

Simulation of the effects of climate change on barley yields in rural Italy

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Abstract: The Greenhouse effect is considered to be one of the most influential factors on climate change today, especially where temperature and rainfall levels/distribution are concerned, making it of considerable importance in the field of Agronomy.

Crop growth and development simulation models are a valuable cognitive tool in understanding water and nutrient dynamics in soil/plant systems.

This paper looks at the direct and indirect effects of climatic changes on average barley yields. The complex nature of the study rendered the use of mathematical simulation models essential, both for predicting future climate conditions and for the simulation of crop growth and development.

Of the different simulation models currently employed in the agricultural sector, the DSSAT (Decision Support System for Agrotechnology Transfer) model was used with the help of ENEA - Ente Nazionale per le Nuove Tecnologie, l'Energia e l'Ambiente (National Centre for New Technologies, Energy and the Environment) in Rome.

Initial research included the calibration and validation of the CERES – Barley growth model with agronomic experimental data taken from areas belonging to the national network of the Experimental Institute for Cereal Cultivation, each from four macro land areas in Italy (S. Angelo Lodigiano (MI) for the North of Italy; Jesi (AN) for Central Italy; Foggia (FG) for the South of Italy; Cammarata (AG) for the Islands). The calibrated and validated model was used to simulate crop yields for 99 years under increased interannual climate variability conditions. The implementation of adequate monitoring systems, with advanced data management and the development of models such as those used in this study, is crucial to sector policy-making and in choosing methods for effect mitigation.

Furthermore, the application of prediction models is essential in determining correct agronomic practices which are profitable, eco-compatible and long-lasting.

Keywords: Simulation model, climate variability, barley yields in rural areas,

1. Introduction

Climate changes can effect crop yields considerably, leading to significant economic and socio-political repercussions worldwide. One of the main contributing factors to climate change is the greenhouse effect which causes changes in temperature in the atmosphere and in rainfall, both in terms of precipitation levels and its distribution. The outlook for the environment is in constant evolution and often cause for disagreement within international scientific circles. It is the task of research to provide specific adaptation strategies in response to possible climate changes in an attempt to protect soil

fertility and to guarantee adequate agricultural production – both in terms of quantity and quality, coupled with economic sustainability.

Cereal production is considered to be particularly important in satisfying world food demand. Despite genetic improvements and the use of fertilizers and pesticides, cereal production is still closely linked to climate conditions, due to the fact it is grown in open fields over vast areas and, in many cases, without irrigation. Specific research, therefore, is needed in order to evaluate the effects of climate change on cereal production. This work focuses on possible variations in barley production as a result of climate change, based on variations in temperature and rainfall. The study was carried out in four large areas in Italy which can be considered representative of the many soil-climate conditions found in Italy.

2. Agronomic and economic aspects of Barley production

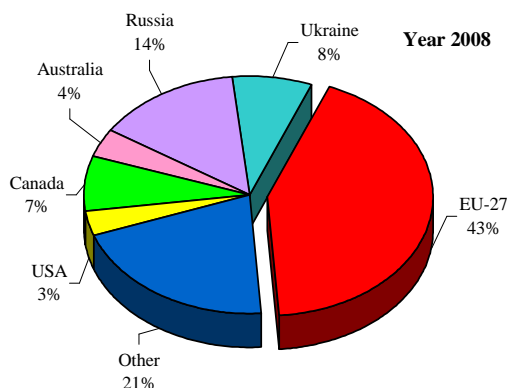
Barley is a cereal which is growing in importance worldwide. It is the 4th most cultivated cereal in the world, following wheat, rice and maize. Barley grain is used both for human consumption and animal feed. It is used in the production of malt and in the drinks industry for roasting, and the plant can also be used as a fodder crop when harvested green.

Good genetic variability gives it outstanding adaptability to climate and location. Its ability to thrive in adverse conditions, as shown in studies carried out by a number of scientists, leads to lower production costs and a reduced use of synthetic pesticides compared to durum wheat. This is a good indication of the crop's potential, especially as a sustainable, environmentally friendly crop. Although barley is highly resistant to drought and high temperatures throughout its whole growth cycle, the level of resistance varies with the variety.

