Climate change and its impact on agricultural production, with a focus on the Mediterranean area

Seguin B.

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López-Francos A. (comp.), López-Francos A. (collab.).
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Climate change and its impact on agricultural production, with a focus on the Mediterranean area

B. Seguin

INRA, Domaine Saint Paul, Site Agroparc, 84914 Avignon cedex 9 (France)

Abstract. Climate change will impact and has already impacted a large range of physical/biological systems and sectors of the human activity, among them agriculture (including livestock) and its main output as food production. A large number of existing works allows to identify a reliable perspective on the predicted consequences for the various productions and the various regions, which may significantly differ from one to the another: they result from the combination of a large set of elementary components of the plant ecophysiology, including the stimulation of photosynthesis by the carbon dioxide. These diverse effects may vary from positive (by some 20%) in some temperate conditions to highly negative (down to 50% reductions) in warm conditions. This range may be encountered within the Mediterranean basin, but there is a general tendency to a worsening of climatic conditions, by the combination of warmer and drier conditions. More than in other geographic areas, water availability will be the major limiting factor. The agricultural sector will have to face this worsened future and to adopt a range of adaptive measures. The observed recent evolution, which appears similar to the long-term projections, gives a first perception of the necessary changes, but the near future is still rather uncertain about the velocity of climate change in the mid-term horizon (2030, for instance).

Keywords. Climate – Climate change – Drought – Mediterranean area – Agriculture.

Le changement climatique et son impact sur la production agricole à l'échelle globale et en région méditerranéenne

Résumé. *Le changement climatique va impacter, et a déjà notablement impacté, un large éventail de systèmes physiques/biologiques et de secteurs de l'activité humaine, parmi lesquels l'agriculture (incluant l'élevage) et sa principale fonction de production de l'alimentation. Un assez grand nombre de travaux existent qui permettent d'avoir une perspective fiable sur les conséquences prévisibles pour les différentes productions et dans les différentes régions, qui peuvent varier significativement de l'une à l'autre. Elles résultent en effet de la combinaison d'un large jeu d'actions élémentaires sur l'écophysiologie des plantes, intégrant l'effet de stimulation de la photosynthèse par le dioxyde de carbone. Ces effets divers, qui peuvent aller de légèrement positifs (jusqu'à 20%) dans des conditions tempérées à fortement négatifs (jusqu'à 50% de réduction) dans des climats chauds peuvent être rencontrés dans les différentes parties du bassin méditerranéen. Mais la tendance générale est très probablement celle d'une détérioration des conditions climatiques, par la combinaison de conditions plus chaudes et plus sèches. Plus que dans d'autres aires géographiques, c'est la disponibilité de l'eau qui va devenir le facteur limitant. Le secteur agricole va devoir s'adapter à ces nouvelles conditions, globalement plus défavorables. L'évolution climatique récente, observée, assez semblable aux tendances projetées, donne un avant-goût des changements nécessaires, mais il subsiste une interrogation sur la vitesse d'évolution à moyen terme (horizon 2030, par exemple).*

Mots-clés. *Climat – Changement climatique – Sécheresse – Région méditerranéenne – Agriculture.*

I – Introduction

Climate change will impact and has already impacted a large range of physical/biological systems and sectors of the human activity, among them agriculture (including livestock) and its main output as food production. Several other driving forces, especially in the economical and societal domain, will determine the evolution along the present century. But climate change has to be considered as a major factor in the context of the enormous challenge of furnishing food for about 9 billions of people instead of about 6 now.

If this statement is valid at a global scale, it is especially relevant when considering the Mediterranean basin, where climatic models combine disturbing tendencies with negative impacts of elevated temperatures and reduced water availability.

II – The consequences of global warming on agricultural production

1. Existing knowledge

The main lines of the foreseen impacts have been established in the years 1990, when considering at this date the simple assumption of a doubling of CO_2 concentration. Their findings are summarized in a large number of books or conference proceedings (among them Parry *et al.*, 1988; IRRI, 1989; ASA, 1995; Rosenzweig and Hillel, 1998; Reddy and Hodges, 2000).

