APPENDIX 1

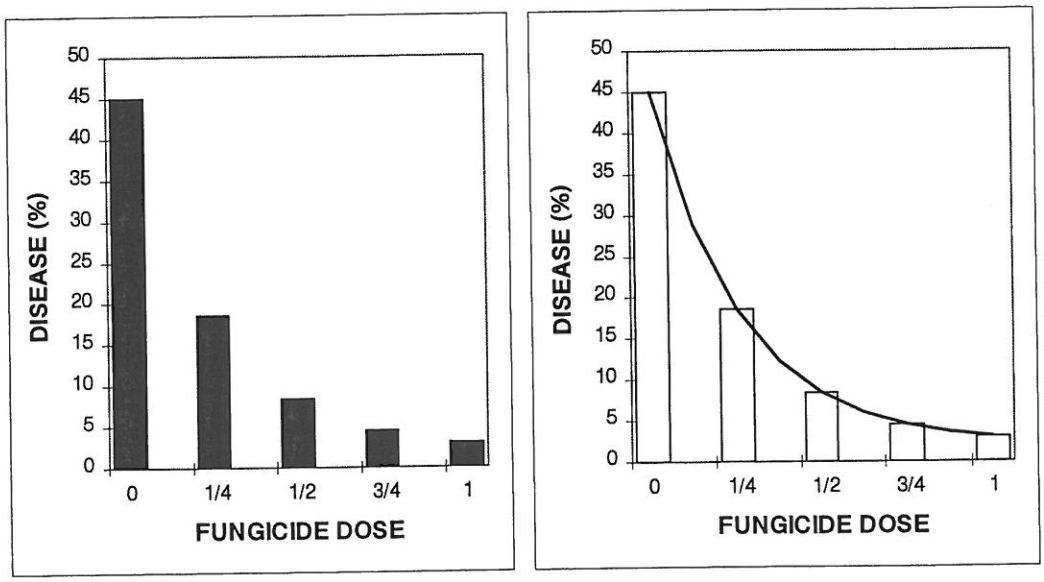
An introduction to appropriate fungicide doses

The dose-response curve

If the severity of foliar disease is measured in experimental plots which received fungicide treatment, at a range of doses, some time before, the results will typically look like those in Figure 1. Those plots which received no treatment will suffer a level of disease determined by the local 'disease pressure'. Fungicide treated plots will suffer less disease and the higher the dose, the lower the disease severity. However, a law of diminishing returns operates and each successive increase in dose causes a smaller additional effect.

The decrease in disease with increasing dose is commonly represented by a line, rather than bars, and is described as a 'dose-response curve'.

Figure 1. Disease severity following fungicide treatment at a range of doses and the dose-response curve



The maximum dose that can be used is specified on the label, as the recommended dose, and must not be exceeded. However, there is no legal limit to the minimum dose that should be applied, and the majority of crops now receive fungicides at doses substantially below those recommended (Paveley *et al.*, 1994). To understand why, it is helpful to consider how the recommended dose is set.

The recommended dose

The process of setting the recommended dose for a new product has been described by Finney (1993). He noted that 100% control is usually either technically unachievable in the field on a consistent basis, or is not cost effective. Furthermore, when the same fungicide is applied to control the same disease at a range of locations, the response to the applied chemical varies from place to place. The dose which gives 90% control in

one field can be quite different to that which gives 90% control in another. To allow for this inherent variability and avoid product dissatisfaction, the label recommended dose is usually set at a level which consistently gives a high level of control across locations and seasons, typically 80-90% control 80-90% of the time.

It follows that on many, but not all, occasions the recommended dose is higher than that required to achieve satisfactory control.

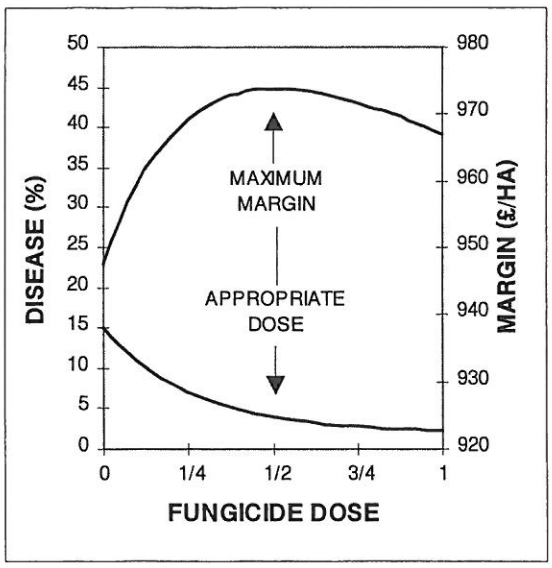
Reduced doses

During the late 1980's and early 1990's, growers recognised the safety margin built into the label recommended dose and, under pressure to reduce input costs, began to reduce the doses of fungicides applied to cereal crops. Survey data suggest that these reductions were (Paveley *et al.*, 1994) and still are (Stevens *et al.*, 1997) often made in an arbitrary manner.

