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STUDIES OF YIELD LOSSES II. INJURY AS A LIMITING FACTOR OF YIELD[1]

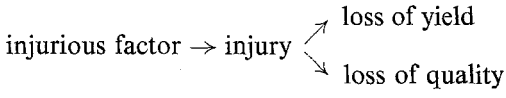
Met een samenvatting:
Studiën over oogstverlies II. Beschadiging als beperkende factor van de oogst

BY

P. M. L. TAMMES
Plant Protection Service, Wageningen

INTRODUCTION

Often loss of yield, due to injury, is so evident that the economic value of protective measures is obvious. Sometimes, however, the cost of treatment is more difficult to justify and information is needed on the relationship between injury and loss of yield. This relationship is illustrated as follows:



Injury can be caused by various factors e.g. diseases, pests, toxic substances, unfavourable climatic conditions, weeds, lack of nutrients or mechanical damage. The effect can be counteracted by recovery and compensation or by better development of neighbouring unaffected plants. Maximum injury such as the destruction of all leaves of a plant, does not always lead to total loss of harvest, because recovery can be rapid, especially at the beginning of the growing-season, when there is plenty time for recovery. But, at the end of the growing season when part of the yield is already produced, maximum injury leads to limited yield losses, except when injury is to the yield product itself e.g. the rotting of potato tubers by late blight in the soil. Consequently susceptibility to injury varies from season to season.

Besides yield losses the quality of the product may be reduced, especially when the product itself is attacked. This often leads to major financial losses for often quality is as important as direct loss of weight. Occasionally quality is improved by injury. Quality will not be discussed. Loss in quality can often be estimated by the differences in market value of products from injured and non-injured fields. Below only the relationship between injury and yield losses is discussed.

The assessment of losses caused by diseases or pests in the field is difficult because conditions are usually not uniform. Therefore some have approached the problem by injuring plants artifically to varying degrees (JONES, 1955; GRAINGER, 1956; HEUVER, 1960).

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Upper level of injury

When yield is plotted against the severity of an injurious factor an upper level may be observed giving a range where production is no longer limited by the injurious factor. E.g. the yield of a crop can be plotted against the increase in the amount of potash fertilizer applied. The curve starts with a proportional increase but the line gradually becomes horizontal where some other factor is limiting, possibly phosphorus or nitrogen. This graph may also be plotted as a lack of potassium (fig. 1). Here a threshold is formed by the upper level of the curve. Such an upper level or threshold may also be observed with injury by diseases, pests, herbicides (van der Zweep, 1958) or other toxic substances.

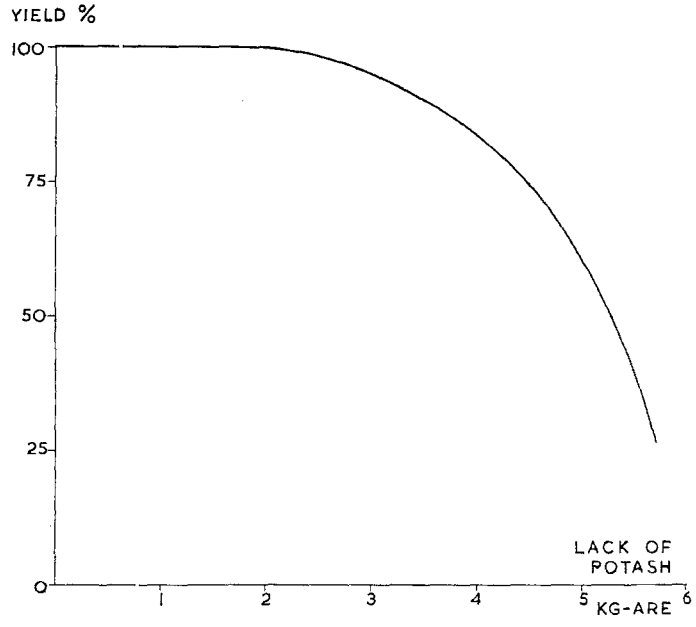

Fig. 1. Decrease of yield with lack of potash. The upper level as a threshold.
Produktieafname als gevolg van kaligebrek. Het bovenste niveau als drempelwaarde.

