The use of crop life tables as a tomato yield loss management tool

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ABSTRACT. The objective of this work was the identification and quantification of tomato yield loss components in the field and in greenhouse, evidencing the tomato critical production component and the loss key-factor, using the crop life table methodology. Two experiments (field and greenhouse) consisting of two treatments (variety Santa Clara and hybrid Débora Plus) and five replications were conducted in Viçosa, state of Minas Gerais, Brazil. During the tomato plant cycle, the number of dead plants and the death causes were evaluated and the number of flowers and fruits/plant was recorded. During harvesting, the healthy and damaged fruits were counted, weighed and classified and the causes of loss of the damaged fruits were identified. In the field, plants were considered the critical production component of tomato yield. The TSWV virus was considered the loss key-factor. In the greenhouse, fruits were considered the critical production component. Blossom-end rot was considered the loss key-factor.

Key words: *Lycopersicon esculentum* Mill., integrated pest management, TSWV, blossom-end rot.

RESUMO. Uso de tabelas de vida das culturas como ferramenta de manejo de perdas de produtividade no tomateiro. O objetivo deste trabalho foi a identificação e quantificação dos componentes de perdas de produtividade do tomateiro no campo e ambiente protegido, evidenciando o componente crítico e o fator-chave de perdas de produtividade da cultura, utilizando a metodologia tabela de vida das culturas. Dois experimentos (campo e ambiente protegido), consistindo de dois tratamentos (variedade Santa Clara e híbrido Débora Plus) e cinco repetições, foram conduzidos em Viçosa, Estado de Minas Gerais, Brasil. Durante o ciclo do tomateiro, o número de plantas mortas, causas de morte e o número de flores e frutos/planta foram avaliados. Na colheita, os frutos comerciais e danificados foram contados, pesados e classificados e as causas de perda foram identificadas. No campo, o componente de produção *plantas* foi considerado o componente crítico de perdas. O vírus TSWV foi considerado o fator-chave de perdas. Em ambiente protegido, *frutos* foi considerado o componente crítico de perdas. Podridão apical foi considerada o fator-chave de perdas.

Palavras-chave: *Lycopersicon esculentum* Mill., manejo integrado de pragas, TSWV, podridão apical.

Introduction

Tomato production is considered a high-risk activity in Brazil, mainly due to the great variety of culture systems, great susceptibility to pests and diseases, and great demand for inputs and services, requiring high investment of financial resources per hectare. The high risk in the rainy period is due to high temperature and high humidity that promote favorable atmosphere for pests, diseases, and physiological disorders. The greenhouse (used as *umbrella effect*) modifies the humidity conditions, soil thermal amplitude, evaporation, and foliar wetting period, allowing for an increase in yield and fruit quality.

Pests constitute one of the principal problems faced by vegetable producers. Production losses usually range from 10 to 30% of the gross income. However, in certain situations the attack of pests can compromise the whole yield (Picanço *et al.*, 1998; Bento, 1999). Furthermore, over 200 diseases have been reported to affect the tomato plant (Watterson, 1986). Early and late blight, caused by *Alternaria solani* and *Phytophthora infestans*, respectively, are the most destructive diseases in Brazil (Lopes and Santos, 1994). In the rainy season, the largest demand of defensive sprays and cultural treatments burdens the production cost and reduces the number of producers; the yield is smaller and the fruit quality is frequently precarious. Fortunately, because of significant research advances in chemical (selective pesticides), biological (mass release of natural enemies), cultural (IPM) and genetic control (resistant cultivars), the damage resulting from tomato diseases and pests has been substantially reduced and in some cases eliminated. For many physiological disorders, like blossom-end rot, little in-depth research has been done and the causes are poorly understood both in terms of why cultivars differ in susceptibility and why certain environments or cultural practices predispose plants to the disorder.

Thus, it is important to recognize the loss factors, such as diseases and pests in the first place. Understanding the major sources of a disease or pest attack and the conditions which favour its progression allow us to make more intelligent decisions about the use of effective control procedures.

