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ABSTRACTS OF COMMUNICATIONS

Proceedings of the Thirty-fourth Meeting of the Agricultural Research Modellers' Group

EDITED BY

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This group, which is concerned with the applications of mathematics to agricultural science, was formed in 1970 and has since met at approximately yearly intervals in London for one-day meetings. The thirty-fourth meeting of the group, chaired by Professor D. I. Givens of ADAS Nutritional Sciences Research Unit, Drayton, was held in the Kohn Centre at the Royal Society, 6 Carlton House Terrace, London on Friday, 19 April 2002 when the following papers were read.

A model for overland flow over agricultural land and application to particle transport. J. P. F. CHARPIN[1], C. A. LLEWELLYN[2], T. G. MYERS[3], J. N. QUINTON[2] AND C. P. THOMPSON[1]. [1]*Applied Mathematics and Computing Group, School of Engineering, Cranfield University, Cranfield, Bedfordshire MK43 OAL, UK,* [2]*Landcare Group, National Soil Resources Institute, Cranfield University at Silsoe, Bedfordshire MK45 4DT, UK,* [3]*Department of Mathematics and Applied Mathematics, University of Cape Town, Private Bag, Rondebosch 7701, South Africa*

Each year, millions of tonnes of faecal waste are applied to agricultural land in the UK. Due to their low density and resistance to shear, they may easily be detached and transported to surface waters (Schofield 1988). The potentially harmful microorganisms they contain together with other chemical components and soil particles may seriously endanger the water quality. These elements are mainly transported by overland flow, that is the water running off fields during storms. An event-based model has been developed to simulate the behaviour of surface water and transported particles during a storm. The objective is to apply this model to fields with a surface of up to one square kilometre.

As in most fluid applications, the Navier–Stokes equations would provide a valid model for overland flow. However, they are notoriously complex to solve and do not exploit the thin geometry of the film. Our model is based on lubrication theory, an asymptotic simplification of traditional equations (Ockendon & Ockendon 1995, Myers 1998). This results in a single transient non-linear equation for the film thickness, driven by gravity. However, fields are rough surfaces and this may significantly affect the flow. The equation is then modified to include the soil roughness, through two parameters inherent to the catchment that may be evaluated from the flux and velocity (Myers 2002). Results were compared with small-scale experiments.

This model of overland flow is then coupled with a transport equation to study the behaviour of soil particles or microorganisms during a storm. The particle detachment is based on a model developed for the EUROSEM code (Morgan *et al.* 1999). Simulations based on the lubrication/EUROSEM transport model are presented for test cases and some real field data. Experiments to evaluate the model are currently underway on a specially designed flume.

This research is funded by BBSRC under grant 63/MAF12260.

MORGAN, R. P. C., QUINTON, J. N., SMITH, R. E., GOVERS, G., POSEN, J. W. A., AUERSWALD, K., CHISCI, G., TORRI, D. & STYCZEN, M. E. (1999). The European soil erosion model (EUROSEM): a dynamic approach for predicting sediment transport from fields and small catchments. *Earth Surface Processes and Landform* **23**, 527–544.

MYERS, T. G. (2002). Unsteady laminar flow over a rough surface. *Water Resources Research*, in press.

MYERS, T. G. (1998). Thin films with high surface tension. *SIAM Review* **40**, 441–462.

OCKENDON, H. & OCKENDON, J. R. (1995). *Viscous Flow*. Cambridge: Cambridge University Press.

SCHOFIELD, K. (1988). The Impact of Farm Pollution on River Quality: Progress Report on the Cleddau Field Study, PRS 2016-M, Water Research Centre, Medmenham.

Instantaneous canopy photosynthesis: analytical expressions for sun and shade leaves based on exponential light decrease down the canopy and an acclimated non-rectangular hyperbola for leaf photosynthesis.
J. H. M. THORNLEY. *Centre for Ecology & Hydrology, Bush Estate, Penicuik, Midlothian EH26 0QB, UK*

Analytical expressions for the sun and shade leaf contributions to instantaneous canopy photosynthesis are derived (Thornley 2002). The analysis is based on four assumptions. First, the canopy is closed in the sense that it is horizontally uniform. Second, there is an exponential profile of light down the canopy with the same decay constant for light from different parts of the sky. Third, leaf photosynthetic response to incident irradiance can be described by a three-parameter non-rectangular hyperbola (NRH). And last, light acclimation at the leaf level occurs in only one parameter of the NRH, that describing light-saturated photosynthetic rate, which is assumed proportional to the local averaged leaf irradiance. These assumptions have been extensively researched empirically and theoretically and their limitations are quite well understood. They have been widely used where appropriate. Combining these assumptions permits the derivation of algebraic expressions for instantaneous canopy photosynthesis which are computationally efficient because they avoid the necessity for numerical integration down the canopy. These are valuable for modelling plant and crop ecosystems, for which canopy photosynthesis is the primary driver. Ignoring the sun/shade dichotomy can result in overestimates of canopy photosynthesis of up to 20%, but using a rectangular hyperbola instead of a NRH to estimate canopy photosynthesis taking account of sun and shade leaves can lead to a similarly sized underestimate. It is suggested that the method can be applied with confidence to situations that satisfy the four assumptions. This includes many crops and plant ecosystems. However, the model has not been tested predictively; such tests would be difficult. Other work aimed at calculating canopy photosynthesis has been reported by De Pury & Farquhar (1997), Kull & Kruijt (1998) and Wohlfahrt *et al*. (1999). None of the suggested models has been tested definitively at the predictive level against observational data, and some rest on uncertain theoretical foundations.

