Statistical Model Estimates Potential Yields in ‘Golden Delicious’ and ‘Royal Gala’ Apples before Bloom

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ABSTRACT. Spring frosts are usual in many of Spain’s fruit-growing areas, so it is common to insure crops against frost damage. After a frost, crop loss must be evaluated, by comparing what crop is left with the amount that would have been obtained under normal conditions. Potential crop must be evaluated quickly through the use of measurements obtainable at the beginning of the tree’s growth cycle. During the years 1998 and 1999 and in 62 commercial plots of ‘Golden Delicious’ and ‘Royal Gala’ apple (*Malus ×domestica* Borkh.), the following measurements were obtained: trunk cross-sectional area (TCA, cm²), space allocated per tree (ST, m²) trunk cross-sectional area per hectare (TCA/ha), flower density (FD, number of flower buds/cm² TCA), flower density per land area (FA, number of flower buds/m² land area), cluster set (CS, number of fruit clusters/number of flower clusters, percent), crop density (CD, number of fruit/cm² TCA), fruit clusters per trunk cross-sectional area (FCT, number of fruit clusters/cm² TCA), fruit clusters per land area (FCA, number of fruit clusters/m² land area), fruit number per cluster (FNC), average fruit weight (FW, g), average yield per fruit cluster (CY, g), yield efficiency (YE, fruit g·cm⁻² TCA), and tree yield (Y, fruit kg/tree). FCT and average CY were related to the rest of the variables through the use of multiple regression models. The models which provided the best fit were $FCT = FD - TCA/ha - FD$ and $CY = -FCA - FCT$. These models were significant, consistent, and appropriate for both years. Predicted yield per land area was obtained by multiplying $TCA/ha \times FCT \times CY$. The models’ predictive ability was evaluated for 64 different plots in 2001 and 2002. Statistical analysis showed the models to be valid for the forecast of potential yields in apple, so that they represent a useful tool for early crop prediction and evaluation of losses due to late frosts.

Spring frosts are usual in many of Spain’s fruit-growing areas, so it is common to insure crops against frost damage. Frosts affect mainly flowers or young developing fruit, so that any damage must be estimated comparing the amount of fruit left on the tree to the number that would have been produced under normal conditions. Insurance technicians face two main difficulties in their work: the study must be performed after the frost has occurred (that is, must be performed using variables which can be measured after the frost event) and it must be performed in the field, quickly and without complex equipment.

Tree yield is a function of the number of both fruit on the tree and their weight. The number of fruit depends on the flower density (number of flower clusters per TCA, Lombard et al., 1988), the tree’s size and percentage of set. The percentage of fruit set decreases as the flower density increases, but this relationship is heavily influenced by climate (Dennis, 1986; Tromp and Borsboom, 1994). When fruit set is too large for the tree’s size, it becomes necessary to thin to ensure both return bloom and a good fruit development (Wertheim, 2000).

Typical fruit size is different for each cultivar (Faust, 1989), although it is also highly dependent on the number of fruit left on the tree (Chang et al., 1987; Gu and Lombard, 1994; Miranda and Royo, 2003a), climate (Lakso et al., 1995; Warrington et al., 1999) and cultural techniques (Berman and DeJong, 1996; Naor et al., 1997). Fruit growth rate is faster for early cultivars but, since growth time is shorter, final size tends to be smaller (Faust, 1989).

Only tree size, plantation density and number of flower buds

after pruning are available at the beginning of the active period to estimate potential yield in a simple, rapid way. Potential yield increases with tree size, although not linearly since bigger trees are less efficient (Barritt et al., 1997; Faust, 1989; Robinson et al., 1991). Many studies have shown that tree size and trunk cross-sectional area (TCA) are closely related, so that TCA is used regularly to compare different plots’ vigor (TCA/ha), efficiency (kg/TCA), flower load (number of flowers/TCA), etc. (Barritt et al., 1997; Carusso et al., 1999; Dennis et al., 1996; Lombard et al., 1988; Strong and Azarenko, 2000; Westwood and Roberts, 1970). Plant density also influences yield, since it affects the amount of light intercepted by the trees. Robinson and Lakso (1991) found that the amount of light intercepted by a tree was correlated with TCA per available area (TCA/ha). TCA/ha has been shown to be a good parameter to estimate potential yields in peach, nectarine and pear orchards (Miranda and Royo, 2003a, 2003b).

