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Modelling Sweet Cherry (*Prunus avium*) Fruit Yield in Norway

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ABSTRACT

Data from commercial sweet cherry growing in two regions of Norway were collected, and the relationship between yield and climate data was studied. Data were obtained from the two regions Ullensvang and Valldal, both in the fjord district of Norway. For Ullensvang two reliable datasets were available; one from Gartnerhallen 1963-1991 and one from three packing houses 1955-2002. The third dataset was from Gartnerhallen in Valldal 1954-2001. The relationship between relative yield levels as a percentage of a moving average and climate data was studied. The long time series and reliable datasets for Ullensvang made a good basis for statistical calculations. Multiple regression equations with meteorological data as predictors were developed for predicting yield per June 1st and for explaining yield after harvesting. The predictors and their coefficients in the regression models might explain the effect of weather on yield. Yield level was positively correlated to temperatures in July-September in the year previous to the fruiting year. Yield was negatively correlated to number of sun hours in November-December and to temperatures in January-February. Warm and dry weather during flowering in May was favourable for yield. Much rain in May reduced yield; 1 mm more rain in May reduced yield 0.25%. Much rain and high humidity in June or July had a negative influence on yield level; one more day with precipitation in July reduced yield with about 3% in Ullensvang. Climate factors before June 1st had a strong influence on yield, making it possible to develop multiple regression models to predict yield levels. Such models for predicting yield can be very useful for both growers and marketing.

Keywords: climate, meteorological, precipitation, prediction, regression, temperature

INTRODUCTION

Norway has the northernmost fruit growing in the world. Marginal and varying weather causes extreme variations in fruit yield. Modelling and predicting fruit yields have been of great interest for the fruit industry. Sweet cherry is an important fruit worldwide, but in Norway the production is relatively limited. The northern climate and the varying weather conditions make the study of climate effects on yield especially interesting. The weather at the different phases of physiological development can be crucial for the sweet cherry yield. Fruit buds and fruit trees can be vulnerable to winter damage. The weather conditions at certain periods of development are possible explanations for yield variation (Måge 1975, 1976). Very low winter temperatures are rare in the fjord district near the west coast of Norway, but possibly also extreme variation in temperature within a short period might cause damage to the fruit buds. Sekse (2007) suggested that winter damage and blossom frost in plum are rare in these districts. Måge (2007) also reported that blossom frost in sweet cherry is very rare in the fjord district of western Norway, but that it can be seen occasionally in eastern Norway. Miranda *et al.* (2005) suggested that sweet cherry was the most sensible species to spring frost from several *Prunus* species tested. Måge (1975) described the sweet cherry yield variations in an orchard in Ullensvang Norway 1934-1974. Regression models for explaining the fruit yield of various fruit crops with climate data as variables has been developed by several authors; plums (Måge *et al.* 2007), strawberries (Rudolph 1983; Døving and Måge 2001), apples (Beattie and Folley 1978; Stanley *et al.* 2000, 2001), and plums and peaches (Mimoun and Dejong 1999). Rumayor-Rodríguez (1995) developed multiple regression models to analyse potential growing areas for Japanese plums. Also tree size has been used as predictors for peach and plum yield (Jimenez and Diaz 2003a, 2003b). Måge and Grønnerød (2007) discussed growth of plum fruitlets in relation to time in the growing season and climatic conditions. It is likely that there is a similar correlation for cherries.

The relationship between weather conditions and fruit firmness of sweet cherries is discussed by Sekse *et al.* (2009). It can be of great value to get early and precise predictions of cherry yield. The purpose of the present work was to develop better models for predicting and explaining the sweet cherry yield. Through these models the effect of climate on yield can be explained and make it possible to improve yield levels.

MATERIALS AND METHODS

The data for this study were obtained from several sources. Data on sweet cherry fruit yield were collected for the years 1955-2002 from three packing houses in Ullensvang Hardanger; Ullensvang Fruktlager, Hardanger Frukt og Bær and Nå Fruktlager. Also the grower's organisation Gartnerhallen contributed with yield data for Ullensvang for the period 1957-1991, these data are representing other packing houses in the same district. The data for Valldal the northernmost district were also available from Gartnerhallen (Gartnerhallen Møre 1954-2001). Ullensvang and Valldal both belong to different regions of the fjord district of Norway, Ullensvang at about 60 °N and Valldal at about 62 °N. Because no data about area or tree number were available, yield per hectare or tree could not be calculated. Therefore relative yield as % of a ten years moving average were used. By using a moving average the effects of different cultivars and changing cultural techniques were smoothed out.

