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Monitoring Strategies for Precise Production of High Quality Fruit and Yield in Apple in Emilia-Romagna

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Research has shown that pomefruit orchard production can be forecast. Basic information about orchard characteristics as tree density, fruit load and fruit size can translate into useful information on orchard production. In most cases the complete flow of this information is only available after harvest. Precision horticulture integrates this information in order to evaluate the management performed by the grower, and to assess whether it is in line to achieve the desired targets or not. The Department of Agricultural Sciences of the University of Bologna and HK-Horticultural Knowledge (HK, 2011) after several years of conducting experiences of precise fruit growing in commercial orchards cooperate to bring to fruition this novel approach. Precise measurement of fruit growth is justified on the concept that the fruit can be considered as the most relevant indicator of how well is the process progressing. A four year experiment will be presented. Fruit maximum diameter was recorded every other week during the cell expansion phase of growth. The data were processed and a diagnosis was released in real time to the grower, assessing the progress of the crop, and serving as a verification that the applied management techniques are yielding the expected production result. The real time forecast has been used to evaluate a comparison between predicted and the real breakdown of the total yield into size categories, which allows to release also a very accurate estimate of orchard yield for the packing house.

1. Introduction

Decisions on orchard management are in most cases based on visual and subjective observation, a result of experience rather than based on objective information (Manfrini et al. 2012). The monitoring strategies mostly used release information on environmental variation, which is not directly/easily referred to crop status, often making the interpretation of the seasonal production system difficult (Schueller et al. 1999). Horticultural systems contain a lot of unused or hidden information on the crop (Zadravec et al. 2013). These data are an important source of information for growers, technicians and pack-houses but often untapped. Parameters such as fruit diameter (Morandi et al. 2007), crop load (Manfrini et al.,2009) or calculated production information (Manfrini et al. 2012) can be recorded or calculated along the season. However real-time monitoring systems on fruit production are not common and management is usually performed using subjective practices (Ellis et al. 2010). Growers need real time information for many issues related to crop status. In apple production systems, the control of fruit size, and consequently apple quality (Link, 2000), can be achieved through the application of plant growth regulators (Marini et al. 2003) and other managing practices as irrigation scheduling for controlling both vegetative and fruit growth (Ebel et al., 1995). However, not many activities related to production and quality are the focus of monitoring or subjected to quality control processes to assess their usefulness before harvest (Manfrini et al. 2009). Although Decision Support Systems (DSS) has increased since the 1980s, and have been developed in similar fields as viticulture (Rossi et al. 2014) DSS for managing fruit growth are missing because of the absence of a quick and effective indicator that can be easily implemented in commercial fruit production. Because they are busy and have little time, fruit growers need monitoring schemes that are both rapid and accurate. The main aim of this paper is to present an approach that may help fill this knowledge gap. The intention is to provide both the grower and the consultant with a real time decision support system at critical times of the season and to provide information to help packing-houses to better plan harvest and logistics. In this case study, fruit growing monitoring tools have been applied to an apple orchard in Italy along the four different years.

2. 2. Materials and Methods

2.1 Location and Plant Material

The study was conducted between 2010 and 2013 growing season in a commercial apple orchard located in the province of Cesena, Italy. Data were collected from a 1.36 ha block of Pink Lady® apple trees planted in 2004, grafted on M9 rootstock and trained as slender spindle at the density of 2381 trees ha^{-1} (4.2 X 1.0 m); the trees were under a standard management protocol.

2.2 Data Collection and Rational Use of Tools

In the four years of the experiment, beginning after completion of cytokinesis, i.e. the final week of June or the first of July, the maximum equatorial diameter of 20 fruit on 14 randomly selected trees among the rows for a total of 280 fruit/orchard was recorded as described in figure 1.

