Modelling Apple Flower and Fruit Damage to Frost

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Introduction

Good quality apples are grown in relatively cold areas. However, frost frequently causes damage to flowers and small fruits. When the percentage of frost damage losses is higher than the thinning requirement of the cultivar, production is reduced. In addition to reducing yield, frost damage to the skin and malformation of the fruits often devalues the quality and reduces profits.

Critical temperature tables in relation to phenological stage are available for apples and other deciduous crops (Ballard and Proebsting, 1978; Proebsting and Mills, 1978). Some of the data came from field observations using temperatures from standard shelters and some came from excised branch chamber studies. Since plants adapt to the short term temperature environment and there are biological and physical phenomena that influence the critical damage temperature, extrapolation of these critical temperatures to a given crop and environment is questionable. For a thorough discussion see Snyder et al. (2004).

In this paper, a program that predicts the fraction of damage to flowers and fruits, and hence the reduction of high quality production, is presented and validated using minimum temperature data and the observed fraction of damaged apple flowers of three cultivars from 13 locations over two years of multiple frost events.

Methods

Field trials were conducted in a 10-ha hedgerow apple orchard located in Carrazeda de Ansiães (41º 17´ N, 7º 19´ W alt. 690 m) in the Northeast of Portugal during the spring (1999–2000). The orchard was planted in 1989 with a row spacing of 4.65 m, and rows were oriented in the NE-SW direction. The height of the orchard canopy was approximately 3.5 m.

A wind machine was installed in the orchard and was operated during all frost nights. Air temperatures were monitored using 0.2 mm wire copper-constantan thermocouples shaded from radiation with white-painted thin aluminium caps. Air temperature was measured at the height of 1.5 m, mostly within the influence of the wind machine, at four directions (NW, NE, SW and SE) at distances of 30, 70, 110, and 160 m from the wind machine. A CR10X datalogger (Campbell Scientific, Inc., Logan, Utah, U.S.A.) sampled every 10 s and the data were averaged every minute. Near each temperature measurement tower, two or three randomly chosen clusters were collected from two trees per cultivar (Hi Early, Jonagolden, and Erovan) at the heights 0.60, 1.5 and 3.0 m. To evaluate damage, flowers were dissected longitudinally and were observed with a magnifying glass. The developmental stage was observed for each variety when samples were collected, and frequently in the orchard.

The Damage Estimator application program 'DEST' (Figure 1) was used to predict frost damage and crop yield using site-specific minimum temperature (Snyder et al., 2004). Critical temperatures associated with 90 % (T_{90}) and 10 % (T_{10}) damage are input corresponding to specific phenological dates. It is assumed that damage is directly related to the minimum temperature and it is unrelated to the duration at a minimum temperature. For multiple events of frost, damage is assumed to be multiplicative. Half-hourly minimum and maximum temperatures and the critical temperatures reported by Proebsting and Mills (1978) for Golden Delicious apples were used.