Recent studies have added more detailed estimates of the consequences for global food production (Parry *et al.*, 2004), mainly confirming the previous lines. They differ above all by considering a range of emission scenarios (as the family of SRES defined by IPCC around 2000), which gives a corresponding range of impacts depending upon the hypotheses of warming. The analysis of the recent scientific literature performed by IPCC for the edition of the Fourth Assessment Report (AR4) allows to have a summary of these recent progresses, either in their main lines (IPCC, 2007a) or in the detailed analysis of future impacts (Easterling *et al.*, 2007) and already observed changes (Rosenzweig *et al.*, 2007).

When considering the outputs in quantified terms and in order to avoid serious confusions, it is necessary to realize that they correspond to the consequences of a given set of emissions (for instance A_2, A_1B or B_2 for the most often used) at a precise temporal horizon (generally, 2030 2050 or 2100). The combination of these two entries may be expressed by impacts considered as a single function of global temperature increase, which here includes changes for all the other associated climatic variables (climate change and not only climate warming).

2. Expected effects on crop functioning

For assessing changes in the eco-physiological functioning of vegetal production, it is firstly necessary to consider the stimulation of photosynthesis by the elevation of atmospheric CO_2 concentration. It will concern pastures, forests and natural vegetation as well as annual crops.

For these, even if there is some controversy about the results of experiments with free-air enrichment, the well-established curves of photosynthesis enrichment on an instantaneous basis (Fig. 1) lead to consider an increase of about 10-20% with 550 ppm for C_3 temperate species as wheat, rice, soybean, whilst it seems to be limited to 0-10% for C_4 tropical species as maize, sorghum (Easterling *et al.*, 2007). This increase of potential production is a first component, on which direct effects of changes in the climatic variables have to be superposed.

They firstly involve temperature, whose effects may be quite variable: higher temperatures are generally favourable for growth in cold and temperate climates, except however when they exceed the optimum and even attain detrimental thresholds in the case of extreme events. On the contrary, they are generally unfavourable for warm areas. For the development, the advance in phenology will have as main consequence to reduce the duration of the cycle of determinate species, thus the time during which photosynthesis is working. But it leads also to shift the periods during which plants are more sensitive to a given factor, as for example the flowers of fruit trees, which may result in an increase of spring frost risks, in spite of a reduction of purely climatic frost conditions. For indeterminate cycle species like grass or forests, warmer conditions will speed the budburst at spring and delay the browning in autumn, which on the whole results in a significant increase of the duration of growth season.

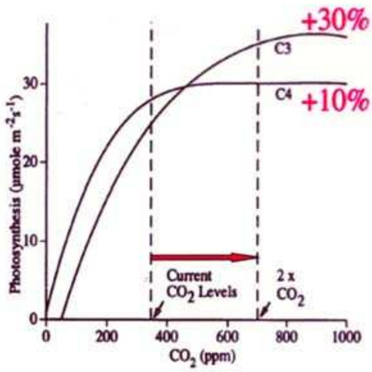

Fig. 1. Typical increase of photosynthesis with increase in carbon dioxide concentration.

Rainfall on a first range and other water balance components like potential evapotranspiration will also seriously modulate the potential changes in plant resulting from these effects of temperature increase. Tendencies towards drier conditions may fully cancel the positive potential impact with higher CO_2 or milder temperatures! More generally, we also have to state that this general figure only considers the continuous effect of mean values for the climatic conditions, but that their variability and the occurrence of extreme events (frosts and heat-waves, droughts or torrential rainfall) would totally confirm or inverse this mean tendency. On the whole, the combination of these various influences leads to a variety of contrasted effects, depending upon the type of crop production and the geographical zone.

3. Expected effects on crop production

Resulting effects on crop production may be grossly estimated by setting some in-field experiments or using empirical tools like climatic indices, but there is a general agreement for considering that only the use of well-defined and validated deterministic crop models is able to give valuable predictions. A synthetic view of recently published studies is available from the IPCC AR4 report, as depicted in Fig. 2.

In this figure, grey curves correspond to simulations for crops supposed to be cultivated as they are now. Evidently, in the future climate, there will be adaptation measures, which will involve changes in the crop/livestock system combining changes in varieties and cultural practices. As it is possible to estimate from Fig. 2, by considering the black curves involving adaptation techniques, they seem able to improve yield by 10 to 15%.

The final statement given in IPCC (2007a) states that "temperate regions, moderate to medium increases in local mean temperature (1 to 3℃), along with associated CO_2 increase and rainfall changes, can have small beneficial impacts on crop yields. At lower latitudes, especially the seasonally dry tropics, even moderate increases (1 to 2℃) are likely to have negative yield impacts for major cereals. Further warming has increasingly negative impacts in all regions".