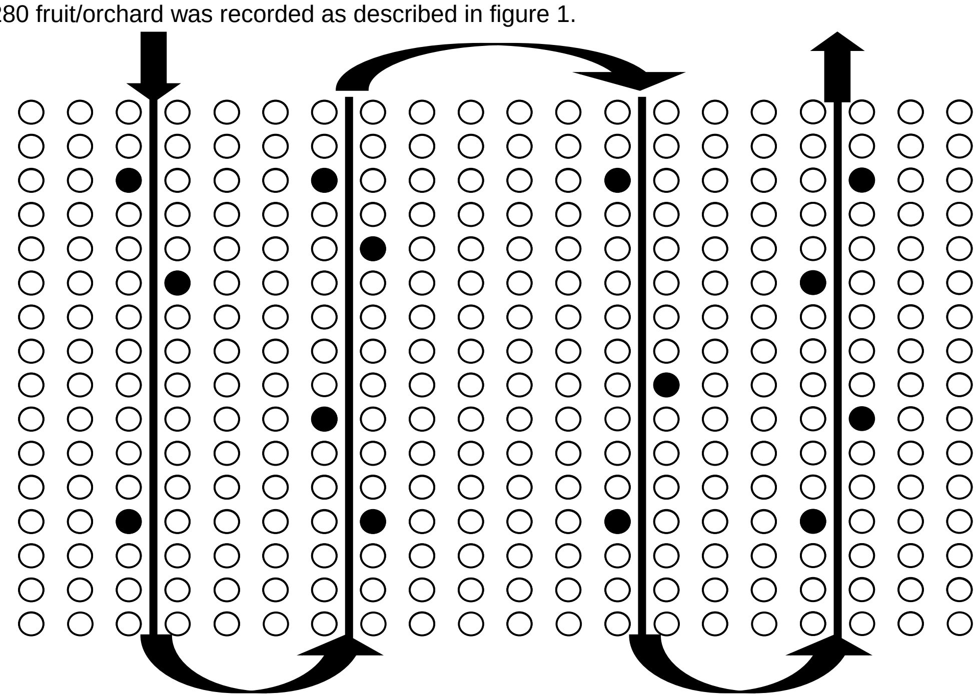

Figure 1. Tree selection strategy for data collection. The trees and rows selection have been randomly executed every measurements. On each tree 20 maximum diameter measurements have been performed.

The measurements normally took place every other week for a total of 5/6 times along the growing season. Data were recorded by a Calibit (Calibit, 2013) a digital calliper fitted with an onboard datalogger (figure 2). This calliper allows a single person to record all 280 measurements in less than 30 minutes each time and a total of a less than 3 hours in a season. Because the growth rate of apple fruit has been shown to be linear in the second part of the season (Goffinet et al. 1995) when the fruit enlargement is driven by cell expansion, an accurate prediction of fruit diameter (size) at a nominal harvest date can be made as reported in table 1 (Lakso et al. 1995). In this experiment the harvest date was set on October 20th. A linear regression has been calculated on all the predicted vs. actual data and an R^2 value >0.98 was found. Since the diameter of the fruit has also been shown to be strongly related to the mass of the fruit (De Silva et al. 1997) this information can be used to predict fruit weight by the equation (1):

$$W = a * D(mm)^b \qquad (1)$$

where W is the fruit weight in grams, D is the fruit diameter expressed in millimetre and a and b are parameters specific to Pink Lady®. These parameters were obtained in 2007 by regressing diameter and weight data from a large number of fruit picked during the whole season; the R^2 of the relationship was > 0.99. The same equation allows forecasting fruit distribution in size class categories both in percentage (table 2) and t/ha (table 3). This was done according to the commercial standards, which increase by 5 mm, starting from 65 mm to 90 mm, was also assessed (table 2 and 3). The data for this paper was analysed comparing predicted values with real orchard production data using as a variate the different years applying respectively the glimmix procedure and a Mixed model analysis. Crop load was assessed by fruit counts on the last measurement performed in August, following the protocol described by Manfrini et al. (2009). The crop load (number fruit/tree) was 106, 160, 67, 161, from 2010 to 2013 respectively. The multiplication between the expected fruit size at harvest obtained in the last measurement prediction (table 1), the crop load and the tree density, permit predicting the orchard production of the current year (table 2).

Figure 2. Digital Caliper with onboard datalogger (Calibit). 1Datalogger; 2Recording Button; 3 Data display

Table 1. Growth measurement among the years and predicted diameter . First day of measurement do not include a predicted diameter because two subsequent dates are needed to obtain the forecast

Year				**2013**		
Day of Measurement		**3/7**	**12/7**	**26/7**	**9/8**	**2/10**
Average diameter measured (mm)		42.7	46.0	51.8	55.0	67.0
Predicted diameter at harvest (mm)			69.9	73.7	72.0	71.8
Year				**2012**		
Day of Measurement		**22/6**	**10/7**	**26/7**	**10/8**	**25/9**
Average diameter measured (mm)		40.1	47.6	54.1	60.1	69.6
Predicted diameter at harvest (mm)			71.2	73.7	75.9	74.6
Year				**2011**		
Day of Measurement		**15/6**	**30/6**	**13/7**	**27/7**	**9/8**
Average diameter measured (mm)		38.9	43.8	49.6	54.0	59.1
Predicted diameter at harvest (mm)			64.7	69.8	71.0	73.1
Year				**2010**		
Day of Measurement	**22/6**	**6/7**	**20/7**	**3/8**	**16/8**	**10/9**
Average diameter measured (mm)	41.3	48.3	53.5	59.8	62.8	67.3
Predicted diameter at harvest (mm)		75.4	75.2	77.7	77.4	75.8

