doi: 10.17221/259/2014-HORTSCI

Effect of two-spotted spider mite population (*Tetranychus urticae* Koch) on growth parameters and yield of the summer apple cv. Katja

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Abstract

Warabieda W. (2015): **Effect of two-spotted spider mite population (*Tetranychus urticae* Koch) on growth parameters and yield of the summer apple cv. Katja**. Hort. Sci. (Prague), 42: 167–175.

The effect of two-spotted spider mite populations (*Tetranychus urticae* Koch) on the yield and growth parameters of the early-season apple cv. Katja was evaluated during a 3-year study. In the case of the colonisation of apple trees exceeding 1,462, 2,760 and 1,548 cumulative mite days (CMDs) in the subsequent years of research, a significant reduction of the cumulative yield (14 kg/tree) and of the cumulative trunk cross sectional area increase (5.7 cm^2) was observed. No significant effect of spider mites on the average weight of the fruit was observed, while the pest affected fruit colouration. The calculated values of economic injury level were 60.5, 155.5 and 51.8 CMDs in subsequent years of the study, respectively. These values are much lower than the action threshold recommended in Poland and elaborated for the European red mite – *Panonychus ulmi* (Koch) on apple trees. The results suggest that the tolerance of early-season apple cultivars to *T. urticae* may be lower when compared to late-season varieties infested with *P. ulmi;* therefore, the decision to implement pest management for two-spotted spider mite should be taken at a lower infestation threshold than previously thought.

Keywords: economic injury level; action threshold

In Poland, two species of spider mites may cause significant problems to apple growers, among which the European red mite i.e. *Panonychus ulmi* (Koch) is the most common. However, in recent years the two-spotted spider mite (*Tetranychus urticae* Koch) is gaining importance. One of the reasons could be the capability of this polyphagous species to develop resistance to pesticides (Van Leeuwen et al. 2010). According to the "Arthropod Resistance to Pesticides Database", *T. urticae* has shown resistance to 94 active ingredients while *P. ulmi* has shown resistance to only 48 (Whalon et al. 2014).

Under favourable conditions, spider mites can build up very large populations which cause important economic losses. Heavy infestation of apple trees by mites can lead to the current-year reduction of tree growth (Chapman et al. 1952; Avery, Briggs 1968), and to yield drop (Croft et al. 1983; Hardman et al. 1985). However, some studies concerning the impact of mites on apple trees give contradictory results. Some of these discrepancies can be explained by the different timing of pest occurrence (phenological phase of the plant) and the different dynamics of the pest population. There are studies indicating that the severity and type of damage caused by mites depends on the time of the season when a large population of the pest occurred (Beers, Hull 1990). Some of the researches showed that the appearance of a large population of mites is especially dangerous early in the season, i.e. before abscission of fruits in June (Lienk, Minns 1980; Marini et al. 1994). The basis for the decision to im-

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plement plant protection treatments is to identify the pest population for which a certain minimal measurable loss in the yield or its quality can be observed. This value corresponds with the plant tolerance to the pest and is defined as the crop damage threshold. Another categorisation is the economic injury level (EIL). This is a pest population density at which the benefits of investing in pest control measures equal the cost of implementing those same control measures (Pedigo et al. 1986; Stejskal 2003). However, inaction during the time before the pest population reaches the EIL value could risk unacceptable losses. Therefore management activities should be carried out earlier, when the population reaches the action threshold (AT) (Pedigo, Higley 1992).

In Poland, it is assumed that the action threshold for spider mites in apple orchards is the presence of 3 or more motile forms per leaf in the period from pink bud until the second half of July and 7 or more motile forms per leaf after that time. These thresholds have been developed for *P. ulmi*; however, separate studies for other species of spider mites including *T. urticae* have not been carried out so far. It should be emphasised that the harmful effects of these pests depend not only on the instantaneous size of the population but also on the length of time they feed. Therefore, in the studies done on the plant damage thresholds related to spider mites, plant colonisation by pests should also be expressed using cumulative mite days (CMDs). Taking into account the current action thresholds, the calculated value of CMDs for the period from June 1 to the end of August is about 450.