Observed changes in agriculture and livestock resulting from the recent warming are still hardly detectable, except for advances in phenology (i.e. flowering of fruit trees, harvest dates of vines and cereals) and the case of wine production in terms of quality, with a noticeable increase in sugar and alcohol content and a simultaneous decrease in acidity. The effect of warming is difficult to isolate from other driving forces in the evolution of regional yield and global production. These are rather, at least up to now, sensitive to the climate variability. Among the recent events, both in Europe and in Australia, severe droughts have confirmed the high sensitivity of pasture production, with large-scale losses of 50% and more.

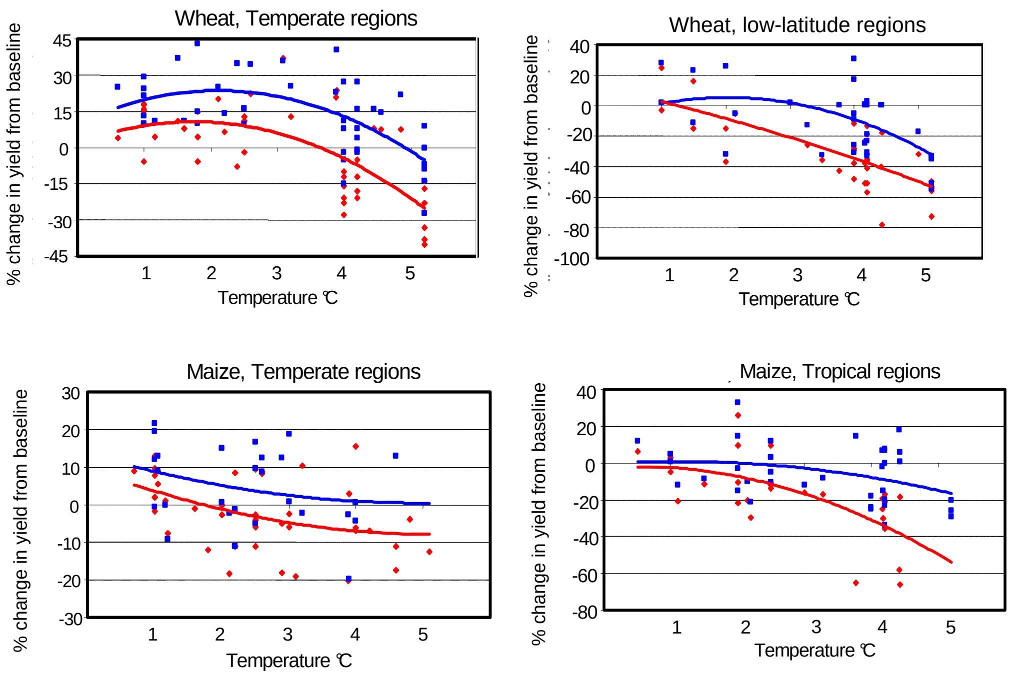

Fig. 2. Effects of temperature change on wheat and maize (from Easterling *et al.*, 2007).

4. Consequences for the global food production

Having a full viewing of the future would also need to incorporate an assessment of the future adaptation by geographical displacement of production zones. It seems easy to give a general idea of possible shifts, like the potential extension of grain maize or vine towards the north or the east in Europe. But it is much more difficult to quantitatively assess the large-scale consequences. Also, the forcing function of the market on the agricultural production is such that it is only possible to give the main tendencies caused by the component of the climate change alone. When these are aggregated up to the scale of the global trade market, it is confirmed that most of the increase in production will come from the agriculture of developed countries, which mostly benefit from climate change. It will have to compensate for declines projected, for the most part, in developing countries (Parry *et al.*, 2004): the reduction of agricultural productivity could approach 20 to 25% for some countries like Mexico, Nigeria or South Africa (Cline, 2008) or some crops like wheat in developing countries (IFPRI, 2009). The resulting increase of the number of people at risk of hunger marginally could grow from 380 millions up to 1300 millions in 2080, depending upon the future emission scenarios. It could even be underestimated in the case of unexpected surprises due to increased frequency and severity of extreme events.

