

Effect of host plant nitrogen fertilization on the biology of the two-spotted spider mite, *Tetranychus urticae*

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Keywords: Acarina, Tetranychidae, *Tetranychus urticae*, nutrient stress, apple, bean

Abstract

Females of *Tetranychus urticae* Koch were reared on leaf discs of apple trees and bush beans grown at different N concentrations (0.6–75 mM NO₃⁻). N-deficiency increased pre-imaginal development time, pre-oviposition period, and decreased female weight, fecundity and oviposition rate of the mites. N, water, amino acid, and sugar content of the apple leaves were positively correlated with weight and egg production and negatively correlated with development time and pre-oviposition period. The reverse correlations were found with total phenol content of the leaves and above mite parameters. A reduction of leaf N by 50% was related with a tenfold decline in fecundity on apple leaves. The stress mainly affected the oviposition rate and to a lesser extent the oviposition period. On apple leaves the net reproductive rate (av. no. ♀ offspring per ♀, R₀), mean length of a generation (T), and innate capacity for increase (r_m) were R₀ = 40.3, T = 17.1, and r_m = 0.22 for the standard N concentration, and 4.7, 25.0, and 0.06 for strong N-deficiency, respectively.

Introduction

The two-spotted spider mite (*Tetranychus urticae*) has been known as a polyphagous pest for a long time. Numerous investigations were made concerning the influence of the macronutrients N, P and K on the dynamics of pests. Watson (1964) and van de Vrie *et al.* (1972) summarized the often contradictory results.

Our study tries to evaluate the effect of nutritional conditions of the host plant on the development of the economically still important two-spotted spider mite. For this purpose, mites were examined on apple trees and bush beans growing in nutrient solutions with varying amounts of N under controlled conditions. As methods of plant analysis have changed since the detection of the N influence on spider mites, improved and more extensive analyses of various metabolites were carried out.

Material and methods

All plants were grown in a modified Hoagland solution (Epstein, 1972) with four different N concentrations (= treatments) and constant P and K concentrations. The solutions were placed in 30-l plastic containers, continuously mixed and aerated by compressed air, and renewed monthly.

Apple trees. The experiments with apple trees were carried out in a growth chamber at 27 °C/19 °C (day/night temperature), a L 16:D 8 regime, and 70% r.h. The cloned apple trees (cv Glockenapfel), all originating from one seed, were propagated and rooted as tissue cultures and transferred at the age of 4 months (5–10 cm high) to the solutions. N concentrations were 5 N (5-fold), 1 N (standard Hoagland solution = 15 mM NO₃⁻), 0.2 N (1/5-fold), and 0.04 N (1/25-fold). The pH was adjusted to 6.0. For each N concentration eight apple trees in two containers were used. After 1 month the

trees were about 50–60 cm high; at this stage four discs of 2 cm diameter from each tree were punched out of young leaves and placed on a moist fibrous tissue kept in plastic trays. Thus there were 32 replications for each treatment. The discs were used to measure the fecundity and pre-imaginal development time of the mites.

For the fecundity, one newly emerged female *T. urticae* which had developed on the same type of leaf, was placed on each disc. The egg production was recorded daily until death of the mites occurred and at the same time eggs were removed. The leaf discs were replaced weekly.

The pre-imaginal development time was calculated in day °C as mean of 20–25 females. In addition, 10–15 females, which had developed on leaf discs, were killed with CO₂ and immediately weighed individually on a microbalance (fresh weight).

Bush beans. The experiments with bush beans (*Phaseolus vulgaris* L. cv Gazelle) were conducted in a growth chamber at 25 °C/21 °C (day/night temperature), a L 16:D 8 regime and 70% r.h. The beans were germinated in the soil. At the cotyledon stage, six plants per treatment were transferred to two plastic containers with nutrient solutions after the roots had been washed. Four N concentrations were used, i.e. 5 N, 1 N (standard), 0.1 N and 0.02 N. The pH of the solutions was adjusted to 6.5.

After a 3-week growing period two discs (diam. 4 cm) per plant were punched out and placed in above mentioned plastic trays. Thus there were 12 replications per treatment. The remaining procedures were the same as those used for apple trees, except that no development time was measured for the mites.

