THE ROLE OF SYNOPTIC MODELS IN THE DEVELOPMENT OF CROP PROTECTION FOR SUSTAINABLE CROP PRODUCTION SYSTEMS.

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ABSTRACT

Crop protection practices in sustainable production must be more closely tied to the requirements of individual crops. Currently in intensive production, crop protection takes the form a number of reactive steps, which are generally triggered either by rather arbitrary threshold values for pest (invertebrate, disease, or weed) damage, or by crop growth stages, in which case no account is taken of the actual risk to the crop in any individual year. More efficient and sustainable crop protection systems can be developed when chemical and cultural control measures are seen as components of the overall production method and not as add-in solutions to the occurrence of individual pests. Our approach to developing these new systems has similarities to recent developments in several tropical production systems. Initially the crop production system is modelled by multivariate methods to identify advisory domains. The domains are described by different sets of management and pest variables and are therefore associated with different levels and types of risk. Farms (or individual fields) can be classified by the type of domain to which they belong and the crop production system designed from this starting point. Variation in occurrence of individual pests, or combinations of pests, may be modelled further to develop advisory aids through the application of generalised linear or probability-based models. Crop monitoring is essential both in the obtaining the initial data to describe the domains and in operating successful sustainable crop protection within them. Particularly in the case of chemical control measures, significant reductions in use without loss of reliability of yield, will be possible if pesticides are applied only when required and the applications are timed for maximum efficiency. These objectives will not be achieved if the farmer or advisor has no idea of the pest status of the crop throughout the season.

INTRODUCTION

The approach adopted in this paper follows from the view expressed by Vereijken (1992) that the development of sustainable agricultural systems depends on increased localisation of markets and production systems. This philosophy, when applied to crop protection, leads to the idea that in order to obtain sustainability each crop (field) must be treated individually, or at least its general features must be characterised, and crop protection measures applied specifically in response to locally important problems which arise. One way by which this objective might be achieved is through the development of synoptyic models for the crop production system which can be used strategically to improve the efficiency of extension work and applied research. A number of different types of model which can be classed as synoptic will be introduced and one of these approaches will be described in more detail using data from the COIRE (Crop Optimisation by Integrated Risk Evaluation) project.

SYNOPTIC MODELS IN CROP PROTECTION

Qualitative analysis

In the most general sense a synoptic model is one which provides an overview or summary of a system. One such model is shown in Figure 1, which is redrawn from Vereijken's (1992) paper and is a representation (causal graph) of the interacting factors in the world agricultural market. Although this type of model cannot be used directly for quantitative analysis of the system it may identify interactions which need to be studied in more detail.

One argument put forward by Vereijken (1992) was that the system represented in Figure 1 is essentially unstable. While this assertion cannot be tested directly with the model in its original format it can be explored in a second type of synoptic model developed in community ecology (May, 1974) and system analysis (Taber, 1991). An analysis of Vereijken's model has been conducted (Figure 2). In this approach the interacting factors are represented as a square matrix, in which each row represents the effects of one of the factors on each of the others in turn. A Markov chain process is used to examine the stability of the system over time by multiplying the matrix by a vector of initial conditions (given as cycle 0 in Figure 2) to produce a rectangular output matrix, as shown in Figure 2. The models briefly introduced so far may be used for qualitative analysis of systems. However, for more detailed examination of individual systems a quantitative approach to synoptic modelling is required.

Quantitative analysis

The term synoptic was introduced to crop protection by Stynes (1980) to describe a synecological approach to modelling crop losses. Stynes's method attempted to capture the complex interactions between the crop, its environment and production constraints (pests, weeds, diseases, and poor management practices) in simple regression models following initial data reduction by multivariate analysis. Related techniques have subsequently been developed by Savary, Zadoks and co-workers, and their application demonstrated in a number of tropical