III – Focus on the Mediterranean area and drought consequences

1. Climatic projections

Climatic perspectives for the Mediterranean basin are now well established, with a main tendency to a worsening of conditions (high temperatures and drought) in a region already vulnerable to a great climate variability. This statement is formulated by IPCC (2007a) in the summary for policymakers, but the classical partition between geographic chapters does not allow a proper analysis of the Mediterranean ensemble, which is shared between Africa (IPCC, 2007b), Europe (IPCC, 2007c) and a very tenuous part of Asia.

However, some comprehensive surveys exist at the scale of the whole basin for completing the diagnosis. Among them, the recent review by Giorgi and Lionello (2008) allows to give a robust and consistent picture with the following main components:

(i) Even if some climatic projections indicate extremely high levels of warming for the end of the century by up to 9℃ in June to August for North Africa, the general figure for the annual warming lies between 3 and 4℃.

(ii) Annual rainfall will decrease, by a factor generally around 20%, especially in the summer period. Higher amounts may occur in other seasons, but in a reduced number of events, which would lead to increased runoff and soil erosion. The demand for water expressed by the potential evapotranspiration will increase during the hot period by a possible similar order of magnitude of 20 to 30%. With at least 20% water less coming from rainfall and 20% more needed by plants, the resulting water balance will be dramatically worsened, with a significant shifting towards aridity.

Evidently, these general features will vary between the various parts of the basin, as a consequence of the great diversity of climatic features within it. However, the figure is sufficiently largely valid for a consensus to consider the Mediterranean basin as a primary hotspot for climate change impacts (Giorgi, 2006). Although we have to take into account the still significant degree of uncertainty for a proper consideration of climate projections (Giorgi, 2005), the fact that the whole set of 20 climate models used for the simulations supporting the AR4 IPCC report gave the same general tendencies considerably enhances their degree of confidence for the future.

2. Consequences for agriculture

The Mediterranean region is a transition zone between the arid climate of North Africa and the temperate and rainy climate of the central Europe (Giorgi and Lionello, 2008). The impacts will then cover the two cases (temperate and low-latitudes) described in Fig. 2 , with a large number of situations closer to the latter, with the potential advantage given by the carbon enrichment and more favourable temperatures counteracted by negative components as the reduction of cycle duration, excessive temperatures and enhanced water stress. For this last point, an illustration of foreseen conditions in soil moisture for southeast France is given in Fig. 3. Apart form the noticeable year-to-year variability, it displays the trend towards drier conditions along the century, especially after 2050.

Global studies previous reported in 2.3 confirm this statement: the projections by Cline (2008) for the region Middle east-North Africa give a global reduction of 9.4%, which may amount to 21.2% without the effect of the carbon fertilization. Similar orders of magnitude have been obtained by IFPRI (2009), with detailed estimates by crops (20% for rice, 7% for wheat, 8% for maize, 4% for millet, but + 1% for the sorghum). The more geographically precise estimates given by Giannakopoulos *et al.* (2009) also lead to the same values, with a supplementary information on the geographical heterogeneity within the basin: in spite of the effect of CO_2 enrichment, yield for cereals would be reduced by 4.9% in the southeast (Serbia, Greece and

Turkey), 3.4% in the southwest (Tunisia, Algeria and Morocco), but only 0.3% in the northwest (Portugal, Spain and France), and increased by 4.4% in the southeast (Jordan, Egypt and Libya). Summer C_4 projections give respectively -7.9%, -9.4%, +4.2% and -0.6%, which displays the interaction between crop specificities and geographical sub-regions for the various consequences on crop production. Globally, they confirm global mean values ranging from reductions by 20% and unchanged or slightly increased yields in some sites, mainly in southern and eastern parts.

