Report on climate change impacts on gastro-intestinal parasites

Zsuzsanna Zsuppan, Maurice Mahieu

ANIMALCHANGE

SEVENTH FRAMEWORK PROGRAMME

THEME 2: FOOD, AGRICULTURE AND FISHERIES, AND BIOTECHNOLOGIES

Grant agreement number: FP7- 266018

DELIVERABLE 4.3

Deliverable title: Report on climate change impacts on gastro-intestinal parasites

Abstract: The goal of task 4.3 of Animal Change project is to clarify the interactions between climate and management for the health of small ruminants exposed to helminths.

Due date of deliverable: M36 Actual submission date: M36

Start date of the project: March 1st, 2011 Duration: 48 months

Organisation name of lead contractor: INRA, Maryline Boval

Authors: Zsuzsa Zsuppan (INRA), Maurice Mahieu (INRA)

Revision: V1

Dissemination level: PU

Table of Contents

1 Summary

Background

Everywhere in the humid tropics, gastrointestinal nematodes as *Haemonchus contortus* and *Trichostrongylus colubriformis* still represent a major constraint on goat production, animal health and welfare. As the magnitude of consequences, the degree of damage to host can be strongly correlated by the overall abundance of parasite populations. Some of the latest advancements in research have firmly established that temperature and humidity and other climatic variables strongly affect the population dynamics of free-living stages of nematodes of grazing ruminants *(Kao et al., 2000; O'Connor et al., 2006; Langrová et al., 2008)* and climate change might therefore be expected to alter parasite epidemiology. There is now abundant evidence that ecological responses to climate change are clearly visible *(Walther et al., 2002; Parmesan and Yohe, 2003).* Therefore, the complex behavior of the climate system could lead to increased pathogen transmission, rapid development and spread of anthelmintic resistance, decreasing the effectiveness of optimal control strategies *(van Dijk et al., 2010)* and eventually new climate-driven parasitic diseases can emerge *(Taylor, 2012)*. As anthelmintic resistance is now largely widespread, integrated methods of control are needed to achieve sustainable goat farming and required to better understand host-parasite relationships. However, the net effect of climate change on parasite infection levels could be complex and even complicated to study. Firstly, we must understand how climate affects infectious diseases today before we can predict climate change's impacts of the future *(Brownlie et al., 2006)*. The objective of this deliverable is to present a view of the epidemiological factors that we consider can be important in identifying the relative importance of animal husbandry performance and climatic factors for the infestation risk of free-living L3 nematodes on Creole goats reared at pasture under humid tropical climate. Furthermore, we try to find a mixed model including both animal performance and climatic factors, taking into consideration the sire, as a genetic random effect and their impacts on faecal helminth egg counts.

2 Methods, results and implications of the study

Methods

The experiment was undertaken in a Creole goat flock at INRA-Gardel in Guadeloupe.
Three data sets comprise animal performance, parasitological data and climatological observations were used to assess the objectives. The main data set was applied to point out how faecal egg count is affected by animal husbandry and climatic parameters.

Experimental design

To provide suitable grazing, the observed pastures are based on irrigated *Digitaria decumbens* where in all years the flock can graze at all times. The pasture is divided into 5 paddocks (1 week grazing and 4 weeks resting). Faecal samples are collected individually for all the goats on the day when they need to be drenched. Kids are drenched every 8 weeks during the post-weaning period, at 5, 7, 9, 11 months of age, respectively. In this study, faecal egg counts (FEC) correspond to the presence of nematode parasite burdens, given rise to the available number of L3 established in the infection period. Because of the rotational system of grazing and the delay in egg maturation and larval migration *(Aumont et al., 1989)*, the infection period goes from 21 days before the beginning of contamination and the day when kids are drenched. The infective L3 are derived from eggs shed in the plots and grazed up during this previous grazing cycle period [-84-21 days] which could be influenced by climatic conditions from the egg shedding stage to the later L3 infection.

Animal performance

Over the 10-year period from 1995 to 2005, a large data set of Creole goats is used in this study with dates of performance (birth, weaning, culling dates) and live weights recorded on kids at birth, at weaning and intervals thereafter during their post-weaning period. A total of 3334 kids with their individually growth performance is analyzed. The individual average daily gain ($ADG_{50-350)}$ is also monitored till 11-month age to estimate the potential growth of kids. The added animals are taken into account for animal husbandry variables.

