Revista Ceres,46(268):597-606,1999.

CHARACTERIZATION OF SEASONAL FRUIT GROWTH OF `PACKHAM'S TRIUMPH' PEAR[1]

Patricia I. Garriz[2]
Graciela M. Colavita[2]
Hugo L. Alvarez[2]

1. INTRODUCTION

Methods for accurate prediction of fruit crop volumes, size distribution and quality attributes are increasingly required as tools for achieving competitive advantages for fresh-marketing services. Prediction and forecasting methodology ideally should provide estimates with known precision that can be calculated using the smallest sets of easily collected, simple measurements (*3*). WINTER (*17*) reported that the fruit growth curve and the relationship between fruit weight and diameter of each particular cultivar were essential components in the development of mathematical models.

In commercial fruit-growing, knowledge of the seasonal course of fruit growth is essential to correct timing of the different cultural practices like fertilization, pruning, fruit thinning, etc. (*15*).

In higher plants, carbon is partitioned from organs that fix CO_2 or store long-term carbohydrate reserves (source organs) to those organs or plant parts that require imported carbon for growth and maintenance (sink organs). The competitiveness of a particular organ as a sink is related to its number of cells and physiological state, and is, therefore, a consequence of

[1] Research supported by proyect A-038, Comahue National University. Accepted for publication May 2, 1999.
[2] Departamento de Biología Aplicada, Facultad de Ciencias Agrarias, Universidad Nacional del Comahue, c.c. 85, 8303 CiNco Saltos, R. N., Argentina. E-mail: pigarriz@uncoma.edu.ar.

both genetic determination and environmental influences (*1*). Carbohydrates, nitrogenous compounds and lipids in the form of fats and fatty acids are used in virtually all physiological processes. Energy, carbon skeletons and other metabolites are produced for the development of new tissues, initiation of reproductive structures, maintenance of vegetative organs and storage of reserves (*14*).

Different types of seasonal growth curves of pears were reported (*4, 5, 6, 12*). For apple, GARRIZ *et al.* (*8, 9*) have developed logistic models that describe the seasonal fruit growth. Regardless of the apparent growth pattern, BOLLARD (*2*) has emphasized the need to measure volume or weight rather than diameter to properly express growth, as this does not account for the three-dimensional changes which actually are taking place. Irreversible weight increase is a standard biological definition of growth.

The objective of this study was to develop a model to predict the seasonal growth for *Pyrus communis* L. cv. `Packham's Triumph' using data sets collected over several years in the High Valley region, and test its validity.

2. MATERIALS AND METHODS

A mature crop of `Packham's Triumph' pear trees on *P. communis* L. rootstock, planted at 5 × 4 m spacing, was studied at the Experimental Farm of the National Comahue University, Rio Negro, Argentina, on a sandy loam soil (*11*). The orchard was located in an arid region, with average annual rainfall of 250 mm. It was irrigated by surface flooding and was kept weed-free, fertilized, hand-thinned and sprayed for pest and disease control according to the local standard program for pears. Trees were trained to a multiple leader.

Five trees were selected at random and one fruit from each of the four quadrants (N, S, E and W) was sampled at weekly intervals, during three consecutive growing seasons: 1992-93, 1993-94 and 1994-95. The range of sampling dates was 27 and 178 days after full bloom (DFB). Fresh fruit weight (FW) and maximum fruit diameter (FD) were measured with an electronic scale (model Mettler P1210, Mettler Instrumente AG, Zürich, Switzerland) and a Vernier caliper (model 30-410-5, General Supply Corporation, Jackson, Miss., U.S.A), respectively. A total of 1169 fruits were measured. Full blossom was estimated to be at September 23, 1991, September 14, 1992 and September 26, 1993, respectively, for each successive season. In addition, fruits were sampled in the 1995-96 growing season at 2-weekly intervals (n = 200), using the same sampling method, to test the accuracy of the models being developed. The average crop load was

630, 821, 945 and 808 fruits per tree in 1993, 1994, 1995 and 1996, respectively.

Equations were developed with SYSTAT procedure. Model suitability was evaluated using goodness-to-fit measures.