This research has been supported by the European Union through the MEGARICH project and COST 619; it also contributes to contract 1/1/64 of DEFRA.

DE PURY, D. G. G. & FARQUHAR, G. D. (1997). Simple scaling of photosynthesis from leaves to canopies without the errors of big-leaf models. *Plant, Cell and Environment* **20**, 537–557.

KULL, O. & KRUIJT, B. (1998). Leaf photosynthetic light response: a mechanistic model for scaling photosynthesis to leaves and canopies. *Functional Ecology* **12**, 767–777.

THORNLEY, J. H. M. (2002). Instantaneous canopy photosynthesis: analytical expressions for sun and shade leaves based on exponential light decay down the canopy and an acclimated non-rectangular hyperbola for leaf photosynthesis. *Annals of Botany* **89**, 451–458.

WOHLFAHRT, G., BAHN, M. & CERNUSCA, A. (1999). The use of the ratio between the photosynthesis parameters P_{ml} and V_{cmax} for scaling up photosynthesis of C_3 plants from leaves to canopies: a critical examination of different modelling approaches. *Journal of Theoretical Biology* **200**, 163–181.

Developing a universal model of methane emissions from dairy cattle. Alternatives to linear regression analysis.
J. A. N. MILLS[1], E. KEBREAB[1], C. M. YATES[1], L. A. CROMPTON[1], S. B. CAMMELL[1], R. E. AGNEW[2] AND J. FRANCE[1]. [1]*The University of Reading, School of Agriculture, Policy & Development, Earley Gate, Reading RG6 6AR, UK,* [2]*Agricultural Research Institute of Northern Ireland, Hillsborough, Co Down BT26 6DR, UK*

Previous attempts to apply statistical models, which correlate nutrient intake with methane production, have been of limited value where predictions are obtained for intake levels and diet types outside those used in model construction. Dynamic mechanistic models have proved more suitable for extrapolation, but they remain computationally expensive and are not applied easily in practical situations. The first objective of this research focused on employing conventional techniques to generate statistical models of methane production appropriate to UK dairy systems. The second objective was to evaluate these models and a model published previously using both UK and North American data sets. Thirdly, non-linear models were considered as alternatives to the conventional linear regressions. The UK calorimetry data used to construct the linear models were also used to develop the three non-linear alternatives that were all of modified Mitscherlich form; $y = a-(a+b)e^{-cx}$ where a and b are the maximum and minimum values, respectively, of y, and c affects the shape of y. Of the linear models tested, Moe & Tyrrell (1979) proved most reliable across the full range of evaluation data [root Mean Square Prediction Error (MSPE) 21·3% of observed mean]. However, the Mitscherlich models demonstrated the greatest degree of adaptability across diet types and intake level. The most successful model for simulating the independent data was a Mitscherlich equation with the shape parameter set to represent dietary starch to acid detergent fibre ratio (root MSPE 17·9% of observed mean). Although, where such data were unavailable, simpler Mitscherlich forms relating dry matter or metabolizable energy intake to methane production remained better alternatives relative to their linear counterparts.

DEFRA is thanked for funding this research through project WA0320.

MOE, P. W. & TYRRELL, H. F. (1979). Methane production in dairy cows. *Journal of Dairy Science* **62**, 1583–1586.

Using the PSALM model to simulate losses of phosphate in drainage from arable land. T. M. ADDISCOTT, P. D. FALLOON AND G. TUCK. *IACR-Rothamsted, Harpenden, Hertfordshire AL5 2JQ, UK*

Phosphate is lost from arable land either dissolved in water draining from the soil or carried on detached soil material. The PSALM (Phosphate Sorption And Loss Model) simulates both modes of loss. The concentration of phosphate in water passing through the matrix of the soil is determined in the model by rapid sorption or desorption described by the Freundlich equation and a time-dependent pseudo-diffusive process. By-pass flow occurs when rainfall exceeds a critical amount determined daily in the model, and this carries both dissolved phosphate and phosphate on detached soil material from the top layer to the base of the profile without any interaction with the soil matrix. This by-pass-flow could become overland flow with only very minor modifications to the model. The amount of phosphate-carrying detached material depends on the clay content and wetness of the soil and the amount of rain; the intensity of the rain should ideally be used, but data are often not available. The model takes account of primary and secondary tillage, crop uptake and mineralization, but does not discriminate at present between inorganic and organic phosphate.