Studies carried out by various research centres throughout the country have shown that, of the two-rowed barley types, some varieties showed high adaptability to soil-climates conditions with medium-high production levels and good grain quality.

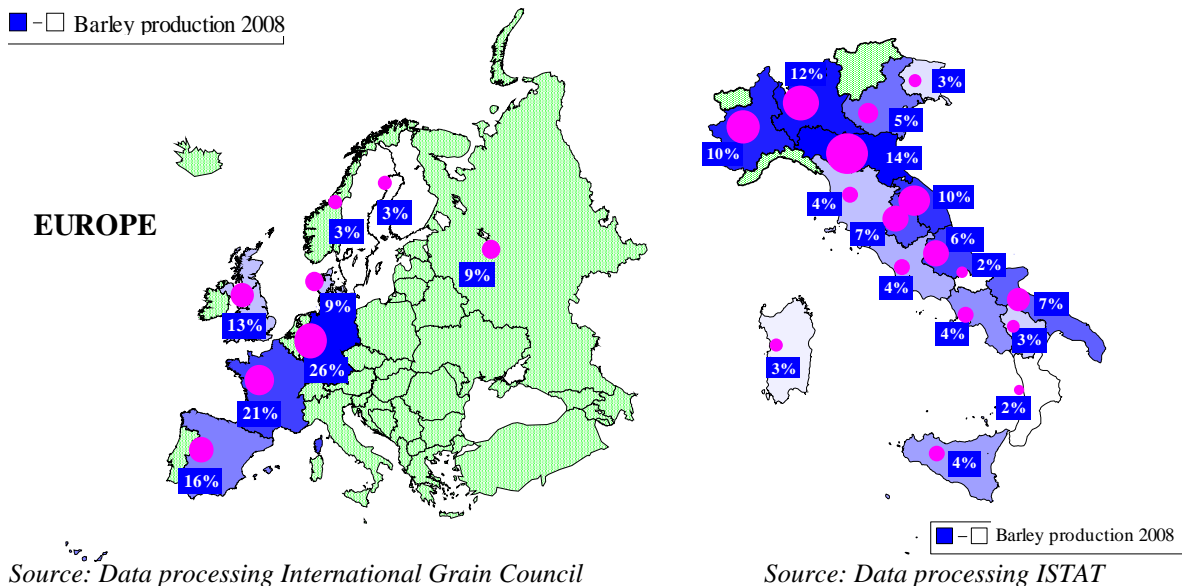
World barley production estimates for 2008 (ISTAT) show production at 153 million tonnes, up 15% on figures for 2007. Europe, with its 27 nations, is the largest world producer (Fig. 1) of barley at 66 million tonnes (43% of the world's total). In Italy, overall production in 2008 was 1,240,000 tonnes. North Italy produces 45% of the country's total, confirmation that the areas of Lombardy and Emilia Romagna are highly suited to barley production (Fig. 2).

Figure 1 - World barley production (%)



Source: Data processing Toepfer, International, USDA, Canada, ABARE

Figure 2 - Barley production in Europe and Italy (%)



2. Simulation of barley production in 4 selected rural areas of Italy

The following papers aims to examine the direct and indirect effects of climate change on average barley yields. The two-rowed cultivar *Baraka* was favoured as it is widely cultivated and produces good quality yields throughout Italy and a good deal of experimental data on this cultivar was available.

The CERES model was used to simulate barley growth and development coupled with climate change scenarios taken from the regional climate model (RegCM) MM4 developed by NCAR (National Center for Atmospheric Research, Boulder, Colorado, USA). This methodological approach has been used in a series of studies on climate change impact (Mearns, 1992; Rosenzweig et Parry, 1994; Mavromatis et Jones, 1998; Minguez et Iglesias, 2001), and was approved by the IPCC (Intergovernmental Panel Climate Change) in its 1996 report.

