Logrank Test and Interval Overlap Test for *Bactericera cockerelli* (Hemiptera: Triozidae) Under Different Fertilization Treatments for 7705 Tomato Hybrid

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**ABSTRACT.** It is known that some nutrients can have both negative and positive effects on some populations of insects. To test this, the Logrank test and the Interval Overlap Test were evaluated for two crop cycles (February–May and May–August) of the 7705 tomato hybrid, and the effect on the psyllid, *Bactericera cockerelli* (Sulc.) (Hemiptera: Triozidae), was examined under greenhouse conditions. Tomato plants were in polyethylene bags and irrigated with the following solutions: T1—Steiner solution, T2—Steiner solution with nitrogen reduced to 25%, T3—Steiner solution with potassium reduced to 25%, and T4—Steiner solution with calcium reduced to 25%. In the Logrank test, a significant difference was found when comparing the survival parameters of *B. cockerelli* generated from the treatment cohorts: T1–T2; T1–T3; T1–T4; T2–T3; and T3–T4, while no significant differences were found in the T2–T4 comparison in the February–May cycle. In the May–August cycle, significant differences were found when comparing the survival parameters generated from the treatment cohorts: T1–T2; T1–T3; and T1–T4, while no significant differences were found in the T2–T3; T2–T4; and T3–T4 comparisons of survival parameters of *B. cockerelli* fed with the 7705 tomato hybrid. Also, the Interval Overlap Test was done on the treatment cohorts (T1, T2, T3, and T4) in the February–May and May–August cycles. T1 and T2 compare similarly in both cycles when feeding on the treatments up to 36 d. Similarly, in T1 and T3, the behavior of the insect is similar when feeding on the treatments up to 40 and 73 d, respectively. Comparisons T2–T3 and T2–T4 are similar when feeding on both treatments up to 42, 38, and 37, 63 d, respectively. Finally, the T3–T4 comparison was similar when feeding in both treatments up to 20 and 46 d, respectively.

**RESUMEN.** Se sabe que algunos nutrientes pueden tener efectos tanto negativos como positivos en algunas poblaciones de insectos. Para probar esto se evaluó la prueba de rango logarítmico y la prueba de Overlap intervalo de dos ciclos de cultivo (febrero–mayo y mayo–agosto) del híbrido de tomate 7705 y el efecto sobre el psíldo, *Bactericera cockerelli* (Sulc.) (Hemiptera: Triozidae) fue examinado bajo condiciones de invernadero. Las plantas de tomate estaban en bolsas de polietileno y regadas con las siguientes soluciones: T1: Solución de Steiner, T2: solución de Steiner con Nitrógeno a 25%, T3: solución de Steiner con Potasio a 25% y T4: solución de Steiner con Calcio a 25%. En la prueba de Logrank se encontró diferencia significativa al comparar los parámetros de supervivencia que se generaron en las cohortes de los tratamientos, T1 – T2; T1 – T3; T1 – T4; T2 – T3 y T3 – T4. En la comparación de T2 – T4, no se encontraron diferencias significativas, entre los parámetros de supervivencia de *B. cockerelli*; para el ciclo Mayo–Agosto, se encontró diferencia significativa al comparar los parámetros de supervivencia que se generaron en las cohortes de los tratamientos, T1 – T2; T1 – T3; T1 – T4; en las comparaciones de T2 – T3; T2 – T4; T3 – T4, no se encontraron diferencias significativas, entre los parámetros de supervivencia de *B. cockerelli* alimentados con el híbrido de tomate 7705. De igual manera se realizó la Prueba de Traslape de Intervalos para las cohortes de los tratamientos (T1, T2, T3 y T4) en los ciclos de Febrero–Mayo y Mayo–Agosto, se puede observar que la comparación de T1 con T2, son similares cuando se alimenta en ambos tratamientos hasta los 36 días, respectivamente. De igual manera, en la comparación (T1 y T3), siendo similar cuando el insecto se alimenta en ambos tratamientos hasta los 40 y 37 días, respectivamente. Las comparaciones (T2 y T3) y (T2 y T4) es similar cuando se alimenta en ambos tratamientos hasta los (42, 38) y (37, 63) días, respectivamente. Finalmente, la comparación para (T3 y T4) fue similar cuando se alimenta en ambos tratamientos hasta los 20 y 46 días, respectivamente.