The productivity of an apple tree also depends on the bud load after pruning, i.e., the magnitude of flowering (Dennis, 1986; Kappel, 1990; Lombard et al., 1988). Some pomologists have proposed flower bud density (number of flower buds per TCA) as an index to express the magnitude of flowering (Lombard et al., 1988). Flower density per land area (number of flower buds/m²) in pear cultivars ‘Blanquilla’ and ‘Conference’ (Miranda and Royo, 2003a) was found to be the most influential parameter in multiple regression models that allowed cluster set and cluster yield estimation.

The purpose of this study was the development of a mathematical model, using parameters which can be easily measured at the beginning of the active period, to estimate potential yield for ‘Golden Delicious’ and ‘Royal Gala’ apple (*Malus ×domestica* Borkh.), two of the main cultivars grown in Spain (Prognosfruit, 1999).

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Materials and Methods

DATA COLLECTION. Data were collected during 1998 and 1999 in fully producing commercial plots, with trees ranging between 6 and 16 years of age. Most orchards were grafted on M.9 rootstock ($\approx 70\%$), while $\approx 20\%$ were on M.106, and $\approx 5\%$ were on M.26. Orchards were located in the Ebro River Valley, in the provinces of La Rioja, Navarra, Zaragoza and Lérida in Spain. The sampled area was comprised between lat. 42.28°N long. 2.27°W , and lat. 41.36°N long. 0.38°E , with altitudes ranging from 150 to 400 m. Both years chilling hours below 7°C in the sampled orchards were >1100 , enough to satisfy apple chilling requirements. Besides, in the average growing season for ‘Gala’ cultivars (from April to August) cumulative growing degree days (CGDD), considering a 10°C base temperature (Fischer, 1962), ranged from 1000 to 1300. In the average growing season for ‘Golden’ (from April to September) CGDD ranged from 1400 to 1700. A total of 62 plots were included in the study, out of which 36 were of ‘Golden Delicious’, and 26 of ‘Royal Gala’. The plots represented a wide range of growth conditions (pruning systems, tree sizes, rootstocks, etc). Means, standard deviations, minimum and maximum values are shown for cropping characteristics of each cultivar (Table 1). Cultural practices were carried out as is normally done commercially in the area. Trees were chemically thinned with NAA at 10 to $15\text{ mg}\cdot\text{L}^{-1}$, at the 10 to 12 mm stage of fruit development. Supplementary hand thinning was performed by the growers between 50 and 70 d after full bloom (DAFB), with ‘Royal Gala’ being thinned earlier.

For each plot and year, 20 trees were chosen randomly between winter pruning and bloom. Trunk cross-sections (measure 15 cm above the graft union), number of flower buds left after pruning on the whole tree and distance to neighboring trees were measured. Fifty buds were marked in each of the chosen trees, so that all of them were on the same main branch and that they represented all positions (interior, exterior, upside and downside) and the ratio at which they occurred in the trees.

Harvest maturity was determined by measuring flesh firmness at the greenest part of 100 randomly chosen fruit in the plot, using a Penefel penetrometer (Agro-Technologie, Tarascon, France) with a 1.0-cm^2 point. Harvest took place when average firmness was 6 to 7 kg for ‘Golden Delicious’ and 6.5 to 7 kg for ‘Royal

Gala’ (Iglesias et al., 2000), and all fruit on a tree were picked on one day. At that time, number of fruit clusters and number of fruit per cluster were counted, and the largest equatorial size was measured for the fruit on the 50 marked buds per tree. At the same degree of ripeness, 100 fruit were chosen randomly and their largest equatorial size and weight measured. Table 1 reflects all the measurements that were made, and their units. For each plot, the values used in the regression analysis were the averages for all 20 sampled trees.

