MODELS FOR ANALYSING THE GROWTH AND YIELD OF PEA CROPS

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ABSTRACT

The use of a modelling approach to analyse the growth and yield of pea crops, and thus identify the causes of yield variations, is described. The value of the approach for establishing research priorities is highlighted and progress in two current research projects which are focussing on specific aspects of pea yield variability is outlined. One project aims to define the effects of timing and severity of water deficit on pea crops in terms of the responses of the main determinants of yield. In the second project harvest index stability, which is an important contributor to yield variability, is being studied. The aim is to identify environmental conditions and genotypes associated with stable, high harvest index.

***Additional key words:** yield variability, water deficit, harvest index, yield determinants, environment, genotypes.*

INTRODUCTION

Yields of pea crops are more variable than most other arable crops. Identification of the management, cultivar and environmental factors which cause the variations is an important research objective. The aim is to find ways to reduce the variations and thus improve average yield.

Good crop management advice is already available (Jermyn, 1984). In contrast, much less is known about environmental influences on the growth and yield of pea crops, or cultivar characteristics associated with stable, high yield potential. Gallagher *et al.* (1983) pointed out that environmental influences on crops are usually much greater than the effects of crop management. This is especially true for peas. Thus it is important to understand the processes which contribute to the growth and yield of pea crops, how these processes vary among genotypes, and the effects on them of environmental factors which cause the most yield variability.

One way to achieve this is to use a modelling approach to analyse the growth and yield of pea crops. This approach was discussed by Wilson (1987) who advocated it as a way to identify causes of yield variation. In this paper we review the approach briefly, describe how it can be used to identify research priorities for reducing pea yield variability, and then discuss progress in two current research projects.

CROP MODELS

The development and use of models which simulate crop growth and development has become popular over the last 20 years as advances in computer technology have made it possible to handle the complex calculations required.

A model is a simplified, quantitative description of a crop expressed as a series of equations. It consists of relationships representing the main physiological processes which contribute to growth and yield. These include genotype-specific parameters, and the effect of environmental factors on them. Plant processes previously studied separately are thus organized in a logical manner. Therefore, a model allows improved understanding of a complex system such as a crop and its environment by combining fragmented knowledge about it into a unified whole.

Once developed, models can be used to analyse and predict the behaviour of the systems they represent. Crop models have varied uses:

* Setting research priorities by identifying those environmental and plant factors which most influence crop performance.
* Helping identify gaps in knowledge of plant processes and crop-environment relationships.
* As frameworks for logical analysis of experimental results.
* Defining crop responses to the environment.
* Predicting likely effects of management decisions on crop performance.
* Identifying crop and cultivar characteristics associated with high yield potential.

Many models of varying complexity have been developed for a range of crops, particularly wheat, maize, soybeans and cotton. Most use a reductionist approach which synthesises understanding of a crop system from knowledge of its constituent parts. However, in our research on peas and other crops we follow the holistic approach of Charles-Edwards (1982) and Charles-Edwards *et al.* (1986). This approach aims to understand crop performance by deduction or inference, using models to analyse observations of the behaviour of whole, intact crops. It has the advantage that the models are relatively simple, and contain only a few parameters which can all be estimated directly from field measurements. They are defined at the crop level of biological organisation, rather than in terms of processes occurring at some lower level of organisation as in reductionist models. Nevertheless, the parameters can be further analysed in terms of more basic physiological and physical processes of plant growth (Charles-Edwards & Vanderlip, 1985).

APPLICATION OF MODELLING TO PEA CROPS

Our main reason for using a modelling approach to analyse the growth and yield of pea crops is to establish research priorities by identifying the main crop and environmental factors which cause yield variation. The analyses are based on the approach proposed by Charles-Edwards (1982) which identified five major determinants of yield:

1. The amount of solar radiation intercepted by a crop canopy (Q).
2. The efficiency with which intercepted radiation is used in growth (e).
3. The duration of growth (t).
4. The partitioning of total dry matter between different crop parts, especially into those of economic interest (n).
5. The amount of dry matter lost during growth (V).

