10. IMPACTS ON THE AGRARIAN SECTOR

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ABSTRACT

An increase in CO_2 concentration and air temperature, as well as changes in seasonal rainfall will have counteracting and non-uniform effects in Spain. The positive effect of CO_2 on photosynthetic rates can be compensated by greater temperatures and less precipitation. On the other hand, milder winter temperatures will allow greater crop growth rates if water is sufficiently available, and greater productivity in certain areas. Greater temperatures can increase evaporative demand, especially during summer, affecting irrigation requirements. In the South and Southeast of Spain, water demand could increase and thermal stress appear more frequently.

Crop simulation models using climate data from Regional Climate Models are nowadays the most efficient tools for impact analysis, as they are able to quantify the non-linear effects of climate change. Identification of regions differently affected is necessary.

Establishment of areas with different levels of impact and adaptation. Short term adaptation strategies can rely on simple management practices such as changes in sowing dates and cultivars. Nevertheless, in the long term, adaptation of cropping systems to future climate conditions is required. Implications on vegetable crops, fruit orchards, olive groves and vineyards should specifically addressed to assess adaptation at minimum cost.

The expected increase in extreme weather years will difficult crop management and will require more analysis of the sustainability of agricultural systems. Distribution and control of pests and diseases will differ. Their natural control during winter by frost and low temperature could diminish, so crop sequences would need to be adapted. With milder temperatures, current pests and diseases can be displaced to other latitudes and allow new problems too.

Effects of climate change on livestock are complex because of the diversity of the production systems as well as the direct and indirect effects on agriculture. Variations in temperature and precipitations will affect animal metabolism, reproduction and health issues.

Diseases produced by arthropods or helminths will vary in distribution, population and intensity, with different prognosis depending on the Spanish region considered. The epidemic control and the gravity and extension of the transmission process depend exclusively on the relations host-vector-environment, so effects on their biological adjustment are expected. Milder and wetter winters will increment significantly parasite survival. Parasite activity will appear earlier in the year due to milder winters. Dry and warm summers will increase mortality rates of arthropods due to loss of water.

Research is needed to predict the effect of climate change on the intake capacity and on the parameters indicative of animal welfare. With this information and previous experiences the construction of dynamic models could be possible. Also, the establishment of risk maps for each parasite is necessary as well as for the distribution of each parasite.

10.1. INTRODUCTION

10.1.1. Agricultural systems in Spain. Distribution, current area and productivity

Agricultural production in Spain contributes 12.1 % to the European Union's total production, behind France (23.1%) and Germany and Italy (both 15.4%) (MAPYA 2003, http://www.mapya.es/es/agricultura/pags/hechoscifras/cifras.htm). The most productive crop sectors, that contribute over 50% of national agricultural production, are, fruit and vegetables, vineyards, olive groves and cereals. A wide range of livestock products constitute around 40%.

Approximately 30% of national territory (50 Mha) is farmed or used for pastures. The diversity of productivity can be seen in the wide range of cereal yields across the peninsula and the contrasting high productivity of vegetable crops, the latter usually grown under irrigation and often within greenhouses. Productivity relative to water and nutrient use remains low in many parts of the country due to suboptimal management of soil, water, crop rotation, irrigation systems, etc. – but ways are known to improve performance.

10.1.2. Influence of the Common Agricultural Policy (CAP) in agricultural systems

The influence of the CAP can be seen in the crop sequences in both dry farming and in irrigation systems. Crop choices are not always the best in agronomic terms, especially in relation to climate and soil, so the sustainability of these agricultural systems is questionable. The progressive reduction of EU subsidies is beginning to affect management decisions, as can be seen in the restructuring and changing geographic distributions of olive groves and vineyards. Changes are also evident in the livestock sector, especially in mountainous regions of low productivity and changing environmental values, with evidence of increasing farm size and reduction in farm numbers due to amalgamations.

10.1.3. Components of climate change and basic principles of the impacts

10.1.3.1. Influence of climate change in the different agricultural systems

The possible effects of climate change on agricultural systems, discussed at length in the IPCC report (1997 2001a), indicated widespread and serious impacts on agriculture. Changes in CO_2 concentrations and in air (and soil) temperature, along with variations in seasonal precipitation, will have opposing and non-uniform impacts on the Iberian Peninsula, and in particular in Spain. That is to say, the impacts will be beneficial or harmful, depending on the nature of the agricultural systems and their locations in a peninsula of complex orography (Rosenzweig and Hillel 1998).

The nature of the opposing forces is well known. While, greater CO_2 concentration are expected to increase crop photosynthesis (e.g. Amthor and Loomis 1996) and reduce transpiration due to decreased stomatal conductance (Rodríguez *et al*. 2001), two responses that will together promote greater productivity and water-use efficiency, increasing temperature will have counteracting and compensating effects. Increasing temperature will increase thermal stress and reduce photosynthesis, especially of crops in already hot areas, for example of southern Spain, and will shorten crop cycles. The latter response will have the effect of reducing productivity and water use, although any savings in water may be offset by greater rates of water use in response to greater evaporative demand at higher temperature.

Change in total annual and seasonal rainfall is an important aspect to be studied in dry farming systems and in the design and planning of irrigation systems. Water demand must be adapted to water supply. Where insufficient water is available to meet crop demand, different cultivars or crops are required in dry farming. In irrigation, deficit irrigation may be needed to stabilise fruit and vegetable production in the various areas.

These simple considerations identify the complexity of the potential impacts associated with climate change and the need to identify those factors that are most critical to the productivity of Spain’s varied agricultural systems. If the current crop management is maintained, crop life cycles will be shortened and flowering and maturation dates will change. Productivity and water use may increase or decrease depending upon interacting factors. This identifies the need for studies and individual analyses for vegetable crops, fruit orchards, olive groves and vineyards to identify least-cost adaptation strategies for crops, cropping sequences and management. This must be done with a clear understanding of the interdependence of agriculture with other sectors - hydrology, insurance (agricultural), energy (e.g. generation of electric energy versus use for irrigation) and the maintenance or expansion of areas for “natural” ecosystems, etc.

10.1.3.2. Influence of climate change in the different livestock farming systems

The implications of climate change for livestock farming (exploitation of animals for production) are potentially more complex than those for cropping systems. This arises because of the great diversity of livestock farming systems but also because climatic change will impact on both the animals and their feed base. Complex interactive effects are possible. The effect of climatic change on crop production is discussed elsewhere. For the animals themselves, variation in temperature and rainfall due to climate change can affect livestock in many ways (reproduction, metabolism, health, etc.), although these effects can be summarised in two parameters (intake, and animal wellbeing), which can be used as indicators of climate change in the different livestock farming systems due to their direct influence on the profitability of the farms. In extensive grazing systems, for example, climate impacts on fodder production but also on animal health and performance. In order to handle this complexity, the approach adopted seeks to establish the effects of climate change on parameters that are common to all production systems, and then to establish specific characteristics on individual systems

10.1.4. Analysis of possible tools for evaluating the repercussions of climate change in livestock farming

It should be pointed out that there are few studies in Spain of the influence of climate change on the aforementioned parameters (intake, and animal wellbeing). Although scientific-technical information does exist in relation to the influence of temperature in nutrition and stress in animals, and these results could be used as an initial working reference.

The clearest and most direct effect of climate change is upon the availability of fodder throughout the year, which conditions intake and the profitability of livestock farms. In this sense, a change in rainfall distribution in grazing areas would lead to a reduced amount of pasture, and, which is more important, to a reduction of potential grazing time, which would lessen the carrying capacity (cap/ha). In these systems, variations in available plant matter and carrying capacity could constitute two tools for evaluating the effects of climate change.

In intensive systems, the tools to be used are the parameters indicating the degree of stress in animals (levels of cortisol, adrenaline, ionic balance, etc.) and the effects of this on the production parameters of farms.

10.1.5. Data on Iberian ecosystems, area and types, and suitability for animal pathology

There are two main aspects of diseases in domestic animals that are particularly sensitive to the effects of climate change and are clearly distributed with regard to ecosystem or habitat. One of these is related to parasitic diseases that depend on the particular biology of certain parasites. Indeed, all arthropods (fundamentally flies, mosquitoes and ticks) depend completely on environmental climate to modulate their biological cycle. A given area may be appropriate or not for a determined arthropod (the disease thus appearing or not), depending on the delicate balance of certain climatic variables which will subsequently be dealt with. Other parasites, such as helminths or worms (etiological agents of widely distributed diseases in Spain) can have free stages. All the epidemiology of these helminthoses is regulated by the variables temperature and humidity, and life cycles are once again based on prevailing conditions (Soulsby 1982). It must also be kept in mind that arthropods are vectors of a great deal of other processes, both parasitic and infectious, with serious economic repercussions for animal health. The epidemiological regulation and the seriousness and extent of the process transmitted depend exclusively on the host-vector-environment relationships, and obvious effects on the delicate biological balances of complex processes are therefore to be expected (Lindgren 1998).