3. RESULTS AND DISCUSSION

3.1. *Growth pattern.*

Several models were considered to determine the most consistent in being an adequate representation of the data. The R^2 values and residual plots were used to evaluate the goodness-to-fit of the equations for the 1992/93, 1993/94 and 1994/95 data sets and for the combined data. It was found that the following logistic regression provided the most satisfactory fit with the highest percentages of accounted variances for the pooled data (>84%), compared to the power (>83%) and linear (>80%) models:

$$Y = a/(1 + e^{b-cX}) \quad [I]$$

(Y = FW; X = **DFB**; a, b and c are constants). Additionally, the residual mean square from fitting the logistic model was the smallest (Table 1).

TABLE 1 - Regression models of fruit weight in grams (Y) and days after full bloom (X) for `Packham's Triumph' pears, df = degrees of freedom, R^2 = coefficient of determination

Model	Mean square	df	R^2
Logistic $\hat{Y}=316.081/(1+e^{5.030-0.039X})$	1299.87	1166	0.84
Power $\hat{Y}=2\cdot10^{-3}X^{2.311}$	1360.34	1167	0.83
Linear $\hat{Y}=-93.492+1.973X$	1661.64	1167	0.80

Based on the previously described criteria, we selected the following general predictive equation:

$$FW\ (g)=316.081/(1 + e^{5.030-0.039DFB}),\ R^2=0.84,\ P < 0.001\ [II].$$

Furthermore, the logistic equation was also the most appropriate to describe fruit growth across seasons; the graphic analysis of fit and the specific models for each growing season are indicated in Figure 1.