The growth of crop portion h (e.g. seeds, stems, leaves, roots, etc.) over a duration of t days (Wh) can be written in terms of the five determinants to form a simple model:

$$W_n = \int_o^t (n_n.e.Q - Vn)dt$$

Wilson (1987) discussed how this model has been used successfully to describe the growth of pea crops in a range of conditions, and how it was used to help identify why yield varied considerably among seasons, cultivars, sowing times and irrigation treatments (Jamieson *et al.*, 1984; Wilson *et al.*, 1985). In this paper we describe two current research projects which focus on particular aspects of pea yield variability.

One project aims to define the effects of water deficit on pea crops. Water availability is usually the main environmental factor responsible for yield variability.

The next section describes a current experiment which has the main objective of defining how water deficits of different severities and at different times during crop growth affect the determinants of the model and, ultimately, seed yield.

In the second project, harvest index (HI) stability in peas is being studied. Partitioning of dry matter to the seed is not only sensitive to management and environmental factors, but also differs substantially among genotypes. It is therefore an important contributor to yield variability. The challenge to pea breeders is to identify genotypes with stable, high HI, and the final section describes another current experiment in which individual plant HIs within crops of contrasting genotypes are being examined.

EFFECTS OF TIMING AND SEVERITY OF WATER DEFICIT ON FIELD PEAS

Traditional irrigation management practice is to water pea crops twice, at flowering and again at pod fill, unless rainfall is significantly above or below average. The disadvantage of this rule-of-thumb approach is that it takes little account of water availability to the crop during growth. More recently, irrigation scheduling has been related better to crop water need, with water budgeting and/or soil moisture monitoring being used to account for crop water use, rainfall and irrigation.

Despite this progress important questions remain unanswered, especially about the timing of irrigation in relation to crop development. There are conflicting views about the effect on the growth and yield of pea crops of irrigation close to flowering and during vegetative growth, well before flowering. In previous experiments (Jamieson *et al.*, 1984), we found that yields were reduced by 0.2% for every mm that the maximum potential soil moisture deficit exceeded a critical deficit of 88 mm in a deep silt loam, regardless of when the drought occurred. However, the results were incomplete because we were unable to subject crops to severe water deficits early in the season.

In the 1989-90 season, an experiment with field peas is being conducted in the DSIR/MAF rainout shelter at Lincoln which should answer these questions conclusively, and therefore lead to optimum irrigation management guidelines.

The rainout shelter has the advantage that it allows a crop to be grown under natural field conditions except that it is covered automatically whenever rainfall occurs. Timing and severity of water deficits can therefore be controlled precisely.Twelve irrigation treatments will be applied to the experimental crop using a trickle system which allows measured quantities of water to be applied to individual plots.

The treatments have been designed to expose the crop to a range of timings, severities and durations of water deficit. Except during deficit treatment periods, plots will be irrigated each week with enough water to replace the water used in evapotranspiration during the previous week, as determined by a water budget based on neutron probe measurements of soil moisture. Thus each deficit treatment will start one week after the last irrigation. Plots will be subjected to deficits of several severities either early in growth, during mid-season, or late in crop development. Also, two treatments will be irrigated fully, one to field capacity and the other to replace weekly evapotranspiration. Details of the twelve treatments are given in Table 1.

Crop growth and water use in all plots will be monitored throughout the season to define deficit severities and identify the model determinants associated with yield responses. Radiation interception by the crops and dry matter distribution to seeds, stems and leaves will also be measured because they are likely to be associated prominently with yield differences. Seed yield and yield components will be measured at maturity.

HARVEST INDEX STABILITY

Variable partitioning of dry matter to seed, quantified by HI, has been identified as an important contributor to yield instability in pea crops (Ambrose & Hedley, 1984). Harvest Index is sensitive to management and environmental factors, and also differs substantially among genotypes. The challenge is to identify conditions and genotypes associated with a stable, high HI.