However, in a number of experiments, carried out under different experimental conditions, where the population of mites exceeded the proposed action threshold, as stated above, no significant effects on the yield and its quality, as well as on the growth of apple trees, was observed (Ames et al. 1984; Beers, Hull 1987; Beers et al. 1990; Warabieda, Olszak 2002). These studies indicate that the action threshold could be established at a higher level. With the exception of the study by Warabieda and Olszak (2002), which was carried out on *T. urticae*, all of the studies involved *P. ulmi*. The question arises whether the action thresholds should be the same for both species.

Moreover, the great majority of these experiments were conducted on late-season apple varieties. It should be noted that in apple orchards, the max. populations of spider mites usually occur in July and then decrease as a result of natural processes, as well as the activity of predatory mites or the use of selective pesticides (Hardman et al. 2007; Duso et al. 2009). Thus for late-season apple cultivars, in contrast to early-season varieties, harvesting can take place up to about 2–3 months after the max. level of the spider mite population. In this case, the question arises about the opportunity of using a uniform EIL for all apple varieties, regardless of the time of fruit ripening.

In the presented paper the effect of two-spotted spider mite feeding on summer apple cv. Katja is reported. Simultaneously an attempt was made to determine the economic injury level in relation to mites on this early-season apple cultivar.

MATERIAL AND METHODS

The study was conducted in the Experimental Orchard of the Research Institute of Horticulture in Dąbrowice on the early-season apple cv. Katja in 2009, 2010 and 2011. Experiments were carried out on trees planted in 1994. All trees were grafted on M.9 rootstock and the planting density was 1,900 trees/ha (3.5 m × 1.5 m). Standard cultural practices were followed, including water supply by drip irrigation. Insects and diseases were controlled in accordance with the Integrated Pest Management practices but specific acaricides were omitted.

In the experimental orchard, 6 apple cultivars were grown including cv. Katja. The plants were arranged within the rows in groups of 18 trees belonging to each apple cultivar. These groups of apple trees were distributed randomly in each row.

We established three levels of infestation of trees by *T. urticae*: A1 – (check) below AT (0–450 CMDs from June 1 to the end of August), A2 – medium (1,000 to 3,000 CMDs), and A3 – high population of mites, greatly exceeding AT (above 3,000 CMDs). In the experiment twenty four replications (plants) were used for each level of infestation. The trees belonging to the particular treatments were distributed randomly.

Every year in May, the two-spotted spider mites reared on bean plants were artificially introduced onto trees of combination A2 and A3. The pest population size was determined on 10 leaves randomly taken from each tree every 2–3 weeks. Motile stages of spider mites were counted under a stereo microscope. Based on the observed number of mites per leaf in each period of observation, the population densities were expressed as cumulative

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mite-days (CMDs) (Wratten et al. 1979). Every year, the fruit yield from each tree was recorded and the mean fruit weight was calculated. Taking into account three years of research, the annual yield measurements were the basis for the calculation of the cumulative yield of trees in each treatment. Every year, the trunk circumference of the trees were measured at a height of 20 cm above the grafting point and the trunk cross-sectional area (TCA) was calculated. The number of fruits on the apple trees and TCA were used to calculate the crop density coefficient (CD). The impact of mites on the quality of the yield was analysed on the basis of the average weight of each fruit and the area of red colour on the fruit peel. The colouring of apples were visually categorised into four groups: 1. 0–25 %; 2. 26–50 %; 3. 51–75 % and 4. with more than 75% of blush area, which is typical for this apple cultivar and it is the most desirable feature on the fruit market.