**Key Words:** natality parameter, mortality parameter, nutrient analysis, *Bactericera cockerelli*

Tomato growing is affected by a great number of factors that limit production quality and quantity. The most important of these factors are disease vector insects such as aphids: *Myzus persicus* (Sulzer), *Macrosiphum euphorbiae* (Thomas), *Aphis gossypii* (Glover); white flies: *Bemisia tabaci* (Gennadius), *Bemisia argentifolii* (Bellows and Perring), Trialeurodes vaporariorum (Westwood); thrips: *Frankliniella fusca* (Hinds) *Frankliniella occidentalis* (Pergande); and one of the most important because of the direct and indirect damages that it causes, *Bactericera cockerelli* (Sulc.) (Hemiptera: Triozidae) (Alarcón 1993, Badí et al. 2000). Bujanos et al. (2005) mention that the activity of this insect causes losses in solanaceous crops in Mexican production. *B. cockerelli* reported causing damage because of its toxic effect on host plants and responsible for the transmission of phytoplasmas in solanaceous crops in several regions of Mexico. *B. cockerelli* is considered one of the most serious insect pests of Mexico and parts of USA as it affects potato cultivars, pepper, and tomato (Garzón-Tiznado 2002, Liu and Trumble 2007, Munyaneza et al. 2007). This insect causes direct and indirect damages to plants, besides acting as disease vectors (Carter 1939, Cranshaw 2007); this is the main reason why it is considered economically important vegetable cultivars (Richards 1928,
Leyva-López et al. 2002, Hansen et al. 2008, Liefling et al. 2008, Crosslin and Munyaneza 2009). B. cockerelli has recently been identified as a vector of Candidatus Liberibacter solanacearum, the causal agent of the disease called Potato Zebra Chip disease that causes loss of millions of dollars in the potato industry in Central America, USA, New Zealand, and Mexico; currently the most effective strategy to control this disease is the application of insecticides, however to improve disease management, knowledge of population dynamics, biology, ecology, and geographical distribution of the populations of the insect vector (Munyaneza et al. 2007, Gharalari et al. 2009). In this regard, some evidence can be used to provide information about the biological behavior of an insect such as Logrank Test and Interval Overlap Test, the first is used to compare the survival distribution of two populations with the theoretical growth of two or more populations under simulated, the second, to compare the innate capacity for increase to two cohorts, and the theoretical growth of two or more populations under simulated, as has been done for Brevicoryne brassicae (L.) in different cultivars of the Brassicaceae family and A. obtectus (Say) in four genotypes of bean (Phaseolus vulgaris) (Rivera 1990, Ramírez-Serrano et al. 2003). The objective of this study was to determine the effects on the Logrank Test and the Interval Overlap Test of B. cockerelli cohorts in the 7705 tomato hybrid using T1—Steiner solution, T2—Steiner solution with the nitrogen level reduced to 25%, T3—Steiner solution with the potassium level reduced to 25%, and T4—Steiner solution with the calcium reduced to 25%, during two crop cycles.

Materials and Methods

The experiment was conducted under greenhouse conditions at the Colegio de Postgraduados, Campus Montecillo, Texcoco, the State of Mexico, during two crop cycles, February–May and May–August, 2012. The data collection of daily temperature and relative humidity was taken from the weather station located in the Colegio de Postgraduados, Campus Montecillo. The tomato variety used in this study was the hybrid: ‘SUN-7705’, which are grown frequently by tomato farmers in México because of their good agronomic behavior, i.e., very long fruiting periods (indeterminate development) and long post-harvest shelf life (De la Cruz-Lázaro et al. 2009, Martínez et al. 2013).

B. cockerelli Colonies

The tomato variety was seeded in planting trays; 20 plants of the variety were selected for the study. Seedlings were transplanted into polyethylene bags containing 2 kg of 50% Canadian Growing Mix 1VM and 50% Tezontle (porous volcanic rock) when the plants were 31-d-old. Plants were moved to growth chambers [62 by 95 cm (length by width by height)] framed with wooden boards and covered with plain weave mesh to exclude insects, especially Be. tabaci Gennadius (Hemiptera: Aleyrodidae). The materials were maintained under a 14:10 (L:D) h with temperatures ranging from 10 to 25°C.

No insecticides were used while rearing B. cockerelli on the variety of tomato. B. cockerelli fourth and fifth instars were collected from the ‘Río Grande’ tomato variety grown in growth chambers of the Biological Control Greenhouse in the Colegio de Postgraduados and later taken to the experimental greenhouse. These insects were cultured for seven generations on the tomato variety mentioned above. Subsequently, these B. cockerelli were maintained for four generations in new growth chambers on the variety ‘SUN-7705’ and this was done to avoid parasites or depredation of any kind. The plants were irrigated with a modified Steiner nutrient solution to keep breeding that would be used in the experiment.