Appropriate fungicide doses

Fungicide cost increases in direct proportion to the dose applied. As the loss of yield and grain quality is proportional to the level of disease, a point can be found on the dose-response curve, beyond which the cost of any further increase in dose would not be paid for by the resulting yield increase. At this point, profit is maximised (Figure 2) and unnecessary pesticide use minimised - by definition the **appropriate dose** to apply.

Figure 2. Dose-response curve, margin[1] over fungicide cost and appropriate dose



[1] Margin over fungicide cost: potential yield 10 tonnes/ha; grain value £100/tonne; yield loss 0.35% per 1% disease severity; fungicide cost £25/ha/dose. The effects of variation in grain price, fungicide cost and disease-yield loss relationships are dealt with later in the report.

At doses below the appropriate dose, profit is reduced by ineffective disease control. At doses above the appropriate dose, profit is reduced by excessive fungicide cost.

It is important to note that the loss of profit is more severe if the dose is reduced below the appropriate dose than if increased above it. Hence, where there is uncertainty about the appropriate dose to apply, it is prudent to apply more, rather than less. The greater the uncertainty, the greater the safety margin required.

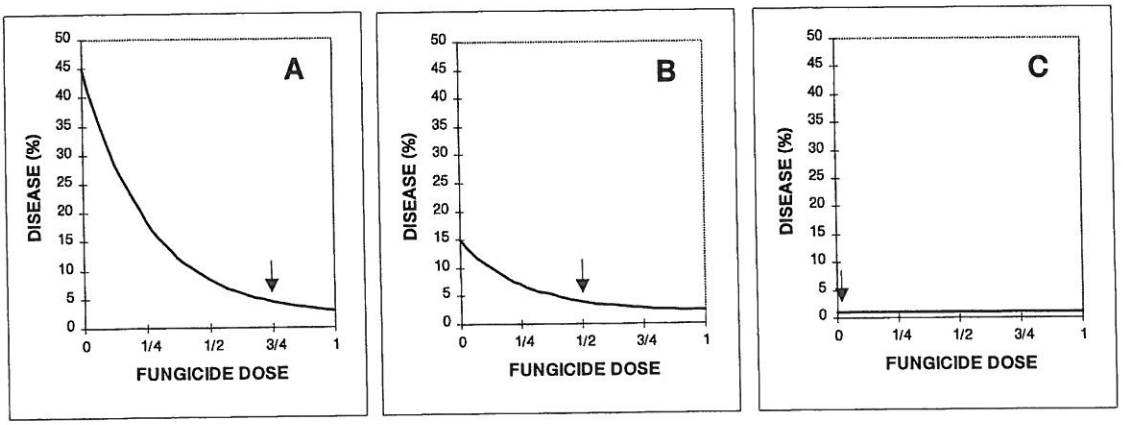
On what basis can a crop manager decide on the appropriate dose to apply - given that, as the shape of the dose-response curve varies from site to site and season to season, so must the appropriate dose ? And how can the uncertainty surrounding the choice of dose be minimised, to allow doses to be applied that are consistently close to the economic optimum, without suffering occasional severe losses due to under-application ?

The answers must come from taking account of the causes of the variation in disease control between sites and seasons; otherwise we are not *managing* crops, but merely playing the averages.

Variation in dose-response curves

One of the main reasons for variation in disease control between sites and seasons is that, in the absence of treatment, disease severity varies between sites and seasons. Figure 3 shows the effect on the dose-response curve and the appropriate dose, of different levels of untreated disease. Curve (A) represents, for example, a crop of a disease susceptible variety, that experienced weather conditions favourable to disease development; curve (B) a more resistant variety or a susceptible variety under conditions less favourable to disease; and curve (C) a variety with complete immunity to that disease.