Traditionally, HI is defined on a whole-crop basis, with little regard to the performance of individual plants within crops. However, in pea crops it has been shown that the plant harvest index (PHI) of individual plants can vary from 0 to 70% (Ambrose & Hedley, 1984; Hedley & Ambrose, 1981). Therefore, to improve seed yields the aim should be to have more individual plants with high HIs. As HI is amenable to genetic improvement (Passioura, 1981), it is important to identify the degree to which HI stability varies among pea genotypes. Such an approach should lead to a clearer definition of breeding and selection objectives.

Pea plants are not naturally adapted to growing in crop communities. Hedley and Ambrose (1985) suggested that because of their ancestry as wild, solitary plants not growing in monocultures, it is difficult to define their most efficient form for growing them at the community level. In spite of these uncertainties, individual pea plants are traditionally selected in early generations of breeding programmes because of their superior performance as single, spaced plants.

The plants chosen are usually dominant competitive types, and may have the greatest PHI variability when grown in crop communities (Ambrose & Hedley, 1984). Donald (1968) and Evans (1981) proposed the idea that to achieve the highest efficiency at the community level each plant has to suffer minimum interference from its neighbours, and therefore should be a weak competitor. The success of a pea crop at producing a high yield would thus depend on the ability of individual plants to adapt to a community level.

A project is in progress at Lincoln to test these ideas by aiming to identify pea plant phenotypes which are most suited to growing in communities and therefore have stable, high PHIs and superior yield potential.

As a first step, it was necessary to determine the degree of variation of stability of PHI among different genotypes. Hence, in 1988-89 four lines with contrasting morphological characteristics were selected

Table 1. Irrigation treatments in the rainout shelter experiment. A dash indicates no irrigation for the week and an 'i' indicates an irrigation.

Week		Full Irrigation		Early Deficit			Middle Deficit			Late Deficit			
		1*	2*	3	4	5	6	7	8	9	10	11	12
Nov	9	i	i	-	-	-	i	i	i	i	i	i	i
	16	i	i	i	-	-	i	i	i	i	i	i	i
	23	i	i	i	i	-	i	i	i	i	i	i	i
	30	i	i	i	i	-	-	-	-	i	i	i	i
Dec	7	i	i	i	i	i	-	-	-	i	i	i	i
	14	i	i	i	i	i	i	-	-	-	i	i	i
	21	i	i	i	i	i	i	i	-	-	-	i	i
	28	i	i	i	i	i	i	i	i	-	-	-	i
Jan	4	i	i	i	i	i	i	i	i	-	-	-	-
	11	i	i	i	i	i	i	i	i	-	-	-	-
	19	i	i	i	i	i	i	i	i	-	-	-	-
Expected deficit severity (maximum potential soil moisture deficit, mm):		35	95	50	70	120	55	85	120	175	140	105	70

* Treatment 1 irrigated to replace weekly water use and treatment 2 irrigated to field capacity.

from sixty F_{12} lines in a yield trial in the DSIR Crop Research field pea breeding programme. The lines were classified in three ways: as conventional (C) or semi-leafless (S) foliage type, vigorous (V) or non-vigorous (N) and growth of uniform (U) or non-uniform (N) appearance.

Samples from the trial exhibited variability among the lines in their PHI distribution. For example, the CVN line had a higher proportion of barren (PHI = 0) and poor performing (PHI < 33%) plants than the SVU line (Figure 1).

In the 1989-90 season, a field experiment is being conducted to determine if the differences among the four lines are attributable to agronomic, physiological or genetic influences, and thus to identify if any one of them produces a stable, high PHI.

The lines have been sown at five plant populations: 9, 64, 100, 225 and 400 plants/m^2. The lowest population approximates the spaced planting arrangement used for single plant selection in the early generations of breeding programmes, the 100 plants/m^2 is a commercial plant density, and the two highest populations should force inter-plant competition early in canopy development.