MODEL BUILDING. To obtain expected yield for an apple plot, yield was separated into its individual components (fruit clusters per TCA and yield per fruit cluster) and multiple linear regression models linking each with parameters that could be measured at the beginning of the activity cycle were examined. Therefore, two models were evaluated: in the first one FCT was the dependent variable and the independent variables were TCA, ST, TCA/ha, FD, FA, and their respective squared terms. In the second model, CY was the dependent variable and the independent variables were TCA, TCA/ha, FD, FA, FCT, FCA, CD, FNC, and their respective squared terms. The relationships were evaluated by fitting polynomial regression models with the linear regression procedure of SPSS (SPSS Inc., Chicago, Ill.) and the backward stepwise elimination option, as described by Miranda and Royo (2003a). The internal validity of the models was tested by coefficient of determination (R^2), mean square error (MSE), the prediction sum of squares (PRESS), and the adjusted coefficient of multiple determination (R_a^2) (Miranda and Royo, 2003a). Residuals were analyzed to determine the presence of outliers and nonconstant error variance. Variance inflation factor (VIF) for the parameter estimates was calculated to detect inter-correlation between variables. The best models were, for FCT, $\text{FCT} = \text{TCA/ha} - \text{FD}$ and, for CY, $\text{CY} = -\text{FCA} - \text{FCT}$. Analysis of covariance was then performed with the GLM Procedure of SPSS (Marini, 1999) to test equality of models for different years. The categorical variable (year) was included as the indicator or dummy variable and the continuous variables for FCT model (FA and TCA/ha) and for CY model (FCT and FCA), were included as the covariates. Type III sums of squares were used to evaluate the significance of the indicator variable and any interaction terms involving the indicator variable (year $\times$ FD or year $\times$ TCA/ha, for example). Because year and the interaction terms containing

Table 1. Mean ($\pm$ standard deviation), maximum (max) and minimum (min) values for the main agronomic characteristics of the orchards sampled. Data for 1998–99 are pooled.

Characteristic	‘Golden Delicious’			‘Royal Gala’		
	Mean $\pm$ SD	Min	Max	Mean $\pm$ SD	Min	Max
N° of orchards sampled	36			26		
Trunk cross-sectional area (TCA, cm^2)	62.4 ± 35.2	13.7	131.0	69.0 ± 24.1	26.1	108.9
Trunk cross-sectional area per hectare (TCA/ha, $\text{m}^2\cdot\text{ha}^{-1}$)	7.3 ± 3.5	2.6	16.1	9.2 ± 3.2	3.0	17.0
Area allocated per tree (ST, m^2/tree)	8.2 ± 2.7	4.8	12.6	7.7 ± 1.4	4.2	9.2
Flower density (FD, no. flower buds/ cm^2 TCA)	9.1 ± 5.7	1.2	24.0	5.9 ± 2.8	1.5	11.6
Flower density per land area (FA, no. flower buds/ m^2)	53.1 ± 23.6	11.4	105.1	48.3 ± 19.7	17.3	97.6
Cluster set (CS, no. fruit clusters/100 flower clusters, %)	43.3 ± 15.5	22.6	99.2	51.3 ± 13.8	32.0	84.2
Crop density (CD, no. fruit/ cm^2 TCA)	3.8 ± 1.6	0.8	7.6	3.8 ± 1.5	1.4	7.5
Fruit clusters per TCA (FCT no. fruit clusters/ cm^2 TCA)	3.4 ± 1.6	0.7	7.1	3.0 ± 1.5	1.1	6.0
Fruit clusters per land area (FCA, no. fruit clusters/ m^2)	21.0 ± 6.7	8.6	32.0	23.1 ± 6.3	11.8	36.9
Average fruit number per cluster (FNC)	1.2 ± 0.2	1.0	2.0	1.2 ± 0.2	1.0	1.8
Fruit weight (FW, g)	157.4 ± 19.7	112.5	198.6	128.6 ± 17.2	95.6	174.8
Cluster yield (CY, g)	191.0 ± 24.9	153.0	244.0	176.0 ± 26.5	140.2	225.3
Yield efficiency (YE, g fruit/ cm^2 TCA)	612.6 ± 221.1	200.6	1005.2	495.7 ± 211.7	231.4	1073.6
Yield per tree (kg/tree)	33.2 ± 15.4	9.3	61.2	30.3 ± 7.5	17.1	47.7
Yield per hectare (T/ha)	39.1 ± 10.5	19.2	60.3	39.5 ± 7.9	26.6	56.8

year were not significant ($p > 0.05$), data from all the orchards were pooled to develop two models for each cultivar: one for fruit cluster per TCA estimation and another one for yield per cluster estimation. Analysis of covariance was also performed to test equality of FCT models for both cultivars. Cultivar was included as the dummy variable and FA and TCA/ha were included as the covariates. Because cultivar and the interaction terms containing cultivar were not significant ($p > 0.05$), data from all the orchards were pooled to develop one fruit clusters per TCA model for both cultivars.

MODEL VALIDATION. To validate the models obtained, a validation data set was obtained using 35 'Golden Delicious' plots and 29 'Royal Gala' plots, different from the previous ones in years 2001 and 2002. Validation data were obtained in the same way as described earlier. Two techniques were used to validate the models.

