DISCUSSION

A New Concept of Economic Injury Level that Includes Penalization of Damage to Quality and Safety of Agricultural Products

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Abstract

STEJSKAL V. (2001): **A new concept of economic injury level that includes penalization of damage to quality and safety of agricultural products.** Plant Protect. Sci., **37**: 151–156.

The traditional model of Economic Injury Level (EIL) does not allow to directly incorporate aspects of damage to quality and safety of a product (D_q) into the decision-making process to control a pest (pathogen, weed, arthropod, vertebrate). This work now attempts to generalize a concept of EIL by (i) separating damages to quality and safety (i.e. D_q and EIL_q) from quantitative (i.e. D_w and EIL_w) types of damage (D) in the traditional EIL-equation, and (ii) by establishing a new way of estimation of EIL_q based on the penalization of quality and/or safety damage. The importance to distinguish between the terms EIL, EIL_w and EIL_q is discussed, and a calculation of the new index (Z), enabling the comparison of the relative economic importance of qualitative and quantitative damage caused by a particular level of pest infestation or disease severity, is proposed.

Key words: integrated pest management; economic injury level; damage; quality; safety; human food

The concept of Economic Injury Level (EIL) is one of the keystones of Integrated Pest Management (IPM) (PIERCE 1934; STERN *et al.* 1959; MUMFORD & NORTON 1991). PEDIGO & HIGHLEY (1992) even claim that the "EIL equation is the only truly unifying principle of IPM". Although other and more complex decision-making IPM models have been proposed so far, their popularity have been negligible in comparison with the traditional EIL. PEDIGO *et al.* (1986) explained that it was the simplicity and lucidity that was responsible for the success of EILs in routine pest control. I think though, that the EIL concept and probably also the whole IPM paradigm (HARRIS 2000) gained its popularity not only for its easy use in pest control practice but also for its didactic power. In fact, one could hardly find a current textbook on pest control and applied ecology that does not discuss topics related to EILs. The main didactic advantage of the traditional model of EIL (equations 2 and 3) stems from the absence of any abstract mathematical terms, so that any change in the value of EIL-equation parameters gives straightforward and practical predictions. The EIL concept thus becomes an invaluable tool for both farmers and students to understand the basic principles of the socio-economy of pest management. Nevertheless, analyses of the traditional EIL model, in which a certain critical pest population and the cost of control are related only to quantitative losses, leave little doubt that this concept originated in the 60^{ies} of the previous century (STERN *et al.*1959). Since then, at least in the developed countries, the priorities of agricultural production have changed considerably. Nowadays it is obvious to everyone that "farm economy" is influenced not only by quantitative but increasingly by qualitative aspects of the production. The globalization of world food trade has also prompted the competitive forces to further increase the cosmetic aspects of quality (PIMENTEL *et al.* 1993) of food-agri-

Supported by the Grant Agency of the Czech Republic, Project No. 522/99/1255.

cultural products, as is especially apparent in the production of fruits, vegetables, rice and malting barley. Moreover, besides quality the "food safety" aspect (OLSEN 1998a, b, c) emerged as a new phenomenon in EC and US legislation in the last two decades (MCDONALD 1996). In these countries, stringent quality and safety standards for food are ensured through rapid implementation of a relatively new safety doctrine known as HACCP (= Hazard Analysis and Critical Control Points) (SCHOTHORST 1989). These processes illustrate that the public health issue became a global political priority, thereby strongly influencing the economic behaviour of all aspects of the food-industry in developed countries. In his review WILKIN (2000) points out, however, that the most rigorous codes on quality and hygiene in UK are set not by government but the major retailing chains. These pressures tend to be reflected back to the farmers as primary producers of the raw constituents. WILKIN (2000) also predicts that the pressure from retailers for improved food standards will continue.

However, I think that the current EIL and IPM theory, in contrast to agricultural practice, does not reflect the above-mentioned changes at the agricultural and food industry market very flexibly. Indeed, the traditional model of EIL does not contain any term that allows the simple incorporation of quality and safety aspects of damage in the decision-making process for pest control. Therefore, the aim of this work was to generalize the basic concept of EIL by (i) a separation of qualitative and quantitative damage (D_q and D_w) from economic injury level (EIL_q and EIL_w) in the tradition EIL-equation, and by (ii) establishing a new way of estimation of EIL_q based on the penalization of damage to quality and safety.