The meteorological data for Ullensvang were obtained from the Norwegian Meteorological Institute (1954-2005) for the stations in Ullensvang, Kvam and Bergen. For most of the calculations for Ullensvang meteorological data from Kvam were used as this meteorological station had the longest time series. The sweet cherry growing in Valldal is close to the meteorological station in Tafjord, which has long time series of climate data.

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Table 1 Regression models explaining sweet cherry fruit yield for Ullensvang based on one dataset from three packing houses (1963-2001), and from the grower's organisation Gartnerhallen in Ullensvang (1963-1991) and in Valldal (1954-2001) in Norway, b=regression coefficient, p=significance.

	Data from three packing houses in Ullensvang		Data from Gartnerhallen in Ullensvang		Data from Gartnerhallen in Valldal	
	b	**p**	**b**	**p**	**b**	**p**
Constant	115.6	0.001	368.5	0.000	203.2	0.236
In the year before fruiting						
Aug. maximum temp.					4.98	0.083
Sep. mean max. temp. °C	7.1	0.003			13.58	0.001
Oct. precipitation mm	0.051	0.017	0.101	0.000		
November sun hours	-0.577	0.046				
December sun hours	-2.263	0.001	-1.24	0.082		
December minimum temp.					7.26	0.006
In the fruiting year						
January minimum temp.					-5.85	0.008
Feb. mean max. temp. °C			-4.63	0.026		
March precipitation mm	-0.0887	0.000				
March sun hours			0.302	0.000		
May precipitation mm	-0.245	0.000				
May number of rain days					-3.46	0.063
May rel. humidity %			-3.10	0.000		
June precipitation mm	-0.125	0.005	-0.251	0.000		
July precipitation mm						
July number of rain days	-1.76	0.007	-2.98	0.000		
July rel. humidity %					-4.80	0.009
R^2	84.6		90.3		48.2	
R^2-adj	80.3		87.0		40.2	
R^2-pred	73.5		83.2		28.0	
p - regression	0.000		0.000		0.000	
SEE rel. yield %	17.0		15.2		44.6	

The long time series make a good basis for statistical calculations, which is necessary when working with climate variables. In the dataset from Gartnerhallen in Ullensvang the total yield varied from 18 to 806 tons per year. In the data from the three packing houses in Ullensvang total yield varied from 12 to 414 tons. The Gartnerhallen in Valldal had a small quantity varying from 1 to 17 tons per year. The large variation is due to climate, cultivar and cultural practice. Better cultural practice has reduced yield variations the last decades, especially rain cover has reduced the percentage of rotten and cracked fruits. The total yield is the sum of deliveries from many growers each with a small quantity. With many growers included in the data some random errors will be reduced.

The selection of predictors for the models was based on correlation matrix and on what could be biological reasonable effects. From a biological point of view, winter and blossom were regarded as critical periods for sweet cherry growth and development. Due to the high number of possible regression models a combination of methods for selecting variables was useful; a forward selection, backward elimination and stepwise regression. For the statistical calculations the computer programs Excel and Minitab were used. The Minitab regression and best subset regression procedures were used, and the regression equations were selected in consideration to R^2, R^2-adjusted, R^2-prediction and SEE (standard error of estimate). The regression equations were tested for autocorrelation by residual plots and by Durbin Watson statistics. The four or five best models for each district were also tested by cross validation. The regression procedure includes p-value, t-value, standard error of coefficient and VIF (variance inflation factor - multicollinearity diagnostic) for each variable in the regression equations.

RESULTS

The correlation between the two datasets from Ullensvang was very strong (r= 0.936, p=0.000), and the data from Valldal was significantly (p=0.000) correlated with the two datasets from Ullensvang. A tendency to biannual bearing can be seen (**Fig. 3**), but it was not statistically significant. The sweet cherry yield varied more in Valldal (standard deviation=58.5) than farther south, probably because of a more marginal and variable climate. The two datasets from Ullensvang had standard deviations of 40.1 for Gartnerhallen, and 51.5 for the three other packing houses. The relative yields for all the three datasets were normally distributed according to Anderson-Darling normality test. Meteorological data are often interrelated; in most cases the temperature data within the same month were positively correlated. In spring, summer, and autumn there was a negative correlation between temperature and precipitation. There was no significant change in climate during this period.