1) Reestimation of the model parameters with the validation data set using the backward elimination option, and model comparison for consistency.

2) Prediction of outcomes for observations in the validation data set with the estimation models and comparison of the mean squared prediction error (MSPR) with the mean square error (MSE) of the regression fit to the model-building data set (Neter et al., 1996).

Graphical procedures (Bland and Altman, 1986) were used to compare the predicted yield to the observed yield (OYA) for each orchard. Predicted yield per land area (PYA) was obtained by multiplying TCA/ha $\times$ FCT $\times$ CY. Scatter plots of values for the predicted against the true yields are presented. GLM Procedure of SPSS was used to evaluate the linear relationship for OYA and PYA. Values for PYA were subtracted from OYA for each orchard, and differences were plotted against the OYA for an orchard. Lack of agreement was evaluated by calculating the relative bias, estimated by the mean of the differences (d) and the standard deviation (sd) of the differences. Normality was visually evaluated with a frequency distribution of individual differences. Bias Plot Procedure of Analyse-It (Analyse-It Software

Ltd., Leeds, U.K.) was used to obtain a Shapiro-Wilks W statistic as a formal test for normality (Marini, 2001).

Results

Parameter estimates and statistics obtained from SPSS output are presented for the estimation and validation models developed for fruit clusters per TCA (Table 2) and yield per cluster (Table 3). Parameter estimates, R^2 , and R_a^2 values are quite similar for the estimation and validation models, providing some assurance about the applicability of the model to data beyond those on which the model is based (Neter et al., 1996). The VIF for all parameter estimates in the estimation models were far below the value of 10 considered as an indicator of the presence of correlation (Neter et al, 1996). Therefore the coefficients obtained are uncorrelated and reliable, and the standardized regression coefficients (the regression coefficients divided by their respective standard deviations) can be used as a valid indicator of the relative influence of each parameter on the dependent variable (Neter et al, 1996).

For the fruit clusters per TCA model (Table 2), FD had the greatest impact (standardized coefficient of -0.88), greater than TCA/ha (standardized coefficient = -0.02). For the yield per cluster model (Table 3), FCT was the most influential factor for both cultivars (-0.64 and -0.71 for 'Golden Delicious' and 'Royal Gala', respectively), whereas FCA had less influence (-0.24 and -0.32 for 'Golden Delicious' and 'Royal Gala', respectively).

A means of measuring the actual predictive capability of the models is to use them to predict each case in the validation data set and then to calculate the mean of the squared prediction errors, MSPR. If the MSPR is fairly close to the MSE based on the regression fit to the estimation data set, then the MSE for the selected regression model is not seriously biased and gives an appropriate indication of the predictive ability of the model. In this case, the MSPR from the validation data set for the fruit clusters per TCA model (1.12) does not differ greatly ($\approx 15\%$) from the MSE of the estimation data set (0.96). The same case was true for both yield per cluster models (for 'Golden Delicious', MSPR

Table 2. Statistics and parameter estimates from regression models for fruit clusters per TCA (FCT, no. of fruit clusters/cm² TCA) estimation. The estimation models were developed from 36 'Golden Delicious' and 26 'Royal Gala' apple orchards sampled in 1998 and 1999. Validation models were developed from 35 'Golden Delicious' and 29 'Royal Gala' orchards sampled in 2001 and 2002.

Statistic or parameter estimate	Estimation model	Validation model
Intercept	1.11	1.89
Standard error of intercept	0.64	0.31
Regression coefficient for TCA/ha ²	-0.01	-0.12
Standard error for TCA/ha	0.06	0.02
Standardized regression coefficient for TCA/ha	-0.02	-0.33
Variance inflation factor for TCA/ha	2.03	1.30
Regression coefficient for FD ³	0.30	0.34
Standard error for FD	0.03	0.03
Standardized regression coefficient for FD	0.88	0.71
Variance inflation factor for FD	2.03	1.30
Prediction sum of squares (PRESS)	56.33	
Error sum of squares (SSE)	58.63	20.10
Mean squared prediction error (MSPR)	1.12	
Mean square error (MSE)	0.96	0.34
$P > F$	<0.0001	<0.0001
Coefficient of multiple determination R^2	0.80	0.84
Adjusted coefficient of multiple determination R_a^2	0.79	0.83
Total DF	61	63

²TCA/ha: Trunk cross-sectional area per hectare (m²·ha⁻¹).

³FD = flower density per TCA (no. of flower clusters/cm² TCA).