Thus, the effects of climate change can be expected to be seen in all those parasitic and infectious processes, the etiologic agents or vectors of which are closely related to climate. Arthropods are temporal parasites. This implies that the parasitic phase constitutes only a fraction of the total duration of the parasite's life cycle. Under these circumstances, climate has a predominant regulating effect. Each species of arthropod has a variable number of phases in its life cycle, depending on the species or even on its taxonomic group. Thus, Diptera (flies and mosquitoes) usually have a larval form that hatches from an egg. The development speed of the egg depends exclusively on prevailing temperature. Above and below certain critical temperatures, development is interrupted. Furthermore, mortality in this phase derives from relative humidity, or, to a lesser degree, from the deficit of atmospheric saturation. A high deficit implies a high death rate, responsible for great population losses. As with the Diptera, it could be said that this regulation of the embryonic phase is identical for ticks, which form a group of Arthropods separate from the previous ones, but with important implications for the health of domestic animals (Estrada-Peña 2001). In both groups, the egg develops and the larva hatches. In some cases, this larva develops in water (some mosquitoes), in others it can be an animal parasite (certain flies) and in others it develops in the environment and only temporarily parasitises the host (as in the case of ticks). It is in the latter case that the most evident effects of climate change on their life cycles are to be expected, for two reasons. On one hand, the larvae of ticks are exposed to environmental climate for almost 99% of the duration of this stage. Besides, the larval phase in ticks is responsible for the whole complex numeric population regulation of the rest of the tick's life cycle (Gray 1982). A high death rate in the larval phase would cause a drastic decrease in tick populations. Likewise, a huge increase in numbers during this stage, would lead to a dramatic rise in the numbers of the parasite in the field.

All of these effects should be considered not only from the point of view of an increase or decrease in population, but also in relation to sanitary conditions and to the potential transmission of different diseases to the animals (Randolph *et al*. 2002). Indeed, we cannot contemplate parasitic disease without observing the immune response of the host, which is explicitly adjusted to the parasitic pressure it is subjected to. Changes in this pressure appear to be accompanied by subtle but profound variations in the response the animal presents to the hostile environment constituted by the parasite.

One of the most obvious effects can be seen in the adaptation of the parasite to its habitat. The suitability of the habitat depends on the adjustment of a series of climatic variables to certain possible preferences of the Arthropod. The other effect derives from changes in the seasonal dynamics that are to be expected as a consequence of the acclimatisation of the pathogenic agent (parasite) to the changing climatic situation. Studies carried out with ticks, which are ideal indicators of climate change, have demonstrated two fundamental details of the effects of climate change. On one hand, milder and wetter winters cause a clear survival rate of certain stages of the parasite's life cycle. These milder winters also cause an advance in the time of year in which the tick commences its activity, due to the fact that the duration of the lower temperatures that prevent activity by the arthropod is shorter, and the life cycle is therefore extended (Randolph *et al*. 1999). There is, however, another effect that should be mentioned here, related to hot, dry summers. These summer periods are believed to increase the death rate among ticks, which is a simple question of water loss. The effect that climate change will have on two important factors for ticks is still unknown: soil and vegetation, as it is here that their life cycles take place, and where the effects of climate are modulated. In other words, the effects of climate change on the biological cycles of these arthropods will be complex, and will give rise, as will be described in the chapter on "impacts", to a whole new relationship between ticks, climate and animals.

As has been mentioned, there are also other parasites whose life cycles are highly influenced by climate change. Normally, several larval phases of the parasites known as nematodes (parasitic worms found in domestic and wild animals and in man) are exposed for long periods of time to environmental climate conditions in the grass (Almería 1994). As with arthropods, and as in the aforementioned specific case of ticks, nematodes have optimum temperatures, different for each species, at which development of the species is maximum. Above and below these temperatures, development speed is lower, and can even come to a halt. This is the case of winter temperatures and of the larvae of these nematodes in the grass. Low winter temperatures cause the metabolism of these nematodes to slow down or to stop. Although in certain parts of Spain, there are sufficiently high winter temperatures to maintain a level of development which is low but above zero, and although each species prefers a different optimum interval, it can be said that these winter processes cause an adjustment in the life cycle, so that development of infestant forms coincides with the appearance of pastures for the animals in springtime.

Other parasitic entities which are expected to be modulated by the effects of climate change are included within the helminthosis transmitted by freshwater snails. Although the larval forms of the agents causing these processes as less associated with the environment as free stages, like the aforementioned arthropods or helminths, the fact that they are transmitted by freshwater snails implies that modifications in the fresh water spots profoundly affect the transmission cycles of these helminths. Indeed, snails acting as vectors of these entities also need a series of finely tuned environmental factors for their development. Likewise, the parasite cannot develop inside the reservoir snail without the right combination of temperatures for its development cycle. Regardless of the geographic variations that can occur in the maintenance of the water spots necessary for the survival of the snails (see chapter on continental waters), changes in water temperature can be expected to cause variations, as yet unquantified, in the development, spread and distribution of these helminthosis.

10.2. SENSITIVITY TO THE PRESENT CLIMATE

10.2.1. Sustainability of systems and stability. Indicators of impacts on agriculture. Current state of basic resources (soil, water, genetic information)

General studies of the agriculture sector that have been requested by official organizations such as the *United States Department of Agriculture* (USDA) (Reilly *et al*. 2001) emphasise not only quantitative estimates of changes in production, water use, etc., but also the problem of variatiability. In the case of the Iberian Peninsula, and Spain in particular, this is one of the most critical issues, because the stability and sustainability of any system is affected by interannual and seasonal variations in rainfall, water availability for irrigation, the greater or smaller frequency of frost in springtime or the torrential rains that have especial impact on the fruit and vegetable sector.

10.2.2. Variability in water supply (dry farming and irrigation)

Dry farming systems and pastures encompass most of the farmed area, and therefore comprise the major agricultural resource base of the nation. It is critical that this resource base be maintained so that adverse effects of any land-use practices can be corrected. As climate changes, this may require not just changing management practices but also land use, either towards an increase in area, towards afforestation, or towards an increase in the area under irrigation. Increased variability in the supply of rain or irrigation water, could initiate a process of change previously unexperienced in these systems.

The availability of water for orchards, olive groves and vineyards is a crucial theme for study, and requires close connection with the other sectors involved in this project. A fundamental step is an estimation of water demand, i.e. evapotranspiration (ET), by crops in future climates. One of the most difficult questions involves the transfer of predictions of variation in precipitation to the water available to crops, in particular vegetable crops.

10.2.3. Importance of extreme years and events (water, pests, diseases)

In the case of Spain, greater frequency of years with low rainfall, more storms or longer heat waves (see chapter 1) will have many effects on the population and their activities, including farming. Farmers will have to adjust their short-term tactical management and long-term strategic plans. The rigid rules under which they now receive financial aid, or subsidies from CAP, will need adaptation to new conditions if they are to assist and not hinder the essential process of adjustment.

In particular, there is a wide and variable distribution and scope for deleterious effects of pests and diseases in the economically important crops. Changes in temperatures or in relative humidity or rainfall will affect the way in which appropriate adaptations can be implemented (IPCC 2001a). Natural control that is currently possible, for example low winter temperatures in some areas on the Plateaux, may diminish so that solutions may require modifications to crop rotations. On the other hand, temperature changes will allow current pests and diseases to be displaced to new areas and also allow new problems too.

10.2.4. Importance and evolution of the different livestock farming systems in relation to land use

In general terms, changes in the livestock farming systems in our country in the last few decades have led to increasingly intensive systems, as a result of the fact that from the 50s to the 80s the objectives of animal production were based on reaching the maximum possible amounts, as rapidly and cheaply as possible. At the time, this objective was logical, as it was intended to cover the existing needs (meat and milk, fundamentally) of the population. This approach based upon maximising production is easier to achieve in intensive systems with farms with a large number of animals, and with more homogeneous production. Furthermore, in these decades, the traditional grazing areas (for instance, mountain areas) were abandoned by the population, which led to a decrease in the number of livestock farms and changes in the traditional uses (sustainable) of the territory, because of the integrating factors of the production system, the factor land gave way to the human factor (labour), the most important one.

