Developing a simple method to predict berry harvest volume for a given day-neutral strawberry production field

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Abstract

While Quebec-grown strawberries are generally afforded a prominent place on food retailers' shelves during the summer season, their marketing presents a number of challenges. For example, Quebec strawberry producers are under a weekly obligation to provide food retailers with three weeks notice of anticipated fruit volume. This requirement arises in part from the lead-time required to prepare store flyers. Moreover, it represents a key step in the process of setting the retail price. Based largely on past yield history, the reliability of producer estimates of anticipated yields has often been inconsistent. To maintain Quebec-grown strawberries' market share, steps were taken to develop a new yield forecasting approach, grounded in field-measurable parameters. Initiated in the summer of 2011 on two Île d'Orléans (Quebec) farms' commercial day-neutral strawberry (cv. 'Seascape') production fields, research into this new forecasting approach was concluded in the fall of 2013.

The first reliable yield forecasts were generated in the summer of 2013. The approach then employed consisted in a weekly inventory of new green fruit per plant over a given period of time. Given the difficulty in determining the number of new green fruit per plant under commercial production conditions, the proposed approach was amended to a more manageable weekly inventory of green fruit on 60 strawberry plants randomly-selected within a given field.

Anticipatory harvest scheduling, based on seasonal variability in days from flowering to fruit maturity, strongly influenced the timing of green fruit inventories. These inventories potentially allow the number of mature fruit per plant at harvest to be estimated, and thereby provide a forecasted mean mass of harvestable fruits per plant.

Being an evaluation of the approach's potential rather than an example of its implementation, this study's weekly-inventory-based yield forecasts, based on both years (2012, 2013) of inventory/yield data, were drawn up after the 2013 season. While 2013 forecasts compared favourably with measured yields, those for the 2012 season were less reliable, unless based solely on 2012 inventories. Forecasts based on two years of data fared relatively poorly in the difficult task of taking into account differences in weather conditions from one growing season to another. Using proven count-yield equations to generate both generous and conservative yield forecasts could help address the variability brought on by variations in forecast-to-harvest weather conditions.

1 INTRODUCTION

1.1 Background

While the United States and Mexico supply the majority of strawberries entering Quebec's major food distribution chains, Quebec-grown fruit are favoured during the summer season (June-October). However, because Quebec producers are under a weekly obligation to provide food retailers three weeks' notice of anticipated fruit volume, marketing Quebec strawberries remains difficult. This requirement arises in part from the lead-time required to prepare store flyers. Moreover, it represents a key step in the process of setting the retail price. High anticipated yields will exert a downward pressure on the price per basket (selling unit), while, conversely, lower anticipated yields will tends to raise the per unit price. While one might expect the laws of supply and demand to readjust prices in the face of a shift in supply, preset prices for Quebec strawberries preclude any restoration of the market balance. Therefore, besides their use in marketing, reliable forecasts might also prove useful in human resources planning and fertigation regime design.

Unlike single-harvest crops (e.g., corn, soybean) or those which can be stored for extended periods of time (*e.g.*, cabbage, carrot, apple, potato, etc.), the highly perishable strawberry is harvested several times a week, at widely varying yields, thereby significantly complicating their marketing.

Another small fruit produced in Quebec, the raspberry, provides an example of a production sector quickly losing its market share in food distribution chains. Given the sector's inability to meet large retail chains' demands, the Quebec raspberry is gradually being edged out of supermarket shelves in favour of what are excellent quality imported raspberries. Highbush blueberries are another example of an imported fruit with a privileged place on our shelves, though this in part reflects the fact that U-Pick operations predominate in the marketing of local blueberries.

Estimates of anticipated fruit volumes being at present largely based on past seasons' yield history, forecasting anticipated fruit volume from quantitative parameters monitored in the current season would prove to be a useful and innovative endeavour.

Published strawberry yield-forecasting models, integrate current-day or historical weather conditions in their calculations, thereby severely limiting the reach of their predictions, while doing little to address the present issue (Doving and Mage, 2001; Mackenzie and Chandler, 2009). Another study's results lead to a method to forecast when peak production would occur (Chandler and Mackenzie, 2004). Likewise, models which integrate regional historic data or means ignore site-specific conditions. Funded by private enterprises such as Driscoll Strawberry Associates, research in this field has been undertaken in the United States; however, their results are proprietary and likely not applicable to the different growing conditions which prevail in Quebec.

1.2 General objective

The project sought to enhance the marketing of Quebec strawberries, and thereby the sector's profitability and competitiveness, by developing a reliable method to forecast weekly-cumulated fruit volume and thereby allow a better coordination of harvests and sales.

1.3 Specific objectives

- Investigate correlations between a number of strawberry plant development parameters;
- Develop yield forecasts based on a weekly characterisation of strawberry plants;
- Quantify the accuracy of forecasts;
- Propose a method adapted to commercial production;
- Evaluate forecasts' potential utility in scheduling fertigation applications over the growing season.

2 MATERIALS AND METHODS

2.1 Experimental sites, plant material and cropping practices

Located in the municipalities of Saint-Laurent (46° 52' N, 71° 01' W) and Saint-Jean (46° 55' N, 70° 54' W) on Île-d'Orléans (Quebec, Canada), two farms specialized in the commercial production of day-neutral strawberries each housed two experimental sites. Each site was located in a different field housing 5 plots of 12 strawberry plants, for a total of 60 plants per experimental site, and 240 plants across all sites.

Strawberries (cv. '*Seascape*') were grown on raised beds covered in black polyethylene mulch, irrigated through a drip irrigation system. The producer's sole responsibility, crop management included early season blossom removal to encourage plant recovery and subsequent vigour. The analysis of relationships between production and yield parameters followed a regression approach.

2.2 Collecting weather data

Rainfall (HOBO model RG3-M rain gauge) was measured on both farms. Set up on the farm situated in Saint-Laurent, a weather station allowed the monitoring of temperature and relative humidity (HC-S3, Campbell Scientific), rainfall events (*Leaf wetness sensor*, Model 237 Campbell Scientific), solar radiation (LI-200SZ, LI-COR), as well as wind speed and direction (*Wind monitor*, Young Model 05103-10). These data (measurements at 15 sec intervals, averaged over 15 min) were recorded on a datalogger (CR10X, Campbell Scientific). Potential evapotranspiration (ET_p) values were calculated by the Penman-Monteith method (ASCE, 2005).

2.3 Chemical characterization of the soil

At the end of the production season a single sample of topsoil (0-0.20 m depth) was taken from each plot. Sifted through a 2 mm mesh, soils samples were then air-dried at 21°C. Soil water pH was measured at a 1:1 (w/w) soil/water ratio (Conseil des Productions Végétales du Québec, 1988). Total soil organic matter (SOM) was measured by the Walkley Black wet oxidation method (Allison, 1965). Phosphorus (P) and micronutrients were extracted in Mehlich-3 soil extractant (Tran and Simard, 1993) and quantified by inductively coupled plasma optical emission spectroscopy (ICP-OES). Mineral nitrogen was extracted by stirring soil in a 2M KCl solution [1:10 (w/w) soil:extractant ratio] for 1 hour. The extract was filtered and analysed by automated colorimetric segmented flow analysis (Technicon) (Isaac et Johnson, 1976). End-of-season soil soluble salt levels were estimated by measuring a 1:2 soil:water (w/w) solution's conductivity using a conductivity meter.

2.4 Monitoring soil moisture and salinity

Throughout the growing season an array of HORTAU tensiometers (model Tx-80) continuously monitored selected plots' soil water tensions, which were recorded through HORTAU's Irrolis-Light software (ver. 1.9). Certain plots having been found, post-installation, to lie beyond the chosen tensiometer model's wireless range, tension readings were taken manually during weekly site visits.

Electrical conductivity (dS/m) probes equipped with capacitance sensors (5TE, DECAGON) were used to monitor evolving soil solution salinity within the volume of soil under the irrigation system's influence, estimated on the basis of the soil's apparent electrical conductivity (EC_a). For each farm, five plots — two in one field and three in the other — were equipped with a 5TE probe, installed 0.30 m below the drip tape. One probe per field was linked to a datalogger (Em50, DECAGON) which recorded EC_a at 15 min intervals throughout the growing season.

2.5 Weekly surveys of strawberry plants and fruit yield assessments

The 1st survey (Table 1), done on a weekly basis from planting through the end of the 2011 growing season, consisted in making an inventory of each strawberry plant's leaves until their number reached nine, as well as the number of flowers, green and mature fruit by flower cluster (cyme) and then by hierarchy (primary, secondary and tertiary). It should be noted that the number of ripe fruit was obtained upon their classification. In addition, at harvest the number of days from flowering to mature fruit were determined thanks to the tagging of selected pedicels upon the opening of the flower they supported.

A 2nd survey, consisting in making an inventory of flowers and green fruit per plot (*i.e.*, per 12 strawberry plants), was added to the weekly routine in 2012, while the 1st survey was simplified to no longer account for flower hierarchy (Table 1). In 2013, there remained two surveys scheduled per week, but these were identical and only accounted for per plant cyme and green fruit numbers. Moreover, the number of fruit was assessed at harvest, while the tagging of pedicels to evaluate the number of days from flowering to fruit maturity was limited to the 1st survey. In 2013, a 3rd survey, implemented concurrently with the 2nd survey, was added to the weekly routine (Table 1). It consisted in making an inventory of the total number of green fruit on 60 randomly-chosen strawberry plants per field. Survey elements are summarized in Table 1.

In 2011, in order to avoid producer-hired pickers from accidentally picking from study plots, experimental plot harvests were made to coincide with or precede by one day those set by the producer. In 2012 and 2013, when netting (4.5 cm mesh) was installed to protect research plots from accidental picking (see Figure 28 in Appendix), harvests occurred during surveys of strawberry plant characteristics. Harvested fruit were weighed individually, sorted by weight, and then checked for any defects. Individual marketable fruit were categorized as 'saleable' ($\geq$ 6 g) or 'small' ($<$ 6 g), while fruit that were misshapen or suffered from biotic or abiotic damage were categorized as 'other.'

Table 1.Weekly growing season surveys of strawberry plants.

	Hierarchy	2011	2012		2013		
		1st	1st	2nd	1st	2nd	3rd
Number per strawberry plant							
Leaves (max 9)		X	X				
Cyme					X	X	
Flower position on cyme	Primary	X					
	Secondary	X					
	Tertiary	X					
	Not considered		X				
Green fruit					X	X	
Green fruit per cyme	Primary	X					
	Secondary	X					
	Tertiary	X					
	Not considered		X				
Mature fruit					X	X	
Mature fruit per cyme	Primary	X					
	Secondary	X					
	Tertiary	X					
	Not considered		X				
Per strawberry plant — fresh weight							
Mature fruit					X	X	
Mature fruit per cyme	Primary	X					
	Secondary	X					
	Tertiary	X					
	Not considered		X				
Per plot bearing 12 strawberry plants — number							
Flowers				X			
Green fruit				X			
Days from flowering to mature fruit harvest		X		X	X		
Per field – 60 strawberry plants – number							
Green fruit							X

2.6 Strawberry plant dry matter

Following the last fruit harvest, strawberry plant dry matter was assessed. Individual plants were cut off at their base and their remaining green fruit removed. Transported to the laboratory in plastic bags, individual plants were dried to a constant weight at 105°C, then weighed. Since a strawberry plant's dry matter is strongly correlated with its fruit yield, this measure can help highlight factors underlying apparent fruit yield outliers and allow an informed quality control of data.

3 RESULTS AND ANALYSIS

Presented graphically in Figure 1 to Figure 6, total daily rainfall, along with daily minimum, maximum and mean air temperatures were measured daily at both St. Laurent and St. Jean sites in 2012 and 2013. Daily potential evapotranspiration (ET_p), calculated on the basis of data from the weather station located on the St-Laurent site, are similarly presented in Figure 5 and Figure 6). A function of weather conditions, the volume of water lost through ET_p represents the amount of soil water lost through both evaporation at the soil surface and plant transpiration. When evapotranspirative demand exceeds a plant's soil water uptake capacity, the plant may be subjected to both water and heat stress.

Upon comparing the two season's ET_p values at the Saint Laurent site (Figure 5 and Figure 6), the number of days in 2012 when plants were deemed at risk for water stress exceeded that in 2013. Indeed, the number of growing season (1 June-1 October) days in 2012 when $2 \text{ mm} \leq ET_p < 4 \text{ mm}$, and particularly when $4 \text{ mm} \leq ET_p < 6 \text{ mm}$, exceeded the number of equivalent days in 2013. Evapotranspirative demand being therefore greater in 2012 than 2013, plants were at greater risk of developing developmental aberrations in 2012 than 2013.