Because of the nature of the Freundlich equation, the relation between the loss of soluble phosphate simulated by the model and the Freundlich sorption parameter is strongly non-linear. This non-linearity interacts with any (statistical) error in the parameter (Addiscott & Tuck 2001), which means that the loss of soluble phosphate depends on its standard error as well as its mean. The model was evaluated against the phosphate losses measured in drainage from plots of the Broadbalk experiment by Heckrath *et al*. (1995). The simulations of soluble phosphate concentrations in drainage were good: those of phosphate carried on detached soil material were somewhat poorer but statistically acceptable. These simulations depended on the assumption that the drainage did not interact with the subsoil.

Simulations with the model suggested that omitting primary (inversion) tillage on Broadbalk would cause a small increase in losses of phosphate attached to soil material but a much larger decrease in losses of dissolved phosphate.

This research was funded by DEFRA and the grant-in-aid received by IACR-Rothamsted from BBSRC.

ADDISCOTT, T. M. & TUCK, G. (2001). Non-linearity and error in modelling soil processes. *European Journal of Soil Science* **52**, 129–138.

HECKRATH, G., BROOKES, P. C., POULTON, P. R. & GOULDING, K. W. T. (1995). Phosphorus leaching from soils containing different phosphorus concentrations in the Broadbalk experiment. *Journal of Environmental Quality* **24**, 904–910.

Two-dimensional computer modelling of physical and biological changes inside a cylindrical silo with dynamic visualisation. G. XANTHOPOULOS AND J. L. WOODS. *Heat and Mass Transfer Laboratory, Department of Agricultural and Environmental Science, University of Newcastle, Newcastle upon Tyne NE1 7RU, UK*

The seasonal changes taking place inside a grain store are difficult and expensive to monitor, particularly moisture and biological changes, such as mould growth and germination loss. Given current awareness of mould growth and toxins, and the need for minimizing pesticide use, there is a demand for an improved understanding of physical control measures (e.g. interaction between winter aeration cooling and summer surface heating). The computer program presented here and evaluated against existing data provides a cost-effective approach to the problem.

The model predicts the axisymmetric distributions of temperature, moisture content, cumulative dry matter loss (respiration) and germination loss in a vertical plane through the axis of a cylindrical silo. The overall model presented by Xanthopoulos (2002) employed non-linear and coupled balance equations for energy and moisture. The energy equation incorporates two energy source terms (latent heat of vaporization and respiration heating), and the moisture equation contains a moisture production term due to respiration. Respiration is calculated by the model of Jacobsen (2001). Germination is described by a probit model (Woods *et al*. 1994). It is assumed that no natural convection occurs for small grains like wheat or barley. The model also assumes heat and mass transfer by molecular diffusion through the voids during unaerated periods and enhanced diffusion due to aerodynamic dispersion during aeration.

At regular intervals, contour maps for the four variables are drawn in real-time providing a dynamic visualization.

The model was evaluated and used to investigate the wet storage of rapeseed initially at 14% moisture content wet base (wb) and 20 °C before drying, and the long term storage of malting barley initially at 12% moisture content wb and 30 °C. Different fan capacities and control algorithms were tested to minimize the dry matter loss in the first example and the germination loss in the second.

JACOBSEN, E. E. (2001). Prediction of Respiration from Stored Barley in Dependence of Water Activity and Temperature, Internal Report, Bioteknisk Institut, Koldïng, Denmark.

WOODS, J. L., FAVIER, J. F. & BRIGGS, D. E. (1994). Predicting the germinative energy of dormant malting

Table 1.

			Estimated	Original model		Adjusted milk enrichments	
Measured	Mean	S.E.		Mean	S.E.	Mean	S.E.
E_a	5·38	0·18	Bypass (F_{va})	18·6	4·6	12·0	3·8
E_m	3·55	0·09	Inward transport (F_{ma})	12·9	1·6	19·6	2·7
E_v	4·94	0·16	Outward transport (F_{vm})	5·8	1·3	12·5	2·3
EC_a	15·54	0·40	Protein breakdown (F_{mo})	6·5	0·5	3·07	3·8
EC_m	12·08	0·39	HMB conversion (F_h)	0·84	0·20	0·54	0·07
EC_v	15·46	0·41	Protein synthesis (F_{om})	13·7	0·9	10·7	0·8
E_h	96·95	0·27	From newly produced [^{13}C]Met	0·59	0·11	0·25	0·02
F_{in}	31·6	6·1	From recycled [^{13}C]Met	1·46	0·13	1·40	0·13
F_{out}	24·4	5·8	% from [^{13}C]HMB	14·85	0·43	15·40	0·40
Milk output	8·1	0·5	Adjustment of milk enrichment ($1+x$)	—	—	1·28	0·03

barley during storage. *Journal of the Institute of Brewing* **100**, 257–269.

XANTHOPOULOS, G. (2002). *Simulation of Heat and Mass Transfer and Biological Changes in a Grain Store*. Ph.D. thesis, University of Newcastle upon Tyne, UK.