Table 3. Statistics and parameter estimates from regression models for cluster yield (CY,g) estimation. The estimation models were developed from 36 'Golden Delicious' and 26 'Royal Gala' apple orchards sampled in 1998 and 1999. Validation models were developed from 35 'Golden Delicious' and 29 'Royal Gala' orchards sampled in 2001 and 2002.

Statistic or parameter estimate	'Golden Delicious'		'Gala'	
	Estimation model	Validation model	Estimation model	Validation model
Intercept	261.31	249.41	245.07	197.32
Standard error of intercept	6.71	6.37	8.47	6.52
Regression coefficient for FCT ²	-15.18	-11.87	-12.82	-8.09
Standard error for FCT	3.18	1.45	1.79	1.58
Standardized regression coefficient for FCT	-0.64	-0.75	-0.71	-0.80
Variance inflation factor for FCT	1.82	1.43	1.35	2.92
Regression coefficient for FCA ³	-0.88	-0.87	-1.35	-0.27
Standard error for FCA	0.48	0.34	0.41	0.40
Standardized regression coefficient for FCA	-0.24	-0.23	-0.32	-0.10
Variance inflation factor for FCA	1.82	1.43	1.35	2.92
Prediction sum of squares (PRESS)	13543.93	3385.67		
Error sum of squares (SSE)	11157.80	3971.90	2894.54	3787.97
Mean squared prediction error (MSPR)	416.91	146.02		
Mean square error (MSE)	338.12	124.12	125.85	145.69
P>F	<0.0001	<0.0001	<0.0001	<0.0001
Coefficient of multiple determination R ²	0.68	0.81	0.83	0.78
Adjusted coefficient of multiple determination R _a ²	0.66	0.80	0.82	0.77
Total DF	35	34	25	28

²FCT = fruit clusters per TCA (no. fruit clusters/m² TCA).

³FCA = fruit clusters per land area (no. fruit clusters/m² land area).

= 417, MSE = 338; and for 'Royal Gala', MSPR = 146, MSE = 126). This implies that the MSE based on the estimation data set is a reasonably valid indicator of the predictive ability of the estimation regression model (Neter et al., 1996).

PRESS criterion and the error sum of squares (SSE) are measures of how well the use of the fitted values for a subset model can predict the observed values of the response value Y_i . Some evidence of the internal validity of the fitted model is to compare PRESS and SSE (Miranda and Royo, 2003a). PRESS values are reasonably close to SSE, as for FCT model PRESS = 56.33, SSE = 58.63, for 'Golden Delicious' yield per cluster model PRESS = 13544, SSE = 11158, and for 'Royal Gala' yield per cluster model PRESS = 3386, SSE = 2894, and support the validity of the fitted regression models and of the MSEs as indications of the predictive capability of these models (Neter et al., 1996).

Predicted yield per land area (PYA) was obtained by multiplying FCT $\times$ CY $\times$ TCA/ha. Estimates for PYA were plotted against the true values (OYA) and plot contains a line of equality on which all points would lie if the estimation methods gave exactly the same value as the true value (Fig.1). Data for yield tend to be clustered fairly close to the line. Correlation coefficients were calculated for the plot to test the null hypothesis that the values for the estimation method are not linearly related to the true values. Values obtained from the estimation methods were linearly related to the true values ($r = 0.916$ $P < 0.0001$). However, correlation is an inappropriate analysis for the agreement of the method to the real values, and a plot of the difference between the method against the true values may be more informative (Bland and Altman, 1986; Marini, 2001). Plotting differences against the true value also allow investigation of possible relationships between measurement error and the true values. The plot in Fig. 2 indicate no obvious relation between the differences and the true values of yield.

Lack of agreement between an estimation method and the true value can be evaluated by calculating the bias, estimated by the mean of the differences ($\bar{d}$) and the SD of the differences. In

Fig. 2 a solid line represents the mean of the differences. If the differences are normally distributed, 95% of the differences will lie between $\bar{d} \pm 2$ SD. These values are referred to as the limits of agreement (Bland and Altman, 1986). The frequency distribution and the W statistic for the plot of the differences indicate that the

Fig 1. Plot of predicted yield per land area, estimated from multiplying FCT $\times$ CY $\times$ TCA/ha (see Table 1 for definitions) vs. the observed yield per land area (OYA) for each orchard in the validation data set. Along with estimated PYA for each orchard is the line of equality on which all points would lie if the estimation method gave the true value for every orchard.