The durations of the nymphal and adult stages of B. cockerelli were determined on the variety of tomato in the greenhouse. Possible presence/absence of ‘C. L. solanacearum’ and its effects on the Logrank technique and The Interval Overlap Test on the different stages of insect were not measured. In the B. cockerelli colony, 65 adults in their reproductive stage were taken randomly to guarantee a cohort of 100 eggs on 1 d in each growth chamber. Four growth chambers were set up for each treatment, the compositions of the solutions used each treatment are shown in Table 1. Four different solutions were used: T1 is the Steiner solution, T2 is the Steiner solution with the nitrogen level reduced to 25%, T3 is the Steiner solution with the potassium level reduced to 25%, T4 is the Steiner solution with the calcium level reduced to 25%, with 5 plants per growth chamber, and 65 adults were introduced per chamber. After 24 h, the adults were removed out and the number of eggs laid was recorded. This was later adjusted to 100 eggs. Egg hatching and mortality were registered daily, and nymph growth was registered until reaching adulthood. Nalality (b) and mortality (d) were obtained for each of the treatments (T1, T2, T3, and T4) for both crop cycles. On the basis of the data of mortality of each of the development stages of B. cockerelli in each of the treatment and their corresponding age, the life tables were constructed, following the method described by Vera-Graziano et al. (1997). These tables were compared by means of the nonparametric test of Logrank (Méndez et al. 2001, Vera-Graziano et al. 2002). With the equation used $f_{x} n_{o(x)}/N_{x}$, comparing all treatments, where $f_{x}$ is the number of dead individuals x to x + 1, a, b, c, and d, $n_{o(x)}$ is the life table of the population under the conditions, $N_{x}$ is the absolute number of individuals at risk of death. The basis of the test is that taking the death observed-frequency in each population, these discrepancies-frequency (O) with those expected to occur (E) when the null hypothesis is true are valued. These discrepancies are measured with a $x_{c}$ compared with a $x_{o}$, to determine the likelihood of these discrepancies. To compare the innate capacity for increase of each cohort, the Test of Overlapping Intervals was applied (Vera-Graziano and Sotres 1991, Vera-Graziano et al. 2002), which simulates the theoretical increment of two or more populations taking the cohorts and determining if there are significant differences between both populations of the treatments, under the stochastic model $E(n_{t}) = n_{t} \exp(r_{o}t)$, and its respective confidence intervals for any moment (t), where $n_{t}$ is the population size at moment t, $n_{t}$ is the number of specimens with which the study was initiated, and $r_{o}$ is the innate capacity for increase.

Nutrient Analysis

The nutritional tissue concentrations of nitrogen, calcium, and potassium were determined by digestion of the dried wet material with a mixture of nitric and perchloric acids according to Alcántar and Sandoval (1999). One plant per treatment was chosen to be mashed and as sample, 0.05 N was taken to determine total nitrogen in each treatment. The reading of the extracts obtained after digestion was filtered and atomic emission spectroscopy induction plasma (ICP-AES VARIAN® modelo Liberty II; Mulgrave, Australia). The nutrient solution used was based on the Steiner (1961) universal solution. Two 300-mL irrigations were applied daily to each plant. In order to learn the effects of N, K, and Ca, their levels were reduced in the aforementioned solution to 25% for 100 liters of water.

Results

The natality (b) and mortality (d) values were obtained for each of the treatments (T1, T2, T3, and T4) for both crop cycles: February–May and May–August.

Table 1. Nutrient solutions used in the research of B. cockerelli life tables in the greenhouse (Montecillo, the State of Mexico; February–May and May–August, 2012)

| Elements | T1 (Steiner solution) | T2 (N at 25%) | T3 (K at 25%) | T4 (Ca at 25%) |
|----------|-----------------------|--------------|--------------|---------------|
| N        | 167                   | 41.75        | 167          | 167           |
| Ca       | 179                   | 179          | 179          | 44.8          |
| K        | 276                   | 276          | 69           | 276           |
| P        | 31                    | 31           | 31           | 31            |
| Mg       | 46                    | 46           | 46           | 46            |
| S        | 141                   | 141          | 141          | 141           |
| Fe       | 3                     | 3            | 3            | 3             |
| Mn       | 1.14                  | 1.14         | 1.14         | 1.14          |
| Cu       | 0.13                  | 0.13         | 0.13         | 0.13          |
| Zn       | 0.48                  | 0.48         | 0.48         | 0.48          |
According to the results obtained for the natality ($b$) in the February–May cycle, the highest value was that of treatment T2, whereas for the May–August cycle, the treatment with the highest values was T3. Mortality ($d$) for the February–May cycle was highest in T3, whereas in the May–August cycle, it was in T2. This indicates that these treatments were the least favorable for insect survival (Table 2).

When carrying out the Logrank Test for the February–May cycle, significant differences were found in the comparison of the survival parameters generated for the cohorts of treatments: T1–T2; T1–T3; T1–T4; T2–T3; and T3–T4. In the comparison of T2–T4, no significant differences were found in the survival parameters of *B. cockerelli*. With regard to the May–August cycle, significant differences were found when comparing the survival parameters generated in the cohorts of treatments: T1–T2; T1–T3; T1–T4, whereas in the T2–T3, T2–T4, and T3–T4 treatments, no significant differences were found in the survival parameters of *B. cockerelli* fed with the 7705 tomato variety (Table 3).