The employment of the life table in the study of production losses of cultures was initially accomplished by Harcourt (1970) who studied the mortality of cabbage plants. Picanço (1992) developed a model to estimate quantitative loss per unit of area for each production component, making it possible to determine the critical loss component and the loss key-factor. Varley and Gradwell (1960) consider as key-factor the one whose variation of specific losses presents larger correlation with the fluctuation of total losses. Thus, crop life tables can identify the critical loss component (key-stage) (Harcourt, 1970) and the critical loss factor of the crop (key-factor) (Morris, 1963). The critical loss component, or the key-stage, is a crop life stage that contributes most to the total crop losses and the critical loss factor, or key-factor, is a factor that contributes most to the total crop losses in the critical loss component.

The objective of this research was to identify and to quantify the tomato yield loss components, between summer and autumn, in two different conditions of cultivation, field and greenhouse, evidencing the tomato critical loss component and the key-factor, using the crop life table.

Material and methods

This work was conducted in the Crop Research Facility (Horta de Pesquisa) of the Federal University of Viçosa (Universidade Federal de Viçosa), Viçosa (state of Minas Gerais, Brazil), from January to May, 2001. Two experiments were arranged in random blocks, one in the field and another in a greenhouse covered plastic (0.1 mm of thickness), with dimensions of 10 x 40 m and height of 5 m, with lateral retractile curtains. Both experiments consisted of two treatments (cultivars Santa Clara I 5300 and Débora Plus) and five replications. The area of the experimental plot was 4.8 m^2.

The seedlings were produced in polyethilene trays, measuring 68 x 34 cm, with 128 cells and the transplantation was done after 29 days of sowing when the seedlings presented, on average, four definitive leaves. The seedlings were transplanted in the spacing of 1.0 x 0.6 m, being trellised in the vertical system with narrow ribbon. The plants were pruned to one stem, three leaves above the sixth truss (Oliveira, 1993).

The soil of the two experiments was plowed, disked and furrowed, and 10 t ha^{-1} of chicken manure, 10 kg ha^{-1} of boric acid, 200 g ha^{-1} of sodium molibdate, 200 kg ha^{-1} of magnesium sulfate were applied in the planting furrow. 240 kg ha^{-1} of N, 700 kg ha^{-1} of P_2O_5 and 800 kg ha^{-1} of K_2O as ammonium sulfate, simple super phosphate and potassium chloride, respectively, were used in the field experiment. 240 kg ha^{-1} of N, 400 kg ha^{-1} of P_2O_5 and 500 kg ha^{-1} of K_2O as ammonium sulfate, simple super phosphate and potassium chloride, respectively, were used in the greenhouse experiment. In both experiments, the NPK fertilizers were divided in eight applications, by fertirrigation, every two weeks.

In the greenhouse experiment lateral retractile curtains were handled along the greenhouse. The lateral curtains were lowered at the end of the afternoon and raised at the beginning of the morning, from April until the end of the cultivation period.

Integrated pest management was used to control pests. Insecticides were used when the pests reached the control level. The pests were separated in three groups according to their loss characteristics in the culture. Control levels were established for each one of the three groups (viruses vectors = 1 vector/top of the stem; leaf miners = 20% of mined leaves; fruit borers = 5% of borered fruits) (Sinigaglia *et al.*, 2000). The inseticides applied against *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae), *Neoleucinodes elegantalis* (Guennée) (Lepidoptera: Crambidae), *Bemisia tabacci* (Guennée) (Homoptera: Aleyrodidae), *Frankliniella schultzei* (Trybom) (Thysonoptera: Thripidae) were abamectin, permethrin, buprofezin e imidaclorprid, respectively. Plants were sprayed with chlorothalonil and tebuconazole in alternate weeks for the prevention and control of diseases, such as *Phytophthora infestans* (Mont.) de Bary and *Alternaria solani* (Sorauer). Pesticidal sprays were applied using manual knapsack sprayers (Costal Manual PJH Jacto) equipped with hollow cone hydraulic nozzles (JD 14-2) at high volume (300-500 L ha^{-1}) and 3 bar pressure.

