AGROMETEOROLOGICAL MODELS FOR ‘VALENCIA’ AND ‘HAMLIN’ SWEET ORANGES TO ESTIMATE THE NUMBER OF FRUITS PER PLANT

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ABSTRACT: The development of models that allow forecasting yield tendencies is important to all sectors of the citrus industry. This work evaluated the influence of meteorological variables in different phases of the crop cycle in order to propose empirical models to estimate the number of fruits per plant (NFP) of ‘Valencia’ and ‘Hamlin’ sweet oranges. NFP sampling data from the citrus juice industry of the State of São Paulo, on the total of 15 harvests (1990/91 to 2004/05), classified into three age classes, and meteorological data of maximum and minimum air temperature and rainfall of Limeira, SP, Brazil, were utilized. Correlation coefficients were initially computed between the number of fruits per plant and each meteorological variable used for water balance and variables related to air temperature, in different periods. Linear multiple regression models were fit to describe the empirical relationship between NFP and the subsets of agrometeorological predictors that presented higher correlations in different phases of the crop cycle. The meteorological conditions during the phases of vegetative summer flush, pre-flowering, flowering and beginning of fruit growth influenced the number of fruits per plant. The proposed models presented adequate goodness-of-fit with determination coefficients varying from 0.72 to 0.87.
Key words: citrus, harvest, modeling, yield

MODELOS AGROMETEOROLÓGICOS PARA ESTIMAÇÃO DO NÚMERO DE FRUTOS POR PLANTA EM LARANJEIRAS ‘VALÊNCIA’ E ‘HAMLIN’

RESUMO: O desenvolvimento de modelos para previsões de tendências de produtividade é de grande importância para todos os elos da cadeia produtiva de citros. Buscou-se avaliar a influência de variáveis meteorológicas, em diferentes fases do ciclo da cultura, para propor modelos empíricos para estimação do número de frutos por planta em laranjeira ‘Valência’ e laranjeira ‘Hamlin’. Utilizaram-se dados amostrais, provenientes da indústria de suco paulista, de número de frutos por planta (NFP), em três classes de idade, referentes aos valores estimados anuais de produtividade, no total de 15 safras (1990/91 a 2004/05), e dados meteorológicos (temperatura do ar e precipitação pluvial) para o município de Limeira, SP, Brasil. Foram determinados os coeficientes de correlação linear entre NFP e variáveis meteorológicas componentes do balanço hídrico e temperatura, em diferentes períodos. Modelos de regressão linear múltipla foram ajustados para os subconjuntos de variáveis meteorológicas que apresentaram as maiores correlações significativas com o NFP em diferentes fases do ciclo da cultura. As condições meteorológicas durante as fases de crescimento vegetativo de verão, pré-florescimento, florescimento e início de crescimento dos frutos influenciaram a produção de frutos por planta. Os modelos apresentaram boa qualidade de ajuste, com coeficiente de determinação variando de 0,72 a 0,87.
Palavras-chave: citros, modelagem, produtividade, safra

INTRODUCTION

Brazil is the current major world citrus producer, which is mainly commercialized for industrial processing of frozen concentrated orange juice for export. The use of statistical models for yield forecast is a key factor for citrus agricultural business, mainly on a commercial basis, because they allow knowing in advance the tendency of yield increase or reduction. Among several factors affecting citrus plant growth, the climate has been considered as the main factor, when all the other variables are maintained constant to determine yield variability between localities and cropping seasons.

Sample surveys are carried out every year by the São Paulo juice industry in the citrus production regions in order to estimate fruit production per plant for the main sweet orange cultivars destined to juice processing. Those surveys are usually performed mid-April for harvest prediction, and are helpful in the establishment of marketing strategies for the sector. To evaluate the influence of meteorological variables in different stages of crop cycle on citrus yield, this work proposes empirical models to estimate the number of fruits produced per plant on 'Valencia' and 'Hamlin' sweet oranges.

MATERIAL AND METHODS

Data on the number of fruits per plant (NFP) for 'Valencia' and 'Hamlin' sweet oranges (*Citrus sinensis*, L. Osbeck) were obtained from sampling surveys carried out during 15 consecutive harvest seasons (1990/91 to 2004/05) for the Limeira region, SP, Brazil. These samplings were performed each year on mid-April and are part of the annual production estimates of the São Paulo State juice industry (Paulino, 2000; Paulino & Volpe, 2001).

A stratified sampling plan was utilized considering three plant age classes: (i) class 1: 3-5, (ii) class 2: 6-10, and (iii) class 3: above 10 year-old plants, with the number of samples being determined for each class as a function of its variability and number of plants. Each sample was comprised by all the fruits of the 20th plant at the 10th row of the tree stand, except for disease affected plants or those out of the age class. In such cases, the immediately following plant was sampled. The block stand was randomly selected amongst those available for each class. The measured trees were strip-harvested and all their fruits counted; the total fruit number for each age class was obtained by averaging data from all the samples.

Daily data of maximum air temperature, minimum air temperature and rainfall between 1989 and 2004, were collected in Limeira (22º32'S, 47º27'W, 639 m). Daily average air temperature was calculated from the average of daily maximum and minimum temperatures. The data was utilized to calculate the water balance with the computational program "Bhidrico" (version 3.21) (Dourado Neto et al., 1991), using the Thornthwaite & Mather method (Thornthwaite & Mather, 1955) on a daily basis. Estimates of reference evapotranspiration were obtained by the method proposed by Thornthwaite (1948). For calculation of the real evapotranspiration, the citrus crop coefficient (Kc) was set to 1. The available water capacity (AWC) was estimated as 100 mm according to the predominant regional soil type (Oxisols), assuming a mean effective root depth of 100 cm, due to the lack of detailed information on effective root depth as related to plant age.

The hypothesis of this study was that NFP can be adequately predicted by the components of the water balance and air temperature at the different stages of crop cycle. Each evaluation period was considered from the flowering season before fruit harvest, until January of the harvest season. Periods defined as 1, 2,…12 corresponded to the months of January, February,… and December of the flowering year before harvest, and the period defined as 13 corresponds to the month of January of the harvest season.

