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The role of biotic and abiotic stress factors on sheep welfare: The example of parasites and climatic changes in European countries

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Abstract. Traditional Mediterranean small ruminants' production systems mostly involve local breeds, which are kept in outdoor conditions with natural ligneous vegetation and cereal stubble, as major dietary components. Biotic stress factors, in particular, gastrointestinal nematodes remain one of the main threats for the health and the welfare in such 'low input' production conditions. Gastrointestinal parasites can cause production losses, increased susceptibility to other diseases and/or pests, and even death. Abiotic stress factors (e.g. temperature stress and imbalanced diets) are known to result in significant reductions in yield and product quality and may increase the susceptibility of animals to parasites and other diseases. Predicted changes in climate are expected to increase heat stress incidence, especially in Southern Europe. Abiotic stress is also known to increase the susceptibility of sheep to gastrointestinal parasites. The predicted impacts of climate change include increased heat stress, changes in semi-natural vegetation cover used for grazing, damaged ecosystems, and rising sea levels. The actual effects are predicted to heterogeneous and to differ between regions. Yet, in most cases, the negative effects are expected to outweigh the benefits and disproportionately hurt traditional small ruminant farmers which in many regions are among the poorest population groups, and have the least capacity for adaptation. Climatic changes will reduce grain yields, will impair pasture composition, quality and quantity, will direct affect pathogen prevalence, incidence and severity and thereby influence animal health and productivity and resource (especially feed) use efficiency. Adaptation of livestock to the more variable environmental conditions predicted as a result of climate change should therefore be a primary focus of R&D focused on improving small ruminant management and breeding systems/strategies. A particular focus should be on improving the sustainability and robustness via the utilization of robust, indigenous breeds rational waste utilisation and management, development of more balanced diets and re-integration of (and nutrient cycling between) local small ruminant and crop production systems.

Keywords. Stress – Sheep – Gastrointestinal nematodes – Climatic changes.

Le rôle des facteurs de stress biotique et abiotique sur le bien-être des ovins: L'exemple des parasites et des changements climatiques dans les pays européens

Résumé. *Les systèmes de production traditionnels méditerranéens des petits ruminants concernent surtout les races locales, qui pâturent et qui utilisent la végétation ligneuse et les chaumes de céréales comme principaux composants alimentaires. Les facteurs de stress biotique, tels que l'infestation par des parasites gastro-intestinaux, restent l'une des principales menaces pour la santé et le bien-être des petits ruminants élevés en conditions extensives. Ces parasites gastro-intestinaux peuvent provoquer des pertes économiques dues aux baisses de production, aux coûts de la lutte, à une augmentation de la sensibilité aux maladies et parfois même la mort des animaux. Les facteurs de stress abiotique (ex : température, régimes alimentaires déséquilibrés) sont connus pour influencer la quantité et la qualité des productions* et ils peuvent augmenter la sensibilité des animaux aux parasites et autres maladies*. Selon les prévisions de changement climatique il faut s'attendre à une hausse du stress thermique, en particulier dans le sud de l'Europe. Ce stress thermique est aussi connu pour augmenter la sensibilité des petits ruminants aux parasites gastro-intestinaux. L'impact du changement climatique comprend une augmentation de la chaleur, des modifications de la végétation seminaturelle, le bouleversement des écosystèmes et l'augmentation du* *niveau de la mer. Les prédictions sur les effets réels sont hétérogènes et spécifiques à chaque région. Pourtant, dans la plupart des cas, il est apparent queles effets négatifs sont supérieurs aux effets bénéfiques et qu'ils toucheront spécialement les éleveurs de petits ruminants, un groupe de population peu favorisé et à faible capacité adaptative. Le changement climatique va réduire les rendements en grains, affaiblir la qualité et la quantité des pâturages, affecter la prévalence, l'incidence et la sévérité des pathogénies , influençant l'état de santé et la productivité des animaux. L'adaptation de l'élevage dans un environnement en mutation devrait être un élément clé dans tous les choix et stratégies de recherche et développement. Ces stratégies devraient soutenir le développement durable et une gestion moderne de la production animale qui inclura l'adaptation de systèmes d'élevage appropriés, la sélection de races indigènes robustes, la gestion rationnelle des déchets et des régimes alimentaires équilibrés, ainsi que la ré-intégration (à travers des cycles de nutriments) entre systèmes de production de petits ruminants et de cultures.*