At each stage of plant development the number of plants that died was assessed on a weekly basis from the beginning of the vegetative period until the end of the reproductive period, as described by Harcourt (1970). At harvest, the fruits were collected, then counted, weighed, and graded as extra AA (best quality), extra A, extra, and special, following an adaptation of the methods by the Brazilian Department of Agriculture (Portaria nº 553 MA, Diário Oficial da União, 19/9/95 - Brazil), which considers the diameter of the fruit: extra AA (≥ 69.6 mm), extra A (≥ 60.0 e < 69.6 mm), extra (≥ 54.8 e < 60.0 mm), special (≥ 50.0 e < 54.8 mm), small (≥ 40.0 e < 50.0 mm) and non-commercial (< 40.0 mm). Fruits with diameter greater than 40 mm were classified as commercial. Fruit losses, due to various factors, were also determined. At the end of the cultivation period, ten plants were randomly collected from each experimental unit for evaluation of the number of flowers and number of fruits per plant, following the methods by Chandler (1984).

Tomato life tables were constructed for each treatment (Picanço, 1992) using the following components: x (production component of tomato plants per developmental stage); Lx (estimated production at the start of each x, in t fruits/ha); dxF (causative factor of production losses); dx (estimated production losses in t fruits ha^{-1}); 100 qx (non-cumulative losses in percentage); and 100 rx (cumulative losses in percentage). Lx was estimated using the following formulas: Lx plant = Pl x (FI/Pl) x FrW; Lx flowers = Pla x (FI/PI) x FrW; Lx total fruits = Pla x (Fr/PI) x FrW; Lx marketable fruits = Pla x (Frm/PI) x FrWm; where PI = number of plants per hectare at the start of age x; Fl/Pl = mean number of flowers per plant; FrW = mean fruit weight (kg); PIa = number of plants alive; Fr/Pl = mean number of fruits per plant; Frm/Pl = mean number of marketable fruits per plant; and FrWm = mean weight of marketable fruits (kg).

The estimated yield loss (dx) was calculated after the harvest on the basis of the yield of the healthy plants. The crop life table model (Varley and Gradwell, 1960), modified by Picanço (1992), was used to determine the critical loss component of the crop. Life table data for each treatment were used to construct a table with the following components: x, Lx, log (Lx), k (partial losses obtained by subtracting from each current log (Lx) value, its preceding value), and K (total losses obtained by the summation of the k values). Total and partial losses were plotted on the y-axis and the treatments on the x-axis. Pearson's correlation coefficients (r) between total (K) and partial (k) losses were calculated, and factors whose partial fluctuation of production losses were significantly correlated ($p < 0.01$) with the fluctuation of total losses were considered key components of production losses. Regression analyses were carried out between partial and total losses for the factors whose losses showed significant correlation with the total losses. The factors whose regression curves had the highest slope ($p < 0.05$) were considered critical production components (Podoler and Rogers, 1975).

Analyses of variance (ANOVA) were carried out for each experiment and afterwards for both together. Tukey´s Test was used to compare means ($p < 0.05$) (Ribeiro Júnior, 2001).

Results and discussion

The interaction effect between condition of cultivation (field or greenhouse) and cultivars (Santa Clara or Débora Plus) was not significant. No significant difference was found between the commercial productivities of the treatments (Table 1) ($p < 0.05$) nor among the commercial productivities in both experiments. In the meantime, the commercial productivity in the greenhouse was 10 t ha^{-1} bigger than the commercial productivity of the field. The productivity of extra A fruits in the greenhouse was three times bigger than the productivity of the field experiment (Table 1). Although the averages of commercial productivity are similar, there was significant difference among the fruit losses in the field and in the greenhouse (Table 1).

Table 1. Commercial, classified (extra A, extra, special + small), total fruit yield (t ha^{-1}) and fruit losses of two tomato cultivars cultivated in two different conditions (field and greenhouse).