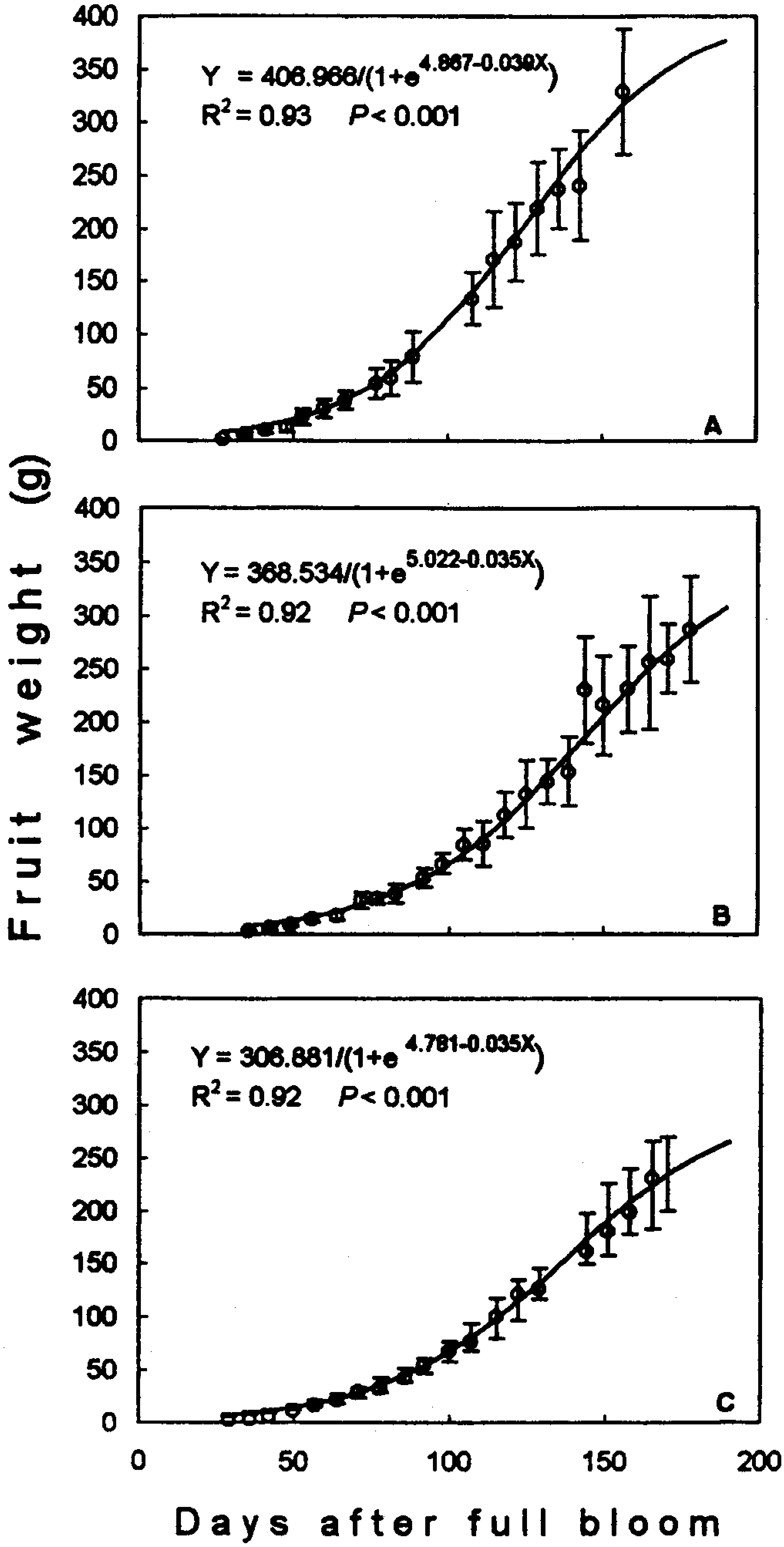

FIGURE 1 – Changes in 'Packham's Triumph' pear fruit weight plotted on a time-from-bloom basis during the growing season 1992-93 (A), 1993-94 (B) and 1994-95 (C). The line is the fitted model to the data.

In model [I], the constant a is the maximum size attained by the fruit (*13*). The rate at which the organ grows is controlled by the constants b and c and they affect the slope of the growth curve.

WESTWOOD (*15*) reported that the growth pattern of the apple fruit is typically sigmoid (S-shaped). The curve of the pear is similar to that of the apple except that it does not show the slow growth period at the end, because pears are picked green mature and ripened off the tree.

The seasonal course of growth and development is a life process genetically determined, hormonally regulated and modified by climate and location. In our study, model [II] describes the fruit weight obtainable in the specified orchard conditions and represents the integration of the environmental and internal factors that affect pear growth.

3.2. *Model testing*

The accuracy of predictions, made using the pooled model [III], was tested on an independent crop grown at the Experimental Farm in the 1995-96 growing season, to see how well it performed. According to the values of the statistical F test, no significant differences ($P \geq 0.05$) were detected. The lack-of-fit-test showed that equation [II] was appropriate to represent the independent data set. This is an indication of the validity of the general equation to predict fruit growth. Figure 2 shows the good agreement between the predicted and the observed data.