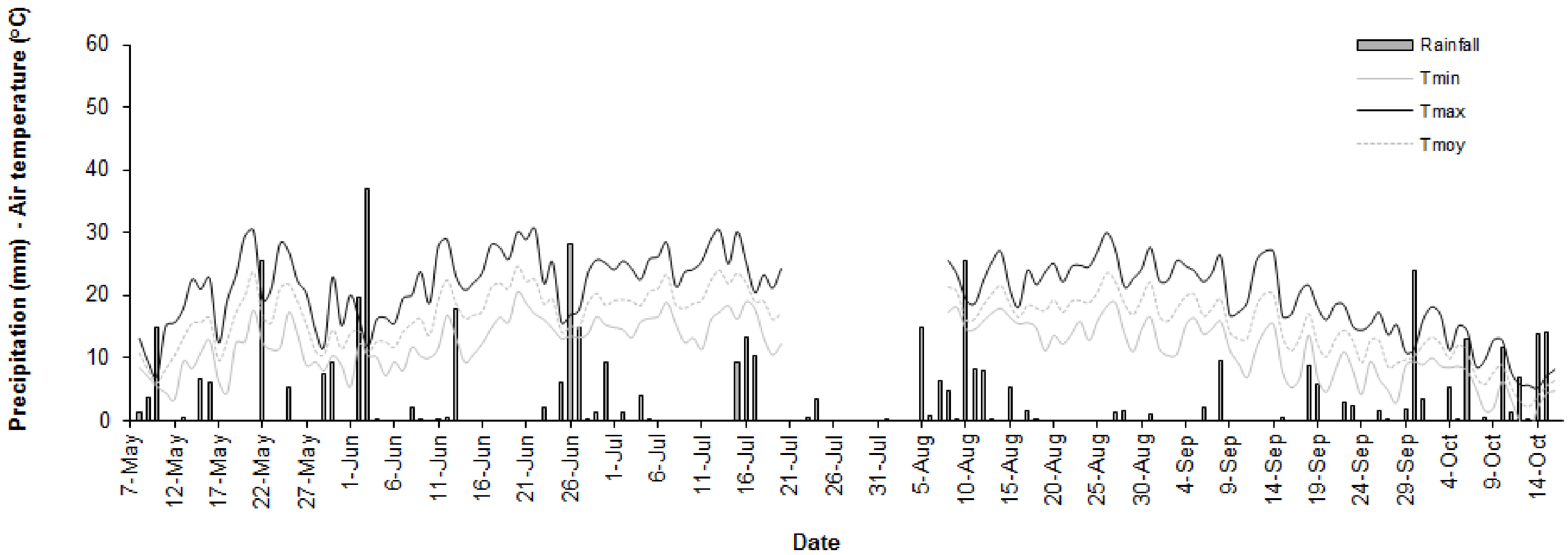

Figure 1. Daily rainfall (mm) and daily minimum, maximum and mean air temperature (T_{min}, T_{max}, T_{avg}; °C) - Saint-Laurent site, 2012.

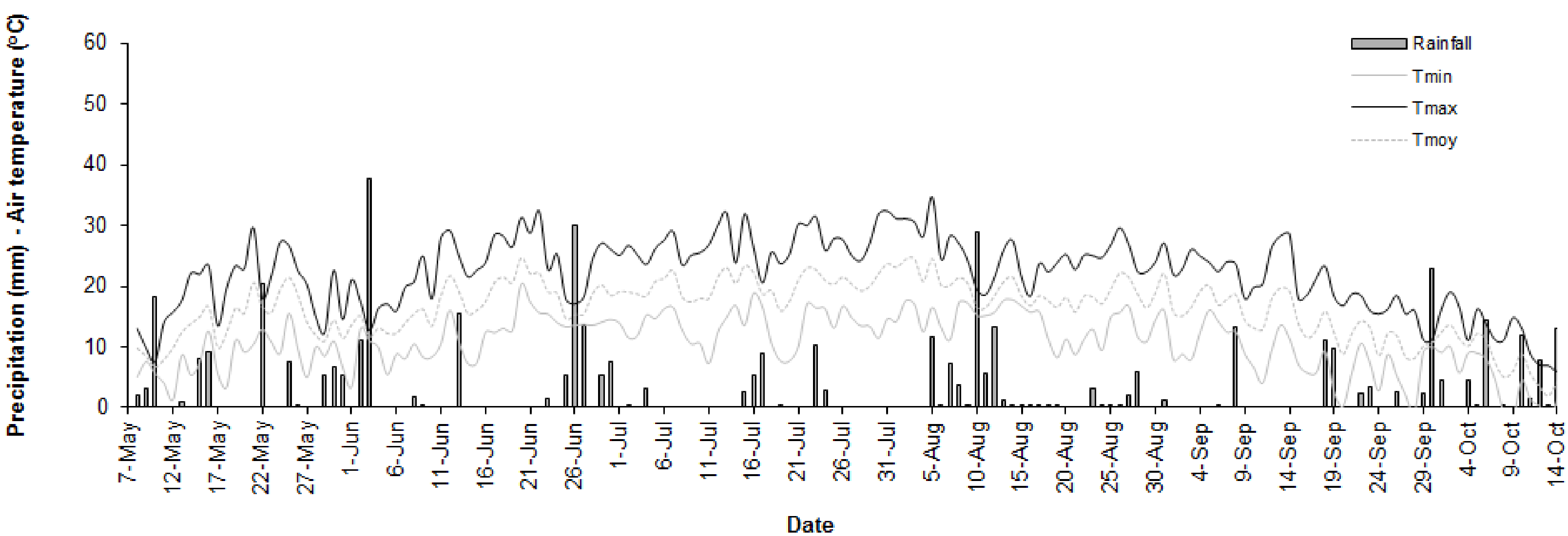

Figure 2. Daily rainfall (mm) and daily minimum, maximum and mean air temperature (T_{min}, T_{max}, T_{avg}; °C) - Saint-Jean site, 2012.

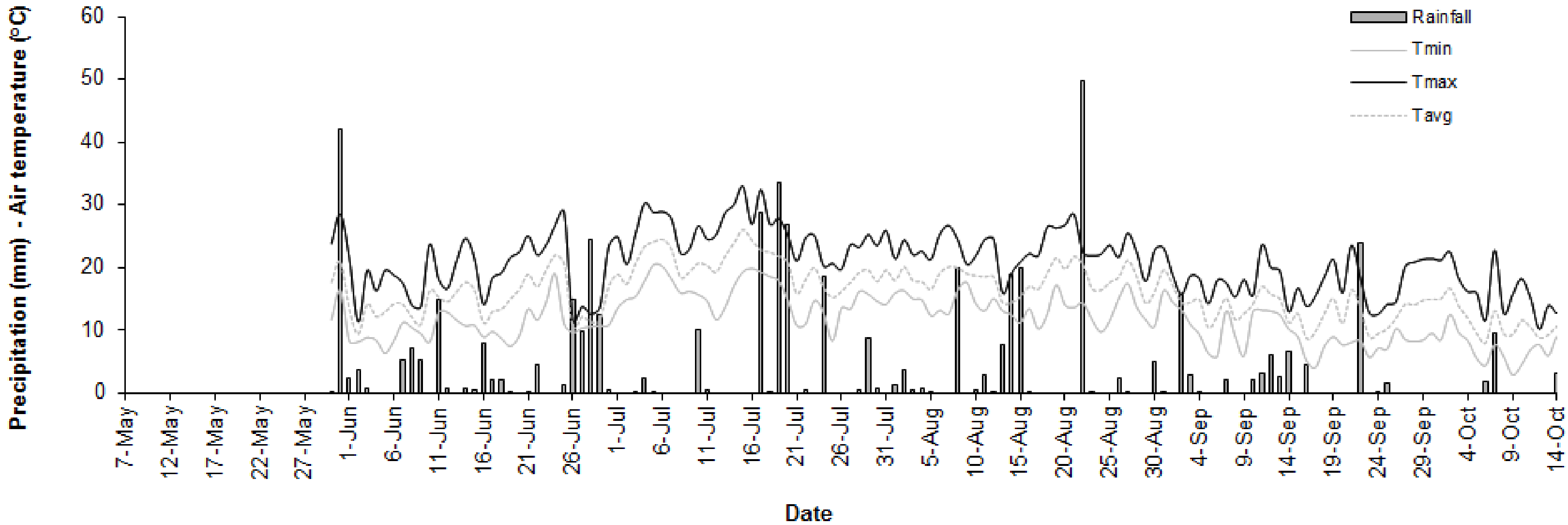

Figure 3. Daily rainfall (mm) and daily minimum, maximum and mean air temperature (T_{min}, T_{max}, T_{avg}; °C) - Saint-Laurent site, 2013.

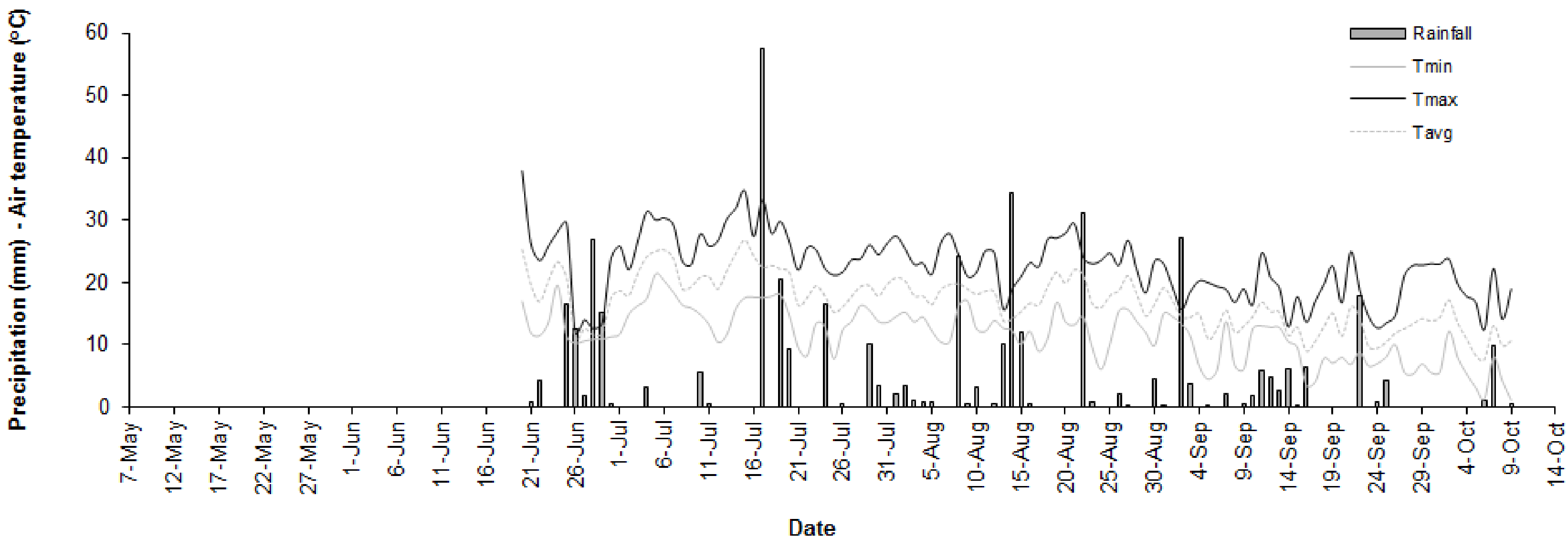

Figure 4. Daily rainfall (mm) and daily minimum, maximum and mean air temperature (T_{min}, T_{max}, T_{avg}; °C) - Saint-Jean site, 2013.

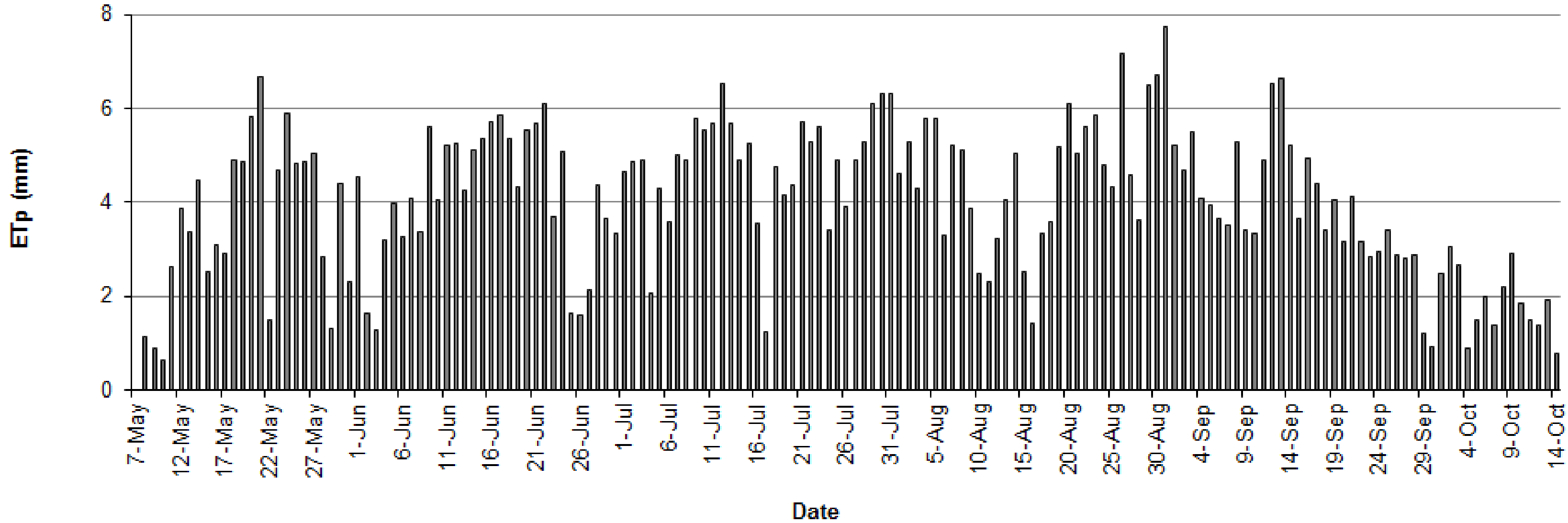

Figure 5. Daily potential evapotranspiration (ET_p; mm) - Saint-Laurent site, 2012.