Once the fertility ratios of *B. cockerelli* were obtained for the different treatments (T1, T2, T3, and T4), natality and mortality values were determined for the same treatments. Then, the Interval Overlap Test (Vera-Graziano et al. 2002) was done taking two cohorts and determining if there are significant differences between both populations where the treatments were applied. When carrying out the Interval Overlap Test for the cohorts of treatments T1 and T2, it was found that until days 36 and 37, for the cycles February–May and May–August, respectively (Fig. 1A and B), the disappearance of limit overlap occurs. These results indicate that the rate of development of *B. cockerelli* is similar when it is fed under both treatments until days 36 and 37, respectively. Later, there is a differentiation, where natality is 0.085 (February–May cycle) and 0.073 (May–August cycle); and mortality is 0.019 (February–May cycle) and 0.014 (May–August cycle), being greater in T2 in both cycles (Table 2).

| Cycles | 7705 hybrid | Natality | Mortality |
|--------|-------------|-----------|-----------|
| February–May | T1 | 0.082 | 0.015 |
| May–August | T1 | 0.069 | 0.009 |
| February–May | T2 | 0.085 | 0.019 |
| May–August | T2 | 0.073 | 0.014 |
| February–May | T3 | 0.070 | 0.023 |
| May–August | T3 | 0.078 | 0.010 |
| February–May | T4 | 0.058 | 0.016 |
| May–August | T4 | 0.061 | 0.012 |

Later, the test was carried out for the cohorts of treatments T1 and T3, finding that until days 40 and 37 (Fig. 2A and B) the disappearance of limit overlap occurs. This shows that the development ratio of *B. cockerelli* is similar when it is fed under both treatments until days 40 and 37, for the cycles February–May and May–August, respectively. Later, there is a differentiation in the February–May cycle, where natality is 0.082 and mortality is 0.015, being greater for T1. For the May–August cycle, there is a differentiation where natality is 0.078 and mortality is 0.010, being greater for T3 (Table 2).

Similarly, the test was done for the cohorts of treatments T1 and T4, finding that until days 36 and 59, for the cycles February–May and May–August, respectively (Fig. 3A and B), the disappearance of limit overlap occurs. These results indicate that the rate of development of *B. cockerelli* to 36 and 59 d when it is fed is equal in both treatments, later, there is a differentiation, where natality is 0.082 (February–May cycle) and 0.069 (May–August cycle), and mortality is 0.015 and 0.009, for the cycles February–May and May–August, respectively, being greater in T1 in both cycles (Table 2).

The cohort test of treatments T2 and T3 showed that until days 42 and 37, for the cycles February–May and May–August, respectively (Fig. 4A and B), the disappearance of limit overlap occurs. These results show that the development ratio of *B. cockerelli* is similar when it is fed under both treatments until days 42 and 37, for the cycles February–May and May–August, respectively. Later, for the February–May cycle there is a differentiation where natality is 0.085 and mortality is 0.019, being greater for T2. For the May–August cycle, there is a differentiation where natality is 0.078 and mortality is 0.010, being greater for T3 (Table 2).

When carrying out the cohort test of treatments T2 and T4, it was found that until days 38 and 63, for the cycles February–May and May–August, respectively (Fig. 5A and B), the disappearance of limit overlap occurs. These results show that the development ratio of *B. cockerelli* is similar when it is fed under both treatments until days 38 and 63, for the cycles February–May and May–August, respectively. Later, there is a differentiation where natality is 0.085 (February–May cycle) and 0.073 (May–August cycle), and mortality is 0.019 and 0.014, for the cycles February–May and May–August, respectively, being greater for T2 in both cycles (Table 2).

Finally, when carrying out the cohort test of treatments T3 and T4 (Fig. 6A and B), it was found in the February–May cycle, it is until day 20 when the disappearance of limit overlap occurs. This indicates that the development ratio of *B. cockerelli* is similar when it is fed under both treatments until day 20, and then there is a differentiation, being greater for T4. For the May–August cycle, it is similar when fed with both treatments until day 46, when there is a differentiation where natality is 0.078 and mortality is 0.010, being greater for T3 in both cycles (Table 2).

