EFFECT OF CITRUS RED MITE INFESTATION ON FRUIT QUALITY, YIELD AND TRUNK GROWTH OF SATSUMA MANDARIN

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Introduction

Citrus red mites (*Panonychus citri* McGregor) are among the most important mite pests in Japan. When they reach outbreak status in autumn, October-November, the fruit color of Satsuma mandarin (*Citrus unshiu* Marcov.) and other varieties changes to a pale-grayish or silverly color due to their continuous feeding for a few months prior to the harvest. As they adversely affect the appearance of the mature fruit resulting in depreciation, the market price of the injured fruit is often reduced to one-third or less than that of the uninfested fruit, even if there is no difference in quality between them. No one would dispute their potential for economic damage on foliage as well as on fruit appearance. However, we have had only scant knowledge about the maximum level of mite population on citrus tree that can be tolerated without economic loss, in spite of miticides having been so frequently sprayed for many years.

We report here a method for evaluating the tolerance limit of Satsuma mandarin tree and its fruit to citrus red mite infestation by analyzing the influence of mite feeding upon fruit quality, yield and trunk growth of the tree.

Rate of population increase, r', and influence of mean temperature, θ, upon r'

Matsunaga and Furuhashi (1977) observed that the number of adult females of citrus red mites increased exponentially with the lapse of time during certain periods of the annual occurrence (note high values of correlation coefficients between t and ln N_t in Table 1). Field A (20a) with 126 nine-year-old Satsuma mandarin trees and Field B (2a) with 24 eight-year-old trees were subjected to application of chemicals according to the routine spray program throughout the experimental period, in 1969. Field C of about 5a with 45 six-year-old Satsuma mandarin trees was kept free from any chemical application. For the investigation in growth chamber three-year-old potted Satsuma mandarin trees were used. Numbers of sampled leaves were 30 or 50 for each tree. The following equation was obtained:

$$N_t = N_0 e^{r't} \quad (1)$$

where N_0 and N_t are the number of adult females per 100 leaves at the start of the experiment (t + 0) and on the t - th day respectively, and r' is the observed rate of population increase.

The symbol r' can be used instead of the intrinsic rate of population increase, r, which is calculated theoretically because the values of r' obtained here are as high as those of r derived from the examinations under comparable temperature conditions (Matsunaga and Furuhashi, 1977 and Furuhashi and Nishino, unpublished data).

Eq. 1 can be rewritten to the following equation if the mean generation period, T replaces t:

$$N_T = N_0 e^{r'T} \quad (2)$$

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Table 1 Relationship between exponential increase of mite population and mean temperature during the observation period (After Matsunaga and Furuhashi, 1977)

Investigation	Date	Days after start of experiment (t)	Number of adult females /100 leaves (N_t)	Correlation coefficient between t and lnN_t	Rate of population increase (r')	Mean temperature in the period (°C)
Field A (Sprayed according to standard schedule)	Sep. 4, 1969	0	1.2	0.996	0.1463	23.6
		7	4.9			
		14	11.4			
		21	31.4			
	Oct. 2	28	78.8			
	Sep. 14, 1970	0	1.3	0.994	0.1157	21.8
		11	7.3			
		24	24.0			
	Oct. 15	31	53.7			
	Oct. 29, 1970	0	14.4	0.993	0.0566	13.9
		15	41.6			
	Dec. 3	35	106.0			
	Jun. 5, 1971	0	8.8	0.999	0.1214	21.7
		9	26.3			
		17	63.3			
	Jul. 5	30	341.0			
	Aug. 19, 1971	0	3.9	0.962	0.1855	24.9
		7	46.0			
		14	82.9			
	Sep. 10	22	299.7			
Field B (Sprayed according to standard schedule)	Apr. 30, 1969	0	4.3	0.994	0.1039	18.7
		6	7.6			
		14	16.1			
	May 20	20	36.0			
	Jul. 1, 1969	0	6.3	0.996	0.1175	23.5
		8	15.3			
		14	27.6			
	Jul. 22	21	77.2			
	Sep. 16, 1969	0	9.3	0.998	0.1155	21.0
		8	26.3			
		14	51.3			
	Oct. 7	21	105.4			
	Oct. 21, 1969	0	68.8	0.980	0.0714	17.2
		7	135.2			
	Nov. 4	14	187.1			
	Jul. 14, 1970	0	19.6	0.992	0.1134	25.6
		7	34.0			
		15	85.4			
	Aug. 5	22	236.1			