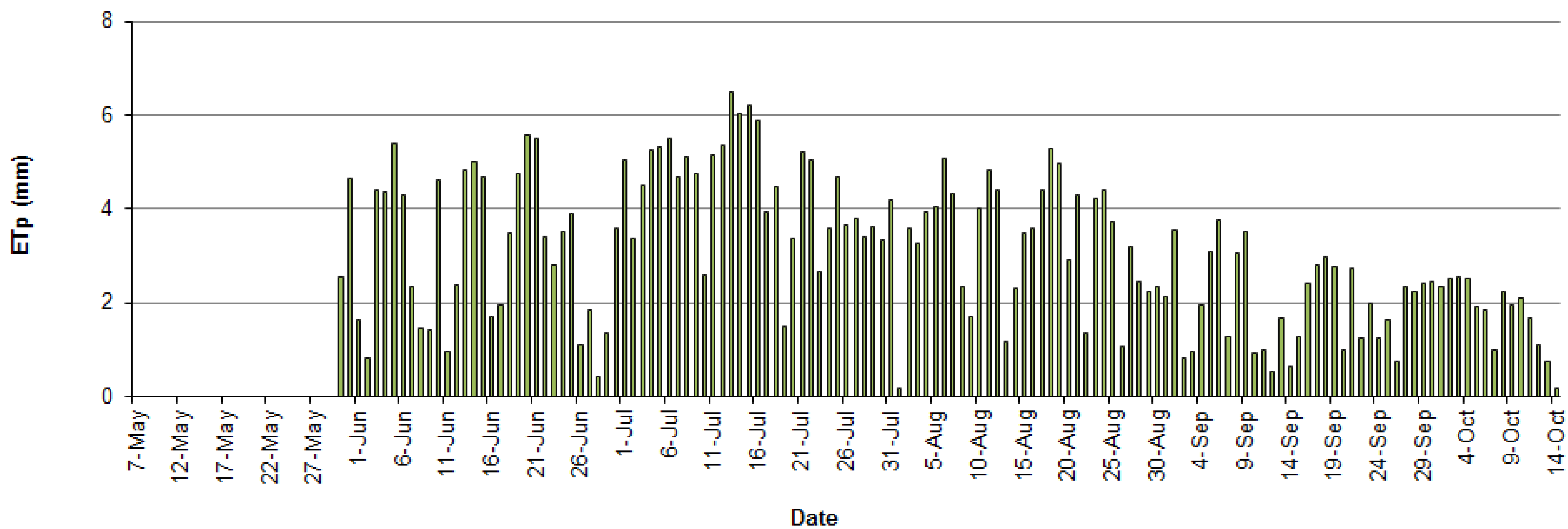

Figure 6. Daily potential evapotranspiration (ET_p; mm) - Saint-Laurent site, 2013.

3.1 Correlations between variables allowing a characterisation of strawberry plant development

The number of new green fruit produced in a given interval of time was identified as the parameter best suited to accurately forecast yields at future harvests. The strength of the relationship between these two variables should be excellent considering that each mature fruit was once green and no mature fruit was culled prior to harvest. At any given time, correctly establishing the number of new green fruit requires one to subtract from the present number of green fruit, the number of such fruit present at the last survey or harvest, along with the number of mature fruit removed at the last harvest. Therefore, in addition to monitoring the same plants until season's end, the fruit harvested from each plant must also be recorded.

At the end of the 2012 growing season, a linear regression was developed across all 35 harvests — each including up to 240 plant records — between the number of mature fruit harvested per plant and the corresponding fruit yield per plant on a fresh weight basis (Figure 7). The strength of this linear relationship was quantified using the coefficient of determination ($0 \leq R^2 \leq 1$) or its square root, the correlation coefficient ($-1 \leq R \leq 1$). The R value is positive or negative, respectively, according to whether a direct (slope > 0) or inverse (slope < 0) relationship exists between the independent variable (*e.g.*, number of fruit) and the dependent variable (*e.g.* weight of fruit). The strength of the regression increases as the absolute value of R ($|R|$) approaches 1.0 (one). The R value can be expressed in percentage form, such that the independent variable (*e.g.*, number of fruit) can be said to explain a certain percentage $|R| \times 100$ of the variation in the dependent variable. Therefore, the greater the value of $|R|$ the better the independent variable describes the dependent variable.[1] In the present case, the relationship is strong ($R^2 = 0.61$, $R = 78$ %), which is all the more noteworthy given that all experimental sites are included in the regression.

[1] For an $R^2 = 0.6059$ (Figure 7) and a direct relationship (slope > 0) between fruit number and fruit weight, $R = \sqrt{R^2} = \sqrt{0.6059} = 0.78$ or 78%.

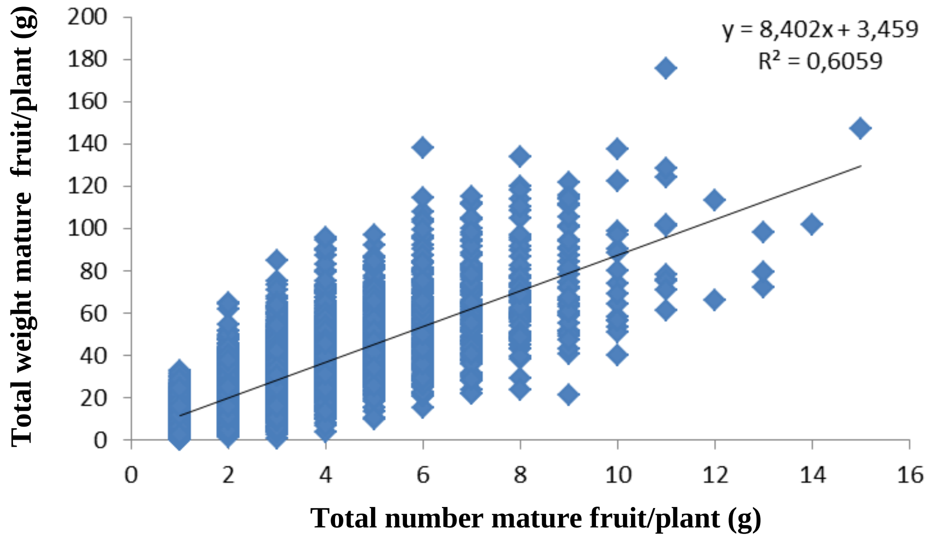

Figure 7. Linear relationship between the number of mature fruit per plant at a given harvest and the corresponding fresh weight of mature fruit — 2012 Season.

The equation linking these parameters,

Equation 1. [*g fruit/plant*] = 8.402[*no. fruit/plant*] + 3.459

served to predict yields for 2013 harvests, where the dependent variable was the forecasted yield of fruits at harvest expressed on a fresh weight basis (f.w.b.), and the independent variable was the number of new green fruit in existence roughly 21 days before the harvest of interest. Therefore, assuming no green fruit to be lost before its eventual maturity and harvest, the number of new green fruit for each of the 60 monitored plants per field could serve in forecasting the weight of mature fruit at harvest. Based on planting density, the yield could then be expressed in terms of kg/ha.

3.2 Yield forecasting based on weekly monitoring of strawberry plants

3.3 Assessing the accuracy of forecasts

The project's first season (2011) was dedicated to collecting data which might contribute to the development of preliminary yield forecasting equations to be validated during the following growing season (2012); consequently, no yield forecasts were made for 2011. The equations tested and the method employed proved to be ineffective in yielding accurate yield forecasts for harvests occurring during the 2012 production season. In 2013, yield forecasts were based on new green fruit per plant and derived using Equation 1. These results are presented below.

3.3.1 Timing of on-site surveys and harvests for fourteen periods spanning the 2013 growing season.

The growing season of 10 June to 6 September 2013, during which 1st and 2nd surveys were undertaken at each of the four fields, was split into 14 periods (Table 2). The participating farms were provided with field-specific yields forecasts soon after completion of each period's 2nd survey. These forecasts covered the full range of harvests from 1 July and 4 October, 2013. For example, data collected in the 1st and 2nd surveys of Period 4 (3 July to 9 July, 2013), were employed in forecasting fruit yields (f.w.b.) to be obtained from 24 July to 30 July.

Table 2. Timing of on-site surveys and harvests for fourteen periods spanning the 2013 growing season.

Period (2013)	1st and 2nd surveys		Harvests	
	Beginning	End	Beginning	End
1	10 June	18 June	1 July	8 July
2	19 June	25 June	9 July	16 July
3	26 June	2 July	17 July	23 July
4	3 July	9 July	24 July	30 July
5	10 July	14 July	31 July	5 August
6	15 July	21 July	6 August	11 August
7	22 July	26 July	12 August	16 August
8	27 July	1 August	17 August	22 August
9	2 August	7 August	23 August	29 August
10	8 August	12 August	30 August	2 September
11	13 August	19 August	3 September	9 September
12	20 August	26 August	10 September	16 September
13	27 August	2 September	17 September	23 September
14	3 September	6 September	24 September	4 October

3.3.2 Measured and forecast (Equation 1) yield, 2013 season total.

Yields were recorded and predicted for each of the periods in which mature fruit were harvested, cumulated from period to period over the season and expressed as a percentage of the growing season's total yield (Figure 8 to Figure 11). The yield presented for any given period therefore represents the sum of the previous and current period's yields, up to the 14th period where the cumulated yield corresponds to the total (100%) yield for the growing season.

Measured and forecast relative yields were compared on a field-by-field basis, in such a manner that each period's cumulative yield corresponded to a specific fraction of the final period's and thus full season's cumulative yield. Thus, to evaluate the extent of the deviation between the forecast and measured yields for each period, these yields are expressed relative to the full season's cumulative yield (100%). For example, in Figure 11 (Field 4), the cumulative measured yield recorded for the last harvest period (24-28 Sept.) represents 100% of the mature fruit harvest over the entire season, whereas the forecast cumulative yield for the same period is 106% of the measured value. Therefore, the full-season sum of forecast yields exceeded the full-season sum of measured yields by 6%. Moreover, this manner of presenting yield data highlights how, for Field 4, 62% of the full season's cumulative yield had been harvested by the end of the 10th period (30 August - 2 September). Similarly, in Fields 1, 3 and 4, roughly half the full season's cumulative yield had been achieved by the end of the 9th period (23-29 August), whereas this threshold was reached by the end of the 8th period in field 2.

With the exception of Field 4 where a 6% difference was noted, cumulative basis comparisons of total measured yields and associated forecasts for the other fields showed only very minor differences. However, since forecasts ended 21 days before the final harvest, the yield potential represented by green fruit never reaching maturity (*i.e.*, green fruit remaining on the plant when the field production infrastructure is dismantled after the first frosts) would lead to a disparity in number between forecast and harvested fruit. Finally, the forecasts prior to the 11th period (3-9 September) can be seen to slightly underestimate cumulative yield, while overestimating it slightly thereafter (dotted line).

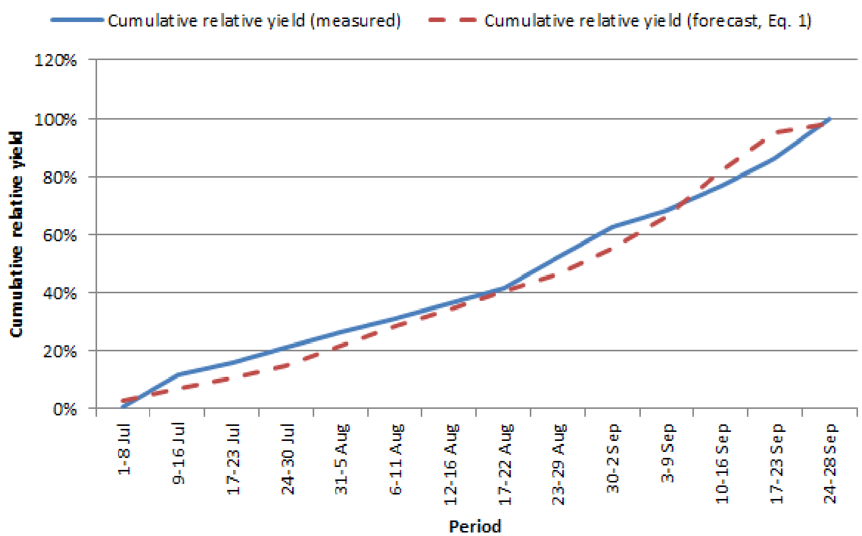

Figure 8. Period to period cumulative measured and forecast (Equation 1) yields as a percent of total yield for the 2013 season - Field 1.