Figure 3. Effect of disease pressure on dose-response curve and appropriate dose (represented by an arrow)

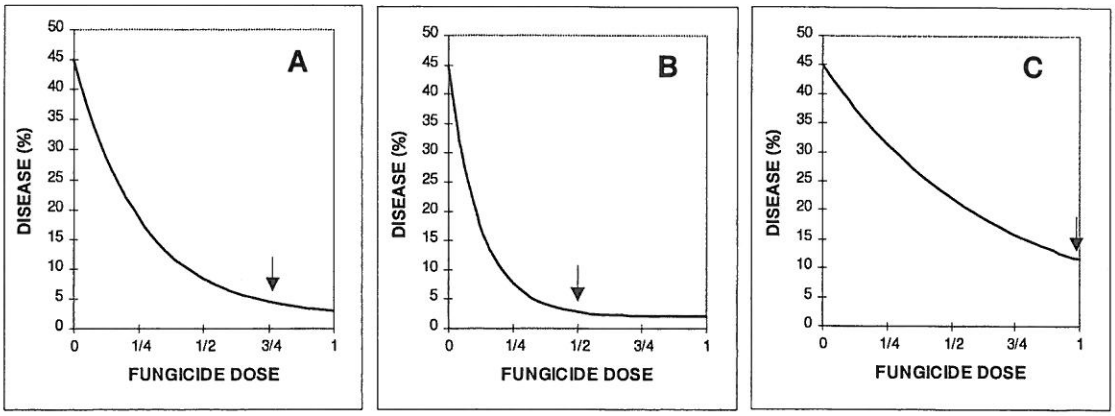


Clearly, higher disease pressure justifies higher inputs.

However, the appropriate dose also depends on efficiency of control. Figure 4 takes the high disease pressure case (A) and shows the effect of applying alternative products that are more (B), or less (C), effective.

All else being equal, more effective products have lower appropriate doses. However, efficacy is often reflected in price, so the best product/dose combination needs to be selected to do the job.

Figure 4. Effect of fungicide activity on dose-response curves and appropriate dose.



Input management for minimum unit cost

It can be seen, from the examples shown above, that the appropriate dose in a range of circumstances can vary between the recommended dose and zero.

A crop manager who is better able to quantify disease pressure and predict efficiency of control, will be able to apply doses that are consistently closer to the economic optimum - to the benefit of unit cost of production and the defensibility of pesticide use.

APPENDIX 2

Interpretation of dose-response curves and parameter estimates

Biological data are subject to natural error variation, exacerbated in the case of disease data, by the subjective nature of visual disease assessments (Parker, 1992). Figure 1 shows typical percentage disease data points for untreated, quarter, half, three quarter and full doses of a range of fungicide products. The curves represent exponential functions fitted to the data. The extent to which data points depart from the fitted dose-response curves provides a measure of the error variation in the data. Where the scatter about the curve is small in proportion to the size of the treatment effect, the parameter estimates which describe the shape of the fitted dose-response curve can be compared with greater confidence.

