

Assessing Wheat Management Options in the Tiaret Region of Algeria with the DSSAT Model

*Wafa Rezzoug, Benoit Gabrielle **

ABSTRACT

Crop simulation models are important research tools to design cropping systems and aid in agricultural decision making. In environments with severe water limitations, this is especially useful since strategies to mitigate the adverse effects of drought on crop yields involve a range of management practices with potential interactions among them. The use of a crop model makes it possible to explore many combinations and to identify the best options, avoiding the need for costly field experiments.

In Algeria, water availability is the prime factor limiting wheat yields, and is expected to worsen in the near future due to climate change. Here, we used the CERES-Wheat model (within the DSSAT package) to explore various management strategies for wheat production in the Tiaret region of north-western Algeria. The model was previously tested against grain yield data from a 3-yr field trial. Simulations were run using 20 years of historical weather data to establish probabilities for different combinations of management factors involving variables planting densities, fertiliser nitrogen rates, sowing dates and cultivars. The interannual variability of climate (and essentially seasonal rainfall) accounted for 95% of the overall variance of simulated yields. Regarding crop management, sowing date was the most influential agronomic factor, followed by cultivar and fertiliser N rate. There was little response of wheat yields to N inputs above 60 kg N ha⁻¹, and no significant effect of plant density. As a consequence, under the current climate, the optimal management involved sowing during the last week of December, a plant density of 300 plants m⁻², a 60 kg N ha⁻¹ fertilizer rate and the use of the cultivar Vitron. Thus, the simulation model appeared capable of differentiating between a range of management options and identifying the best combination to optimize wheat yield under high weather variability. It will be used in a near future to seek strategies to mitigate the impact of projected future climate changes in Algeria.

Keywords: Wheat, Algeria, DSSAT, Crop Model, Yield simulation, Crop Management.

1. INTRODUCTION

Crop growth models have considerable potential in agricultural research, in the development of cropping technologies, and in the exploration of management and policy decisions (Boote et al., 1996). Management decisions regarding cultural practices have a major impact on yields, however their direct effect is strongly constrained by soil and climate variability. Crop

simulation models explicitly take these factors into account, and allow the specification of management options. Thus, they offer a relatively inexpensive means of evaluating a large number of strategies, which would rapidly become too costly if the traditional experimentation approach was used. For instance, crop simulation models have been used in developed countries to support investment and management decisions aimed at increasing farm productivity (Paz et al., 1999). In environments with severe water limitations, such applications are especially useful since the outcome of management strategies are strongly influenced by interannual climate variability, essentially seasonal rainfall amounts (Pecetti and Hollington, 1997). Also,

* Department of agricultural and biological sciences, Ibn Khaldoun University, Tiaret, Algeria; and AgroParisTech, INRA, UMR1091 Environment and Arable Crops, Thiverval-Grignon, France. Received on 21/1/2009 and Accepted for Publication on 4/8/2009.

strategies to mitigate the adverse effects of drought on crop yields involve a range of management practices with potential interactions among them (Ghaffari et al., 2001). The use of a crop model makes it possible to explore many combinations and to identify the best options (Heng et al., 2007).

Durum wheat (*Triticum durum* L.) production in Algeria offers a challenging case for such test of crop models. Water availability is the prime factor limiting grain yields, and in recent years, the inter-annual fluctuations of climate have been characterized by a higher frequency of drought episodes, enhancing the vulnerability of crop yields to water availability. This shift is expected to increase in the near future due to climate change (Alexandrov and Hoogenboom, 2001). Adaptation to this trend requires a capacity to investigate the relationships between crop management practices (such as cultivar selection and planting date), and the environmental factors (essentially soil properties and weather conditions), whose interplay ultimately determine final crop yields. In a previous piece of work (Rezzoug et al., 2008) we tested the ability of the DSSAT package to predict wheat yields in the Tiaret region of Algeria, a major wheat-growing zone. Here, we set out to explore a range of management options to optimize wheat management in the same region. Studies with similar purposes have already been carried out in neighboring countries in the Mediterranean (Pecetti and Hollington, 1997; Rinaldi, 2004; Heng et al., 2007; Ouda et al., 2005). However, since none of these regions reflect the actual pedoclimatic or agronomic conditions of Algeria, their results could not be readily transferred to the Tiaret area. There was also scope for demonstrating the usefulness of crop models for providing decision-support for agriculture in Algeria, which has not been done yet to the best of our knowledge.

The DSSAT package (for Decision Support System for Agrotechnology Transfer) version v4.0 is a comprehensive modeling system (Tsuji et al., 1994; Hoogenboom et al., 2004) that includes CERES-Wheat. The CERES models were designed to simulate the effects of cultivar, planting density, weather, soil water and nitrogen on crop growth, development and yield, in relation to their environment (Jones and Kiniry, 1986; Ritchie and Otter, 1985). Among the wealth of soil-crop models currently available (see e.g. Jamieson et al. (1998) for wheat), we selected DSSAT because it was successfully used under various climates and

management strategies worldwide, and for a variety of purposes: as an aid to crop management (Hunkár, 1994; Ruiz-Nogueira et al., 2001; Sarkar and Kar 2006), in fertilizer N management (Gabrielle and Kengni, 1996; Gabrielle et al., 1998; Zalud et al., 2001; Landau et al., 1998; Saarikko, 2000), and environmental assessment (Hoffmann and Ritchie, 1993). In particular, Pecetti and Hollington (1997) indicated that CERES-Wheat was applicable with sufficient reliability under Mediterranean conditions. Other authors pointed it as a realistic approach to the study of genotype and environment interactions over the entire life of the crop (Jagtap et al., 1999; Ghaffari et al., 2001).

The objective of the present study was to assess the effect of a range of crop management practices and their interactions for wheat growing in the Tiaret area, and to identify optimal combinations. The DSSAT model was run for various sowing dates and densities, fertiliser N rates and cultivars on a 20-year series of historical weather data. The outputs were analysed in the form of cumulative probability distributions and analysis of variance.

2. MATERIALS AND METHODS

2.1. Brief Description of the DSSAT Model

The Decision Support System for Agrotechnology Transfer (DSSAT) was initially developed by an international team of scientists cooperating in the International Benchmark Sites Network for Agrotechnology Transfer project (IBSNAT, 1993; Tsuji, 1998; Uehara, 1998; Jones et al., 1998) to facilitate the application of crop models in a systems approach for agronomic research. We used the latest release of this package (DSSAT v4), which includes more than 18 different crops under the Cropping System Model (CSM), a modular modelling approach. CSM uses one set of code for simulating soil water, nitrogen and carbon dynamics, while crop growth and development are simulated with the CERES, CROPGRO, CROPSIM and SUBSTOR modules (Hoogenboom et al., 2003). The model simulates daily growth and development for a wide range climate and agronomic practices.