Investigation	Date	Days after start of experiment (t)	Number of adult females /100 leaves (N_t)	Correlation coefficient between t and $\ln N_t$	Rate of population increase (r')	Mean temperature in the period (°C)
Field C (Unsprayed)	Jun. 8, 1973	0	8.8	0.999	0.1033	21.2
		5	15.7			
	Jun. 20	12	30.7			
Growth chamber (Under constant temperature conditions)	Jul. 6, 1973	0	57	0.984	0.0931	17
		7	52			
		12	71			
		17	212			
		27	773			
		35	1054			
		41	1588			
		48	3893			
	Aug. 31	56	5944			
	Jul. 6, 1973	0	44	0.989	0.1505	24
		7	99			
		12	391			
		17	551			
	Aug. 2	27	2392			
	Jul. 6, 1973	0	32	0.984	0.1722	28
		7	181			
		12	390			
		17	1231			
	Aug. 2	27	3354			

where T is also a variable which changes with the temperature. Therefore, if the law of total effective temperature can be applied to T, the relationship between r' and θ is theoretically expressed by a simple linear equation. Fig. 1 shows that the T value is in good agreement with this law, even if the two hollow circles corresponding to lower temperatures are omitted from the regression line, because this experiment has been carried out under fluctuating temperature conditions. Thus,

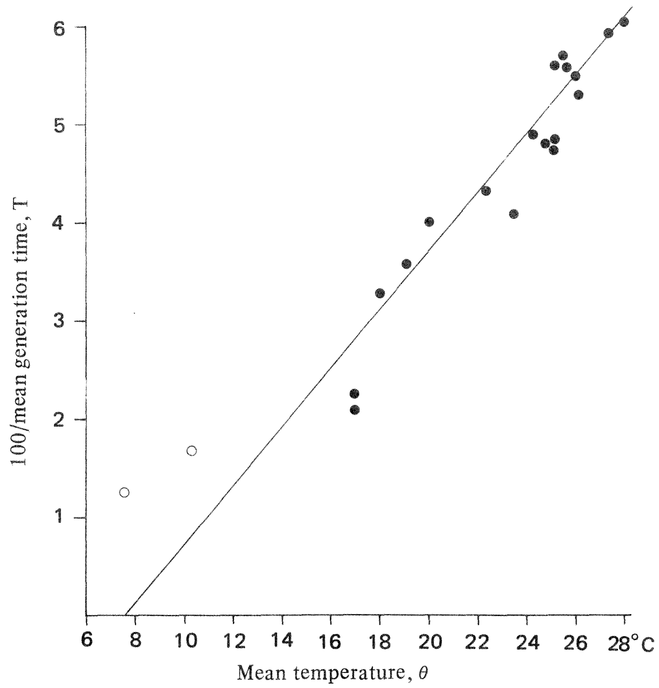
$$r' = \frac{\ln N_T - \ln N_0}{K} (\theta - k) \tag{3}$$

where K is the thermal constant, k is the temperature for developmental zero, ($\ln N_T - \ln N_0$) expresses the rate of population increase per generation, and θ is the averaged daily mean temperature. The observed relationship between r' and θ is given in Fig. 2.

Mean effective population, FN_m

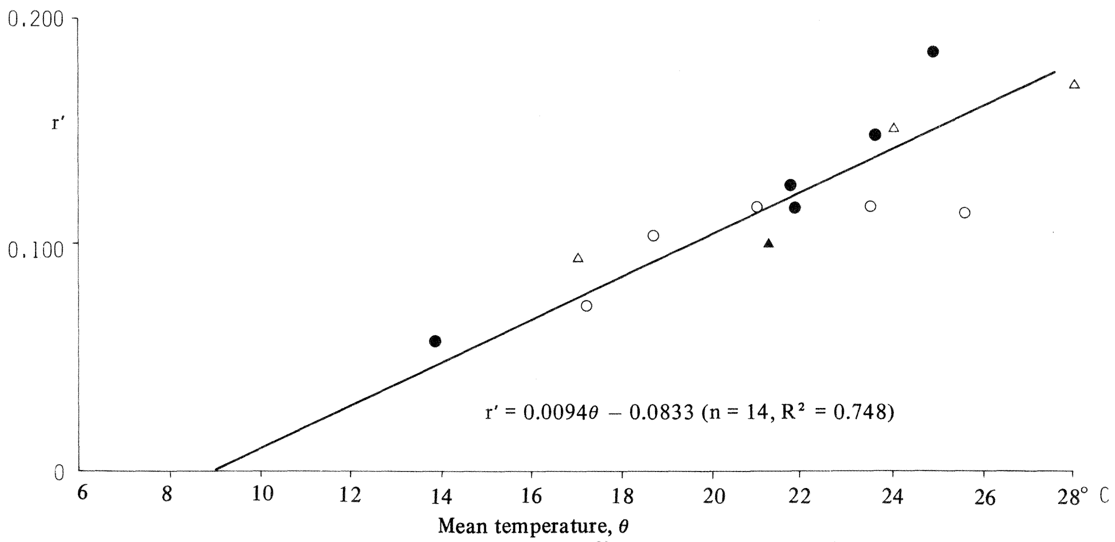
When the mite population is in the phase of positive growth, it is considered to be in the steady growth stage. If a given level of nutrition, E_t, is required to maintain the normal life and fecundity of one female mite, the following equation can be given:

$$E_t = x t_n E_n + t_a E_a \tag{4}$$



Note: Hollow circles were omitted from the calculation of regression line.