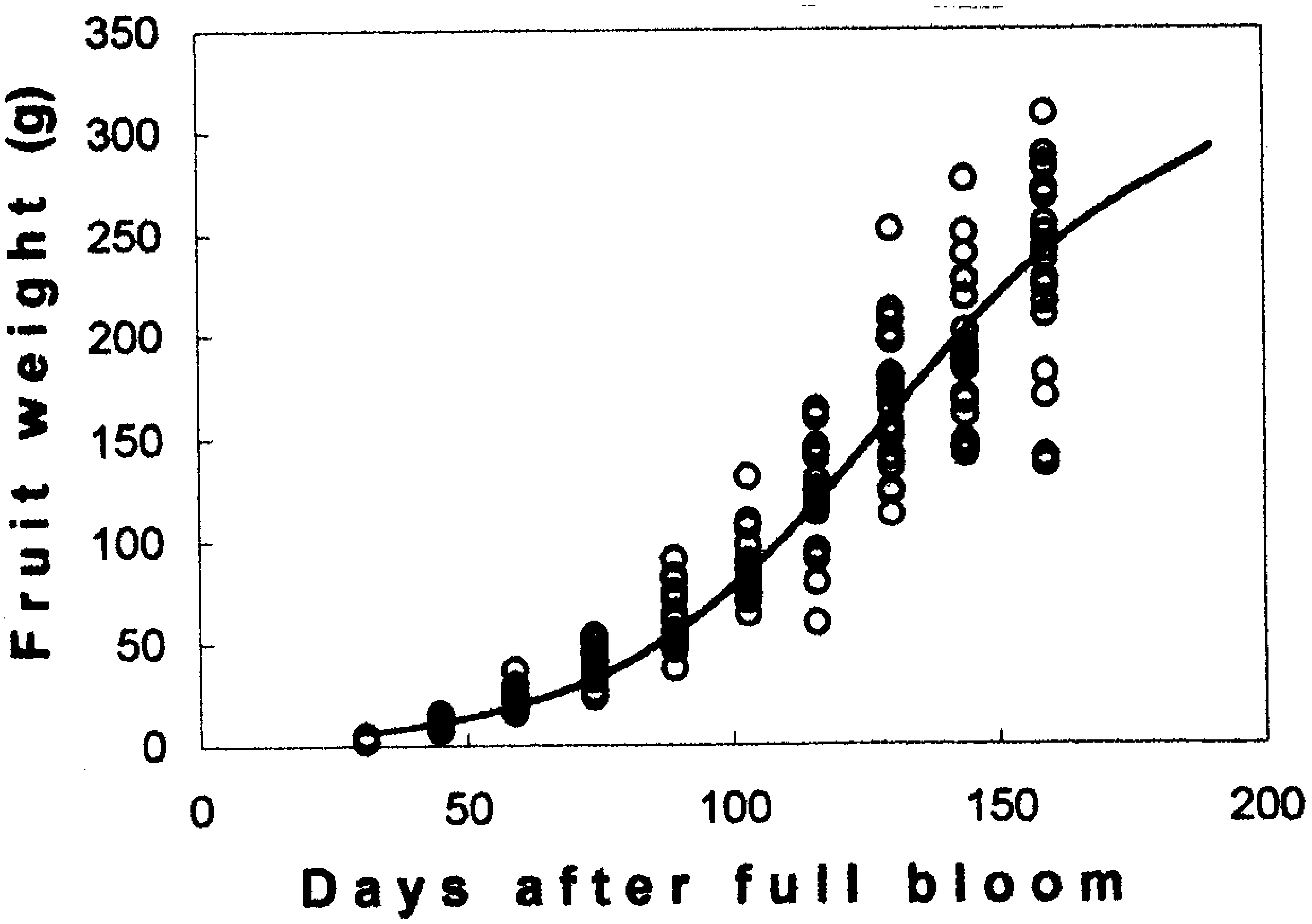

FIGURE 2 – Relationship between fruit weight (Y) and days after full bloom (X). Data for the three growing seasons were fitted to model: FW (g) = $316.081/(1+e^{5.030-0.039DFB})$, $R^2=0.84$, $P<0.001$ (line). Symbols represent data measured on an independent crop.

3.3. *Model application*

`Packham's Triumph' pear sizes at various times after 130 DFB, based on the development of equation [II], are shown in Table 2. This size prediction chart is important from a practical point of view. It can provide growers with a tool to determine adequate fruit weight at harvest, considering that unless a certain minimum size is obtained, the fruit will be given a lower grade and price (*16*). The rate of the biochemical reactions during pear ripening may be modified by environmental and internal factors. Temperatures during the growing season have a profound effect upon maturity. Thus, determination of harvest time is a compromise between size and storage quality (*4*). HANSEN (*10*) reported that cool weather prior to harvest induced some premature ripening, and any extended delay in harvest could result in a substantial loss to the grower.

TABLE 2 – Rate of increase in fruit weight of 'Packham's Triumph' pears during the harvest time, at various days after full bloom (DFB)

DFB	Fruit weight (g)	Increase in weight (g) every 2 days	Increase in relation to fruit weight at 130 DFB (%)
130	161.20	----	0.00
132	167.35	6.15	3.80
134	173.48	6.13	7.83
136	179.56	6.08	11.39
138	185.57	6.01	15.12
140	191.50	5.93	18.80
142	197.34	5.84	22.42
144	203.06	5.72	25.97
146	208.66	5.60	29.44
148	214.12	5.46	32.83
150	219.43	5.31	36.12
152	224.58	5.15	39.32
154	229.57	4.99	42.41
156	234.39	4.82	45.40
158	239.02	4.63	48.27
160	243.47	4.45	51.03
162	247.75	4.28	53.69
164	251.83	4.08	56.22
166	255.73	3.90	58.64
168	259.45	3.72	60.95
170	262.99	3.54	63.31