The experiment will be managed to achieve potential yields by keeping all disease, water and nutrient conditions non-limiting. The emergence date and seedling growth of 100 plants per plot will be recorded to examine their influence on final harvest performance. The harvest index and other parameters of the yield of individual plants will be measured at maturity.

CONCLUSIONS

We have aimed to show how modelling can be used to identify how genotypic, management and environmental factors cause yield variations in pea crops, and have used two examples to show how the approach can lead to:

* Better understanding of the mechanisms underlying yield variation.
* Identification of strategies to improve yield stability.
* Development of experimental approaches to investigate the principal factors causing yield variation.

These results are usually not possible using traditional agronomic approaches to yield improvement.

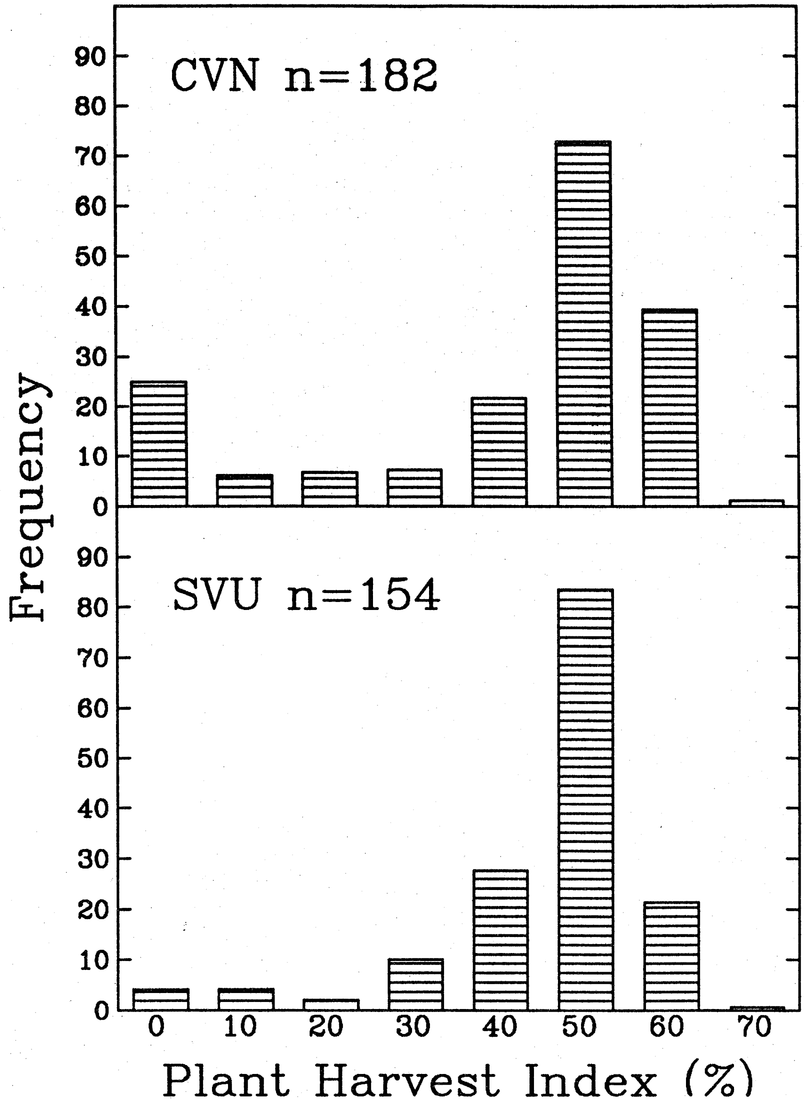

Figure 1: **Plant harvest index frequency distributions for the conventional, vigorous, non-uniform (CVN) and the semi-leafless, vigorous, uniform (SVU) lines from the F_{12} pea yield trial in 1988-89.**

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