Fig. 1 Relation between mean temperature, θ, and velocity of development, 1/T, after Furuhashi



Note: The different symbols indicate different experiments in Table 1.

Fig. 2 Relationship between mean temperature, θ, and rate of increase, r'

where x is the mean number of eggs per female, t_n and t_a are the durations of the nymphal and adult female stages respectively, E_n and E_a represent the given level of nutrition required for the life of nymphs and adults, respectively and E_a expresses the nutrition requirements for laying eggs. However, the amount of food required for adult males and females which have completed oviposition is negligible. Thus the nutrition requirement per mite-day, E_d is expressed by the following equation:

$$E_d = \frac{E_t}{t_n + t_a} \tag{5}$$

If a certain amount of cell sap corresponding to E_d is given to an adult female and some nymphs at the steady growth stage, the mite population is expected to increase at the rate of r' per day. Therefore, r' appears to be a good parameter as it is proportional to the feeding incidence of mite. Then, another parameter, F, which is the coefficient of feeding incidence, can be introduced to simplify the relation between r' and:

$$F = fr' \tag{6}$$

where f is a constant. According to the equation given in Fig. 2, the r' value is 0.1517 when $\theta = 25°C$. Then, if $F = 1$ when $\theta = 25°C$, $f = F/r' = 1/0.1517 = 6.6$. Therefore,

$$F = 0.06200\theta - 0.5491 \tag{7}$$

So long as $F > 0$, the coefficient of feeding incidence, F, can also be approximately applied to the population which is not in the phase of increase. According to Furuhashi (in press), the population decrease which is frequently observed in August (cf. Fig. 8) is mainly caused by the increase of the mite population which abandoned the tree for a short time after moulting to the adult form. It is not due to the increase of mortality of eggs or nymphs, and it represents a phenomenon independent of the density in citrus orchard. It is, therefore, possibly related to the seasonal change of leaf quality. As a result, the period of infestation of the plant by adult female is shorter than that in other seasons. Accordingly, the F value calculated from the data obtained in the phase of population decrease tends to overestimate the actual intensity of feeding. Therefore, the amount of nutrients removed from the plant by the mite population per day can be correlated to $F_{(i)} N_{(i)}$, and if it is assumed that a given value of $F_{(i)} N_{(i)}$ corresponds to the same extent of damage to plant at any time when $F > 0$, the mean of $F_{(i)}N_{(i)}$ is significant, and is expressed as follows:

$$FN_m = \sum_{i=0}^{s} t_{(i)} (F_{(i)}N_{(i)} + F_{(i+1)}N_{(i+1)}) / 2T_p \tag{8}$$

where FN_m is referred to as the mean effective population, hereafter, $F_{(i)}$ the coefficient of feeding incidence calculated from the mean temperature for five days including the day of i-th observation, $N_{(i)}$ the number of adult females per 100 leaves, $t_{(i)}$ the days between i-th and (i + i) - th observations, s the number of observations and T_p the mean period (days) when $F > 0$ during the time from March 1 to December 25.

However, the population occurring on fruit before August does not affect the qualitative properties such as fruit appearance, because recovery from the damage is more complete for younger fruit with successive development until harvest. The FN_m value is, therefore, calculated only from populations observed in the "autumn build-up" of mite.

Application of Seinhorst's model

Seinhorst (1965) proposed a mathematical model which described the relation between nematode density and extent of damage to plant. In this regard, he also proposed an easier procedure for the calculation of linear regressions (Seinhorst, 1973). We intend to apply these works to clarify the relation between the citrus red mite density and the damage to some properties of Satsuma mandarin.

A simple relation between mite population and the plant attacked can be developed if two assumptions are made:

(1) The size or activity of "average mite" is the same for all densities and all seasons.

(2) Whether a mite will attack a leaf and a fruit or not is not influenced by the absence or presence of other organisms attacking the same plant.

If one mite present on citrus plant attacks a proportion d $(0 < d < 1)$ of the plant, the proportion (1-d) is not attacked by the first mite. Two mites, therefore, attack a proportion d + d(1-d) and $(1\text{-}d)^2$ is not attacked. In general at a population density p a proportion

$$y = (1-d)^p = Z^p \qquad (9)$$

will be left intact by the mite. This equation could also express the relation between the rate of plant growth as well as the fruit quality and the mite population.

The actual relationship is complicated, however, by two phenomena:

(1) Plants may have more leaves than they really need to support the growth of plant.

(2) The plant can replace lost parts.