Condition of cultivation	Commercial yield	Classified yield			Total yield	Losses
		Extra A	Extra	Special + Small		
Field	37.22 A*	9.70 B	6.87 A	20.62 A	76.80 B	39.58 B
Greenhouse	47.58 A	28.35 A	9.18 A	10.05 B	139.51 A	91.93 A
Treatment	**Commercial yield**	**Classified yield**			**Total yield**	**Losses**
		Extra A	**Extra**	**Special + Small**		
Sta. Clara	39.79 A*	18.82 A	7.49 A	13.45 B	97.85 A	58.05 A
Débora Plus	45.01 A	19.24 A	8.56 A	17.21 A	118.46 A	73.45 A

*Means followed by the same letter do not differ by Tukey's multiple range test ($p < 0.05$).

The fruit mean yield averaged over the two treatments in the field was 35.88 t ha^{-1} and the production component with heaviest losses was the fruit (Table 2).

Table 2. Crop life table of tomato plants cultivated in the field. The data represent the averages of the different treatments.

Component of production (x)	Estimated production at the start of each x (t ha^{-1}) (Lx)	Causative factor of Production losses (dxF)	Production losses (t ha^{-1}) (dx)	Non-cumulative Losses (%) (100qx)	Cumulative Losses (%) (100rx)
plants (veget. stage)	75.47	-	-	0,00	0,00
plants (reprod. stage)	75.47	TSWV	11.28	14.94	14.94
Flowers	64.19	Aborted	2.75	4.28	3.64
Fruits	61.44	Blossom-end rot	14.44	23.51	19.14
		Neoleucinodes elegantalis	4.2	6.83	5.56
		Erwinia carotovora	0.84	1.36	1.11
		Fruits cracked	1.1	1.79	1.46
		Tuta absoluta	0.12	0.2	0.16
		Alternaria solani	3.26	5.3	4.32
		TSWV	0.09	0.15	0.12
		Birds	0.93	1.51	1.23
		Phytophthora infestans	0.1	0.17	0.14
		Non-marketable size	0.48	0.77	0.63
			25.56	41.60	52.45
fruits harvested	35.88		39.58		52.45

The total accumulated losses reached 52.45%, so the tomato plants produced only 47.55% of their potential yield. The fluctuation in fruit losses (r = 0.82) ($p < 0.05$) accounted for 41.60% of the total losses. Flower drop (4.28% of the losses) and plant mortality in the reproductive stage (14.94% of the losses) also influenced fruit yield (Figure 1 and Table 2). However, plant mortality contributed at most to the fluctuation of total production losses, being considered the critical production component (Figure 2). The *Tomato Spotted Wilt Virus* (TSWV) was considered the key-factor of loss. Besides TSWV, fruit blossom-end rot (23.51% of the losses) and *Neoleucinodes elegantalis* (Guenée) (Lepidoptera: Pyralidae) (6.83% of the losses) also greatly contributed to a reduction of yields.

The fruit mean yield averaged over the two treatments in the greenhouse was 47.58 t ha^{-1} and the production component with heaviest losses was the fruit component (Table 3). The total accumulated losses reached 65.89%, so the tomato plants produced only 34.11% of their potential yield. The fluctuation in fruit losses (r = 0.89) ($p < 0.05$) accounted for 54.32% of the total losses and Pearson's correlation coefficient (r) calculated between total and partial losses, indicates that fruits can be considered critical production component. However, flower drop (3.20% of the losses) and plant mortality in both vegetative (0.98% of the losses) and reproductive stages (22.10% of the losses) also influenced fruit yield (Figure 3, Table 3).