Analyses. Two months after planting in the plastic containers, the apple trees were about 1.5 m high. Leaves from these trees were dried at 110 °C for 1 h and subsequently at 60 °C for 2 days. Nitrogen was analyzed volumetrically by means of an automatic N-analyzer (Merz, 1968). Amino acids were extracted by cold water and analyzed by an automatic amino acids analyzer. These data represent the sum of the four main amino acids in the apple leaves, aspartic acid, glutamic acid, alanine and serine. Sugars were determined enzymatically in a cold water extract. The data express the sum of the main

sugars sorbitol, glucose, sucrose and fructose. Total phenols were analyzed in a methanol extract by a colorimetric method (Allen *et al.*, 1974). Potassium was determined from dry-ashed material by means of an atomic absorption spectrophotometer.

Life parameters. To estimate the effect of the increased fecundity on the population in the apple experiment, two assumptions had to be made. First, the sex-ratio of the offspring was assumed to be 0.67 (2/3 ♀♀), according to most references in literature (Gasser, 1951), though in a recent publication (Jackson & Hunter, 1983) the sex-ratio at N deficiency was reported to be altered in favour of the males. Secondly, for the rate of females reaching the adult stage the value of 0.8 was taken for all treatments, according to Herbert (1981). For the calculation of the mean length of a generation (T) and the innate capacity for increase (r_m) the approximate formulae were used (Krebs, 1972).

Statistical analysis. Data were tested for significance by means of the multiple range test ($p < 0.05$). Correlation factors for linear regressions were determined for mite and plant parameters with the probability of error p .

Results

The development of the oviposition rate on apple leaves is shown in Fig. 1. Each replacement of the leaf discs (4th, 12th, 19th day) caused a decrease of oviposition rate on the following day, probably due to accommodation to the new environment and production of new webbing. Maximum rate was mostly reached at the fourth day after emergence.

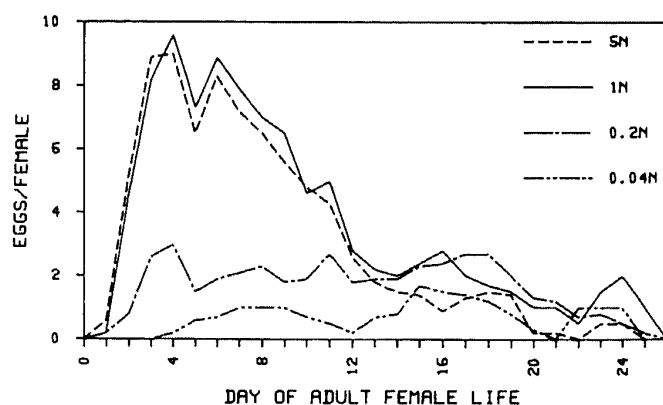


Fig. 1. Daily oviposition rate of *T. urticae* on apple leaf discs.