The input data required by DSSAT include weather records, soil properties, plant characteristics, and crop management. Climatic inputs include daily solar radiation (MJ m^{-2}), maximum and minimum air temperature at 2 m ($^{\circ}\text{C}$), and precipitation (mm). Management input includes

planting date, density and depth, row spacing, and timing and rates of irrigation and fertiliser N applications. Soil inputs include soil albedo, evaporation limit, pH, phosphorus, potassium, drainage and runoff coefficients. The model also requires water holding characteristics, saturated hydraulic conductivity, bulk density and organic carbon for each individual soil layer. Cultivar characteristics are entered as genetic coefficients related to vernalization needs, photoperiod sensitivity, grain filling duration, phyllochron interval, and yield components (spike number, kernel number, and kernel filling rate).

2.2 Simulation Experiments

Simulation experiments were conducted with the DSSAT-wheat model to investigate the effect of management practices (plant density, nitrogen rate, sowing date, and cultivar) on wheat yields. The model was run on a 20-year series of daily historical weather recorded at Tiaret (35°22' N; 1°22' E), a major wheat production area in northwestern Algeria.

The climate of Tiaret is considered typically Mediterranean and semi-arid with wet winter and dry summer but the rainfall distribution is irregular during the year. The mean air temperatures of the hottest month vary from 22 to 26 °C, while those of the coldest month range between 5 and 10°C. The total annual precipitation varies from 169 mm to 445 mm.

The weather data included maximum and minimum air temperature (°C), rainfall (mm), and solar radiation (MJ.m⁻²). The latter was estimated using daily sunshine hours using the Angstrom formula. Twenty years of suitable weather data (1986-2005) were used for the simulation. The soil tested at Tiaret was a sandy clay loam (USDA, 1972), representative of the soils cropped to wheat in the area. The model runs started in July prior to sowing on day of year (DOY) 288, assuming soils were relatively dry (ie soil moisture content at wilting point), and that the soil profile contained a residual inorganic N stock of 30 kg N ha⁻¹ (Rezzoug et al., 2008).

The DSSAT-wheat model was run on all combinations of the above-mentioned managements practices, which were ascribed three levels each (ie a minimum, median and maximum value). Such discretization of variation ranges is often sufficient to assess the effects of management strategies and their interactions (Ghaffari et al., 2001). Plant density was thus set at 200, 300, or 400 plants m⁻² according to

current practices in the region. Three fertiliser N rates were tested: 0, 60, and 180 kg N ha⁻¹. Winter wheat may be sown from early October to end of December in Algeria, but performs best if sown between the last 2 months. The first sowing date was therefore set at DOY 305 (1 Nov.), the second at DOY 330 (26 Nov.), and the third at DOY 354 (20 Dec.).

We selected two wheat cultivars (Vitron and Semito), which are the most commonly grown genotypes in the area, and present contrasted phenological characteristics (Table 1). Their genetic coefficients were obtained from a previous calibration and testing study involving nine cultivars and three growing seasons, from 2000 to 2003 (Rezzoug et al., 2008). DSSAT was tested against data from field experiments located in an experimental farm center at Tiaret. In the independent model evaluation phase, DSSAT achieved a root mean squared error of 0.79 t DM ha⁻¹ for grain yield.

2.3 Statistical Analysis

The simulation results were presented as cumulative probability distribution (CPD) for grain yields, across the 20 growing seasons. Analysis of variance (ANOVA) was performed using the Statgraphics Plus package (Version 5.0, Statistical Graphics Crop.) to evaluate the significance of each treatment on yield (one factor), and the overall ranking of the agronomic factors and growing season. Contrast statements were used to compare treatment means and sets of treatment means when the ANOVA indicated treatment effects.

Treatment means were separated by the least significance difference (LSD).

3. RESULTS

3.1 Management scenarios

1. Plant Density

Simulations were run for 20 growing seasons to illustrate the effect of the plant density and variety technology strategies on wheat grain yields, in the form of cumulative probability distribution (CPD), as depicted on Fig.(1). To interpret the CPDs of two or more technologies, Uehara and Tsuji (1991) indicated that the CPD of the dominant strategy is the one that lies entirely to the right of the dominated strategy.

Fig. (1) compares the CPD of the DSSAT simulated grain yields between the three plant densities selected, and for the two cultivars (Vitron and Semito). Between 0