Of the work carried out in the Montaña de León mountains (Serrano *et al*. 2002) the changes indicated in the livestock farming system in this area were characterised and quantified, and evidence was seen of the viability of production alternatives, because this area now produces highly prized, top-quality livestock products. Although the dependence on economic subsidies threatens the feasibility of some of these farms, except in the case that the aid received was linked to a rational use of the territory in order to avoid unfair competition from other production systems, which in spite of receiving economic aid, do not benefit the environment.

In mountain areas, livestock farming systems traditionally coexisted which were based on different species of herbivores (cattle, sheep, goats and horses) with mixed production (milk, meat, wool, work, etc.). Changes in recent years have led to a big increase in livestock farming systems producing beef, and the practical disappearance of the other systems, with a direct effect on land uses and changes in plant cover.

10.2.5. Data on main environmental features and current climatic tendencies involving the presence/absence of a pathogenic process

(See section 10.3.3.)

10.2.6. Relatively stable seasonal patterns and cycles that change drastically over short time periods

(See section 10.3.3.)

10.2.7. Foodstuffs quality

At present, no evaluation exists of the effects upon the quality of foodstuffs. These effects could be related, for instance, to: transfers of periods with high temperatures and the protein quality of hard wheats (pasta production), changes in rainfall patterns during the maturation process of the grape, greater nutrient leaching in intensive systems with irrigation, such as vegetable crops. We are, however, aware of the effects of frost temperatures on the quality of agricultural products and the consequences of excessive temperatures or of heat waves on production, like what occurred during the heat wave in the summer of 2003. We are aware of the consequences, but what now interests us is to know whether the frequency with which these phenomena occur will be altered in a scenario of climate change.

10.3. FORESEEABLE IMPACTS OF CLIAMTE CHANGE

10.3.1. Dry farming and irrigation-based agricultural systems

The first studies of the impacts of climate change on agriculture systems in Spain made use of General Circulation Models (GCM) to provide input data for crop simulation models. The GCMs considered came from: the *Goddard Institute for Space Studies* (GISS), the *Geofluids Dynamics Laboratory* (GFDL), and the *UK Meteorological Office* (UKMO). This allowed the first analyses to be made of the impact of climate change on biomass generation and yield, and on the water consumption and irrigation needs of certain crops (Iglesias and Mínguez 1995, Mínguez and Iglesias 1996). The low resolution of the GCMs, however, did not allow differences, that exist in the present climate between neighbouring regions, to be applied to crop production scenarios.

The second stage was initiated with the use of GCM models with atmospheric-oceanic coupling (AOGCM, specifically HadCM2) together with a regional climate model (PROMES) with greater resolution (see chapter on Climate). The crop simulation models used are included in the *Decision Support System for Agrotechnology Transfer* (DSSAT) v. 3.1. (Tsuji *et al*. 1994)

These are the models of the CERES group, *Crop Estimation through Resources and Environment Synthesis* (Ritchie and Otter 1985; Jones and Kiniry 1986; Otter-Nacke *et al*.

1991). Wheat (winter) and maize (summer) were selected as reference crops because their growth cycles covered all the seasons of the year and because, with different photosynthesis systems (C3 and C4), included different responses to CO_2 increase in the analyses.

The impact of climate change was assessed in terms of changes in water use and crop yields for the summer and winter growing seasons. The methodology used, along with some of the impacts on water consumption rates, are described in Guereña *et al*. (2000). This study was the first in Spain to use data from a RCM in crop simulation models and the first to make a comparative study between impacts derived from low (AOGCM) and high resolution (RCM) models. This study describes changes in yields, biomass, evapotranspiration (ET) and the irrigation needs of “reference” crops.

A current research project is PRUDENCE: *Prediction of Regional Scenarios and Uncertainties for Defining European Climate Change Risks and Effects* (EVK2-2001-00156) (see also Chapter on CLIMATE). This study attempts to evaluate the uncertainties associated with predictions of change in climatic parameters, and to evaluate how the predictions are transferred or reflected by the impact models. The impact models are either crop simulation models (DSSAT, Tsuji *et al*. 1994) or models of cropping systems, CropSyst (Stöckel and Nelson 1994).

The studies are again being applied to winter and summer cereal crops, with and without irrigation. Fig. 10.1 shows the simulation of impacts through the changes in yield of a cultivar winter-grown farming barley under rainfed conditions, without irrigation, in present climate (“*current*”) and A2 (see chapter 1), future, generated by the systems simulation model CropSyst connected to different regional climate models: RCM, ETH, GKSS, Promes, HIRHAM (see chapter 1). The commercial cultivar used requires vernalisation (exposure to low temperatures to induce flowering) was assessed in north, central and southern Spain under both present and future climates. The results reveal yield impacts that include crop. This comparison enables the testing of the sensitivity of the models in the present climate.

10.3.1.1. Use of General Circulation Models (GCM) for climate, with low resolution and crop simulation (DSSAT). (studies for the National Hydrological Plan)

During the years 1998 and 1999 some initial studies were carried out for *the Centro de Estudios y Desarrollo Experimental* (CEDEX) – Centre of Studies and Experimental Development – on the impact of climate change upon irrigation systems (Mínguez *et al*. 1998; Mínguez *et al*. 1999). In the design of the National Hydrological Plan, the importance of establishing the future trends of water demand by the Agriculture Sector led to the initiatiation this collaboration. These studies showed the usefulness of climate and crop models as evaluation tools, highlighted the spatial variation in the impacts and the need to work with high resolution (RCM+Impact models).

Estimation of the impact of climate change was based on the irrigation needs of maize, as a summer crop, and of wheat, as a winter crop. The scenarios were generated by the General Circulation Model (HadCM2) for 250x250 km. grids. This initial approach revealed the need for higher resolutions for the Peninsula, because the response to conditions of higher temperature and variations in precipitation, in some cases predicted threefold increases of maize yield, very high biomass production and abnormally low harvest indices. The irrigation needs of maize were smaller in the future climate, in spite of the temperature increase, due to the shortening of the crop cycle and to the increased rainfall predicted by the general circulation model. In some cases, predicted rainfall exceeded 1000 mm per year.