| Cycles | Compared treatments | $E$ | $O$ | Calculated $\chi^2$ | $\chi^2$ tables, $\alpha = 0.05$, g. l. = 1 |
|--------|---------------------|-----|-----|---------------------|-------------------------------------|
| February–May | (T1–T2) | 259.05 – 120.95 | 400 | 65.125 | 3.841 |
| May–August | (T1–T2) | 259.55 – 143.45 | 400 | 35.955 | 3.841 |
| February–May | (T1–T3) | 250.92 – 153.08 | 400 | 24.714 | 3.841 |
| May–August | (T1–T3) | 252.41 – 139.59 | 400 | 37.025 | 3.841 |
| February–May | (T1–T4) | 266.38 – 129.62 | 400 | 54.755 | 3.841 |
| May–August | (T1–T4) | 264.49 – 134.51 | 400 | 47.610 | 3.841 |
| February–May | (T2–T3) | 166.33 – 225.67 | 400 | 9.735 | 3.841 |
| May–August | (T2–T3) | 195.57 – 208.43 | 400 | 0.0441 | 3.841 |
| February–May | (T2–T4) | 188.99 – 194.01 | 400 | 0.826 | 3.841 |
| May–August | (T2–T4) | 210.18 – 191.82 | 400 | 0.841 | 3.841 |
| February–May | (T3–T4) | 233.69 – 176.31 | 400 | 8.040 | 3.841 |
| May–August | (T3–T4) | 217.27 – 191.73 | 400 | 1.729 | 3.841 |

$E =$ Theoretical mortality expected from treatment interactions, $O =$ Mortality observed, $\chi^2 =$ calculated, $\chi^2$ tables, $\alpha = 0.05$, g. l. = 1.
Fig. 1. Overlap of the natural increase ratios of *B. cockerelli* between treatments T1 and T2 in the 7705 tomato hybrid [Montecillo, the State of Mexico. (A) February–May, (B) May–August].

Fig. 2. Overlap of the natural increase ratios of *B. cockerelli* between treatments T1 and T3 in the 7705 tomato hybrid [Montecillo, the State of Mexico. (A) February–May, (B) May–August].
Fig. 3. Overlap of the natural increase ratios of *B. cockerelli* between treatments T1 and T4 in the 7705 tomato hybrid [Montecillo, the State of Mexico. (A) February–May, (B) May–August].

Fig. 4. Overlap of the natural increase ratios of *B. cockerelli* between treatments T2 and T3 in the 7705 tomato hybrid [Montecillo, the State of Mexico. (A) February–May, (B) May–August].
Fig. 5. Overlap of the natural increase ratios of *B. cockerelli* between treatments T2 and T4 in the 7705 tomato hybrid [Montecillo, the State of Mexico. (A) February–May, (B) May–August].

Fig. 6. Overlap of the natural increase ratios of *B. cockerelli* between treatments T3 and T4 in the 7705 tomato hybrid [Montecillo, the State of Mexico. (A) February–May, (B) May–August].
Nutrient Analysis and Its Effect on *B. cockerelli*. According to the variance analysis of the nutrient content in dry plant matter for the 7705 tomato hybrid in the February–May cycle, significant and highly significant (P ≤ 0.05) differences were found among treatments. Boron, calcium, potassium, sodium, magnesium, zinc, and phosphorus concentrations were affected, while copper, iron, manganese, sulfur, and nitrogen contents showed no significant differences. In the May–August cycle, analysis of the nutrient concentrations in dry matter of the 7705 tomato hybrid showed highly significant differences in copper content, while the rest of the elements showed no significant differences (Table 4).

Table 5 shows the results of the means comparisons to determine treatment effect on nutrient content. The February–May cycle shows the greater boron concentrations in T2 and T4, than T3. Calcium was elevated in T2, while decreased in T3. The greater potassium concentrations were those of T1 and T4, as compared against T3. T2 elevated magnesium content, while T1 and T4 had lower contents. The greatest sodium content was found in T3 and the lowest in T2. T2 had the highest phosphorus content. Treatments T1 and T2 had a greater amount of zinc, as compared against T3. Copper, iron, manganese, sulfur, and nitrogen contents were statistically equal among treatments. For the May–August cycle, the greatest copper content was in T3. There were no statistical differences in any of the other elements among treatments.

According to the variance analysis to determine treatment effects on the sap nutrient content in the February–May cycle, Table 6 shows that sodium content was significantly affected. In the case of the May–August cycle, during part of the plant development, there were significant and highly significant differences among the dates on which the sap samples were taken among treatments. Calcium, potassium, phosphorus, and zinc concentrations were affected by the treatments, showing highly significant differences.

According to the means comparison for dates when the nutrient analysis of the sap was done in the May–August cycle, it can be seen that the amounts of boron, calcium, and copper were obtained 92 d after planting (dap); iron at 130 dap; the highest content of potassium, magnesium, and manganese at 104 dap; sodium at 92 dap; phosphorus at