The coefficients in the regression models can explain the effect of the various climate variables (**Tables 1, 2**). **Table 1** includes climate variables during about 12 months before harvest. **Table 2** presents regression models for predicting fruit yield per June 1st and only variables before that date are included. The weather in the year before fruiting influenced the yield in perennial fruit crops. Relatively high temperatures in July, August and September had a positive effect on sweet cherry yield (**Tables 1, 2**); but with different significance for the three datasets. The strongest effect was found in Valldal; 1°C higher mean maximum temperature in September gave 13.6% higher yield. Also precipitation in October the year before fruiting had a positive correlation with yield. Sun hours in November and December were negatively correlated with yield in Ullensvang. High temperatures in January and February were negatively correlated with cherry yield; 1°C higher mean maximum temperature in February resulted in 4.6% lower yield level for the data from Gartnerhallen, but these results were not consistent for the different temperature variables. For March there seems to be a positive effect of number of sun hours and a negative effect of precipitation. The flowering is crucial for cherry yield and it normally occurs in May; high yield level was positively correlated to warm, sunny and dry weather in May. One mm more precipitation reduced yield level with 0.25 or 1% higher relative humidity reduced yield with 3.1% in Ullensvang. Similarly there is a tendency that higher temperatures in May were positively correlated to high yield, but this was not significant. Also much rain and high humidity in June or July had a negative influence on yield level (**Table 1; Figs. 1, 2**); one more rain day in July reduced yield with about 3% in Ullensvang. High precipita-

Table 2 Regression models for predicting sweet cherry fruit yield per June 1st for Ullensvang based on one dataset from three packing houses (1963-2001), and from the grower's organisation Gartnerhallen in Ullensvang (1963-1991) and in Valldal (1954-2001) in Norway, b=regression coefficient, p=significance.

	Data from three packing houses in Ullensvang		**Data from Gartnerhallen in Ullensvang**		**Data from Gartnerhallen in Valldal**	
	b	**p**	**b**	**p**	**b**	**p**
Constant	94.1	0.011	57.0	0.010	-187,5	0.075
In the year before fruiting						
July mean temp.	2.73	0.093				
August maximum temp.					6.54	0.040
Sep. mean max. temp. °C	6.42	0.017			11.70	0.011
Oct. precipitation mm	0.049	0.031	0.112	0.000		
November sun hours	-0.865	0.006				
December sun hours	-2.32	0.002	-3.52	0.000		
December min. temp. °C					7.23	0.010
In the fruiting year						
January min. temp. °C					-6.96	0.005
February precipitation mm	-0.047	0.041	-0.131	0.000		
March precipitation mm	-0.0734	0.002				
May precipitation mm	-0.277	0.000				
May number of rain days					-3.83	0.058
May sun hours			0.371	0.000		
R^2	82.4		77.5		36.0	
R^2-adj	77.4		73.8		28.2	
R^2-pred	68.9		69.0		15.9	
p - regression	0.000		0.000		0.002	
SEE rel. yield %	18.4		21.7		49.8	

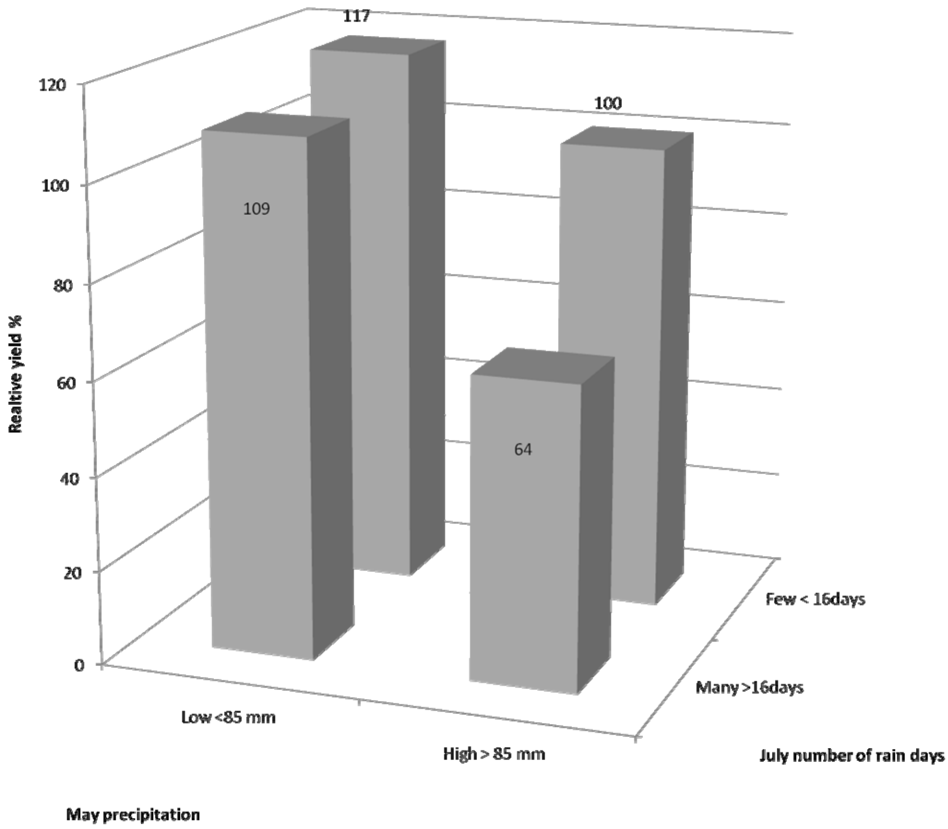

Fig. 1 Sweet cherry yield. Interaction between May precipitation and July number of rain days on sweet cherry yield 1963-2001, data from three packing houses in Ullensvang.