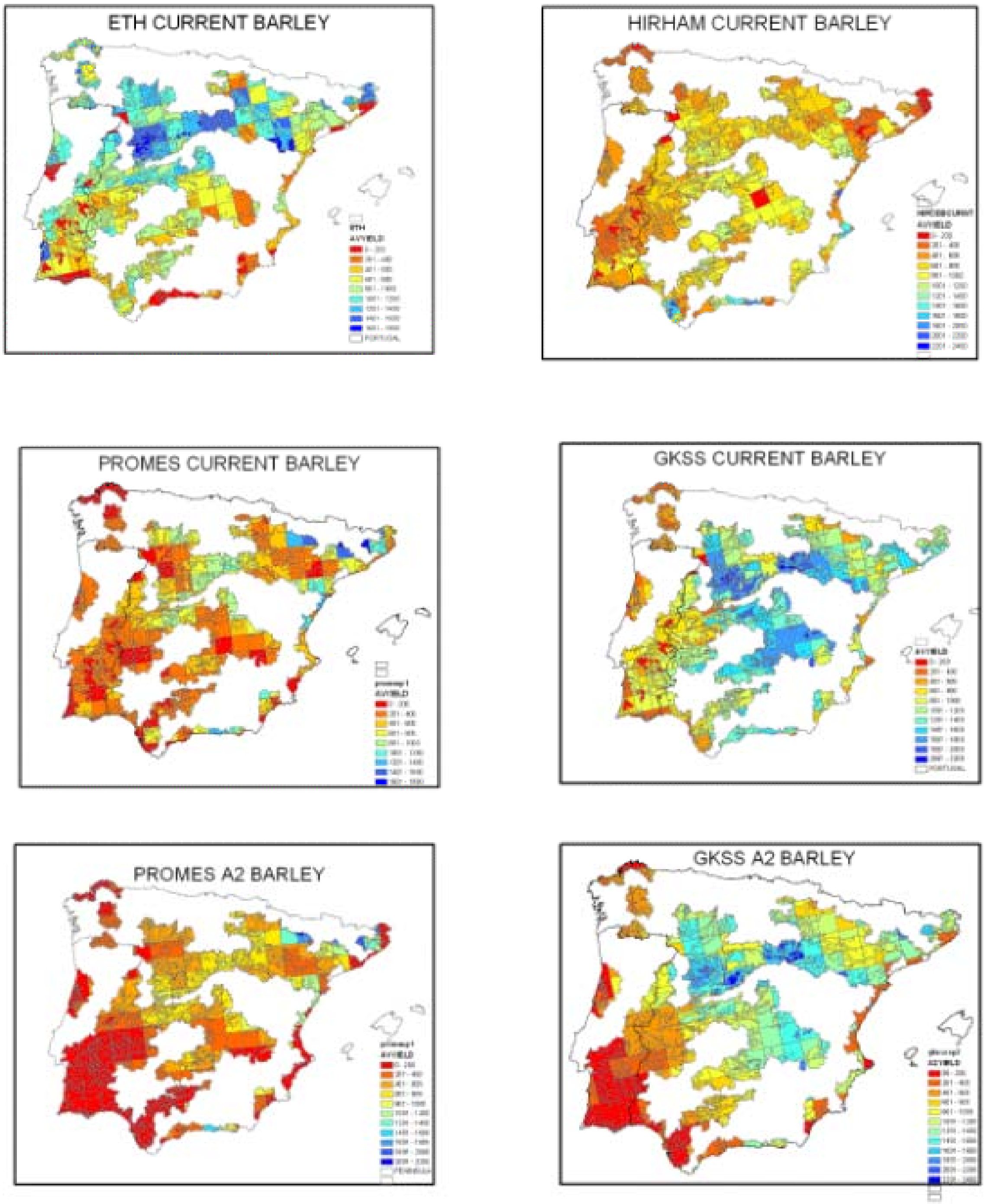

Fig. 10.1. *Simulation of impacts through changes in dry farming barley yields, unirrigated, under current or control climate scenarios and A2, future, generated by the crop simulation model CropSyst connected to different regional climate models*

10.3.1.2. Impacts on phenology and on crop yield and biomass

Within these previous studies, and in the absence of adaptation strategies by farmers, the major response is the acceleration of phenological development and the shortening of vegetative. However, responses of crop yields and biomass production vary among zones.

If the climate models have low resolution (see Fig. 10.2) it is difficult to establish trends of crop performance. In some areas, yields and biomass production under irrigation remain around potential production, although increasing in some cases in the winter cereal. Temperature increase in areas that currently have cold winters, and greater solar radiation and rainfall in most cases, operate to prevent yield loss. For example, in Fig. 10.2, in the blue cells, the grain maturation time of maize is advanced by 13 to 44 days, with great variation between locations (cells). Whereas grain yield decreases in cell 2-2, it increases threefold in 4-4 and by just 20% in 3-3.

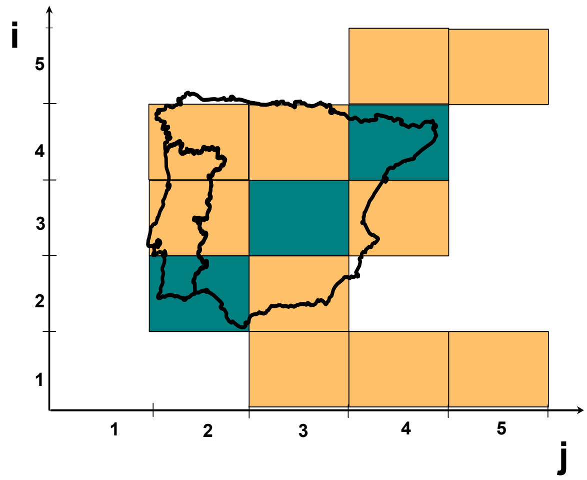

Fig. 10.2. *Cells (i, j) showing the resolution of the low resolution AOGCM models in most of the previous studies, including those by the IPCC*

The studies currently being carried out with higher resolution climate models (Fig. 10.3) enable us to demarcate the areas positively and negatively affected by changes in precipitation and temperatures.

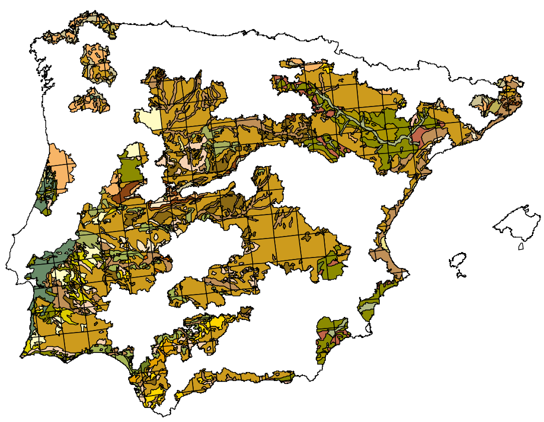

Fig. 10.3. *Soil map of the agricultural areas currently being studied. The superimposed mesh shows the cells corresponding to the Regional Climate Model (RCM) PROMES*

10.3.1.3. Water consumption by crops

The evaluation of changes in water consumption by crops was made for the CEDEX (see this Chapter, section 10.3.1.1). Fig. 10.4 highlights the smaller irrigation requirement and yield potential of maize caused by the severe shortening of the vegetative. The strategies that might compensate for the effect of the shorter are not shown. The negative impact of greater daily evapotranspiration, a consequence of the higher temperatures, can, however, be counteracted by more rapid development and by more efficient water use in an environment with a higher CO_2 concentration.

10.3.2. Livestock farming systems

10.3.2.1. Effects on ingestion of food by animals

From the point of view of nutrition, and as a consequence of the need to release the heat produced in the energy metabolism of the animals, if environmental temperature surpasses the interval of thermal neutrality, ingestion by the animals will be reduced; the temperature values defining this interval depend on the species and on its physiological state. The relationship between the temperature values involved in climate change and the references of intervals of thermal neutrality allow initial ideas to be established in relation to the possible impact on ingestion by the animals. Climate change can also affect the animals' ingestion indirectly, on conditioning the evolution of the availability of pastures throughout the year. In this sense, botanical diversity, altitude, etc., should be taken into account when evaluating the repercussions of climate change.

The behaviour of grazing animals with regard to intake is also directly conditioned by environmental temperature. In this sense, when temperature is high, for example, in the middle of the day in summer, grazing activity is practically zero, this being transferred to the start and end of the day and during the night.

10.3.2.2. Effects on animal wellbeing

Society is obviously interested in a type of animal production that respects the animals' rights to be bred in conditions of minimum stress. This fact, which initially appears to be relatively abstract and difficult to evaluate, can in fact be measured by analysing concentrations of certain substances in the bloodstream (cortisol, for example), as well as the incidence of pathological processes in the animals, resulting from the immunosuppression caused by stress.
One of the causes of stress that has most frequently been indicated is the variation in environmental temperature. The degree of influence of this factor on the wellbeing of animals is variable, and they can even die if suitable body temperature is not maintained.

10.3.3. Parasitosis with free life stages

In view of what has previously been stated, the types of impacts to be expected will subsequently be indicated. It ought to be pointed out that there is a limited number of studies involving a determined impact, and in some cases, we only avail of different laboratory studies under controlled conditions, in particular the life cycle of parasites, based on which deductions can be made with regard to the effects of determined types of climate change on the biology of the parasite and the epidemiology of the disease.

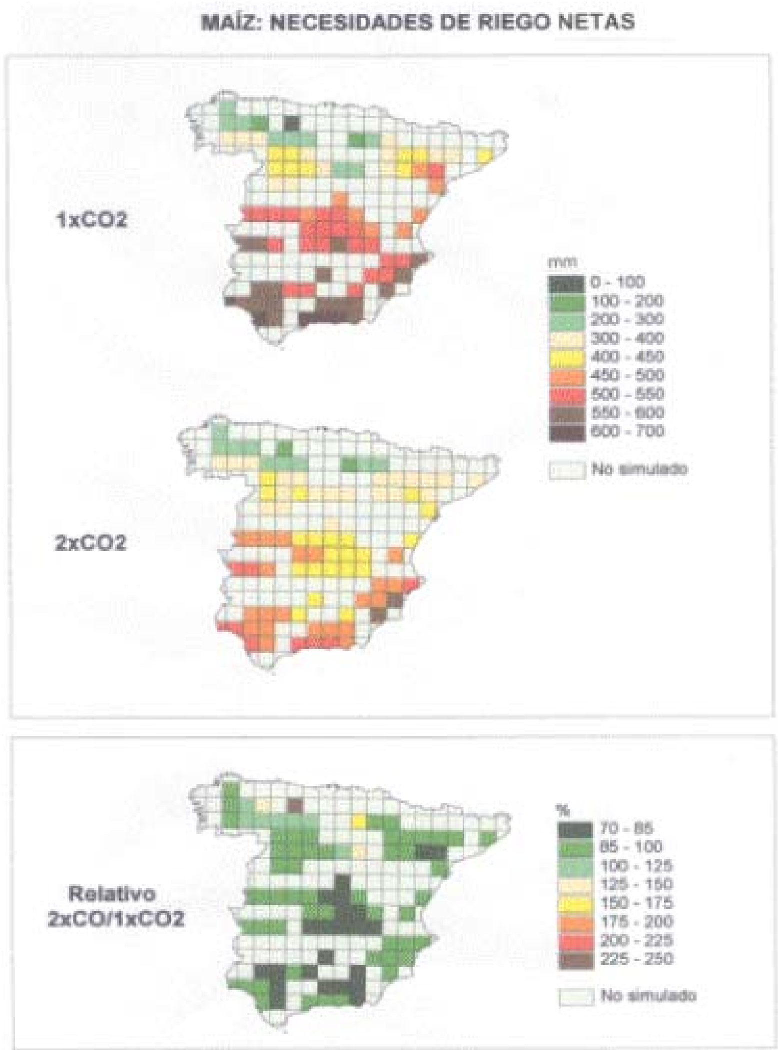

Fig. 10.4. *Studies of the impacts on the irrigation requirements (necesidades de riego) of maize, using previous versions of the climate model PROMES and the crop model DSSAT (CEDEX 1999). Irrigation corresponds to total net irrigation requirements and the adaptation strategies are not shown (e.g. changes in varieties)*