A tracer kinetic model for metabolism of 2-hydroxy-4-[methylthio]-butanoic acid (HMB) by the mammary gland of lactating cows. G. ZUUR[1], G. E. LOBLEY[2], M. VAZQUEZ-ANON[3] AND H. LAPIERRE[4]. [1]*Biomathematics and Statistics Scotland, Rowett Research Institute, Bucksburn, Aberdeen AB21 9SB, UK*, [2]*Rowett Research Institute, Bucksburn, Aberdeen AB21 9SB, UK*, [3]*Novus International Inc, St Louis, MO, USA*, [4]*Agriculture and Agrifood Canada, Dairy and Swine R&D Research Centre, CP 90 Lennoxville, Quebec J1M 1Z3, Canada*

HMB (Alimet® feed supplement, Novus International Inc) is converted to methionine (Met) in various tissues throughout the body (Wester *et al.* 2000). To investigate the contribution of HMB to milk production, four multi-catheterized cows (mean ± S.D., milk output 31·6 ± 2·4 kg/day, 18·0 ± 0·8 kg DMI/day) received a continuous intra-jugular infusion of [1-^{13}C]HMB (1·5 g/h) and [methyl-^{2}H$_3$]Met (0·2 g/h). After 8 h, samples from mammary artery, mammary vein and milk (taken between 7–8 h, oxytocin assisted) were collected and Met concentrations and enrichments determined. The [^{2}H$_3$]Met allows for determination of the various Met flows, while the [^{13}C]Met indicates the extent of HMB conversion to Met across the mammary gland (MG). The following model, extended from one based on muscle (Biolo *et al.* 1994), was developed:

$$F_{in} = F_{ma} + F_{va} \quad (1)$$

$$F_{ma} + F_{mo} + F_h = F_{om} + F_{vm} \quad (2)$$

$$F_{out} = F_{vm} + F_{va} \quad (3)$$

$$E_a\,F_{ma} = E_m\,F_{om} + E_m\,F_{vm} \quad (4)$$

$$E_v\,F_{out} = E_m\,F_{vm} + E_a\,F_{va} \quad (5)$$

$$EC_a\,F_{ma} + E_h\,F_h = EC_m\,F_{vm} + EC_m\,F_{om} \quad (6)$$

$$EC_v\,F_{out} = EC_a\,F_{va} + EC_m\,F_{vm} \quad (7)$$

F_{xy} denotes flow (mmol Met/h) to pool x from pool y (a, artery; v, vein; m, intracellular; o, protein), and E and EC denote the [^{2}H$_3$] and [^{13}C]Met enrichments (atom per cent excess), respectively. F_{in} and F_{out} (plasma flow × concentration) are the MG in- and out-flows, respectively. F_h is the amount of HMB converted to [^{13}C]Met in the intracellular pool, and E_h is the HMB enrichment. Equations (1)–(7) can be solved for the unknowns F_{ma}, F_{va}, F_{mo}, F_{om}, F_{vm} and F_h, using F_{in}, F_{out} and the enrichments as inputs.

The observed [^{13}C]:[^{2}H$_3$]Met ratio was higher in milk than in the artery (3·4 *v.* 2·9), indicating intracellular conversion of HMB to Met. Initially, the intracellular free pool enrichments were assumed equal to those of milk protein, but this revealed inconsistencies. From the [^{2}H$_3$]Met movements [equations (3) and (5)], the bypass (F_{va}) was estimated as 57% of F_{in}, while the [^{13}C]Met data [equations (3) and (7)] gave a 74% bypass. This violates the assumption that isotopic forms behave identically so other factors need to be considered. The imbalances would arise if the enrichment in milk underestimated that in the intracellular pool. Defining $E_m = (1+x)\,E_m$(observed) and $EC_m = (1+x)\,EC_m$(observed), the inconsistencies would disappear for $1+x = 1·28$. Results (Table 1; flows, mmol Met/h; enrichments, atom per cent excess) for the full model, based on the adjusted milk enrichments, show that HMB-derived [^{13}C]Met contributes 15% to protein synthesis, of which 15% is derived from conversion in the MG with the remainder derived from synthesis elsewhere in the body.

Does the estimated adjustment of 28% on milk enrichment make biological sense? Possible reasons for a lower enrichment in milk than in the intracellular pool include the 0·5 h taken for polypeptides to be translated, processed and secreted from mammary cells. Such a delay would yield a 6% difference. In

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addition, incomplete previous milking will also lower the enrichment. Based on $k_{milk} = 0{\cdot}21\ h^{-1}$ (Bequette *et al*. 1996) the predicted intracellular enrichment would be 16% greater than in the milked protein and could be accounted by 0·4 litres of milk remaining in the gland.

This research was funded by Novus International Inc and SEERAD.

BEQUETTE, B. J., METCALF, J. A., WRAY-CAHEN, D., BACKWELL, F. R. C., SUTTON, J. D., LOMAX, M. A., MACRAE, J. C. & LOBLEY, G. E. (1996). Leucine and protein metabolism in the lactating dairy cow mammary gland: responses to supplemental dietary crude protein intake. *Journal of Dairy Research* **63**, 209–222.