The population size of spider mites, the influence of spider mites on the yield and tree growth as well as fruit weight and colour were analysed by one-way ANOVA. Tukey´s HSD test at 0.05 level was performed to analyse the significance of the difference between means. In order to determine the relationship between the apple yields, the level of mite infestation expressed as cumulative mite days and the crop density of the trees (the number of fruits per TCA), a multifactorial linear regression analysis was performed. The obtained equation of regression was used to calculate the economic injury levels (*EIL*) in particular years of the study according to the formula:

$$EIL = \frac{C}{V \times D \times I \times K}$$

where

- C – costs of pest control per production of one unit (€/ha)
- V – market value per unit production (€/kg)
- D – damage (yield loss) per unit injury (kg/ha/leaf injury)
- I – injury per pest density (e.g. leaf injury/CMD)
- K – proportion of injury prevented by management, which in many instances is assumed to be near 1 and can be omitted (Pedigo et al. 1986)

In the case of pests with piercing-sucking mouthparts, calculation of the parameters D and I is difficult, so the product of $D \times I = D'$ e.g. the amount of yield loss (kg/tree on 1 CMD increase) was obtained from the slope of regression equations (Higley, Pedigo 1996). In order to use this parameter for 1 ha of orchard, this value was multiplied by 1,900 (No. of trees/ha). This allows the yield loss to be determined if mite infestation from June to the end of August increases by 1 CMD as $D'' = D' \times 1{,}900$ (kg/ha/CMD). Thus, finally, the EIL for our orchard was calculated for particular years of the study according to the formula:

$$EIL = \frac{C}{V \times D}$$

In Poland it is assumed that the cost of spraying 1 ha of orchard using a tractor sprayer is about 47.6 €, while the average cost of an acaricide per 1 ha is about 63.4 €. Thus, the cost of protecting 1 ha of apple orchard was calculated as C = 111 €. For calculations we assumed a price of V = 0.54 €/kg of apples. The values expressed in euros were calculated at the current exchange rate of 1 € = 4.1 Polish Zloty. The Statistica 10 (Statsoft Inc. 2011) software package was used for all statistical analyses.

RESULTS AND DISCUSSION

During the three years of the study, as a result of the annual introduction of *T. urticae*, different levels of pest infestation were achieved on trees belonging to particular experimental plots for most observation dates. The level of infestation of apple trees with mites, expressed both as a number of mites per leaf as well as CMDs calculated from June to the end of August, varied depending on the year and exceeded several times the actual action threshold (Table 1, Fig. 1).

It was found that mites significantly affected the parameters of both fruit yield and apple tree growth. Taking into account three years of research, the cumulative yield harvested from control trees was significantly higher compared to trees infested with the pest (F = 11.19, df = 2, 68, P < 0.001) (Fig. 2a). Similarly, the negative effect of mites on the growth of trees, measured in increments of trunk cross-sectional area, was statistically significant (F = 16.13, df = 2, 62), P < 0.001) (Fig. 2b). It can therefore be concluded that the tolerance of apple trees to *T. urticae* (Crop Damage Threshold) was exceeded in both cases.

As for the quality of harvested fruits, in most cases, two-spotted spider mite infestation of the apple trees was accompanied by a decrease of the mean fruit weight. However, no significant differences were stated in the particular years of the study (F = 1.19, df = 2, 52, P = 0.31 in 2009; F = 0.69, df = 2, 43, P = 0.51 in 2010; F = 0.61, df = 2, 46,

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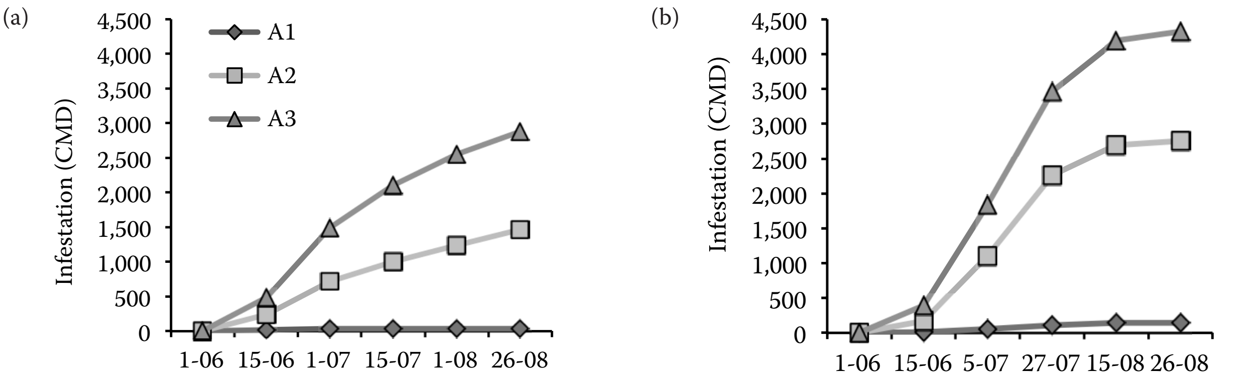
Table 1. Mite population size on cv. Katja during the study (Dąbrowice 2009–2011)