Parasitological data

There are a total of 2850 faecal egg count records between 1995 and 2005. Faecal samples, as usually reported, are counted for FEC using a modified McMaster technique (Aumont et al., 1997), in which 1 egg detected equivalent to 15 eggs per gram of feces.

Climatological observations

Meteorological data are recorded at two sites, one located at Gardel Experimentation Station in Moule (north shore of the Atlantic coast) and the other at Godet INRA Station in Petit-Canal (from the east coast of Atlantic Ocean to the west shore of Caribbean Sea) in the Grand Terre. Le Moule is situated at 16°33’ North latitude, 61°33’ West longitude and 3 meters elevation above sea level. Coordinates of Petit-Canal are 16°23’ N and 61°29’ W at an elevation of 23 meters above sea level. Climatic records, i.e. global radiation, rainfall, temperature (minimum, maximum and mean), air humidity (minimum, maximum and mean) and wind speed are observed with daily measurements and integrated over the whole experimental period between 1995 and 2005. The resulting data set included 6472 daily climatological data from Gardel site and missing data are filled in from Godet Station.

Data analyses

Year effect is tested by a generalized linear model (options family=quasi, link="log", variance="mu" provided by R) to identify inter-annual variations on number of faecal worm egg counts over the 10-year period.
Fixed effects analyses are carried out, as source of sex, contemporary group (13 levels from 1999-3 to 2004-1), litter size (single, twin and multiple), rearing mode (single reared, twin born-twin reared, multiple born-twin reared and artificially reared), mortality and twenty meteorological indices, by using a generalized linear mixed-effects model. The mean is calculated for each variable as global radiation, rainfall, minimum and maximum temperature, minimum and maximum humidity and wind speed. Other numeric vectors, as average number of wet days with more than 0, 1, 5 and 10 mm rain, and then average number of sunny days lower than 1647 J/cm^2 and higher than 2319 J/cm^2 are computed. Moreover, average number of chilly days below 22.2 C° and above 31.2 C°, average number of days less humid below 60% and, finally, average number of days with wind speed lower than 1.5 m/s and higher than 2.60 m/s are also involved in the statistical analysis. The $ADG_{50\text{-}350}$ is tested with weight at weaning and age at weaning as covariates on FEC measures. Effect of sire (n=45) is, with 5 or more progenies, considered as random factor also added to the model.
A reduced model is performed, based on live weight at 7 months of age to assess a group of kids (n=627) that are similar in age and can be accurately compared. As for the final reduced model selection, the same fixed effects for (log10 (FEC+15)) are included in the linear mixed model, fitted by restricted maximum likelihood (REML), except that contemporary group effect is omitted due to the large proportion of variance. In order to reduce the dimensionality of multivariate data two types of information criterion are defined: the Bayesian Information Criterion (BIC) *(Schwarz, 1978)* and the Akaike information criterion (AIC) *(Akaike, 1974).*

In AIC and BIC, we choose the model that has the minimum value of:

$$AIC = -2 \log (L) + 2 m,$$

$$BIC = -2 \log (L) + m \log n,$$

where:

- L is the likelihood of the data with a certain model,
- n is the number of observations and
- m is the number of parameters in the model.

The procedure of backward elimination is applied, as a computer-based iterative variable-selection procedure which involves starting with all candidate variables, testing the deletion criterion, deleting the variable that improves the model the most by being deleted, and repeating the process until no further improvement is possible. Therefore we find a model where AIC is the smallest and provides an objective way of determining which model among a set of models is most parsimonious (the smaller the value of AIC compared to the BIC, the better the model fits). ANOVA is used to test differences among set of models for statistical significance. Only significant effects are included in the final REML model. Adjusted R squared is measured, as the proportion of the variation in the dependent variable accounted for by the explanatory variables. The % of variance gives the ration, expressed as a percentage of the variance accounted for by each component to the total variance in all of the variables. Effect sizes are equal to the explained sum of squares divided by the total sum of squares and residuals.

FEC data were log-transformed (log10 (FEC+15)) before analysis to normalize residual variances and the output values are then back-transformed to give the geometric mean.
In order to make a prediction for different climate change scenarios, back-transformed regression coefficients are estimated according to a prediction interval, by computing the high and low limit values of each weather indexes and tested on the average infection pressure of kids.
All statistical analyses are conducted in R-2.15.3 (R Development Core Team 2013, package lme4 version 0.999999-0).