Mots-clés. *Stress – Moutons – Nématodes gastro-intestinaux – Changements climatiques.*

I – Introduction

Small ruminants (sheep and goats) are a major component of the dairy sector in the Mediterranean basin. Sheep and goat production often occupies marginal lands that are unsuitable for crop (including feed crop) production. As such, the major areas where sheep production is the dominant agricultural activity are often relatively mountainous and/or arid regions, for example the hills of the northern Europe and the Mediterranean basin (Dyrmundsson, 2006; de Rancourt *et al.*, 2006). However, sheep and goats are also widely distributed as part of diversified farming systems and have a role in the conversion of grain and other feed crops into meat, milk and wool, as well as forming an important part in nutrient cycling into crop rotations. Local tradition and demand for sheep products, not only basic economics, underpin the wide distribution of grazing-based systems of small ruminant production and in semi-natural environments they deliver important environmental benefits such as biodiversity conservation, wildfire risk reduction and landscape management (de Rancourt *et al.*, 2006).

Climate change is projected to increase the average temperature, affect rainfall pattern and increase the length of the growing season in Europe (e.g. IPCC, 2007). The projected influence on the timing and volume of crop biomass production is expected to affect a number of interlinked ecosystems. Changes in the timing and length of the growing season may not only have far reaching consequences for plant and animal ecosystems but persistent increases in growing season length may lead to long-term increases in carbon storage (White *et al.*, 1999) and changes in vegetation cover which may in turn affect the global climate system (Robeson, 2002; Linderholm, 2006). It is estimated that there has been an average global decadal increase of 0.13^{o}C between 1956 and 2005; a further increase of around 0.4^{o}C is expected within the next 2 decades (IPCC, 2007). Changes in the phenology, distribution and biomass of several species in response to climate change have been observed worldwide; a meta-analysis of published data for over 1700 species from a range of taxa, estimated that the range limits of these species had shifted on average 6.1 km (±2.4 km) per decade towards the poles. Other species have shifted their range to higher altitudes. In addition, the timing of spring events such as frog breeding and tree budburst has advanced, on average, 2.3 days per decade (Parmesan and Yohe, 2003).

Parasitic helminths are commonly found in all ruminant species and farming systems worldwide. The economically most important helminths are members of a group of gastrointestinal nematodes, lungworms or trematodes (liver and rumen flukes). Among the gastrointestinal nematodes, *Teladorsagia circumcincta, Haemonchus contortus, Trichostrongylus* spp. and *Nematodirus battus* have become the major production-limiting nematode parasite species affecting sheep in temperate climates, with their relative importance being influenced by regional and temporal differences in climate and sheep management. Other genera, such as *Cooperia*, *Chabertia*, and *Oesophagostomum* can be important in some contexts but usually as part of a mixed parasitic infection. Parasites reduce the animals' productivity by feeding on the host or its blood (e.g. *H. contortus*), taking up nutrients from the hosts' gastrointestinal tract, damaging the absorptive lining of the gastrointestinal tract and stimulating the immune system (Greer, 2008). The outcome is inefficient feed utilisation, inducing a state of relative protein deficiency, fluid and electrolyte or macro-element imbalances and anaemia, leading to clinical signs, such as hyporexia, daily weight gain decrease, diarrhoea, and in some cases death. The uptake of parasites is ubiquitous in grazing sheep and control of parasitism is generally achieved by frequent administration of anthelmintic drugs to suppress egg output and consequently decrease infection pressure. The spread and increasing prevalence of resistance to anthelmintic drugs, however, threatens the efficacy of this control approach and the sustainability of nematode control in sheep (Coles, 2002). Overall, the greatest economic importance of nematode parasites is suboptimal productivity arising from continuous low-level exposure to infective larvae (Coop *et al.*, 1982).

In relatively recent times, the evolutionary balance between parasites and, for example, their sheep hosts has been upset by domestication and the subsequent development of intensive livestock management practices, which create environments that are suited to the development and survival of free-living stages of the parasites, enhance sheep exposure to infective larvae, inadvertently alter the host innate or adaptive immune responses to infection and thus enable exposure to previously unrecognised parasitic nematode species or strains. Furthermore, these conditions may have affected different parasitic nematode species to differing extents, upsetting the equilibrium that may exist within the sheep host between different parasites (Mapes and Coop, 1973; Dobson and Barnes, 1995), affording a competitive advantage to some and allowing potentially pathogenic species to predominate.