Mite infestation level	Mean number of mites per leaf					
	2009					
	June 1	June 15	July 1	July 15	August 1	August 26
A1	0.0	2.4[a]	0.0[a]	0.0[a]	0.0[a]	0.0[a]
A2	0.0	34.2[b]	25.3[b]	15.4[b]	13.1[b]	4.5[b]
A3	0.0	69.1[c]	57.1[c]	30.8[c]	21[c]	5.6[b]
	2010					
	June 1	June 15	July 5	July 27	August 15	August 26
A1	0.0	1.9[a]	2.8[a]	1.9[a]	1.0[a]	0.0[a]
A2	0.0	24.6[b]	69.1[b]	35.5[b]	10.1[b]	2.0[b]
A3	0.0	55.1[c]	90.3[c]	57.1[c]	20.0[c]	4.0[c]
	2011					
	June 1	June 20	July 6	July 26	August 6	August 16
A1	0.0	0.0[a]	0.0[a]	0.0[a]	0.0[a]	0.0[a]
A2	0.0	9.0[b]	36.4[b]	27.7[b]	0.5[a]	0.0[a]
A3	0.0	38.2[c]	76.4[c]	45.01[c]	1.8[b]	0.6[b]

mite infestation level: A1 – check, A2 – medium, A3 – high; mean values marked with the same letters do not differ significantly at $P < 0.05$ (one-way ANOVA)



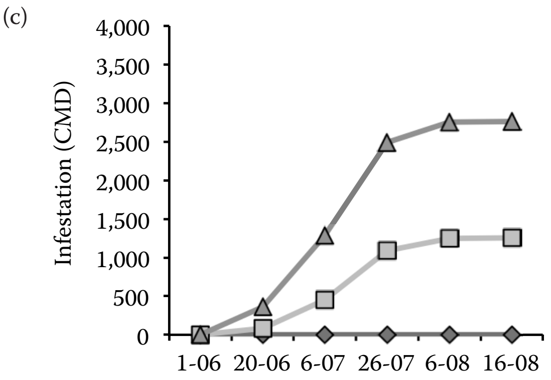


Fig. 1. Seasonal cumulative mite day curves for two-spotted spider mite on cv. Katja (Dąbrowice) – (a) 2009, (b) 2010, and (c) 2011
mite infestation level: A1 – check, A2 – medium, A3 – high; CMD – cumulative mite day

$P = 0.55$ in 2011) (Fig. 3a). Similarly, in each year of the research, the largest number of the fruits was collected from check trees (A1), however, only in 2009 it was confirmed statistically ($F = 3.42$, $df = 2, 52$, $P = 0.04$ in 2009; $F = 0.33$, $df = 2, 43$, $P = 0.72$ in 2010; $F = 0.66$, $df = 2, 42$, $P = 0.52$ in 2011) (data not shown). Finally, the decrease in the yield of trees infested with spider mites, was

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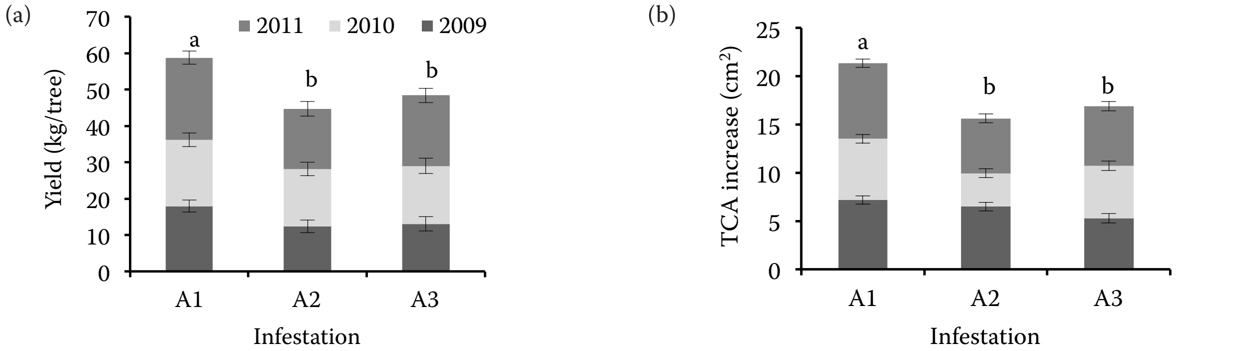