By taking both phenomena into account, Seinhorst (1963) modified plant growth eq. (9) as follows:

$$y = C_1 C_2 Z^p = Z^{p-L} \qquad (10)$$

where y becomes 1 if $p = L$. When $p < L$ the growth is not affected by the mite. Seinhorst (1963) therefore called L the tolerance limit. In eq. (10), p can be replaced by FN_m in eq. (8). The tolerance limit L can be estimated if the relation between p and relative plant growth or fruit quality is adequately described by the arbitrary equation

$$y = m + (1-m)Z^{p-L} \qquad (11)$$

where m is the relative minimum plant growth or fruit quality ($m<1$). Then the relation between y and $p^{0.5}$ is linear for values of Z^{p-L} between values 0.2 and 0.95 of the line ($y = a\text{-}bp^{0.5}$).

Tolerance limit expressed by FN_m value

1 Methods

In 1975, an orchard of about 5a with 72 three-year-old Satsuma mandarin (Sugiyama strain) trees was selected for evaluating tolerance limit. The orchard was divided into 12 blocks of 6 trees each, and the respective blocks were allotted to 4 levels of citrus red mite, with 3 replications. In the plots for the highest population level, no miticide was sprayed, and in the others, the mite populations were maintained by means of the following miticidal applications, benzomate and amitraz:

Sep. 27, 1976	Benzomate
June 20, 1977	Amitraz
Sep. 27, 1977	Amitraz
Nov. 9, 1977	Benzomate
Mar. 21, 1978	Amitraz
June 15, 1978	Amitraz
July 28, 1978	Amitraz
June 2, 1979	Amitraz
Sep. 17, 1979	Amitraz

For each of these 2 miticides, 3 concentration levels [(benzomate (EC. 20%): 1,500X, 2,000X and 5,000X; amitraz (EC. 20%): 1,000X, 2,000X and 5,000X)] were sprayed to maintain the difference in mite populations, and a few applications of insecticide were made to control insect pests.

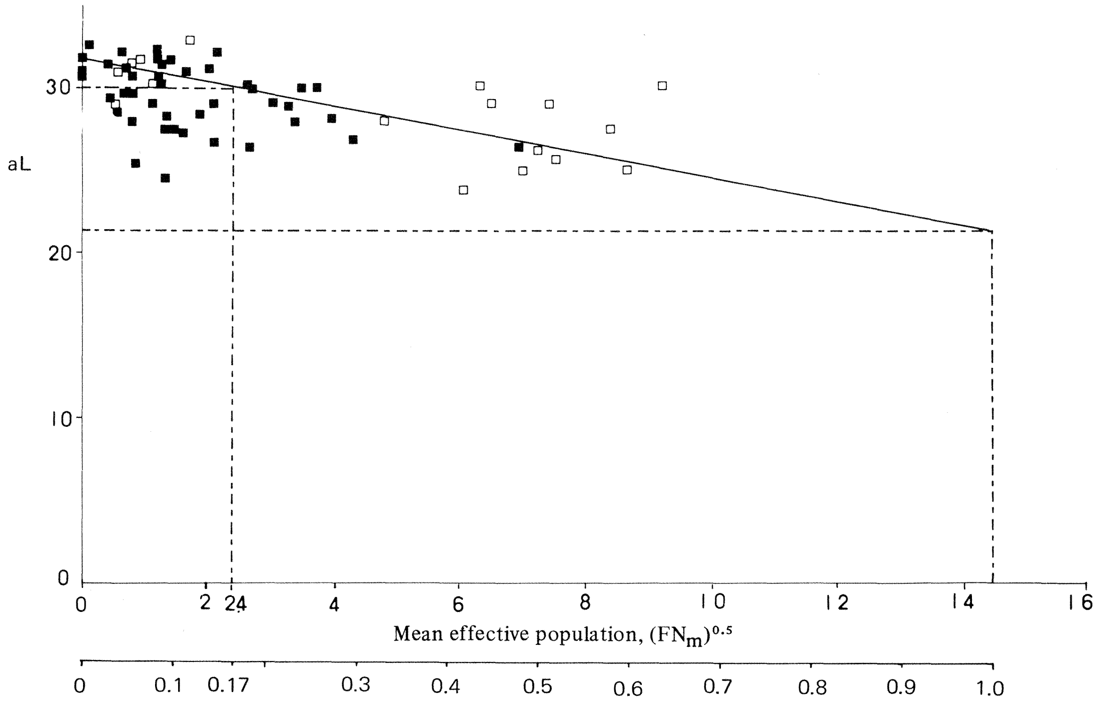
Adult females were counted on 30 leaves randomly selected (in 1976 and 1977) or 20 leaves (in 1978 and 1979) with intervals of about 15 days from spring to late autumn.