If the above mentioned changes in climate are sustained as predicted, various effects on sheep and goat production could be foreseen. Climate influences the abundance of infective larval stages of parasites via direct effects on the development and survival rate of the free-living stages in pastures leading to an increase of animals' infection rates (O'Connor *et al.*, 2006). Also, the spatial distribution of different species and the fauna is closely related to climatic conditions. Fig. 1 shows some ways in which climate change may affect different parasites species and therefore the risk of disease. The consequences of climate change are, therefore, particularly important in helminth parasites because of its potential impact on their free-living stages and/or their intermediate or paratenic hosts.

II – Climate and parasites

The rates of physiological processes in the majority of invertebrates are highly dependent on ambient temperature. The existing level of challenge and seasonal patterns of infection also show climate-driven spatial variation (Smith and Grenfell, 1994; Kao *et al.*, 2000; O'Connor *et al.*, 2006, Morgan, and van Dijk, 2012).

Changes in climate might be expected therefore to have a direct effect on parasite distribution, abundance, and population dynamics leading (depending on the species) to an increased or a decreased prevalence. For example, eggs of the several ovine trichostrongylids develop into the infective third larval stage (L3) above a threshold of around 4°C, some species, such as *H. contortus*, have a higher threshold of around 8°C (Kao *et al.*, 2000; O'Connor *et al.*, 2006). Above the threshold, development rate is proportional to temperature. The rate of this increase, which is likely to be an important determinant of the response of these nematodes to global warming, varies between species. Since mortality also increases within increasing temperature, optimal temperatures, at which the maximum number of larvae is produced from a given number of eggs, are difficult to predict. The optimum temperature for development also varies in a large range from 16.30°C for *T. circumcincta* to 25.37°C for *H. contortus* (O'Connor *et al.*, 2006). Early stage larvae (L1 and L2) are more vulnerable to extreme temperature and desiccation than L3, the last are able to withstand much harsher conditions. L3 can survive to for several months in water at 3°C; they are destroyed by freezing (Jasmer *et al.*, 1987; O'Connor *et al.*, 2006). At higher temperatures, L3 survival declines with increasing temperature. In part, this is due to the persistence of the second larval stage cuticle, while protecting them from adverse environments effects, it enables it from feeding, leading to a decrease of lifespan when temperature decreases. Thus, L3 *H. contortus*, for instance, has a population half-life of around 93 days at 12°C and only 9 days at 28°C (Barger *et al.*, 1972; O'Connor *et al.*, 2006).