The upper level is not always observed. It may be absent when the injurious factor limits the production directly from the beginning. Also the upper level may not be flat but exhibits an optimum, as in the pruning of roses or fruit trees which results in an increase in the number of flowers and fruits. When the injurious factor limits production, a slope is formed when yield is plotted against the injury. However, especially if injury is light, the effect can be offset by compensation so that the line starts almost horizontally as an upper level or threshold. Losses of young plants can be partly compensated by growth of neighbouring plants which develop more strongly and fill their places. Jones, Dunning & Humphries (1955) thinned beet seedlings artificially in the four leaf stage giving the results shown in fig. 2.

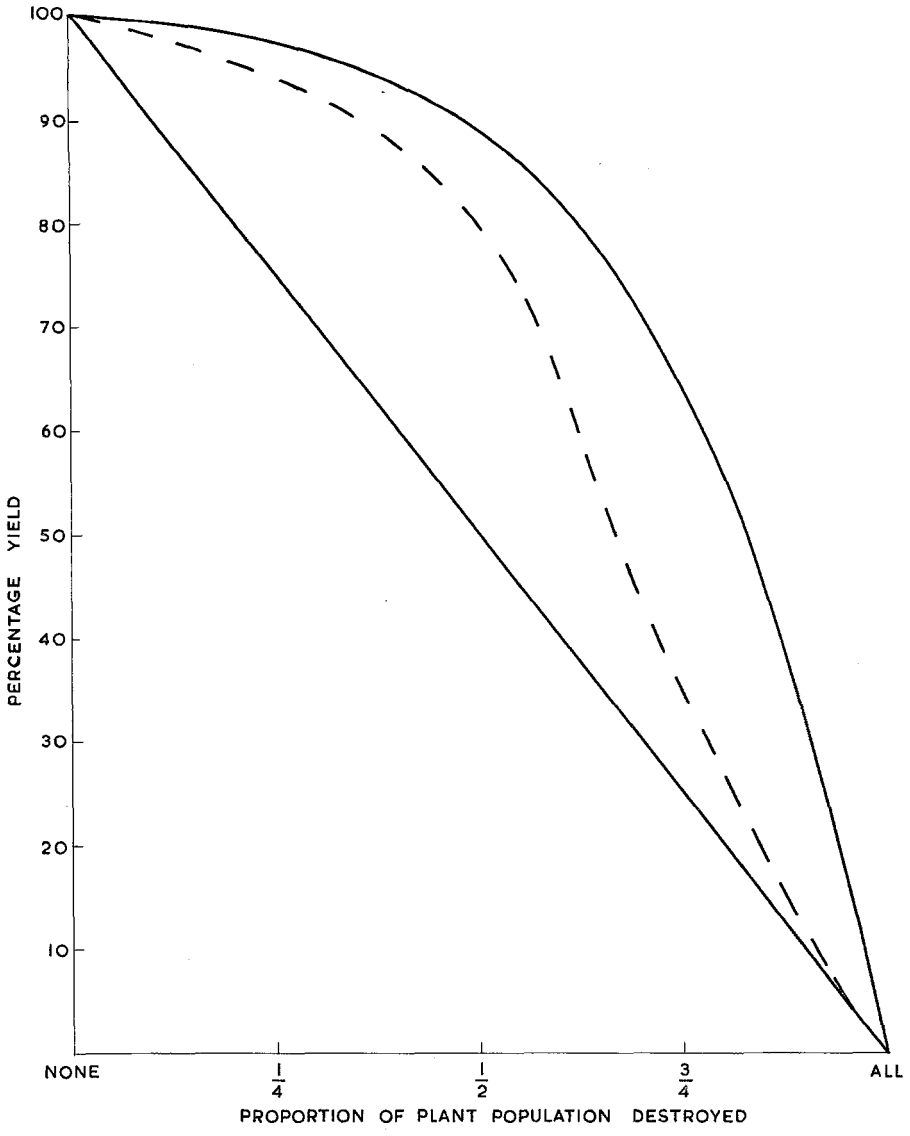

FIG. 2. The relationship between yield and artificial thinning in the field. Upper curve: yield when plant losses are systematic. Dotted curve: yield when plant losses are random. Lower curve: yield in the absence of compensation, as when a compact area of crop is destroyed (JONES et al., 1955).
De verhouding tussen opbrengst en uitdunnen. Bovenste lijn: opbrengst by systematisch uitdunnen. Stippellijn: opbrengst bij willekeurig uitdunnen. Onderste lijn: opbrengst bij uitschakeling van compensatie, dus als een aaneengesloten stuk in het veld wordt vernietigd.

Compensation within the plant is observed after thinning of flowers or young fruits, often without a decrease in the production. In grape vines judicious pruning gives larger grapes with about the same total weight of products. TAMMES (1937) observed that after cutting away half the flowers from the inflorescences of coconuts the yield of nuts was only slightly reduced. Removing all nuts in various stages of development resulted in a much higher fruitsetting of young inflorescences. MACKELVIE (1960) observed that the yield of cocoa is dependent on the nutrient status of the tree and independent on cherelle wilt. Compensation was also observed by HEUVER (1960) after cutting flowers from peas when the plants were at various heights. This resulted in better fruitsetting in flowers higher up the plant and in larger seeds over the whole plant.