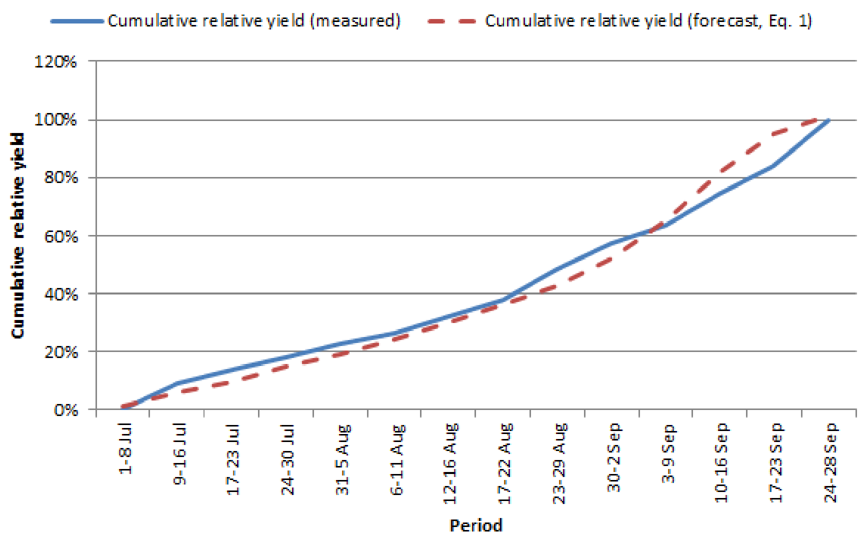

Figure 9. Period to period cumulative measured and forecast (Equation 1) yields as a percent of total yield for the 2013 season - Field 2.

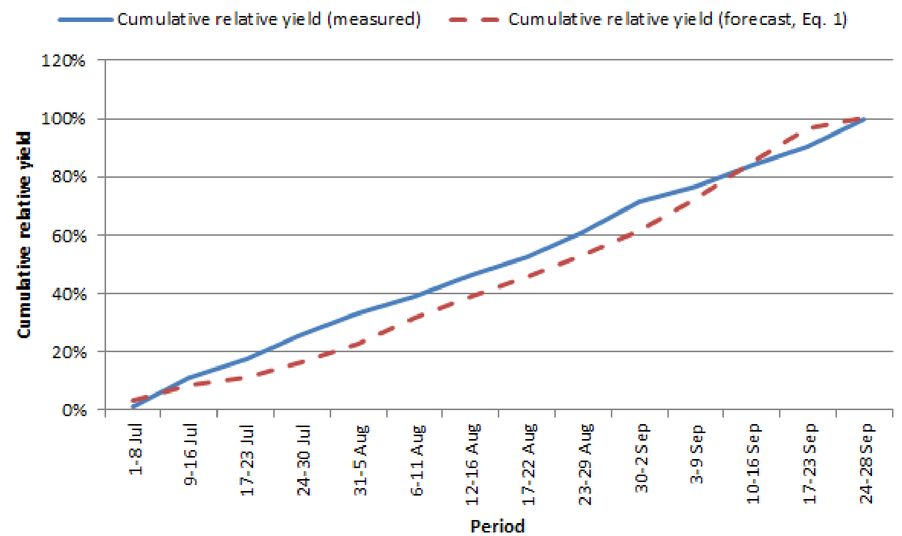

Figure 10. Period to period cumulative measured and forecast (Equation 1) yields as a percent of total yield for the 2013 season - Field 3.

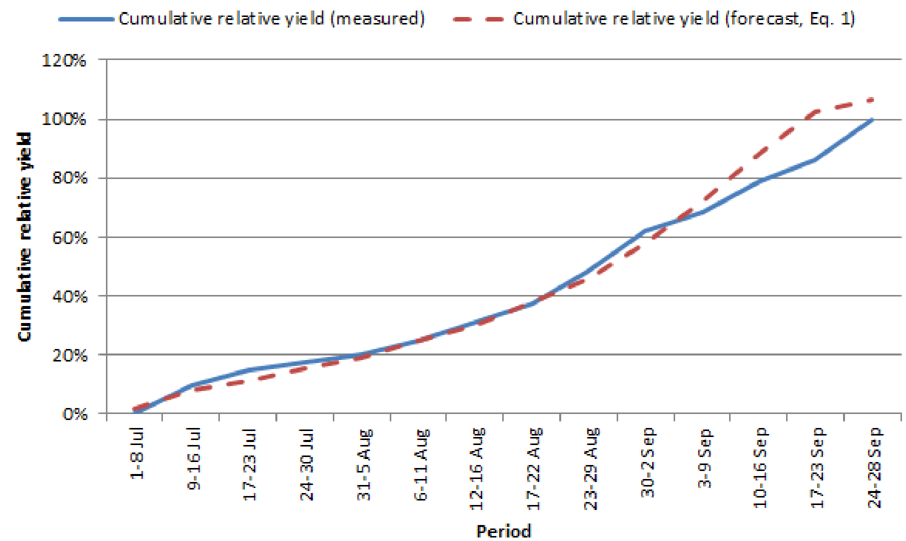

Figure 11. Period to period cumulative measured and forecast (Equation 1) yields as a percent of total yield for the 2013 season - Field 4.

3.3.3 Seasonal totals of measured and forecast yield, Equation 1.

For each field, measured or forecast yields can be presented (Figure 12 to Figure 15) as the percent contribution of each individual period to the measured yield cumulated over the full production season (*i.e.*, summed across all 14 periods). Measured and forecast per period yields for a given field are both expressed relative to the measured total. Such a presentation of yields for a given field highlights the relative contribution of a specific harvest period to seasonal totals.

For example, for the 5^{th} harvest period (31 July - 5 August) on Field 1 (Figure 12) the measured yield represents 5% of the measured production season total, while the forecast yield for the same period represents 7% of the measured production season total. Up to the 11th period (3-9 September) forecast yields match measured yields fairly closely for all fields (Figure 12 to Figure 15), which can also be said for the cumulative yields previously discussed (Figure 8 to Figure 11).

Since, with the exception of Period 2, individual forecast and measured yields for Periods 1-11 are closely matched, the forecasting equation does show some promise. It is after the 11^{th} period (3-9 September) that a significant difference develops between individual periods' forecast and measured yields. Forecasts are all made 21 days prior to harvest, regardless of the period in the season. Within-season variation in days from flowering to mature fruit, a parameter worth exploring in explaining these late season discrepancies, is discussed in the following section.

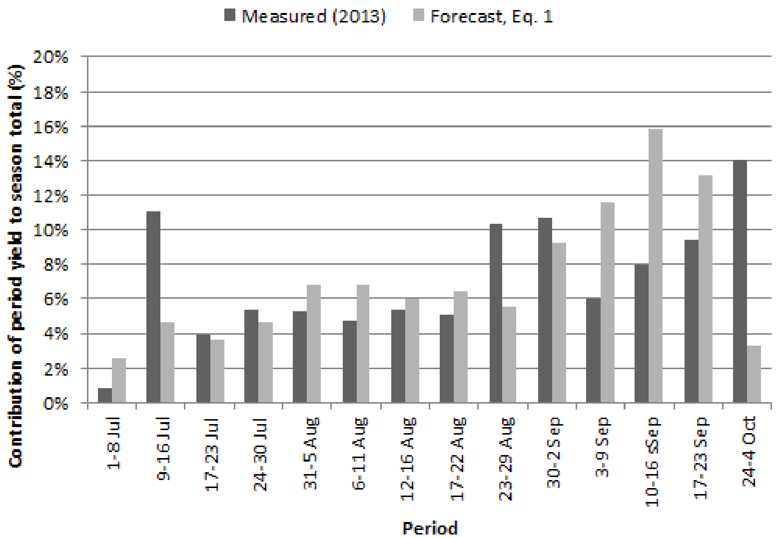

Figure 12. Percent contribution of individual harvest period yields (measured or forecast with Eq. 1) to measured 2013 season total yield - Field 1.

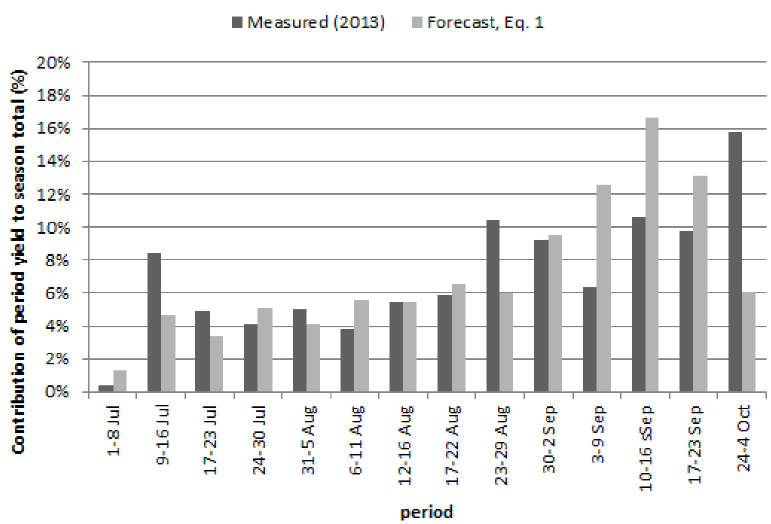

Figure 13. Percent contribution of individual harvest period yields (measured or forecast with Eq. 1) to measured 2013 season total yield - Field 2.

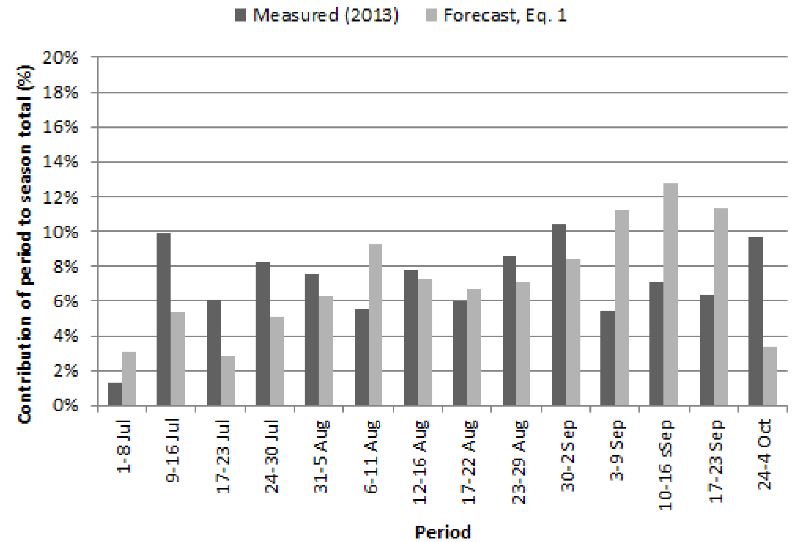

Figure 14. Percent contribution of individual harvest period yields (measured or forecast with Eq. 1) to measured 2013 season total yield - Field 3.

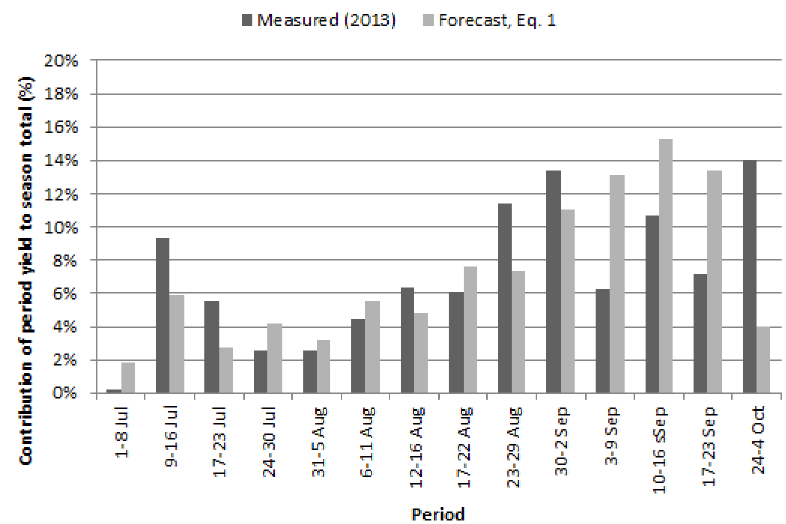

Figure 15. Percent contribution of individual harvest period yields (measured or forecast with Eq. 1) to measured 2013 season total yield - Field 4.