Combinations of consecutive months were also tested, and the periods defined as 1 to 2 and 1 to 3, corresponded to the periods of January to February and January to March, respectively, from the year before harvest, when flowering took place. In total, 46 periods were analyzed (Paulino, 2000; 2005; Paulino & Volpe, 2001).

Linear correlation coefficients (r) were calculated between NFP for each age class, and meteorological variables from several periods before sampling, aiming to evaluate the individual effect of each of those variables during periods that are not part of the crop cycle. For all periods, the evaluated meteorological variables were: mean air temperature (TMED, ºC), maximum (TMAX, ºC) and minimum (TMIN, ºC) air temperature, rainfall (PREC, mm), reference evapotranspiration (ETM, mm), real evapotranspiration (ETR, mm), water deficit (DEF, mm) and water excess (EXC, mm), number of days with water deficit (NDH) and the ratio ETR/ETM. According to the magnitude and significance of their respective correlation coefficients, sub-groups of predictor variables were selected for each regression model, being first selected those variables with the highest correlation with NFP. However, other crop features were also considered, such as the time of occurrence within the phenological cycle, in order to include different plant cycle stages.

Multiple linear regression models were then fitted for predicting NFP as a function of the selected variables for each plant age class, represented by the expression:

$$Y_{ijt} = b_{ij0} + \sum_{k=1}^{n} b_{ijk} \cdot X_{ijt} + e_{ijt}$$

where Y_{ijt} is the number of fruits per plant in cultivar i ($i=V$: 'Valencia', H: 'Hamlin'), in the age class j ($j=1,2,3$) and in the cropping season t, (t=1990,..., 2004); b_{ij0} is the intercept of each model; b_{ijk} is the coefficient representing the effect of each predictor variable X_{ijt} over Y_{ijt}; e_{ijt} is the random error associated with each observation and n is the number of predictor variables. The backward option of the REG procedure of the SAS System (SAS, 1989) was utilized for selecting sets of predictors, considering the following criteria: (i) p values < 0.20 for the t tests corresponding to each predictor variable; (ii) among the models that did not satisfy criterion (i), the one with the highest determination coefficient was selected.

RESULTS AND DISCUSSION

Influence of meteorological variables on the crop cycle

The time of occurrence of the different phenological stages of citrus varies from season to season within the same region (Reuther, 1973). In this study, the most frequent time of occurrence of the phenological sequence of vegetative growth, flowering and fruit development for sweet orange under the conditions of the São Paulo State, were considered as reference.

Significant correlations between NFP and agrometeorological predictors were observed for 'Valencia' (Table 1) and for 'Hamlin' sweet oranges (Table 2) along the flowering year before harvest and at the beginning of the harvest year, at four stages, in the three age classes: during the summer months (January and February), in the pre-flowering period (April to September), during the flowering (October to No-

Table 1 - Correlation coefficients (r) between the number of fruits per plant and meteorological variables corresponding to different periods during harvest seasons from 1990 to 2004. 'Valencia' sweet orange in three age classes, Limeira, State of São Paulo, Brazil.

Age class[1]	Period[2]	Agrometeorological variable[3]									
		TMAX	TMIN	TMED	PREC	ETM	ETR	DEF	EXC	NDH	ER/EM
1	1 to 2	0.27	0.50*	0.45*	0.27	0.53**	0.71***	-0.25	0.19	-0.14	0.29
1	2	0.10	0.62**	0.36	0.48*	0.42	0.67***	-0.29	0.43	-0.29	0.33
1	4	-0.26	-0.02	-0.16	0.18	-0.15	0.43	-0.45*	0.17	-0.29	0.47*
1	4 to 6	-0.53**	-0.33	-0.50*	-0.06	-0.46*	0.07	-0.34	-0.11	0.13	0.30
1	5	-0.49*	-0.17	-0.33	-0.33	-0.31	-0.11	-0.04	-0.06	0.42	0.00
1	5 to 6	-0.54**	-0.37	-0.52**	-0.21	-0.49*	-0.18	-0.16	-0.26	0.30	0.07
1	6	-0.48*	-0.43	-0.49*	-0.06	-0.48*	-0.20	-0.18	-0.24	0.04	0.09
1	8	0.17	-0.01	0.07	-0.44*	0.12	-0.19	0.27	-0.58**	0.08	-0.23
1	10	-0.62**	-0.73***	-0.73***	-0.19	-0.76***	-0.49*	-0.21	-0.05	-0.15	0.02
1	10 to 11	-0.67**	-0.71***	-0.76***	-0.40	-0.78***	-0.59**	-0.09	-0.32	0.06	-0.08
1	11	-0.43	-0.58**	-0.59**	-0.41	-0.57**	-0.49*	0.18	-0.34	0.21	-0.23
1	12	-0.46*	-0.19	-0.36	0.45*	-0.40	-0.50*	0.27	0.42	0.26	-0.34
1	12 to 13	-0.21	-0.08	-0.15	0.60**	-0.18	-0.17	0.01	0.65***	-0.16	-0.05
1	13	0.15	0.05	0.11	0.43	0.10	0.23	-0.36	0.53**	-0.41	0.40
2	1	0.37	0.56**	0.58**	-0.02	0.60**	0.58**	0.00	-0.10	0.16	0.04
2	1 to 2	0.59**	0.65***	0.71***	0.15	0.76***	0.79***	0.03	0.08	0.22	0.07
2	2	0.43	0.62**	0.59**	0.20	0.63**	0.63**	0.03	0.18	0.14	0.04
2	5	-0.51*	-0.14	-0.33	-0.04	-0.44	0.11	-0.35	0.09	0.04	0.30
2	5 to 6	-0.43	-0.28	-0.40	-0.07	-0.51*	0.08	-0.41	-0.07	0.08	0.34
2	7	0.52**	0.39	0.49*	-0.26	0.46*	0.25	0.10	-0.06	0.16	0.09
2	7 to 8	0.50*	0.34	0.44	-0.43	0.43	-0.08	0.37	-0.12	0.16	-0.28
2	6 to 9	0.32	0.22	0.29	-0.47*	0.31	-0.26	0.35	-0.30	0.34	-0.35
2	7 to 9	0.47*	0.34	0.44	-0.47*	0.45*	-0.27	0.44*	-0.34	0.29	-0.41

Continue...