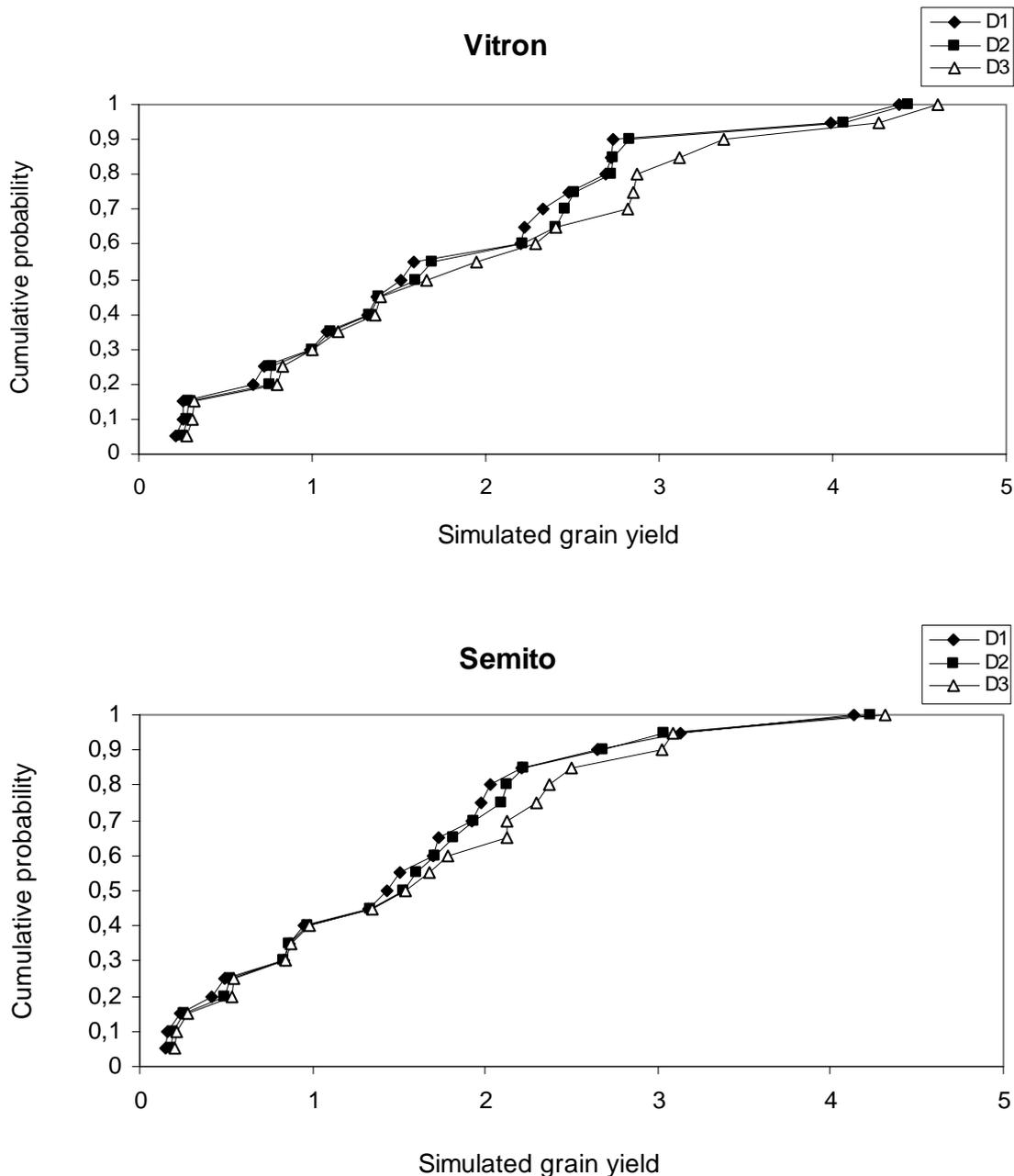


Fig. 1. Cumulative probability distribution of simulated wheat yield in response to three plants densities: 200 (D1), 300 (D2) and 400 (D3) plants m⁻², respectively.

and 50% of cumulative yield probabilities, there was virtually no effect of plant densities, and the three curves merged. In the upper range of probabilities, the lower density (200 plants m⁻²) started differentiating from the other two densities (300 and 400 plants m⁻²), with a relative yield gap as large as 10%. This gap closed again for the two years with the highest yield values, at the top end of the probability curves. Regardless of plant density effects, simulated yields varied across a wide range, from 0.15 to 4.6 t DM ha⁻¹, evidencing a strong influence of

inter-annual climate variability. Yield distributions were also affected by cultivar type, but only in the upper range of yields. There was for both cultivars a 30% probability that yields did not exceed 1 t DM ha⁻¹, but there was a 30% probability that yields of 2.8 t DM ha⁻¹ could be obtained with cultivar Vitron, and of only 10% for cultivar Semito. Lastly, the maximum yield achievable with both cultivars was similar.

As could be expected, the highest yields were always obtained with the higher density of 400 plants m⁻² (Fig.

2), for both cultivars, but by a narrow margin and with considerable inter-annual variations. A single-factor ANOVA between plant density and yield showed no significant differences between the three densities ($P>0.01$), implying that there is scope for choosing the planting density 300 plants m^{-2} to save seeds without

reducing yields. Although the model did not predict any notable yield differences with the lowest density (200 plants m^{-2}), the latter should not be recommended since it is likely to lead to insufficient tillering and heading, as observed in the region of Tiaret.

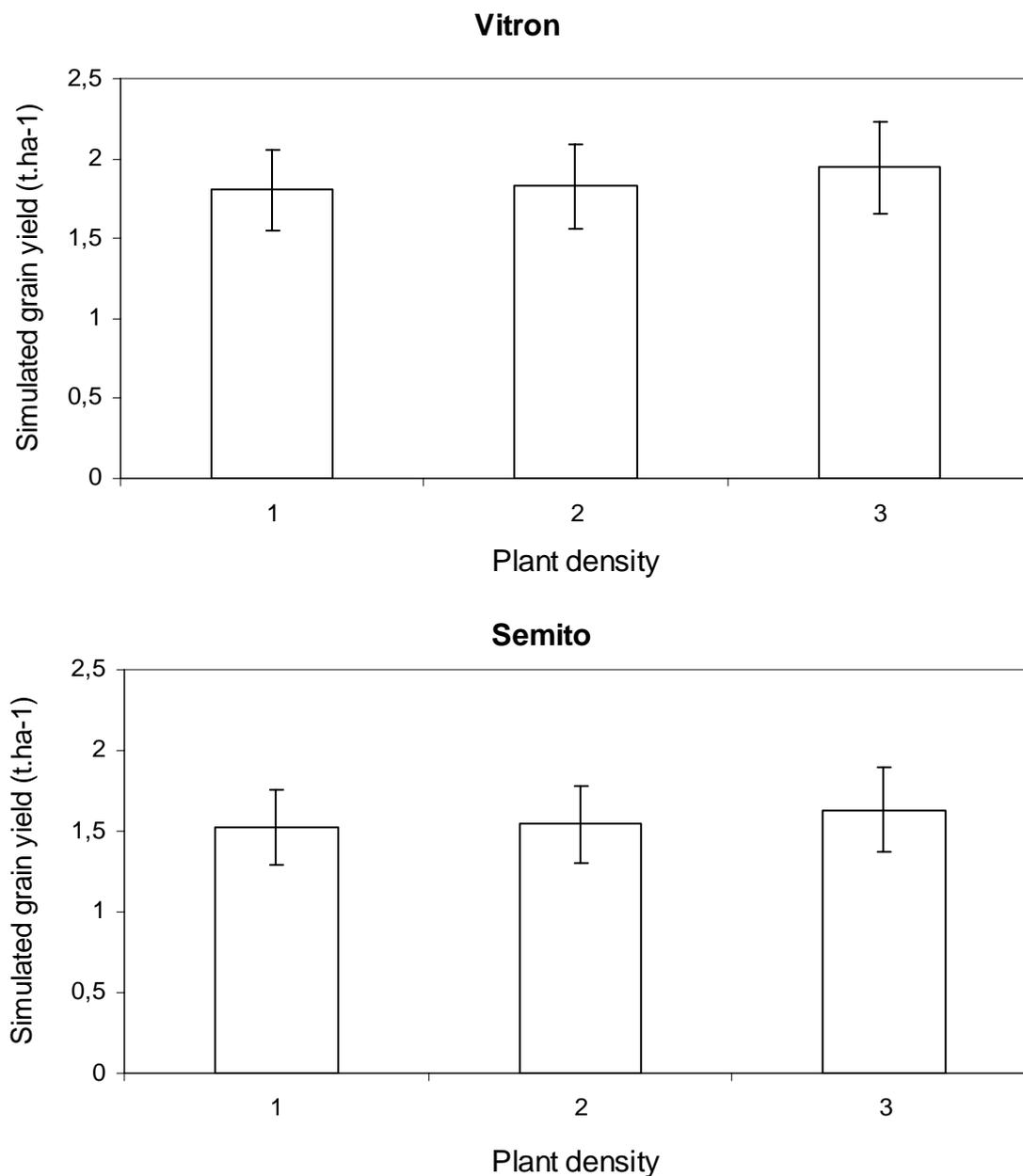


Fig. 2. predicted grain yields (t ha⁻¹) with three plants densities (200, 300, and 400 plants m²) from the farm ITGC at Tiaret (1986-2005). Bars indicate bars one standard error of the mean.