Soluble solids in juice (expressed by Brix hydrometer value), specific gravity of fruit and peel color were determined for 10 fruits sampled from the yield in each of the trees. As an indicator for peel color, Hunter aL value was measured wtih the "color and color difference meter" TPC-85D constructed by Tokyo Denshoku Co., Ltd. The yield and the trunk diameter were annually recorded for each plant.

2 Tolerance limit for some properties concerning fruit quality

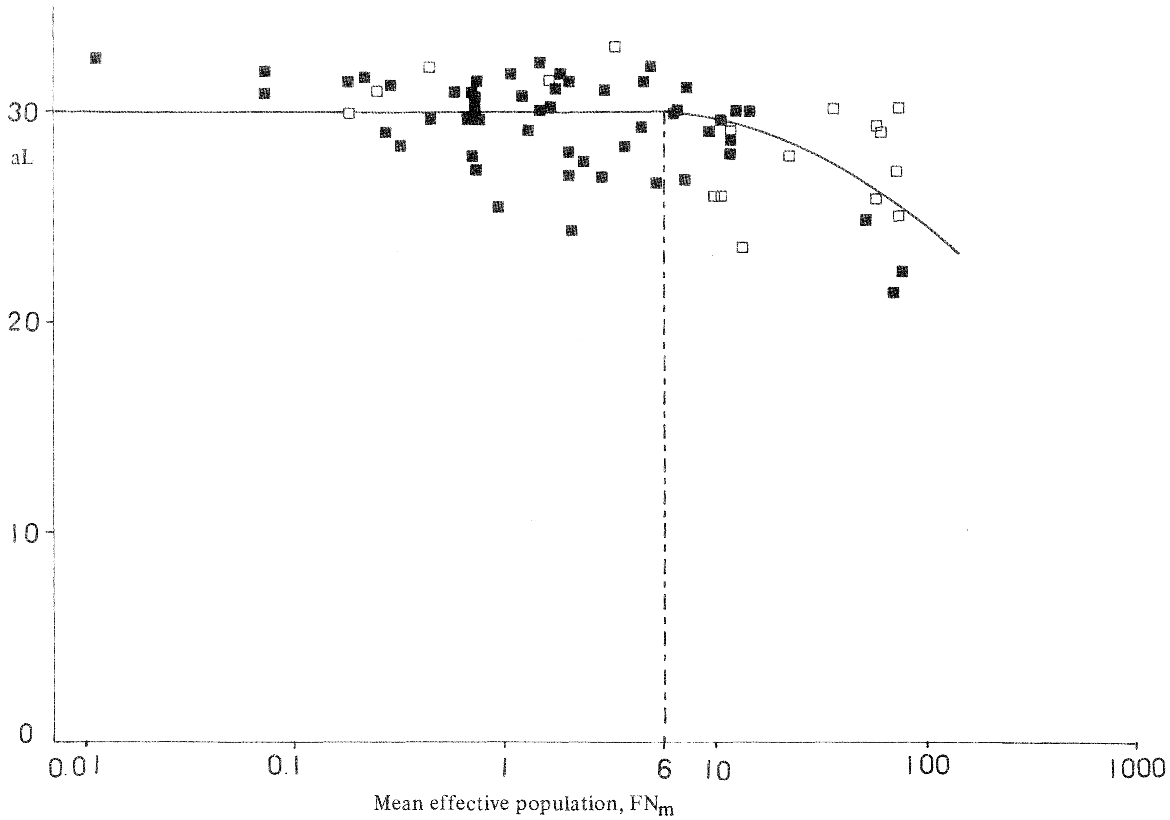
On the basis of the 1978 data, the relationship between FN_m given in eq. (7) and aL is shown in Fig. 3 and Fig. 4. In Fig. 3, a procedure for the estimation of tolerance limit, L, is indicated when the minimum value of aL, m, can be obtained (cf. eq. (11)). The m value used here is a value which is estimated from the yellow color measured on peels of Natsudaidai (*Citrus natsudaidai* Hay.) instead of Satsuma mandarin which is injured by the maximum level of mite population. Even if the estimated value, m, is not accurate the value of L is not markedly influenced by the variation of m (Seinhorst, 1973). Thus, we can say that as far as the peel color is concerned, the most probable value of tolerance limit is $FN_m = 6$.

Soluble solids in juice did not change with increasing FN_m values (Fig. 5), suggesting that juice quality is less affected by the mite infestation than peel color. It was also observed that specific gravity of fruits was influenced by FN_m values above 20, although this tolerance limit was much higher than that for peel color. (Fig. 6)



Note: Hollow squares indicate the data obtained from the plot without miticidal applications.

Fig. 3 Procedure for estimation of tolerance limit from peel color, aL, (Seinhorst, 1973)



Note: Hollow squares indicate the data obtained from the plot without miticidal applications.

