly (*Mayetiola destructor say.*) is an insect pest that prevails on wheat in areas prone to droughts with mild winters. Losses are heavier if planting is late. Average losses in Morocco were estimated at 36% (Lhaloui et al., 1992). With the droughts that became more frequent since the mid seventies, the new obligatory objectives were to develop drought tolerant and Hessian fly resistant varieties. Six varieties with such qualities were released since the year 2000.

The objectives of this study are:

1) To compare varieties from different breeding eras and assess the yield advantage in different geographical areas.

2) The definition of sub-regions for specific breeding on the basis of observed GxL interaction effects.

3) The comparison of AMMI Vs joint regression methods for describing adaptive responses and GxE interaction effects.

MATERIALS AND METHODS

Yield trials of twenty-three Moroccan durum wheat varieties were planted in six experiment sites ('Sidi-El-Aydi', 'Jemaa-Shaim', 'Khemis-Zemamra', 'Tassaout', 'Deroua', and 'Marchouch') of the 'National Institute of Agricultural Research'. The sites general attributes are shown in Table 1. The trials were planted over a previous fallow using a seeding density of 200 grains/m^2 in dry environments and 300 seed/m^2 in favorable areas and 400 seeds/m^2 in irrigated sites. Supplemental irrigations were brought during critical times in one of the sites (Khémis-Zemamra), whereas in the Tassaout and Deroua stations, irrigation was the prevalent source of water supply. In the remaining sites the production was completely rainfed. The trials were repeated during four consecutive seasons: From 2001 to 2005.

The plant material included nine varieties that were released between 1984 and 1990, eight varieties that were released between 1993 and 1997, and six new varieties that were released after 2003. The last group varieties are characterized by Hessian fly resistance and by drought tolerance. These varieties and their general attributes are shown in Table 2. The variety Karim was derived from CIMMYT's 'Yavaros79'; it was first released in Tunisia, followed by Morocco.

The individual experiment layout was a randomized complete blocks design with three replicates. Individual plots were made out of 6 rows that were five meter long and 1.8 m wide. Inter-row spacing was 30 cm. The area of each individual plot was 9 m^2, and only 6 m^2 (4 lines) were harvested and evaluated.

An analysis of variance was carried out for each test (Each station and each year). The statistical model used within each site is:

Table 2. Varieties studied and their main characteristics.

Cultivar	Registration date	Adaptation zone	Hessian fly resistance	Mean yield (kg/ha)
Old varieties				
Marzak	1984	Large, High yield potential	S	2.837
Karim	1985	Large, Irrigated, High yield potential	S	3.079
Sebou	1987	Semi arid + favorable	S	3.193
O.Rabia	1988	Semi arid	S	3.335
Sarif	1988	Large	S	3.344
Massa	1988	Large, rainfed	S	3.068
RGL 0095	1988	Large	S	3.048
RGN 0027	1988	Large	S	2.926
Isly	1988	Large	S	3.237
Mean yield				**3.119**
Medium era varieties				
Jawhar	1993	Large, Irrigated	S	2.873
Anouar	1993	Large	S	3.032
Yasmine	1993	Large	S	3.096
Amjad	1995	Large	S	3.442
Tarek	1995	Large	S	3.083
Ouregh	1995	Large	S	3.253
Marjana	1996	Large	S	3.030
Tomouh	1997	Large, North,	S	2.904
Mean yield				**3.089**
New varieties				
Irden	2003	Semi arid, drought tolerant	R	3.532
Nassira	2003	Semi arid, drought tolerant	R	3.330
Chaoui	2003	Semi arid, drought tolerant	R	3.546
Amria	2003	Semi arid, drought tolerant	R	3.351
1806 (Telset)	2003	Semi arid, drought tolerant	T	2.630
Marouane	2003	Semi arid, drought tolerant	R	3.236
Mean yield				**3.271**

Yield = Variety + Block + Error

An analysis of the combined variance was then carried out for all the tests, the statistical model used is:

Yield = Variety + Location + Year + Block (Location) + (Variety × Location) + (Variety × Year) + (Variety × Location × Year) + Error

In this model, the genotype and the location factors are fixed while years and blocks are random. Genotypes × Location interactions are modelled by the joint regression (Finlay and Wilkinson, 1963) and by the AMMI (Gauch, 1992) methods. GxL Interaction is broken down in a following step by using the model of joint regression and the AMMI analysis. The IRRISTAT Software (International Rice Research Institute, IRRI, Manila) was used for the analysis of the variance and in modelling the results by joint regression, AMMI.

