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Damage threshold for *Thrips tabaci* (Thysanoptera: Thripidae) in monocropped and intercropped leek

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Thysanoptera, *Thrips tabaci*, leek, *Allium porrum*, clover, *Trifolium subterraneum*, intercropping, crop loss assessment, damage threshold

Abstract. Based on field data collected during three consecutive years, in experiments with leek and leek intercropped with subterranean clover (*Trifolium subterraneum*), the relationship between larval populations of *Thrips tabaci* on leeks, the level of injury and the market quality of the product were described. This resulted in a way to monitor both thrips populations and market quality during the growing season by the feeding symptoms and in damage thresholds in monocropped and intercropped leeks. It was found that a given number of thrips larvae per plant caused less injury on intercropped leek plants than on monocropped leeks. This proved to have consequences for the damage thresholds in both growing systems. The total effect of intercropping in leeks is based on thrips population suppression and a reduced development of feeding symptoms.

INTRODUCTION

Leek (*Allium porrum* L.) is an important field vegetable in Europe and currently *Thrips tabaci* Lindeman (Thysanoptera: Thripidae) is its most important pest. In many countries a variety of insecticides is used to control this pest, often without success. The frequency of treatments is usually high and the sensitivity of thrips to the compounds used is decreasing. Hence, thrips populations become chemically uncontrollable.

Recently, it has been found that undersowing of leek with subterranean clover, *Trifolium subterraneum*, considerably reduces thrips populations in leeks (Theunissen & Schelling, 1993, 1996). These results were obtained in intercropping experiments during a number of consecutive years, in which clover-undersown leek crops were compared to monocropped leeks. During these experiments, thrips populations were monitored by regular sampling of plants from the crops and counting of the larval and adult thrips on the individual plants. At the same time an assessment was made of the class of thrips feeding symptoms on the same plants. This combination of data permits the establishment of a relationship between numbers of thrips and the thrips feeding symptoms which are developing on that plant. Observations of yield quantity and quality of these experiments provided data on thrips feeding symptoms and market quality. When marketable yield is expressed in financial result, expected damage can be related to thrips population density.

This paper describes the relationship between thrips populations and the damage to be expected, based on experiments with monocropped and intercropped leeks.

MATERIAL AND METHODS

Intercropping experiments with leek were carried out from 1992 to 1995. During the cropping season of 1992, thrips populations at the site of the experiment were very low. Therefore, data from 1992 were not used for this paper. The intercropping experiments in 1993 were carried out at a Regional Research Center Horst-Meterik on sandy soil, in 1994 and 1995 at the experimental farm of IPO-DLO on loamy soil and river clay respectively. In all experiments, leek cv. Albana and subterranean clover cv. Geraldton as undersown intercrop were used as standards. Both monocropped and intercropped leeks received the same standard amount of NPK fertilizer, split up in three gifts during the cropping season. Details of these experiments were described earlier (Theunissen & Schelling, 1996). In 1994, twice the number of data on intercropped leeks were available compared to the monocrop because of four, clover, drilling time treatments were compared to two untreated monocrops. The data of two monocrops during that season were combined and those of the four corresponding intercrops. In 1995 the performance of four cultivars of subterranean clover was tested as intercrops and compared with a monocrop of leek. According to the purpose of the trials, a slightly different set up of the experiments was used as presented in Table 1.

TABLE 1. Experimental setup of the intercropping experiments.

Year	Plot size (m^2)	Replicates	Number of plots in	
			monocrop	intercrop
1993	232	4	4	4
1994	232	3	6	12
1995	56	3	3	12

Thrips populations were monitored weekly (1993) or fortnightly (1994, 1995) in the crops by random sampling of 15 (1993), 10 (1994) or 5 (1995) plants/plot. These plants were individually examined for their degree of thrips feeding symptoms, according to a scale of categories, and for the numbers of thrips larvae and adults by counting these insects leaf by leaf. The scale of thrips injury contained four categories, with each given numerical values: no symptoms (0), slight symptoms (1), moderate symptoms (2) and heavy symptoms (3). "Slight symptoms" include the tiniest specks of thrips symptoms, even if there is only one! "Moderate symptoms" mean visible but not conspicuous symptoms. In this way, per individual plant data on thrips population and thrips feeding symptoms were coupled. These data contributed to data sets for plots and treatments per observation date during the cropping season. Since the larvae are far more numerous than adults and cause the actual damage (Theunissen & Legutowska, 1991), data on larval populations were used to represent thrips populations. Because of the variability of the population data and the arbitrary character of the symptom class assessment, the mean per plot per date was used as a basis for evaluating the relationship between thrips populations and feeding symptoms, although frequency distributions would have been appropriate as well. Exponential curves were fit to these data. Results of curve fitting were adjusted for number of degrees of freedom.