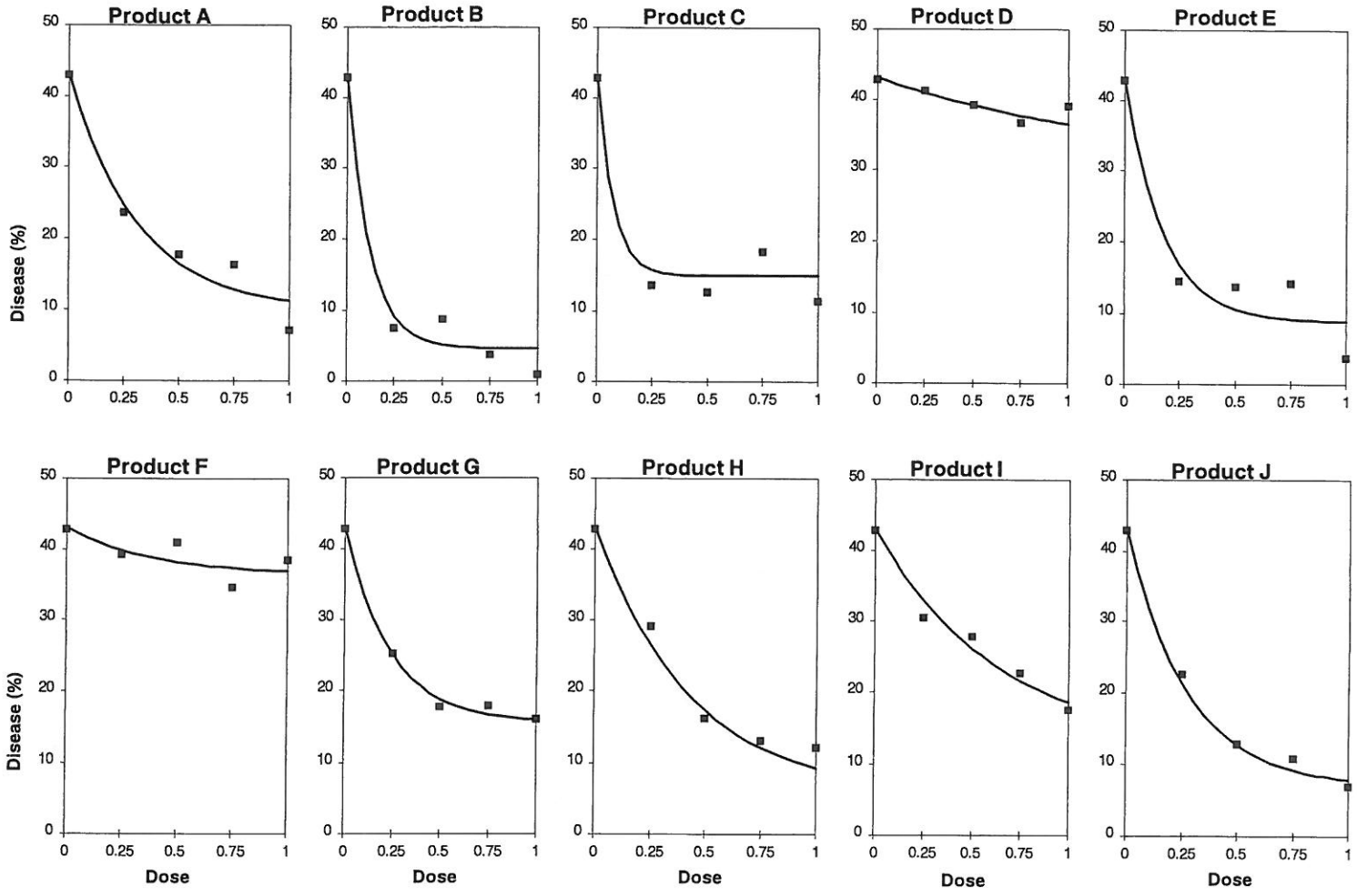
Table 1 shows the parameter estimates for the example dose-response curves in Figure 1. The parameter a represents the level of disease that would have been recorded if an infinite dose of fungicide had been applied (the lower asymptote). In practice, with effective products, the level of disease at the recommended dose is close to a. Parameter b represents the difference between the lower asymptote and the untreated. Hence a + b = the level of untreated disease. The parameter k represents the curvature of the response curve, with low (more negative) values being associated with greater curvature. Where dose=1, disease = $a+be^k$; providing a value for the lowest level of disease that could be obtained with a recommended dose of that product.

Table 1. Example parameter estimates for fitted product dose response curves

Product	Parameter estimates				
	a	b	k	a + b	$a+be^k$
A	10.0	33.2	-3.26	43.2	11.2
B	4.6	38.6	-8.52	43.2	4.6
C	14.9	28.3	-14.23	43.2	14.9
D	31.7	11.5	-0.86	43.2	36.6
E	8.7	34.5	-5.78	43.2	8.8
F	36.5	6.7	-2.77	43.2	36.9
G	15.6	27.7	-4.26	43.2	15.9
H	5.7	37.5	-2.34	43.2	9.3
I	12.8	30.4	-1.64	43.2	18.7
J	7.0	36.2	-3.70	43.2	7.9

Clearly, the products in the example vary substantially in their efficacy, with a full dose of product B reducing 43 % disease (a+b) to less than 5% ($a+be^k$), whereas product F was largely ineffective. The high k value for product B, suggests that disease control at low doses was almost as effective as at high doses.

Figure 1. Example dose-response curves for a range of fungicides, fitted to percentage disease data.



Taking product B as an example, dose-response curves for disease severity are reflected in the shapes (Figure 2) and parameter estimates (Table 2) of the fitted curves for green leaf area, grain yield and specific weight.

Figure 2. Example disease, green leaf area, yield and specific weight dose-response curves, for product B.