With apple, fruit diameter was used to monitor changes in size with time, and equations were applied to convert diameters into fruit weights (*3*). In a previous study, we compared a number of weight-diameter equations, for their potential use in indirect measurement of fruit weights of `Packham's Triumph' pear (*7*). A two-parameter power function was the most suitable model and it might be used to meet industry requirements for monitoring fruit weight through the season in the production region.

The relationship between FD and DFB for the pooled data is presented in Figure 3. The following logistic function provided the best fit to the data:

$$FD\ (mm)=88.238/(1 + e^{2.154-0.026DFB}),\ R^2=0.92,\ P < 0.001\ [III].$$

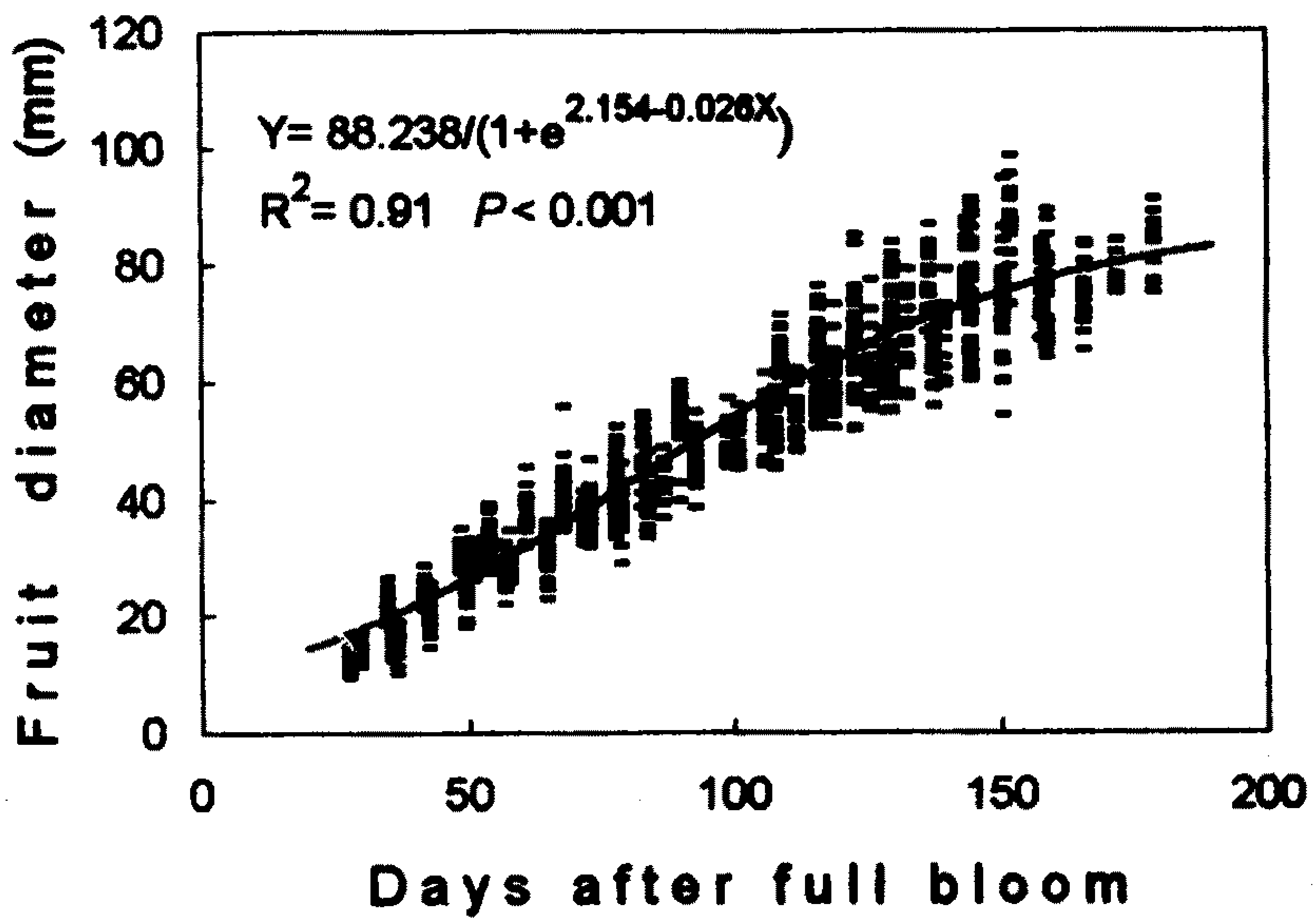

FIGURE 3 – Changes in 'Packham's Triumph' pear fruit diameter plotted on a time-from-bloom basis for the pooled data (growing seasons 1992-93, 1993-94 and 1994-95). The line is the fitted model to the data.

In summary, according to the results reported here, logistic equations gave the best fit to describe growth of `Packham's Triumph' pear in the specified orchard conditions. These models can be used as tools for predicting the time at which fruits reach a given size and as such should have considerable practical application to aid crop marketing.

4. SUMMARY

The objective of this work was to predict fruit growth of `Packham's Triumph' (*Pyrus communis* L.) as a function of time using an empirical mathematical model. A mature crop was studied at the Experimental Farm of the Comahue National University, Rio Negro, Argentina, during the 1992-93, 1993-94 and 1994-95 growing seasons. Fruits were collected at weekly intervals and the range of sampling dates was 27 and 178 days after full bloom (DFB). Fresh fruit weight (FW) and maximum fruit diameter (FD) were measured (n = 1169). Equations were developed with SYSTAT procedure and model suitability was evaluated using goodness-to-fit measures. In addition, fruits were sampled in the 1995-96 growing season to test the accuracy of the models being developed. Results showed that the following logistic model provided the most satisfactory fit to the pooled data (as compared to the power and linear models):