Results & implications

Kids' performance

A quadratic model is the best explaining growth curves of kids. The fixed-effects estimates obtained are intercept=0.91±0.003; average value of linear coefficient=0.34±0.451 and quadratic term= -0.002±0.001. Intercept is interpreted as kid birth weight and gives level at time=0 of the study. The spontaneous growth rate, ADG_{50-350}, is 34 g/day. Eventually, the acceleration of growth rate at which the negative quadratic term is exerting a minor downward force on the equation indicates that the increase is less than linear. This means that the growth rate actually depends on time and considering first a simple linear relation but we obtain the fitted equation with R^2=0.975. A quadratic model improves the fit with a change in slope at about 210 days where the linear growth of kids stops.

Fixed effects on animal performance and climatic factors

Figure 1 shows the annual trend for FEC at each sampling time over a period of 10 years. The density of egg production tends to show a rhythmic rise till 1999, and then fall and to decrease from 2000 (P<0.001). It is well established that year causes variation on number of egg output due to climatic variation and can be also explained by a new drenching policy applied to goats against previous generalized anthelmintic resistance on *Trichostrongylus spp.* R-squared value is measured for the significant year effect which represents 22.6% of the total variation.

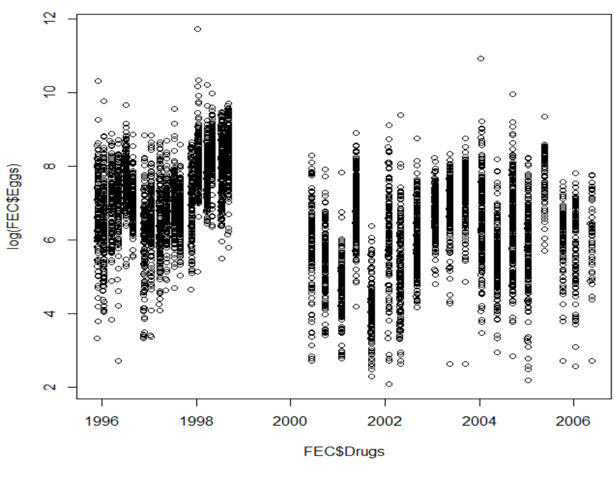

Figure 1. Egg production dynamics over the 10-year evaluated period under study. No data available from 1999-June 2000

The numbers of fixed effects parameters of different algorithms are displayed with the AIC, BIC and log-likelihood criteria in Table 1. Alternatively, we start from all candidate variables and reducing AIC with dropping choice of scale parameters. Given two models fit on the same data, the model [3] is reported with the smallest AIC value (AIC = 887.5, 850, 848.9 and 843.8 for models [0], [1], [2] and [3]). The same model seems to be slightly accurate than that of the algorithm models (R^2 = 0.55, 0.56, 0.56 and 0.56 for models [0], [1], [2] and [3]). Among the set of models, only model [1] shows any statistical differences (P<0.05) which can relate to fewer observed variables.

Table 1. Number of parameters in different summary of models corresponding to log-likelihood, defined by two types of information criterion (AIC and BIC criteria)

Model ID[1]	**AIC[2]**	**BIC[3]**	**Loglik[4]**	**Nb of fixed parameters[5]**	**Pr (>Chisq)[6]**
Model [0]	887.5	1034	-410.7	27	0.150
Model [1]	850	947.7	-403	17	0.026
Model [2]	848.9	942.2	-403.4	16	0.169
Model [3]	843.8	932.6	-401.9	15	

[1]Model identity; [2] Akaike's Information Criteria; [3] Bayesian Information Criteria; [4] Optimized log-likelihood values; [5] Number of fixed parameters; [6] Chi-square p-value

The significant fixed effects (P<0.05) in the included model are listed in Table 2 for percentage of the variance accounted for by each variable to the total variance and in Table 3 for FEC measures according to the values of coefficients. The percentage of variance of predictive variables related to animal husbandry represents 6.83, respectively. Daily weight gain of kid is significantly negative correlated with log10 (FEC+15) (r = - 0.135). When ADG_{50-350} increases by one hg/day, infection rate of kids decreases by 0.100±0.178 logarithm unit (Table 3). This effect represents 1.62% of the total variance.