Fig 2. The difference between predicted yield per land area, estimated from multiplying $FA \times CY \times TCA/ha$ (see Table 1 for definitions) vs. the observed yield per land area (OYA) for each orchard in the validation data set. The solid line is the mean of the differences. The broken lines are the limits of agreement, calculated as $d \pm 2 SD$; where d = the mean of the differences and SD = the standard deviation of the differences. If the differences are normally distributed, 95% of the differences in a population will lie between the limits of agreement.

Fig 3. Frequency plot of the differences plotted in Fig. 2. Also presented are coefficient and P value for Wilkes Shapiro W test where the null hypothesis is that the differences come from a normal distribution.

data adequately approximate Normality for parametric test to be valid (Fig. 3) (Marini, 2001).

Provided that differences within the limits of agreement are not important, the estimation methods can be used to predict the yield of an apple orchard. Estimates from the validation data set may be $0.74 \text{ kg} \cdot \text{m}^{-2}$ below or $0.71 \text{ kg} \cdot \text{m}^{-2}$ above the true yield. Most values for OYA were $<5.2 \text{ kg} \cdot \text{m}^{-2}$, thus the prediction method provided estimates within $\approx 15\%$ of the true yield. This level of error can be considered acceptable since the purpose of this research was to estimate the yield of apple orchards in a very large area through the use of parameters that can be measured at the beginning of the cycle.

Flower density (FD) had the greatest influence and a positive effect in explaining fruit clusters per TCA, which is supported by previous research (Dennis et al, 1996, Knight, 1980; Stover, 2000). Similar results were obtained by Miranda and Royo (2003b) in peach, where the bud load per TCA, expressed as the length of productive shoots per TCA due to the growing patterns of peach trees, also was the most influential parameter and had a positive effect to explain crop density. TCA/ha had a minor, though significant, effect in explaining FCT. This matches the results reported by Miranda and Royo (2003a, 2003b) in pear and peach. Robinson and Lakso (1991) determined in apple that TCA/ha is a factor that can be used to explain tree efficiency and to predict crop densities or fruit set. Fruit set decreases with increasing planting densities or TCA/ha because light distribution is poorer (Robinson and Lakso, 1991) and abscission rate increases. Byers et al (1990) found that artificial shading for 1 or 2 d, 30 to 50 d after full bloom, had a thinning effect in apple, even higher than chemical thinning. Moreover, chemicals that inhibit photosynthesis, including the herbicide terbacil (3-tert-butyl-5-chloro-6-methyluracil) can also thin apple and peach (Dennis, 2000).

The negative influence of fruit load on fruit weight has been shown in previous studies (Gu and Lombard, 1994; Kappel, 1990; Miranda and Royo, 2003a; Robinson et al, 1991). FCA and FCT are indices to express fruit load, and both have proven to be negatively related to the yield per cluster, though FCT had the greatest influence in explaining yield per cluster. Similar results were obtained in peach by Miranda and Royo (2003b), where crop density was the most influential parameter in explaining fruit weight. Miranda and Royo (2003a) found in pear that FCT had a significant effect in explaining yield per cluster, though flower density per land area (FA) had a higher influence. FA is a factor for explaining yield per cluster in pear, but not in apple probably because, in our region, apple trees are customary chemically thinned at early stages of fruit development, whereas pear trees are usually only hand thinned at 50 to 80 DAFB (Miranda and Royo, 2003a). This late thinning in pear allows more developing fruitlets in the first 7 to 9 weeks, when fruit growth is due to cell division (Faust, 1989), and consequently, stronger competition between developing fruitlets before the June drop (Dennis, 1986).

In this study, predictive models generated with linear regressions analysis indicated that FCT and CY could be estimated fairly accurately. Additionally, correlation analyses indicated sample values were correlated with true values. Graphical techniques showed predictive models provided estimated yields that agree with the true yields, though with differences within $\approx 15\%$ of the true yield. Since the purpose of this research was to estimate the yield of apple orchards in a very large area through the use of parameters which can be measured at the beginning of the cycle, it can be considered valid within reasonable error limits. Thus, the models are acceptable to forecast crop efficiency, and so provide a useful tool for early forecast of yield and evaluation of crop losses due to late frosts.

The results of this study show that the models developed are good predictors of fruit clusters per TCA and yield per fruit cluster in the Ebro River Valley, so the potential yield of an apple orchard for 'Golden Delicious' and 'Royal Gala' can be determined reasonably well from the knowledge of TCA/ha, FD, FCT, and FCA.

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