EVALUATING THE ECONOMIC IMPACT OF QUALITY-REDUCING, SEED-BORNE DISEASES: LESSONS FROM KARNAL BUNT OF WHEAT

John P. Brennan[ab], Elizabeth J. Warham[a], Derek Byerlee[a] and Julio Hernandez[c]

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a: International Maize and Wheat Improvement Center, Mexico.
b: Present address: NSW Agriculture and Fisheries, Agricultural Research Institute, Wagga Wagga, N.S.W.
c: Instituto Nacional de Investigaciones Forestales, Agricolas y Pecuarias, Mexico.

ABSTRACT

Estimates of the aggregate costs of the losses caused by a disease can be used as a basis for assigning research resources or to evaluate the appropriateness of control measures. Most diseases cause production losses, but others affect quality and marketability of the output. Seed-borne diseases involve additional issues relating to the seed production and distribution industry. The aim in this paper is to examine the issues involved in determining the economic impact of a quality-reducing, seed-borne disease, and to highlight the additional issues involved compared to non-seed-borne diseases affecting yield only.

The economic evaluation of quality-reducing, seed-borne diseases needs to incorporate additional data and analysis relating to price and marketing impacts and issues related to trading restrictions such as quarantines or embargoes imposed by purchasers. The costs of measures taken to control diseases also represent part of the economic impact of the disease. Thus the full economic costs of a disease include the direct costs imposed by the losses caused by the disease itself, and costs of the control measures taken to reduce the direct costs. The economic costs of Karnal bunt of wheat in Mexico were found to include many control costs that have tended to be overlooked. Hence, any economic evaluation of such a disease without accounting for the control costs is likely to understate, perhaps grossly, the economic importance of the disease.

The amount of resources that it is optimal to invest in controlling a disease depends on the likely annual losses and the costs of the control measures and their effectiveness. Therefore, before implementing policies in relation to the disease, both the costs and the benefits of the policies need to be considered, taking the risks of each option into account. Research is needed into the benefits and costs of each policy option for such diseases, to ensure that the policy itself does not impose greater costs than the uncontrolled disease.

1. ECONOMIC COSTS OF PLANT DISEASES

Agricultural production faces a continual threat from evolving or introduced pests and diseases, often causing substantial economic losses. The literature on the losses caused by diseases is extensive (James 1974, James and Teng 1979, Teng 1985), particularly that related to economic strategies for farmers to control diseases (Carlson and Main 1976, Teng and Gaunt 1980, Reichelderfer, Carlson and Norton 1984, Onstad and Rabbinge 1985).

Less attention has been paid to estimates of the aggregate or regional costs of crop diseases (King 1977, James and Teng 1979, Brennan and Murray 1988, Long 1988). Aggregate estimates of the costs of the losses caused by a disease can serve two main purposes. First, losses for specific diseases can be a basis for assigning research resources to developing disease resistance. Second, estimated costs of preventative measures can be compared to the potential losses if the disease becomes more severe in already infested areas, or if it was to spread to new areas. Measuring the costs and benefits of attempts to control a disease is important if resources are to be efficiently allocated to regional control programs (Carlson and Main 1976).

Measures taken to control such diseases also have an economic cost. The presumption is that the control measures, such as pesticide use or quarantine or regulatory restrictions imposed on the production and/or marketing of output, reduce the direct losses from the disease. Indeed, economically effective control measures can be considered as those that reduce the direct losses by more than their cost. The full economic costs of a disease include the direct costs imposed by the losses caused by the disease itself and the costs of the control measures taken to reduce the direct costs.

The yield loss caused by a disease can be measured from disease-yield loss assessment (James 1974). The economic effects of a disease that causes yield losses can then be estimated by considering that the disease causes a shift in the supply curve, and measuring the consequent impact on price and economic surpluses. Such analysis relies on estimating supply with and without the disease, and measuring the differences in economic surpluses under each situation. Under small country assumptions, this generally involves estimating lost production and valuing it at prevailing prices (for example, Brennan and Murray 1988).