### Table 4. Concentrations of values obtained for nutrients in the dry matter of the 7705 tomato hybrid (Montecillo, the State of Mexico; February–May and May–August, 2012)

| Element | February–May cycle | May–August cycle |
|---------|---------------------|------------------|
|         | TRE | CV | TRE | CV |
| B       | 0.0062** | 2.22 | 0.3049NS | 12.30873 |
| Ca      | 0.0415NS | 11.18 | 0.0805NS | 30.65958 |
| Cu      | 0.4600NS | 16.51 | 0.0098** | 13.63411 |
| Fe      | 0.4175NS | 16.15 | 0.8954NS | 14.88211 |
| K       | 0.0122* | 12.56 | 0.0027** | 8.51277 |
| Mg      | 0.0007** | 2.34 | 0.2422NS | 22.79184 |
| Mn      | 0.1105NS | 9.53 | 0.2770NS | 23.16763 |
| Na      | 0.0307* | 9.18 | 0.1357NS | 34.48741 |
| P       | 0.0079** | 12.56 | 0.0929NS | 14.35002 |
| S       | 0.1198NS | 14.45 | 0.7872NS | 31.28317 |
| Zn      | 0.0315* | 5.97 | 0.3989NS | 34.19963 |
| N       | 0.5058NS | 15.49 | 0.1864NS | 11.0397 |

NS = Not significant; *Significant (P ≤ 0.05); **Highly significant (P ≤ 0.01). TREA = Treatment; CV = Coefficient of variation. B = boron; Ca = calcium; Cu = copper; Fe = iron; K = potassium; Mg = magnesium; Mn = manganese; Na = sodium; P = phosphorus; S = sulfur; Zn = zinc; N = nitrogen.

### Table 6. Concentrations of values obtained for nutrients in the sap of the 7705 tomato hybrid (Montecillo, the State of Mexico; February–May and May–August, 2012)

| Element | February–May cycle | Date | May–August cycle |
|---------|---------------------|------|------------------|
|         | TRE | CV | TRE | CV |
| B       | 0.4350NS | 20.4193 | 0.0007** | 0.0841NS | 18.95127 |
| Ca      | 0.4049NS | 43.6031 | <0.0001** | <0.0001** | 23.21201 |
| Cu      | 0.7833NS | 57.0296 | 0.0189* | 0.1896NS | 41.28947 |
| Fe      | 0.6664NS | 28.7296 | <0.0001** | 0.4798 | 66.63491 |
| K       | 0.1807NS | 27.4025 | 0.0031** | <0.0001** | 13.93916 |
| Mg      | 0.8979NS | 30.8476 | 0.0076** | 0.1142 | 25.23648 |
| Mn      | 0.0362NS | 41.6004 | <0.0001** | 0.3147NS | 23.00404 |
| Na      | 0.0284** | 15.7046 | <0.0001** | 0.7864NS | 23.15436 |
| P       | 0.5339NS | 22.6431 | 0.0102* | <0.0001** | 30.65749 |
| S       | 0.2404NS | 16.7274 | <0.0001** | 0.1507NS | 17.65796 |
| Zn      | 0.0795NS | 8.01052 | <0.0001** | 0.0048** | 36.88968 |

NS = Not significant; *Significant (P ≤ 0.05); **Highly significant (P ≤ 0.01); TREA = Treatment; CV = Coefficient of variation. B = boron; Ca = calcium; Cu = copper; Fe = iron; K = potassium; Mg = magnesium; Mn = manganese; Na = sodium; P = phosphorus; S = sulfur; Zn = zinc.

### Table 5. Means comparisons of nutrient concentrations in the dry matter of the 7705 tomato hybrid (Montecillo, the State of Mexico; February–May and May–August, 2012)

| Element | T1 | T2 | T3 | T4 | MSD |
|---------|----|----|----|----|-----|
| B       | 61.973ab | 67.269a | 57.031b | 65.993a | 5.7092 |
| Ca      | 11932ab | 1384a | 10810ab | 8093b | 5081 |
| Cu      | 4.727a | 3.657a | 4.4125a | 4.823a | 2.9598 |
| Fe      | 246.95a | 252.37a | 207.91a | 222.16a | 110.18 |
| K       | 3884.4a | 3039.6ab | 1647.3b | 3977a | 1603.9 |
| Mg      | 4772.5c | 6301.1a | 5418.2b | 4757.4c | 506.59 |
| Mn      | 36.359a | 45.733a | 39.048a | 48.483a | 16.459 |
| Na      | 1278.6ab | 997.6b | 1613.1a | 1361.3ab | 490.76 |
| P       | 2591.2b | 4186.8a | 1876.9b | 2111.8b | 1376.1 |
| S       | 26.42a | 26.896a | 20.273b | 23.881ab | 5.9175 |
| Zn      | 2351.6a | 1888.4a | 20665a | 23516a | 13645 |

a, b, and c = Same letter in a row indicates statistically equal (α = 0.05). TRE = Treatment; MSD = Minimum significant difference; ppm = parts per million; B = boron; Ca = calcium; Cu = copper; Fe = iron; K = potassium; Mg = magnesium; Mn = manganese; Na = sodium; P = phosphorus; S = sulfur; Zn = zinc; N = nitrogen.
Table 7 shows the means comparison of sap nutrient content in the sap for the February–May cycle. The highest levels of sodium were those of T1 and T4, as compared against T3. The rest of the sap elements showed no statistical differences in content. This indicates that the nutrient content in the sap is stable as far as their concentrations are concerned. For the May–August cycle, the highest concentration of potassium was that of T4, statistically higher than all other treatments, with the lowest concentrations of potassium in T3. The highest calcium concentrations were in T1, T2, and T3, respectively, with the lowest in T4. The highest concentrations of phosphorus were in T2 and T4, and the highest concentrations of zinc were in T2 and T1, respectively. The lowest concentrations of phosphorus were in T1 and T3, and zinc in T3 and T4.