Fig. 2. Influence of mite infestation levels on (a) the yield of apple trees and (b) the increase of trunk cross-sectional area (TCSA) (±SE)

columns with the same letters are not significantly different at $P < 0.05$ with regards to the cumulative yield per tree for the years 2009–2011 (one-way ANOVA); mite infestation level: A1 – check, A2 – medium, A3 – high

the result of additive effects of reducing the number of fruit and decrease in mean apple weight. On the other hand, we found a significant positive impact of mite density on fruit colouration ($F = 20.86$, $df = 2, 52$, $P < 0.001$ in 2009; $F = 9.86$, $df = 2, 45$, $P < 0.001$ in 2010; $F = 3.60$, $df = 2, 46$, $P = 0.035$ in 2011) (Fig. 3b). The red colouration of apples is influenced by numerous factors such as light exposure, temperature and nitrogen or potassium fertilisation (Lancaster 1992; Telias et al. 2011). It is possible that the better colouration of fruits observed on trees infested by *T. urticae* was related to the induction of biochemical processes in the skin of apples. It seems that in this case jasmonic acid or its volatile ester methyl jasmonate, which are signalling molecules in a number of stress situations, including tissue damage caused by pests, could have played an important role. Methyl jasmonate could have been enhanced in plants, including the apple fruits, and as a result, anthocyanin accumulation could have caused the more intense colouration of the fruits (Kondo et al. 2001; Rudell et al. 2005; Wasternack 2007). Of the studied parameters of apple trees that can be affected by spider mites, the yield quantity is of a particular practical significance. The level of apple trees colonisation by mites, which were found during the three years of the experiment, was sufficient to cause a significant decrease in the cumulative yield of the trees (Fig. 2a). However, the results of variance analysis did not give a clear answer regarding the actual value of the crop damage threshold. For a more precise determination of the negative effect of spider mites on apple yield and calculation of the economic injury level, multiple regression analysis was used. In the study the pest population size and density of the crop were included as independent variables (Fig. 4, Table 2). The results proved that the yield of apples is negatively correlated with infestation of trees by mites (CMD) and positively correlated to crop densities (CD). In our experiment the slope in the regression equation shows the reduction of fruit yield per tree

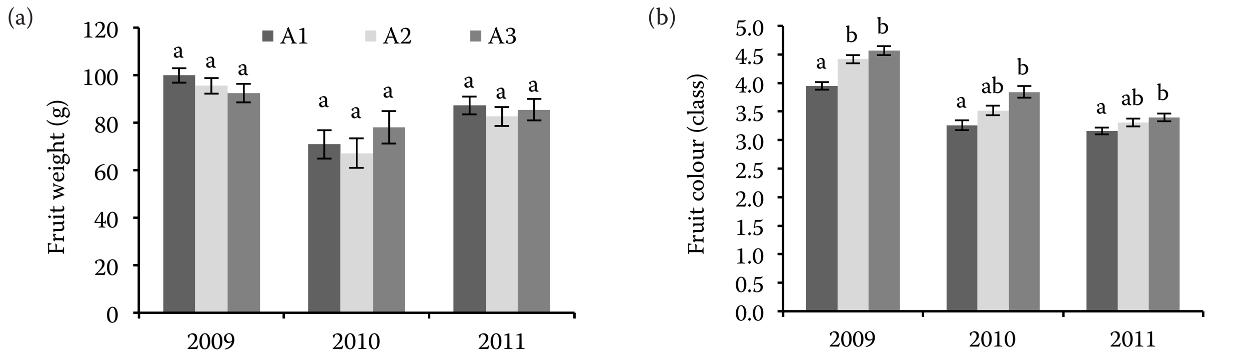

Fig. 3. Effect of spider mites on (a) the fruit weight and (b) fruit colour of apple cv. Katja (± SE)