Some diseases lead to economic losses due to a change in output quality rather than a loss in output quantity. The economic impact of diseases that affect quality and marketability is more difficult to identify and measure.

Changes in output quality have been formulated as a shift in demand for the output (Unnevehr 1986) or have been measured by the value of the price discount applied to the affected production (Brennan and Murray 1988). The estimation of losses associated with quality-affecting diseases involves consideration of quantity, price and marketing effects (since such diseases can attract quarantine or marketing restrictions). Direct economic costs caused by a disease affecting quality include: (a) the value of quality losses; (b) the cost of handling and marketing infected product; and (c) the economic cost of the loss of markets through restrictions imposed following the presence of the disease.

Control costs aimed at preventing the spread of the disease or reducing its severity include: (a) costs of in-crop control measures, such as pesticides; (b) costs of quarantine or regulatory restrictions imposed on the production and/or marketing of the crop; (c) regulatory costs associated with monitoring the disease; and (d) costs associated with extra processing or fumigation of the output from infected areas.

One means by which diseases can be spread is through the use of infected seed. Analysis of the economic costs of seed-borne diseases involves consideration of the impacts of the disease on the seed production and distribution industry, in addition to the impact on quantity and quality of output. Control costs associated with restrictions imposed on seed production and distribution in view of the risk of the disease spreading include: (a) losses incurred by seed producers because of minimum allowable infestations in certified seed; (b) extra costs incurred where seed has to be obtained from disease-free areas; and (c) extra costs of seed treatment because of the disease.

The various direct and control costs of diseases may be paid by several different participants in the industry, from farmers to consumers, including taxpayers who can pay for some enforcement measures. This paper is primarily concerned with measuring the total costs, rather than with identifying the distribution of those costs between different entities.

The aim in this paper is to examine the issues involved in determining the economic impact of a quality-reducing, seed-borne disease, and to highlight the additional issues involved compared to a disease affecting yield only. In the following section, a general framework for evaluating such diseases is presented. In section 3, findings of a study of Karnal bunt of wheat in Mexico are examined in this context. The results are discussed and conclusions presented in the final section.

2. GENERAL FRAMEWORK FOR EVALUATING DISEASE CONTROL STRATEGY

While severe losses can be incurred in an epidemic, diseases vary from year to year in their severity with changes in environmental conditions. Ideally, control measures would also be varied annually (or within season) with the expected severity of the disease. However, many control measures, particularly those imposed at regional levels (planting restrictions, seed quarantines, etc) cannot be varied annually on the basis of expected incidence. Hence the economic justification for such control measures must be based on the expected average annual losses over a period of years. The expected annual losses in an average year can be estimated from the expected average level of severity of the disease and the losses incurred at that level. Effective control measures reduce the expected annual losses be reducing either: (a) the losses incurred by the disease; or (b) the probability of the potential losses being incurred.

The expected annual value of production is a function of the control measures applied:

(1) $$V_C = f(C) + u,$$

where V_C is the expected annual value of production under the current control measures, C is the cost of the control measures, and u is a stochastic term to reflect the uncertainty of the level of control.

The relationship between the expected annual value of production and the costs of control measures is illustrated in Figure 1. The expected annual value of production is V_C with the disease partially controlled by control expenditure, C. V^* is the expected annual value of output with the disease completely controlled, and V_0 is the expected annual value of production with no control measures. The shape of the curve will be concave to the origin if the most cost-effective control measures are employed first.[1]

(Figure 1 here)

The total economic costs of the disease, T_C, then, are the sum of the loss of output from the disease $(V^* - V_C)$ and the cost of the control measures:

(2) $$T_C = (V^* - V_C) + C.$$

The relationship between the amount spent on control and the expected total costs of the disease is illustrated in Figure

[1] One general functional form of this relationship is:

$$V_C = V^* - 1/(a+bC)^n,$$

where a,b and n are parameters to estimate for each disease and environment.

2. Total costs initially fall where cost-effective control measures are employed, but begin to rise as non-cost-effective controls are used. The objective is to find the control measures that minimise the expected annual total costs (T_C).