According to the correlation analysis done on the two crop cycles, a positive correlation was found, between the nutrient content of the dry matter and the life parameters of B. cockerelli, between iron content and mortality of the psyllid (Fig. 7) although it is low in the May–August crop cycle. However, no correlations were found regarding the other parameters: mean life expectancy ($e_x$), reproduction ratio ($R_0$), intrinsic natural increase ratio ($r_m$), finite increase ratio ($l$), and natality ($b$).

**Discussion**

With regard to natality ($b$) and mortality ($d$) of B. cockerelli in the February–May crop cycle, the greatest natality was that of T2 while the greatest mortality was that of T3. For the May–August crop cycle, the greatest natality was that of T3 and the greatest mortality was that of T4.

**Table 7. Mean comparison of nutrient concentration per date in the sap of the 7705 tomato hybrid (Montecillo, the State of Mexico; May–August, 2012)**

| Element | Date                | MSD   |
|---------|---------------------|-------|
|         | 29 June 2012 (73 dap) |       |
| B       | 1.1188b             |       |
| Ca      | 422.2b              |       |
| Cu      | 0.455b              |       |
| Fe      | 1.448b              |       |
| K       | 716.89b             |       |
| Mg      | 1671.9b             |       |
| Mn      | 8.396bc             |       |
| Na      | 284.16b             |       |
| P       | 337.72b             |       |
| S       | 398.22b             |       |
| Zn      | 2.954c              |       |
|         | 17 July 2012 (92 dap) |       |
| B       | 1.6188a             |       |
| Ca      | 932.2a              |       |
| Cu      | 0.9288a             |       |
| Fe      | 5.793b              |       |
| K       | 851.42b             |       |
| Mg      | 1621.2b             |       |
| Mn      | 7.513c              |       |
| Na      | 650.35a             |       |
| P       | 522.37ab            |       |
| S       | 626.91a             |       |
| Zn      | 7.009ab             |       |
|         | 28 July 2012 (104 dap) |       |
| B       | 1.6913a             |       |
| Ca      | 1078.7a             |       |
| Cu      | 0.9263a             |       |
| Fe      | 1.984b              |       |
| K       | 965.58a             |       |
| Mg      | 2376.6a             |       |
| Mn      | 16.253a             |       |
| Na      | 621.04a             |       |
| P       | 612.53a             |       |
| S       | 693.76a             |       |
| Zn      | 10.168a             |       |
|         | 22 August 2012 (130 dap) |       |
| B       | 1.7538a             |       |
| Ca      | 1082.5a             |       |
| Cu      | 0.9238a             |       |
| Fe      | 12.644a             |       |
| K       | 830.92ab            |       |
| Mg      | 2277.1ab            |       |
| Mn      | 11.798b             |       |
| Na      | 661.4a              |       |
| P       | 550.51ab            |       |
| S       | 763.51a             |       |
| Zn      | 5.45bc              |       |

**Table 8. Mean comparison of nutrient concentrations in the sap of the 7705 tomato hybrid (Montecillo, the State of Mexico; February–May and May–August, 2012)**

| Element | TRE          | MSD   |
|---------|--------------|-------|
|         | February–May cycle (ppm) |       |
| B       | 0.71a        |       |
| Ca      | 597.2a       |       |
| Cu      | 0.485a       |       |
| Fe      | 1.27a        |       |
| K       | 255.5a       |       |
| Mg      | 1689.8a      |       |
| Mn      | 1885.5a      |       |
| Na      | 10.145a      |       |
| P       | 326.86ab     |       |
| S       | 379.72b      |       |
| Zn      | 2.954c       |       |
|         | May–August cycle (ppm) |       |
| B       | 1.3875a      |       |
| Ca      | 741.4b       |       |
| Cu      | 0.6525a      |       |
| Fe      | 6.651a       |       |
| K       | 960.8a       |       |
| Mg      | 441.28b      |       |
| Mn      | 2009.1a      |       |
| Na      | 10.118a      |       |
| P       | 537.68a      |       |
| S       | 641.19a      |       |
| Zn      | 5.45bc       |       |

**Fig. 7.** Correlation analysis between iron levels and mortality ($d$) of B. cockerelli under different fertilization treatments in the 7705 tomato hybrid, Montecillo, the State of Mexico during May–August, 2012.
T2. These results agree with those reported by Vargas-Madríz et al. (2011), who state that natality and mortality of B. cockerelli are variable from one cycle to the next.