A similar recommendation was obtained by Ghaffari et al. (2001), after screening a wide range of plant

population scenarios (from 200 to 450 seeds m^{-2}) to establish a suitable seed density in the north of Kent

(UK). No significant differences were evidenced between densities of 450 and 300 seeds m^{-2} , the optimal value. In the rainfed environments of West Asia and North Africa (in Morocco and Jordan), Heng et al.(2007) showed that wheat yields were little affected when reducing sowing density from 300 to 150 plants m^{-2} , using the APSIM-

Nwheat model. In northern Syria, Stapper and Harris (1989) compared a standard plant density of 200 plants m^{-2} with a lower density of 50 plants m^{-2} with wheat a simulation model, and recommended the higher density to improve grain yields.

Table 1. Genetic coefficients of the two wheat cultivars (Vitron and Semito) used in the DSSAT simulation model (Rezzoug et al., 2008)

Cultivar	Coefficients						
	P1V	P1D	P5	G1	G2	G3	PHINT
Vitron	60	55	221	21	46	2.99	95
Semito	58	43	320	19	37	2.99	95

P1V : Days at optimum vernalising temperature required to complete vernalisation.

P1D : Percentage reduction in development rate in a photoperiod 10 hour shorter than the optimum relative to that at the optimum

P5 : Grain filling (excluding lag) period duration (GDD₀)

G1 : Kernel number per unit canopy weight at anthesis (g^{-1}).

G2 : Standard kernel size under optimum conditions (mg).

G3: Standard, non-stressed dry weight (total,including grain) of a single tiller at maturity (g).

PHINT : Phyllochron interval (GDD₀).

Table 2. Means of simulated yield (t DM ha⁻¹) of two durum wheat cultivars (Vitron and Semito) for three nitrogen fertilizer levels; in parentheses are the lowest and highest simulated values

	0 kg N ha ⁻¹	60 kg N ha ⁻¹	180 kg N ha ⁻¹
Vitron	1.68 (0.20- 3.26)	1.87 (0.24- 4.45)	1.90 (0.25- 4.72)
Semito	1.53 (0.13- 3.07)	1.70 (0.13- 41.2)	1.72 (0.13- 4.62)

Table 3. Means of simulated grain yield (kg ha⁻¹) of two wheat cultivars (Vitron and Semito) for three sowing dates; in parentheses are the lowest and highest simulated values

Cultivars	1 Nov (DOY 305)	26 NOV (DOY 330)	20 Dec (DOY 360)
Vitron	1943 (197- 4602)	2039 (246- 4611)	2270 (250- 5756)
Semito	1631 (110- 4277)	1806 (117- 4315)	2000 (152- 4620)

Table 4. Analysis of Variance of simulated wheat yields as a function of management factors and climatic year (20 years of weather data).

Source	Sum of Squares	Df ¹	P-Value
Model	1.05 10 ⁹	33	0.0000
Residual	5.52 10 ⁸	1046	
Total	1.60 10 ⁹	1079	

Df¹ : degrees of freedom

Table 5. Multi-factor analysis of variance results

Factors	Sum of Squares	Df ¹	P-Value
Sowing date	4.11 10 ⁶	2	0.0207
Cultivar	0.10 10 ⁶	1	0.6545
Plant Density	2.09 10 ⁶	2	0.1379
Fertilizer N rate	8.81 10 ⁶	2	0.0003
Rainfall	9.69 10 ⁸	1	0.0000
Sowing*Cultivar	0.33 10 ⁶	2	0.7311
Sowing*Density	0.13 10 ⁶	4	0.9929
Sowing*Fertilizer N rate	1.22 10 ⁶	4	0.6766
Sowing*Rainfall	9.56 10 ⁶	2	0.0001
Cultivar*Density	0.03 10 ⁶	2	0.9688
Cultivar*Fertilizer N rate	0.21 10 ⁶	2	0.8539
Cultivar*Rainfall	0.47 10 ⁶	1	0.3451
Density*Fertilizer N rate	0.08 10 ⁶	4	0.9974
Density*Rainfall	3.83 10 ⁶	2	0.0269
Fertilizer N rate*Rainfall	1.55 10 ⁷	2	0.0000
Residual	5.52 10 ⁸	1046	
Total (corrected)	1.60 10 ⁹	1079	

Df¹ : degrees of freedom.

2. Nitrogen Rates

Simulations were run for 20 growing seasons, 2 cultivars (Vitron and Semito), and 3 nitrogen fertilizer levels (0, 60 and 180 kg N. ha⁻¹), to establish suitable rates for Tiaret.

The simulation results as indicated in Table (2) show a similar response to fertilizer N for both cultivars. The highest simulated yields were always obtained for the 180 kg N.ha⁻¹ rate and the lowest yields for the 0 kg N ha⁻¹rate (Fig.3), but the relative difference between the two extremes was rather small (less than 15%). A single-factor ANOVA between nitrogen rates and yield revealed significant differences only between the 0 and 60 kg N ha⁻¹rates (p=0.01). The intermediate rate should thus be recommended, a figure close to actual practice.

In a similar analysis in southern Italy with the CERES-Wheat model, Rinaldi (2004) reported an optimum application rate of 100 ± 20 kg N ha⁻¹ for durum wheat.

Long-term simulations of both RZWQM and CERES for winter wheat growth using historical weather data showed that a fertilizer broadcast rate of 56 kg ha⁻¹ N was a viable option in eastern Colorado (Saseendran et al., 2004), where the seasonal rainfall during crop growth is similar to that of Tiaret.

3. Sowing Date

Simulations were run for three sowing dates: DOY 305 (1 Nov.), DOY 330 (26 Nov.) and DOY 360 (20 Dec.) over the 20-yr period (1986-2005) to illustrate the effect of the planting dates and variety technology strategies. The highest simulated yields were obtained for the late sowing (DOY 360) and the lowest simulated yields for the early sowing (DOY 305), for both cultivars (Fig. 3 and Table 4). A single-factor ANOVA between dates and yield showed significant differences ($P<0.01$) between the three sowing dates. This pattern may be explained by two reasons. With the early sowing (1 November), the growth of wheat seedling was affected by relatively high air temperatures, resulting in lower yield potentials. Conversely, late sowing in December preserved soil moisture and reduced drought stress in the final growth stages.

The literature on the effect of sowing date for wheat under Mediterranean or semi-arid environments is generally in agreement with our findings. The simulation analysis by Ouda et al.(2005), using CERES-Wheat (within DSSAT v3.0) in Egypt indicated that the highest grain yields were as obtained when wheat was sown in early December compared to earlier dates. Under rainfed

environments in western Asia, Morocco and Jordan, Heng et al. (2007) indicated that there was no advantage

in sowing earlier than November with the APSIM-Nwheat model.