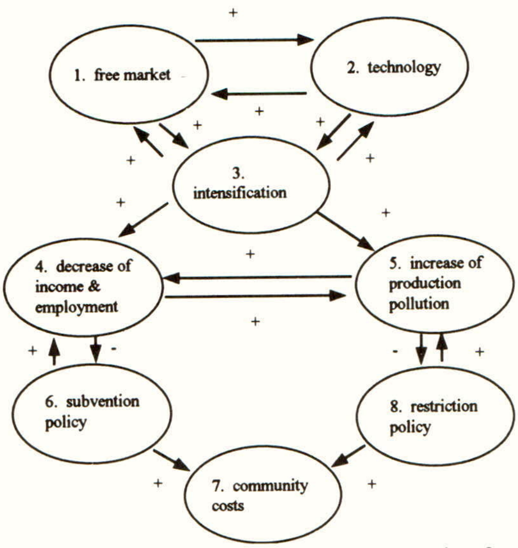

Figure 1. A causal graph model of interacting factors in intensive agricultural production. Redrawn from Vereijken (1992).

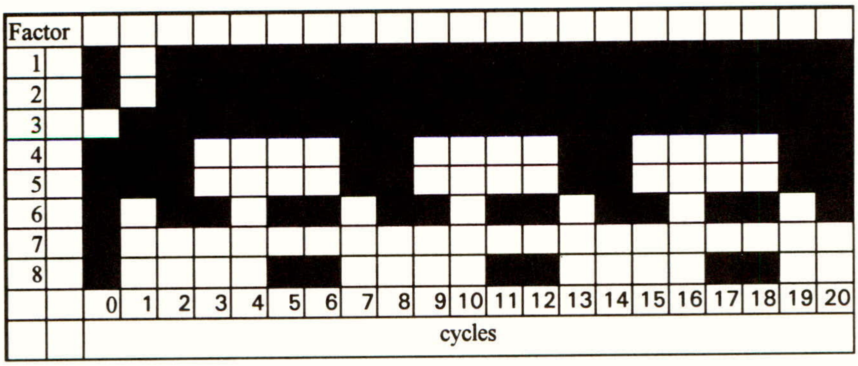

Figure 2 The predicted behaviour of the system represented in Figure 1. A solid cell in a any column indicates that the factor represented by the corresponding row will increase in the cycle represented by the column, while empty cells indicate that the factor will reduce or be unaffected for that cycle. The first three factors (free market, technology and intensification continually increase after the first cycle, while factors such as income and subvention policy oscillate on cycles of different periods.

cropping systems (Savary, 1991; Savary *et al*., 1994). Recent interest in the application of GIS technology to crop protection has added a further class of related modelling techniques which may be termed synoptic (Nelson *et al*., 1994). Irrespective of the analytical details, all of the quantitative synoptic modelling methods involve three general steps:/

1. Collection of multivariate data by surveys of real crops.
2. Data reduction.
3. Extraction of categories for the crops in the data set.

This group of modelling techniques share one further characteristic which is of interest in the context of developing sustainable production systems. In all of the methods variation between crops at different locations is taken into account and examined in detail. However, while these methods provide the potential to characterise the production constraints on the local scale required for efficient crop protection, they also provide a summary of the production system at a larger spatial scale; *e.g.* at a regional or national scale depending on the extent of the complete survey programme.

Example Of A Possible Methodology: Autumn-Sown Wheat In Scotland

The general aims and methodology of the COIRE project have been described previously (McRoberts *et al.*, 1994). For each of 50 fields, chosen to represent the arable area of Scotland, approximately 300 items of data were collected, including information on surrounding land use, pest, weed and disease populations, soil characteristics, and husbandry practices. In the COIRE project, which will end in 1996, data collection will be repeated for three full growing seasons for both wheat and autumn sown oilseed rape, and synoptic models for the crops will be developed from these sets of data. However, for simplicity, the current example will illustrate the approach using data collected at one survey only, immediately before harvest in 1994.

Field Characteristics

Data for 20 field characteristics were recorded on a presence/absence basis. The data matrix of fields by characteristics was analysed by principal components analysis to obtain a graphical representation of the variability in the sample of fields and a ranking of the important field characteristics which determine the variability. The separation of the fields in the first two principal components of this analysis is shown in Figure 3.

Weed data and Disease data

The number of visible weedy patches and the species composition of the patches were recorded in each field. A principal components analysis of the correlation matrix of these data was conducted to examine inter-field variation, as in the case of the field characteristics data, and is summarised in Figure 4 . The severity of 11 types of fungal infection was recorded in each of the 50 fields. The data were analysed in a similar manner as the other two sets of data. The separation of the fields and the association of the disease variables with the first two principal axes are shown in Figure 5.