At harvest, thrips feeding symptoms at the moment of harvest and the quality class of the product trimmed and cleaned for the market were determined per individual plant. The number of harvested plants was 100/plot (1993) or 30/plot (1994, 1995). From these samples, random groups of 10 plants were selected. The means of symptom values and quality class values were used as data points for assessment of their relationship. The official rules of the Dutch Central Bureau of Horticultural Auctions (Dutch acronym: CBT) were used as criteria for quality class, although on the real market these criteria are much more flexible and responding to the laws of offer and demand. This means that our quality assessments were severe and conservative. The quality classes are: quality 1 – unblemished product, quality 2 – some, but tolerable amounts of thrips damage present, marketable, and quality 3 – not marketable due to intolerable amounts of thrips damage. These harvest data allow a translation of thrips feeding symptoms of the intact plant to the quality class of the product. This relationship is established for harvestable plants, but in principle, the amount of thrips injury can be used as a measure for the current state of quality of the crop during the entire season. The cumulative character of the feeding symptoms, which fade away or grow very slowly out of the marketable part of the plant, enables the grower to assess the market quality maintained at any moment. The financial result of the crop is dependent on the distribution over the quality classes during the actual harvest.

Statistical analyses were carried out on the fitted curves. Significances were tested using ANOVA and confidence intervals were calculated. The difference between the coefficients of determination of the fitted curves of the relationship number of larvae-class of symptoms was tested using a z-transformation (Fisher) of the corresponding correlation coefficients (r is the hyperbolic tangent of z) and calculation of the confidence intervals of r^2 (Sachs, 1982).

RESULTS

The relationship between the mean population density of thrips larvae/plant and the mean symptom class/plant per plot on each observation date in monocropped and intercropped fields is illustrated in Fig. 1. Based on the data, the relationship is satisfactorily described by an exponential function of the general form: $y = a + be^{(-x/c)}$, where a, b and c are the descriptive parameters to be estimated using the data. The corresponding values and coefficients of determination are given in Table 2. These figures are given to demonstrate the similarity of this relationship during the various seasons. Per experiment a set of data is shown for monocropped and intercropped leeks separately because of the difference in range of infestation. The coefficients of determination, r^2, for monocropped and intercropped leeks in Table 2 indicate a larger variability of the relation between larval population and symptoms in the intercrop data and a higher percentage of explained variability in symptom expression by larval population size in monocrops, but only the values of r^2 for 1994 and the pooled data are significantly different ($P < 0.05$). The 99% confidence intervals for the pooled curves (Fig.1, bottom row) of monocropped and intercropped leeks differ significantly at larval populations > 7.5 larvae/plant. The differences between the asymptotes (coefficient "a" in Table 2) of monocropped and intercropped leeks during 1993 and 1994 are significant ($P < 0.01$). The values for 1995 are similar in both systems because of a deliberate experimental increase of thrips populations and corresponding loss of quality in the intercropped leeks later in that season.

TABLE 2. Regression analysis of the relationships between larval thrips populations, symptoms and product quality. Coefficients and r^2 of the exponential function: $y_1 = a + be^{(-x/c)}$, where x = the mean number of thrips larvae/plant and y_1 = the mean symptom class of the same sample of plants, and the linear function: $y_2 = d + fy_1$, where y_1 = the mean symptom class/sample of plants and y_2 = the mean market quality of that sample.

	a	b	c	r^2*	d	f	r^2*
monocrop							
1993	2.60	−2.50	5.88	0.943	0.78	0.71	0.659
1994	2.97	−2.63	7.14	0.888	1.01	0.65	0.865
1995	2.97	−2.99	10.25	0.998	–	–	–
pooled	2.87	−2.68	7.09	0.921	1.00	0.63	0.786
intercrop							
1993	1.21	−1.09	2.68	0.708	0.55	0.73	0.684
1994	1.54	−1.31	1.36	0.589	0.92	0.58	0.868
1995	2.70	−2.67	11.36	0.961	0.37	0.76	0.559
pooled	1.70	−1.50	3.01	0.656	0.89	0.53	0.748

* r^2 adjusted for degrees of freedom.