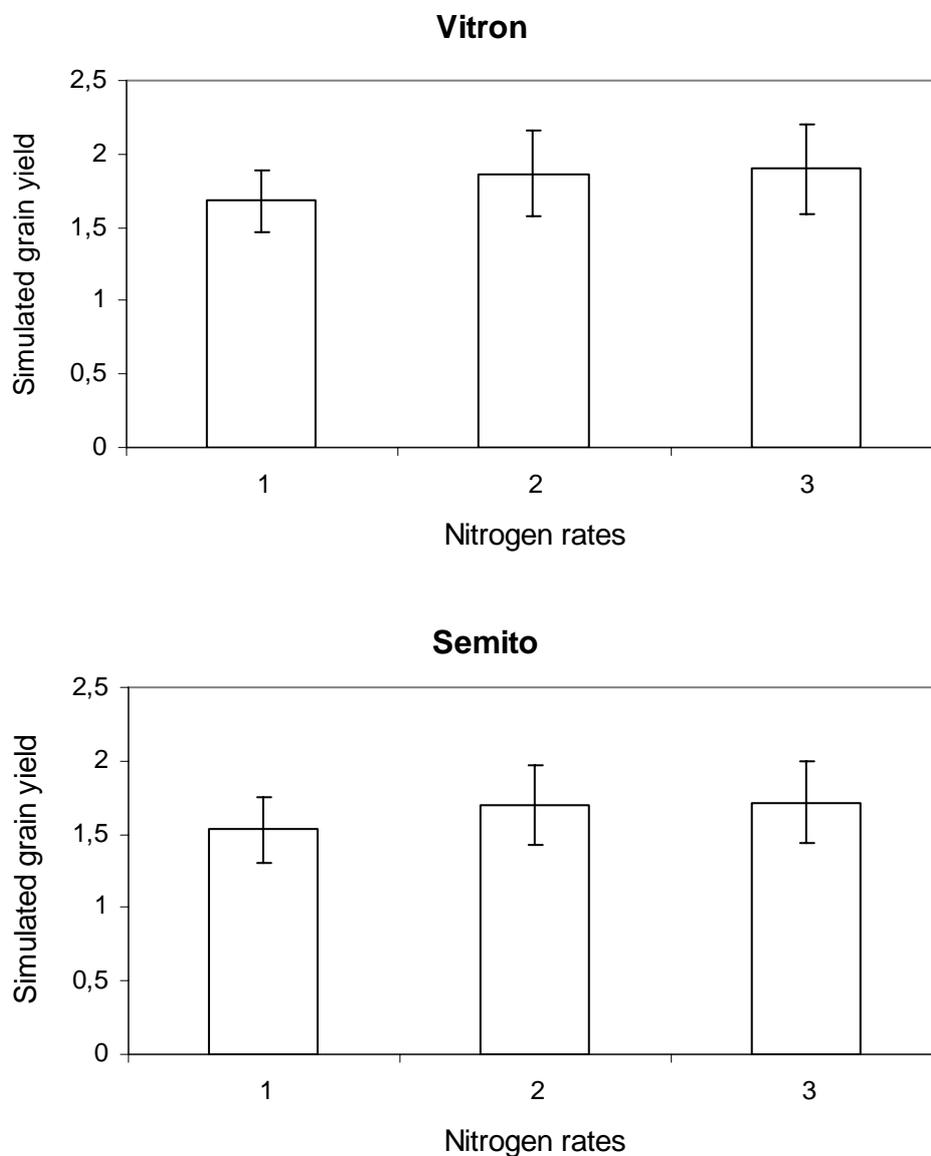


Fig. 3. Predicted winter wheat grain yields (t DM ha⁻¹, \pm 1 s.e. of mean) with three nitrogen application rates (0, 60, and 180 kg N ha⁻¹) at Tiaret (1986-2005).

However, some references point to opposite trends. Stapper and Harris (1989) estimated that wheat grain yield declined by 4.2% every week when sowing was delayed after the beginning of November in Syria, using a simulation model. Similarly, Pecetti and Hollington (1997), applied CERES-Wheat to simulate the growth and yield of durum wheat in two diverse Mediterranean environments (northern Syria and eastern Sicily), and found yields to be highest with early sowing (1 November) and lowest with late sowing (20 December).

This contradiction with our results may be explained by a different pattern of rainfall distribution throughout the growing season in the latter cases, compared to Tiaret. In the Syria location, Pecetti and Hollington (1997) for instance, 85% of the seasonal rainfall occurred by the end of December, while in the Sicilian location the total rainfall was unusually high, and about double the Tiaret average. This underlines the marked regional and inter-annual variations in rainfall patterns across the Mediterranean basin.