The first stage of the study involved the calibration and validation of the CERES model using experimental agronomic data (base-line) taken from areas belonging to the national network of the Experimental Institute for Cereal Cultivation, each from the four macro land areas in Italy – S. Angelo Lodigiano (MI) for the North of Italy; Jesi (AN) for Central Italy; Foggia (FG) for the South of Italy; Cammarata (AG) for the Islands. The barley cultivar *Baraka* was used in the study and agronomic data from the various stations was collected using the reference period 1989-2001.

The minimum data set (MDS) included:

- weather data: daily weather variables including maximum and minimum temperatures, precipitation, sunlight and atmospheric CO₂ levels etc.;
- soil data: data on the chemical and physical composition of the soil (Table 1), soil water content, nitrogen and carbon, colour, albedo, etc.;
- crop data: data on the characteristics of the variety, yield, phenological phases, etc.;
- management data: technical information on management techniques, such as sowing, irrigation, fertilizers, tillage, rotation.

The calibrated and validated model was used to evaluate the effects of climate change

on barley yields and to analyse the interannual variability of productions.

With the help of statistical methodology, rainfall was estimated using a two-state Markov chain of first-order which takes into consideration stochastic dependency on the dry and wet series of days.

The precipitation on the rainy days was generated with a gamma distribution function:

$$f(x) = \frac{x^{\alpha-1} e^{-x/\beta}}{\beta^\alpha \Gamma(\alpha)}, x \geq 0$$

α = shape parameter;

β = scale parameter;

$\Gamma(\alpha)$ = gamma function regarding α parameter.

The mean μ of distribution is $\alpha\beta$ and the variance σ^2 is $\alpha\beta^2$.

The minimum and maximum temperatures and sunlight were simulated using a multivariate first-order autoregressive model. The figures obtained reproduce the observed data series fairly closely.

The simulations were carried out on 99 years taking into consideration the soil type and cultivation techniques found at the stations under study.

In order to analyse vulnerability to climatic variability for each station, 5 weather sets of 100 years were generated.

The 5 weather sets were generated with a constant mean for the observed data (Base) and by varying the temperature data (T) and the precipitation (P) by a factor of ½ and 2, considering CO₂ concentrations of 330 ppm.

The resulting sets were:

- Base (constant mean of observed data and constant variability of observed data)
- P ½ (constant mean of observed data, variability of the temperature equal to that observed and variability of precipitation halved);
- P2 (constant mean of observed data, variability of the temperature equal to that observed and variability of precipitation doubled);
- T ½ (constant mean of observed data, variability of the temperature halved and variability of precipitation equal to that observed);
- T2 (constant mean of observed data, variability of the temperature doubled and variability of precipitation equal to that observed).

For each of the areas studied, a sensitivity analysis was carried out, thereby obtaining 5 weather scenarios (Base, P½, P2, T½, T2).

The “physical” meaning of the scenarios consists in the differing probability, compared to the observed data, of the occurrence of temperature and rainfall extremes, and in the increased variability of the same size scenarios occurring on a daily basis.

By reducing the variability, the probability of extreme events falls appreciably and the climate generated in this way is more uniform over time.

Alternatively, by doubling the variability observed, extreme values are more likely to be obtained, further removed from the mean, due to, for example, unexpected frosts, drought or heavy rainfall – all of which effect farming yields considerably.

The analysis is shown graphically in figure 3 and table 2 shows the statistical results obtained by simulating various climate scenarios and their effects on yields for the cultivar Baraka in the 4 study areas.