Table 1 - Continuation.

2	8	0.34	0.18	0.26	-0.31	0.25	-0.28	0.46*	-0.36	0.12	-0.42
2	8 to 9	0.41	0.23	0.37	-0.37	0.39	-0.35	0.46*	-0.32	0.29	-0.45*
2	10	-0.63**	-0.34	-0.54**	-0.11	-0.60**	-0.29	0.25	-0.16	-0.37	0.12
2	10 to 11	-0.56**	-0.39	-0.52**	-0.51*	-0.57**	-0.52**	0.03	-0.44*	0.12	-0.19
2	11	-0.17	-0.38	-0.33	-0.67***	-0.35	-0.57**	0.48*	-0.56**	0.49*	-0.52**
2	12 to 13	-0.16	0.13	0.01	0.54**	-0.01	-0.11	0.19	0.51*	-0.06	-0.19
2	13	-0.16	0.06	-0.07	0.55**	-0.06	0.01	-0.16	0.58**	-0.27	0.15
3	1 to 2	0.55**	0.59**	0.66***	0.09	0.69***	0.60**	0.23	0.03	0.26	-0.15
3	2	0.51*	0.63**	0.67***	0.09	0.68***	0.52**	0.24	0.05	0.22	-0.17
3	4 to 6	-0.34	-0.42	-0.42	-0.10	-0.52**	0.16	-0.46*	-0.23	-0.01	0.42
3	5	-0.30	-0.27	-0.34	-0.22	-0.46*	0.12	-0.38	-0.08	0.10	0.34
3	5 to 6	-0.29	-0.48*	-0.42	-0.26	-0.57**	0.02	-0.40	-0.27	0.15	0.34
3	6	-0.27	-0.52**	-0.39	-0.18	-0.50*	-0.13	-0.25	-0.25	0.09	0.16
3	7 to 8	0.38	0.18	0.30	-0.47*	0.30	-0.07	0.27	-0.24	0.12	-0.23
3	7 to 9	0.48*	0.16	0.36	-0.57**	0.39	-0.35	0.46*	-0.30	0.31	-0.45*
3	8 to 9	0.50*	0.11	0.36	-0.45*	0.39	-0.42	0.51*	-0.25	0.35	-0.51*
3	9	0.52**	0.07	0.42	-0.39	0.43	-0.44	0.52**	-0.24	0.42	-0.53**
3	10 to 11	-0.26	-0.26	-0.28	-0.53**	-0.34	-0.61**	0.37	-0.50*	0.39	-0.48*
3	11	-0.02	-0.40	-0.26	-0.57**	-0.30	-0.59**	0.54**	-0.47*	0.61**	-0.58**
3	12 to 13	0.09	0.25	0.22	0.52**	0.21	0.10	0.17	0.44*	-0.05	-0.16
3	13	-0.09	0.06	-0.02	0.44*	0.00	-0.02	0.05	0.43	-0.03	-0.08

[1] Age class: (1) 3 to 5 year-old plants; (2) 6 to 10 year-old plants; (3) > 10 year-old plants.

[2] Periods 1,…12= January, … until December of the year of flowering; period 13 = January of the harvest year.

[3] TMED, TMAX, TMIN = mean, maximum and minimum air temperature; PREC, ETM, ETR, DEF, EXC, NDH, ER/EM: total rainfall, potential and real evapotranspiration, water deficit and excess, days with water deficit and ratio ETR/ETM.

*, **, ***: significant at probability levels of 0.10, 0.05 and 0.01, respectively.

vember) and at initial fruit set and development (December to January); only those predictors corresponding to periods for which correlations were significant are discussed.

For 'Valencia' sweet orange (Table 1), positive correlations were observed between the NFP and the following predictors: TMIN and TMED, ETM and ETR, for the age class 1, during the periods of January and February of the flowering year before harvest (period 1 to 2). For ETR the highest correlation was also registered in the period 1 to 2, (r = 0.71, $P < 0.01$). PREC during February was also positively correlated with the NFP. For age classes 2 and 3 positive correlations were observed for TMAX, TMIN and TMED, ETM and ETR in the periods corresponding to January and February; highest correlations were observed in the 1 to 2 period for ETR in the age class 2 (r = 0.79; $P < 0.01$), and for ETM in the age class 3 (r = 0.69; $P < 0.01$). For 'Hamlin' sweet orange, in age class 1 (Table 2), positive correlations between NFP and the predictors TMIN, TMED, ETM and ETR were observed for the same periods as for 'Valencia ' sweet orange.

PREC and EXC were also positively correlated with fruit production. In the 1 to 2 period, the ETR/ETM ratio was directly related with NFP. The highest correlations between NPF and predictor variables occurred during the 1 to 2 period, for ETR (r = 0.66; $P < 0.01$) and for PREC (r = 0.65; $P < 0.01$). For age classes 2 and 3, positive correlations occurred between NFP and the following predictors: TMAX and TMIN, ETM and ETR, during the periods corresponding to January and February. The highest correlations were found during the 1 to 2 period for ETM: in age class 2 (r = 0.60; $P < 0.05$) and age class 3 (r = 0.63; $P < 0.05$). Therefore, in those periods which coincide with

Table 2 - Correlation coefficients (r) between the number of fruits per plant and meteorological variables corresponding to at different periods, during harvest seasons from 1990 to 2004. ‘Hamlin’ sweet orange in three age classes, Limeira, State of São Paulo, Brazil.