RESULTS

The analyses of variance in individual experiments showed that the differences between the genotypes are significant in all stations and in every year except for two individual trials: Khémis Zemamra in 2004/2005 season (p=0.15) and Marchouch in 2004/2005 season (p=0.32). However, the statistical non significance of the variety factor does not prohibit from using these data for a pooled analysis. The first trial is to be accepted since p=0.15 and the results of the second experiment should are to be accepted since the coefficient of variation was less than 20 (that is, 19.91) (Annicchiarico, 2002). The combined analysis of variance was therefore carried out.

The data was tested for a need for data transformation. The coefficient of regression between the logarithm of the stations average (Log m) and the logarithm of the variance (Log Var) is of 0.197 (≈ 0), which means that it is not required to compute any transformation of these data (Dagnelie, 1975).

The combined analysis of variance (balanced analysis

Table 3. Results of the ANOVA and of the variance components estimation by regression and AMMI of grain yield.

Source of variation	DF	SS	MS	F	Prob.		(%) SS
Genotype(G)	22	84.52	3.84	3.46	0.000	***	-
Location (L)	5	3 273.26	654.65	8.39	0.001	***	-
Year (Y)	3	135.55	45.18	128.92	0.000	***	-
G x L	110	133.07	1.21	1.71	0.000	***	-
+ Joint Regr.	22	50.17	2.28	2.42	0.002	***	**37.70**
Dev. of Reg.	88	82.89	0.94	1.33	NS	**NS**	-
+ AMMI (IPCA1)	26	80.42	3.09	4.94	0.000	***	**60.44**
Residual	84	52.64	0.89	0.15	NS	**NS**	
G x Y	66	73.23	1.11	3.17	0.000	***	-
L x Y	15	1 170.03	78.00	222.56	0.000	***	-
G x L x Y	330	233.29	0.71	2.02	0.000	***	-
Residual	1 056	370.10	0.35				-

DF: Degree of freedom, SC: Sum of square, MS: Mean square; F: Fisher test; Prob: % of significance; (%) SS: Percentage of explanation of GXL by the method; (%) VSSS/VSDL: Average square of the component compared to the GXL; Sc2: Estimated variance of the character.

with 6 locations and 4 seasons), reveals highly significant effects of genotype, location, season and their interactions : GxL, GxY, LxY and GxLxY (Table 3). The single factors that were responsible for the highest mean squared errors (MS) were ranked as follows: 1) Location, (with MS = 654.65), 2) Year, (with MS= 45.18) and, 3) Genotype, (with MS= 3.84). The interactions between any two factors were ranked as follows: 1) Location x Year, (with MS= 78.00), 2) Genotype x Location, (with MS= 1.21), and 3) Genotype x Year (with MS= 1.11).

The GxL interaction was broken down in the following step. In order to integrate the result of the joint regression and the AMMI in the ANOVA table, the sum of square variations obtained by the joint regression and the AMMI methods was multiplied by a coefficient of 12. This coefficient value is obtained by multiplying the number of year and the number of replication in the trials (that is, 4×3). The results in Table 3 show that the sum of squared errors (SS) due to regression could explain 37.7% of the SS attributed to GxL interaction. The AMMI method showed that the principal components (PCA1) is highly significant, and explained 60.44% of GxL interaction sum of squares. The other PCAs and the residuals are not significant (Fr = 0.89 < 1.2).

By modeling the above shown AMMI-1 results, the effects of the experiment sites were removed, and the nominal yields of the genotypes were calculated according to the scores of the first principal component (Figure 1). The stations are presented on the x-axis according to their scores on the principal component of AMMI-1, and the nominal yield are represented on the y axis.

The grouping of the experiment sites is shown in Figure 1 (x-axis); The 'Marchouch' and 'Afourer' experiment stations form a first group; the 'Jmaat Shaim', 'Sidi El Aidi', 'Khmis Zemamra' and 'Tassaout' stations form a second group. The same chart (Figure 1) shows the existence of different types of varieties: a) the varieties adapted to the arid conditions (negative slope), b) the varieties adapted to the favourable conditions (positive slope) and, c) the remaining stable varieties but with average and stable yields (slope ≈ 0). This classification corresponds to the recommendations that accompanied the release of these varieties.