Weaning weight is found to be less correlated with log10 (FEC+15) (r = - 0.076). The relationship between the independent and dependent variables is negative, in which weaning weight increases by 10 hg as FEC decreases by 0.000±0.001 logarithm unit (Table 3).

Sex differences lead to difference in faecal egg count that can be one of the reasons in which females are less infected than males (Table 3).

The percentage of explained variance of rearing mode represents 3.33, respectively. Kids raised up by their mothers are less infected than kids artificially raised. The high standard error of the mean can be explained by the size (number of observations) of the sample (Table 3).

Number of dead animals up to 7 months of age is positively correlated with infection rate, in which the explanatory variable rises by one animal as FEC goes up by 0.183±0.121 logarithm unit (Table 3).

The single random site effect has significant (P<0.0001) impact on faecal egg count.

Table 2. Total variance explained by significant fixed effects

Fixed effects	Degree of freedom	Sum of squares	% of variance
$ADG_{50\text{-}350}$	1	3.88	1.62
Weaning weight	1	2.30	0.96
Sex	1	1.55	0.64
Rearing mode	3	7.98	3.33
Mortality at age of 7 months	1	0.68	0.28
Average global radiation	1	3.24	1.35
Average temperature	1	0.60	0.25
Average minimal temperature	1	3.67	1.53
Average humidity	1	1.08	0.45
Average minimal humidity	1	7.24	3.02
Average maximal humidity	1	35.27	14.74
Average number of wet days with more than 1 mm of rain	1	32.81	13.71
Average number of wet days with more than 5 mm of rain	1	17.29	7.22
Average number of sunny days inferior to 1647 J/cm^2	1	3.80	1.58
Average number of chilly days inferior to 22.2 C°	1	5.36	2.24
Residuals	609	112.40	
Total			**52.92**

Climatological factors explain 46.09% of common variance. The $\log_{10}$ (FEC+15) estimates according to weather indexes, as for animal husbandry variables, are presented in Table 3 and the estimated back-transformed FEC curves are displayed in Figure 2 and Figure 3. Back-transformation of climatic parameters with positive coefficients refers to as the 'global warming scenario' which can have important modifying effects on levels of parasitism of kids (Fig. 2).

Table 3. Values of coefficients for significant fixed effects (P<0.05) on parasitological measures

Fixed effects	Estimate for FEC	Std. Error[1]
Intercept	40.755	3.082
ADG_{50-350}	-0.100	0.178
Weaning weight	-0.000	0.001
Sex2[3]	-0.142	0.046
Twin born-twins reared rearing mode	-0.110	0.054
Multiple born-twins reared rearing mode	-0.142	0.099
Artificially rearing mode	0.016	0.306
Mortality at age of 7 months	0.183	0.121
Average global radiation	0.004	0.000
Average temperature	0.073	0.421
Average minimal temperature	-1.037	0.449
Average humidity	-0.027	0.074
Average minimal humidity	0.195	0.064
Average maximal humidity	-0.335	0.033
Average number of wet days with more than 1 mm of rain	-0.132	0.010
Average number of wet days with more than 5 mm of rain	0.120	0.013
Average number of sunny days inferior to 1647 J/cm^2	-0.118	0.017
Average number of chilly days inferior to 22.2 C°	0.070	0.012

[1] Standard Error; [2] Female.

Among these predictive variables, while FEC levels indicates a range of low category nematode burden with 591.26 eggs per gram at unit of 600 J/cm^2 average solar radiation until at unit of 650 J/cm^2 the level of parasitism can be already categorized as medium with 1019.73 FEC.

According to the prediction interval, if the range of minimal value (51.28 %) of average minimal humidity goes up by 18 %, the level of infestation is determined in high category with 3238.44 eggs per gram of faeces. This infection pressure can be lethal for young goats. In spite of the small percentage (3.02 %) of total variance explained by this parameter, the category of parasite loads can be rapidly changed in the prediction interval.

Average number of wet days with more than 5 mm of rain can strongly impact the parasite burden during our experimental design. Less humid days, inferior to 25 days are considered to be more favorable in reducing parasite burden influences. This explanatory variable counts for 13.71% of explained total variance.