Comparison of the groupings of fields suggested by the independent analyses

Overall agreement between the principal components for the three independent analyses was conducted by pair-wise canonical correlation analysis (CCA) (Digby & Kempton, 1987) Results from the CCAs are shown in Table 1.

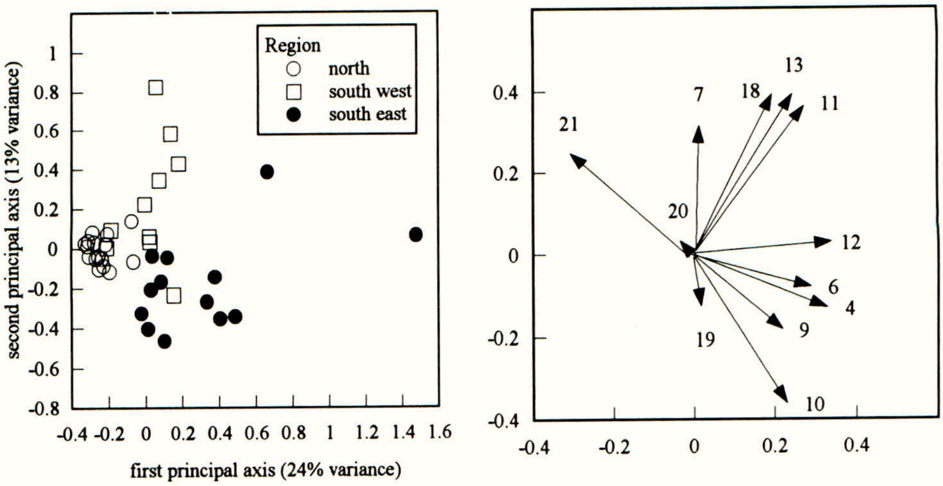

Figure 3. *The separation of wheat fields (left-hand figure) in the first two principal axes of an analysis of 20 field characteristic variables, and the association between the variables and the principal axes (right-hand figure, only a sub-set of the variables are shown for clarity). 4, fresh water; 6, salt marsh; 7, moor land; 9, farm buildings; 10, shelter belt; 11, fallow land; 12, urban area; 13, waste ground; 18, uncultivated strip; 20, water course; 21, crop growth stage.*

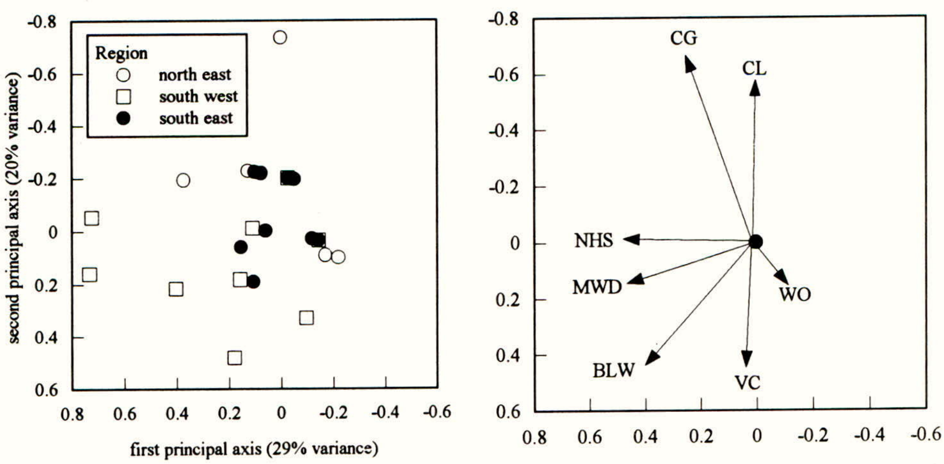

Figure 4. The separation of wheat fields in the first two principal axes of an analysis of their pre-harvest weed populations (left-hand figure) and the association between the weed variables and the principal axes (right-hand figure). NHS, number of weed hot-spots; MWD, mayweed, BLW mixed broad-leaved weeds; VC, volunteer cereal; WO, wild oat; CL, cleavers; CG couch grass.