columns marked with the same letters are not significantly different at $P < 0.05$ (one-way ANOVA); mite infestation level: A1 – check, A2 – medium, A3 – high; fruit colour class scale: 1 – 0–25%; 2 – 26–50%; 3 – 51–75% and 4 – more than 75% of blush area

doi: 10.17221/259/2014-HORTSCI

Table 2. Summary of multiple regression models used for prediction yield of apple trees in the subsequent years of the study

Year	Regression equation and model evaluation	Parameters evaluation			
			Intercept	Slope for CMD	Slope for CD
2009	Yield = 6.51 – 0.0018 × CMD + 1.57 × CD; R^2 = 0.742; F(2, 43) = 61.83; P < 0.0001; SE est.: 2.88		6.51	–0.0018	1.57
		SE	1.2206	0.00031	0.160
		P	< 0.0001	< 0.0001	< 0.0001
2010	Yield = 6.31 – 0.0007 × CMD + 1.29 × CD; R^2 = 0.766; F(2, 42) = 68.91; P < 0.0001; SE est.: 3.33		6.31	–0.0007	1.29
		SE	1.301	0.0002	0.113
		P	< 0.0001	0.0029	< 0.0001
2011	Yield = 4.50 – 0.0021 × CMD + 2.49 × CD; R^2 = 0.911; F(2, 42) = 216; P < 0.0001; SE est.: 3.22		4.50	–0.0021	2.49
		SE	0.9995	0.0004	0.1197
		P	< 0.0001	< 0.0001	< 0.0001

CMD – cumulative mite day; CD – crop density (No. fruits/cm^2 trunk cross-sectional area); R^2 – coefficient of determination; F – F statistic; P – significance level; SE – standard error of estimate; est. – estimate

in kilograms if the mite density expressed as CMD increases by one unit. This value was used to predict the losses of yield as well as the assessment of economic injury level (Table 3). Calculated for individual years of the study, the EIL values (60.1, 154.5 and 51.5 CMD/leaf for 2009, 2010 and 2011, respectively) corresponded to a yield loss of 205.5 kg. On the other hand, for a mite population equal to the action threshold recommended in Poland (450 CMD from June 1 to August 31), the predicted yield loss is, on average, 1,311 kg/ha. Such a yield loss would not be acceptable for fruit growers. It should be pointed out that the EIL values calculated in our experiment for *T.urticae* feeding on early-season cv. Katia are much lower than the actual action threshold which is recommended in Poland, regardless of the ripening time of apple cultivar and species of spider mite.

In our earlier experiment conducted on the late-season cv. Jonagold and the early-season cv. Close infested with *T. urticae* neither 2-fold nor 4-fold exceeding of the action threshold for spider mites on apple trees recommended in Poland had any effect on the yield quantity and quality of apples, measured by the average size of fruits and their colouration (Warabieda, Olszak 2002). Simultaneously, the overall apple yield was low, with only 8 t/ha, for cv. Close and 15 t/ha for cv. Jonagold, which is much less than in the presented experiment with the cv. Katja. These experiments seems to confirm the results of other studies which point out that harmful effect of spider mites increase with increasing crop load (Marini et al. 1994). Most of the experiments regarding the influence of spider mites on apple trees were conducted on late-season apple cultivars infested with *P. ulmi*.