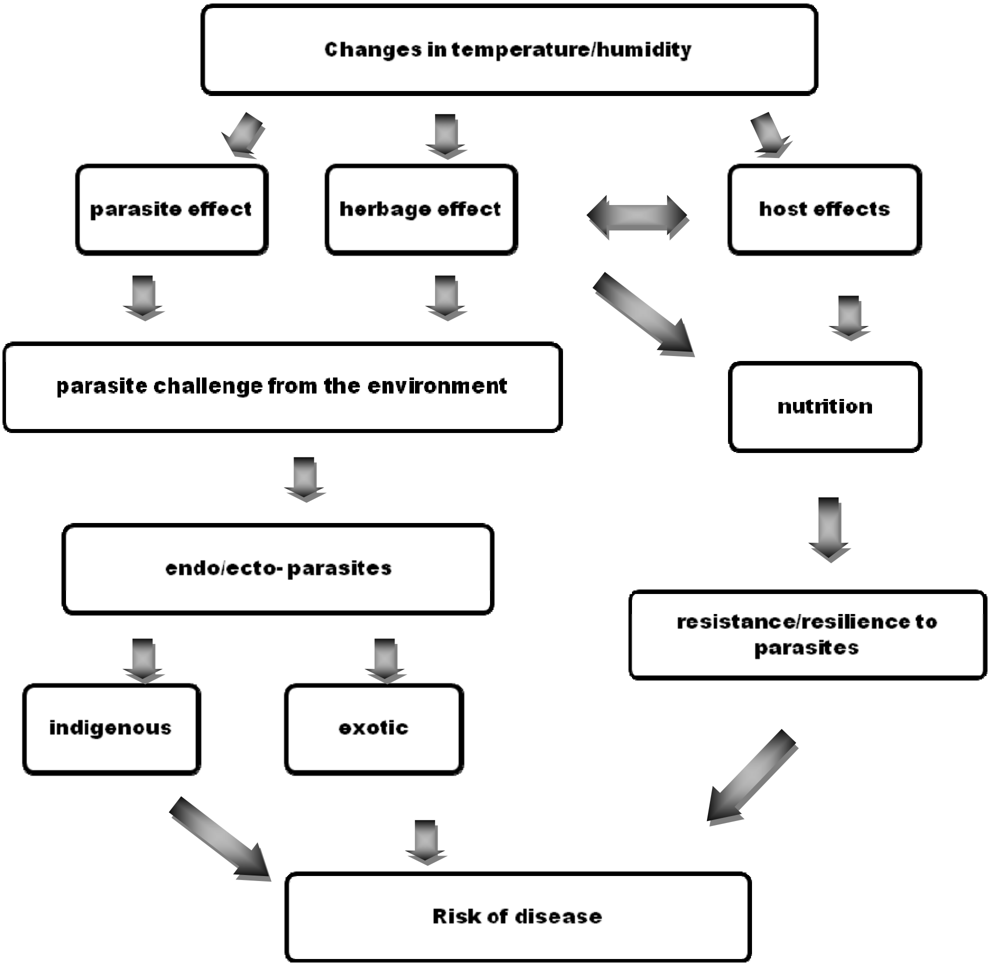

Fig. 1. Scheme on how climate change may affect different parasites and the risk of disease (Kenyon *et al.* 2009, modified).

Other climatic variables can also have high impact on L3 survival. For example, desiccation and ultraviolet irradiation increase mortality, but there are differences in susceptibility between parasite species (Kao *et al.*, 2000; Van Dijk *et al.*, 2009). At 25°C in water, continuous exposure to ultraviolet radiation at comparable levels to temperate areas resulted in the death of over half of *H. contortus* L3 population within 5 days, *T. circumcincta* within 3 days and *N. battus* within 2.5 days (Van Dijk *et al.*, 2009). Under natural solar irradiation in the United Kingdom, the mortality rate of trichostrongyloid L3 was lower than under artificial ultraviolet irradiation, but was more than twice higher that of sheltered control L3 in sunny days (Van Dijk *et al.*, 2009). In the field in Europe, high temperatures often occur alongside dry and sunny conditions, so desiccation and ultraviolet irradiation should be considered in addition to temperature when estimating the persistence of L3 in pastures. In temperate regions, the seasonality of trichostrongylid infections in ruminants is driven by temperature variation (Roberts and Grenfell, 1992; Stromberg, 1997). Thus, the L3 of most species overwinter well on pastures and remain infective for especially newborn lambs. Increasing temperatures through spring accelerate development and result in rising L3 levels on pasture through summer, before immunity establishment, decreasing stocking rates and slower development lead to falls in L3 levels in autumn and through winter (Armour, 1986; Smith and Grenfell, 1994). Most clinical cases of nematode infection therefore occur in growing lambs in late summer (Van Dijk *et al.*, 2008). Where L3 survival over winter is low, especially for *H. contortus* in cooler climates, survival in the host becomes relatively more important and hypobiosed larvae in the mucosa play a large role in carrying infection from year to year (Waller *et al.*, 2004). In milder climates, temperature can be high enough during autumn and winter to allow development of some species, such as *Trichostrongylus* spp. and, possibly, *T. circumcincta* to the infective stage, so that extended end-of-season grazing carries an elevated infection risk (Van Dijk *et al.*, 2008).

III – Climate and husbandry

Parasites' infection patterns are impossible to understand and predict and control without considering sheep management/husbandry systems. Management systems vary between regions and are themselves strongly influenced by climate (Chiotti and Johnston, 1995). Understanding the interactions between climate, larval availability and sheep management practices therefore provides the key to designing effective and sustainable parasite control programmes (Barger, 1999).