The canonical correlations can be interpreted in the same way as standard correlation coefficients and are the highest correlations which can be obtained between principal axes of the separate sets of data.

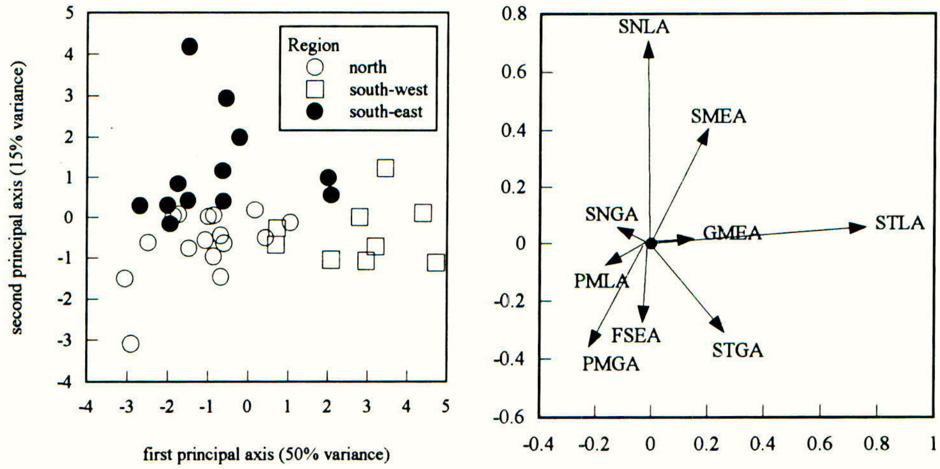

Figure 5. The separation of wheat fields in the first two principal axes of an analysis of their pre-harvest disease populations (left-hand figure) and the association between the disease variables and the principal axes (right-hand figure). SN; Septoria nodorum; ST, Septoria tritici; PM powdery mildew; FS Fusarium spp.; GM, grey mould; EA; % ear area infected; LA; % leaf area infected; GA, % glume area infected.

TABLE 1. Canonical correlations between the principal axes of analyses of site characteristics, weeds and diseases for fields of autumn-sown wheat.

sites and weeds data		sites and diseases data	
Canonical axis		Canonical axis	
1	2	1	2
0.6	0.3	0.7	0.6

Summarising the model of the crop system

Synoptic modelling should lead to a series of practical conclusions. The conclusions will vary depending on the aims of the modelling exercise (*e.g.* crop loss prediction, risk assessment, etc.). The following list of conclusions is illustrative of the type of information which one might expect to gather from synoptic modelling as described above. It is stressed that the example analyses and the conclusions drawn from it are intended only as examples of the methodology.

1. Two or three advisory domains can be recognised in the current analysis. The first domain consists of arable production in a mixed farming background (predominantly in the south west), with a variety of surrounding land uses. Cropping in this domain tends to be associated with weed infestations and diseases which attack the ears and glumes of the plant. The second domain (which may be split into two geographical areas) contains

crops in predominantly arable areas where weed control is apparently efficient, but where crops are more likely to be attacked by common leaf diseases.

2. Advisory domains in the cropping system should be established at a geographical scale no larger than the regions represented in the original data, since there is a clear regional variation at this scale irrespective of the type of data analysed. The agreement between the three sets of data probably results from the underlying correlation of all three types of data
to broad climatic differences between the regions. Given the intra-regional variation expressed in some the data, further analysis should be conducted to determine whether a smaller geographical scale should be adopted for the advisory domains.
3. Increased productivity might be expected in the south west region by the adoption of improved weed control, particularly for broad-leaved weeds and volunteer cereals. Farmers may be asked to consider adoption of additional cultural methods to control these weeds if required, or alerted to the possibility of reducing herbicide doses by applying herbicides at an early stage of weed growth.
4. Farmers in the south west should be encouraged to consider early maturing varieties to reduce the effects of fungal diseases which damage the leaves and ears of the crop during wet weather (*Septoria tritici*, grey mould).
5. Crops in the south east and north east were more commonly attacked by leaf infecting diseases such as powdery mildew. The occurrence of these diseases is at least partly related to the density of wheat growing in these regions, and farmers should be encouraged to consider using mosaics of varieties from different resistance groups, within and between farms. If control of common leaf diseases is likely to be a priority in the south and north east, farmers should be encouraged to adopt assessment-based reduced dose spray programmes such as those discussed by Wale (this volume). A practical extension priority in this area would be to demonstrate the management, economic, and environmental benefits to the farmer of adopting this approach over a critical-point threshold approach.