Age class[1]	Period[2]	Agrometeorological variable[3]									
		TMAX	TMIN	TMED	PREC	ETM	ETR	DEF	EXC	NDH	ER/EM
1	1	0.20	0.66***	0.54**	0.39	0.55**	0.62**	-0.20	0.32	-0.21	0.23
1	1 to 2	0.03	0.61**	0.35	0.65***	0.41	0.66***	-0.36	0.60**	-0.41	0.45*
1	5 to 6	-0.18	-0.10	-0.16	-0.03	-0.31	0.40	-0.57**	-0.13	0.00	0.56**
1	6 to 8	0.29	0.21	0.27	-0.45*	0.25	0.14	0.05	-0.16	0.33	0.00
1	7	0.36	0.24	0.32	-0.46*	0.26	0.05	0.14	-0.05	0.51*	-0.06
1	7 to 8	0.40	0.29	0.37	-0.47*	0.37	-0.03	0.29	-0.08	0.35	-0.23
1	10	-0.45*	-0.26	-0.40	-0.13	-0.40	-0.19	-0.17	-0.24	-0.09	0.07
1	10 to 11	-0.44*	-0.38	-0.44	-0.47*	-0.47*	-0.41	0.01	-0.44	0.26	-0.12
1	11	-0.21	-0.43	-0.39	-0.47*	-0.42	-0.49*	0.30	-0.35	0.41	-0.36
1	13	-0.51*	0.11	-0.25	0.56**	-0.26	-0.18	-0.17	0.59**	-0.42	0.13
2	1 to 2	0.46*	0.46*	0.52**	-0.05	0.60**	0.50*	0.22	-0.13	0.26	-0.16
2	5	-0.63**	-0.40	-0.58**	-0.11	-0.65***	0.10	-0.46*	0.11	0.05	0.38
2	5 to 6	-0.36	-0.44	-0.44	-0.25	-0.51	0.03	-0.37	-0.18	0.21	0.30
2	6 to 8	-0.06	-0.18	-0.13	-0.44*	-0.16	-0.16	0.03	-0.21	0.15	-0.09
2	10	-0.57**	-0.32	-0.49*	-0.16	-0.54**	-0.03	-0.10	-0.15	-0.19	0.30
2	10 to 11	-0.50*	-0.40	-0.50*	-0.44	-0.53**	-0.41	-0.05	-0.30	0.27	-0.09
2	11	-0.15	-0.41	-0.33	-0.56**	-0.35	-0.64***	0.57**	-0.46*	0.51*	-0.60**
2	12 to 13	-0.41	0.01	-0.19	0.50*	-0.20	-0.18	0.01	0.45*	-0.14	-0.04
3	1 to 2	0.51**	0.50*	0.57**	0.05	0.63**	0.51*	0.26	0.03	0.22	-0.19
3	2	0.41	0.54**	0.55**	0.09	0.58**	0.42	0.23	0.08	0.16	-0.19
3	3 to 4	-0.20	0.23	-0.03	0.41	0.00	0.53**	-0.59**	0.39	-0.71***	0.63**
3	4	-0.21	0.10	-0.07	0.40	-0.07	0.65***	-0.56**	0.31	-0.52**	0.61**
3	4 to 5	-0.35	-0.22	-0.30	0.16	-0.34	0.48*	-0.62**	0.20	-0.21	0.60**
3	5 to 8	0.11	-0.18	-0.06	-0.60**	-0.10	-0.17	0.08	-0.53**	0.36	-0.09
3	6 to 8	0.22	-0.09	0.06	-0.62**	0.06	-0.32	0.27	-0.46*	0.35	-0.30
3	6 to 9	0.29	-0.11	0.09	-0.61**	0.11	-0.43	0.41	-0.44*	0.41	-0.43
3	10 to 11	-0.39	-0.31	-0.38	-0.36	-0.44	-0.53**	0.19	-0.33	0.21	-0.29
3	11	-0.16	-0.30	-0.26	-0.45*	-0.30	-0.54**	0.47*	-0.42	0.48*	-0.48*
3	12	-0.05	0.16	0.08	0.53**	0.04	0.01	0.04	0.48*	-0.18	-0.03
3	12 to 13	-0.33	-0.01	-0.15	0.60**	-0.19	-0.14	-0.06	0.58**	-0.28	0.02

[1] Age class: (1) 3 to 5 year-old plants; (2) 6 to 10 year-old plants; (3) > 10 year-old plants.
[2] Periods 1,…12= January, … until December of the year of flowering; period 13 = January of the harvest year.
[3] TMED, TMAX, TMIN = mean, maximum and minimum air temperature; PREC, ETM, ETR, DEF, EXC, NDH, ER/EM: total rainfall, potential and real evapotranspiration, water deficit and excess, days with water deficit and ratio ETR/ETM.
*, **, ***: significant at probability levels of 0.10, 0.05 and 0.01, respectively.

the summer vegetative flush of citrus for both cultivars under study, an adequate water supply together with the high temperature and evaporative demand have a positive impact on fruit production of the following season, probably as function of the increased photosynthetic area due to an increased vegetative growth. Vegetative growth of citrus plants depends on the summer vegetative flushes (Spiegel Roy & Goldschmidt, 1996). Shoot growth distribution and extension are affected by temperature, with the largest dry matter accumulation occurring under conditions of long days and high diurnal and nocturnal mean temperatures (Davies & Albrigo, 1994). Lower temperatures reduce the potential growth, resulting in lower annual increments of vegetative growth and mostly, smaller tree size and lower productive potential (Gat et al., 1997). Higher temperatures increase the vegetative growth, while the water deficit reduces the vegetative growth (Chaikiattiyos et al., 1994).

For 'Valencia' sweet orange, in some of the periods corresponding to the initial months of pre-flowering (April to June), the predictor variables TMAX, TMED and ETM were inversely correlated with fruit production per plant for age class 1, with the largest correlation being observed for TMAX in the period 5 to 6 ($r = -0.54$; $P < 0.05$). DEF during period 4 was inversely correlated with yield ($r = -0.45$; $P < 0.10$) and therefore, in the same period, the ratio ETR/ETM was positively correlated with yield ($r = 0.47$, $P < 0.10$). For age class 2, the maximum air temperature in the period 5 and the maximum evapotranspiration in the period 5 to 6 (both with $r=-0.51$, $P < 0.10$), were also negatively correlated with NFP. For age class 3 in the periods 5 to 6 and 6, the TMIN and ETM were inversely correlated with NFP. This inverse relationship was also observed for DEF in the period 4 to 6 ($r = -0.46$, $P < 0.10$).