10.3.3.1. Seasonal accentuation of life cycle patterns of parasitosis with free life stages

Milder winters and increased rainfall would cause a lower death rate in all parasite populations, which would be seen in greater population numbers in springtime. This would mainly affect those animals starting to graze at this time of year. It should be remembered that young animals start to graze for the first time at this time of year. The immune system of these animals is deficient due to their age, which would cause substantially greater economic losses, resulting from the higher death rate. But this parasite population increase in winter, and the consequently high springtime parasitic load can also cause a greater summertime parasitic load, resulting from the high reproductive success of the pathogenic agents during spring. This would generate an abundant population for summertime. Although this population is expected to suffer a high death rate due to the temperature increase and to the low relative humidity to be expected during summer, the big number of individuals will cause a greater population availability during autumn. In short, the foreseeable climate changes will cause a series of changes in parasitosis at temporal scale, apart from the aforementioned geographic one, among which we can highlight:

- An increase in parasite populations during spring.
- An increase in the parasite load per host, with greater economic losses due to decreased production or death. Increased treatment costs.
- Appearance of parasite populations at times of the year in which these are not habitual.
- Application of medicaments at times of year considered optimum for treatment, but not valid in the predictable new patterns of seasonal dynamics. Error in the application of the treatment and new increases in the costs associated with the disease.

10.3.3.2. Colonisation of new areas, previously free from any given parasitic or infections processes

This type of impact derives from changes in the geographic distribution of parasitosis. Areas in which certain parasites are common would cease to be a suitable environment for these, which would disappear. Other areas that are currently free from determined parasitosis, however, could foreseeably be invaded by these. Whatever may be the case, an altitudinal and latitudinal deviation of the parasitosis influenced by climate is to be expected. For example, determined species of ticks currently existing in areas in the south of the Peninsula could move northwards, settling previously uninfested areas. In this sense, an increase in altitude can be applied in particular to valleys. Whereas a determined process may now be common in valley bottoms, the predicted climate changes may cause them to move to greater elevations. This would involve a radical change in the way animals are managed, specifically in relation to the management type known as “mountain pass transhumance”. In this type of management, large herds of animals are moved to the highest zones of mountain passes, in search of fresh pastures, free from parasitosis, due to the effect of the low winter temperatures currently observed at these altitudes. The rise of parasitosis to high-mountain pastures at greater altitudes, however, will cause a profound change in management practices. We can expect to observe this altitude effect both in helminthosis and in the processes produced and transmitted by ticks. All this will cause three clear impacts of a geographic nature:

- Increased diarrhoeic processes caused by helminths in areas where they are unknown or rare at the present time. Changes in classical treatment patterns.
- More problems caused or transmitted by ticks in areas in which they are currently unknown or rare.
- Exacerbation or disappearance (depending on the species involved) of these processes in the southern areas of the Peninsula. We should highlight the phenomenon related to the appearance of “new” diseases in areas where they were previously unknown, with the consequent problems involving diagnosis and treatment by veterinarian staff in these areas.

10.3.3.3. Substitution by parasite species on colonising areas abandoned by endemic species (immunity problems for the livestock maintained in the affected areas)

One of the effects expected is the one known as “species substitution”. In this case, parasite species that were common in a given area (to which the animals have adapted as a result of a long period of coexistence) disappear because they have not adjusted to the new climatic conditions. These species, however, are substituted by others that have been displaced for the same reasons, to which the animals have no humoral or cellular resistance. Thus, the livestock maintained in these areas is negatively affected.

10.3.3.4. Appearance of resistance to antiparasite treatments

when man is faced with an unknown situation involving parasites (seasonal change or population increase, or the appearance of new processes) his only response involves applying treatments. This higher therapeutic pressure causes the response of the parasite populations, which involves a brusque increase in the genetic selection of the population subjected to pressure by the antiparasite treatment. Resistance to the antiparasite compounds is a serious situation, and we lack the most basic measures to prevent the parasites from appearing or to re-establish the sensitivity of the parasite population to treatment.

10.4. MOST VULNERABLE AREAS

10.4.1 Dry farming systems. Arid and semiarid areas. Maintenance of soil quality. Erosion. Traditional olive groves

Dry farming systems are still the most widespread ones and the quality of the resource base should therefore be maintained in order to facilitate changes towards possible extensification, forestation or, on the other hand, intensification of the system. Within the forecasts associated with low resolution climate models (AOGCMs) these areas are the ones presenting the biggest negative impacts (IPCC 2001a). Greater resolution is needed in climatic parameters in order to discriminate in which areas the effects will be additional. These systems generate less crop residues, so soil cover is therefore low (Díaz-Ambrona and Mínguez 2001), and residue return may be insufficient to maintain soil quality.

10.4.2. Irrigation systems. Salinity and nitrate pollution

There is great demand for water in the south and southeast where fruit and vegetable production is concentrated, and where risk is high due to the low quality of irrigation water, suffering from marine intrusion into aquifers and from nitrate pollution.

Strategies for the recovery or maintenance of present water quality should be planned under future climate scenarios. For this, a fundamental step involves estimating the water needs of crops (evapotranspiration, ET) in future climate conditions. Also, one of the most difficult tasks is the transfer of forecasts of variation in precipitation to crop water supply, particularly the vegetable crops.

10.4.3. Coastal areas and marshes

A rise in sea level and possible changes in sea currents would affect cultivated marshlands. Analysis of impacts in these areas must be made in collaboration with others responsible for studying responses in coastal areas. The same applies to river mouths and deltas that would suffer changes in recharge flows, in turn causing alterations in sediment deposits and in water quality. A gradual temperature rise in coastal areas would cause a concomitant I increase in crop water demand that would exacerbate the pressure on water supply sources. In particular, increased irrigation, from subterranean waters would increase the risk of marine intrusion in coastal aquifers.

10.4.4. Distribution of livestock farming systems (extensive versus intensive) throughout the different regions

By way of an outline, intensive livestock farming systems are located in areas where there is local production of fodder for the animals or fundamentally, close to consumption centres, or where there are feasible channels for marketing the products.
Figure 10.5 se presents the distribution of the most important livestock farming species in Spain.

Apart from a few quantitatively unimportant exceptions, pig and poultry livestock farming is done intensively, on big farms with a high degree of technology.

Cattle for milk production has undergone changes towards more intensive systems, with an increase in the size of the farms and the virtual absence of grazing at the present time. Sheep breeding for milk production is in a transitory situation, and is becoming more intensified, and the farms on which the animals are permanently stabled, with no grazing involved, now represent over 30%.

Still based on the grazing system are fundamentally the cattle and sheep systems for meat production, but we should take into account the limited profitability of these calving cow production systems in intensive conditions.

10.5. MAIN ADAPTATIONAL OPTIONS

10.5.1. Change in systems

It is necessary to delimit the different areas of the Peninsula in order to establish broad lines of adaptation. The opposed effects of climate change could cause the environmental conditions in parts of the Peninsula to improve, whereas the negative effects might be disastrous for other areas.

Specific studies are also needed for more inert systems, such as crops of woody species. The olive, vineyard, citric sector and the fruit sectors in general, require knowledge of the associated tendencies and degrees of uncertainty, which will vary according to areas.

Agricultural systems will adapt towards the extensification or forestation of the areas in which instability is increasing, or where EU subsidies, if these are maintained, promote this. Intensification or stabilisation by means of irrigation constitute another possibility to be analysed.