DISCUSSION

Modelling methods which allow a detailed analysis of cropping systems and a hypothetical set of recommendations arising from one of these procedures have been presented. While the qualitative analyses may be useful in identifying areas for research, their application to examination of specific cropping systems is more limited, and Murdoch (1975) has pointed out several difficulties which may arise in attempting to apply analyses from theoretical ecology to crop protection problems.

The quantitative synoptic analyses presented here produce recommendations which could form the basis of general policies for crop protection in the development of sustainable systems. In addition, the comprehensive surveys conducted during the modelling process provide a snap-shot of the system which can be used as a reference as more sustainable production methods are adopted. The importance of monitoring as part of the development and practice of sustainable crop protection is stressed. The cost of making accurate assessments of crops is an inevitable part of making crop production more sustainable. It should not be taken for granted that farmers will respond positively or uniformly to suggestions about improving the efficiency of crop protection (Zadoks, 1989) or increasing sustainability (Fujisaka, 1994). Farmer's responses to advice can be included as a separate set of variables in the synoptic model (Savary *et al.*, 1994), and the rapidity with which new practices are taken up by farmers can then be related to the features of the advisory domain.

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REFERENCES

Digby, P.G.N. ; Kempton, R.A. (1987) *Multivariate Analysis of Ecological Communities*. Chapman & Hall, London, 206 pp.

Fujisaka, S. (1994) Learning from six reasons why farmers do not adopt innovations intended to improve sustainablility of upland agriculture. *Agricultural Systems*, **45**, 409-425

May, R.M. (1974) *Stability and Complexity in Model Ecosystems*. Princeton University Press, Princeton, 265 pp.

McRoberts, N. ; Foster, G.N. ; Duffus, C. ; Evans, K.A. ; McKinlay, R.G. ; Davies, K. ; Wale, S.J. (1994). COIRE: Crop Optimisation by Integrated Risk Evaluation. A new approach to crop protection in arable crops. In: *Sampling to Make Decisions* P. Brain, S.H. Hockland, P.D. Lancashire, L.C. Sim (Eds) *Aspects of Applied Biology*, **37**, 207-215.

Murdoch, W.W. (1975) Diversity, complexity, stability and pest control. *Journal of Applied Ecology*, **112**, 795-802.

Nelson, M.R. ; Felix-Gastelum, R. ; Orum, T.V. ; Stowell, L.J. ; Myers, D.E. (1994) Geographical information systems and geostatistics in the design and validation or regional plant virus management programs. *Phytopathology*, **84**, 898-905.

Savary, S. (1991). *Approches de la pathologie des cultures tropicales*. Karthala/ORSTOM , Paris, 288 pp.

Savary, S. ; Elazegui, F.A. ; Moody, K. ; Litsinger, J.A. ; Teng, P.S. (1994) Characterization of rice cropping practices and multiple pest systems in the Philippines. Agricultural Systems **45**, 385-408.

Stynes, B.A. (1980) Synoptic methodologies for crop loss assessment. In: *Crop Loss Assessment. Miscellaneous Publications of the Agricultural Experiment Station of the University of Minnesota*, **7**, 166-175.

Taber, W.R. (1991) Knowledge processing with fuzzy cognitive maps. *Expert Systems with Applications*, **2**, 83-87.

Vereijken, P (1992) A methodic way to more sustainable farming systems. *Netherlands Journal of Agricultural Science*, **40**, 209-233.

Wale. S.J. (1995) An integrated disease risk assessment system for winter barley. In : Integrated Crop Protection: Towards Sustainability? BCPC Publications.

Zadoks, J.C. (1989) EPIPRE, a computer-based decision support system for pest and disease control in wheat: its development and implementation in Europe. *Plant Disease Epidemiology*, **2**, 3-29.