3.3.4 Within-season variation in days from flowering to mature fruit harvest, and associated yields.

The number of days from flowering to mature fruit harvest was plotted by field and by harvest period for the 2013 season (Figure 16). For example, across all fields, the mean number of days from flowering to mature fruit harvest during the 4th Period (24-30 July) was 20. The first thing one notes is that during the first ten periods the number of days from flowering to fruit maturity varies between 20 and 25, numbers consistent with effective yield forecasting on 21 days' notice. Indeed the number of days match, which facilitates the process. However, the accuracy of forecasts based on Equation 1 decreases, when, from the 11th period onward, the number of days from flowering to fruit maturity increases (Figure 12 to Figure 15). Altering the linear model (Eq. 1) to account for the latter portion of the season's extended interval between flowering and fruit maturity could prove useful in correcting the discrepancies observed in this portion of the season. Plotted for comparative purposes, the length of the flowering to fruit maturity interval for each field, and each of 2012's harvest periods (Figure 17), indicates the variation in interval length to parallel that in 2013.

In each of the period in 2013, the mean weight of mature fruit harvested per field, remained fairly constant throughout the season (Figure 18). This constancy, combined with the fact that the accuracy of forecasts based on Equation 1 is strongly influenced by mean fruit weight, proved to be most convenient in the current context. However, the mean weight of mature fruit harvested in 2012 shows a great deal more variation (Figure 19).

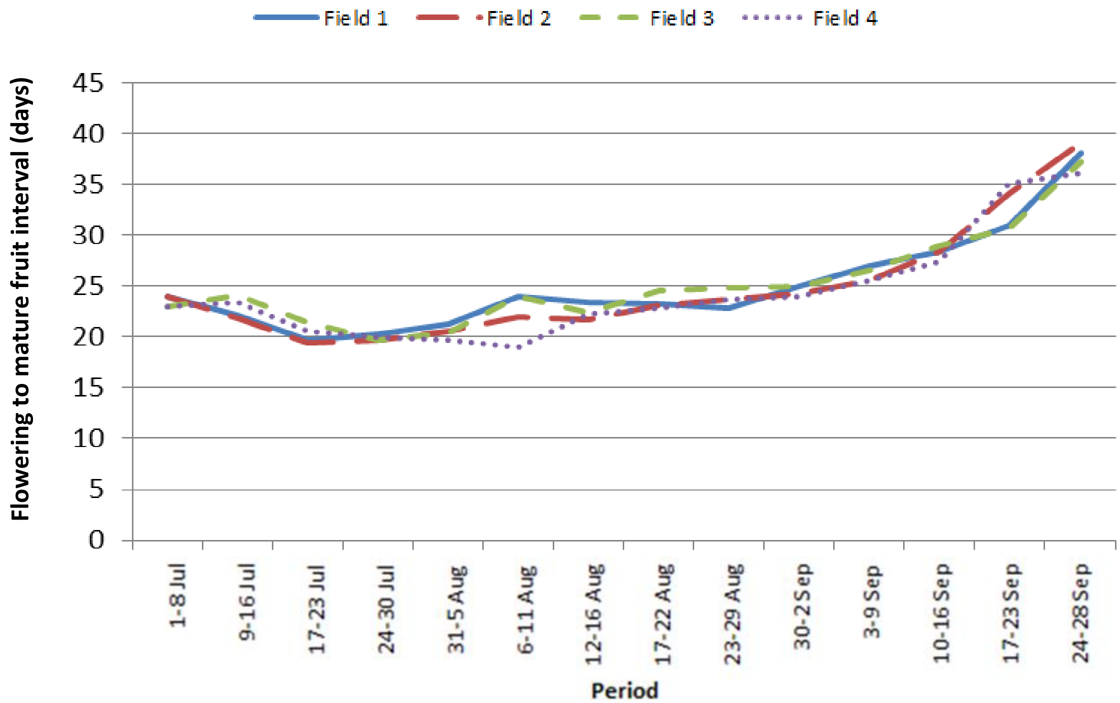

Figure 16. Length of flowering to mature fruit interval (days) by field and harvest period - 2013 Season.

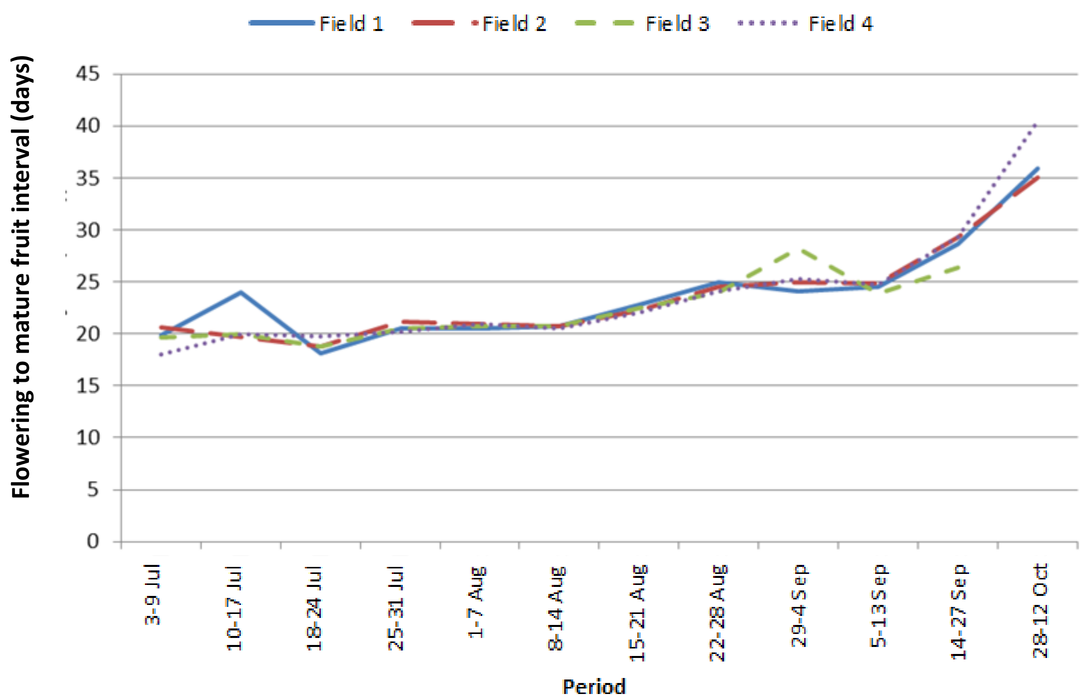

Figure 17. Length of flowering to mature fruit interval (days) by field and harvest period - 2012 Season.

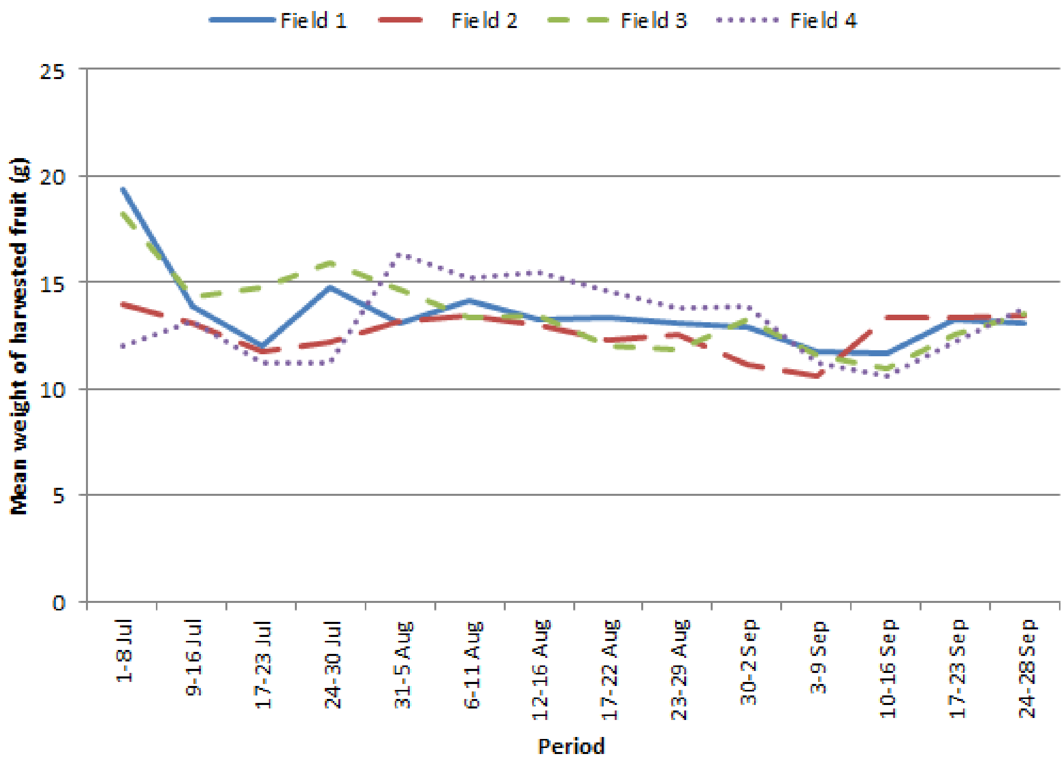

Figure 18. Mean fresh weight of harvested fruit (g) by field and by period - 2013 season.

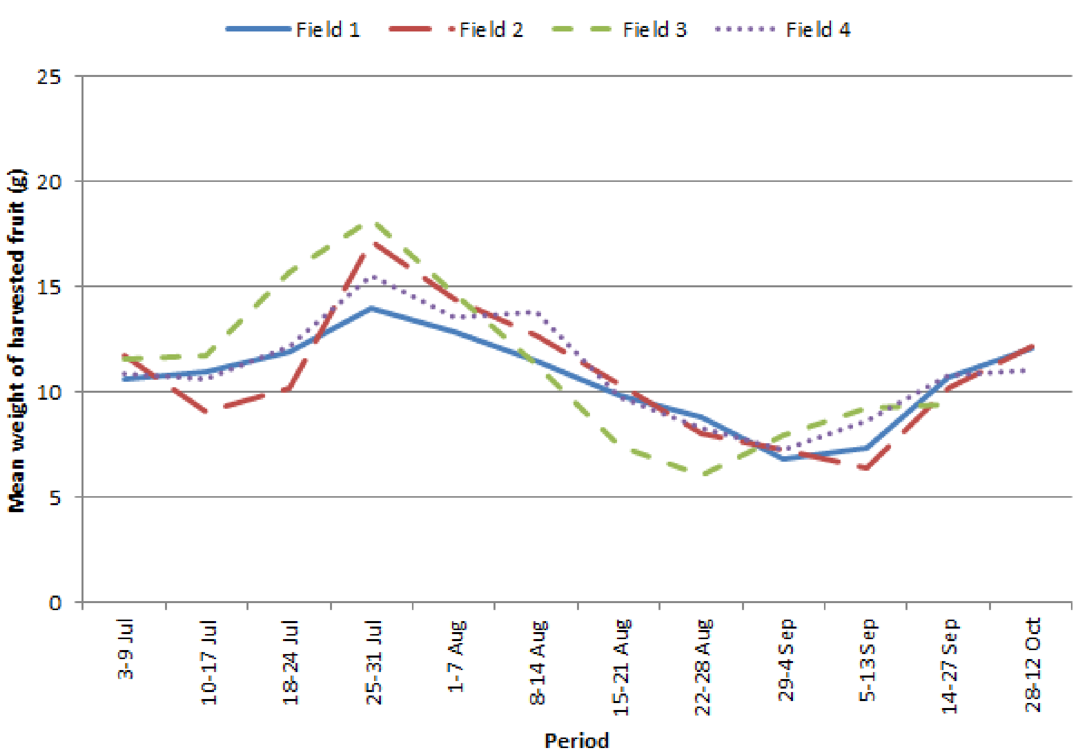

Figure 19. Mean fresh weight of harvested fruit (g) by field and by period - 2012 season.

3.4 Development of a forecasting method applicable to commercial production

The goal was to devise as easy and accurate a method as possible to forecast the total weight of mature fruit to be harvested at a later date. Since a method based on monitoring the number of new green fruit per plant would be difficult to implement under commercial production conditions, the proposed method will hinge on a weekly inventory of green fruit on 60 randomly-selected strawberry plants.

To achieve this goal, data gathered in 2013 were reworked under different scenarios and new equations generated. These new equations and the proposed method are demonstrated using a set of fictitious values. As shown in Table 3 and Table 4, the original period dates for 2013 (Table 2) and 2012, respectively, were reassigned according to the length of the flowering to mature fruit interval (Figure 16 and Figure 17, respectively), A first step which entailed the forecast of mean numbers of mature fruit per planting at harvest was followed by a period-weighted forecast of the mean fresh weight of fruit per plant. Finally, the equations employed in this approach were validated by forecasting the yields measured in 2012 and 2013 from on-site green fruit inventories. This demonstration completed, a generalized procedure will be proposed.

3.4.1 Realigning of harvest periods for use in forecasting yield based on a period's mean number of days from flowering to mature fruit.