BIOLO, G., GASTALDELLI, A., ZHANG, X.-J. & WOLFE, R. R. (1994). Protein synthesis and breakdown in skin and muscle: a leg model of amino acid kinetics. *American Journal of Physiology* **267**, E467–E474.

WESTER, T. J., VAZQUEZ-AÑÓN, M., PARKER, D., DIBNER, J. J., CALDER, A. G. & LOBLEY, G. E. (2000). Synthesis of methionine (Met) from 2-hydroxy-4-methylthio butanoic acid (HMB) in growing lambs. *Journal of Dairy Science* **83** (Suppl. 1), 269.

The provision of solar radiation data to crop growth models. M. RIVINGTON. *Macaulay Land Use Research Institute, Craigiebuckler, Aberdeen AB15 8QH, UK*

Crop simulation models often require climate data as input variables. Whilst precipitation and temperature data are usually available, there is often a dearth of representative solar radiation data in most countries. Methods are available to estimate solar radiation using temperature data, or by conversion from sunshine duration. A method is described for conversion of sunshine duration to solar radiation. An illustration is made of the spatial distribution of meteorological stations with records of solar radiation and/or sunshine duration in the UK. In the absence of site-specific data, the nearest meteorological station data are often used to run models at a particular location. This paper compares sources of solar radiation data for the site-specific application of a crop model (CropSyst) (Stöckle & Nelson 1998).

Three methods of providing solar radiation data were tested: conversion from sunshine duration; an un-parameterized Campbell–Donatelli model used within CropSyst; and the two nearest meteorological stations. Generic simulations of spring barley were run with CropSyst for 13 separate years, using the three sources of solar radiation data for three geographically similar locations in southern England. Solar radiation predicted from sunshine duration was compared with observed data using regression, giving a mean R^2 of 0·908. Crop yield output derived from the three data sources was compared with results from observed solar radiation. For the three locations tested, the order of most suitable data source was: conversion of sunshine duration; nearest meteorological station; and the Campbell–Donatelli model. The nearest meteorological station does not necessarily give the best results. The results demonstrate that crop models should use an appropriate source of solar radiation data. The results are discussed in the context of utilizing CropSyst within the Land Allocation Decision Support System (LADSS) (Matthews *et al*. 1999), a spatial multiple-objective land-use planning tool for considering farm-scale environmental, social and economic trade-offs.

MATTHEWS, K. B., SIBBALD, A. R. & CRAW, S. (1999). Implementation of a spatial decision support system for rural land use planning: integrating GIS and environmental models with search and optimisation algorithms. *Computers and Electronics in Agriculture* **23**, 9–26.

STÖCKLE, C. O. & NELSON, R. (1998). *CropSyst Users Manual*. Pullman WA, USA: Washington State University. http://c100.bsyse.wsu.edu/cropsyst/.

Using a probability theory model to test if cows select a consistent diet within meals. M. P. YEATES, B. J. TOLKAMP AND I. KYRIAZAKIS. *Animal Biology Division, Scottish Agricultural College, West Mains Road, Edinburgh EH9 3JG, UK*

Animals offered a choice of two similar foods that differ in one dimension (e.g. protein content) select a consistent combination of these foods in the long-term. Long-term diet choice is, at least in the formal sense, the result of short-term feeding behaviour. The shortest unit of feeding that can be measured is often a visit to a feeder supplying one food type only. With the mixed distribution model developed by Yeates *et al*. (2001) visits can be clustered into meals, and these can be subjected to the analysis of diet choice. Previous work led us to hypothesize that animals may attempt to select a consistent diet within a meal.

In three experiments, cows were offered a choice between high (H) and low (L) protein foods and visit data were collected using computerized feeders. Cows selected a consistent non-random diet in the long term by visiting H feeders more frequently than L feeders. If cows attempted to select a consistent diet within meals then we expected to see a high frequency of meals with a composition of visits similar to the long-term average diet choice. To test this, the observed frequency distribution of meal composition, in terms of the proportion of visits to H feeders, was calculated. Subsequently, the observed visits were randomly re-clustered into bouts using probability theory. These bouts represented the expected composition of the visits within meals if cows did not regulate diet choice within meals. Initially we assumed that the probability of visiting a feeder was dependent only on the food type that it supplied, i.e. that all feeders supplying a given food were equally likely to be visited. However, subsequent analysis showed that, within a meal, cows had a higher probability of revisiting the feeder they had just left. Therefore, the compositions of bouts

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were recalculated to allow for this. We also investigated if cows attempted to regulate diet choice within meals by adjusting their intake per visit depending on the food type visited. To test this, we first calculated the diet choice, as if this was not regulated within a meal. Subsequently, differences between this and observed diet choice were calculated and regressed on the proportion of visits to H feeders. A significant negative regression coefficient would provide evidence for diet choice within meals.