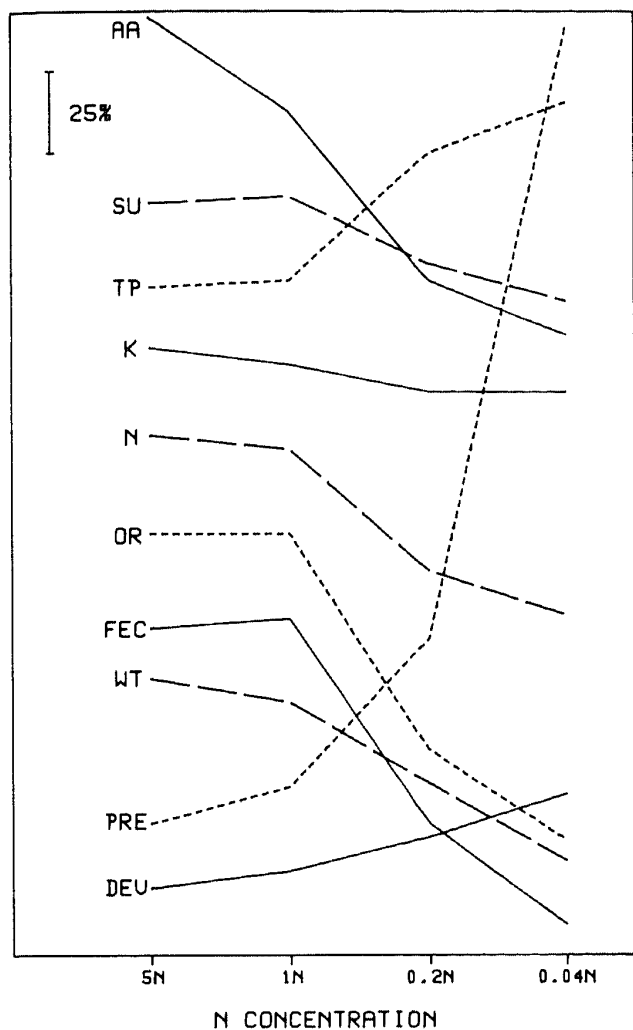


Fig. 2. Main parameters of apple plant and *T. urticae* depending on N treatments (AA = amino acids, SU = sugars, TP = total phenolic compounds, K = potassium, N = nitrogen, OR = oviposition rate, FEC = fecundity, WT = female fresh weight, PRE = pre-oviposition period, DEV = pre-imaginal development time (standard 1 N = 100%).

The results of the apple experiment showed significant differences between the standard treatment and the deficiency treatments for all mite and plant parameters except K (Fig. 2). The results of the 5 N treatment did not differ from the 1 N treatment (control) with the exception of the development time and the amino acid content.

The pre-imaginal development time was measured as day °C above 10 °C (= threshold for development; Herbert, 1981). It was correlated ($p < 0.05$) with the N content of the leaves. Reduction of N content to one half was associated with a development time prolonged by 2.6 days (= 30%) and a pre-oviposition period prolonged by 4 days (= 220%).

Mites subjected to deficiency stress had a reduced

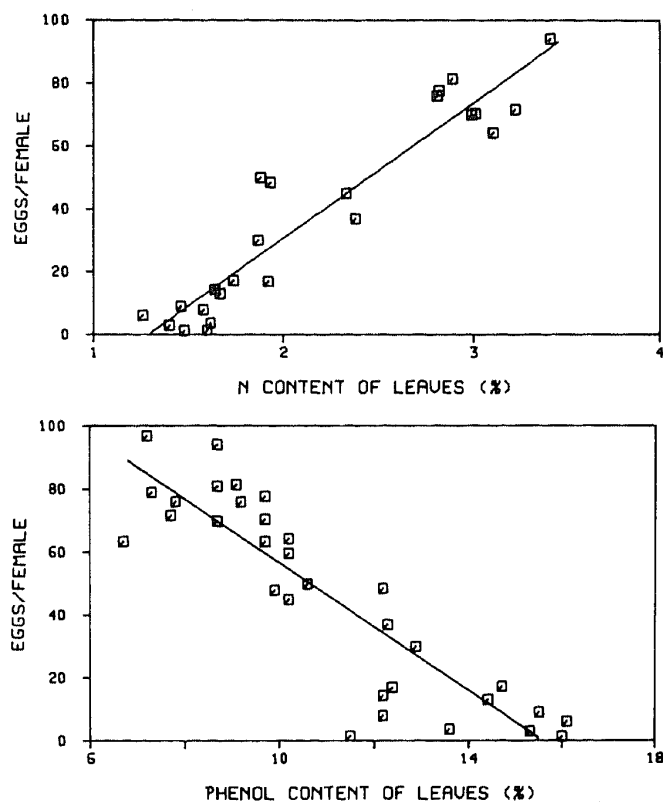


Fig. 3. Correlation ($p < 0.001$) between daily oviposition rate of *T. urticae* and (above) total N content, and (below) total content of phenolic compounds of apple leaves. Each value is mean of four mites feeding on discs from the same tree.

weight (0.04 N: 8.5 μ g) as compared with the control (17.0 μ g). Weight fell proportionally to the N content of the leaves ($p < 0.05$). It was the actual dry mass of the mites which decreased since relative water content of the females remained constant (ca. 73%).