All the estimated parameters relevant to the quality of the methods and models used are in favor of the AMMI method (Table 3). The joint regression could explain only 37.7% of GXL interaction SS, whereas the first axis of the AMMI could explain 60.44% of the same interaction.

DISCUSSION

This study showed significant main effects (G, L, Y) and significant interactions between all main effects. The analysis of variance also showed that while 'Location' factor and 'Year of testing' factor are respectively the first and second most important sources of variance in yield in Morocco, their interactions are as important as, or even more important than the effect of 'Year of testing' which is a single factor. This shows the predominant importance of the environmental factors (L and Y) in determining durum yield in Morocco. Since 'Genotype', as a single factor, was the third most important in yield determination, and since 'Genotype by Location' and 'Genotype by Year', as interactions, were significant factors affecting yield, it is fair to conclude that the genotypes used in this study have demonstrated a significant additive effect and were, in the same time, a factor of yield stability by properly responding to the large effect of the environmental factors.

The AMMI analysis enabled us to group the location in

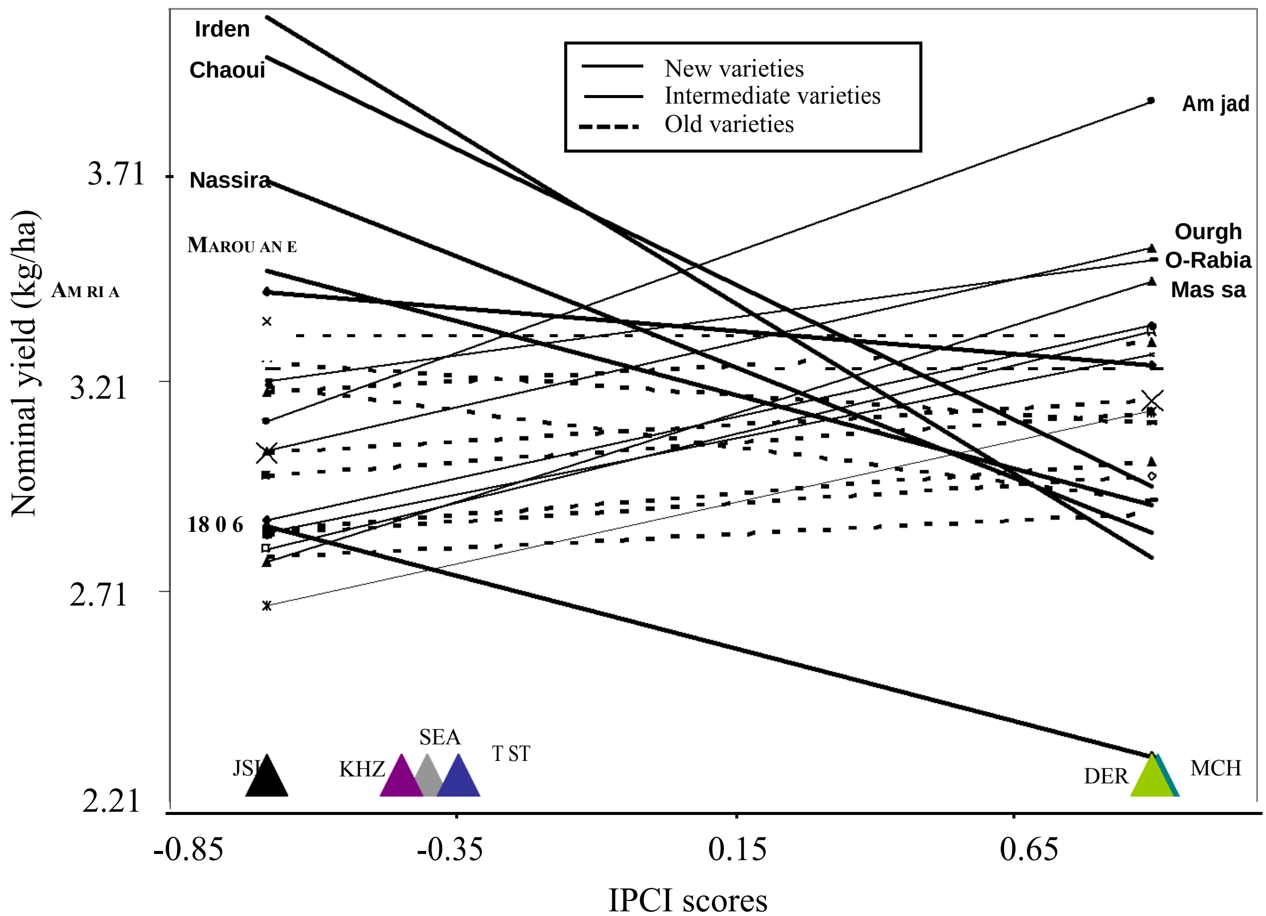

Figure 1. Regression of the varieties' nominal performances according to scores of Ammi-1. JSH: Station of Jmaat Shaim; KHZ: Khmis Zemamra; SEA: Sidi El Aidi; TST: Tassaout; DER: Deroua; MCH: Marchouch