Table 3. *Ex post facto* realignment of 2013 harvest periods according to scheduling of weekly surveys and harvests.

Period (2013)	Weekly surveys	Harvests		Duration End_H - End_S (days)
	End_S	Beginning	End_H	
1	13 June	-	to 4 July	21
2	21 June	5 July	12 July	21
3	27 June	13 July	18 July	21
4	3 July	19 July	24 July	21
5	8 July	25 July	29 July	21
6	14 July	30 July	4 August	21
7	19 July	5 August	9 August	21
8	26 July	10 August	16 August	21
9	2 August	17 August	23 August	21
10	8 August	24 August	30 August	22
11	16 August	31 August	9 September	24
12	23 August	10 September	17 September	25
13	26 August	18 September	27 September	32
14	29 August	28 September	4 October	36

Table 4. *Ex post facto* realignment of 2012 harvest periods according to scheduling of weekly surveys and harvests.

Period (2012)	Weekly surveys	Harvests		Duration End_H - End_S (days)
	End_S	Beginning	End_H	
1	14 June	-	to 6 July	22
2	21 June	7 July	12 July	21
3	29 June	13 July	20 July	21
4	5 July	21 July	26 July	21
5	13 July	27 July	3 August	21
6	19 July	4 August	9 August	21
7	26 July	10 August	16 August	21
8	3 August	17 August	24 August	21
9	9 August	25 August	30 August	21
10	15 August	31 August	6 September	22
11	22 August	7 September	13 September	22
12	27 August	14 September	20 September	24
13	*	21 September	9 October	
14	*	10 October	12 October	

*Missing data

3.4.2 Forecasting the mean number of fruit harvested for any given period

The first step in achieving a meaningful forecast of the mean number of mature fruit per plant at harvest is to inventory the number of green fruit on plants. To serve as an example, a fictitious dataset of the number of green fruit inventoried in a particular field during each of 14 periods' 2nd surveys are presented in column A of Table 5. Since the initial goal is to forecast the total number of mature fruit per plant at harvest, a single survey towards the end of the period in question is all that is required. The total number of green fruit inventoried is then divided by the number of strawberry plants sampled (column B, Table 5), and cumulated from period to period (column C, Table 5).

For example, for Period 6, 370 green fruit were inventoried during a fictitious survey occurring around 14 July (column A, Table 5). This number is divided by 60, the number of plants under consideration, yielding a value of 6.17 fruit per plant (column B). The value of 19.83 in column C is the sum of the fruits per plant for Periods 1 through 6.

Table 5. Total number of green fruit inventoried on 60 plants (A), mean per plant (B) and cumulated mean per plant (C) by period (see Table 4) – Fictitious data.

	A	B	C
Period	Measured Total number of green fruit		
	On 60 plants	Per plant	Per plant, cumulated
1	15	0,25	0,25
2	100	1,67	1,92
3	185	3,08	5,00
4	220	3,67	8,67
5	300	5,00	13,67
6	370	6,17	19,83
7	500	8,33	28,17
8	615	10,25	38,42
9	680	11,33	49,75
10	820	13,67	63,42
11	930	15,50	78,92
12	1000	16,67	95,58
13	1120	18,67	114,25
14	1200	20,00	134,25

From any given period, the cumulative mean number of green fruit inventoried per plant is an excellent indicator of the cumulative mean number of mature fruit obtained 21 to 36 days thereafter. A regression developed between these two parameters was done *ex post facto* since the number of red fruit was only known at harvest. For confidentiality reasons, the values used to generate this relationship are not presented.

Across all fields, for each of the 14 periods, a regression was developed between the cumulative mean number of green fruit per plant ([*no. green fruit/plant*], column C, Table 5) and the cumulative mean number of mature fruit per plant at harvest ([*no. mature fruit/plant*]), where:

Equation 2. $[\textit{no. mature fruit/plant}] = -0.0008[\textit{no. green fruit/plant}]^2 + 0.4372[\textit{no. green fruit/plant}]$

This equation will allow one to forecast the mean cumulative number of mature fruit per plant from the mean cumulative number of green fruit per plant.

Using Eq. 2, the cumulative mean number of mature fruit per plant can now be forecast from the cumulative mean number of green fruit per plant (column C, Table 6). For example, following the Period 6 inventory of green fruit, the mean number of green fruit cumulated since the Period 1 inventory is 19.83 per plant. This value was substituted for [*no. green fruit/plant*] in Eq. 2, to yield a value of 8.36 for the mean cumulated mature fruit per plant (column D, Table 6). Consequently, if the cumulative mean number of green fruit per plant were 19.83, the cumulative mean number of mature fruit per plant at harvest, some 21 to 36 days later, would be 8.36.

Table 6. Cumulative mean number of green fruit per plant (C) and cumulative mean number of mature fruit per plant at harvest (D) – Fictitious data.

Period	C Measured Cumulative mean no. green fruit per plant	D Forecast (Eq. 2) Cumulative mean no. mature fruit per plant at harvest
1	0,25	0,11
2	1,92	0,84
3	5,00	2,17
4	8,67	3,73
5	13,67	5,83
6	19,83	8,36
7	28,17	11,68
8	38,42	15,62
9	49,75	19,77
10	63,42	24,51
11	78,92	29,52
12	95,58	34,48
13	114,25	39,51
14	134,25	44,28

3.4.3 Forecasting cumulative mean fresh weight of mature fruit per plant for a given period

The previously discussed period-by-period cumulated mean number of fruit per plant (see 3.4.2) is an excellent predictor of the cumulative mean fresh weight of mature fruit per plant to be expected 21 to 36 days after their inventory. Developed *ex post facto* since the mean number and weight of mature fruit per plant were only know at harvest, a quadratic regression equation was developed between the cumulative mean number of mature fruit per plant and the cumulative mean fresh weight of mature fruit per plant at harvest, across all periods and fields. For confidentiality reasons, the values used to generate this relationship are not presented.

Equation 3. [*g mature fruit/plant*] = -0.01[*no. mature fruit/plant*]^2 + 13.262[*no. mature fruit/plant*] + 0.489

The mean cumulative weight of mature fruit per plant will therefore now be determined from the cumulative mean number of mature fruit per plant at harvest (column D, Table 7), using Eq. 3. For example, for Period 6, the cumulative (Periods 1-6) mean number of mature fruit per plant at harvest, 8.36, replaces [*no. mature fruit/plant*] in Eq. 3, yielding a [*g mature fruit/plant*] value of 110.2 g (column E, Table 7). Therefore, when the cumulative number of mature fruit per plant is 11.68, the cumulative mean weight of mature fruit per plant will be 153.6 g, 21 to 36 days later.

Table 7. Forecast cumulative mean number of mature fruit per plant at harvest (D) and forecast cumulative mean weight of mature fruit per plant at harvest (E) - Fictitious data.

Period	D Forecast (Eq. 2) Cumulative mean no. mature fruit per plant at harvest	E Forecast (Eq. 3) Cumulative mean weight mature fruit per plant at harvest
1	0,11	1,5
2	0,84	11,1
3	2,17	28,7
4	3,73	49,4
5	5,83	77,0
6	8,36	110,2
7	11,68	153,6
8	15,62	204,7
9	19,77	258,3
10	24,51	319,1
11	29,52	382,8
12	34,48	445,4
13	39,51	508,4
14	44,28	567,6

3.4.4 Forecast of fruit weight to be harvested

To obtain the mean weight of mature fruit per plant at harvest for a given period one need only subtract the previous period's cumulative mean weight of mature fruit per plant from that of the period of interest. For example, the 33.2 g mean weight of mature fruit per plant forecast for Period 6 (column F, Table 8) is derived from the subtraction of Period 5's cumulative mean weight of mature fruit per plant (column E, Table 8) from that of Period 6 (*i.e.*, 110.2 g - 77.0 g = 33.2 g per plant). Finally, as this is a mean weight per plant, multiplying this value by the planting density or number of plants in the field, one can obtain the total yield for the field.

Table 8. Forecast cumulative mean weight of mature fruit per plant at harvest (E) and forecast mean weight of mature fruit per plant at harvest by period (F) – Fictitious data.

Period	E Forecast Cumulative mean weight mature fruit per plant at harvest	F Forecast Mean weight mature fruit per plant at harvest by period
1	1,5	1,5
2	11,1	9,6
3	28,7	17,6
4	49,4	20,6
5	77,0	27,6
6	110,2	33,2
7	153,6	43,4
8	204,7	51,1
9	258,3	53,6
10	319,1	60,7
11	382,8	63,8
12	445,4	62,6
13	508,4	63,0
14	567,6	59,2

3.4.5 Validation of Equations 2 and 3 for the 2013 season

Field inventories of green fruit were used in validating Eqs. 2 and 3. For each field, single period measured and forecast yields (f.w.b.) are plotted as each period's relative contribution to *measured* season yield totals (Figure 20 to Figure 23). This presentation highlights the temporal evolution in yields and their relative contribution to seasonal totals over the season, and indicates each period's relative contribution to seasonal yield totals. With the exception of the 2nd period (5-12 July) wherein relative yields were significantly underpredicted, overall forecast yields matched measured ones fairly closely. The accuracy of forecasts for Field 4 were relatively poor compared to the other fields (Figure 23); indeed, the 2nd and 9th Period yield forecasts were significant underestimates of those measured for these periods, while yield forecasts for the 5th, 6th, 11th and 12th periods represented significant overestimates.

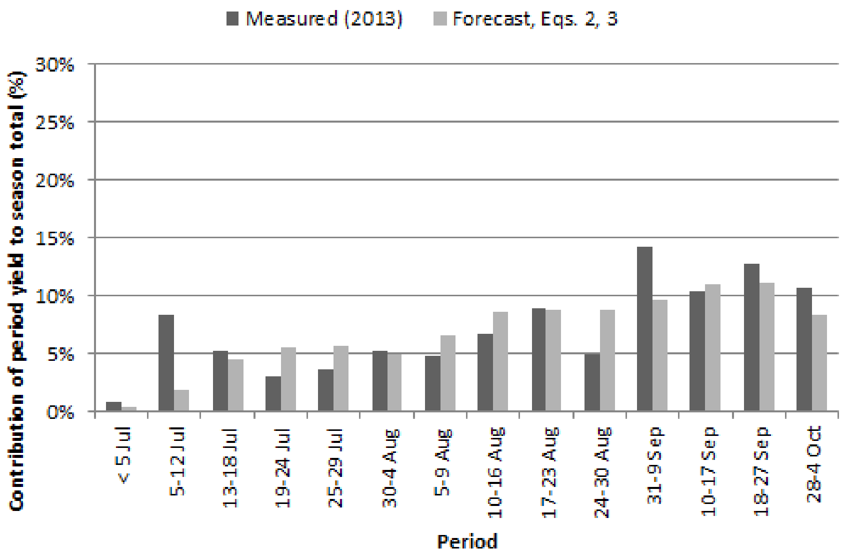

Figure 20. Percent contribution of individual harvest period yields (measured or forecast with Eqs. 2 and 3) to measured 2013 season total yield - Field 1.

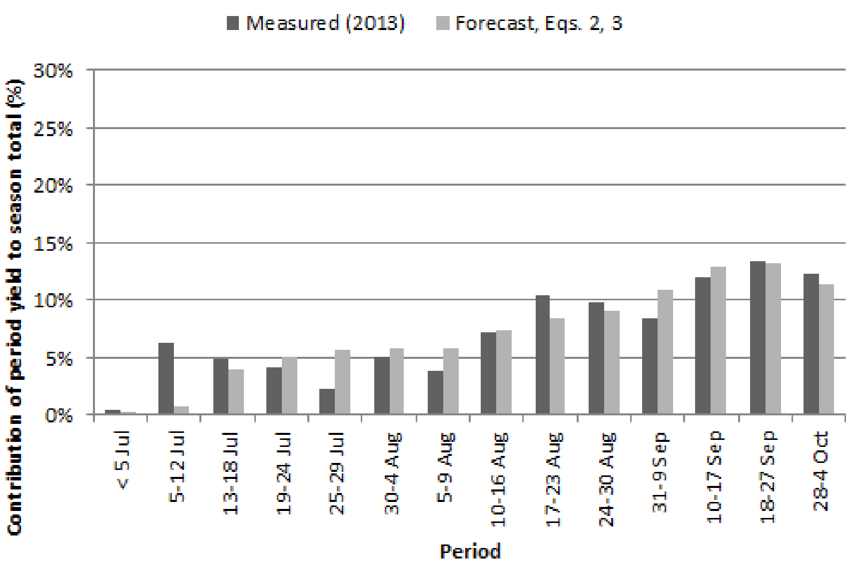

Figure 21. Percent contribution of individual harvest period yields (measured or forecast with Eqs. 2 and 3) to measured 2013 season total yield - Field 2.