Climate change is likely to affect many aspects of animal husbandry, both directly and indirectly. For example, it may influence the reproduction cycles, housing period and duration, sheep diet's quality and quantity, breed selection, and management interventions such as shearing. Changing growth patterns of grassland and semi-natural vegetation used for grazing, for instance, may change grazing pattern, with strongly affects the seasonality of parasite infection. Thus, in temperate grasslands, global change is predicted to increase grass growth early and late in the year and could extend the grazing season (Fitzgerald *et al.*, 2005; Keady *et al.*, 2007), while decreasing rainfall in more arid areas could, conversely, increase the need for grain/conserved forage supplementation during the dry season (Nääs *et al.*, 2010), and possibly increase housing periods. Some parasites, such as lice, are transmitted more efficiently in housed or constrained livestock, whereas for others such as gastro-intestinal nematodes longer grazing seasons into a warmer and wetter spring or autumn may result in a stronger challenge and/or longer period of exposure. As well as effects on overall parasite abundance, changes in the timing of transmission could affect disease risk in a non linear way, for example by exposing livestock of different age or nutritional status to infestation (Colditz *et al.*, 1996; Bianchi *et al.*, 2003; Faccini *et al.*, 2004). Climate change may indirectly affect host susceptibility, for example via increasing nutritional stress by reducing the digestibility of protein in grass grown at higher temperatures (Craine *et al.*, 2010). Poor nutrition from grass could in turn be offset by increased legume growth (and availability of feed crops) due to higher atmospheric CO_2 concentrations (Campbell and Stafford Smith, 2000). Interactions between crop growth, parasite transmission patterns and livestock susceptibility are, therefore, likely to be strongly modified by management.

There is a great diversity of small ruminant production systems. They may have contrasting grazing practices, production cycles and economic expectations and, therefore, modify the climate-driven epidemiology of nematode infection outlined above. For example, management systems, and the sheep breeds varies depending on whether meat, milk or wool production is the primary aim. Meat is mainly produced from lambs in their first year of life, which in many regions are grazed following lambing at the beginning of the season during which forage is most abundant. In some locations, lambs are finished on grain or other feed indoors or kept over the winter for finishing in the second grazing season. To maximise use of grass, especially in dry summer or cold winter period, and/or to achieve more convenient utilisation of feed, seasonal movement of sheep (e.g. through transhumance) is still used in mountainous regions (Vatn, 2009). The extent and timing of grazing therefore varies widely depending on location and sheep production system and this has a major effect on the level and timing of nematodes' challenge. GI nematodes infection, for instance, is generally much attenuated in housed or very early lambing flocks. The selection and development of sheep farming systems takes place in a complex environment and is shaped by physical (including climatic) factors, as well as immediate and more general aspects of agricultural economics/timing of demand for lamb and dairy products (de Rancourt *et al.*, 2006). Although much academic research on the factors shaping livestock production systems has focused on economic and social factors (Pardos *et al.*, 2008; Sturaro *et al.*, 2009), climate is increasingly recognised as an important factor, since the majority of systems rely on grazing/pasture growth, which depends on temperature and rainfall (Chiotti and Johnston, 1995).

The production system will affect the age structure of the sheep population, stocking density, seasonality of grazing and many other factors that underpin the epidemiology of nematode infection. Precisely in the case of meat lamb production on pasture, the scenario involves high concentrations of susceptible hosts (i.e lambs just after weaning which have no fully developed immunity) and potentially rapid cycling up of infection, while co-grazing with lactating ewes which contaminate the pasture with nematode eggs especially during the periparturient rise (Armour, 1986). The impact of infection on growth rates of untreated lambs is likely to be high, and financially highly significant, because of small margins and a need to finish lambs early. By contrast, milk production system involves mainly ewes, having already, at least a proportion of them, acquired immunity to these parasites leading to more tolerable low infestation intensities. However, as milk production is concentrated in warmer parts of Europe, *H. contortus* is more likely to cause problems and immunity to this species is not as strong as to other trichostrongylids species. By virtue of its high biotic potential and rapid development in warm conditions, *H. contortus*, can cause sudden disease outbreaks. In meat lambs, nourished by milk produced by ewes affected by the emergence of hypobiosed larvae in the spring, growth rates could be adversely affected. The timing of lambing and weaning in relation to peak of challenge can therefore strongly influence the epidemiology of nematode infection in sheep. In parts of Europe, where autumn and winter temperatures determine the duration of the grazing season, and, thereby, the likelihood of finishing meat lambs on grass, it is likely that global warming will provide farmers with an opportunity to lamb earlier in the year. This can be achieved through the use of either reproductive control methods or by using breeds, such as the Dorset, with the capacity to achieve reproductive activity for long periods. The potential impact of using such breeds on the epidemiology of gastrointestinal nematodes may vary significantly between parasite species. For *H. contortus* (which predominantly over-winters in its host) the effect of early lambing would expected to be marginal, assuming that the time frame between the periparturient rise and the onset of egg development and grass growth, would remain constant. In the short term, any decoupling of the timing of lambing and outdoor temperatures consistent with parasite development could negatively affect *Haemonchus* populations. In contrast, for *T. circumcincta* (where a large proportion of the parasite population over-winters at pasture), the overall effects may vary strongly between years and are likely to depend on an interplay between autumn and winter temperatures. A warm autumn may result in high numbers of L3 at pasture; thus, bringing the lambing season forward could result in heavier infections of lambs during winter or early spring. The importance of the phenomenon will depend on winter temperatures. Warmer winters are likely to negatively influence survival of L3 of this originally