10.5.1.1. Choice of species and varieties

The introduction of new crops under new climate conditions should be approached, in the first instance, from a strictly agronomic point of view. The initial approach would be based on productivity and the optimisation of water use. Cultivars with longer life cycles could be introduced to counteract the accelerated development resulting from higher temperatures. This step establishes crop options that can be subsequently reviewed with respect to aid or subsidies by the Common Agricultural Policy (CAP).

In the case of plantations of woody species, temperature increases, more extreme summers or the displacement of rainfall periods will lead to a reconsideration of the choice of varieties in the different agricultural regions, if we consider that reduced springtime frosts are expected.

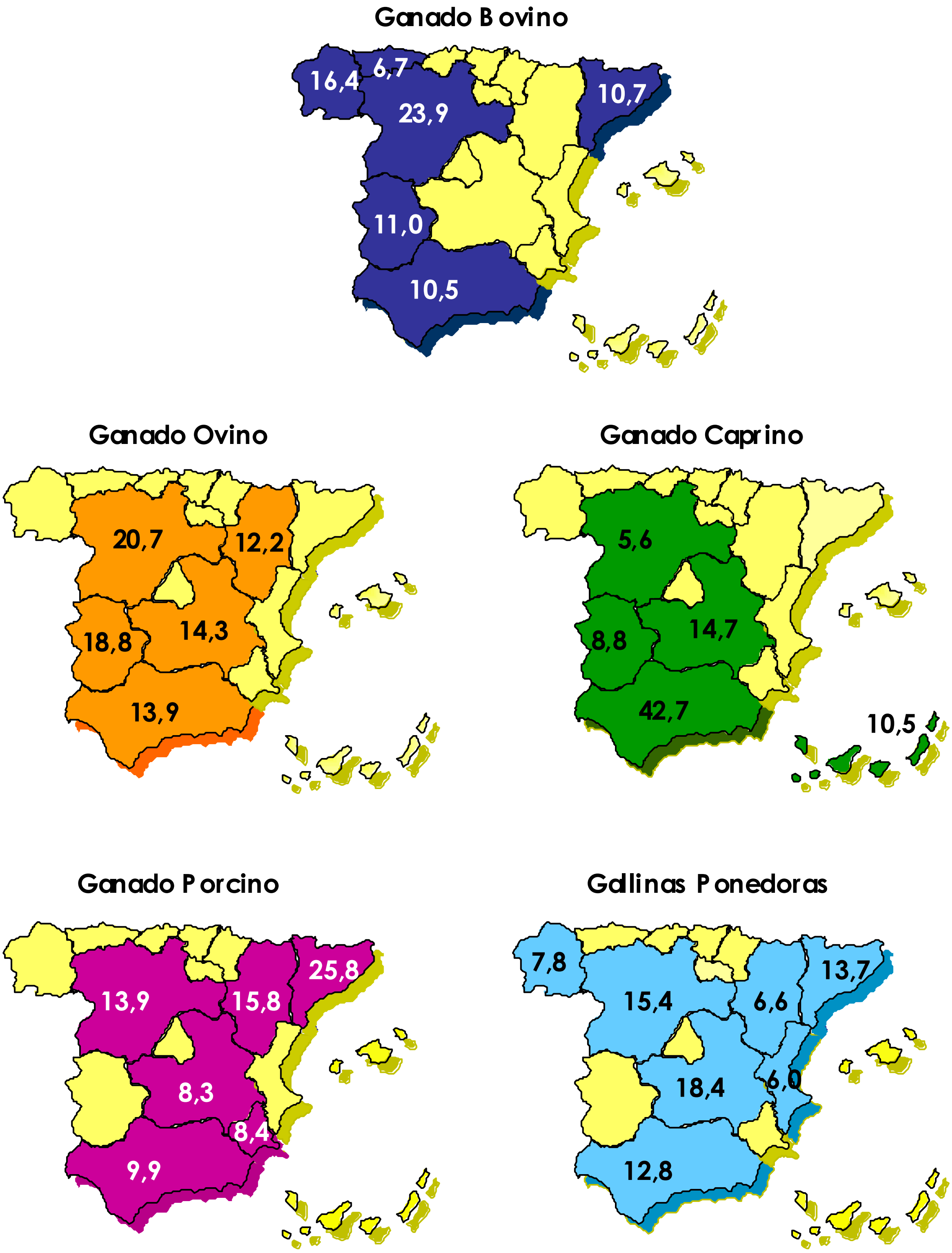

Fig. 10.5. *Distribution map of livestock inventory (Livestock survey 2003, MAPA)* (*Cattle, sheep, goats, pigs, laying hens)*

10.5.1.2. Changes in crop rotations

In areas where water is the limiting factor, sequences that optimise water use will have to be established. New areas should be delimited where agronomic fallow is vital for maintaining the stability and sustainability of the systems.

10.5.2. Adoption of new dry farming and irrigation management strategies

Once areas have been demarcated according to predictable impact, changes can be considered in cultivars, sowing dates and irrigation requirements. These are strategies that have already been well explored and which the farmer can easily adopt. Emphasis should be placed on strategies for the optimisation of resource use that have a minimum impact. Extensification (lower inputs), strategic or support irrigation and deficit irrigation are developing technologies that ought to be applied in such new environments.

New integrated design may be needed for the control of pests and diseases, as these organisms respond to future climate change.

10.5.3. Adaptation of the Common Agricultural Policy (CAP)

Collective regulations are considered by the IPCC (2001b) as one of the tools for mitigating the impact of climate change and possibly for reducing the costs of the adaptation processes. The CAP could therefore be considered within this perspective.

10.5.4. Reduction of livestock carrying capacity

The alternatives that could be considered, in view of reduced ingestion as a result of climate change, and those that would need to be contrasted previous to being applied, are the following:

- Reduction of the animal carrying capacity (heads of livestock per area unit).
- Increased needs for supplementation in grazing systems.
- Changes in the management of grazing systems.
- Higher energy and facilities costs for the maintenance of correct environmental temperatures.

10.5.5. Protecting areas against changes in uses

The effect of temperature increases, apart from those of variations in rainfall, involve a northward displacement of areas suitable for crops (as we have seen in the case of maize, wheat or barley), and above all, of vegetable production. This displacement should be evaluated, because to the direct effect of climate change on a determined areas can be added the loss of competitiveness compared with others, which can accelerate the process of transformation and abandonment of agricultural activity in sensitive areas.

10.5.6. Appraising the suitability of the habitat and invasion capacity through studies of climate and habitat

The expected climate change will cause a variation in parasitic and infection processes, as has been previously mentioned, both in space and in time. The best adaptation to the changing scenario cause by climatic variation lies in the knowledge of the precise biological and abiotic patterns regulating the association between the parasite, the pathogenic agent it can transmit and the environment. In this sense, an absolute priority involves the development of simulation models that can account for different data on the behaviour of the agent in relation to the environment, such as its capacity to adapt to the biotype (maps predicting the risk of determined pests) and models explaining the seasonal dynamics of the process to be studied. Likewise, the models should include estimates of the economic implications to be expected in the case of the different evaluable climate change scenarios. Likewise, the simulation models should include the landscape component, understood as the ecological processes occurring at microscale, which is very useful for evaluating the composition of the habitat as a determinant factor of the existence and abundance of the parasite. In this sense, we wish to insist upon the fact that models based on large areas of territory (macroclimatic models) can be of great epidemiological value, but that we must come down to the microhabitat scale, with the complexity that this involves, in order to understand the real effects of climate change on parasite populations. In relation to the models dealing with the behaviour of tick populations, important advances have been made which enable the predictable effects to be explained to a great degree. These models, however, need to be generalised to other species and to the whole geographic environment of Spain, and the resolution of the model must be increased to functional level.

There is a need for the imbrication of the models of host behaviour or of the modifications climate change can cause in vegetation, in order to obtain a broad view of the parasitic, ecological and epidemiological processes underlying climate change and acting, above all, upon all the members of the equation. Thus, a generalist model is needed, linked to general climate predictions and to the effects of changes in vegetation and in the parasite dynamics affected by these variables.

In the case of parasite nematodes, these models already exist, but the are not public, having been developed by private companies as a market strategy. It is important that these models be applied to the research sector, in order to establish suitable adaptation strategies. Furthermore, models dealing with parasitosis transmitted by freshwater snails have been suitably developed and linked to geographic information technologies, and they have a simple form of treatment, producing results that are clearly comparable with reality. These technologies, however, have never been applied to studies in Spain, and we therefore lack minimum data on the effects to be expected in conditions of different environmental variables.