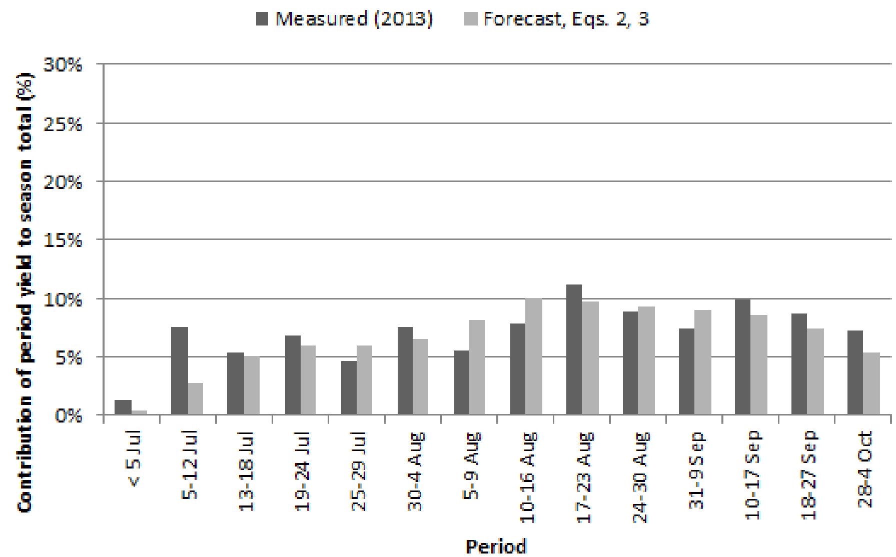

Figure 22. Percent contribution of individual harvest period yields (measured or forecast with Eqs. 2 and 3) to measured 2013 season total yield - Field 3.

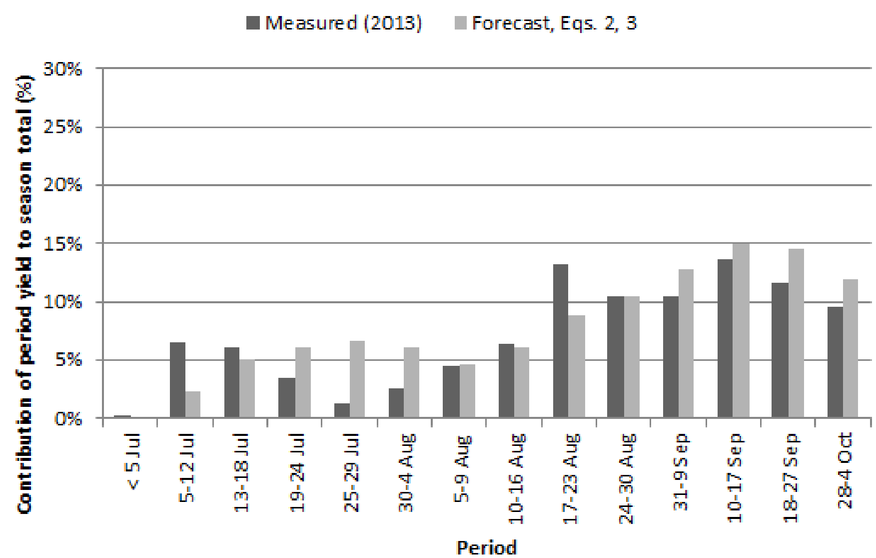

Figure 23. Percent contribution of individual harvest period yields (measured or forecast with Eqs. 2 and 3) to measured 2013 season total yield - Field 4.

3.4.6 Validation of Equations 2, 3 and 4 for the 2012 season

Before validating Eqs. 2 and 3 with 2012 yield data, a fourth equation was generated. As with the 2013 season, in 2012 a regression, spanning all fields, was developed between the cumulative mean number of mature fruit per plant at harvest and the cumulative mean weight of mature fruit per plant at harvest, which occurred some 21 to 36 days after the initial inventory of green fruit. For confidentiality reasons, the values used to generate this relationship are not presented.

Equation 4. [*g mature fruit/plant*] = -0.0363[*no. mature fruit/plant*]^2 + 11.904[*no. mature fruit/plant*] + 5.0668

This analysis was undertaken *ex post facto* since the mean number and weight of mature fruit per plant were only known at harvest. Therefore, Eq. 4 allows one to forecast the cumulative mean weight of mature fruit per plant at harvest from the cumulative mean number of mature fruit per plant at harvest.

The Figures 24 to 27 shows measured and forecast (Eqs. 2-3 or Eqs. 2-4) yields for harvests between July 5 and 20 September 2012, those thereafter being eliminated as no green fruit inventory data were available. Moreover, measured and forecast yields were again expressed as a proportion of full season yield totals, but where the last harvest was that of 20 September 2012.

Forecast and measured yields were similar for the first four periods regardless of which pair of equations was employed. For the 5th and 6th periods, forecasts substantially underestimated yield. For the 8th period both forecasts overestimated yields, but forecasts using the 2-4 combination outperformed those using the 2-3 combination.

The mean weight of mature fruit per plant at harvest varied more in 2012 (Figure 19) than 2013 (Figure 18). The first of the two equations used in generating the forecast (Eq. 2) calculates the mean number of mature fruit per plant at harvest, while the second (Eq. 3 or 4) derives the total weight of fruit from their number. The second equations — either Eq. 3 generated from 2013 data, or Eq. 4 generated from 2012 data — generate slightly different yield values: for the same cumulative mean number of mature fruit per plant at harvest, Eq. 2 yields a greater cumulative mean weight of mature fruit per plant at harvest than Eq. 3, particularly when mature fruit number per plant exceeds twenty-five.

Weather and growing conditions are both strong influencing factors, and difficult to factor into forecasts once these are made. The 2012 season was more conducive to strawberry plants undergoing water stress than the 2013 season, which was almost ideal for strawberry production. A difference in yield can be explained by different numbers of fruit of a common weight, a common mean number of fruit with a different mean weight, or a combination of both. In the present case, mean fruit weight was the main factor affecting overall yield. When the mean fruit weight is affected it is recent meteorological conditions which are the cause, since only weather patterns weeks before flowering could affect flower and thus fruit number. This is supported by the results of a summer 2006/2007 study in which a micro-sprinkler system was used to cool the strawberry canopy during periods of intense heat (Boivin, 2008).

Further trials must be undertaken before coming to firm conclusions, but at first glance Eq. 4 (2012) would serve best for a season prone to water stress events, while Eq. 3 (2013) would be best suited to years when strawberry plants were under ideal growing conditions.

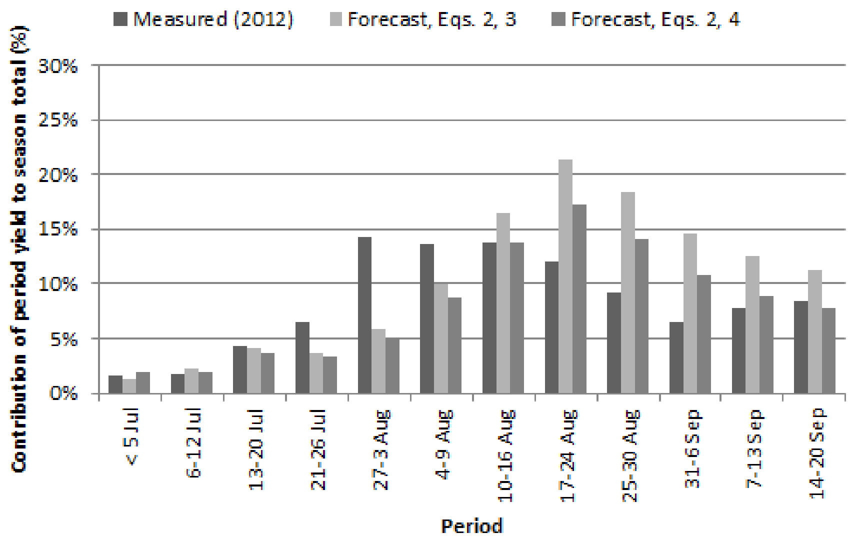

Figure 24. Percent contribution of individual harvest period yields (measured or forecast with Eqs. 2 and 3, or Eqs. 2 and 4) to measured 2012 season total yield - Field 1.

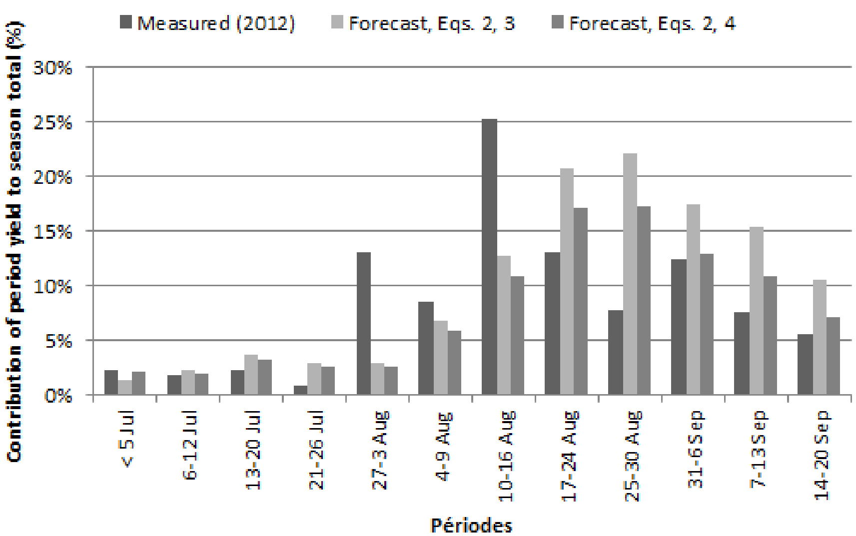

Figure 25. Percent contribution of individual harvest period yields (measured or forecast with Eqs. 2 and 3, or Eqs. 2 and 4) to measured 2012 season total yield - Field 2.

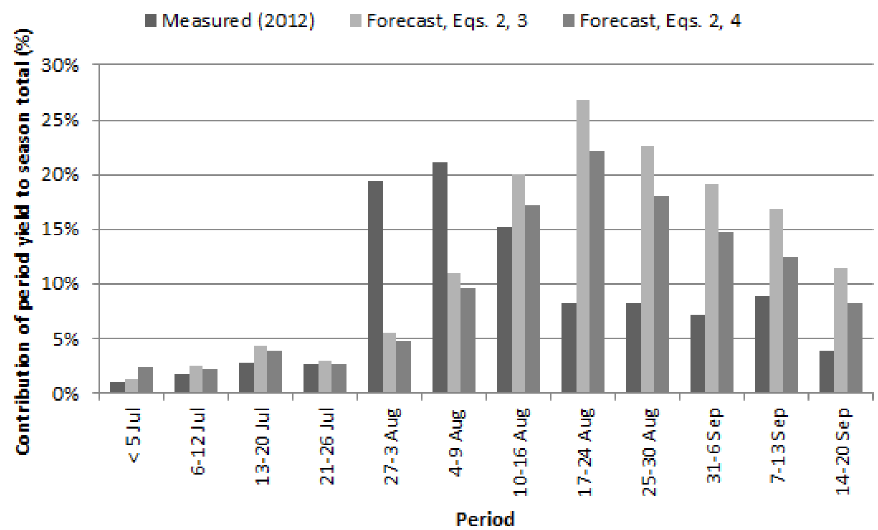

Figure 26. Percent contribution of individual harvest period yields (measured or forecast with Eqs. 2 and 3, or Eqs. 2 and 4) to measured 2012 season total yield - Field 3.

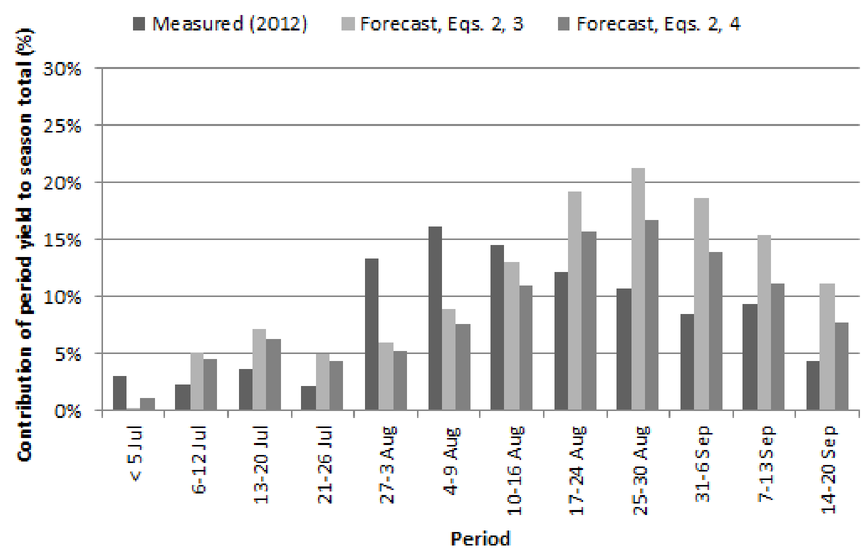

Figure 27. Percent contribution of individual harvest period yields (measured or forecast with Eqs. 2 and 3, or Eqs. 2 and 4) to measured 2012 season total yield - Field 4.