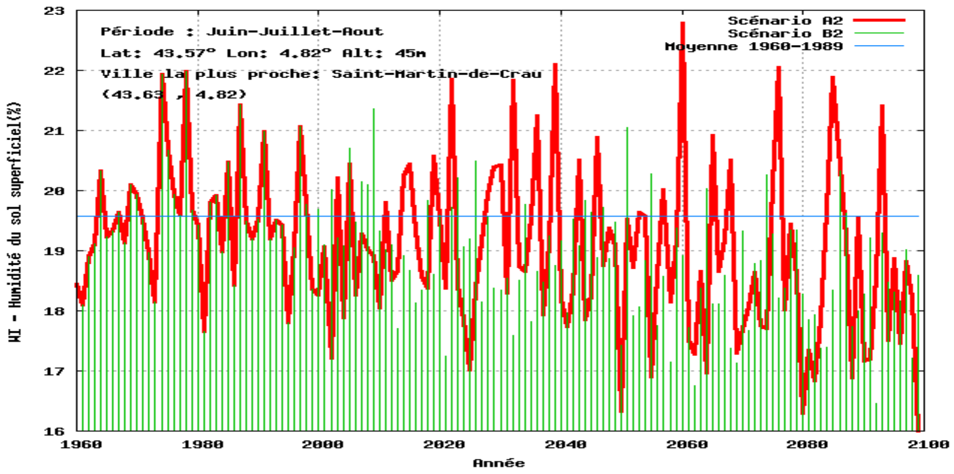

Fig. 3. Projections for surface soil moisture in summer from the CNRM (Météo-France) model for the site of Saint-Martin de Crau (from the website of ONERC: http://www.developpement-durable.gouv.fr/-Impacts-et-adaptation-ONERC-.html).

3. The impact of future extreme events

These projections are only based on climatic inputs in terms of mean value, and do not properly assess both the variability and the occurrence of extreme events. The study by Porter and Semenov (2005) has highlighted their possible first-order effect: for wheat production in Spain starting from a present yield level of 5.6 t/ha, only a slight reduction to 5.2 t/ha is obtained for a future climate which would keep the same variability (CV 0.24). But a much more significant reduction to 3.9 t/ha is predicted if the CV is increased up to 0.48. The probability for having yields lower than 3.5 t/ha would amount to 0.50, to be compared to 0.10 in the other cases.

In terms of extreme events, some effects may come from low temperatures leading to frost occurrence: from the strict climatic point of view, they will be reduced, but damages could be enhanced in some situations because of the advance in the development stages in fruit trees or vine caused by warming. However, the main danger will come from warm conditions, with the high possibility of encountering lethal temperatures when they will approach 40℃. Thresholds are still very poorly known, but there is a serious risk for much more severe damages being caused by future heat-waves, as recently recalled by Battisti and Taylor (2009) from historical warnings with unprecedented seasonal heat.

As rainfall will diminish, the probability of droughts will increase, as well as the gap between the limited water availability and the escalating demand for water from the various economic sectors. Agriculture is generally by far the most consuming of these sectors, up to 85% in some countries like Egypt (IPCC, 2007b). The challenge of reducing this gap is enormous, but so well known now that we will not insist more, except for giving some pieces of useful information about the consequences of climate change for irrigated crops: globally, the IFPRI study gives significant reductions for irrigated crops yield in developing countries in the case of wheat (about 30%) and rice (20%), the effects being smaller for maize. The more precise study for the Mediterranean area by Giannakopoulos *et al.* (2009) rather gives a small positive effect for summer crops in the northern part, but it also indicates that it will be accompanied by an increased water demand which could amount to 40% in some options. This order of magnitude is supported by an estimation of the increase in water demands for vine in northeast Spain: 6 to 14% for every 1℃ warming during the growing season (Ramos *et al.*, 2008). Yield in rainfed conditions will be lowered by more frequent and more intense droughts, and the extension to irrigation for supplying the additional water will be an enormous challenge.

4. Recently observed changes

Overall, the global average surface temperature has risen by 0.6 to 0.7℃ since the start of the 20th century. The recent rate of increase has been 3 times larger in the last 25 years (IPCC, 2007a). It has been greater at high northern latitudes, but also on land surfaces, so that we may assume that the order of magnitude of the warming for the Mediterranean basin is similar to this mean value. Changes in rainfall amount on an annual basis are more variable at the global scale, with an increase for many regions, but a tendency to a decline for the Mediterranean basin (Fig. 4) as for the Sahel, southern Africa or parts of southern Asia. The tendency is not as clear as for temperature, and the detection of a significant trend is largely open to the discussion. Nevertheless, we may observe that the last 25 years are characterized by a lower rainfall for several countries like France (Moisselin *et al.*, 2002), Italy (Brunetti *et al.*, 2002) or Spain (Ramos *et al.*, 2008).