Arctic species in pasture (Van Dijk *et al.*, 2008), thereby potentially nullifying any increased autumn development. Then again, if either lambing is brought forward sharply or a warm autumn is followed by a cold winter, first generation teladorsagiosis may be observed in young lambs (Sargison *et al.*, 2002). *Nematodirus* spp., overwintering at pasture but inside the eggs, is unlikely to be influenced by warmer winters. An earlier lambing season would be predicted to desynchronise the traditional availability of young, susceptible lambs with a spring hatch of *N. battus* eggs, thereby negatively influencing populations of this parasite. However, as both temperatures and ultraviolet levels are low over winter, larvae hatched in autumn are likely to survive very much longer than those hatching in spring. This, combined with a climate-change driven pressure on the parasite to hatch from non-chilled eggs in autumn, could realign the availability of larvae with the presence of non-immune young lambs at pasture in autumn or winter and lead to severe, unexpected, disease establishment. While such modelling studies are valuable, they often assume either that production systems are fixed or that they can be changed easily in the interests of parasite control. In actual fact, dramatic changes in parasite challenge can be driven by small changes in farm management, even if they are motivated by other factors than parasite control (Morgan and Wall, 2009). General advances in understanding the effect of climate on parasite epidemiology will be made by integrating the climatic factors that shape production systems with those that drive nematode epidemiology, but such approaches have yet to gain traction in Europe.

Additionally, patent increase in disease incidence are likely to provoke changes in farmer behaviours that could include altered husbandry practices as well as changes in their approach to chemical prophylaxis and reactive treatment (Morgan and Wall, 2009). A change in the perception of disease risk may lead to changes in approach to intervention, with perhaps a greater willingness to prevent or treat earlier. Since, once triggered, intervention is often targeted at an entire group of animals, irrespective of individual susceptibility, the overall effect may be a reduced incidence of infestation. It must also be borne in mind when considering impact of any changes in climate that livestock face a range of parasites and other health problems, and interactions between them are common. Furthermore, farmers are also likely to respond in a way that maximises overall productivity within the context of the farm and market environment. Farm adaptation to climate change depends strongly on human as well as biophysical factors, and the interactions between them at farm and global levels are only beginning to be properly appreciated by the research community (Chiotti and Johnston, 1995; Olesen and Bindi, 2002; Kabubo-Maraira, 2008; Boomiraj *et al.*, 2010; Morgan, and van Dijk, 2012). These interactions are likely to become even more complex as policy seeks to mitigate greenhouse gas emissions from livestock production (Gill *et al.*, 2010).

Hence, the factors affecting management of livestock are often as complex as those affecting the biology of their parasites, and need to be taken into account when attempting to predict the effects of climate change.

IV – Future climate-driven challenges

Sustainability is even more important when it comes to animal production systems. This translates to the development of such production systems that will produce high quality products with the lowest possible negative effects for the environment. The latter refers not only to the climate but to the protection of environment (water, air, soil, landscape, biodiversity ...) in order to achieve sustainability. Especially as regards sheep and goats breeding parasites are among the most important animal health and welfare problems and a major cost factor in sheep production in Europe. Due to the intensification of production, the use of anthelmintics and antibiotics to control these diseases has increased rapidly over the last 20 years. With increasing anthelmintic resistance, there is a need to target treatment more effectively, to suppress nematode infection below economically damaging levels, while preserving susceptible genotypes in refugia (Van Wyk, 2001; Coles, 2002).