Also, during the first months of pre-flowering of 'Hamlin' orange, the predictor variables DEF and ETR/ETM ratio were significantly correlated with NFP for age class 1, and during the period 5 to 6, when the highest correlations were observed, the DEF had a negative correlation ($r = -0.57$; $P < 0.05$), while ETR/ETM ratio, consequently, presented a positive correlation with fruit production ($r = 0.56$, $P < 0.05$). For age class 2, in the period 5, the variables TMAX ($r = -0.63$, $P < 0.05$), ETM ($r = -0.65$, $P < 0.01$) and DEF were also negatively correlated with NFP. For age class 3, several positive correlations occurred for the periods corresponding to months 4, 5 and 6, mainly for the variables DEF and NDH, which were negatively correlated with NFP, with the higher correlation being observed for the NDH in the period 3 to 4 ($r = -0.71$; $P < 0.01$). Therefore, the occurrence of high temperatures, high evaporative demands and intense water deficit during the period from April to June had a depressive effect over fruit production per plant. Previous studies demonstrated a negative influence of high temperatures on fruit yield of 'Pêra' sweet orange occurred in these months in the Limeira region (Paulino, 2000; Paulino & Volpe, 2001). Climatic conditions of the pre-flowering period affect fruit set, since they determine the time of flowering (early or late) and its duration (extended or concentrated) (Ben Mechlia & Carrol, 1989). Therefore, the occurrence of stress conditions due to water deficit, high temperatures and high evaporative demands during those months (much earlier than the normal flowering period, in October/November), probably leads to the anticipation of flowering to a period when meteorological conditions are less adequate for pollination and fruit set (Lomas & Burd, 1983).

Regarding the final period of pre-flowering (July to September), a negative correlation was observed in 'Valencia' orange between NFP and the predictor variables PREC ($r = -0.44$; $P < 0.10$) and EXC ($r = -0.58$, $P < 0.05$), during the period 8, for age class 1. For age class 2, positive correlations were observed for the variables TMAX, TMED and ETM in the periods 7, 7 to 8 and 7 to 9. Water deficit during the periods 7 to 9, 8 and 8 to 9 was also directly related with NFP. PREC presented a negative correlation with NFP during the periods 6 to 9 and 7 to 9 ($r = -0.47$, $P < 0.10$). For age class 3, the predictors TMAX and DEF during periods 7 to 9, 8 to 9 and 9 were positively correlated with NFP while PREC presented opposite relationship during the periods 7 to 8, 7 to 9 and 8 to 9.

Negative correlations were observed for the 'Hamlin' sweet orange in age class 1, between July and September, between rainfall (periods, 7, 6 to 8 and 7 to 8) and NFP. NDH in period 7 was positively correlated with NFP. For the age class 2, PREC during period 6 to 8 was negatively correlated with fruit production ($r = -0.44$, $P < 0.10$). Yet for age class 3, PREC presented similar negative correlations ($r = -0.60$ to 0.62; $P < 0.05$) with fruit production for the periods 5 to 8, 6 to 8 and 6 to 9. EXC also presented negative correlations with NFP for the same periods. Therefore, the occurrence of high temperatures, high evaporative demand and water deficit, during the months preceding flowering, result in higher fruit yield per plant and, consequently, the occurrence of rainfall and water excess that lead to lower fruit yield per plant. Pre-flowering is the period when floral induction occurs, and it may be promoted by water deficit during the drying season in winter in the tropical regions, or by low temperatures in subtropical regions

(Reuther, 1988; Valiente & Albrigo, 2004). Any reduction or stop of vegetative growth, common under water stress or low temperatures, may be considered as the triggering stimulus for floral induction of citrus (Gat et al., 1997). As the stress intensity increases, more reserves (carbohydrates and ammonia) are accumulated, which will be directed to the development of reproductive structures (Lovatt et al., 1988). The results obtained in this study meet these statements, once the factors that generate stress in the period (water deficit, high temperatures and high evapotranspiration demands) resulted in larger fruit production per plant, probably due to an enhanced reserve accumulation caused by the intense stress.

For 'Valencia' sweet orange of the age class 1, during the periods related to flowering and initial fruit set stages (months 10 and 11), the variables TMAX, ETM and ETR were inversely correlated with fruit production, with the highest correlation occurring during the period 10 to 11 for ETM ($r = -0.78$, $P < 0.01$). For the age class 2, besides temperature and evapotranspiration, rainfall and water excess were also negatively correlated with the number of fruits per plant. The highest correlation was found for PREC in period 11 ($r = -0.67$, $P < 0.01$). For the age class 3, ETM, PREC and EXC had a negative effect over fruit yield, with the highest correlation found in the period 10 to 11 for ETM ($r = -0.61$, $P < 0.05$). Positive correlations observed between NFP and DEF and NDH during the period 11, for age classes 2 and 3, were derived from the low rainfall occurrence and the consequent lower water excess.

For 'Hamlin' sweet orange, during the months 10 and 11, for age class 1, TMAX, ETM, ETR, PREC and EXC were inversely correlated with fruit yield, with the highest correlation occurring in the period 11 for ETR ($r = -0.49$, $P < 0.10$). For age class 2, the same variables described for age class 1 were also negatively correlated with the number of fruits per plant. The highest correlation was observed for the ETR in period 11, with ($r = -0.64$, $P < 0.01$). For age class 3, PREC and ETR were negatively correlated with NFP, with the highest correlation occurring in the period 11 for ETR ($r = -0.54$, $P < 0.05$). As mentioned for the 'Valencia' sweet orange, the positive correlations found between NFP and DEF and NDH, for age classes 2 and 3, were derived as a consequence of the low rainfall occurrence. Therefore, the occurrence of high temperatures and high evaporative demands, as well as rainfall and water excess during flowering and initial fruit set, reduce the fruit production per plant. Fruit set depends on the rainfall during the flowering period, while the effect of rainfall on flowering and fruit set may be due to direct mechanical injuries of the flowers and pollination restrictions (Ben Mechlia & Carrol, 1989). Anthesis and pollination are negatively affected by high relative air humidity. Stress caused by low or high temperatures may also reduce pollination, damaging and destroying the pollen grains and the pollinic tube, causing floral atrophy, while the occurrence of moderate temperatures and relatively dry air conditions promote flower opening (Nogueira, 1979). Besides, the coincidence of blooming with the rainy and humid season leads to an increased severity of disease symptoms, such as the citrus flower rot, that affects flowers and young fruitlets causing their drop (Prates & Rodrigues, 1995). Rainfall during flowering is inversely correlated with 'Hamlin' sweet orange yield, in Botucatu, SP, Brazil (Tubelis & Salibe, 1989; 1991), and it is also associated with higher occurrence of the citrus flower rot (Tubelis, 1995). The same suppressive effect of rainfall over flowering was also observed for the 'Pêra' sweet orange, in Limeira, SP, Brazil (Paulino & Volpe, 2001).