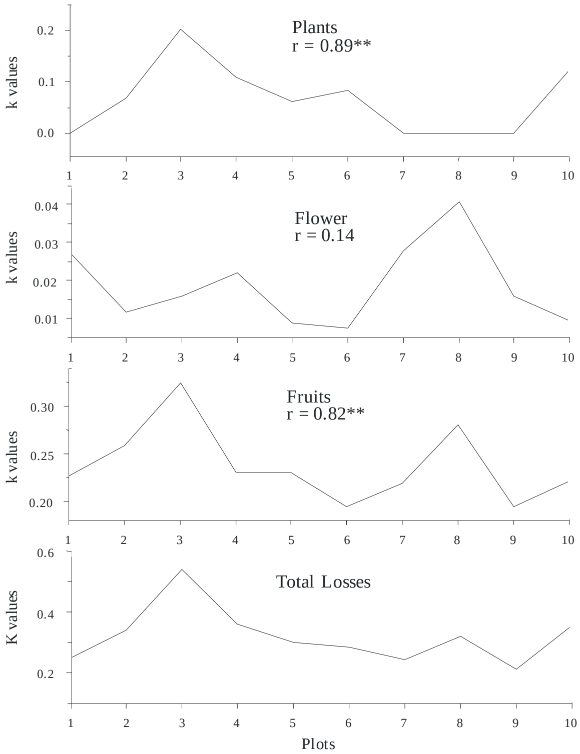

Figure 1. Fluctuations of partial (k) and total (K) losses in the production of tomato plants cultivated in the field. Plots 1 to 5 indicate the hybrid Débora Plus and plots 6 to 10 indicate the variety Sta. Clara. The asterisks indicate that the correlation is significant at $p < 0.01$.

The factors that most influenced the loss in the production component fruits were blossom-end rot (r = 0.97), *N. elegantalis* (r = 0.38) and cracking (r = 0.36), being among these blossom-end rot, the key-factor of loss because of significant correlation with the total losses in the critical production component (r = 0.97) ($p < 0.01$) (Figure 4).

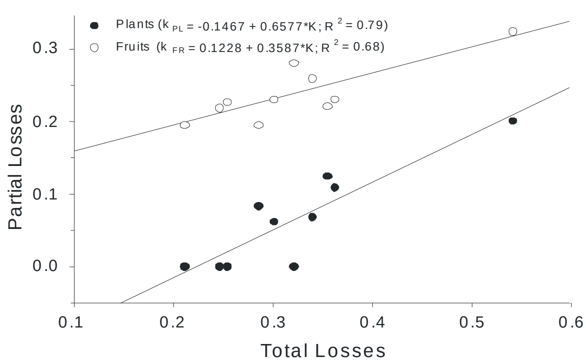

Figure 2. Regression curves between partial (k) and total (K) losses of field tomato plants that showed significant correlation with total losses (R^2, determination coefficient; *$p < 0.05$)

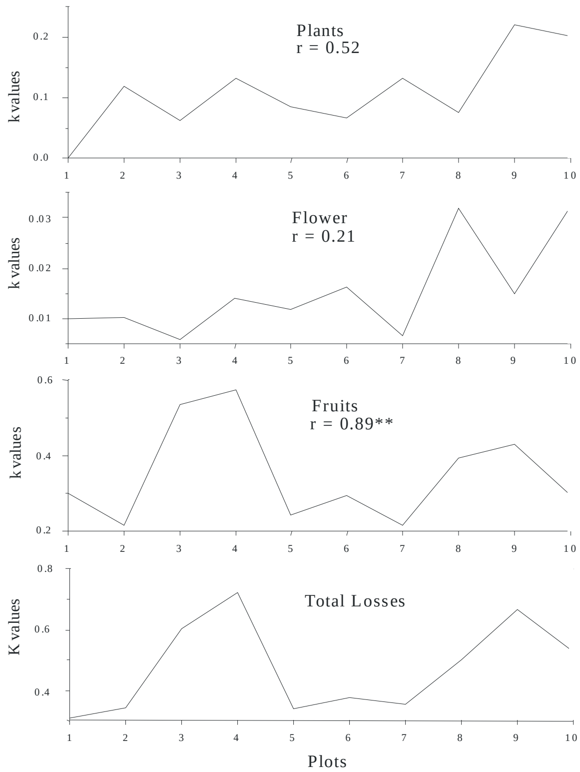

Figure 3. Fluctuations of partial (k) and total (K) losses in the production of tomato plants cultivated in the field. Plots 1 to 5 indicate the hybrid Débora Plus and plots 6 to 10 indicate the variety Sta. Clara. The asterisks indicate that the correlation is significant at $p < 0.01$.