Total fecundity (Fig. 3) as well as oviposition rate showed a strong relationship to N content ($p < 0.001$). They increased ten times as N content of the leaves was doubled. The duration of the oviposition period (ca. 13 days) and longevity (ca. 15 days) was independent of the leaf N.

The N content of the leaves decreased according to supply. After 2 months, the leaves grown at the lowest N level contained half as much N (1.5% of dry weight) as the leaves produced at the standard N level. Water (ca. 68%) and K content (ca. 1.7%) did not decrease significantly with N deficiency, but showed positive correlation with leaf N and such mite parameters as fecundity and pre-oviposition period.

Total sugar content was 31% lower at the 0.04 N than at the 1 N treatment (10.8%), sorbitol amounting to 2/3 of the total sugars. Total phenols in-

creased from 8.4 (5 N) to 13.9 (0.04 N) with N-deficiency. Fecundity was positively correlated ($p < 0.001$) with total sugars (but negatively with sucrose!), and phenols (Fig. 3). A 40% increase in phenolic compounds was associated with a tenfold decline of egg production.

Total N, water, amino acid, and sugar contents were negatively correlated with development time and pre-oviposition period and positively correlated with fecundity, oviposition rate and female fresh weight. Total phenols showed the reverse correlations with these mite parameters.

N content of the bean leaves at the low N concentration was ca. 1/3 of the leaf N at the standard solution (4.5% N). Accordingly, the weight of the females (28.9–19.6 μg), total fecundity (116.0–36.2 eggs/♀), and oviposition rate (8.8–3.3 eggs/♀/day) decreased too, correlating positively with the N content of the leaves ($p < 0.01$), omitting the highest concentration 5 N. This excess N supply caused a decline of mite and bean parameters (dry weight of bean plants).

The development of oviposition rate is similar to the one for apple (Fig. 1). The highest rate was reached on the third day in each case. It was reduced by about 10% for 0.1 N and 5 N treatments and about 60% for 0.02 N as compared with 1 N. Oviposition period and longevity decreased only slightly under N stress (deficiency and excess). The threshold of 50% mortality was reached with the 1 N concentration about 8 days later than at low concentrations, but the difference is not significant.

Discussion

The results of apple and bean experiments indicate that weight, oviposition rate and fecundity of the mites are higher on beans than on apple (cf. Storms, 1969). The female weight at the lowest N concentration on beans is still higher than that of females on apple leaves with the highest N supply. At approximately the same N content of the leaves of bean and apple the weight of the mites on bean is much higher (300%). The mite parameters obtained from the two deficiency treatments in the bean experiment are different in spite of their equal leaf N content. All these facts indicate that there are other factors besides total N content of the leaves influencing fecundity (e.g. toughness of the leaves,

water content, differences in N compounds and other substances). Unfortunately, the sugar, amino acid, and phenol contents cannot be compared on account of lacking bean data. Fritzsche (1960) demonstrated that the fecundity of spider mites feeding on different plant species and even on different varieties of the same species was different, correlating with reducing sugars.

Both experiments have an upper threshold of N content beyond which the life parameters of *T. urticae* have the tendency to decrease. This N threshold is higher for beans than for apples. Overfertilization with N also affects the plants by reducing the biomass.

The correlation of fecundity with water and phenol content indicates that also non-nutrient compounds might affect biological parameters of the mite. Already a few percent difference in leaf water would have a strong effect. As N supply increases, leaf water content also increases (correlating with N content) and this may facilitate feeding of the mites (Rodriguez, 1958), due to thinner cell walls or larger cells or higher turgor.

The pre-imaginal development time of 135 day °C at 1 N (apple) corresponds well to that of 140 found by Herbert (1981). Low N concentration mainly affects the size of oviposition rate maxima. The two deficiency treatments of the apple experiment didn't produce any peak and remained more or less constant after a weak rise at the beginning of oviposition time.

The increase of oviposition rate by a factor of ten at double N content in the leaves is considerably greater than that found by Storms (1969). This may have been caused by greater longevity he observed with the best N supply. Since oviposition rate declines towards the end, the average daily rate was reduced.