Table 3. Economic injury level values (EIL) and predicted yield losses arising from the regression equations obtained in the subsequent years of the study

Year	Regression equation	D' (kg/tree/CMD)	Calculated EIL (CMD)	Predicted losses (L) (kg/ha)	
				for calculated EIL	for 450 CMD (actual action threshold)
			$EIL = C/(V \times D' \times 1,900)$	$L = D' \times EIL \times 1,900$	$L = D' \times 450 \times 1,900$
2009	Yield = 6.51 – 0.0018 × CMD + 1.57 × CD	0.0018	60.1	205.5	1,539
2010	Yield = 6.31 – 0.0007 × CMD + 1.29 × CD	0.0007	154.5	205.5	598.5
2011	Yield = 4.50 – 0.0021 × CMD + 2.49 × CD	0.0021	51.5	205.5	1,795.5

CMD – cumulative mite day; CD – crop density; C – costs of pest control (111 €/ha); V – market value of apples (0.54 €/kg); D' – amount of yield loss in kg/tree on 1 CMD increase; 1,900 – No. of trees/ha in the experimental orchard

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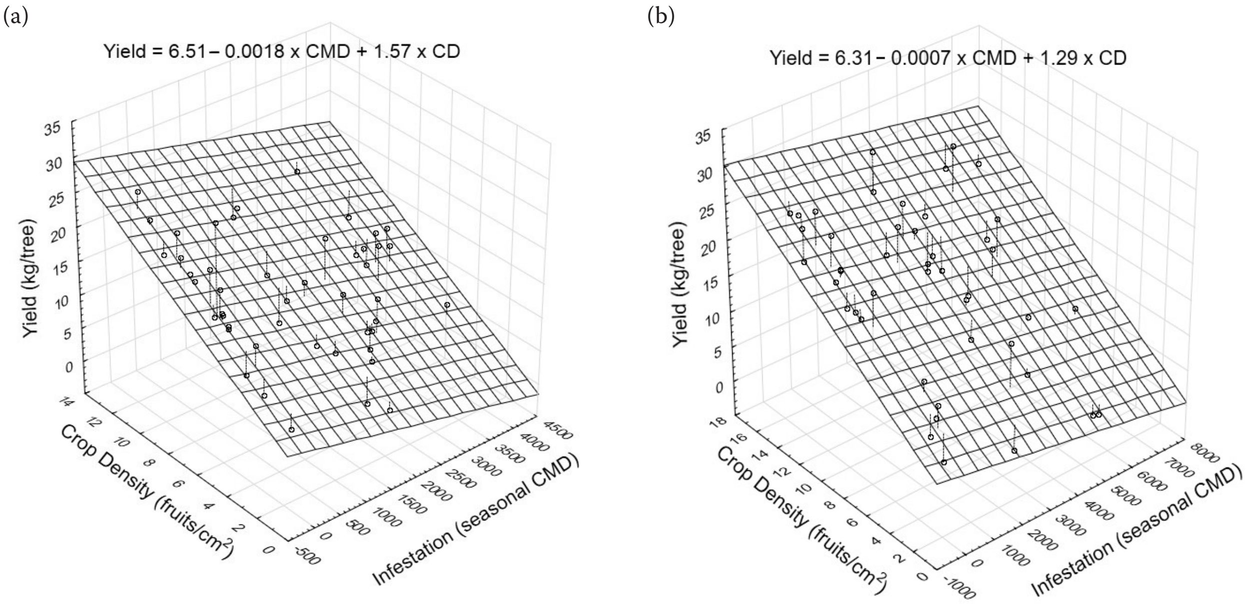

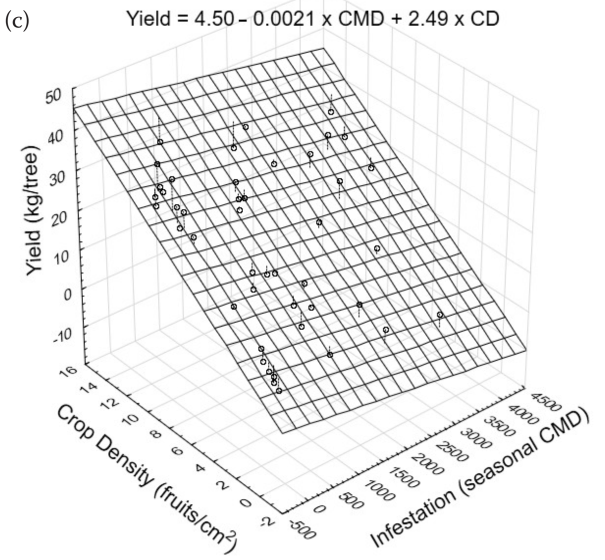

Fig. 4. Regression surface relating yield to crop density (CD) (No. of fruits/cm^2 trunk cross-sectional area) and *Tetranychus urticae* seasonal cumulative mite-days (CMD) on cv. Katja apple trees in (a) 2009, (b) 2010 and (c) 2011