(Figure 2 here)

The continuous relationship shown in Figure 2 is likely to be difficult if not impossible to estimate. The best that can be hoped for in many situations is to examine a number of discrete control options, evaluating each for its cost and effectiveness in reducing the expected annual losses and choosing the option with minimum total cost.

3. THE CASE OF KARNAL BUNT OF WHEAT IN MEXICO

3.1 Karnal Bunt in Mexico

One example of a seed-borne disease that affects output quality is Karnal bunt (*Tilletia indica*) of wheat (Warham 1986). In this section, estimates are presented of the cost to Mexico of Karnal bunt (KB) of wheat in north-western Mexico (Brennan and Warham 1989).

KB, which originated in India, first appeared in Mexico in 1970, but caused little economic loss until the early 1980s when the level of infestation increased sharply in some years. Initially found in southern Sonora, the disease subsequently spread into the neighboring states of Sinaloa and Baja California Sur, although not to northern Sonora or other nearby regions. KB has been considered sufficiently important to warrant the imposition of planting and seed industry quarantines and restrictions since 1983.

3.2 Direct Costs of KB in North-Western Mexico

KB has only a relatively minor effect on yield, as the only yield loss is caused by the (approximately 25%) weight loss in grains infected. The estimated average loss of yield in the KB areas of north-western Mexico (southern Sonora, Sinaloa and Baja California Sur) was 0.12% per year.

While yield losses are relatively small, the price farmers receive for grain infected with KB depends upon the percentage of infected grains found. Growers received a 1% price discount for each 1% of infected grains up to 3.0%. Loads with greater than 3.0% of infected grain are accepted at the price of feed grain, with a discount of 20% from the price for food wheat. In the study of KB in Mexico, the emphasis was on identifying the costs to Mexico rather than to the farmers or other particular sectors. The losses to Mexico were estimated as those relating to heavily infected grain (>3%), and grain with less than 3% infection was assumed to be used in processing without penalty in terms of quality.

Prior to the outbreak of KB in 1982, southern Sonora was exporting wheat seed to a number of countries. Following the KB infestation in north-western Mexico, wheat seed exports from Sonora fell sharply, with some countries imposing embargoes on seed imports from Mexico because of KB. Since 1984, seed exports from southern Sonora have remained at zero, although some seed was exported from northern Sonora in 1987 and 1988. Thus the loss of export seed sales is a direct cost of KB in Mexico. While the estimated loss of seed exports is highly uncertain, because of major changes in the world supply and demand for wheat seed, the average loss of value added from the seed exports sales lost in recent years was estimated from projected volumes and estimated current value added by seed exports.

The value of the direct costs of KB in north-western Mexico (in 1989 US dollars) is shown in Table 1.

Table 1: Estimated Costs of KB in North-Western Mexico

	Average Annual Economic Cost	
	($US 000)	% of total
Direct Costs		
- Yield loss	452	6.4
- Quality loss	2543	36.2
- Loss of wheat seed exports	1100	15.7
- Sub-total	4095	58.3
Control Costs		
- Losses from planting restrictions	2011	28.6
- Costs for Sanidad Vegetal	192	2.7
- Rejection losses for seed growers	47	0.7
- Additional seed transport costs	615	8.8
- Additional seed treatment	63	0.9
- Sub-total	2927	41.7
TOTAL COSTS TO MEXICO	7022	100.0

Source: Derived from Brennan and Warham (1989).

3.3 Costs of Controlling KB in North-Western Mexico

Various measures have been taken to reduce the severity of KB in the infected areas or to prevent its spread to other areas, including quarantine restrictions on the crops planted in KB-infected areas and restrictions on the use of KB-infected seed (Table 1). Quarantine restrictions on planting have been imposed on farmers' fields in southern Sonora since 1983-84. If delivered grain had more than 2% of infected grains, the farmer was restricted from growing wheat on that land for the following three years, on the basis that the teliospores of KB can survive in the soil for several years. If the level of infected grains was 1-2%, the farmer could sow only durum wheat (which has greater tolerance for KB than bread wheat), while if the level was less than 1% there was no restriction. When farmers are prevented from sowing bread wheat, they suffer a loss of income as bread wheat is more profitable than the alternatives. The total losses for farmers from the quarantine restrictions are estimated on the basis of loss of income from producing durum wheat or other crops rather than bread wheat on the areas affected by the restrictions.