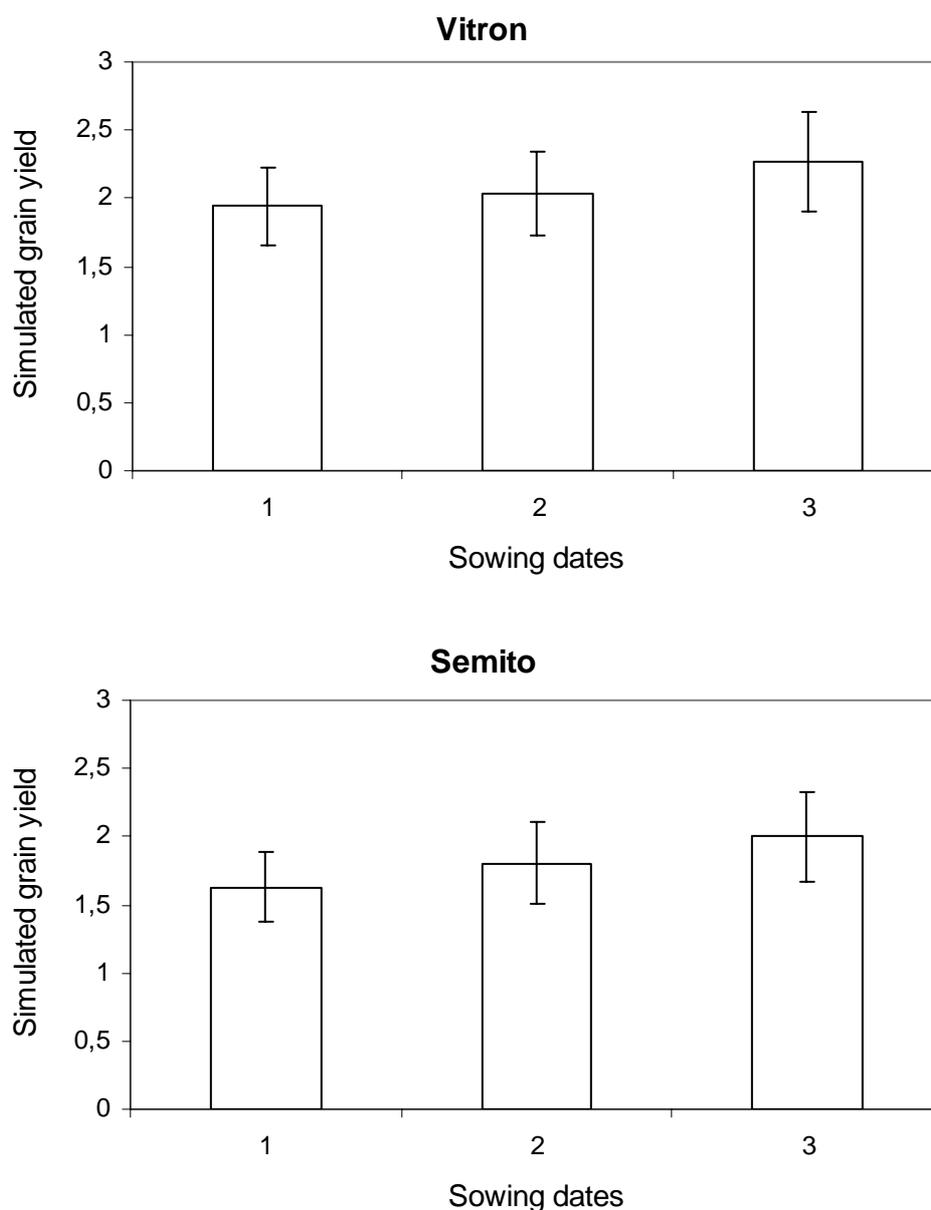


Fig. 4. predicted winter wheat grain yield (t.ha⁻¹) with three sowing dates from the farm ITGC at Tiaret (1986-2005). Bars indicate bars one standard error of the mean.

Interactions

Simulations were run for all combinations of management practices (cultivar, sowing dates, plant density and fertilizer nitrogen rates) over the 20-year period.

Figure (5) summarizes the results of grain yield simulated in relation to two cultivars (Vitron and Semito), with the three sowing dates, fertilizer N rates, and plants densities individually presented in the above paragraphs.

The results of the multi-factor ANOVA on grain

yields in relation to climatic year and all management options evidenced significant effects of all factors (p=0.001, Table 4). The inter-annual variability of climate (and essentially seasonal rainfall) accounted for 95% of the overall variance of simulated yields, while the agronomic factors explained 0.1 to 1% of the remaining variance (the residual variance being negligible; Table 5). The following ranking emerged for the influence of individual management factors:

fertiliser N rate > sowing date > cultivar > density.

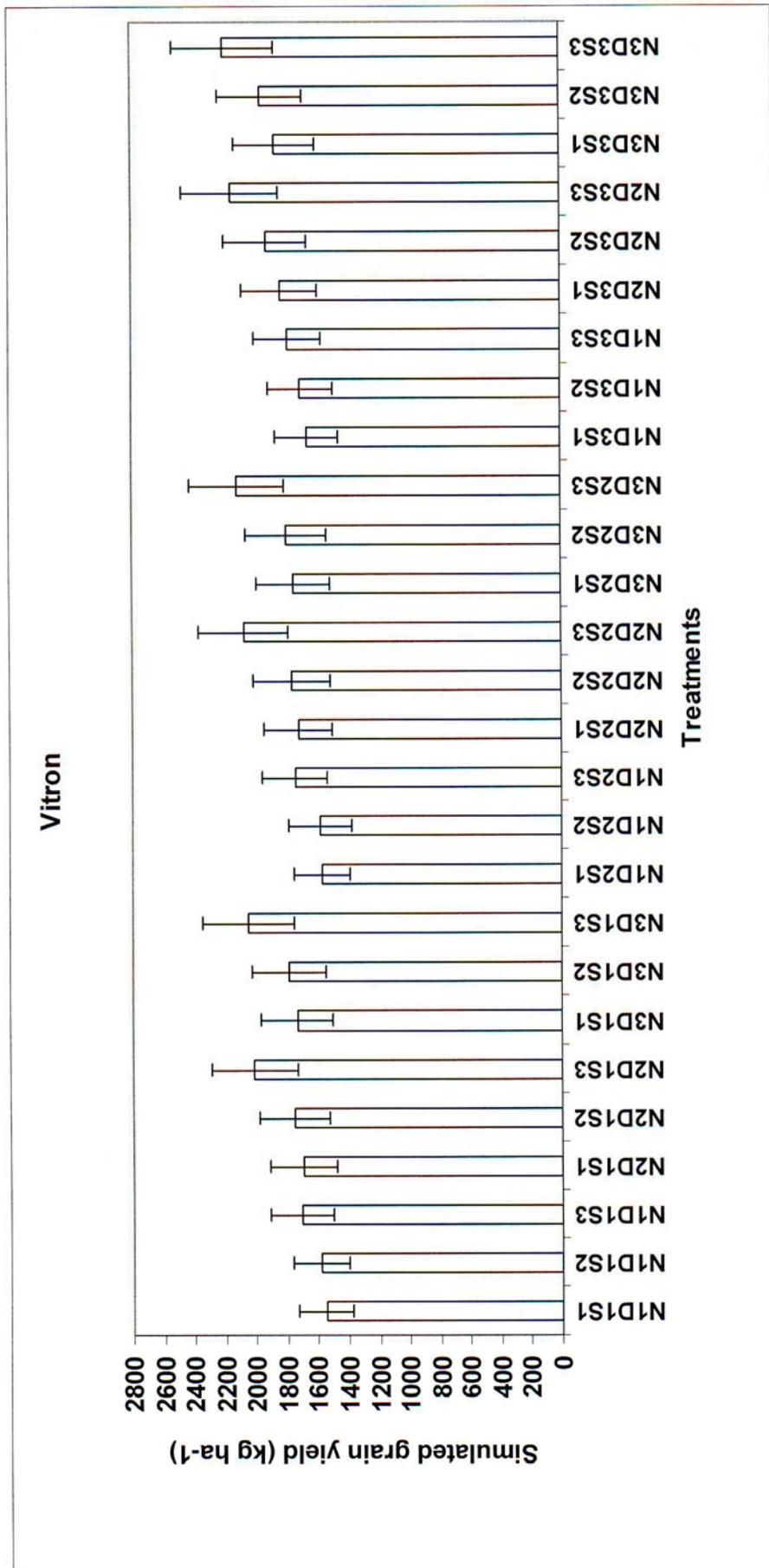


Fig. 5. predicted yield (kg ha⁻¹) for all combinations of nitrogen rates, sowing dates and plants densities at Tiaret (1986-2005). Error bars indicate one standard error of the mean. Key to the factors' levels: sowing dates: S1: DOY 305, S2: DOY 330, S3: DOY 354; fertilizer N rates: N1:0, N2:60, N3: 180 kg N ha⁻¹; plants densities: D1 : 200, D2: 300, D3: 400 plants m⁻².