Traditional Model of Economic Injury Level

The EIL concept stems (PIERCE 1934; STERN *et al.* 1959; MUMFORD & KNIGHT 1997) from a general cost-benefit rule that governs the economic behaviour of all subjects participating in the market based on free enterprise:

$$B \geq C \quad (1)$$

where: B – benefits
C – costs

Based on the equation (1) Norton (1976) derived the first mathematical model of EIL:

$$\theta = C/PDK \quad (2)$$

where: θ (= EIL) – lowest level of pest attack that will cause economic damage
C – cost of control
P – market value per unit of yield
D – loss in yield per pest individual damage
K – reduction in pest attack (efficiency of pest control measures)

Later, PEDIGO *et al.* (1986) were the first who fully recognized the importance of distinguishing between the notions "damage" and "injury" by incorporating the "injury coefficient" (I) into an EIL-equation:

$$EIL = C/VIDK \quad (3)$$

where: V (= P) – market value per unit of yield
I – injury unit per individual

In instances where the critical range of D is distinctly non-linear, it is necessary to replace D with a complex function relating damage to total injury from a population (PEDIGO & HIGLEY 1992).

Incorporation of Penalization of Quality and Safety Damage (D_q) into an EIL-Equation

As already mentioned, the value of the yield is, besides other factors, affected by its quality. Thus, if we compare equal weight units of different consignments of the same commodity (e.g. fruits, grain), their actual market value may differ drastically. Most malign are "safety damages", such as mycotoxin contamination, the presence of which may frequently lower the value of the affected consignment to zero, even though the technological quality is very high. While the aforesaid models of EIL (2, 3) are perfectly suited for the cost-benefit analysis of quantitative damage, the direct introduction of any quality and safety damage (e.g. a certain value for the % of proteins in malting barley, or μg of mycotoxin per unit of food item) into these equations (2 and 3) will obviously result in nonsense. Therefore, it is necessary to separate qualitative (EIL_q, D_q) from quantitative (EIL_w, D_w) EIL and from the damage parameters in the basic equation of EIL (2, 3), and to introduce a new way to calculate EIL_q. Basically, there are two ways to accomplish this goal:

(i) The first is to replace parameter D by a damage equivalent (Q) parameter that can be defined as a weight damage which is equal to the value of the quality and safety damage:

$$EIL_q = C/IQVK \quad (4)$$

However, Q is a composed term which requires an additional calculation and, as a consequence, such construction of the EIL-equation looses simplicity and transparency. In addition, the EIL_q determined in this manner depends on the market value of the commodity, which inherently introduces further uncertainty into the EIL_q estimate.

(ii) The second way is to replace V by a penalization term (α) that enables the direct introduction of quality and safety damage:

$$EIL_q = C/KID_q\alpha \quad (5)$$

where: α – penalty per unit of qualitative damage
D_q – qualitative damage per unit of injury

The concept of penalization is based on punishing any deviation from the market and/or legislation ideal of the quality and/or safety of a product. The advantage of the penalization concept is that it is almost independent from the market value (V) of the commodity, which varies considerably with time. For example, NUTTER (1993) reported that the increase of proteins due to pest infestation decreases the value of the yield of malting barley (α = 1.6 cent/0.1% proteins/t). In agriculture, the penalization of lower quality and safety is also used in milk production either for control of sub-clinical mastitis (YALCIN *et al.* 1999) or milk protein percentage (PULINA *et al.* 1998).

The "total" EIL is obtained:

$$\mathrm{EIL} = C/KI(D_q\alpha + D_w V) \qquad (6)$$

if D_q and D_w is caused by an identical type of injury.