Fig. 4 Relationship between mean effective population, FN_m, and Hunter aL value of peel color (1978)

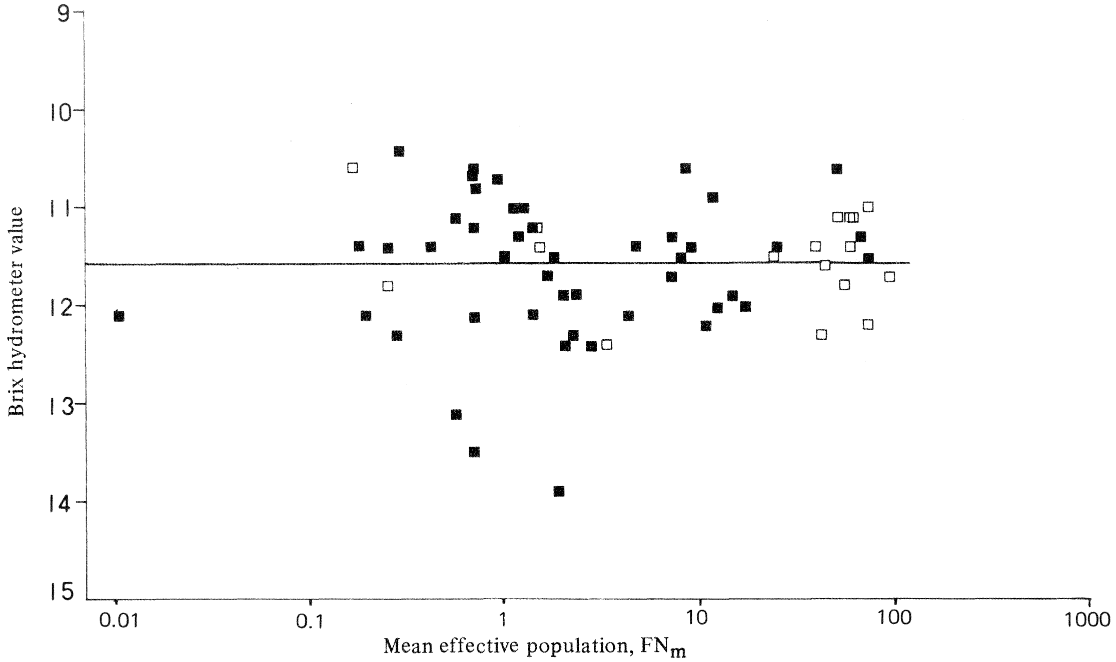


Fig. 5 Relationship between mean effective population, FN_m, and Brix hydrometer value (1978)

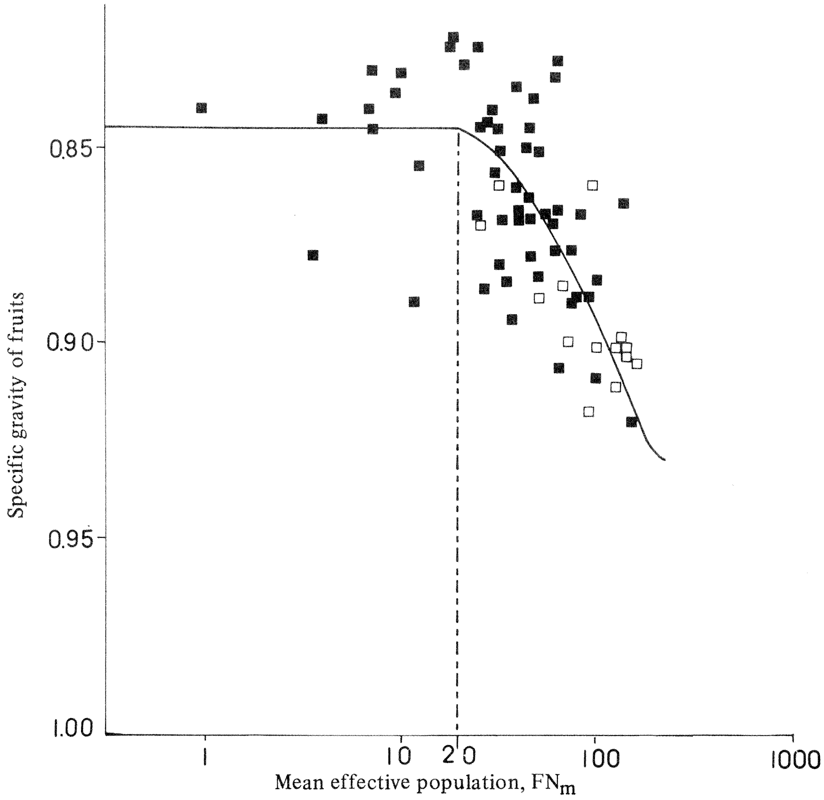


Fig. 6 Relationship between mean effective population and specific gravity of fruits (1977)

3 Tolerance limit for some quantitative properties of the plant.

A matrix of correlation coefficients is given in Table 2. During the period of the experiment as the citrus trees continued to grow, the yield was, therefore, expressed as the accumulation of the annual yields from 1977 to 1979. There was no significant correlation between FN_m and cumulative yield, while the trunk diameter in 1979 was negatively correlated with FN_m. Fig. 7 shows that the trunk growth was adversely influenced to some extent by mite infestation when the FN_m value exceeded about 40.