10.5.7. Appropriate management, integrated into the results of the previous points, using autochthonous breeds

The use of autochthonous breeds is a correct decision with regard to optimising the control of the different parasitic and infectious diseases appearing in Spain. The breeds present a natural adaptation to these processes, resulting from a long history of coexistence. The substitution of imported breeds by autochthonous ones should therefore be considered as an interesting strategy of adaptation to climate change and to the effects of this upon predictable pathologies.

As has been mentioned, it is important to appraise the possible impact of the different management strategies derived from these models on the livestock farming economy. Factors such as the nutritional value of pastures should be highlighted. As has been pointed out, changes can be expected in the way agricultural resources are used by the animals and by their owners, tending towards the search for new areas that present a parasitic load appropriate for animal management. We should therefore take into consideration the economic factors intervening in the new relationships between animals and their habitat, as an integral part of the aforementioned models. It is also necessary to include studies of the patterns involved in antiparasite treatments, because the farmer, or veterinarian, is familiar with the life cycles of the parasites in the area in which the animals are farmed. This knowledge is almost ancestral, and is based on the continuous observation of nature. If the foreseeable variation in these processes occurs, both in space and in time, the currently established treatment patterns will be radically altered. This involves a process of adaptation by the veterinarian and by the breeder, according to the intensity of the impact, gradual, and to the exponential change to be expected in the response by the parasitic and infections processes. In other words, the time in which the adaptation will take place is expected to be a short one, and we should prepare the necessary evaluation tools to deal with the social demand that will occur during this readjustment period.

10.6. REPERCUSSIONS FOR OITHER SECTORS OR AREAS

10.6.1. Environmental impact: quality of the resource base and of the natural ecosystems

Changes in soil organic matter are difficult to predict, given the impact of management on crop residues and the complexity of the processes involved (see chapter 8). In a future scenario, predictions of water content in the soil would add another source of uncertainty. Soil organic matter directly affects the capacity for water retention and nutrient supply, with direct implications for the productivity of the system. In the areas capable of producing a greater amount of biomass, higher soil temperatures could counteract the increase in organic matter through higher mineralisation rates.

The greater runoff associated with storm-related phenomena or increased precipitation promote greater nitrate leaching, reducing the efficiency of the system and possibly affecting neighbouring ecosystems and agricultural systems. Projections based on general circulation models for Spain suggest areas with both increased and decreased annual runoff (IPCC 2001a). Higher resolution models are required to resolve these uncertainties.

10.6.2. Water demand and competition with the industrial, environmental and urban sectors

An increase in world population and in economic development generally leads to greater water consumption, in spite of a decrease in some countries, due to more efficient use (IPCC 2001a). This implies that the competition between the industrial and urban sectors with irrigation (see section 10.1.3.1) will be defined by changes in the evapotranspiration demand of the crops in response to temperature and rainfall.

Furthermore, the new demands on water supply to maintain ecological flows and the necessary resources in wetlands, lakes, etc., will also affect the availability of water for irrigation. It should be emphasised that water markets will have to adapt to an increased variability that water demand for crops might present.

10.6.3. Main repercussions for the foodstuffs and insurance sectors

The consequences for the foodstuffs sector at international level are serious, if we analyse the capacity of the agricultural systems to supply the food needed by a growing population. In this sense, we wish to highlight the more short-term repercussions for the insurance sector.

Changes can be expected in the type of damage that crops might suffer. Higher temperatures will eliminate the risk of frosts in certain areas, which will need to be identified, and will minimise it in others. The risks associated with hydric stress and temperatures will tend to increase, although it will probably be necessary to establish these probabilities according to determined areas or catchments.

Changes in the geographic limits of current crop distribution may lead to the appearance of pests and diseases in new areas. If the frequency of extreme years increases, collaboration will become necessary between the agriculture and insurance sectors, in order to establish new lines of proposals.

10.6.4. Effects of livestock farming on the maintenance of the rural population and the landscape

In many parts of the country (mountain, *dehesa*, etc.) livestock farming is practically the only activity capable of maintaining an economic tissue, as other activities such as agriculture are impossible due to climate conditions, orography, etc. At present, it seems obvious that the livestock farming in this area will have to be based on products (food, leather, wool, etc.) that can be differentiated on the market, and of guaranteed quality (traceability), and there is a growing demand for these products, because consumers are increasingly willing to buy products based on suitable conditions of animal wellbeing, or, based on grazing livestock, which has obvious benefits for environmental conservation and which makes use of resources that would otherwise be lost. The development of mass production systems in these areas would make no sense, because of the risk to the environment involved and because of the lower level of competitiveness due to being so far prom the cereal production areas. Less available pasture at certain times of year, resulting from climate change, could lead to overgrazing and to the risk of erosion in these areas, as it is not easy to vary the pressure applied by grazing (livestock carrying capacity) by decreasing or increasing the number of animals.

The number of family-held livestock farms that can be maintained in a determined area depends on their profitability, aimed at providing a minimum income for the family in question. In turn, the profitability of a farm depends on the number of animals and the production of each one of these. In order to achieve a similar income, for example, a cattle farm with mixed production (meat and milk) requires less animals than a farm that exclusively produces meat, due to the lower level of individual production of these. In recent years in the mountain regions of Aragón, Castilla y León, Catalonia, etc. There has been a restructuring of the livestock breeding system, leading to more big farms exclusively producing meat, which require less labour, and the use of the territory is not a limiting factor, due to the depopulation of these regions.
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10.7. MAIN UNCERTAINTIES AND KNOWLEDGE GAPS

10.7.1. Effect of increased variability on the stability and sustainability of agricultural systems. Effect of extreme years

The more unstable and less sustainable agricultural systems could disappear with an increase in the frequency of extreme dry years. Furthermore, a possible increase in storm-related phenomena similar to those of subtropical climates could increase the erosion of agricultural soils that are still managed with conventional tillage. For instance, current estimates of soil erosion in olive groves are excessively high, and could reach 40 t/ha year.

10.7.2. Capacity for adaptation of low productivity systems

At present, water deficit, low temperatures of long winter seasons and low organic matter content are the factors most characteristic of systems of low. The capacity of these systems for adaptation will therefore depend on the areas in which these systems are located and the predicted trends of changes in rainfall and temperature.

10.7.3. CO2 fixation capacity of agricultural systems. Influence of land and crop residue management

In order to mitigate climate change, (IPCC 2001b) have proposed reductions of CO_2 emissions. CO_2 fixation by herbaceous and woody plants through photosynthesis is one of the processes considered. Studies currently focus on estimates of net CO_2 fixation, the respiration associated with the maintenance and growth of plant biomass, and fixations and emissions by the soil, depending on the management of soil and of crop residues.

Further sources of emission of greenhouse gasses are flooded rice fields (methane and nitrous oxide emission) and the losses of nitrous oxides associated with nitrogen cycle processes in agricultural systems.

10.7.4. Adaptation capacity of the animals

Animals have defence mechanisms for adaptation to climate change that have direct consequences in terms of production. In intensive conditions, the adaptation will involve lower production rates, as the capacity for intake could be affected if the limits of the thermal neutrality interval are surpassed. Furthermore, under these circumstances, there may be a need for greater availability of space, ventilation or cooling systems, etc., and consequently, greater investments.

In extensive livestock farming systems, which depend on the availability of pastures, the possibility, within certain limits, of the body reserves of the animals being used as energy storage at times of maximum availability of resources, to be saved for times of scarcity, together with an adaptation of physiological rhythms, which would make the times of maximum nutritional need (end of gestation and start of lactation) coincide with maximum availability of pastures, are mechanisms the limits of which ought to be studied from the point of view of production.

10.7.5. Reaction times to change by parasites

At present, the response time lapse of parasites to climate change is unknown, but it is believed that the reaction would be rapid. Some laboratory studies indicate that this response could occur in one or two generations of the parasite (approximately one year), which would involve the disappearance of species that have not adapted to the new climate in this period of time, with a slower substitution by the new invasive species. Given that climate change is gradual, the aforementioned seasonal accentuation, as well as species displacement, can be expected to occur gradually and continuously.

10.7.6. Indicators

The only indicator of usefulness is the constant supervision of a series of “reference zones” chosen for their climatic characteristics, their capacity to accommodate determined parasite species, and livestock farming use. Monthly sampling in these areas can allow parasitic activity to be monitored in order to establish the modifications taking place.

10.7.7. Low spatial precision

This is one of the most serious problems in the evaluation of models that study climate change and its consequences for the population dynamics of parasites. Current climate change models evaluate big atmospheric units, 50 km being a typical unit size, which is extremely large for the models that are currently being evaluated in order to predict changes in pressure by parasites.