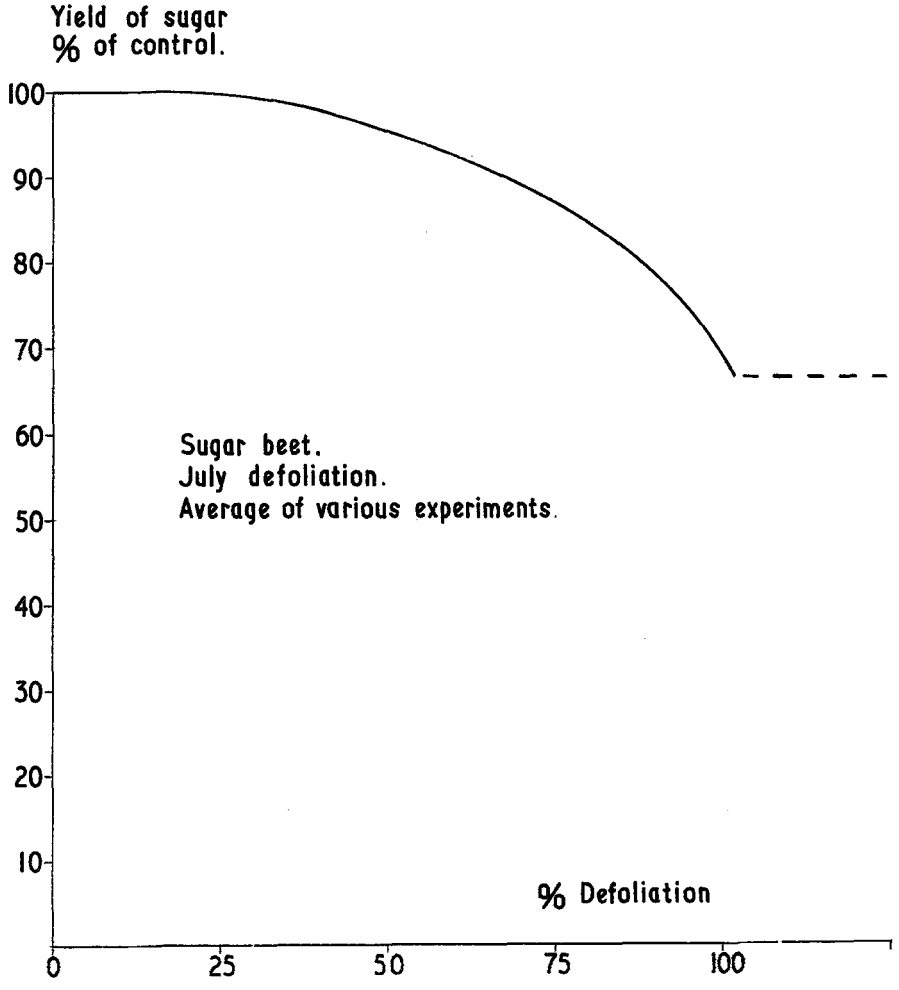

FIG. 3. The relation between the yield of sugar and the percentage of defoliation (from HEUVER, DE LINT & STENVERS, 1960).
De verhouding tussen opbrengst aan suiker en het percentage weggesnoeid bladoppervlak.

Defoliation experiments are described by various authors who attempted to obtain an estimate of yield losses due to leaf injury. Seasonal sensitivity to defoliation is usually observed. In experiments with sugar-beets in the Netherlands (HEUVER, DE LINT & STENVERS, 1960) the most sensitive period was July but even then total defoliation resulted in an average loss of yield of 33% only. Before July recovery was more complete but after July part of the harvest was already produced so that the influence of defoliation became less. Fig. 3 gives the effect of the defoliation of sugar-beets in July. At 25% defoliation no significant effect was observed, either because of a threshold or because of compensation. Total defoliation produces a limited loss of yield only, as has been mentioned above, because of a quick recovery of the plants.

When a factor which causes leaf damage, such as hail or a leaf-eating insect becomes so large that it destroys 100% of the leaves, a further increase in this factor will be without influence so that the relationship between the injurious factor and the loss in yield will be as shown in fig. 3 but including the dotted line. Thus injury ceases when all the leaves are destroyed provided that the germinal shoots are not injured.

ROOT PRUNING

The author is unaware of experiments on the effect of root pruning on production. However, plants are able to recover rather quickly from transplanting, even after severe root pruning and provided they do not die from lack of water in the first few days.

To get more information about root injury, a field experiment with maize was made by Mr. HULSHOF, in which a sector of roots was cut away around the plants to a depth of about 20 cm with a sharp spade at a time when the plants were susceptible to injury, that is just before and after flowering. Roots were cut twice at $\frac{1}{4}$, $\frac{1}{2}$ and $\frac{3}{4}$ of the circumference of the base of the plants. Even after pruning $\frac{3}{4}$ of the circumference, a loss of only 10% in yield was observed; no loss was observed with the other treatments.