Comparison of the frequency distributions of meals and random bouts, using chi-squared tests, provided no evidence that cows attempted to achieve their long-term average diet choice within meals. Additionally, we found no evidence that cows regulated diet choice within meals by adjusting their intake per visit depending on the food type that was consumed. In conclusion, the tests conducted with the probability theory model suggest that the timeframe over which diet choice is regulated must be greater than a meal.

YEATES, M. P., TOLKAMP, B. J., ALLCROFT, D. J. & KYRIAZAKIS, I. (2001). The use of mixed distribution models to determine bout criteria for the analysis of animal behaviour. *Journal of Theoretical Biology* **213**, 413–425.

Modelling the daily progress of light leaf spot epidemics on winter oilseed rape (*Brassica napus*), in relation to *Pyrenopeziza brassicae* inoculum concentrations and weather factors. K. PAPASTAMATI, F. VAN DEN BOSCH, S. J. WELHAM, B. D. L. FITT, N. EVANS AND J. M. STEED. *IACR-Rothamsted, Harpenden, Hertfordshire AL5 2JQ, UK*

Light leaf spot on winter oilseed rape is an economically important disease in the UK. Understanding how epidemics develop and are affected by weather conditions is crucial for forecasting purposes.

Previous work by Papastamati *et al.* (2001) used a simple weather threshold for infection to occur and the latent period between infection and sporulation was constant. However, it has been shown that in field conditions latent period can vary between 150–250 degree-days (Figeuroa *et al.* 1995). More recently, Gilles *et al.* (2001) developed a model to describe temperature and wetness effects in controlled environment experiments on the development of light leaf spot.

The progress of light leaf spot epidemics on winter oilseed rape was monitored in 1998/99 and 1999/2000 at Rothamsted, and weather factors and *P. brassicae* ascospore concentrations were recorded daily. A structured population model was developed to investigate the effects of presence of inoculum (ascospores and conidiospores) and weather factors on the progress of light leaf spot on winter oilseed rape leaves and improve a previous model (Papastamati *et al.* 2001). New susceptible leaves are produced and leaf birth rate is assumed to be linearly dependent on temperature. The infection criterion depends on temperature and leaf wetness duration (expressed as rain duration) and the length of the latent period is temperature-dependent. Model parameters are related to rates of infection of 'susceptible leaves', sporulation of 'infected leaves' to produce 'sporulating leaves' and death of leaves from these three compartments and were estimated by fitting the model to the data sets. The model fitted the disease progress data equally well in both seasons. The model fitting suggested that disease progress could be described only if both ascospore and conidiospore numbers were included. The fit to the data was better in 1999/2000 than in 1998/99. An assumption that the leaf birth rate changed around the time stem extension began (growth stage 2,0) improved the fit of the model. Seasonal variations in temperature had a large effect on the length of the latent period, which increased when mean daily temperatures were less than 5 °C.

FIGEUROA, L., FITT, B. D. L., WELHAM, S. J., SHAW, M. W. & MCCARTNEY, H. A. (1995). Early development of light leaf spot (*Pyrenopeziza brassicae*) on winter oilseed rape (*Brassica napus*) in relation to temperature and leaf wetness. *Plant Pathology* **44**, 641–654.
GILLES, T., FITT, B. D. L., WELHAM, S. J., EVANS, N., STEED, J. M. & JEGER, M. J. (2001). Modelling the effects of temperature and wetness duration on development of light leaf spot on oilseed rape leaves inoculated with *Pyrenopeziza brassicae* conidiospores. *Plant Pathology* **50**, 42–52.
PAPASTAMATI, K., WELHAM, S. J., FITT, B. D. L. & GLADDERS, P. (2001). Modelling the progress of light leaf spot (*Pyrenopeziza brassicae*) on winter oilseed rape (*Brassica napus*) in relation to leaf wetness and temperature. *Plant Pathology* **50**, 154–164.

Towards the development of integrated weather/crop forecasting systems. A. J. CHALLINOR[1,2], T. R. WHEELER[1], J. M. SLINGO[2], D. I. F. GRIMES[3] AND P. Q. CRAUFURD[1]. [1]*Plant Environment Laboratory, School of Agriculture, Policy and Development, The University of Reading, Cutbush Lane, Shinfield, Reading RG2 9AD, UK*, [2]*NERC Centre for Global Atmospheric Modelling, Department of Meteorology, Earley Gate, Reading RG6 6BB, UK*, [3]*Department of Meteorology, The University of Reading, Earley Gate, Reading RG6 6BB, UK*