two distinct sub-regions. One of these sub-regions comprised the sites: 'Deroua', and 'Marchouch' whereas the other sub-region comprised environments represented by the sites: 'Tassaout', 'Jemaat –Shaim', 'Khemis – Zemamra', and 'Sidi - El – Aydi'. Some discussion as to why this grouping is obtained may be necessary. 'Marchouch' site is in the favorable rainfed areas, with precipitations higher than 500 mm/year and has cold winters, whereas 'Afourer' Location is in the fully irrigated semi arid with heavy clay soil. 'Afourer' Location has cold winters and provides for longer growth season because it is tempered by its proximity to the mountains and its lower atmospheric demand on water. These two locations were grouped together because they both provide conditions favorable to a longer growth season. 'Tassaout' location is in the fully irrigated zone where the air is dry and where light intensity is important. Similarly, 'Khmis Zemamra' location is in the semi arid zone and receives supplemental irrigation. 'Sidi El Aydi' location is in the semi arid zone and 'Jmaat Shaim' site is in arid rainfed. The presence of strong sunlight and temperatures, the high evapo-transpiration intensity are probably important in this classification. All the southern stations of the second group, have winters with mild temperatures and higher evapo-transpiration demand. These conditions also explain why Hessian fly resistant varieties were superior in these experiment sites.

On the overall, the data from this study show that environmental differences between the two groups of locations could, regardless of the precipitations or irrigation, be summarized in the following:

1) The length of the growth season and

2) The biotic/abiotic stresses that are associated with the warmer and shorter season (Figure 2).

The data showed that the varieties used in this study belonged to three types (Figure 1), the varieties of the first type (negative slope) relate to the varieties released after 2003, for the arid and the semi arid zones, they are tolerant to drought and resistant to Hessian fly ('Irden', 'Chaoui', 'Nassira', 'Marouane', 'Amria' and '1806'). The varieties of the second type (flat slope) relate to the old varieties that are adapted to several environments ('Marzak', 'Karim', 'Sebou', 'O.Rabia', 'Sarif', 'Massa', 'RGL-0095', 'RGN-0027'and 'Isly'). The varieties of the