LOWER LEVEL OF INJURY

In fig. 3 recovery of sugar-beets was so quick after complete defoliation at the most sensitive stage, that only 33% loss of sugar was observed. This represents the lowest level to which yield can fall. The lower level in other cases, however, may be zero yield. There are other reasons limiting losses which determine the lower yield level. When part of the product is already formed and is not subject to injury, yield cannot decrease below the level that is already present.

Another reason is competition between parasites, so that injury and crop losses do not increase in linear proportion to the density of harmful organisms; the relationship is more or less logarithmic or asymtotic (JUSTESEN & TAMMES, 1960).

PERSISTENT INJURY

The damage caused by an injurious factor is temporary and recovery is possible after the injury. A more complicated problem arises when injury is repeated or persistent. However, there is no reason why the general picture of

the yield losses in relation to permanent injury differs from the temporary injury, as recovery may also be continuous.

In virus-infected plants, a condition of relative stability may be attained with a limit that varies according to the different viruses and physiological states of the host plant. It seems after BAWDEN (1960) to be a continuing rather than a once and for all process, with the content of completed particles at any one time depending on the balance between their formation and break down.

TOXIC SUBSTANCES

Herbicides, toxic pesticides or toxic substances secreted by parasites will, according to experience with toxic substances in general, show a threshold under which no effect is observed. Further the effect of a poison is usually proportional the logarithm of the concentration. So also an upper and a lower level can be expected when graphed against the yield. VAN DER ZWEEP (1958) gives such figures for the herbicide Simazin.