FEC levels of kids according to the average number of chilly days inferior to 22.2 C° doesn't seem to be so affected by this parameter.

Taking into consideration the range intervals of average temperature during our grazing cycle period [-84-21 days], no parasite burden influences can determine with increasing temperature.

No modification of other climatic factors with negative coefficients on FEC is observed (Fig.3).

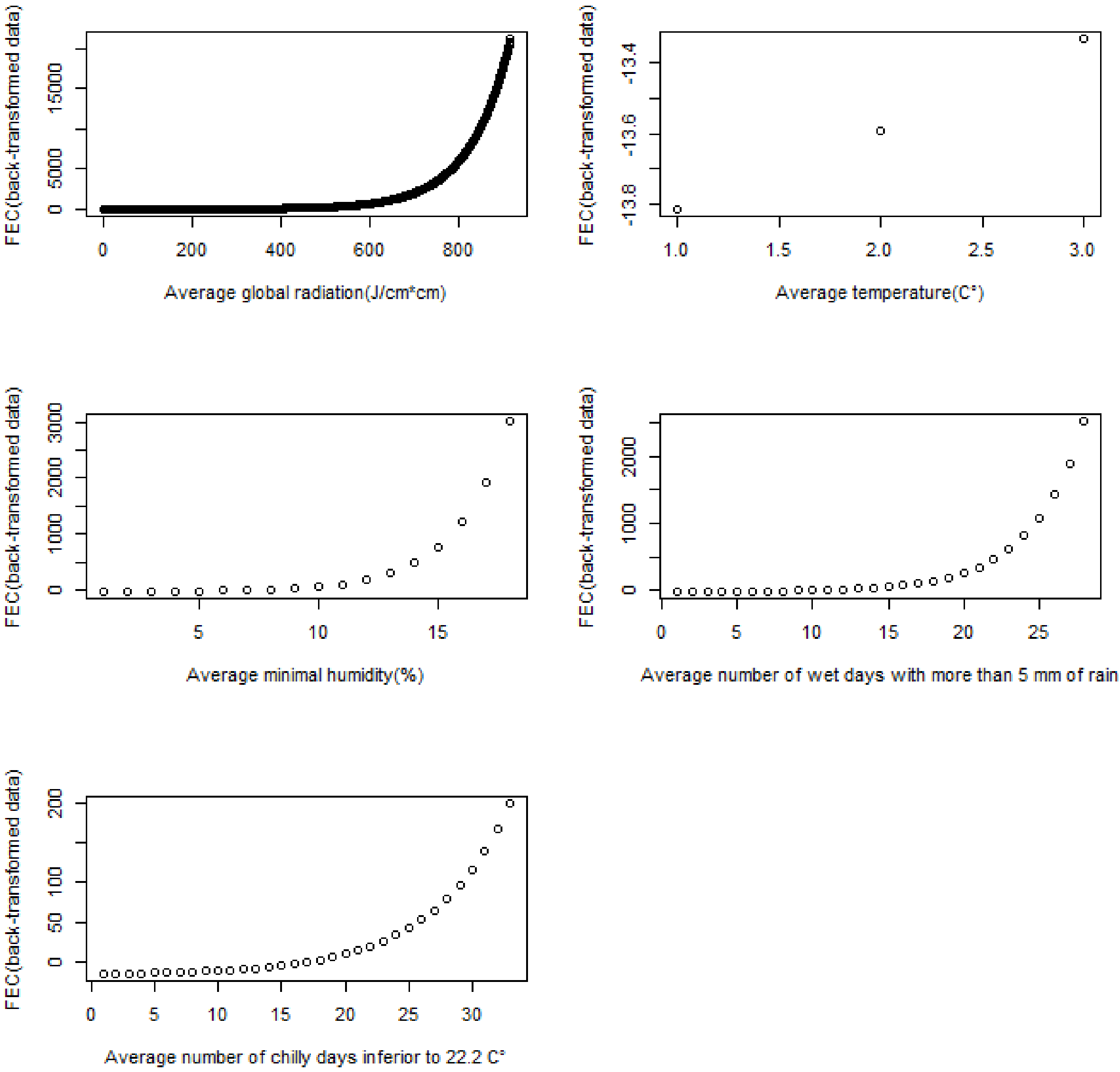

Figure 2. Faecal egg count curves by climatic parameters with positive coefficients