It is widely accepted that animals with large population sizes and high genetic diversity, as well as many endemic parasites, are in a strong position to be able to adapt to any stress factors, including those posed by climate changes. Renewed appreciation of the influence of climate on nematode epidemiology is therefore essential and, in the modern era, can be supplemented by improved quantitative understanding of the effects of climate and management, and interactions between them, on larval availability and infection of sheep (Smith and Grenfell, 1994).

Such understanding can be used, inter alia, in order to (i) predict main infection periods and intervene accordingly, (ii) track the fate of eggs produced by resistant nematodes and ensure adequate dilution in refugia and (iii) model effects of climate changes and suggest rational strategic and farm level responses accordingly.

Early evidence suggests that, on balance, global warming will increase nematode challenge to grazing sheep in temperate Europe, with faster development of L3 in summer and prolonged development into autumn outweighing effects of lower survival in milder winters for *Teladorsagia* and *Trichostrongylus* spp., while milder winters would facilitate overwintering survival of *Haemonchus* spp. L3 (Van Dijk *et al.*, 2008).

Drier summers could compensate to some extent, especially in southern Europe, by limiting development of larvae in summer. However, drought would also substantially reduce grass growth and the viability of summer grazing for sheep production, so the potential benefits of a reduced parasite challenge might not be realised.

Any response to increased nematode challenge that relies on increasing anthelmintic use is likely to be self-defeating through the development of drug resistance. This applies to targeted treatments, as well as generally increased treatment frequency in summer. For example, dose-and-move is likely to select for resistance most strongly if timed to coincide with clean pastures (Waghorn *et al.*, 2009) and if increasingly undertaken in dry summers, as they become more frequent with climate change, could select even more rapidly for resistance.

Similarly, treatment of sheep during winter in colder climates targeting *H. contortus*, on account of low overwinter survival on pasture (Waller *et al.*, 2006), would enable surviving resistant parasites to quickly dominate. Mathematical and simulation models of nematode population dynamics can improve predictive ability in the face of variable nematode challenge and focus judicious use of anthelmintics in the present and in the future. The available toolkit includes general models aiming to improve strategic understanding of nematode epidemiology (Smith and Grenfell, 1994) and farm-specific models for decision support (Learmount *et al.*, 2006). However, application of predictive models to practical nematode control in Europe has been limited to date. Models that require real-time detailed climatic data produce predictions too late to be of practical benefit to farmers in making decisions on treatment or management.

Future advances could incorporate stochastic variation of climatic parameters to generalise predictions and capture uncertainty in outcomes (Morgan *et al.*, 2007) and refine knowledge of the relationships between macroclimatic parameters such as average temperature and rainfall and the microclimates experienced by the free-living stages (O'Connor *et al.*, 2006). Future models should ideally also take explicit account of management factors, which can have a dominant effect on infection patterns (Morgan and Wall, 2009; Wall *et al.*, 2011). The factors that shape management practices should be included in the most resilient models dealing with prediction of future disease patterns, and this is likely to require deeper knowledge of social factors that influence on-farm decision making and the adoption of new technologies (Gibon *et al.*, 1999; Pardos *et al.*, 2008; Sturaro *et al.*, 2009; Marshall, 2010). Precise models will be able to not only focus anthelmintic treatment to maximum sustainable economic effect, but also to identify suitable management interventions to reduce the negative effects of climate change on parasite challenge (Morgan and Wall, 2009). Thus, decreased overwinter survival of *Teladorsagia* and *Trichostrongylus* might create opportunities for control by delayed grazing of contaminated pastures in spring.

All the above mentioned facts may lead us to some conclusions-suggestions in an effort to better face the impact of future climate changes to sheep and goats parasitism. More precisely we need: (i) to better understand the parasite epidemiology, the population genetics and the phenotypic and genotypic basis of adaptation to a continuous and gradual climate change; (ii) to accurately predict the changes in the distribution of vegetation in a precise region, especially in the Mediterranean area, where the combination of an increase of temperature and decrease of annual rainfall may strongly influence vegetation and have an impact on the feeding resources of small ruminants; (iii) to better study the behavioural changes of the animals under the new climatic conditions and their influence on their productivity and generally on their welfare; (iv) to develop/improve robust breeds of small ruminants fully adapted to arid conditions; and (v) to include animal welfare policies in the development research programmes at region level e.g. Mediterranean area and at different climate change scenarios such as Northern European climatic conditions.

All of this knowledge will help the development of sustainable, effective control regimes that can be used implemented farmers in order to maintain animal productivity and welfare.

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