There are also substantial control costs imposed on the wheat seed industry. Since KB can be spread by the use of infected seed, the acceptance of infected seed for certified seed is regulated in north-western Mexico. Even crops with very low levels of infection are rejected as unsuitable for certified seed. Losses are incurred in the infected areas by seed producers when crops that have received extra inputs for seed production are rejected as unsuitable for seed because of KB. To ensure a supply of KB-free seed, seed production has also shifted away from the KB-infected areas in recent years. The shift of seed production to other areas has resulted in extra costs in transporting seed to the KB-infected areas. Although seed treatment is only partly effective against KB, seed produced in the infected areas of north-western Mexico has been treated with a particular fungicide (PCNB) since 1983 in an attempt to give some control of the level of KB spread in the seed. The use of PCNB is more costly than the seed treatment that would have been used in the absence of KB.

Finally, additional costs have been incurred by Sanidad Vegetal, the Mexican plant quarantine authority, associated with sampling and testing for KB and with meetings held in relation to KB.

3.4 Total Costs of KB in North-Western Mexico

The total costs of KB in north-western Mexico are estimated to average $US7.02 million per year (Table 1), representing 2.0% of the value of the average crop of 1.93 million t in the infected areas. The major components of costs are the quality loss of infected crops (36.2% of total costs), the losses from planting restrictions (28.6%), the loss of wheat seed exports (15.7%), the additional costs of transporting seed (8.8%) and yield losses (6.4%). The direct yield and quality effects accounted for only 42.6% of the total costs, and costs imposed by control measures for the remaining 57.4%.

4. DISCUSSION

The need to incorporate additional data and analysis in evaluations of quality-reducing, seed-borne diseases compared to diseases affecting only the quantity of output is demonstrated by the study of KB in Mexico. The economic costs were found to include many control costs that generally have been overlooked. Even with the inclusion of the value of lost seed exports, direct costs covered only 58.3% of total costs. Hence, any economic evaluation of such a disease without accounting for the control costs is likely to understate, perhaps grossly, the economic importance of the disease.

Thus, for example, estimates by Brennan and Murray (1988) of the potential economic cost of common bunt (*Tilletia laevis* or *Tilletia tritici*) of $A361 million per year are likely to understate the total costs of failure to control that disease. If the disease were widespread (and uncontrolled by seed treatment), regulatory controls with similar far-reaching economic implications to those of KB in Mexico may well result.

In determining the policy response to a potentially threatening disease, "it is not sufficient to [show] that disease causes a loss; the magnitude of the loss must be ... related to the gain obtained [from control]" (James 1974, p. 27). As shown above, the amount of resources to invest in controlling a disease depends on: (a) the likely annual losses; (b) the costs of the control measures and (c) the effectiveness of the control measures in reducing average annual costs. Therefore, before implementing policies to control such a disease, both the costs and the benefits of the policies need to be considered.

It is apparent from the estimates for KB in Mexico that control measures often have high costs. For example, the restrictions on planting wheat in KB-infested fields can be difficult to economically justify. The estimated costs imposed by the planting restrictions in southern Sonora are found to be greater than the benefits, measured as the reduction in yield and quality losses in comparison to Sinaloa (where there have been no such resitrictions imposed) (Brennan and Warham 1989). Therefore, prima facie, it appears that the costs imposed by the control measure may be higher than the direct costs prevented by the control, although there are many other factors that can influence the incidence of KB in different regions. It appears, therefore, that the control costs are greater than the optimum level in Figure 2. Before such restrictions are imposed, they need to be examined to ensure that the benefits are likely to outweigh the costs.