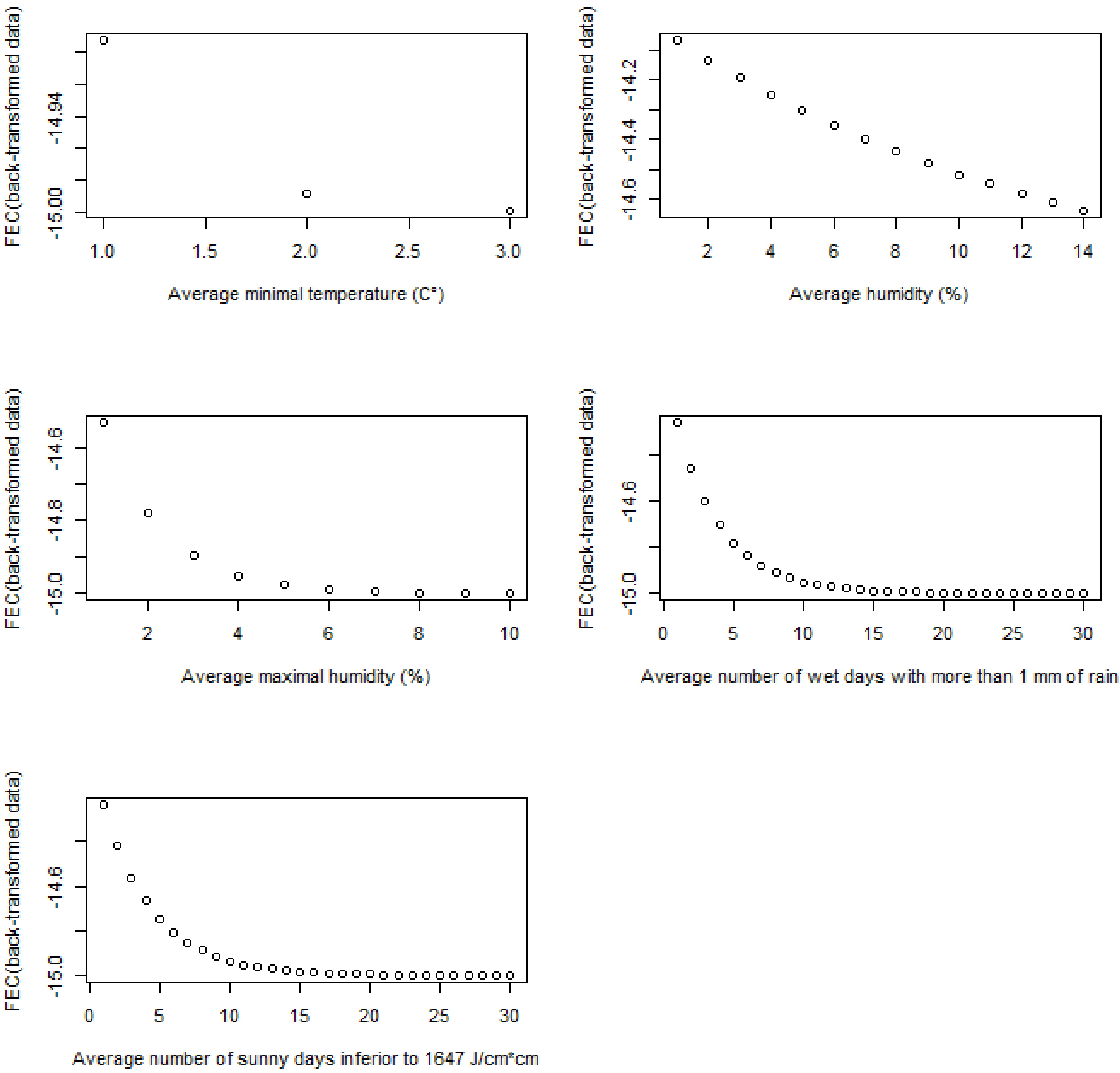

Figure 3. Faecal egg count curves by climatic parameters with negative coefficients