The difference of population density of thrips larvae in monocropped and intercropped leeks is evident from the abcissa scales used. This aspect was worked out already (Theunissen & Schelling, 1996). The general effects of larval population densities in

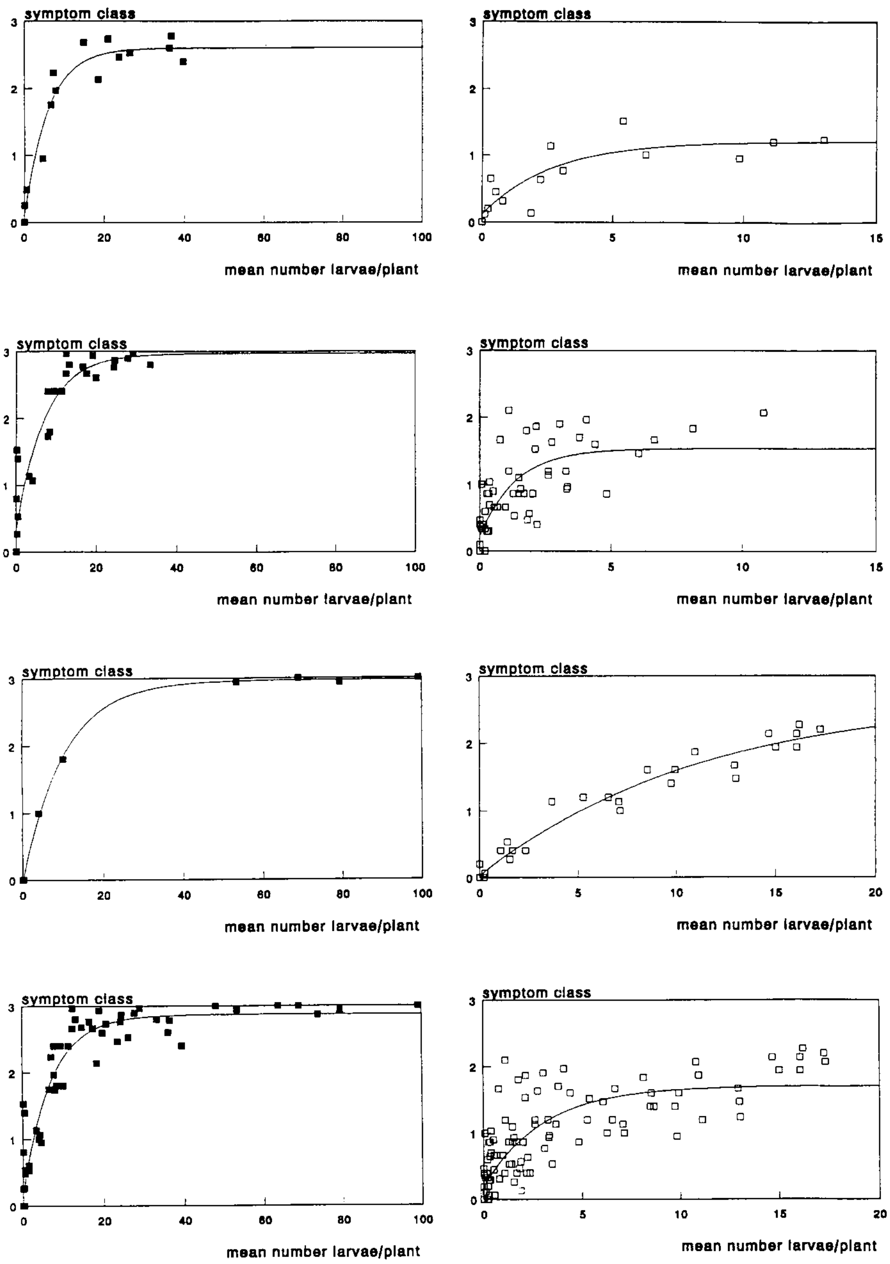

Fig. 1. Relationship of mean number of *Thrips tabaci* larvae/plant to the mean class of feeding symptoms on the same plants on the same date in monocropped (left column) and intercropped (right column) leeks. From top to bottom are shown the data of the years 1993, 1994, 1995 and the total over these years. The corresponding coefficients are found in Table 2. Both in monocrops and intercrops, each symbol reflects the following number of individual plants: 60 (1993), 30 (1994) and 15 (1995).