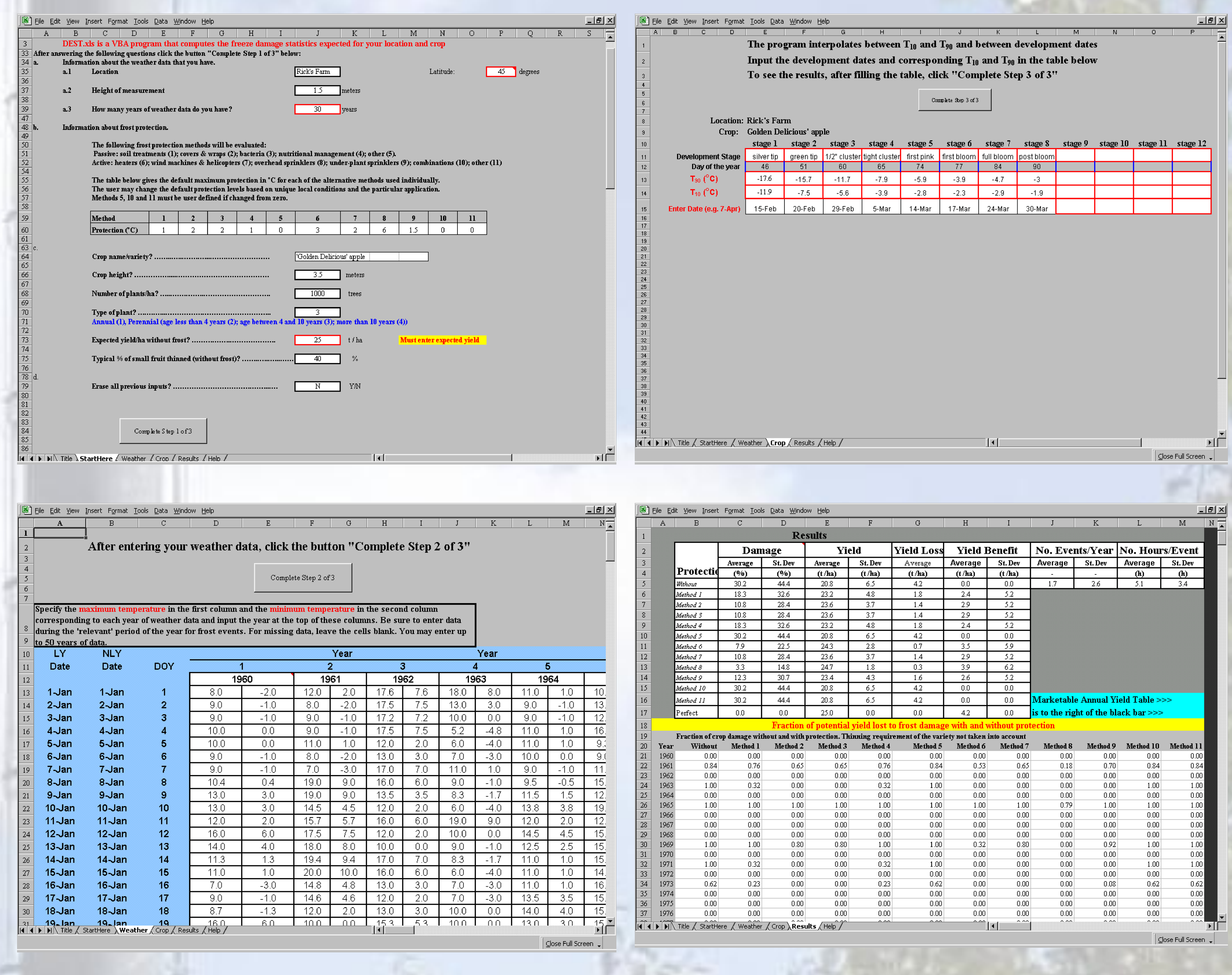

Figure 1. Screens of the data entry procedure and results of the DEST program

Results and Discussion

Figure 2 shows the predicted versus observed plots of the fractions of flowers (i.e., the mean of the three sampling heights) that were damaged by frost in 1999 (A) and 2000 (B). After leaves have developed, the minimum temperature is typically at the canopy top rather than near the ground (Snyder et al., 2004). Although all cultivars had similar phenological development, the cultivar Jonagolden was more prone to frost damage (see Fig. 2 A and B) in both 1999 and 2000.

Figure 2 shows that the DEST model performance was good. Table 1 provides the linear regression statistics for predicted versus observed flower damage fraction. The root mean square errors (RMSE) was about 0.1 and the R^2 values were 0.87 and 0.77 for 1999 and 2000, respectively.

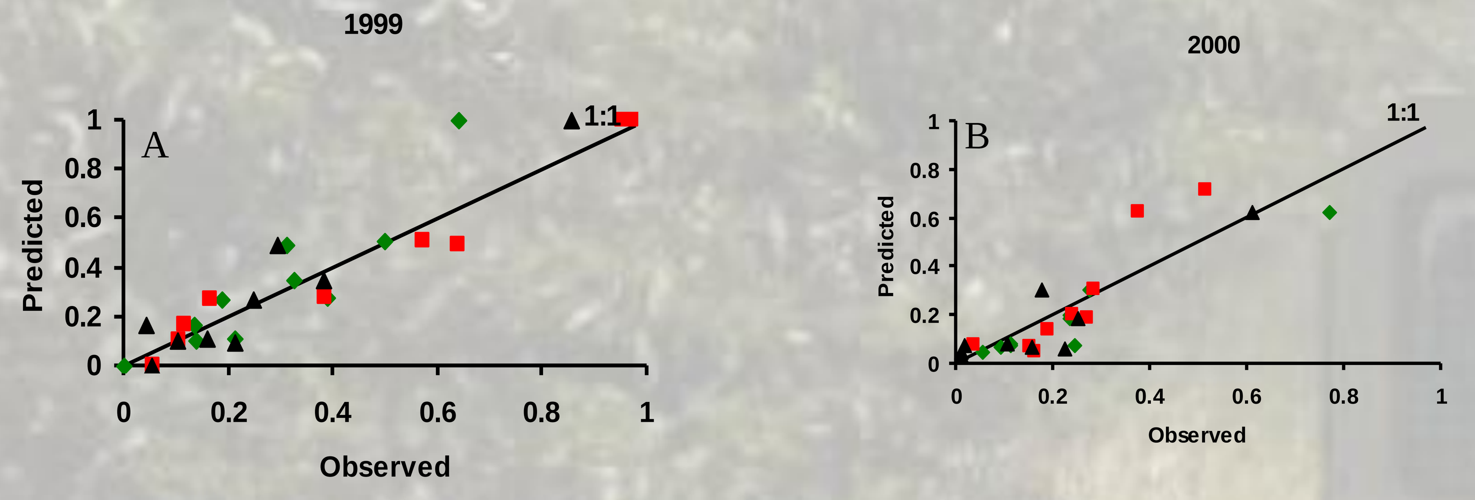

Figure 2. Predicted versus observed fractional damage (◊: 'Hi Early.'; □: 'Jonagolden.'; Δ: 'Erovan')

Table 1. Regression statistics for predicted versus observed fraction of flower frost damage, where $\bar{P}$ and $\bar{O}$ are the means and s_p and s_o are the standard deviations for predicted and observed damage from *N* samples. The variables *a* and *m* are the intercept and slope of the regression line, *RMSE* is the root mean square error, and R^2 is the coefficient of determination.

Simulation year	*N*	$\bar{P}$	$\bar{O}$	s_p	s_o	*a*	*m*	*RMSE*	R^2 (%)
1999	29	0.35	0.33	0.31	0.28	-0.02	1.01	0.11	87
2000	29	0.20	0.22	0.21	0.18	0.00	1.07	0.10	77

References

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