For age class 1 'Valencia' sweet orange plants at the initial fruit set and early fruit growth stages (December to January), TMAX and ETR were negatively correlated with the yield in the period 12. Rainfall during periods 12 ($r = 0.45$, $P < 0.10$) and 12 to 13 ($r = 0.60$, $P < 0.05$), and the EXC during periods 12 to 13 ($r = 0.65$, $P < 0.01$) and 13 ($r = 0.53$, $P < 0.05$) contributed to higher fruit yield per plant. For the age class 2, PREC and EXC were directly correlated with yield in the periods 12 to 13 and 13. For the age class 3, such effect occurred in the same periods (12 to 13 and 13), when rainfall showed a positive correlation with NDH ($r = 0.52$, $P < 0.05$ and $r = 0.44$, $P < 0.10$, respectively).

For 'Hamlin' sweet orange plants of age class 1, during fruit set and early fruit growth, TMAX was negatively correlated with yield in the period 13. Also in this period PREC ($r = 0.56$, $P < 0.05$) and the EXC ($r = 0.59$, $P < 0.05$) were directly correlated with the NFP. For age class 2, PREC ($r = 0.50$, $P < 0.10$) and EXC ($r = 0.45$, $P < 0.10$) were positively correlated with fruit yield in the period 12 to 13. For the age class 3, the same effect occurred in the periods 12 and 12 to 13, when PREC ($r = 0.53$ and $r = 0.60$, $P < 0.05$, respectively) and EXC ($r = 0.48$, $P < 0.10$ and $r = 0.58$, $P < 0.05$, respectively) showed positive correlations with NDH. As observed in 'Valencia' sweet orange, the occurrence of moderate temperatures and adequate water supply during the fruit set and early fruit growth stages led to an increase of NDH (Rodrigues, 1991; Paulino, 2000; Paulino & Volpe, 2001).

For both sweet orange cultivars studied herein, in all age classes, correlation patterns were consistent regarding time of occurrence and sets of variables that had higher influence on NFP, although with different correlation magnitudes and respective significance levels. Such consistence was also found for relationships between meteorological variables and NFP for ‘Pêra’ sweet orange (Paulino, 2005).

Agrometeorological models

Parameter estimates and results of model evaluation for the cultivars ‘Valencia’ and ‘Hamlin’ by age class show (Tables 3 and 4) that despite of the fact that all the potentially predictors of the initial subgroups had significant correlations with the NFP, after applying the selection criteria based on the backward procedure, only those variables with the best predictive ability as a whole did finally remain in the models. Because of that, variables with higher individual correlation with NFP but also correlated to other candidate predictors did not always remain in the final models. The adequacy of the models here represented by the agreement between observed NFP and respective predicted values for each cultivar and age class, is shown in Figure 1.

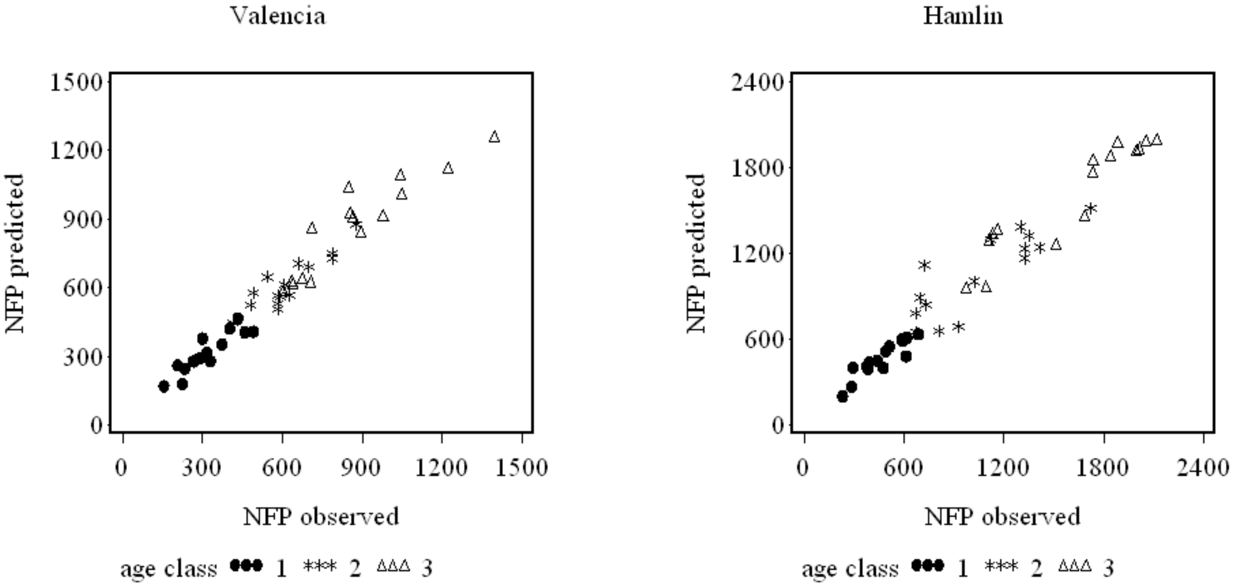

Figure 1 - Agreement between observed number of fruit per plant (NFP) and respective values predicted by the agrometeorological models selected for each cultivar (‘Valencia’ or ‘Hamlin’ sweet orange) and age classes (1, 2 or 3).