The continuing development of seasonal weather forecasting presents opportunities for agricultural and environmental planning on timescales 3–6 months ahead. However, methods that exploit these opportunities need to be developed. In particular, an integrated weather/crop forecasting model needs to combine seasonal weather forecasting models, that commonly operate spatial scales of about 200 km, with crop simulation models usually run at the field scale. A method for developing combined seasonal weather and crop forecasting has been proposed. The first stage of this is the determination of the spatial scale(s) on which the system operates by using historical records of weather and crop yields. This was undertaken for groundnut productivity across India. Rainfall is the dominant climatic factor determining groundnut yield in India. Total seasonal rainfall accounted for 52% of the variance in yield as an all-India average over the period 1966 to 1990. However, this correlation became more variable (and sometimes not significant) when examined separately for each of 17 subdivisions of India. Therefore, the spatial structure of the relationship between rainfall and groundnut yields was examined using Empirical Orthogonal Function analysis. Using the subdivisional data, a coherent, large scale pattern emerged for both rainfall and yield. On this scale ($\sim$ 300 km) the first Principal Component (PC) of rainfall was correlated with the first PC of yield ($R^2 = 0{\cdot}53$, $P < 10^{-4}$). Development of a combined weather/crop forecasting system can now proceed at the spatial scale at which this relationship has been established. The first PCs for yield at the district scale ($\sim$ 30 km) and at the subdivisional scale were highly correlated ($R^2 = 0{\cdot}96$). Further, the first PC of subdivisional yield correlated ($R^2 = 0{\cdot}45$) with a PC for a seasonal large-scale circulation pattern over India (identified by Sperber *et al.* 2000). This establishes a link from the patterns of district scale crop yields through to the large-scale circulation patterns associated with rainfall variations across India.

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Modelling animal social organization and disease dynamics. I. BEARDMORE. *Biomathematics Unit, IACR-Rothamsted, Harpenden, Hertfordshire AL5 2JQ, UK*

The functions of social behaviour among animals are extremely diverse, with both beneficial and harmful consequences. One proposed function is the prevention of epidemics where it is believed that spatial segregation could play a significant part in reducing disease epidemics.

Here, a spatial model for two interacting groups of the same species is presented which allows for the behaviour between susceptible and infected individuals in each group to vary. This is an important feature since field studies indicate that infected animals display a significantly different behaviour from that of healthy individuals. Namely, in a study of tuberculosis (*M. bovis*) amongst the badger population, Cheeseman & Mallison (1982) observed that some of the infected badgers displayed signs of very restrictive movement. On the other hand, some cases were observed where infected badgers exhibited loss of fear of humans and cars followed by increased random movements. Similar observations have also been found in foxes infected with rabies (Kaplan 1977; Bacon 1985).

A system of coupled non-linear reaction–convection–diffusion equations is considered, with reaction functions describing within- and between-group interactions and disease dynamics. The work focuses on the question of how the different behaviours of susceptible and infected individuals and the strength of the contact rate between the groups affect the levels of susceptible population that survive the disease. It also investigates the role of the birth parameter in formation and destruction of spatial structure as a response to disease outbreak. Examples and ecological explanations will be given.

Although this is essentially a theoretical study, applications could be envisaged in agriculture, since many feral populations become segregated for part of the year, acting as reservoirs for the disease and posing a threat to livestock.

This research was conducted while IB was working in the Department of Mathematics, University of Bath, UK, and was funded by an ORS grant and a Bath University Scholarship.

Bacon, P. J. (ed.) (1985). *Population Dynamics of Rabies in Wildlife*. London: Academic Press.

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The prediction of pH in biological systems – potential applications in agricultural science. D. J. HIBBERD and P. D. G. WILSON. *Food Safety Science Division, Institute of Food Research, Norwich Research Park, Norwich, Norfolk NR4 7UA, UK*

Theory, developed recently, at IFR by Wilson *et al.* (2000) provides predictions of the pH of complex, buffering systems in the presence of organic acids. Our computational scheme marries together the behaviour of straightforward components (i.e. those that can be modelled using acid dissociation constants, K_a), with a simple empirical characterization of those parts of the system too complex to model in that way. Where components of the system are able to partition into a lipid phase (such as sorbic acid into oils), the theory is able to predict pH changes caused by this behaviour.

To verify the theory, the acid response behaviour of a range of microbiological media was characterized by titration with a strong acid. A wide range of buffering capacities were seen with, for example Man–Rogosa–Sharpe medium requiring approximately ten times the concentration of strong acid to reduce the pH from 7 to 3 as compared with yeast-malt medium. These characterizations were then used to predict response of the media to weak acid additions using the theory and published pK_a values for a number of weak acids. The media were then titrated with these weak acids, and the results compared with our predictions. In all cases the predicted and measured values of pH were within experimental error.

Though most of our work to date has targeted applications in food systems and in experimental microbiology, we believe this theory has applications in the agricultural science arena too. Possible application areas could include changes in pH during silage production, resulting from the production of acidic metabolites by the fermenting organisms; the prediction of buffering capacity of animal feed formulations and prediction of pH of soils in relation to soil remediation or acid precipitation.

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Wilson, P. D. G., Wilson, D. R. & Waspe, C. R. (2000). Weak acids: dissociation in complex buffering systems and partitioning into oils. *Journal of the Science of Food and Agriculture* **80**, 471–476.