3 Conclusions

Our results demonstrate that non-climatic factors can be just as important as meteorological factors. Combinations of variables linked to animals affect the faecal egg count in Creole goats, e.g. sex, age, rearing mode and average daily gain. Significance of sire effect shows that genetic variability is available for selection on FEC and breeding for improving resistance in this breed is feasible (Mandonnet et al., 2001). Management practices, based on the ability of animals to survive, reproduce and maintain their productivity, are one of the pivotal questions of adaptation to harsh areas as tropical environment. Therefore, physiological traits of adaptation are essential to be considered in selection program for native breeds. The rate of adaptation, i.e whether species are able to adapt fast enough to their changing environment has ecological consequences (Visser, 2008). Environmental conditions include meteorological parameters such as average solar input, number of average number of wet days with more than 5 mm of rain or average humidity have major impact on level of infestation by nematodes. The effects of increasing humidity and number of rainy days with more than 5 mm precipitation are largely explained by changes in parasite burden on kids, expressed as the number of eggs per gram of faeces. However, in our experimental design the average number of wet days is not consecutive; we suppose that a smaller number of humid days with continuous rainfall with the same amount of precipitation could be more favorable for the development of high FEC. Using this linear-mixed effects model on explaining faecal egg counts, as health indicator, in combination animal performance with climatic parameters can make the link to response of an individual to environmental conditions (phenotypic plasticity) on parasite population burden.

References

Akaike, H. 1974. A new look at the statistical model identification. IEEE Transactions on Automatic Control, 19, 716-723.

Aumont, G., Coulaud, G., Grude, A., Gruner, L. 1989. Pasture populations of cattle nematode larvae in Guadeloupe (French West Indies). International Journal for Parasitology 19, 547-554.

Aumont, G., Pouillot, R., Simon, R., Hostache, G., Varo, H., Barre, N. 1997. Parasitisme digestif des petits ruminants dans les Antilles francaises. Productions Animales 10, 79-89.

Brownlie, J., Peckham, C., Waage, J., Woolhouse, M., Lyall, C., Meagher, L., Tait, J., Baylis, M. and Nicoll, A. 2006. Foresight. Infectious Diseases: preparing for thefuture. Future threats. Prepared for the Foresight Project Detection andIdentification of Infectious Diseases. Office of Science and Innovation, London.

Dijk, J.v., Sargison, N.D., Kenyon, F., Skuce, P.J. 2010. Climate change and infectious disease: helminthological challenges to farmed ruminants in temperate regions. Animal 4, 377-392.

Kao, R.R., Leathwick, D.M., Roberts, M.G., Sutherland, I.A., 2000. Nematode parasites of sheep: a survey of epidemiological parameters and their application in a simple model. Parasitology 121, 85-103.

Langrová, I., Jankovská, I., Vadlejch, I., Libra, M., Lytvyvnets, A., Makovcová, K., 2008. The influence of dessication and UV radiation on the development and survival of free-living stages of cyathostomins under field and laboratory conditions. Helminthologia, 45, 1:32.

Mandonnet, N., Aumont, G., Fleury, J., Arquet, R., Varo, H., Gruner, L., Bouix, J. and Vu Tien Khang, J. 2001. Assessment of genetic variability of resistance to gastrointestinal nematode parasites in Creole goats in the humid tropics. Journal of Animal Science 79, 1706-1712.

O'Connor, L.J., Walkden-Brown, S.W., Kahn, L.P. 2006. Ecology of the free-living stage of major trichostrongylid parasites of sheep. Veterinary Parasitology 142, 1-15.

Parmesan, C. and Yohe, G. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature 421, 37-42. (doi: 10.1038/nature01286).

Schwarz, G. 1978. Estimating the dimension of a model. Annals of Statistics, 6, 461-464.

Taylor, M.A. 2012. Emerging parasitic diseases of sheep. Veterinary Parasitology 189, 2-7.

Walther, G.R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T.J.C., Fromentin, J.M., Hoegh-Guldberg, O., Bairlein, F. 2002. Ecological responses to recent climate change. Nature (London) 416, 389-395.

Visser, M.E. 2008. Keeping up with a warming world; assessing the rate of adaptation to climate change. Proceedings of the Royal Society 275, doi: 10.1098/rspb.2007.0997.

Article reference

Zsuppán, Zs., Gourdine, J.L., Pleydell, D., Arquet, R., Coppry, O., Mandonnet, N., Mahieu, M. 2014. Climate impacts on infection pressure of nematodes on grazing goats in tropical humid climate. (Paper to be submitted in Animal)