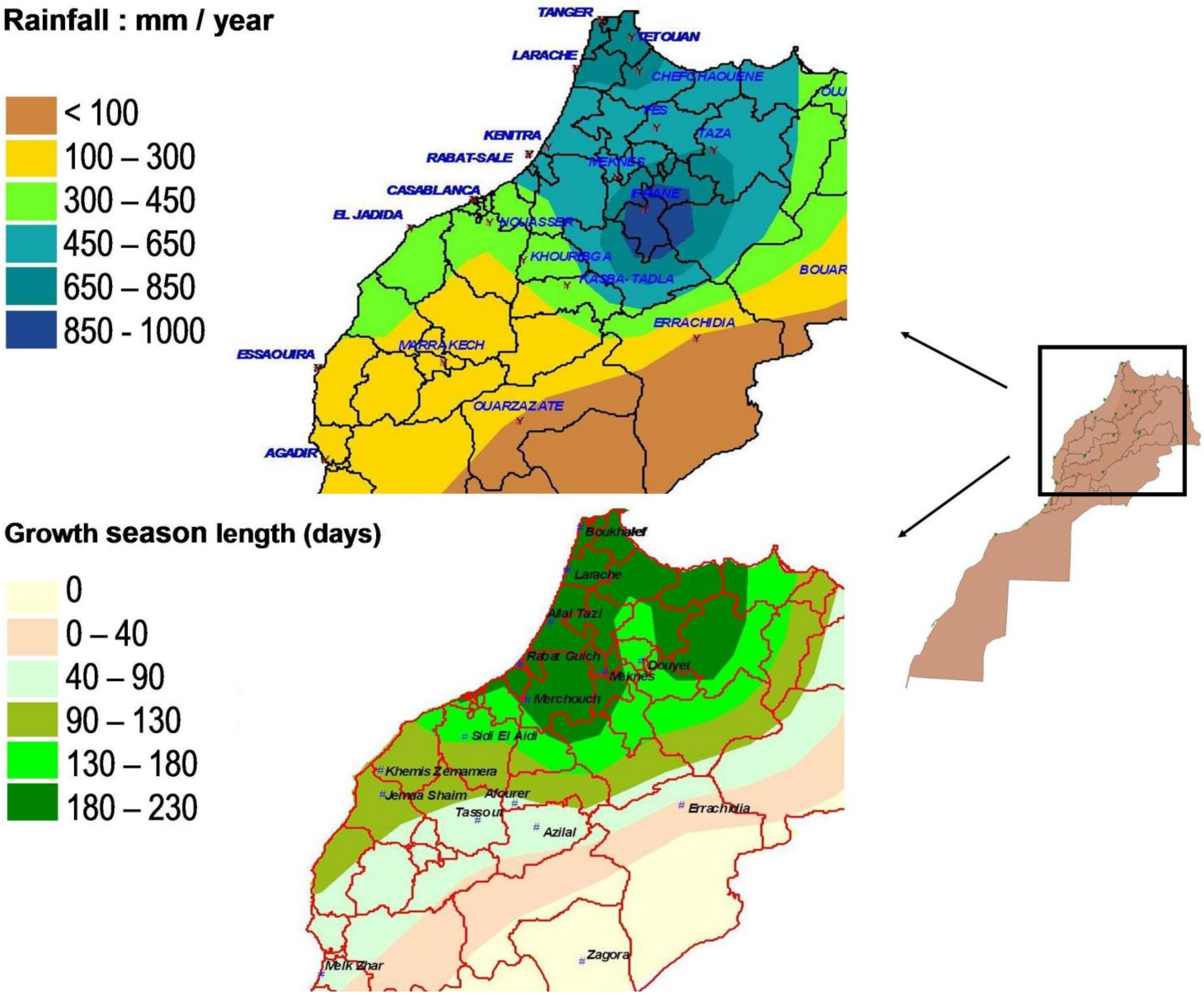

Figure 2. Map of agroecological zones and grouth season length in Morocco.

third type (positive slope) relate to the varieties released for the favorable rainfed areas ('Jawhar', 'Anouar', 'Yasmine', 'Amjad', 'Tarek', 'Ourgh', 'Marjana' and 'Tomouh').

According to this, the varieties: 'Irden', 'Chaoui' 'Nassira', 'Marouane', 'Amria' and '1806', are to be recommended for the semi arid sub-region (represented by the experiment sites; 'Sidi-El-Aidi', 'Jmaat-Shaim' 'Khemis-Zemamra', and 'Tassaout'), whereas the varieties Amjad, Massa, Karim and Ourgh should be recommended for the more favorable second sub-region (northern areas, and irrigated zones represented by the sites 'Afourer' and 'Marchouch'). The remaining varieties should be recommended within the limits of the broad adaptation while noting that they have an average yield potential.

In this study, the joint regression could explain only 37.7% of the SS of interaction GXL, while the first principal component identified by the AMMI method (IPCA) could explain 60.49% of the same SS. The superiority of the AMMI method was therefore shown similarly to work reported by other authors (Annicchiarico et al., 2002b; Zobel et al., 1988; Nachit et al., 1992a; Annicchiarico, 1997a).

Conclusion

This study showed that:

1) The environmental factors (Location and Year) are the most important factors determining yield variability of

durum wheat in Morocco; further, the interactions of these environmental factors with the genotype factor are very important. The genotype effect was significant and was an efficient factor in exploiting environmental variabililty.

2) Two large adaptation zones are identified; they are respectively represented by 2 and 4 experiment sites. This sub-zoning seems to be governed by: 1) the characteristics linked the length of the growth season and

3) the biotic/abiotic stresses that are associated with the warmer and shorter season (Hessian fly infestations, temperatures, droughts or higher evapotranspiration demand).

4) The Moroccan varieties showed differences in adaptation. The varieties released after the year 2003 are adapted to the semi arid zones, and this is especially due to their resistance to Hessian fly and their tolerance to water stress. The varieties from the medium breeding era are widely adapted and possess a better ability to exploit favorable environments. The oldest varieties are widely adapted but they do not possess high yield potential in the more favorable environments.

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