When doing the Logrank test for the February–May crop cycle, significant differences were found when comparing the survival parameters generated from the treatment cohorts. In the May–August crop cycle, significant differences were found in comparisons T1–T2, T1–T3, and T1–T4; while in the February–May cycle, no significant differences were found in the T2–T4 comparison. No significant differences were found in the T2–T3, T2–T4, and T3–T4 comparisons in the May–August crop cycle. These results indicate that the probability of mortality at any moment in the comparisons of the treatments is the same for all individual. The results found in this study are similar to those reported by Vargas-Madríz et al. (2011).

The Interval Overlap Tests’ results show that in all treatments, the overlapping of limits is separated because of the frequent natality and mortality during the crop cycles. This indicates that the ratio of development of B. cockerelli populations grown on the 7705 tomato hybrid when applying the solutions used for treatments T1, T2, and T3 differs from the development on T4. This implies that there should be at least one or two generations for the $r_p$, factor between populations to be different. These results are similar to those reported by Rivera (1990) and Vargas-Madríz et al. (2011) in studies on life tables done with Br. brassicae (L.) and B. cockerelli. On the other hand, Conci and Tamanini (1988) state that the life cycle and the number of generations of Bactericera depend on climatic factors; under controlled conditions, there are up to 11 overlapping generations per year. The first generation differs from the rest in coloring, whereas dimorphism is probably regulated by photoperiod.

**Nutrient Analysis and Its Effect on the Development of B. cockerelli.** The nutrient analysis done for the February–May crop cycle shows that all treatments (T1, T2, T3, and T4) affected the content of Ca, K, Mg, Na, P, and Zn; while in the May–August crop cycle, only Cu and K were affected. In the February–May crop cycle, the sap nutrient analysis show that the treatments affected Na content, whereas in the May–August crop cycle, they affected Ca, K, P, and Zn content. The same tomato material was used for both the dry matter and sap analyses, so the difference of the results in both crop cycles could be due to handling of the crop, mainly preparation and application of the nutrient solutions. It is also necessary to have agronomical variables to determine the direct effect on crop development. In this study, a decrease in nitrogen, calcium, and potassium was seen to alter the concentrations of these elements. Wilkinson et al. (2000) mention that applying N increases the absorption of P, K, S, Ca, and Mg so that these elements are present in sufficient amounts during the middle growth phase of crops. Fageria (2009) mentions that by increasing or decreasing the amount of an element, the absorption of other elements is affected positively or negatively. For example, applying N directly increases the absorption of P, K, Ca, and Mg in beans. This is because of antagonisms and synergisms that happen internally and naturally in plants. An adequate supply of K in the plant favors the metabolism of N (Kramer and Kozlowski 1979). With regard to the distribution of the elements within the plant, there was a greater concentration of N, Ca, Mg, and K in the leaves. It has been well established that this organism has a greater accumulation of essential nutrients for the different physiological processes that allow for the good development of the plant; such as the role of nitrogen in the formation of proteins, Mg in the formation of chlorophyll, Ca in the composition of the cell wall, and the opening of stomas in the leaves is because of K content.

Reis et al. (1982) found in wheat plants (Triticum aestivum) that the disease known as pietin (Gaecumannomyces graminis var. Tritic) decreases its severity with the use of iron supplements combined with other minor elements (Mn and Cu) supplied through the roots, but not so when they were supplied through the leaves. Similarly, then mention that the disease was less severe when a solution containing iron was applied to the rooting medium in wheat plants. Huber (1997), on the other hand, states that different forms (oxidized or reduced) of a nutrient can have opposite effects on a specific disease because of different metabolic routes or availabilities. They also mention that this is especially true for certain elements such as N, Mn, and Fe. The results of these authors can be seen in the correlation analysis of the two crop cycles evaluated between the dry matter nutrient content and the life parameters of B. cockerelli. Here, there is a positive, although low (0.5672), correlation between iron content and mortality of the psyllid; this element affecting the survival of the insect.

Significant ($\alpha \leq 0.05$) differences were found in the Logrank test among the natural increase ratio curves generated for B. cockerelli cohorts fed with the 7705 tomato variety. T1 showed significant differences versus T2–T4. Indicating that development ratios of B. cockerelli populations on the host plant using the solutions are not the same among treatments (T1–T4), nor between crop cycles. Further research is needed as the preliminary evidence suggests that fertilization practices can affect the development of this insect in crops. The Interval Overlap Test for the February–May and May–August crop cycles on the 7705 tomato hybrid indicates that the development ratio of B. cockerelli populations in T1–T3 was different from that of T4. A positive correlation was observed only between iron and the mortality of insect in both cycle crops.

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