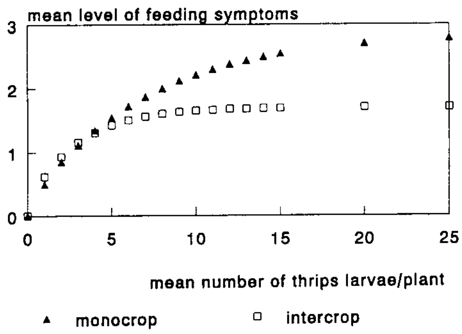

Fig. 2. Relationship between the mean number of thrips larvae/plant and the corresponding level of feeding symptoms in monocropped and intercropped leeks at low population levels, as inferred from the fitted data.

monocropped and intercropped leeks on the feeding symptoms within the crop are also clear. However, the question here is whether the population reduction in the intercropped leeks is sufficient to prevent significant economic damage. To answer this question, thrips feeding symptoms of the harvested plant are to be related to the quality of that plant as a trimmed, cleaned and market-ready product. In Fig. 1, the extent of yearly variation is demonstrated and the result of the pooled data is given for both monocrops and intercrops. From these data generalized relationships were derived by curve fitting (Table 2) and interpolation for different values of infestation levels (x) and feeding symptoms (y), which are given in Fig. 2.

Figure 2 shows that monocropped and intercropped plants do not react differently at low larval populations in terms of symptoms shown. From 5 larvae/plant upwards an increasing difference in the development of symptoms for each added larva/plant can be observed.

Quality class as related to thrips feeding symptoms on the intact plant is shown in Fig. 3. Up to quality 2, the leeks are marketable; beyond quality 2 they become increasingly unmarketable and command a very low price as a product for the industry. The market prices for qualities 1, 2 and 3 are subject to fluctuations but can be averaged for the week of harvest or any other meaningful period of time. The relationships between symptoms and market quality are well described by straight lines ($y = d + fx$) (Fig. 3, Table 2). Although the regression lines are very similar, calculation of the confidence intervals ($P < 0.05$) shows significant differences between these lines. Those for the 1993 data are significantly different for the entire range of x-values; for the 1994 data there is a significant difference for $x > 1.7$. For the 1995 data there is no comparison because no low values in monocropped leeks were available. For the combined data the difference is significant for values of $x > 1$. Having quantitative relationships between symptoms and quality means that field symptoms can be "translated" into market quality and vice versa, given the coefficients of the mutual relationships. Since the level of symptom development in the field coincides with larval populations, market quality can be related to larval populations at any moment of the cropping season. In other words, damage thresholds can be calculated for both monocropped and intercropped leeks.

DISCUSSION

Crop loss assessment for insect pests is usually carried out by determination of yield losses from the crop grown under different pest population levels. Sometimes, under field conditions and being dependent on natural infestation, these levels can be controlled by insecticide applications. In the case of thrips in leek it proved to be impossible to keep the thrips populations at low or even moderate levels by insecticides. Even spraying twice a

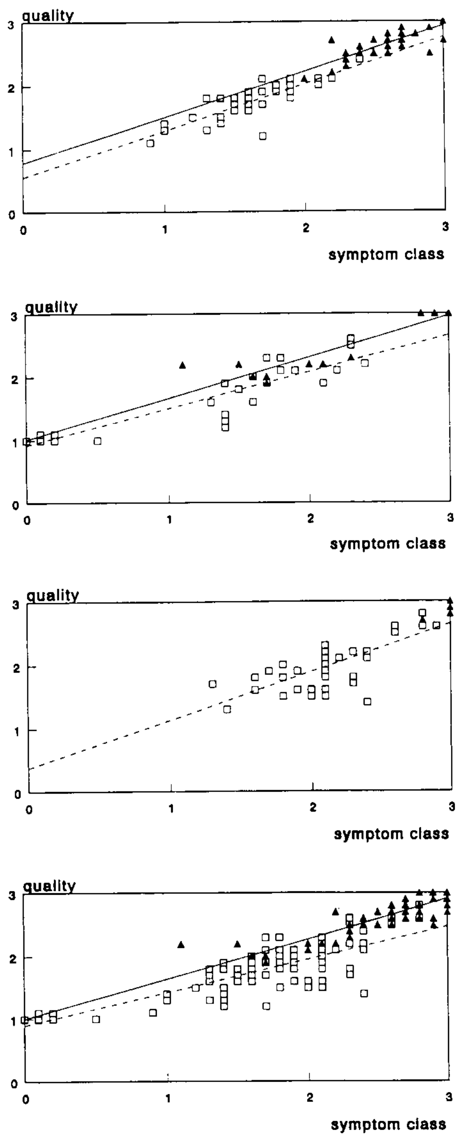

Fig. 3. Relationship of mean class of thrips feeding symptoms and the mean market quality class of the same plants in harvested monocropped and intercropped leeks. From top to bottom are presented the data of the years 1993, 1994, 1995 and the total of these years. The corresponding coefficients are found in Table 2. Each symbol represents 10 plants randomly chosen from the harvest data of monocropped and intercropped leeks. Monocrop – ▲; intercrop – □.