In determining the appropriate policy response to such a disease, an important issue is the level of risk to be accepted in attempting to control it. A policy of 'no risk' in relation to the disease does not take into account the costs imposed by the policy itself in relation to the benefits from that policy. In a recent review of quarantine services, the Australian Government (1988) endorsed the principle of risk management in the operation of quarantine restrictions. Similarly, the appropriate strategy for countering a threatening disease is to assess the risk of disease spread under each of the options available and to compare the costs and net benefits of those options.

Another aspect to consider is the effect that the policies can have on costs and benefits of research programs. One policy option proposed in Mexico was to restrict the movement of viable seed, including breeders' seed, out of north-western Mexico, in order to reduce the risk of the spread of the disease to other parts of the country. From the point of view of the quarantine authorities, this was a reasonable policy to implement if there was any danger of KB spreading through the seed movements. However, restrictions on the flow of seed wheat from the breeding programs in north-western Mexico would have prevented the continuation of the long-established system of two cycles per year in the wheat breeding programs that have played an important part in Mexico's sustained rate of yield improvement in recent decades. That would incur heavy economic costs on the Mexican wheat industry in the future by (a) effectively halving the expected annual rate of yield progress from the program, (b) increasing the vulnerability to diseases such as leaf rust by slowing the rate of release of new varieties, and (c) delaying the development of KB-resistant varieties. The value of the costs imposed by this policy were estimated to be some five times greater than the estimated likely losses from the spread of disease that the restrictions are designed to prevent. Consideration of this extremely high cost of the policy may lead to modification of the proposed policy before final implementation. Again, the imposition of such a policy would have pushed the control costs in Figure 2 further beyond the optimum level.

Large estimated aggregated economic losses from a disease indicates a need for adequate funds for research into that disease, into both the understanding of the disease itself and the possible methods of control. However, it is important that those resources not be transferred from programs trying to overcome diseases with greater potential cost (such as leaf rust which has a potential cost of almost $20 million if the current resistance were to be lost). The results of the study into KB in Mexico also point out the need for research into the benefits and costs of various policy options to ensure that the policy itself does not impose greater costs than the disease it is intending to control.

In conclusion, the economic evaluation of seed-borne diseases that affect output quality and that are subject to quarantine restrictions involve many issues additional to those encountered in evaluating yield-reducing diseases. The costs of control measures, particularly those involving quarantine restrictions on farming operations or the movement of seed or output need to be identified, so that the merits of some of the policies can be evaluated in relation to their costs.

REFERENCES

Australian Government (1988), Australian Quarantine - Looking at the Future: A Government Policy Statement, Australian Government Publishing Service, Canberra.

Brennan, J.P. and Murray, G.M. (1988), 'Australian wheat diseases: Assessing their economic importance', Agricultural Science 1(7), 26-35.

Brennan, J.P. and Warham, E.J. (1989), Economic Losses from Karnal Bunt of Wheat in Mexico, Working Paper, Economics Program, CIMMYT, Mexico, D.F.

Carlson, G.A. and Main, C.E. (1976), 'Economics of disease-loss management', Annual Review of Phytopathology 14, 381-403.

James, W.C. (1974), 'Assessment of plant diseases and losses', Annual Review of Phytopathology 12, 27-48.

James, W.C. and Teng, P.S. (1979), 'The quantification of production constraints associated with plant diseases', in Coaker, T.H. (ed.), Applied Biology, Volume IV, Academic Press, London, 201-67.

King, J.E. (1977), 'The incidence and economic significance of diseases in cereals in England and Wales', Proceedings 1977 British Crop Protection Conference, 677-87.

Long, D.L. (1989), 'Estimated losses from rust in 1988', USDA-ARS Cereal Rust Laboratory, University of Minnesota, St Paul (mimeo).

Onstad, D.W. and Rabbinge, R. (1985), 'Dynamic programming and the computation of economic injury levels for crop disease control', Agricultural Systems 18, 207-26.

Reichelderfer, K.H., Carlson, G.A. and Norton, G.A. (1984), Economic Guidelines for Crop Pest Control, FAO Plant Production and Protection Paper 58, FAO, Rome.

Teng, P.S. (1985), 'Construction of predictive models: II. Forecasting crop losses', Advances in Plant Pathology 3, 179-206.