Table 3 - Parameter estimates of multiple regression models describing the variation pattern of the number of fruits per plant as a function of meteorological variables, determination coefficients (R^2) and p-values associated with the F tests for ‘Valencia’ orange in three age classes (AC)*

AC*	Predictor	Parameter	Estimate	Standard error	p_1**	p_2 ***	R^2
1	Intercept	β_{V10}	82.16	297.91	0.7878	0.0003	0.81
1	ETR 1 to 2	β_{V11}	2.37	1.28	0.0921		
1	ETM 10	β_{V12}	-3.32	0.94	0.0047		
1	EXC 12 to 13	β_{V13}	0.27	0.16	0.1261		
2	Intercept	β_{V20}	-248.01	330.89	0.4693	0.0003	0.81
2	ETM 1 to 2	β_{V21}	3.85	1.49	0.0250		
2	PREC 11	β_{V22}	-0.71	0.21	0.0068		
2	PREC 13	β_{V23}	0.41	0.21	0.0819		
3	Intercept	β_{V30}	2779.32	366.58	0.0000	0.0001	0.85
3	ETM 5 to 6	β_{V31}	-15.71	3.04	0.0003		
3	PREC 6 to 9	β_{V32}	-2.05	0.40	0.0003		
3	PREC 13	β_{V33}	0.48	0.32	0.1612		

*Age class: (1) 3 to 5 year-old plants; (2) 6 to 10 year-old plants; (3) > 10 year-old plants.
***P* values associated with the F tests for quantifying influence each single predictor in each age class model (p_1)
****P* values associated with F tests for quantifying joint influence of all predictors in the each age class model (p_2).

Table 4 - Parameter estimates of multiple regression models describing the variation pattern of the number of fruits per plant as a function of meteorological variables, determination coefficients (R^2) and p values associated with F test for 'Hamlin sweet orange in three age classes (AC)*.

AC*	Predictor	Parameter	Estimate	Standard error	p_1**	p_2 ***	R^2
1	Intercept	β_{H10}	-271.61	221.84	0.2489	0.0007	0.83
1	PREC 1 to 2	β_{H11}	0.35	0.18	0.0779		
1	DEF 5 to 6	β_{H12}	-4.10	1.44	0.0173		
1	NDH 7	β_{H13}	22.03	8.49	0.0268		
1	EXC 13	β_{H14}	0.57	0.24	0.0372		
2	Intercept	β_{H20}	3221.38	807.27	0.0021	0.0023	0.72
2	ETM 5	β_{H21}	-33.14	13.80	0.0351		
2	ETR 11	β_{H22}	-8.84	3.81	0.0407		
2	PREC 12 to 13	β_{H23}	1.12	0.50	0.0487		
3	Intercept	β_{H30}	2381.80	1694.0	0.1900	0.0002	0.87
3	ETM 1 to 2	β_{H31}	10.66	4.58	0.0420		
3	NDH 3 to 4	β_{H32}	-36.71	11.32	0.0088		
3	ETM 5	β_{H33}	-23.26	14.80	0.1472		
3	PREC 6 to 8	β_{H34}	-2.16	1.26	0.1182		

*Age class: (1) 3 to 5 year-old plants; (2) 6 to 10 year-old plants; (3) > 10 year-old plants.

** P-values associated with the F tests for quantifying influence each single predictor in each age class model (p_1)

*** P-values associated with F tests for quantifying joint influence of all predictors in the each age class model (p_2).

'Valencia' sweet orange

For 'Valencia' sweet orange, the joint influence of selected predictors on NFP was high (F test, $P < 0.01$) for all age classes, with determination coefficients (R^2) of 0.81, 0.81 and 0.85, respectively (Table 3).

For 'Valencia' sweet orange plants of age class 1, the predictor variables of the final model were ETR in periods 1 to 2 (ETR1to2), ETM in period 10 (ETM10) and EXC in period 12 to 13 (EXC12to13), which correspond to the stages of summer vegetative flush, flowering and initial fruit growth, respectively. Variables ETR1to2 and EXC12to13 showed a positive effect and ETM10 has a negative effect over NFP. For 'Valencia' sweet orange plants of age class 2 the predictor variables that remained in the model were ETM in the period 1 to 2 (ETM1to2) and PREC during periods 11 (PREC11) and 13 (PREC13), which, as in the case of the age class 1 of the same cultivar, affected the stages of summer vegetative flush, flowering and fruit set and initial fruit growth. The ETM1to2 and the PREC13 variables had a positive contribution and the PREC11 variable has a negative effect over the fruit production per plant. For 'Valencia' orange plants of age class 3, the predictor variables that remained in the model were reference evapotranspiration in the period 5 to 6 (ETM5to6) and rainfall in the periods 6 to 9 (PREC6to9) and 13(PREC13), and their effects were observed over the stages of pre-flowering and initial fruit growth. The first two variables had a negative effect over fruit production per plant, while the third variable had a positive impact. Fitted models for each age class with respective 95% confidence limits are shown in Figure 2.

'Hamlin' sweet orange

As for 'Valencia' sweet orange, the joint contribution of selected predictors for explaining NFP variability was also high ($P < 0.01$) for the 'Hamlin' sweet orange in all age classes, with determination coefficients of 0.83, 0.72 and 0.87 for the age classes 1, 2 and 3, respectively (Table 4).

Selected predictor variables in the model for the age class 1 of 'Hamlin' sweet orange were rainfall in the period 1 to 2 (PREC1to2), water deficit in the period 5 to 6 (DEF5to6), number of days with water deficit in the period 7 (NDH7) and water excess in the period 13 (EXC13), which affected the stages of summer vegetative flush, pre-flowering and initial fruit growth, respectively. Fruit production per plant had a positive response for variables PREC1to2, NDH7 and EXC13 and a negative response for the variable DEF5to6. For 'Hamlin' sweet oranges of age class 2, the final model was composed by ETM in the period 5 (ETM5), ETR in the period 11 (ETR11) and PREC in the period 12 to 13 (PREC12to13), which affect the stages of pre-flowering, flowering and fruit set and initial fruit growth, respectively. The variables ETM5 and ETR11 had a negative impact over fruit production and the variable PREC12to13 had a positive impact. For ‘Hamlin’ sweet oranges of age class 3 the predictor variables were reference evapotranspiration in the period 1 to 2 (ETM1to2), NDH in the period 3 to 4 (NDH3to4), ETM in the period 5 (ETM5) and PREC in the period 6 to 8 (PREC6to8), which affected the stages of summer vegetative flush and pre-flowering, respectively. The variable ETM1to2 had a positive effect over NFP, while the variables NDH3to4, ETM5 and PREC6to8 exerted a negative effect. Observed and predicted NFP values for each age class, with respective 95% confidence limits, are shown in Figure 3.