week with different, available insecticides could not stabilize thrips populations at desired levels at our experimental farm.

Our intercropping experiments yielded detailed data on thrips infestation levels and corresponding development of symptoms from the very beginning of the crop until harvest. Even in unsprayed monocrops, infestation rates are low at the onset of the growing period. During the three years, several thousands of individual plants were observed both in monocrops and intercrops. In a paper (Theunissen & Schelling, 1996) we pointed out that feeding symptoms are not caused by the thrips population observed at that particular moment, but by a preceding population since feeding symptoms take time to develop on the plant. Nevertheless, at any moment in the field a thrips population coincides with a particular level of feeding symptoms, both phenomena being cumulative, albeit in a different manner. It is this combination which was recorded. The variation in this combination between the years is shown in Fig. 1. The observation of the level of symptoms during the growing season gives a good approximation of the infestation level and the market quality attained at that moment. At the end of the "thrips season" when thrips populations within the plants decline but the symptoms remain, this combination does not give reliable information anymore. These data have been excluded from the data used here. With a critical and correct interpretation of the thrips feeding symptoms both thrips population levels and quality can be monitored quite easily during the cropping season. For a correct assessment, however, care must be taken to focus well on the thrips symptoms (Theunissen & Legutowska, 1992).

The reasons for the different response in symptoms of monocropped and intercropped leek plants to larval populations larger than about 5 larvae/plant are not clear. Most likely, intercropping causes physiological changes in the host plant in such a way that (a) the intercropped plant does not react in the same way to the feeding activity of the thrips larvae as a monocropped plant or, (b) the thrips larvae do not feed as vigourously on intercropped plants as on monocropped ones thus causing less injury or (c) both reactions take place. In all cases the intercropped leek plant seems to have been altered physiologically by intercropping with clover. This supports our "host-plant quality hypothesis", which supposes that the pest-population-reducing effects of intercropping are due to a physiological change of the host plant caused by the inter-species competition between the crops involved (Theunissen, 1994, 1996; Theunissen & Schelling, 1996). Injury symptoms are influenced by the physiology of the plants. In chrysanthemums infested by *Frankliniella occidentalis*, den Belder (unpubl. data) found significantly more feeding-injury symptoms on plants intercropped with clover compared to the monocrop in a greenhouse at equal thrips population levels. This finding contrasts sharply with our results, but shows again an influence of the presence of the clover on the physiology of the host plant and indirectly the behaviour of the pest. In other crop-intercrop combinations, mechanisms such as visual or olfactory masking of the host plant, increased biological control, etc. also can play a role. The combination of the mechanisms which cause the overall intercropping effect may be different according to the crop-intercrop-pest/disease complex combination (Andow, 1991). Since suppression of *T. tabaci* populations has been found in clover intercropped cabbage, fennel and leek, the same mechanism of induced resistance seems to be involved. In leeks it is dominant, because so far we found no indication of other mechanisms which could explain the considerable reduction of thrips populations in clover-intercropped leeks.

The parallel symptom development at populations < 5 larvae/plant may be explained by the high probability that low larval populations represent cases of beginning colonization of the crop, when young larvae from eggs of immigrating adults start to feed. Based on our "host-plant quality hypothesis", feeding on intercropped plants may become less or cease, but the first damage is done. What happens next to these larvae is still not clear, but the variability in symptom expression per added larva/plant in intercropped leeks (Fig. 1) suggests problems with feeding. This is supported by the observed suppression of population development (Theunissen & Schelling, 1996).

Based on the different symptom development in monocropped and intercropped leek plants, we may conclude that the total intercropping effect on product quality is caused primarily by thrips population reduction, as described earlier (Theunissen & Schelling, 1996), and secondly by a lower degree of symptom development per added thrips larva/plant, when compared to monocropped plants, above a population level of about 5 thrips larvae/plant.