Towards a strategic whole farm planning model including the nitrogen cycle. D. L. Sanders[1], A. G. Williams[1], P. Leech[2], E. Audsley[1] and K. Goulding[2]. [1]*Silsoe Research Institute, Wrest Park, Silsoe, Bedfordshire MK45 4HS, UK*, [2]*IACR-Rothamsted, Harpenden, Hertfordshire AL5 2JQ, UK*

Farming is profit-driven, but government is increasingly concerned about managing its environmental impacts. Reconciling sustainable farm incomes while achieving multiple environmental objectives presents an interesting modelling challenge.

We have combined environmental with technical and financial relationships in the Silsoe whole **FARM** systems **MOD**el (SFARMMOD), including emissions of methane, phosphate, nitrate, ammonia and nitrous oxide. The last three are part of the nitrogen cycle, which provides a difficult and important modelling challenge, because of the many interactions, such as choices of winter, spring and catch crops and nitrogen-building crops.

Farming systems with changing soil organic nitrogen status are unlikely to be truly sustainable. We therefore quantify a complete mass balance of nitrogen over a rotation with no overall net change in soil organic nitrogen. Most simulation models, however, predict short-term N dynamics, so allowing soil organic nitrogen to change. We have adapted existing models to provide the necessary steady state information.

SFARMMOD is a strategic farm planning tool, which calculates cropping systems for optimal long-term profitability, taking into account factors such as soil workability, which are a function of soil type and climate. It now also calculates the long-term consequences to whole-farm nitrogen cycles.

Data on environmental impacts have been derived from a variety of sources including the national inventories, as well as process models such as SUNDIAL for arable land (Smith *et al*. 1996) and N Fix Cycle for grassland (Scholefield *et al*. 1991). The models (or their outputs) have been adapted as needed to predict offtake and emissions in steady state. Relationships were then derived to link them to the decision variables; N inputs, crop rotation, sowing date and machinery systems as functions of rainfall and soil type.

Scenarios were created to study the outcomes of policies to reduce ammonia emissions or nitrate leaching. These showed that increasing the value that the farmer can confidently ascribe to the nutrients in applied manure (many farmers assume little nutrient value currently) is an ideal way to reduce N losses and increase net profit. Measures required by the Integrated Pollution Prevention and Control legislation reduce some emissions but increase others and the cost of compliance varies greatly with soil type. Actions required to comply with Nitrate Vulnerable Zones and The Code of Good Agricultural Practice for the Protection of Water do not create a large nitrate leaching reduction above that obtained by farmers adopting sound practices. However, farmer reactions to legislation could reduce even these effects by changing rotations to recover lost income, while staying within regulations.

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Smith, J. U., Bradbury, N. J. & Addiscott, T. M. (1996). SUNDIAL: a PC-based system for simulating nitrogen dynamics in arable land. *Agronomy Journal* **88**, 38–43.

A non-linear approach to analysing energy balance studies in lactating dairy cows. E. Kebreab[1], J. France[1], J. A. N. Mills[1], L. A. Crompton[1], R. E. Agnew[2] and T. Yan[2]. [1]*The University of Reading, School of Agriculture, Policy & Development, Earley Gate, Reading RG6 6AR, UK*, [2]*The Agricultural Research Institute of Northern Ireland, Hillsborough, Co Down BT26 6DR, UK*

The current energy requirement system for dairy cows in the UK, the metabolizable energy (ME) feeding system (AFRC 1993), utilizes key parameters such as ME intake (MEI) at maintenance (ME_m), the efficiency of utilization of MEI for milk production (k_l), growth (k_g) and efficiency of utilization of tissue

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energy for milk production (k_b). These parameters also form the basis of the American system (NRC 2001) and traditionally have been estimated using linear equations.

A number of studies have highlighted concerns over current recommendations that are based on experiments conducted over 30 years ago. Underlying these concerns could be the rigid acceptance of linear methods in analysing energy balance data from dairy cows. Therefore, a database of calorimetric data containing 435 records was constructed from experiments conducted at the Agricultural Research Institute of Northern Ireland and The University of Reading. Five functions were considered: a straight line, two diminishing returns equations (Mitscherlich and rectangular hyperbola) and two sigmoidals (logistic and Gompertz).

Based on the definition of k_l as the ratio of milk energy derived from MEI to MEI directed towards milk production, zero energy balances (± 5 MJ) were used to estimate regression parameters to determine ME_m and k_l. Positive and negative energy balance data were used to estimate k_g and k_b, respectively. Values of 0·79 and 0·65 for k_g and k_b, respectively, were obtained with each function. These were significantly different from previous reports of 0·60 to 0·75 for k_g and 0·82 to 0·84 for k_b. When all the data were pooled, the average value for k_l was 0·61. Non-linear analysis showed a decreasing value of k_l as feeding level above maintenance increased. The linear model provided a value of k_l that does not change with level of feeding. The rectangular hyperbola gave large standard errors with its parameter estimates. The sigmoidals tended to underestimate milk energy at higher level of feeding and the efficiency of utilization of energy for maintenance. Among the five functions considered, the Mitscherlich gave relatively lower standard errors and the parameter estimates made biological sense, and therefore this function is appropriate for the analysis of energy balance data.

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