Table 2 Correlation matrix for quantitative properties and mean effective population, FN_m

		1	2	3	4
1.	Cumulative yield (1977–1979)	–	–	–	–
2.	Trunk diameter (1976)	0.42**	–	–	–
3.	Trunk diameter (1979)	0.46**	0.35**	–	–
4.	Mean effective population, FN_m	0.07	0.02	−0.31*	–

* and **: At the 5% and 1% level of significance, respectively.

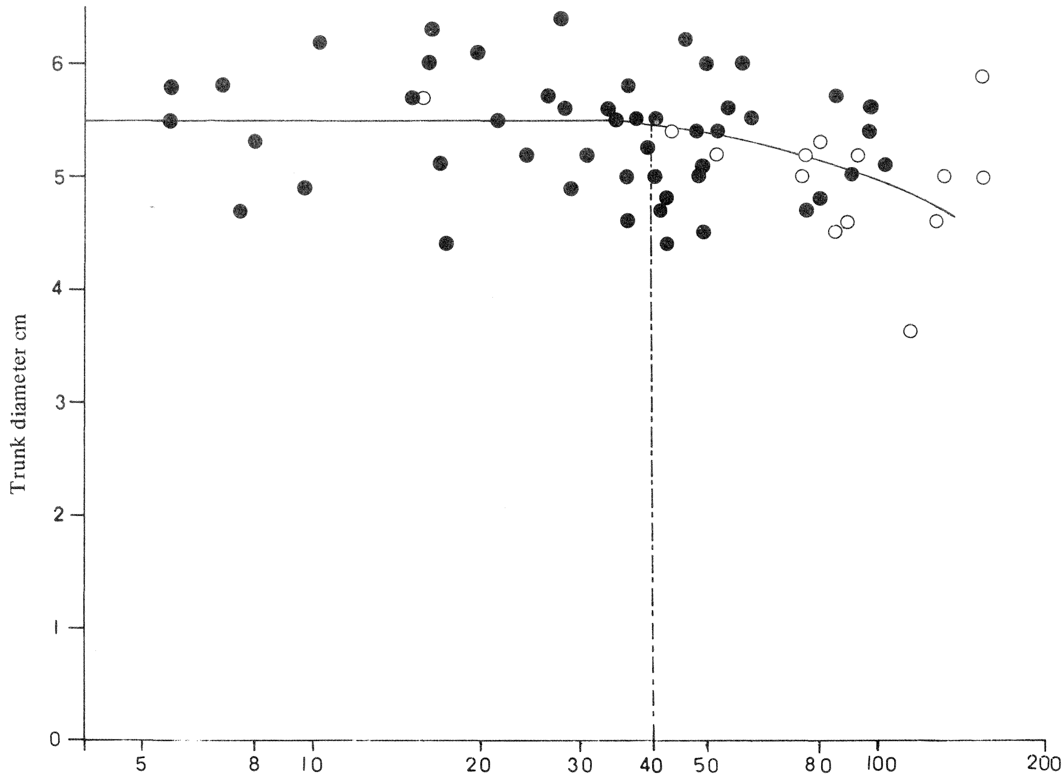


Fig. 7 Relationship between mean effective population, FN_m, and trunk diameter (1979)

Simulation consideration for adequate miticidal applications

The population fluctuation of the mite in 1978 obtained from a plot without miticidal treatment is shown in Fig. 8. There were two periods when the population increased, the first one in July and the second in November. These are called "summer build-up" and "autumn build-up", respectively. This pattern of fluctuation is the most typical one not only in Shizuoka Prefecture but in other parts of Japan.

The mean effective population FN_m, reached the value of 180 on Dec. 25 of this year. This value was 4.5-fold higher than the tolerance limit for trunk growth, indicating the necessity of the application of miticide to reduce the FN_m value under the tolerance limits on the basis of quantitative and qualitative properties. Here a miticide is supposed to kill 95% of each growth stage of the mite. If miticide is applied for the "autumn build-up" late in September when the FN_m value for peel color just reached 6, the actual population corresponds to 100 adult females per 100 leaves as seen in this figure, however, the population will increase after the treatment as shown by the thin solid line. If the rate of population increase is the same as that of the population which is not sprayed, the FN_m value will slowly increase and reach the value of 10 as shown by the thin broken line, which corresponds to a number of 200 adult females on the day of harvest. However the application for the "summer build-up" will affect the level of initial population of the "autumn build-up". Thus, the level of population in early autumn is likely to be less than that of the actual population shown by the thick solid line. Therefore the timing of miticidal application can be delayed to some extent, and the increase of FN_m value after the application will be less than expected.