A decrease of weight of the yield is a universal measure of quantitative damage, whilst there are many different measures of quality and safety damage. For example, KNIGHT (2000) listed 10 criteria of quality (% germination, % proteins, kernel size, % broken grains etc.) for malting barley in the UK. In the case of multiple D_q we can use the following equation with distinctive parameters for a particular quality and safety penalty ($\alpha_1 \ldots \alpha_n$) and quality and safety damage ($D_{q1} \ldots D_{qn}$):

$$\mathrm{EIL} = C/KI(D_{q1} + D_{q2}\alpha_2 \ldots D_{qn}\alpha_n + D_w V) \qquad (7)$$

after rearrangement

$$\mathrm{EIL} = \frac{C}{KI(\sum_{i=1}^{n} D_{qi}\alpha_i + D_w V)} \qquad (8)$$

If the injury-damage or damage-penalty relationships are not linear, some other function must be applied. These complex relationships, which are most typical for a safety penalty, will be discussed elsewhere.

The Reasons for Separation of EIL_w, EIL_q and EIL

Both pest management practice and science require a technical terminology without ambiguity (DENT 1995). However, the current research papers proposing certain EIL that are based only on the analysis of quantitative aspects of the sequence "pest population density/disease severity-intensity" a "injury" a "damage" are clearly terminologically incorrect. We can only speculate to what extent the aspects of quality and safety that are missing in such established but unrealistic EILs are being ignored by agricultural practice. Therefore, I assert that studies should refer either to "total EIL", if all aspects of damage are considered, or strictly separate EIL_q from EIL_w in terms of the nature of the damage evaluated. Nevertheless, if complex analysis reveals an asymmetric importance of the two components of EIL, then it is more practical to consider either EIL_q or EIL_w as an approximate value for "total EIL". Therefore, I think it is useful to establish some comparative coefficients (Z) as follows:

If we directly compare EIL_q and EIL_w:

$$Z_{\mathrm{EIL}} = \frac{\mathrm{EIL}_q}{\mathrm{EIL}_w} \qquad (9)$$

Z_{EIL} **> 1** the quantitative effect of injury/pest population size is more economically important than the qualitative effect,

Z_{EIL} **= 1** both types of effects are of the same economical importance,

Z_{EIL} **< 1** the qualitative effect of injury/pest population size is more economically important than the quantitative effect.

If we compare the monetary value of various damages caused by a particular level of injury or pest population size:

$$Z_D = \frac{D_q\alpha}{D_w V} \qquad (10)$$

Z_D **>1** the qualitative effect of injury/pest population size is more economically important than the quantitative effect,

Z_D **=1** both types of effects are of the same economical importance,

Z_D **< 1** the quantitative effect of injury/pest population size is more economically important than the qualitative effect.

DISCUSSION

The qualitative damage caused by usual populations of stored-product pests is much higher than the quantitative one (HAGSTRUM *et al.* 1996). The appendix below contains an example of the importance of including D_q in establishing a realistic EIL in a stored-product pest. In the current literature can be found, besides stored product pests, some other cases of asymmetrical (non-additive) or equal (additive) economical importance of various types of damage (D_w, D_q) with an identical level of pest infestation. For example, there is asymmetrical importance of D_w and D_q if a commodity is infested by a quarantine pest organism (YAMAMURA & KATSUMATA 1999): the quantitative losses are almost negligible, whereas the level of qualitative damage makes the commodity worthless. Also, each primary producer realizes the high requirements on high cosmetic quality of fruits and vegetables since the current market dictates an intensive chemical control of populations of certain pest species (arthropods and pathogens) although these are too low to do any quantitative damage of economic importance. PIMENTEL *et al.* (1993) provided much evidence on the asymmetric importance of cosmetic and other type of damage. For example, rust mites cause "russeting" or "bronzing" on oranges, so that about 80% of the citrus in Florida are sprayed for rust mites. However, unless the mite population is extremely high, the yield and internal quality of oranges, determined by the content of sugars and other nutrients, are virtually unaffected by the russeting. Similarly, on tomatoes grown for processing, about two-thirds of all insecticide applied is to control the tomato fruitworm, which is essentially a cosmetic pest because it damages only the skin of the fruit. DAEBELER & HINTZ (1980) demonstrated that the cabbage aphid (*Brevicoryne brassicae* L.) can reduce the yield of oilseed rape. Later, however, LAMMERINK *et al.* (1984) showed that this pest can also increase glucosinolate levels in the seed. ELLIS *et al.* (1999) stressed, therefore, that the threshold for control of cabbage aphid should take into account the effects on both yield and quality (= additive affect of D_w and D_q) of the harvested seeds. ARCHER & BYNUM (1998) found that feeding by larvae of the corn earworm (*Helicoverpa zea*) lowers not only the weight of kernels but, more importantly, the quality of food maize by the damage to kernels that results in discoloration of food maize products during cooking. Barley spot blotch, caused by *Cochliobolus sativus*, has been shown (NUTER *et al.* 1985, 1993) to reduce not only the quantity of yield but also the malting quality by increasing the protein content and by decreasing kernel plumpness. Well documented is the extremely high economical impact of quality and safety damage in cereals caused by toxicogenic fungi such as *Fusarium* spp. and *Claviceps purpurea* (PLACINTA *et al.* 1999). Notably, MESTERHÁZY *et al.* (1990, 1999) and MESTERHÁZY & BARTÓK (1993) found that the level of contamination with DON-toxin (deoxynivalenol) of *Fusarium* infected grains is not always proportional to the yield response. Weeds are well known as competitors to cultural plants and frequently decrease yield considerably. Nonetheless, contamination of the yield by toxic seeds of some species pose such a serious health hazard to human and animal health that it results in un-linearly high economic penalty. For example, recently (ANONYMUS 2001) the distribution and sale on the Czech market of a certain batch of herbal tea of fennel was banned because of contamination by jimsonweed seeds (*Datura stramonium*) found only in one sample of tea.