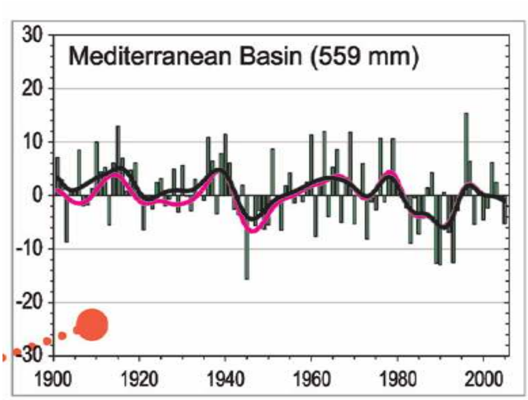

Fig. 4. The evolution of annual rainfall integrated at the scale of the whole basin (from IPCC, 2007a).

Although there are less published studies about it, there are concomitant indications of an increase of the water demand expressed by potential evapotranspiration PET, as we can see for the case of southeastern France (Fig. 5): in Avignon, it has increased from about 800 mm to 1000 mm, and during the same time, the rainfall has diminished from 450 mm to 300 mm, so that the potential deficit in the water balance P- PET has been increased by more than 300 mm (350 to 700 mm)! The tendency to a drier climate is clear and significant. It is also noteworthy that these features have been accompanied by extreme events as the exceptional episodes of heat-waves, accompanied by significant droughts, which occurred during the summer of 2003 in the western part of Europe, but also the eastern part in 2007. So that the future picture of a worsened climate appears to be already present in the area.

Consequences on agriculture are already noticeable too. The first signs have been noticed in crop phenologies, like flowering of fruit trees and vine, as well as harvest dates (IPCC, 2007b). Very recent studies now confirm in France the combined effect of warm temperatures and water stress on cereal yields (Gate *et al.*, 2009), as well as in wine production in southern vineyards where irrigation is not allowed.

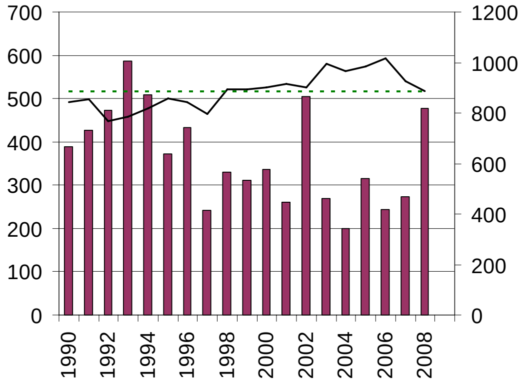

Fig. 5. The evolution of growing season (April-September) mean values for rainfall (bars) and PET (points) from 1990 to 2008 in Avignon (France). ***Data processed by Bernard Baculat, INRA Agroclim.***

IV – Conclusion

Future climate projections have to be considered with some caution by taking into account still large uncertainties, especially for which concerns the rainfall component. However, in the case of the Mediterranean basin, they are so convergent that they lead to consider with a high probability the worsening of climatic conditions by the conjunction of warmer and drier characters. Agriculture will very likely have to face enhanced risks of excessive temperatures and more frequent and severe droughts, with an increasing gap between a growing water demand and a reduced availability. The availability of more spatially precise climatic scenarios is quickly increasing, with a spatial resolution approaching 10 km. They will give enough precise inputs for giving geographically detailed projections which will take into account the specificities of the various sub-regions.

Adaptive capacities exist up to a certain degree in the choice of production systems (less water consuming species) and cropping systems within each crop (genetics improvement, cultural practices, among them sowing dates for annual crops). There is a general agreement about the priority for concentrating all possible efforts for an optimal use of water, both in rainfed and irrigated conditions. It will be also necessary to improve our knowledge about the geographic shifts in crop potentialities as induced by climate change, which have been estimated to about 0.5 km/year for the Mediterranean biomes (Loarie *et al.*, 2009), but could be roughly quantified to 10 times higher when considering the major north-south latitude gradient in France (Moisselin *et al.*, 2002).

Maybe the most important unknown now lies in the medium-term (2030) perspectives: is the present dry period only a temporary spell, or does it inaugurate the end of the century tendencies with a larger than foreseen intensity? We may hope that the next generation of climate models will give soon more information in order to properly address the coming challenges for the adaptation of agriculture, without omitting the companion necessity of GHG mitigation.

References

ASA, 1995. *Climate Change and Agriculture: Analysis of Potential International Impacts*, ASA Special Publication, no. 59. Madison (WI): ASA, 382 p.

Brunetti M., Maugeru M., Nanni T. and Navarra A., 2002. Droughts and extreme events in regional daily Italian precipitation. In: *Climate Research*, 38, p. 1-15.