$$FW\ (g)=316.081/(1+e^{5.030-0.039DFB}),\ R^2=0.84,\ P<0.001.$$

The testing on an independent crop showed that predictions were accurate. The logistic function provided the best fit to predict FD. These models can assist growers with a means of determining the adequate timing of harvest, considering that unless a certain minimum size is obtained, the fruit will be given a lower grade and price.

5. RESUMO

(CARACTERIZAÇÃO DO CRESCIMENTO SAZONAL DOS FRUTOS DA PERA 'PACKHAM'S TRIUMPH')

O objetivo deste trabalho foi o de predizer o crescimento do fruto de 'Packham's Triumph' (*Pyrus communis* L.) como uma função do tempo, usando um modelo matemático empírico. Foi estudada uma cultura madura na Fazenda Experimental da Universidade Nacional de Comahue, Rio Negro, Argentina, durante as estações de crescimento de 1992-93, 1993-94 e 1994-95. Os frutos foram coletados em intervalos semanais e as datas de amostragem variavam de 27 a 178 dias após a plena floração (DPF). O peso do fruto fresco (PF) e o diâmetro máximo do fruto (DF) foram medidos (n = 1169). Equações foram desenvolvidas pelo processo SYSTAT e o modelo apropriado foi avaliado usando medidas de qualidade do ajuste. Ademais, frutos foram amostrados na estação de crescimento de 1995-96 para teste da precisão dos modelos em desenvolvimento. Os resultados mostraran que o seguinte modelo logístico forneceu o ajustamento

satisfatório dos dados combinados (quando comparado aos modelos potência e linear): PF (g)=316,081/(1+e $^{5,030-0,039DPF}$), R^2=0,84, P < 0,001. A testagem numa cultura independente mostrou que a predição foi precisa. A função logística forneceu o melhor ajustamento para predizer DF. Esses modelos podem ajudar os produtores na determinação do tempo adequado para a colheita, considerando que, a menos que um certo tamanho mínimo seja obtido, o fruto terá classificação e preço mais baixos.