Periods that composed the models for both orange cultivars included the months of flowering and initial fruit set stages (up to the months 10 to 11) or the fruit set and initial fruit growth stages (up to months 12 and 13). The exception occurred for ‘Hamlin’ sweet oranges of age class 3, which had data input only until the pre-flowering stage (August).

The determination coefficients obtained in all the models for both cultivars ranged between 0.72 (age class 2 of the ‘Hamlin’ sweet orange) and 0.87 (age class 3 of the ‘Hamlin’ sweet orange). Those coefficients correspond to percent of yield variability explained by the respective sets of predictor variables. According to Albisu (1982), who obtained agrometeorological models for the Mediterranean climatic conditions with R^2 values varying from 0.77 to 0.85, those values are considered high for citrus yield empirical models. Besides the high values for summary measures such as R^2, and high relative contribution of selected predictors (low p-values), the adequate goodness-of-fit of the selected empirical agrometorological models can also be observed in Figures 1 and 2 and 3: no outliers or systematic departures were found, confirming the suitability of selected predictors. Therefore, results of model evaluation indicate that they presented satisfactory performance and are potentially useful for fruit yield prediction per plant in the Limeira region.

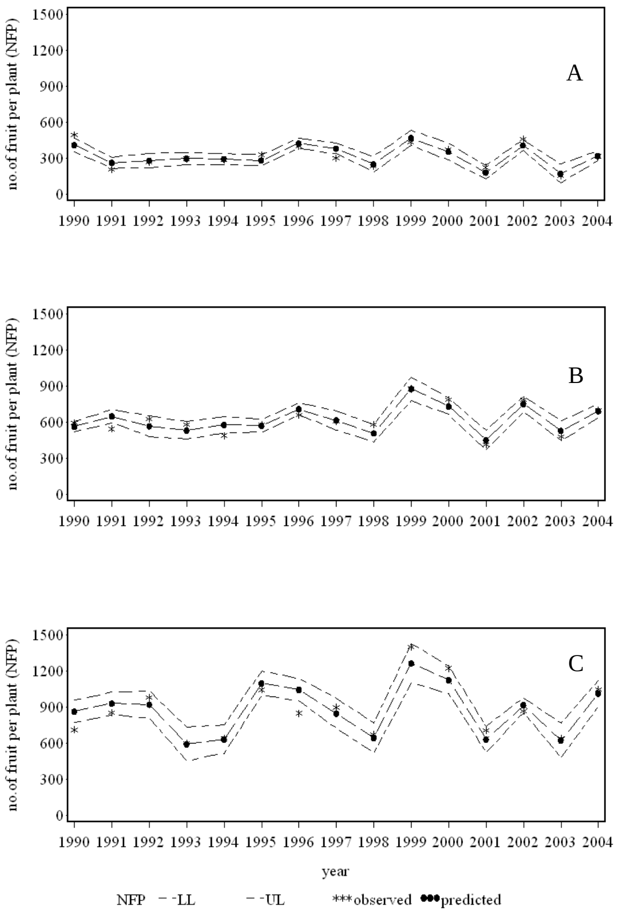

Figure 2 - Observed and predicted values for the number of fruit per plant (NFP) of ‘Valencia’ sweet orange with respective lower and upper 95% confidence limits. Age classes 1(A), 2(B) and 3 (C).

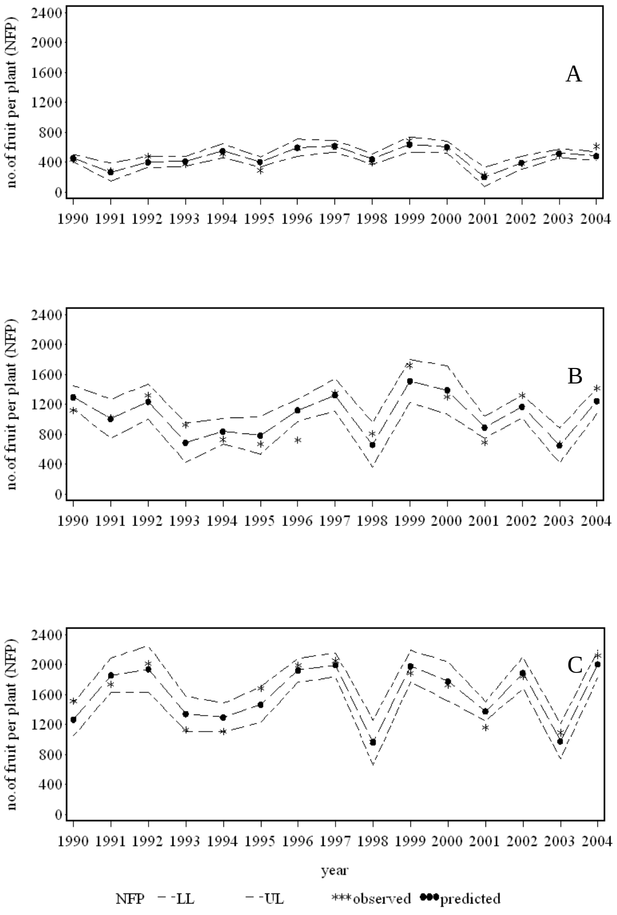

Figure 3 - Observed and predicted values for the number of fruit per plant (NPF) of ‘Hamlin’ sweet orange with respective lower and upper 95% confidence limits. Age classes 1(A), 2(B) and 3 (C).

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