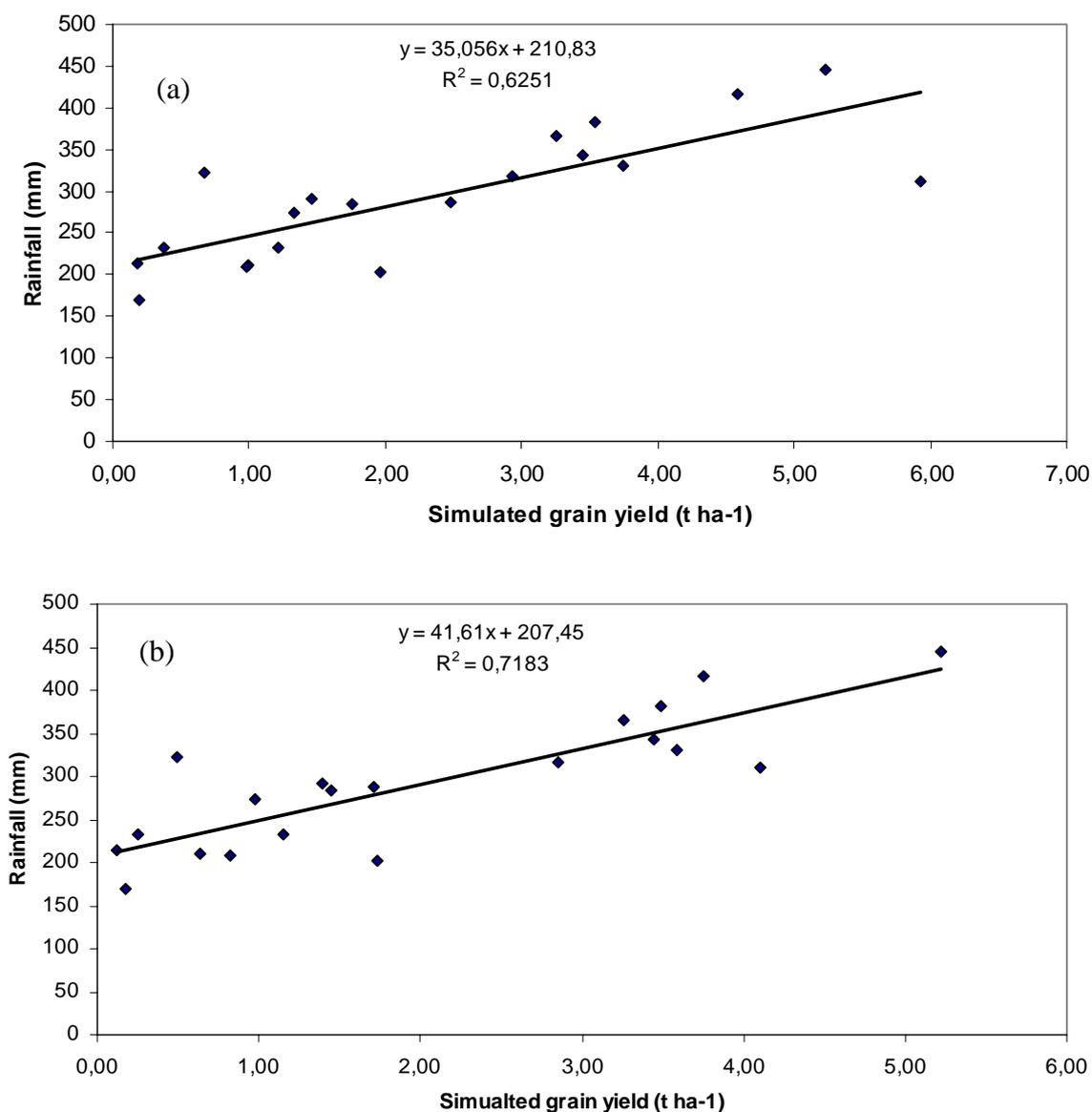


Fig. 6. Regression analysis of simulated grain yield and rainfall for cultivar Vitron (a) and Semito (b).

To elicit the effect of climate year, we regressed the simulated yields against the seasonal rainfall amounts, and obtained a positive, significant relationship $R^2=0.62$ and 0.71 for cultivar Vitron and Semito, respectively; (Fig.6)

The multi-factor ANOVA on simulated grain yields (Table 5) evidenced significant interactions between rainfall and planting dates ($P=0.001$) and fertiliser N rates ($P=0.0001$), although they accounted for only of the fraction of the variance explained by the agronomic factors taken individually.

4. DISCUSSION

4.1 Management, Climate and Genotype Interactions

Clearly, cv. Vitron yielded more than cv. Semito

across the ensemble of the technology combinations tested here, which indicates a contrasted behaviour between the two genotypes. A possible explanation lies in their genetic coefficients, as derived in an earlier study (Rezzoug et al., 2008; Table 1). Compared to Vitron, Semito required about 100 more degree-days more for grain filling, reflecting its longer growing cycle. This hampered its yield potential compared to cv. Vitron because it's matured later into the spring, as the climate got drier. Because yield predictions by DSSAT are controlled by genetic coefficients, proper characterisation of these parameters is crucial to simulate crops' behaviour in new environments.