Table 3. Crop life table of tomato plants cultivated in greenhouse. The data represent the averages of the different treatments.

Component of production (x)	Estimated production at the start of each x ($t\ ha^{-1}$) (Lx)	Causative factor of Production losses (dxF)	Production Losses ($t\ ha^{-1}$) (dx)	Non-cumulative Losses (%) (100qx)	Cumulative Losses (%) (100rx)
plants (veget. stage)	139.51	*Rhizoctonia solani*	1.37	0.98	0.98
Plants (reprod. stage)	138.15	TSWV	28.9	20.92	20.72
		Pseudomonas corrugata	1.63	1.18	1.17
			30.54	22.1	22.87
flowers	107.61	Aborted	3.45	3.2	2.47
fruits	104.16	Blossom-end rot	44.49	42.72	31.89
		Neoleucinodes elegantalis	7.77	7.45	5.57
		Erwinia carotovora	1.88	1.81	1.35
		Fruits cracked	1.22	1.17	0.88
		Tuta absoluta	0.32	0.31	0.23
		Alternaria solani	0.06	0.06	0.04
		TSWV	0.47	0.45	0.34
		Birds	0.06	0.06	0.04
		Non-marketable size	0.3	0.29	0.22
			56.58	54.32	65.89
fruits harvested	47.58		91.93		65.89

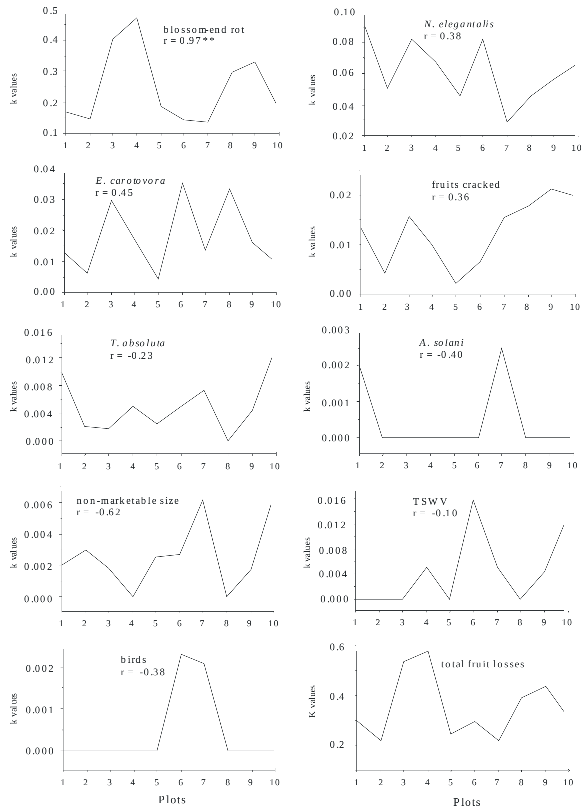

Figure 4. Fluctuations of partial (k) and total (K) fruit losses in greenhouse. Plots 1 to 5 indicate the hybrid Débora Plus and plots 6 to 10 indicate the Sta. Clara variety. The asterisks indicate that the correlation is significant at $p < 0.01$.

The yield analysis evidenced the best greenhouse cultivation conditions for obtaining better quality fruits. The difference between larger and smaller fruits is commercially important, because larger fruits have better market price. Yield differences were also explained due to the superior plant production potentials in the greenhouse (139.51 $t\ ha^{-1}$) in relation to the field (75.47 $t\ ha^{-1}$) (Tables 2 and 3). Barrigossi *et al.* (1988) and Leite *et al.* (1996) observed that bean plants with the highest fruit yield were also the plants with the highest fruit losses, which might have been due to a plant physiological trait or the higher nutritional requirements needed with higher yields.