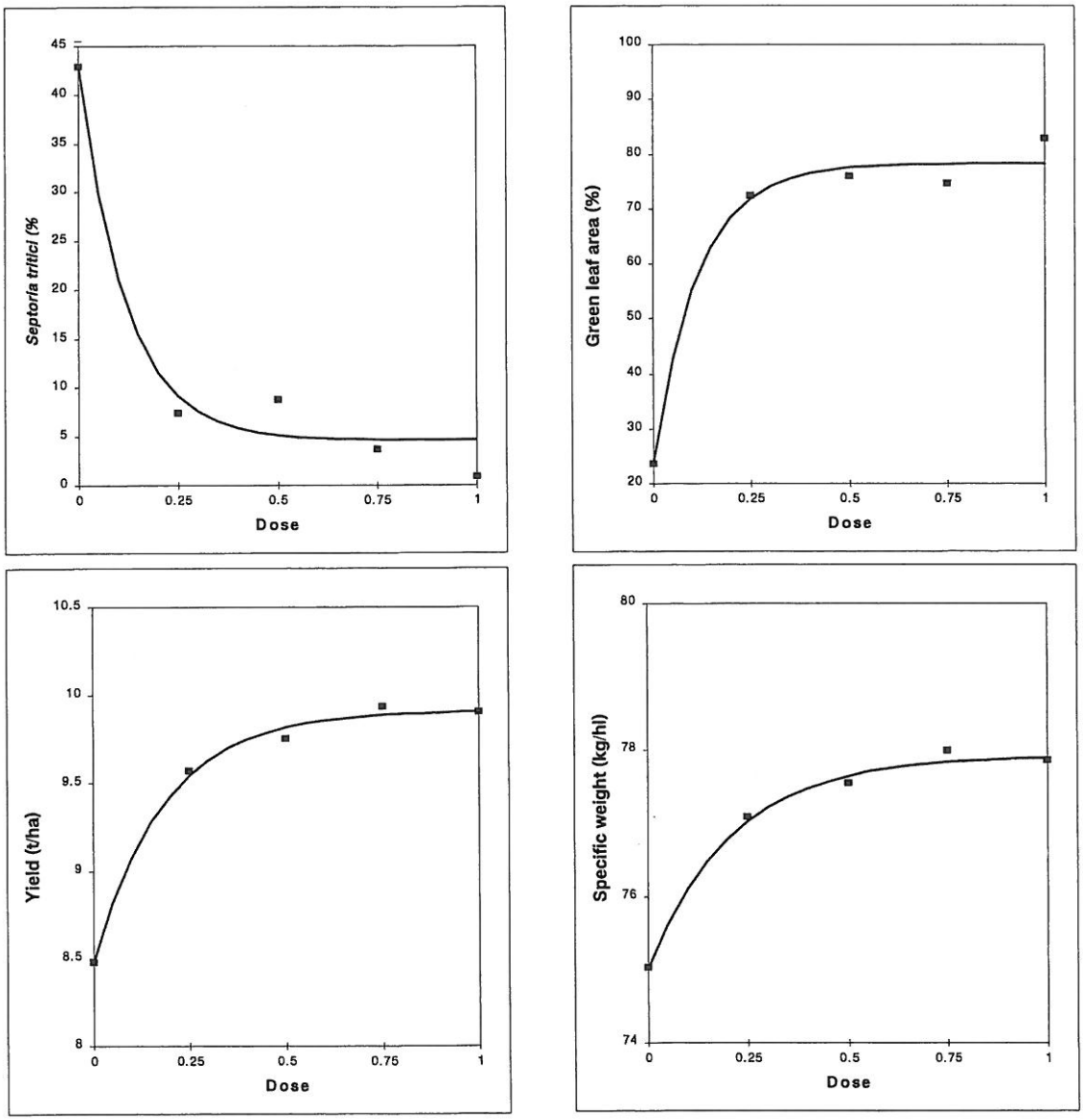
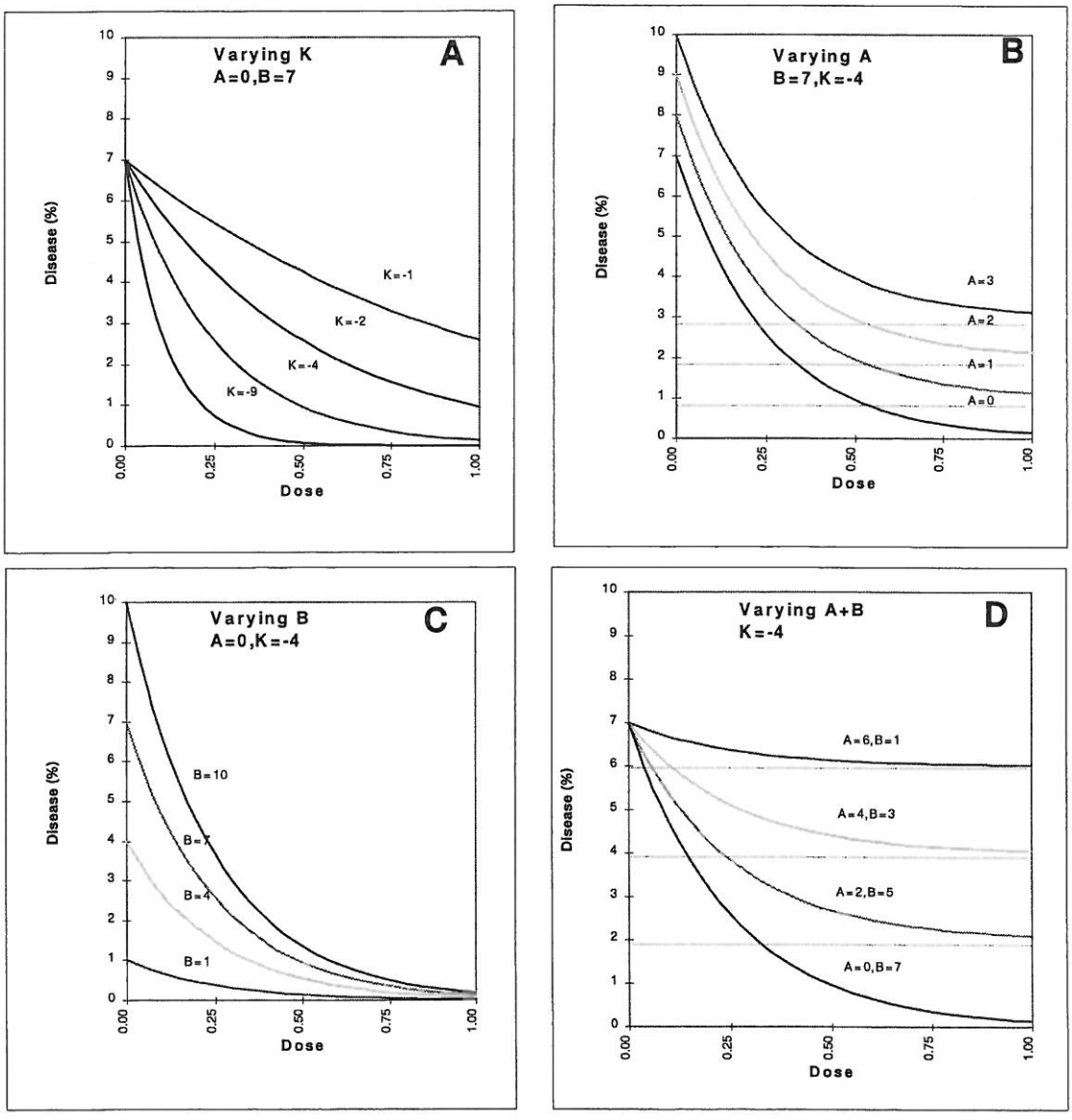


Table 2. Example parameter estimates for fitted product dose-response curves for percentage disease, green leaf area, yield and specific weight, for product B

	Parameter estimates				
	a	b	k	a + b	$a+be^k$
Disease	4.6	38.6	-8.52	43.2	4.6
Green leaf area	78.2	-54.6	-8.62	23.5	78.2
Yield	9.9	-1.4	-5.48	8.5	9.9
Specific weight	77.9	-2.9	-4.72	75.0	77.9

The hypothetical dose-response curves shown in Figure 3 illustrate, more fully, the relationship between curve shape and parameter estimates - in this case for percentage disease. In example A, parameters a and b were held constant and varying curvature produced a range of values for k. In example B, b and k were constant and varying the lower asymptote (a) shifted the whole curve. In example C, a and k were constant, so varying the untreated amount of disease produced a range of b values. And in example D, the untreated value (a+b) was held constant and the lower asymptote and potential degree of control (b) varied in opposition.

Figure 3. Hypothetical dose-response curves to illustrate relationships between curve shape and parameter estimates



In the data from experiment 1, a+b (untreated) values were constant across fungicides (as in examples A and D), but varied across sites, seasons, leaf layers and assessment date. In experiment 2, a+b varied with variety (as in example C).