6. LITERATURE CITED

1. BASSETT, C.L. Comparative abundance of the large subunit of Rubisco in aerial organs of the Japanese morning glory [*Ipomoea* (*Pharbitis*) *nil*] suggests a photosynthetic role for sepals. *J. Amer. Soc. Hort. Sci., 124*(1):67-70. 1999.
2. BOLLARD, E.G. The physiology and nutrition of developing fruits. In: Hulme, A.C. (ed.). *The biochemistry of fruits and their products*. Vol. 1. London, Academic Press, 1970. p. 387-425.
3. DE SILVA, H.N., TUSTIN, D.S., CASHMORE, W.M., STANLEY, C.J., LUPTON, G. & McARTNEY, S.J. Fruit fresh mass-diameter relationship for 'Royal Gala' apple across seasons and among fruit production regions of New Zealand. *HortScience, 32*(7):1169-1173. 1997.
4. FAUST M. *Physiology of temperate zone fruit trees*. New York, John Wiley & Sons, 1989. 131 p.
5. GARRIZ, P.I., ALVAREZ, H.L. & BARTUSCH, A.M. Efecto de la orientación en el árbol sobre la tasa de crecimiento de frutos de pera cv. 'Williams'. In: REUNION NACIONAL DE FISIOLOGIA VEGETAL, XX, San Carlos de Bariloche, Argentina, 1993. *Abstracts*, S. C. de Bariloche, SAFV, 1993. p. 122-123.
6. GARRIZ, P.I., ALVAREZ, H.L. & COLAVITA, G.M. A regression model of the growth pattern of 'Bartlett' pear fruits. *Adv. Hort. Sci., 10*:191-194. 1996.
7. GARRIZ, P.I., ALVAREZ, H.L. & COLAVITA, G.M. Estimación no destructiva del calibre de frutos de pera cv. 'Packham's Triumph'. In: JORNADAS DE INVESTIGACION Y ACTUALIZACION AGROPECUARIAS, Cinco Saltos, Argentina, 1996. *Abstracts*, Cinco Saltos, FCA-UNC, 1996. p. 9.
8. GARRIZ, P.I., BARTUSCH, A.M. & ALVAREZ, A.O. Modelos predictivos del crecimiento en frutos de manzano cultivar 'Red Delicious'. In: REUNION NACIONAL DE FISIOLOGIA VEGETAL, XIX, Huerta Grande, Argentina, 1992. Abstracts, Huerta Grande, SAFV, 1992. p. 23-24.
9. GARRIZ, P.I., BARTUSCH, A.M. & ALVAREZ, A.O. Crecimiento estacional de frutos de manzano cv. 'Granny Smith'. *Agro Sur, 21*(2):136-141. 1993.
10. HANSEN, E. Climate in relation to post harvest physiological disorders of apples and pears. *Oregon State Hort. Soc. Ann. Report, 53*:54-58. 1961.
11. IRISARRI, J., APCARIAN, A., BIANCO, H. & SCHMIDT, P. Mapa de suelos del Campo Experimental de la Facultad de Ciencias Agrarias. *Informe de la Cátedra de Edafología*. Universidad Nacional del Comahue, Argentina, 1987. 50 p.
12. MAGEIN, H. La gestion du marché par la gestion du verger. *Le Fruit Belge, 442*:49-52. 1993.
13. MILTHORPE, F.L. & MOORBY, J. *An introduction to crop physiology*. Cambridge, Cambridge University Press, 1974. 202 p.
14. NZIMA, M.D.S., MARTIN, G.C. & BREIDENBACH, R.W. Fruiting and shading

effects on metabolic heat rates of inflorescence buds, current-year, and one-year-old shoots of 'Kerman' pistachio trees. *J. Amer. Soc. Hort. Sci.*, *123*(6):961-966. 1998.
15. WESTWOOD, M.N. *Temperate zones pomology*. San Francisco, Freeman, 1993. 529 p.
16. WILLIAMS, M.W., BILLINGSLEY, H.D. & BATJER, L.P. Early season harvest size prediction of 'Bartlett' pears. *J. Amer. Soc. Hort Sci.*, *94*(6):596-598. 1969.
17. WINTER, F. Fruta de pepita: Pronósticos de rendimiento según el método Bavendorf. *Corporación de Productores de Fruta de Río Negro, 14*:6-17. 1987.