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Methodology to predict the spatial distribution of cattle dung using manageable factors and a Bayesian approach

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ABSTRACT

The aim of this study was to predict the spatial distribution of cattle dung in paddocks based on Bayesian estimation using generalized linear mixed models with an added intrinsic conditional autoregressive term. The predicted herbage green biomass (GBM) and distance from a water trough (D_w), which can be controlled by farmers, were considered as predictors in the models. This study was conducted in three mixed sown pastures (I and II, 1.02 ha; III, 0.85 ha) in Hokkaido, Japan. After a four-day grazing trial using 20 Japanese Black cows, the paddocks were divided into 10 m × 10 m grid cells (I and II, 102 cells; III, 85 cells) and for each grid cell the number of dung deposits (N_d) was counted and the mean values of the GBM and D_w were computed. The results of Markov Chain Monte Carlo simulations indicated that a higher N_d tend to be associated with a higher GBM and locations closer to the water trough. N_d had spatial autocorrelation and it is likely that the grid cells that have large residual values could be affected by the difference between cattle activities in the daytime and nighttime. Based on our results, we suggest that the spatial distribution of cow dung can be predicted from two controllable factors in short term grazing trials.

1. Introduction

Cattle play an important role in the nutrient cycling in pasture ecosystems (Hirata et al., 2011). They extract nutrients from the plants and return them to pasture through their urine and dung (Betteridge et al., 2010). However, cattle urine and dung in the ecosystems provide not only a source of soil nutrients but are also a major source of greenhouse gas (GHG) emissions (Holter, 1997; Sordi et al., 2014). With the increasing pressure on farmers to minimize environmental pollution from farming operations, better understanding of the spatial distribution of excreta from grazing cattle is required.

Knowledge of the sites where livestock excrete will contribute to ensuring that GHG palliatives such as dicyandiamide and 3,4-dimethylpyrazole phosphate are used economically and efficiently. However, the excreta research of livestock by observation is laborious. Consequently, urine sensors that detect and log each urination event of female sheep and cattle have been developed. In addition, in combination with a global positioning system (GPS), these devices can detect livestock urinary event frequency and location (Betteridge et al., 2010). Using the device, the distribution of cattle and sheep urinary events in target fields is predictable (Betteridge et al., 2008), whereas useful equipment to detect dung position has not yet been developed. Previous research has suggested that the position of dung is related to grazing management and pasture topography. Excretal clumps are influenced by the effects of grazing equipment, such as drinking stations and salt racks (Hakamata and Hirashima, 1978). The proportion of an area occupied by fresh dung pats was considerably greater in a gently sloping site used for resting and decreased with an increase in the slope angle of inclination (Ide et al., 1998). Furthermore, earlier studies suggested that the location of cattle dung was related to the time spent by cattle in a particular area and their activities in that area, which can be affected by grazing management and pasture topography (Yamada et al., 2011), including crude protein (CP) concentrations and sward bulk

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densities (Senft et al., 1985; Ganskopp and Bohnert, 2009), plant species composition and forage quantity (Smith et al., 1992), geographical factors (*e.g.*, slope, aspect) (Yasue et al., 1997), and distance from water (Roath and Krueger, 1982; Ganskopp, 2001). Excretion frequency is influenced by the quantity and quality of forage, outside temperature, humidity, milk yield and individual differences between cattle (Hafetz, 1975).

To improve upon previous knowledge obtained in field studies, considerable effort has been made to predict and understand the spatial distribution of cattle dung in grazing systems using a multiple linear regression (MLR) approach (Yamada et al., 2011). However, Wang et al. (2005) noted that the basic premise that the residual variance of response variable is constant (homoscedasticity) is violated, and the MLR approach is deemed inappropriate. Moreover, failure to account for auto-correlation prevents in-depth interpretation of almost all geographical analyses (Jetz et al., 2005) and can lead to incorrect conclusions. A generalized linear model (GLM) is a framework for statistical models that includes linear and logistic regression as special cases (Gelman and Hill, 2007) and allows for response variables that have error distribution other than a normal distribution. However, a GLM cannot express an individual difference that a researcher cannot measure and did not observe. Variability of the data obtained in the investigation cannot be explained well by a simple Poisson or binomial distribution.

In heterogeneous environments, such as grazed pastures and especially hill country pastures, the variation of parameter values will often occur in unison and therefore show auto-correlation (Fukasawa et al., 2009). We usually anticipate that adjacent locations are more similar than those further apart (Besag et al., 1991). An extension to GLM, generalized linear mixed models (GLMMs), can account for non-normal data when random effects are present (Bolker et al., 2009). A CAR term is added to the GLMM to account for spatial heterogeneity in the data that the simpler GLM does not account for. The CAR term allows us to express the spatial non-independency between adjacent locations by introducing a spatial effect to model some of the random variation. In this way it is possible to infer the unknown factors affecting the subject by estimating the pattern of spatial random effects (Fukasawa et al., 2009).