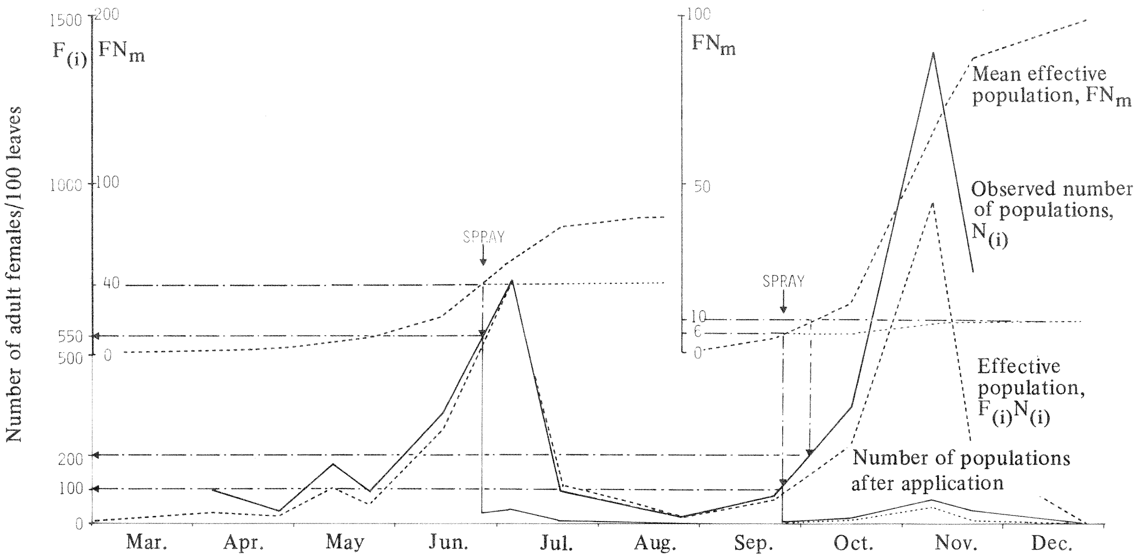


Fig. 8 Graphic model for estimation of threshold population of mite using data obtained in 1978

For the "summer build-up" an application has to be made to reach a FN_m value of less than 40 which corresponds to the tolerance limit for trunk growth. If the "autumn build-up" is omitted, the actual population comprises 550 adult females at this time because of the lower increase of FN_m value after the application as shown by the thin broken line. However as the "autumn build-up" inevitably occurs, its threshold level amounts to 100 adult females. At the time of the "summer build-up", the threshold level of mite population is therefore 450 adult females per 100 leaves which is the level obtained after subtracting 100 from 550. If those levels can be maintained, no damage is expected for either quantitative or qualitative properties of Satsuma mandarin, even though the mite infestation makes apparent scars on the leaves.

Summary

The population increase of citrus red mite could be well approximated by using the equation $N_t = N_0 e^{r't}$, where r' is the actual immediate rate of increase with almost the same value as r, the true intrinsic rate of natural increase. Linear relationship was found between r' and mean temperature during the phase of increase in mite population and it was expected that the relationship between the feeding incidence of mite and mean temperature should also be linear. On the basis of these assumptions, a new index, FN_m, representing the mean effective population was proposed. The tolerance limit of injury due to mite was estimated by incorporating FN_m to the Seinhorst's model. Using graphic models for the population growth and the miticidal applications in relation to the tolerance limits, the threshold levels for both the "summer build-up" and "autumn build-up" were about 450 and 100 adult females per 100 leaves, respectively.

Acknowledgement

We are indebted to Drs. Y. Ito and A. Otake for their helpful suggestions and criticism.

References

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2) SEINHORST, J.W. (1965): The relation between nematode density and damage to plants. *Nematologica* **11**, 137-154.

3) ________ (1973): The relationship between yield and square root of nematode density. *Nematologica* **18**, 585-590.

Discussion

Ishikura, H. (Japan): The speaker dealt with the mite population prevalence. However in order to make the prediction of skin injury of fruit I would like to know when the critical period of the attack in relation to the change in color takes place.

Answer: I cannot answer your question owing to the complex relationships which should be defined in the future.

Otake, A. (Japan): Although I have some reservations about the conclusions drawn by the authors I am aware of the fact that the results of their work stem from exhaustive field studies which are very tedious. However, I would like to emphasize that this elaborate field work is essential for the type of theoretical studies such as those presented here.

Answer: We fully realize that further studies should be carried out.