Cline W.R., 2008. Global warming and agriculture, report from the Peterson Institute for International Economics, 22 p.

Easterling W.E., Aggarwal P.K., Batima P., Brander K.M., Erda L., Howden S.M., Kirilenko A., Morton J., Soussana J.F., Schmidhuber J. and Tubiello F.N., 2007. Food, fibre and forest products. In: Parry M.L., Canziani O.F., Palutikof J.P., van der Linden P.J. and Hanson C.E. (eds). *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press, p. 273-313.

Gate P., Brisson N., Charmet G., Gouache D. and Oury F.X., 2009. Les causes du plafonnement du rendement du blé en France. In: Changement Climatique: Conséquences et Enseignements pour les Grandes Cultures et l'Élevage Herbivore, compilation of the communications of the Meeting of 22 October 2009, Arvalis-Institut de l'élevage, p. 23-34.

Giannakopoulos C., LeSager P., Bindi M., Moriondo M., Kostopoulou E. and Goodess C.M., 2009. Climatic changes and the associated impacts in the Mediterranean resulting from a 2℃ global warming. In: *Glob. Planet. Change*, 68, p. 209-224.

Giorgi F., 2005. Climate change prediction. In: *Climatic Change*, 73, p. 239-265.

Giorgi F., 2006. Climate change hot-spots. In: *Geophys. Res. Lett.*, 33, L08707, doi:10.029/2006GL025734.

Giorgi F. and Lionello P., 2008. Climate change projections for the Mediterranean region. In: *Global and Planetary Change*, 63, p. 90-104.

IFPRI, 2009. Climate change: Impacts on agriculture and costs of adaptation. Internal report, 20 p.

IPCC, 2007a. Summary for Policymakers. In: Parry M.L., Canziani O.F., Palutikof J.P., van der Linden P.J. and Hanson C.E. (eds). *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press, p. 7-22.

IPCC, 2007b. Africa, regional chapter. In: Parry M.L., Canziani O.F., Palutikof J.P., van der Linden P.J. and Hanson C.E. (eds). *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press, p. 433-467.

IPCC, 2007c. Europe, regional chapter. In: Parry M.L., Canziani O.F., Palutikof J.P., van der Linden P.J. and Hanson C.E. (eds). *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press, p. 541-580.

IRRI, 1989. *Climate and Food Security*. Manila: IRRI, 602 p.

Loarie S.C., Duffy P.B., Hamilton H., Asner G.P., Field C.B. and Ackermy D.D., 2009. The velocity of climate change. In: *Nature*, 462, p. 1052-1055.

Moisselin J.M., Schneider M., Canellas M. and Mestre C.O., 2002. Les changements climatiques en France au XXe siècle: Étude des longues séries homogénéisées de température et de précipitations. In: *La Météorologie*, 38, p. 45-56.

Parry M.L., Carter T.R. and Konijn N.T. (eds), 1988. *The Impact of Climatic Variations on Agriculture*. Volume I: Assessments in Cool Temperature and Cold Regions, Volume II: Assessments in Semi-Arid Regions. Dordrecht: Kluwer Academic Publishers, 876 p., 764 p.

Parry M.L., Rosenzweig C., Iglesias A., Livermore M. and Fischer G., 2004. Effects of climate change on global food production under SRES emissions and socio-economic scenarios. In: *Global Environmental Change*, 14, p. 53-68.

Porter J. and Semenov M.A., 2005. Crop responses to climatic variation. In: *Phil. Trans. R. Soc. B*, 360, p. 2021-2035.

Ramos M.C., Jones G.V. and Martínez-Casnovas J.A., 2008. Structure and trends in climate parameters affecting winegrape production in northeast Spain. In: *Climate Research*, 38, p. 1-15.

Reddy K.R. and Hodges H.F., 2000. *Climate Change and Global Crop Productivity*. Wallingford, Oxon: CABI Publishing, 488 p.

Rosenzweig C. and Hillel D., 1998. *Climate Change and the Global Harvest*. New York (NY): Oxford University Press, 324 p.

Rosenzweig C., Casassa G., Karoly D.J., Imeson A., Liu C., Menzel A., Rawlins S., Root T.L., Seguin B. and Tryjanowski P., 2007. Assessment of observed changes and responses in natural and managed systems. In: Parry M.L., Canziani O.F., Palutikof J.P., van der Linden P.J. and Hanson C.E.

(eds). *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press, p. 79-131.