Moreover, the application of a Bayesian approach provides a more flexible strategy that expresses parameters as a probability distribution (Kubo, 2009). One advantage of Bayesian estimation is the ease of including the CAR term in the analysis. Therefore, the use of Bayesian approaches to modeling spatial data is becoming increasingly popular (Clark, 2005).

Hence, as a first step towards predicting the spatial distribution of cattle dung, we used GLMMs with an added CAR term within a Bayesian framework using herbage green biomass (GBM) and the distance from a water trough (D_w) as explanatory variables (Yoshitoshi et al., 2015). We selected GBM and D_w as explanatory variables to predict N_d because several studies have highlighted the relationship between cattle use of pasture, the distance from water (Martin and Wart, 1973; Beck, 1978) and the location of watering points was the major factor influencing forage utilization by cattle (Hodder and Low, 1976). Moreover, livestock prefer to graze in areas with higher forage quality and quantity (Senft et al., 1985; Bailey et al., 2001). Furthermore, the GBM and water troughs can be easily managed, in that, GBM can be trimmed and the data can be obtained by remote sensing (Kawamura et al., 2010; Watanabe et al., 2014), and the land manager can control the location of the water troughs. Our previous results (Yoshitoshi et al., 2015) suggested that the distribution of cattle dung was related to GBM and the position of the water trough and a lower deviance information criterion (DIC) value was obtained for the model with the added CAR term (DIC = 291.5) compared to that for the ordinary GLMM (DIC = 502.6). However, because the models evaluated were constructed using data from a single paddock, it is necessary to validate the models using other paddocks.

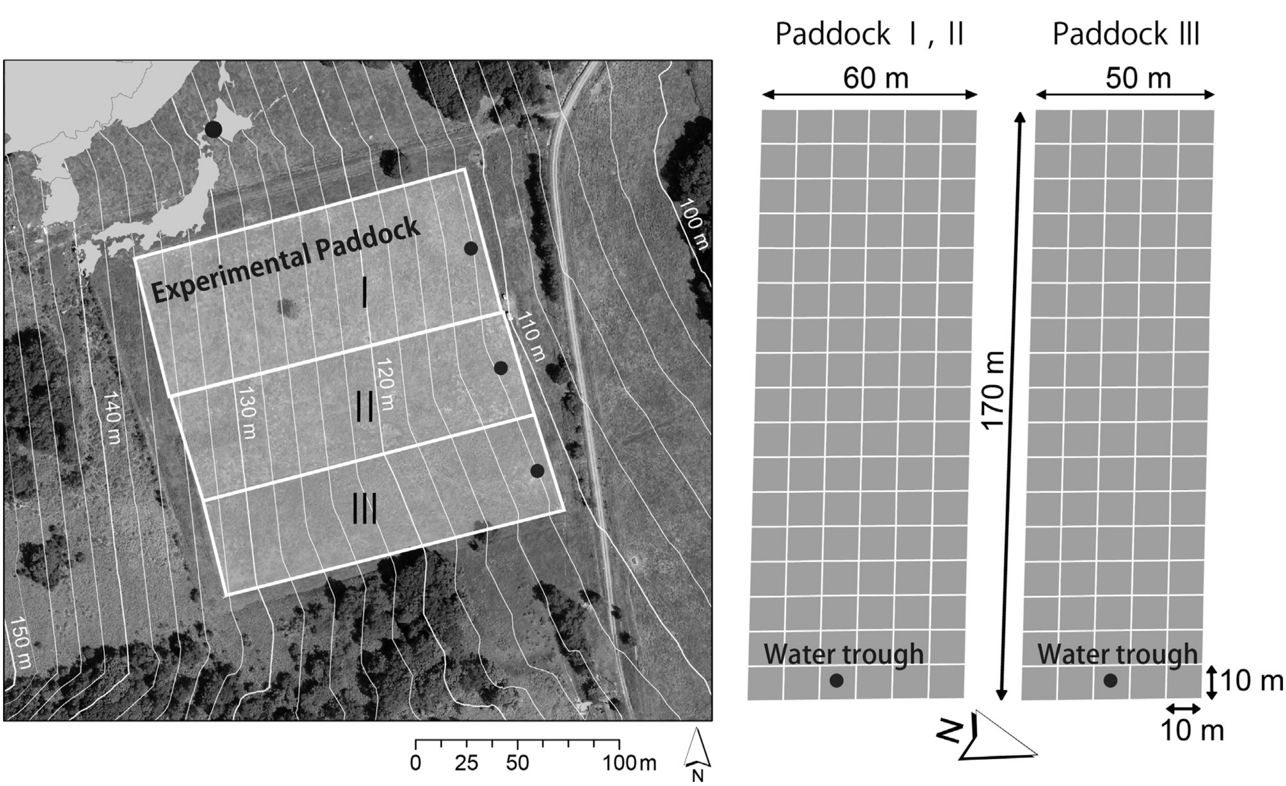

Fig. 1. Location of the experimental paddocks, showing the 2 m contours and the 10 m × 10 m grid cells in each paddock.