3. Result and Discussion

Pink Lady® is a cultivar with a high selling value for growers, but only if fruit size at harvest (not considering the blush color) reaches between 70 and 85 mm. In 2011, the forecast average fruit diameter on June 30^{th}

falls in a smaller category with a size equal to 64.7 mm (table 1). Because in this period fruit growth is still very sensitive to crop load, additional fruit thinning (a key management practice) was suggested. A reduction of the carbon sinks on the tree and a smaller number of fruit among which to partition tree resources would have a positive effect to the fruit growth (Morandi et al. 2011). The response to thinning is apparent in the June 13th forecast, where the predicted diameter at harvest was close to 70 mm (table 1). This indicates the usefulness of the thinning treatment, even more so in this case, since the subsequent August fruit count revealed a still quite high crop load (average of 160 fruit/tree). The effects of excessive crop load can be noticed in 2013, when 161 fruit/tree were estimated and the expected diameter was the smallest (71.8 mm) of the 4 years experiment (table 1). Also the predicted and harvested breakdown in size categories, both in percentage and in quantity (t/ha), confirm a higher occurrence of the smaller fruit categories, with more than 50 of the total production smaller than the 75 mm class, even though the total production was the highest (table 3). This result could be undesired because profit from a high quality apple, such as Pink Lady®, often does not correlate with the quantity but the quality (size) of production. Very few anomalies were recorded in fruit growth in the remaining measurements of the four seasons, indicating a prediction relatively constant and always above the optimum size range. This could have been used for providing feedback for other managing activities such as irrigation scheduling. As well as generating a mean diameter forecast, the last August measurement was used to forecast a harvest size for every single fruit monitored (280 fruit in total), with the goal of building up a total fruit size class distribution (table 2 and 3).

Table 2. Size classes distribution of the harvest and the predicted values

		Size Classes (%)*						
Year	**Data**	**<65**	**65/70**	**70/75**	**75/80**	**80/85**	**85/90**	**>90**
2010	**Forecast**	0.0	4.2	36.7	50.8	8.3	0.0	0.0
	Real	0.0	16.5	47.3	31.5	4.4	0.2	0.0
2011	**Forecast**	0.0	8.1	38.1	43.1	7.5	2.5	0.6
	Real	0.0	12.3	44.1	35.0	8.1	0.5	0.0
2012	**Forecast**	0.0	4.6	12.9	37.5	30.7	11.8	2.5
	Real	0.0	5.4	22.8	33.8	27.8	9.0	1.2
2013	**Forecast**	7.1	26.1	43.2	21.8	1.8	0.0	0.0
	Real	0.0	11.8	53.3	31.7	3.0	0.1	0.0

*Means separation within columns by glimmix procedure

Table 3. Total yield and size classes distribution of the harvest and the predicted values. The expected fruit production per ha was calculated considering a tree density of 2381 tree/ha

			Size Classes (t/ha)*						
Year	**Data**	**Total Production (t/ha)***	**<65**	**65/70**	**70/75**	**75/80**	**80/85**	**85/90**	**>90**
2010	**Forecast**	45.15	0.00	1.88	16.56	22.95	3.76	0.00	0.00
	Real	54.92	0.00	9.09	25.96	17.32	2.40	0.13	0.02
2011	**Forecast**	67.35	0.00	5.47	25.68	29.05	5.05	1.68	0.42
	Real	63.78	0.00	7.85	28.15	22.31	5.17	0.29	0.01
2012	**Forecast**	28.95	0.00	1.34	3.72	10.86	8.89	3.41	0.72
	Real	38.07	0.00	2.04	8.68	12.88	10.58	3.44	0.45
2013	**Forecast**	62.02	4.43	16.17	26.80	13.51	1.11	0.00	0.00
	Real	66.56	0.00	7.89	35.47	21.09	2.02	0.08	0.01

*Means separation within columns by a Mixed model analysis.

The forecast production expressed both in percentage and t/ha was plotted against actual values and no differences were found. This attests to the effectiveness of the protocol implemented and the reliability of the forecasting performed along the season. This information is also highly valuable for the sales department of the packing house, which can thus have a very good idea of the product they have to sell, much earlier than they are currently used to (2 months before harvest time). This provides them with the opportunity to start contacting perspective clients sooner in the season, and with a much clearer picture of the upcoming marketing scenarios.

4. Conclusion

This paper shows a four year case study illustrating the possibility and the advantages provided by adopting precise orchard management, if this is based on sound assessment of orchard performance, and robust modelling tools. It has been possible to provide timely feedback to the grower about a problem of excessive crop load, which would have caused insufficient fruit size at harvest, at a time when it was possible, and practical, to correct it. The removal of fruit carried out in mid-July was effective and allowed to increase fruit growth enough to reach a satisfactory fruit size at harvest. Moreover, due to this real-time decision support, it has been possible to deliver the packing house crucial information on their crop status in terms of size distribution, up to two months before harvest. This is valuable because it allows the best market segmentation and storage management, to minimise losses and to increase efficiency of storage. The effort required by the grower for this type of monitoring, and the costs associated are by far smaller than the associated benefits. In terms of time, the 5/6 measurements performed did not take more than 3 hours per ha. To date, this type of information on apple during the season has not been recorded and used as a driver of labor, resource and other management inputs. This investigation indicates that options are available to growers who would like to increase their knowledge on their crop status and potentially better respond to market demands of higher quality fruit at a lower cost.

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