In many of these studies the population of this pest exceeded the action threshold proposed in Poland without either a negative effect on yield or growth of the apple trees. In an experiment carried out on cvs. Yorking and Delicious, both belonging to late season apples, the European red mite population was close to 1,500 CMD (Hull, Beers 1990). Mean fruit weight, fruit colour, fruit firmness and soluble solids, as well as blooming in the following year, were not influenced by such a level of mite population. The negative impact of this level of mites population on blooming was only found in subsequent years of research on the cv. Yorking. Beers and Hull (1987), in a 3-year experiment on cvs Bisbee Delicious, Triple Red Delicious, Golden Delicious and Red Stayman 201, stated that a European red mite population level up to 2,000 CMDs did not influence such growth parameters as shoot length, leaf numbers and trunk girth. Only flowering of the two latter cultivars was reduced in this experiment.

Some of the authors underline the importance of timing of mite injury pressure as a factor influencing the type and severity of damage of apple trees.

In an experiment conducted on cvs Bisbee Delicious and Rome Beauty, when mite population levels ranged from 0–1,500 CMD, only a marginal negative effect of ERM on fruit weight and return crop was noted (Beers et al. 1990). According to the authors, the reason for this state of things could be the fact, that mite injury occurred relatively late in the season.

doi: 10.17221/259/2014-HORTSCI

It should be emphasised that in our experiments we had a different situation, because our experiment was conducted for *T. urticae* and the rapid increase in the population of spider mites occurred in relatively early stages of plant phenological development. This confirms the information, that the time of mite injury occurrence is important for yield and vegetative growth of apple trees. It seems that early season injury, before June fruit drop when the leaf:fruit ratio is low, is especially dangerous. At this time, mite injury lowers the amount of carbohydrates supplied to the fruit and may cause an increase in fruit drop. It should be noted that while at the beginning of the season the leaf to fruit ratio is 2–4:1, after a wave of fruit drop, the vegetative growth of shoots leads to an increase in the leaf to fruit ratio of up to 40:1 by the end of fruit development (Soltész 1997; Racskó et al. 2006). In our experiment, the maximum mite population was observed just after the June drop. On the other hand, the time of harvesting in each year of the research was in the second half of August, so the trees were under strong pressure from the spider mites almost until harvesting. It seems that in this case, the impact of mite injury on the yield and vegetative growth of trees could have been stronger than that found in other experiments carried out on late season varieties.

In Polish orchards, a natural decline in the population of spider mites usually takes place in August. In contrast to the summer apple cultivars, on the late season varieties, many days elapse between the decline in population size of the pest and harvest time. In this case, fruit growth takes place for a relatively long period of time without pest pressure. This finding, as well as the fact that during this period the leaf:fruit ratio also increases, may mean that late season apple varieties are more tolerant to mite feeding than summer apple varieties.

So far the action thresholds established for spider mites feeding on apple, are based on the research carried out on *P. ulmi*. However, the reproductive and damage potential of *P. ulmi* and *T. urticae* vary (van de Vrie 1972; Youngman et al. 1986), so the question remains whether the thresholds developed for this species are suitable for *T. urticae*. Probably a better solution would be to develop separate thresholds for these species; however, this would require more research on the subject. Additionally, the situation is complicated by the fact that orchards are very often inhabited by mixed populations of these two species.

At the moment it seems that the use of an economic injury level for mites that has been developed in the studies conducted on late-season apple cultivars infested with European red mite carries the risk of unacceptable losses for early-season varieties, infested with two-spotted spider mite. Our results suggest that in the last case the EIL as well as AT should be lowered.

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Received for publication September 24, 2014
Accepted after corrections May 29, 2015

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