DISCUSSION

JUSTESEN and TAMMES (1960) discussed the relationship between injurious factors and the injury to crops and the self-limiting effect of parasites when present in larger numbers. Various factors may influence the relationship between injury and the response of the plant by loss of yield. The effect is illustrated in fig. 4 where there are two levels connected by a line. The upper and lower level may be present or absent and if the lower level is absent yields may decline to zero. The upper level may be an optimum and not a level plateau. Thus an increase of the injurious factor may not be correlated with a decrease in yield.

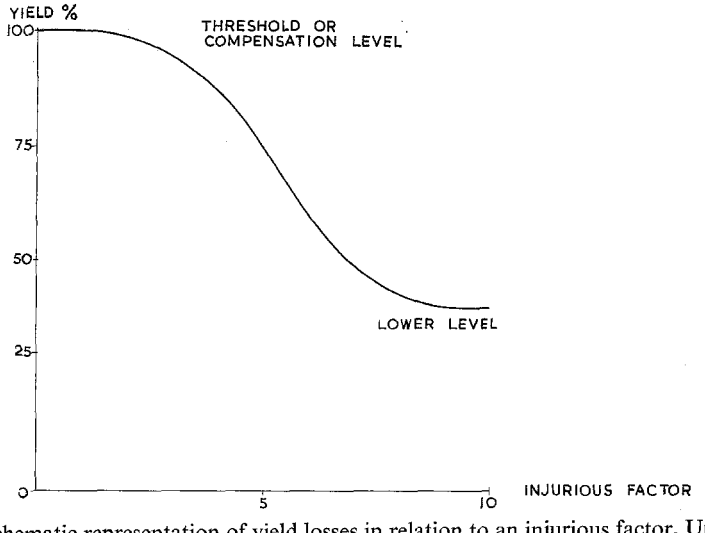

FIG. 4. Schematic representation of yield losses in relation to an injurious factor. Upper level with a threshold or compensation. Slope where yield is limited by the injurious factor. Lower level: stage of maximum injury.
Schematisch overzicht van oogstverliezen als gevolg van een beschadigende factor. Bovenste niveau met een drempelwaarde of compensatie. Helling waar de opbrengst wordt beperkt door de beschadigende factor. Onderste niveau: het gedeelte van maximale beschadiging.

Summary

The relationship between injury and loss of yield is rather complicated and care is necessary in its interpretation. It can be divided (fig. 4) into three stages, each of which according to the circumstances may be present, absent or somewhat modified. In the first stage the injurious factor has hardly any influence on yield because of compensation or the existence of an optimum. The second stage shows a yield loss correlated with increase in the injurious factor. In the third stage the effect of the injurious factor is either a level of maximum possible injury (which may be zero yield) or the selflimiting effect of the injurious factor; also sometimes a certain level is not exceeded because the yield was already partly produced at the time of onset of injury.

Seasonal variation in response to injury is usually observed.

Samenvatting

De relatie tussen beschadiging en oogstverlies is een samengesteld probleem en een interpretatie is daardoor vaak zeer moeilijk. Dikwijls kan de relatie worden verdeeld in drie gebieden, die elk afhankelijk van de omstandigheden aanwezig of afwezig kunnen zijn. In het eerste gebied is er geen of een zeer geringe invloed op de oogst. Dit kan worden veroorzaakt door een drempelwaarde, een compensatie of een optimum. In het tweede gebied is het oogstverlies duidelijk gecorreleerd met toeneming van de schade. In het derde gebied wordt het oogstverlies weer beperkt b.v. door een niveau van maximale schade (het is mogelijk dat dit niveau op de nul-lijn ligt) of een zelfbeperkende werking van de schadelijke factor. Dit niveau kan ook worden veroorzaakt doordat een deel van de oogst reeds was gefixeerd toen schade werd veroorzaakt.

Seizoensvariatie in verband met de gevoeligheid voor schade wordt gewoonlijk waargenomen.

Acknowledgements

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