The characteristics of the habitat are of great importance in the distribution and abundance of certain parasitosis (for example, ticks, Estrada-Peña, in press), and systems should therefore be found that link both types of models, together with those that evaluate the probability (normally with Markovian-type methodologies) of change in the type of habitat. There is a need to evaluate the possibility of downscaling in atmospheric climate models, and to link them to those dealing with habitat change and parasite behaviour.

10.8. DETECTING THE CHANGE

10.8.1. Difficulty to detect changes: technological adaptation in agriculture

The adoption of new technologies in agriculture has prevented the detection of possible trends or changes in climate over the last century. Modifications in cereal crop cultivars in the 60s, during the Green Revolution, led to spectacular increases in yields, and production thresholds were raised in agricultural systems around the world. New irrigation and fertilisation techniques, as well as the control of weeds, diseases and pests have all contributed to much higher yields.

10.8.2. Use of dynamic crop and climate simulation models. Generation of indicators

Dynamic crop simulation models are capable of providing daily information on the processes of interception of solar radiation by leaves, the generation and partition of biomass,, balances of water and nitrogen, and finally, the generation of yield. The capacity to quantify interactions between crops, specifying cultivar, soil and climate, makes these models very powerful tools for both research and agricultural planning and development. Although these models were developed initially for herbaceous crops, more recent development includes versions for woody crops also.

The results obtained from these models of yields, biomass production, water consumption, irrigation needs and phenology are now used to calculate indictors that integrate interactions on productivity and performance throughout the crop cycle (Díaz-Ambrona and Mínguez, under review).

10.8.3. Availability of production data on livestock farming systems over long time series

The dynamic models used in studies of livestock farming systems enable a prediction to be established of the response by the animal to changes in environmental conditions (humidity, temperature, etc.) in housing conditions (intensive).

Under grazing conditions (extensive) it is also possible to predict the effects of climatology (humidity, temperature, etc.) on the response by plant production in a determined area throughout the year. Based on the available quantitative and qualitative information of plant matter, it is possible to predict ingestion rates by the animals, and, having established the animals' needs throughout their production cycle, it is also possible, through extrapolation, to establish to what degree these needs have been covered and when food supplementation is needed, when the animal carrying capacity should be reduced or when there is a need to establish land use systems aimed at making use of the different availability of food throughout the year (for example, the classical systems of livestock transhumance).

There now exists scientific-technical information that would allow for the creation of these models, but there is a lack of available data on animal response over long time series, which is practically non-existent, as the available information, for example, on variation in animal inventories in the different regions, is provided by a host of converging factors.

10.8.4. Indicators (key species such as mosquitoes and ticks)

There is a series of parasites that respond rapidly to climate changes, such as mosquitoes and ticks. Suitable monitoring of these parasite populations, in a series of key sites (chosen for their ecological characteristics) could facilitate a real evaluation of the impact of climate change on this groups of parasites, and help to establish the importance of these factors in the transmission of infectious processes by these vectors.

10.9. IMPLICATIONS FOR POLICIES

10.9.1. Changes in Common Agricultural Policy (CAP). Incentives for the adoption of technologies with less environmental impact in future climate scenarios. Agricultural insurance

Co-ordinated action by several countries can help to reduce the costs associated with the development and implementation of mitigation strategies. The CAP can be considered as the framework for future collective regulations promoting the innovation necessary for adaptations (IPCC 2001b).

Incentives for the implementation of crop systems with less environmental impact in the present climate constitute one of the first steps for assisting transition to crop management systems in future climate scenarios. Indeed, the environmental impact of inappropriate management of land or crop residues, inefficient use of water for irrigation, nitrate pollution, etc., that are currently a concern, will have more serious affects in scenarios of greater seasonal or interannual variability andr water deficit.

Agricultural insurance in Spain could constitute one of the pillars able to sustain specific agricultural systems in areas subjected to the negative impact of climate change.

10.9.2. Land planning

The division of climate change into large impact zones, both positive and negative, would be a basic step for hydrological planning and for other resource-use issues. The productivity of the various agricultural and crop systems in each distinct zone would facilitate the establishment of action proposals.

10.9.3. Optimisation of water uses. Management of water resources

Given that the Iberian Peninsula, and specifically Spain, is located in a transition zone between subtropical and Mediterranean climates that, according to IPCC (2001a), are affected differently by water shortage, the issue of water management is likely to provide the most complex challenges. Management of water distribution among the sectors involved should give priority, among other fundamental economic and social considerations, to the systems that optimise water use, measured as the water-use efficiency of rainwater or that used for irrigation. Water planning should include analyses of such quantifiable concepts as sustainability, productivity, stability and equity of the systems.

10.9.4. Changes in animal management

The effect of climate change on livestock farms has the peculiarity of coinciding with the aforementioned tendency towards an intensification of livestock breeding systems. It is in these systems, which are becoming increasingly intensified, that the economic repercussions of climate change are greatest, as they will lead to reduced yields and an increase in investments aimed at counteracting this effect. A shift towards extensive systems would allow for greater capacity to react to changes, but the limitation constituted by the human factor (farm labour) makes this shift very difficult at the present time.

10.10. MAIN RESEARCH NEEDS

The decision-taking process for the mitigation of the effects of climate change will be a sequential process within an environment of uncertainties (IPCC 2001b) that are being quantified and reduced as research advances.

10.10.1. Simulation models as tools for evaluating impacts. Connection with high resolution regional climate models.

The methodology to be applied is currently being generated in the PRUDENCE research project within the V EU Framework Programme (PRUDENCE: *Prediction of Regional Scenarios and Uncertainties for Defining European Climate Change Risks and Effects*, EVK2-2001-00156).

10.10.2. Generation of impact maps and proposal of indicators for strategy design

Crop productivity is one of the most important indicators, as this integrates the effects of all the environmental factors to which the crops have been subjected through their growth and development. Productivity in relation to the area used (yield), in relation to ET (WUE), and in relation to the amount of irrigation water (IUE) are quantifiable and have represented technological changes down through the years.

The impact of climate change can be assessed with this type of indicator on maps representing the various types of soils and main crops or plantations, thus facilitating economic analysis.

10.10.3. Forecasts of changes in water consumption by dry farming and irrigation systems. Effects on the National Irrigation Programme and the National Hydrological Plan

As was explained in section 10.4.2, the application of the forecasts of variation in precipitation to the available water supply for crops, although feasible, is difficult. The availability of water for orchards, olive groves and vineyards is one of the vital themes for study, that can only be made in connection with the other sectors involved in this project. A fundamental step involves the establishment of water or ET needs of crops in future climates.

Greater knowledge of the response of crops to changes in CO_2 concentration, improved simulation of crops and of impacts, and the improvement of databases currently being developed, allow for the generation of impact maps that would establish the agricultural zones and trends of change.

These plans can be considered as future collective regulations for promoting the innovation necessary for adaptation, as presented in a generic fashion in IPCC (2001b).

10.10.4. strategies for the conservation of the resource base

Given the area of dry farming systems and of their low-productivity, their inclusion in impact assessment studies is recommended. Soil quality is directly related to capacity for water retention, the return of crop residues to the soil, the maintenance of cover in the plantations, mineralization rates of organic matter, etc., and all of these factors are affected by the management techniques adopted by the farmer.

The establishment of broad lines of action is being considered for the different crop systems, such as the "*Good Agricultural Practices*" by the FAO).

10.10.5. Effects of extreme years, forecasts and adaptations

An evaluation of the impact of extreme years using the previously described methodology, would serve as the basis for the economic analysis necessary for choosing suitable mitigation strategies in the context of sustainability, and equity (IPCC 2001 a and b) .

10.10.6. Animal response (intake and wellbeing) and capacity for adaptation to climate changes

The research needed to reliably predict the effects of climate change would involve establishing the effect of variations in temperature, humidity, etc., on ingestion capacity, and the parameters indicating animal wellbeing, and, consequently, learning of the effects on animal response and the quality of products obtained in these conditions. With this information and that available from previous experiences, dynamic models could be constructed, which have been described in section 10.8.3.

10.10.7. Economic evaluation of the effects of climate change on production

Economic evaluation of the effects on productivity and on the implementation of adaptive measures should be based on quantifiable indicators as proposed, not only by the agricultural sector, but also by others, such as water resources, edaphic resources, insurance sector, forestry sector.

This would enable a more complete study than a simple cost-benefit analysis, Recommended techniques are a multi-criteria analysis and compromise programming.

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