Once leek plants have been damaged by thrips, expressed in a particular level of feeding symptoms, loss of quality tends to be different for monocropped and intercropped leeks. Reasons for this difference are not clear yet. One reason might be a systematical error of observation caused by bias. This seems to be unlikely as we are very aware of the dangers of observers' bias and rotate and compare observations frequently and systematically to prevent bias. Another reason might be that in spite of the same rate of symptom expression of the intact harvested plant another, slightly different, impression of quality is found in the cleaned and trimmed plants from monocrops and intercrops. A similar, but more clear, phenomenon we found in harvested, rust (*Puccinia allii*) infected, leek plants in monocrops and intercrops (Theunissen & Schelling, 1996).

Quality can be related to symptoms and to mean number of larvae/plant and vice versa. Since the symptoms are the easiest observed factor during the entire cropping season, the other two parameters can be estimated continuously, using the relationships found. Given some experience with the crop this is easily and routinely done. These relationships are expressed in formulae (Table 2) as:

$y_1 = a + be^{(-x/c)}$, and
$y_2 = d + fy_1$,

where: x = the mean number of thrips larvae/plant
y_1 = mean symptom class
y_2 = mean market quality.

Based on these formulae, the general formula for calculating the market quality from the larval population level is:

$y_2 = d + af + bfe^{(-x/c)}$.

When the market prices for leeks are k, l and m Dutch guilders (fl.) per kg for the qualities 1, 2 and 3, respectively, the price for a given quality level y_2 may be estimated by:

$p_{(1-2)} = l + (2 - y_2)(k - l)$ (fl./kg),

where: $p_{(1-2)}$ is the price within the quality trajectory between quality 1 and quality 2 for the quality offered at the market. Similarly, the price within the trajectory between quality 2 and quality 3 will be:

$p_{(2-3)} = m + (3 - y_2)(l - m)$ (fl./kg).

In general:

$p_{(1-3)} = m + (3 - y_2)(k - m)$ (fl./kg).

Yields per ha of monocropped and intercropped leeks can be included to calculate the economic yield loss potential under various levels of thrips infestation, given current market prices. Note that the above formulated relationships are based on curvefitted field data and that, therefore, variability will occur. However, the calculated results are in good accordance with the empirical tolerance levels used by commercial growers.

To illustrate the calculation of the damage threshold for thrips in leek, the following data are used. Suppose a yield of monocropped leeks of 30 tons/ha and of intercropped leeks 25.5 tons/ha, which are realistic figures. Market prices for the various quality classes are: k = fl. 0.85, l = fl. 0.45 and m = fl. 0.25/kg (average over October, November and December 1995, The Netherlands). Average costs of control are: fl. 90.–/ha/treatment, composed of fl. 35.– pesticide and fl. 55.– labour and machine. Per season 10–25 treatments, average 17, are applied for thrips alone at a cost of pesticides of fl. 400.– to fl. 800.–, on average fl. 600.–. This amounts to fl. 1,535.–/ha/season (17 times fl. 55 = fl. 935 + fl. 600). The damage threshold is the thrips larvae population which causes a loss equivalent to the costs of control. Suppose that one treatment is sufficient. The costs of control are fl. 90.–/ha. The yield loss is the difference between the market price/kg received for quality 1 and the price for the quality offered, multiplied by the yield/ha. At 30,000 kg/ha, the yield loss equivalent to the costs of control is: 90/30,000 fl./kg. Applying the formula above, the corresponding quality class (y_2) is: 2.005. From this, the mean thrips population can be calculated. The damage threshold is 5.27 larvae/plant in monocropped leeks. If we suppose that the average number of treatments is sufficient to control the thrips, the corresponding damage threshold is 6.0 larvae/plant. This small difference is caused by the rapid loss of quality at increasing thrips populations at this level and the very low price of pesticides. From these results it is clear that there can be no tolerance for thrips in leeks, even at very low populations. At higher populations it does not matter for the quality whether the population density is 15 larvae or 150 larvae/plant, the product is not marketable anymore. If thrips in leek are not, or insufficiently, controlled by pesticides, it is clear that investments in chemical control are unprofitable inputs, which can be sustained only because of the low price of pesticide applications.

When the same calculations are applied to the data of intercropped leeks, damage thresholds cannot be determined because the corresponding yield loss and quality are not reached. This confirms our observations that good quality leek can be grown by undersowing with clovers without interfering with pesticides.

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