Considering the breakdown of oviposition rate after each change of the leaf discs (Fig. 1), it seems not advisable to replace the leaves too frequently. Spencer & Titus (1973) reported that, depending on the season, the loss in 1 week of protein and chlorophyll from leaf discs of apple, and partly from bean, was not greater than the loss from attached leaves. The oviposition period either didn't decrease or decreased slightly at low N. A negative influence due to N deficiency has already been reported (Morris, 1961).

Probably most of the compounds influenced by

N supply, as amino acids, sugars, phenolic compounds and water content, which are all correlated with egg production, have a causal effect on spider mites.

For the apple experiment the net reproductive rate (R_0) (average number of female offspring of 1 female) for the standard was 40.3 and for the lowest N concentration 4.7. It reflects the tenfold increase of the egg production (in this range of N content). T (mean period between hatching of parents and the birth of 50% of the offspring) was 17.1 days and r_m (innate capacity for increase) was 0.22 for 1 N (control), 25.0 days and 0.06 for the 0.04 N treatment respectively. Thus at low N, T was more than a week (almost 50%) longer than at 1 N.

In commercial crops smaller N variations occur than were found in this study. Nevertheless, these data indicate that even small differences in leaf N, along with sugars, phenols and others, would have important effects on the population dynamics of *T. urticae*.

Zusammenfassung

Auswirkungen von Stickstoffmangel der Wirtspflanze auf die Gemeine Spinnmilbe Tetranychus urticae

Die polyphage Gemeine Spinnmilbe ist ein wirtschaftlich bedeutender Schädling. Die Rolle einzelner Nährstoffe bei der Milbenvermehrung wurde schon von einigen Autoren mit unterschiedlichen Ergebnissen untersucht. Der Stickstoff scheint aber einer der Hauptfaktoren zu sein.

Ueber Gewebekulturen klonierte Apfelbäume sowie aus Samen gezogene Buschbohnen wurden in Nährlösungen mit verschiedenen N-Angeboten kultiviert. Aus solchen Pflanzen wurden Blattscheiben ausgestanzt und mit Weibchen von *T. urticae* besetzt. Gemessen wurden die tägliche Eiablage bis zum natürlichen Tod, die Entwicklungsdauer und das Weibchengewicht. Mit dem bei N-Mangel abnehmenden N, Aminosäuren- und Zuckergehalt (v.a. Sorbit) im Blatt korrelierend nahmen auch Gewicht, Ablagerate und Fekundität ab, bzw. die Entwicklungsdauer und Praeovipositionsperiode zu. Die umgekehrte Wirkung auf diese Milbenparameter hatte der Gesamtphenolgehalt. Eine Reduktion des N-Gehalts der Blätter auf die Hälfte

(1.5% N) bewirkte auf Apfelblättern eine Abnahme von Fekundität und Ovipositionsrate um das zehnfache, bzw. eine Zunahme der Präovipositionsperiode um mehr als das dreifache. Der Stress beeinflusste v.a. die Maxima der Ablageverläufe und weniger die Lebensdauer. Der Wassergehalt war ebenfalls mit der Fekundität positiv korreliert.

Auf Bohnenblättern legten die Tiere mehr Eier und erreichten ein höheres Gewicht als auf Apfel, dies bei gleichem N-Gehalt beider Pflanzen. Es wirken somit noch andere Faktoren auf die Reproduktion der Spinnmilben.

Die Populationsparameter wurden ebenfalls sehr stark beeinflusst. Auf Apfelblättern ergab sich bei der Kontrolle eine Nettoreproduktionsrate R_0 von 40.3 und bei starker N-Defizienz 4.7. Die mittlere Generationsdauer T sowie die spezifische natürliche Wachstumsrate r_m betragen für die Kontrolle 17.1 Tage, bzw. 0.22 und für starken N-Mangel 25.0 Tage, bzw. 0.06.

Die Ergebnisse zeigen, dass sich bereits kleinere Unterschiede im Stickstoffgehalt und damit zusammenhängend im Zucker- und Phenolgehalt stark auf die Populationsdynamik der Gemeinen Spinnmilbe auswirken können.

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Accepted: December 5, 1984.