Teng, P.S. and Gaunt, R.E. (1980), 'Modelling systems of disease and yield loss in cereals', Agricultural Systems 6, 131-154.

Unnevehr, L.J. (1986), 'Consumer demand for rice grain quality and returns to research for quality improvement in Southeast Asia', American Journal of Agricultural Economics 68(3), 634-41.

Warham, E,J, (1986), 'Karnal bunt disease of wheat: A literature review', Tropical Pest Management 32(3), 229-42.

Figure 1

Relationship between Control Cost and Output Value

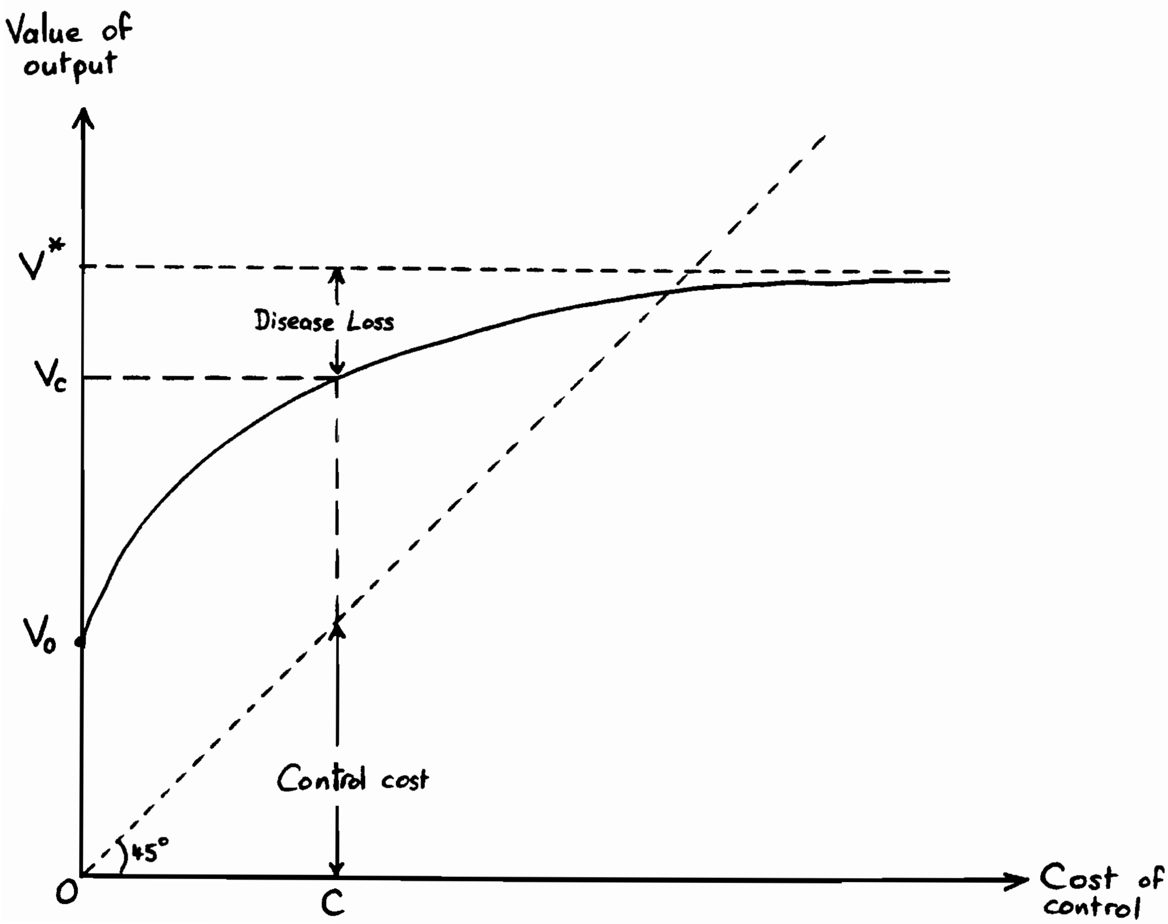

Figure 2

Total Economic Costs of a Disease