Plant mortality happened in the reproductive phase, being the TSWV virus attack the only causal factor of such losses. The production components that regulated, significantly, the fluctuation of total losses were plants (reproductive phase) ($r = 0.89$) and fruits ($r = 0.82$) (Figure 1). However, the regression analysis, used as an auxiliary criterion in the identification of the critical loss component, showed that the production component plants was the critical loss component, because it produced the steepest slope in the regression curve (Figure 2).

Aborted fruits were considered losses in the production component flowers (Tables 2 and 3). The non-fecundation of the ovule is one of the causes of aborted fruits (Kinet and Peet, 1997).

Losses in the production component fruits were caused by blossom-end rot, *N. elegantalis*, *Erwinia carotovora*, cracking, *Tuta absoluta*, *Alternaria solani* (Ell. and Mart.) Jones and Grout (Moniliales: Dematiaceae), TSWV, birds, *P. infestans* and non-commercial fruits. Picanço *et al.* (1998), evaluating the losses in tomato production cultivated with different spacings and applications of insecticides, and Paula (1997), determining the tomato loss factors, verified the occurrence of the same fruit loss factors above-mentioned, besides *Helicoverpa zea* (Bod.) (Lepidoptera: Noctuidae) and fruit fall. The results demonstrated the importance of addressing the appropriate care to those types of losses.

TSWV was the unique factor that contributed to the fluctuation of total losses in the critical production component, thus it was considered the loss key-factor of the culture. The principal insect-vector of these viruses is *Frankliniella schultzei* (Trybom) (Thysonoptera: Thripidae), due to its feeding habits, reproduction easiness, number of produced eggs, and capacity of fast diffusion in the nature. However, the transmission also happens through contact and cultural treatments (Riley and Pappu, 2000).

The crop losses in tropical agroecosystems are not usually caused by a single k-factor, but rather by several factors (Faleiro *et al.*, 1995). In this experiment, fruit losses caused by blossom-end rot (42.72%) and *N. elegantalis* (7.45%) were higher than fruit losses caused by *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) (0.31%) and *A. solani* (0.06%) (Table 3). Blossom-end rot, the key-factor of loss, should be controlled in order to stabilize or to raise the tomato yield. Saure (2001) provided evidence that environmental effects on the incidence of blossom-end rot and on the role of Ca^{2+} deficiency is based on correlative relationships. Taylor and Smith (1957) warned that correlations between Ca^{2+} content and incidence of blossom-end rot do not show a cause and effect relationship between nutrient element composition and plant performance, and Pill *et al.* (1978) pointed out that blossom-end rot is a qualitative phenomenon which implies that quantitative plant parameters are merely associative and not causal. Thus, high or low soil humidity (Shaykewich *et al.*, 1971; Obreza *et al.*, 1996), application of NH_4^+-N fertilizers (Sandoval-Villa *et al.*, 2001), and larger foliar transpiration intensity (Cho *et al.*, 1997), being related with absorption, translocation, and accumulation of Ca in plants and in fruits, were pointed as possible promoters of blossom-end rot in this study.

The development of optimal yield loss control strategies for a particular crop plant requires an insight into the actions, joint actions, and interactions of the different loss factors impacting the crop. One or two life tables will reveal only that severe crop losses may occur at certain age intervals, but a series of tables, suitably replicated in time and place, should provide useful guidelines to the planning of loss management strategies, particularly when coupled with meaningful cost-benefit analyses.

Conclusion

In the field, *plants* are the critical production component of tomato yield and TSWV virus is the loss key-factor.

In the greenhouse, *fruits* are the critical production component of tomato yield and blossom-end rot is the loss key-factor.

A series of crop life tables, suitably replicated in time and place, have to be formulated to provide useful guidelines to the planning of loss management strategies

Aknowledgements

The authors would like to thank Universidade Federal de Viçosa for supporting this project and Centro Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for the financial aid.

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Received on February 16, 2006.
Accepted on April 18, 2007.