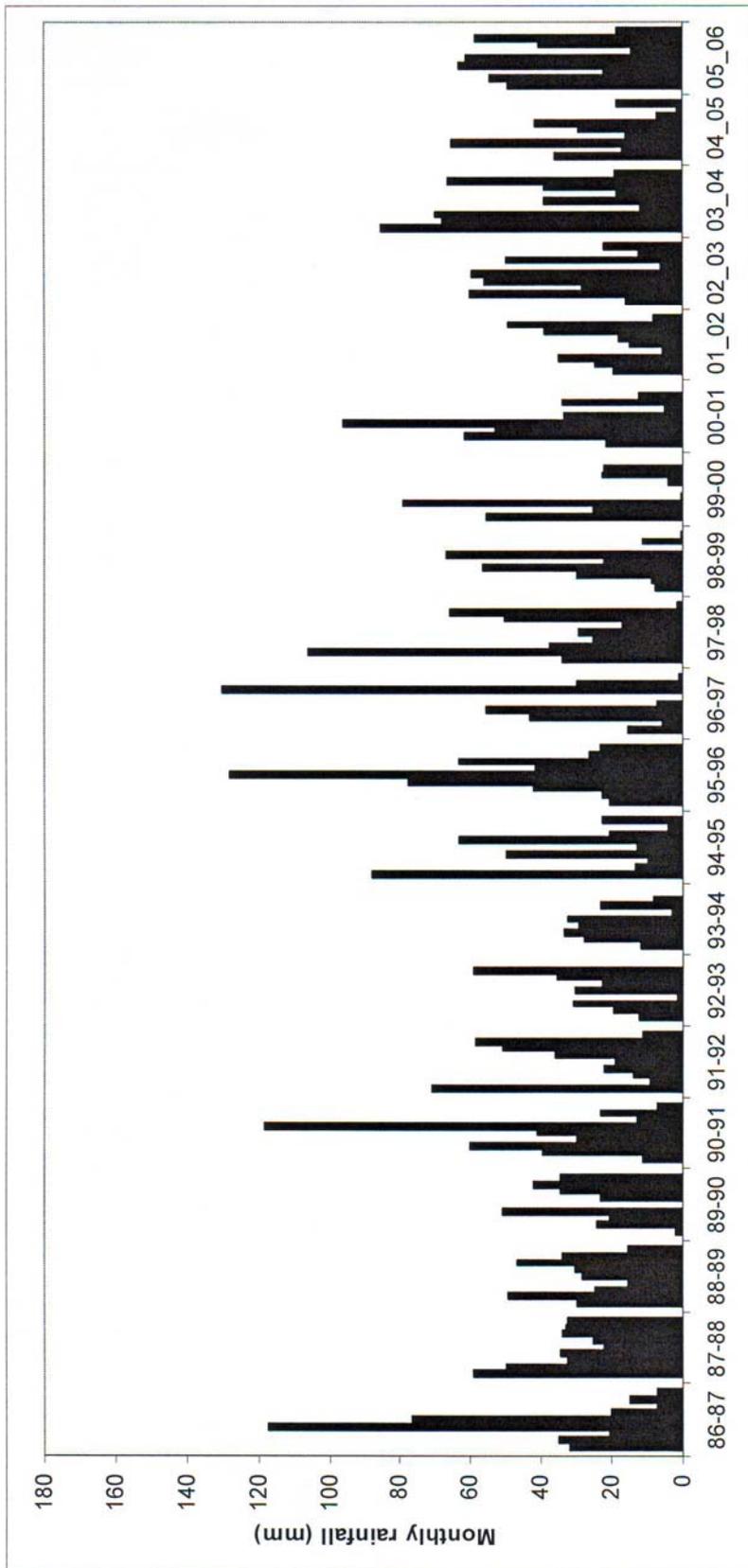


Fig. 7. Monthly rainfall (mm) at Tiaret (1986-2005).

Compared to the crop management practices as a whole, seasonal rainfall played an overwhelming role in determining the yields, explaining a major part of their total variance. The ANOVA showed that yields were very significantly affected by the amount of seasonal rainfall ($P < 0.001$). Fig. (7) gives a graphical representation of monthly rainfall during the wheat growing season (from October to June), over the 20 years considered. The total amounts of rain varied among seasons, as well as the distribution within seasons. Of the 20 seasons, seven were very dry with less than 250 mm of rainfall, four were relatively wet with more than 350 mm rainfall. The greatest decrease in simulated yield occurred in dry seasons with severe spring drought. An increase in rainfall with an even rainfall distribution resulted in an increase in the simulated yield, as was for example the case during the (1995-1996) season (Fig.7). Rainfall distribution also interacted with sowing date in determining the final yield, since the latter affected the time of anthesis and hence the susceptibility of wheat to declining rainfall in the spring during the critical grain filling period. The interactions of rainfall with fertilizer N rate were also significant ($P = 0.01$), and stem from the fact that soil N availability became a limiting factor in the unfertilized treatments in the relatively wet years. This relationship was probably enhanced in the case of the higher-yielding cultivar Vitron, although both cultivars had a similar response to fertilizer inputs. Similar reasons may explain the interaction of rainfall with planting densities, although it was slightly less significant ($P = 0.02$).

As evidenced in the Results section, it appears that the time-windows for 'early' and 'late' sowing vary across the Mediterranean zone, from region to region. There is thus no clear and common optimum planting date for wheat in such environments, and particular dates should be sought depending on local climate and soil conditions. Because traditional experimentation is time-consuming and costly, model simulations and output analysis have an essential role to play in fostering this understanding of management options such as those explored here. DSSAT, thus has the ability to considerably reduce the time and cost of field experimentations necessary for adequate evaluation of new or existing cultivars and novel management practices. Another benefit from such model-based application consists of simulating the climatic change scenarios and their impacts on wheat response to management factors (cultivar, nitrogen,

density and sowing date). The model could be useful to manage the associated risks for wheat production in this region, and design adaptation strategies.

4.2 Strategic Management Recommendations

Farmers may readily adopt improved technologies that can contribute to increase crop productivity. The work carried out here may be helpful in that respect since it pointed at strategies to optimize wheat yields in the Tiaret area in terms of variety, time of sowing, planting density and fertilizer N application.

Overall, simulated yields were little affected by planting density, but using the lowest density (200 plants m^{-2}) does not appear as a viable strategy, therefore the intermediate density of 300 m^{-2} should be recommended.

Conversely, fertilizer N rate had a notable effect on grain yields in the lower range tested here, between 0 and 60 kg N ha^{-1} . The model also revealed significant differences between cultivars, with an overall 10% higher potential for the short-duration genotype Vitron.

Sowing date is crucial in the area of Tiaret, and logically emerged as the most important management factor influencing grain yield. The model simulated a large yield increase of 0.66 t grain DM ha^{-1} on average when sowing was done in late December compared to early November, in combination with optimum N fertilizer rate, cultivar and plant density. However, seasonal rainfall was the prime factor determining wheat yields. As the model utilized 20 years of weather data for the selection of management strategies, it could capture the strong effect of inter-annual variability of the outcome of these strategies, and allowed a robust assessment compared to earlier studies based on single years Pecetti and Hollington (1997).

Our analysis based on the DSSAT model corroborates the advice currently given to farmers in the Tiaret area to delay planting till December.

The overall practical conclusion of this modelling work is that wheat production is optimal with a short-cycle cultivar such as Vitron, a plant density of 300 plants m^{-2} , a fertilizer N rate of 60 kg N ha^{-1} , and planting in the last decade of December.

The model thus proved useful in assessing the effects of climatic variation on crop productivity by using simulated means and cumulative probability. In future work, it may be used to predict the impact of the projected climate changes on wheat yields in the area, which was pointed out as particularly vulnerable due to

increased drought and extreme temperature events. Thus, the DSSAT model would provide guidance in the selection of optimal management strategies for sustainable wheat production in the Mediterranean.

5. CONCLUSION

Model application is a new phenomenon in the Algerian agricultural research system.

Our results indicate that wheat yield markedly depends on rainfall amount and seasonal distribution. The degree of variation yield with rainfall and management practices is difficult to quantify from experimentation alone. Thus, the approach of simulating wheat yield as a function of various management factors (cultivar, nitrogen, seed rate and sowing date) combined with long-term climatic data series is able to provide information for agronomic decision making. Simulation modelling provides a unique

means of integrating all these factors. Our statistical analysis of the DSSAT-Wheat model outputs confirmed that this model could be used to select the most appropriate strategy prior for conducting field experiments, to optimize yield gains and/or minimize losses. Here, we concluded that cultivar Vitron had the highest potential yields and identified optimal management options. The DSSAT-wheat model could therefore be used as a valuable decision making tools for risk management in the Tiaret region and it will be used in a near future to seek strategies to mitigate the impact of projected future climate changes in Algeria.

ACKNOWLEDGEMENTS

This work was supported by the governments of Algeria and France through their joint Research Funding Program.

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