Table 1 – Physical-chemical characteristics of selected study areas

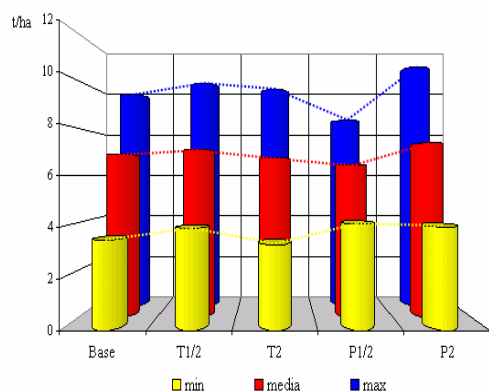
Analisi del terreno	S. Angelo Lodigiano (MI)	Jesi (AN)	Foggia	Cammarata (AG)
Altitudine (m)	70	42	0	460
Giacitura	piano	piano	piano	lieve pendenza
Sabbia (%)	52,3	18	25,1	36
Limo (%)	38	46	21,5	29
Argilla (%)	9,7	36	53,4	35
Calcare totale (%)	0	28,7	2,5	24
Sostanza organica (‰)	0,91	1,97	1,65	0,17
Azoto totale (‰)	1,72	1,13	0,13	0,9
Fosforo assimilabile (ppm)	82,7	31	51	6,1
Potassio assimilabile (ppm)	95,7	238	715	78,3
pH	7,6	7,2	7,4	7,3

Figure 3 - Effects of climate change in the selected study areas

CULTIVAR: BARAKA

AREA: NORD

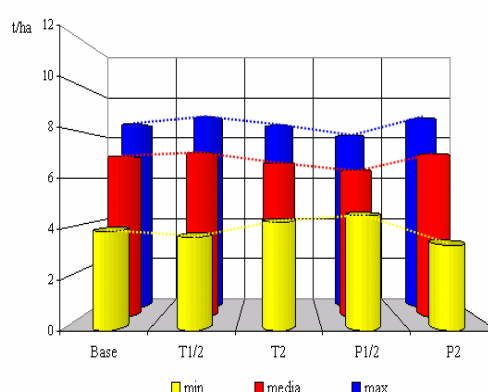
STATION: S. ANGELO LODIGIANO (MI)



CULTIVAR: BARAKA

AREA: CENTRAL

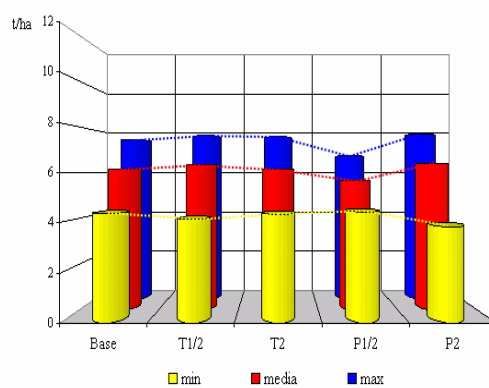
STATION: JESI (AN)



CULTIVAR: BARAKA

AREA: SOUTH

STATION: FOGGIA



CULTIVAR: BARAKA

AREA: SICILY

STATION: CAMMARATA (AG)

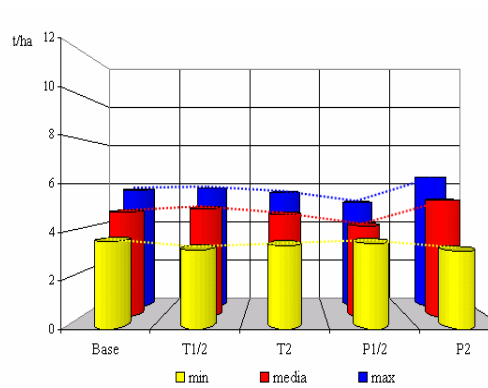


Table 2 - Yield Statistics (t/ha) for the 5 weather scenarios

Area: NORTH Station: S. Angelo Lodigiano (MI)		Weather Scenario				
	Base	T1/2	T2	P1/2	P2	
average	6,89	7,09	6,73	6,47	7,37	
min	3,49	3,94	3,32	4,11	3,99	
max	9,70	10,18	9,92	8,52	10,98	
St. dv.	1,36	1,23	1,11	0,98	1,32	
Cv %	19,7	17,4	16,5	15,1	17,9	

Area: CENTRAL Station: Jesi (AN)		Weather Scenario				
	Base	T1/2	T2	P1/2	P2	
average	6,94	7,11	6,66	6,33	7,03	
min	3,91	3,68	4,28	4,54	3,37	
max	8,53	8,84	8,45	7,98	8,81	
St. dv.	0,89	1,21	1,05	0,77	0,92	
Cv %	12,8	17,0	15,8	12,2	13,1	