3.4.7 Proposed forecast method for strawberry cultivar ‘*Seascape*’

1. Inventory green fruit as soon as flower removal ends (Table 9). Dates of such inventories are listed for informational purposes; however, as it varies over the season, the number of days from flower opening to mature fruit is of greater importance.

Table 9. Dates of on-site green fruit inventory periods and associated total yield (f.w.b.) forecasts according to the number of days from flowering to fruit maturity at any particular portion of the season.

Period	Latest date for inventory since the previous inventory	Days from flowering to fruit maturity based on observations	Latest date for harvest since the last period
1	10 June	21	1 July
2	17 June	21	8 July
3	24 June	21	15 July
4	1 July	21	22 July
5	8 July	21	29 July
6	15 July	21	5 August
7	22 July	21	12 August
8	29 July	21	19 August
9	4 August	21	26 August
10	11 August	22	2 September
11	16 August	24	9 September
12	22 August	25	16 September
13	26 August	28	23 September
14	29 August	32	30 September
15	1 September	36	7 October
16	8 September	36	14 October

2. Inventory of the total number of green fruit on 60 strawberry plants randomly chosen across the production field.
3. Data entry (column A, Table 10), followed by filling in the subsequent columns as instructed below.

Using the fictitious data in Table 10 :

A. For periods 1, 2 and 3 (column A, Table 10), 15, 100 and 185 green fruit were inventoried, respectively, per 60 plants;

B. The mean number of green fruit per plant for a given period was obtained by dividing the total number of fruit inventoried by the number of plants (column B, Table 10);

C. The cumulative mean number of green fruit was obtained by summing the mean numbers green fruit from the present and previous periods (column C, Table 10);

D. Equation 2 :

$$[\textit{no. mature fruit/plant}] = -0.0008\,[\textit{no. green fruit/plant}]^2 + 0.4372\,[\textit{no. green fruit/plant}]$$

was used to forecast the cumulative number of mature fruit per plant (column D, Table 10), from the value of [*no. green fruit*] in Column C (Table 10);

E. Equation 3 :

$$[\textit{g mature fruit/plant}] = -0.01[\textit{no. mature fruit/plant}]^2 + 13.262\,[\textit{no. mature fruit/plant}] + 0.489$$

or

Equation 4 :

$$[\textit{g mature fruit/plant}] = -0.0363[\textit{no. mature fruit/plant}]^2 + 11.904[\textit{no. mature fruit/plant}] + 5.0668$$

are used to forecast the cumulative weight of mature fruit per plant at harvest (column E, Table 10), based on the [*no. mature fruit/plant*] (column D, Table 10)

F. To obtain the weight of mature fruit per plant at harvest for a given period (Column F, Table 10) subtract the value from the immediately preceding period, from the value for a given period in column E (*e.g.*, for Period 3, 28.7 - 11.1 = 17.6);

G. Multiply the value in column F by the per hectare strawberry plant density.

Table 10. Steps to follow to forecast, from inventories of green fruit on 60 randomly selected strawberry plants per field, the per hectare fresh weight basis yield of mature fruit, 21 to 34 days in advance.

	A	B	C	D	E	F	G
Period	Total number green fruit per 60 plants	A/60 Mean number of green fruit per plant	Cumulative mean number of green fruit	Equation 2 Forecast cumulative number of mature fruit per plant at harvest	Equation 3 (2013)* Equation 4 (2012) Forecast cumulative weight of mature fruit per plant at harvest (g)	Forecast weight of mature fruit per plant at harvest (g) by period	Planting density/ha
1	15	0.25	0.25	0.11	*1.5	1.5	
2	100	1.67	1.92 (1.67 + 0.25)	0.84	*11.1	9.6	
3	185	3.08	5.00 (3.08 + 1.92)	2.17	*28.7	17.6	
4							
5							
…							

3.5 Evaluating the potential use of forecasts in scheduling growing season fertigation.

No reference grid for day-neutral strawberry fertilisation by fertigation is presently available for Québec. The fertigation regime was therefore developed through the expertise of the producer and his extension agent, and drawn from information in the literature. Day-neutral strawberry trials run on l'Île d'Orléans in 2011 showed no difference in yield between strawberry plants receiving 50% or 100% of the N delivered under the producer's normal fertigation regime (Landry and Boivin, 2012). Irrigation management in strawberry production also remain a topic of intensive research. Plant nutrient use efficiency under fertigation is strongly linked to irrigation efficiency. Limitations in the soil volume which the drip irrigation system can moisten can lead to issues of the soil drying out around the drip irrigation tape (Boivin and Deschênes, 2011).

While an approach under which the quantity of nutrients supplied would be adjusted according to forecasts of strawberry yield (f.w.b.) at harvest would be of some interest; however, such an approach would only reach its potential when the crop's fertilizer and irrigation needs were determined and adequately addressed. Indeed, variation in fruit yield is greater from one period to the next than from one growing season to the next. Moreover, each strawberry taken from the field represents a net export of nitrogen. Landry and Boivin (2012) found that nitrogen exports from the field attributable to picking and removal of fruit from the field represented 48% and 43 % of the total nitrogen taken up by the crop in 2010 and 2011, respectively. Therefore, since the removal of nitrogen from the field varies from season to season, the nitrogen use efficiency might be improved if yield forecasts were considered.

4 CONCLUSIONS

The on-site green fruit inventories in 2013 allowed the successful formulation of relatively accurate yield forecasts, which were communicated to producers on a weekly basis, according to the field in question. Forecasting precision was improved, *ex post facto*, by adjustments which took into account the variation in days from flowering to mature fruit.

The approach's accuracy in 2013 was founded, in particular, on an inventory of the number of new green fruit per plant; however, as such information was difficult to collect under commercial conditions, an effort was made to develop a simpler approach. The approach now consists in a simple weekly inventory of the number of green fruit on 60 strawberry plants random-selected in a given field.

These periods of fruit inventory were matched with harvest periods according to the variation over the season in number of days from flower opening to mature fruit harvest. Following the inventory of green fruit, their mean numbers per plant can be used to forecast the eventual number of mature fruit per plant, and, in turn, the mean weight of mature fruit per plant at harvest.

Done *after* the compilation of fruit inventories, forecasts for the 2013 season matched measured values closely. Less accurate than those for 2013, the *ex post facto* 'forecasts' for the 2012 season, were based on regressions developed from 2013 data. However, using a regression equation based only on 2012 data was shown to be more accurate in predicting yields for the 2012 season.

Weather conditions have an impact on strawberry plants' productivity. Conditions in 2012 differed significantly from those in 2013: while the latter was ideal for strawberry production, the former was somewhat drier. Once the forecast is made, the effects of weather conditions can no longer be integrated into the forecast. Developing a pair of forecasts, one optimistic and the other conservative, from the regression equations developed, could help to alleviate any errors in forecasting brought on by unexpected and unaccounted for weather conditions occurring between forecast and harvest.

Finally, the currently proposed approach would gain by being further confirmed through additional trials on a greater number of farms; efforts are ongoing to do so.

5 BIBLIOGRAPHY

Allison, L.E. 1965. "Organic Carbon." p. 1367-1677. *In* : Methods of Soil Analysis, Part 2 (C.A. Black, ed.), Agronomy Monograph no. 9, Madison (WI): American Society of Agronomy

Allen, R.G., Walter, I.A., Elliott, R.L., Howell, T.A., Itenfisu, D., Jensen, M.E., and Snyder, R.L. (eds). 2005. *The ASCE Standardized Reference Evapotranspiration Equation*. Report of the ASCE Standardization of Reference Evapotranspiration Task Committee, Reston (VA): American Society of Civil Engineering, 216 p.

Boivin, C. 2008. *Étude d'acquisition de connaissances du pilotage de l'irrigation par tensiométrie et de la gestion du microclimat par micro-aspersion dans la production de la fraise à jours neutres à l'île d'Orléans.*[*Data acquisition as background for both tensiometer-based irrigation regime design for day-neutral strawberry production and microclimate management using micro-sprinklers*] Rapport final déposé au Syndicat de l'UPA de l'île d'Orléans. Quebec (QC): IRDA. 48 p. Seen 19 January 2014 at : http://www.cdaq.qc.ca/content_Documents/5009%20Rapport%20PAECQ_Micro-aspersion%20dans%20la%20production%20de%20la%20fraise%20%C3%A0%20jour%20neutre.pdf

Boivin, C. and Deschênes, P. 2011. *Stratégies d'irrigation dans la fraise à jours neutres*. [*Irrigation strategies for day neutral strawberries*] Rapport final déposé au CDAQ (no. 6348). Quebec (QC): IRDA. 98 p. Seen 19 January 2014 at : http://www.irda.qc.ca/assets/documents/Publications/documents/boivin-et-deschenes-428_rapport_strategies_irrigation_fraise_2011.pdf

Chandler, C.K., Mackenzie, S.J., and Herrington, M. 2004. Fruit development period in strawberry differs among cultivar, and is negatively correlated with average post bloom air temperature. *Proceedings of the Florida State Horticultural Society* 117: 83-85. Seen 19 January 2014 at http://fshs8813.wpengine.com/proceedings-o/2004-vol-117/083-085.pdf

Conseil des Productions Végétales du Québec (CPVQ), 1988. *Méthodes d'analyse des sols, des fumiers et des tissus végétaux. Méthode PH-1. Détermination du pH à l'eau.* Agdex 533. Quebec (QC) : Ministère de l'Agriculture, des Pêcheries et de l'Alimentation.

Døving, A. and Måge, F. 2001. Prediction of strawberry fruit yield. *Acta Agriculturae Scandinavica, Section B — Soil & Plant Science* 51(1):35-42.
DOI: 10.1080/090647101317187870

Isaac, R.A., and Johnson, W.C. 1976. Determination of total nitrogen in plant tissue, using a block digestor. *Journal of the Association of Official Analytical Chemists 59(1): 98-100.*

Landry, C. and Boivin, C. 2012. *Performance des fertilisants à libération contrôlée et d'origine organique dans la fraise à jours neutres fertiguée*. [*Performance of controlled* *release and organic fertilizers in fertigated day-neutral strawberries*] Rapport final déposé au MAPAQ (no. PSIH10-1-355). Quebec (QC) : IRDA. 53 p. Seen 19 January 2014 at : http://www.irda.qc.ca/assets/documents/Publications/documents/landry-boivin-479_rapport_elc_fraise_2012.pdf

Mackenzie, S.J. and Chandler, C.K. 2009. *A method to predict weekly strawberry fruit yield from extended season production systems*. Agronomy Journal, 101(2): 278-287. DOI:10.2134/agronj2008.0208

Tran, T. S. and Simard, R. R. 1993. "Mehlich III-extractable nutrients." p. 43–50, *In Soil sampling and methods of analysis*. (M.R. Carter, ed.) London (UK): Lewis Publishers.

6 DISSEMINATION OF RESULTS

- IRDA Internet site http://www.irda.qc.ca/fr/equipe/carl-boivin/, since April 2011.

- Presentation given at the "Field Day on Innovations in Small Fruit Production." CRAAQ. Île d'Orléans, 29 July 2011
    - http://www.craaq.qc.ca/UserFiles/File/Communication/Articles_Presse/Nouv_fraiches_Act_champs_2011_10.pdf (Mentioned in APFFQ publication)
    - http://www.craaq.qc.ca/Documents/Evenements/EPTF1102/Depliant_EPTF1102.pdf (Field Day program)

- Presentation given at the "Saint Rémi Horticultural Days." 7 December 2011.
    - http://www.mapaq.gouv.qc.ca/SiteCollectionDocuments/Regions/Monteregie-Ouest/Journees_horticoles_2011/7_decembre_2011/Fraise_et_framboises/16h00_Survoldesprojetsderecherche_C_Boivin.pdf (PowerPoint presentation)
    - http://www.mapaq.gouv.qc.ca/SiteCollectionDocuments/Regions/Monteregie-Ouest/Journees_horticoles_2011/ProgrammeJourneesHorticoles2011.pdf (Horticultural Day program)

- Presentation given at the Provincial Day for Scientific Research. APFFQ. Laval University, 14 December 2011.
    - http://www.craaq.qc.ca/UserFiles/File/Communication/Articles_Presse/Nouv_fraiches_Act_champs_2011_10.pdf (Mentioned in APFFQ publication)

- Article in newspaper, LaPresse.ca, 3 July 2013
    - http://www.lapresse.ca/actualites/national/201307/02/01-4666849-predire-la-production-des-fraises-pour-mieux-les-vendre.php

- Interview on Radio Canada International, 3 July 2013
    - http://www.rcinet.ca/fr/2013/07/03/les-fraises-plaisir-dete-pour-le-consommateur-soit-mais-defi-de-taille-pour-le-producteur-de-fraises-a-jours-neutres/

7 APPENDICES

Figure 28. Protective netting used.

Figure 29. Coloured ribbon used in identifying specific pedicels.