In conclusion, I think that the above examples support sufficiently the proposal that IPM-terminology and any crop loss analyses should consistently separate the terms "EIL" from "EIL_w" and "EIL_q, and "D" from "D_w" and "D_q".

Appendix

This appendix presents an example of the use of Z_{EIL} for an evaluation of the relative importance of EIL_w and EIL_q in establishing of EIL for the stored-product pest beetle *Cryptolestes ferrugineus*.

HAGSTRUM *et al.* (1996) reported that a density of two live individuals per kg was the maximum tolerance of any insect pest species in stored grain, which value may be considered as an EIL_q. Since the EIL_w for *C. ferrugineus* has not been established yet, I have estimated its preliminary value as EIL_w = 4871.1 pest/kg grain. The estimation of the EIL_w for populations of *C. ferrugineus* was based on the equation (2) and the following data:

K = 1 since I assume 100% of control efficiency;

D = 5.1mg/kg of grain, which value, according to CAMPBELL & SINHA (1976), represents the grain consumption per devel-opment of one individual of *C. ferrugineus*;

V = 3500 CZK/t (≅ 80 USD), represents the price of stored grain in the Czech Republic;

C = 20 CZK (≅ 0.5 USD)/t, represents a current approximate cost of the pesticide to control stored grain pests (either fumigant or protectant).

The solution of the equation (9) for both types of EILs leads to Z_{EIL} = 0.0004. In this case, the extremely low Z_{EIL} let us approximate EIL ≅ "EIL_q".

Acknowledgment. I thank Drs. J. Hýsek, S. Pekár and V. Jarošík for critical reading of the manuscript.

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Received for publication February 22, 2001
Accepted for publication November 16, 2001

Souhrn

STEJSKAL V. (2001): **Nové pojetí ekonomických prahů škodlivosti založené na penalizaci kvalitativní a hygienické škody na zemědělských produktech.** Plant Protect. Sci., **37**: 151–156.

Tradiční model ekonomických prahů škodlivosti (EIL) nedovoluje přímé začlenění aspektu „kvality a hygienické bezpečnosti" do rozhodovacího procesu při ochraně před patogeny, škůdci a plevely. Tato práce zobecňuje pojetí EIL (i) oddělením kvalitativních (tj. „D_q", „EIL_q") a kvantitativních (tj. „D_w" a „EIL_w") aspektů škody v tradiční rovnici EIL (ii) a zavedením nového způsobu stanovení ekonomického prahu kvalitativní škody pomocí penalizačního členu. V práci je diskutován význam rozlišování EIL, EIL_w a EIL_q a je prezentován nový index (*Z*) umožňující srovnání relativního významu kvalitativní a kvantitativní škody, která odpovídá určité hladině napadení škůdcem nebo intenzitě choroby.

Klíčová slova: integrovaná ochrana před škůdci; práh ekonomické škodlivosti; potraviny; škoda; kvalita; zdravotní bezpečnost

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