Area: SOUTH Station: Foggia		Weather Scenario				
	Base	T1/2	T2	P1/2	P2	
average	6,14	6,35	6,15	5,64	6,41	
min	4,37	4,13	4,33	4,44	3,86	
max	7,53	7,75	7,69	6,79	7,83	
St. dv.	0,87	0,75	0,94	0,88	0,96	
Cv %	14,2	11,8	15,3	15,6	15,0	

Area: SICILY Station: Cammarata (AG)		Weather Scenario				
	Base	T1/2	T2	P1/2	P2	
average	4,71	4,88	4,61	4,11	5,25	
min	3,63	3,28	3,44	3,56	3,23	
max	5,70	5,76	5,58	5,08	6,31	
St. dv.	0,97	1,03	0,69	0,74	0,85	
Cv %	20,6	21,1	15,0	18,0	16,2	

Statistical elaboration highlights the absence of any appreciable differences in the precipitation and temperatures scenarios compared to the Base.

Only the S. Angelo Lodigiano (MI) station showed a difference in yield (minimum and maximum) of less than 18% for the various scenarios generated with differing temperature and rainfall conditions.

It would seem that the continental climate in the north, with more concentrated rainfall events and greater temperature ranges, both at a low and high frequency, has a considerable effect on yields (high yields in favourable weather conditions and reduced yields in unfavourable conditions).

In the stations in the south, and, in particular in Sicily, the gap between the maximum and minimum yields is smaller, with the response to differing temperature and rainfall conditions remaining fairly stable.

Maximum barley yields from the four stations (table 2) ranged from 5-6 t/ha (Cammarata Station in Sicily) to 10-11 t/ha (S. Angelo Lodigiano Station in the north).

The minimum yields showed satisfying levels (3-4 t/ha) for all the stations and the weather scenarios studied with limited variations.

Furthermore, the P½ scenario shows one of the lowest standard deviations and coefficient of variations, which, in terms of productivity, means the absence of either particularly negative or particularly productive years.

2. Conclusions

The study of climate change using the CERES model has highlighted its possible application in the primary sector by carrying out a series of simulations connected to probable future climate conditions and the production response of crops in rural areas of the country.

The use of the model was initially complex, however, once the basic process became clear, its application potential became clear.

Results show that yield variability increases slightly with a rise in the variability of both the temperature and rainfall levels. These effects are greatest in the north and they diminish in the south and island areas.

Analysis of the vulnerability of the cultivar Baraka to climate variability highlighted a greater yield sensitivity to rainfall compared to that of temperatures. A reduction in precipitation variability by half ($P^{1/2}$) led to a considerable fall in yield in all the stations and within the different scenarios. The opposite was found when doubling the values for the precipitation variable (P^2), with the highest yields found in the central-southern stations.

It is important to continue studies on climate change impact on agricultural systems, although these studies are still far from being scientifically advanced and error-free.

Uncertainties on climate variables which have an effect and their level of 'activity' in determining climatic phenomena, many historical data sets on important parameters which are incomplete and, above all, difficulty in predicting the types and quantity of interactions between the variables involved, does not permit a clear interpretation of the results obtained by this study, as in other studies.

However, it is important to highlight the extreme usefulness of prediction models, especially regarding decision-making processes, for which they can provide a scientific and economic basis.

We would hope that, in the next few years, calculus models, such as CERES, can improve simulations on climate change and effects on crops.

In the new European Union Framework Programme for research and technological development, 'sustainable development and global change' are priority themes for the future of humankind.

The implementation of adequate monitoring systems, with advanced data management and the development of models such as that used in this study, is considered crucial for policy making in this sector and when deciding strategies for mitigating effects.

Finally, it is important to highlight that simulation models, although a simplification of the system, are fundamental when outlining future scenarios.

The widespread application of prediction models is to be encouraged given their numerous advantages when choosing agronomic practices which are correct, profitable, eco-compatible and long-lasting.

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