tion in May and many rain days in July showed an interaction and reduced yield considerably (**Fig. 1**). Other not significant variables showed similar effects and support the results in **Tables 1, 2**. For the two datasets from Ullensvang R^2, R^2-adjusted and R^2-predicted were quite similar, confirming that the regression models are consistent and not overfitted (**Tables 1, 2**). The standard error of estimates are low for these two models; 15-17%. The dataset and the model from Valldal (**Tables 1, 2**) showed more deviation between the different R^2 and had generally a higher unexplained variation.

When predicting yield per June 1st the weather in June and July is unknown and these data are not included in the models in **Table 2**. Except the data from June-July the most significant variables mainly are the same in **Table 2** as in **Table 1**, because of less data available the R^2 are bit lower, but still very high for the two datasets from Ullensvang. The R^2 are 82.4 and 77.5, which indicates a high level of explanation. Also in this case the difference between R^2, R^2-adjusted and R^2-predicted were small, confirming that the

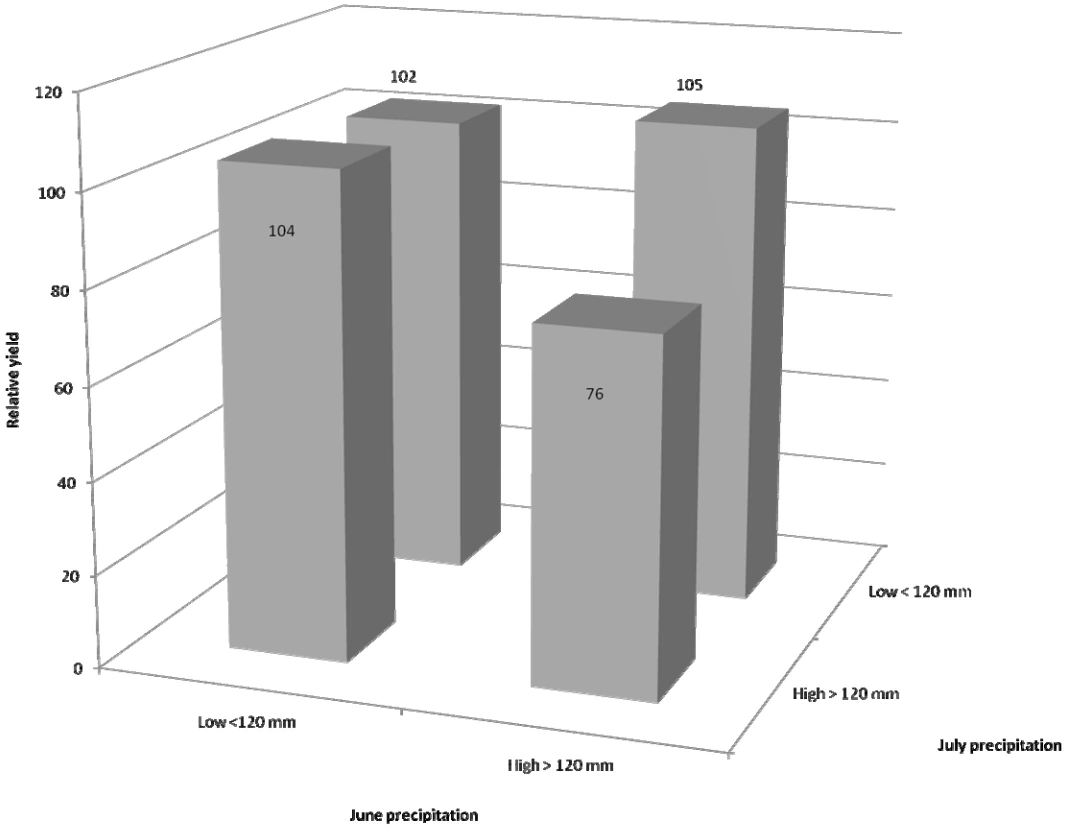

Fig. 2 Sweet cherry yield. Interaction between June and July precipitation on sweet cherry yield 1963-2001, data from three packing houses in Ullensvang.

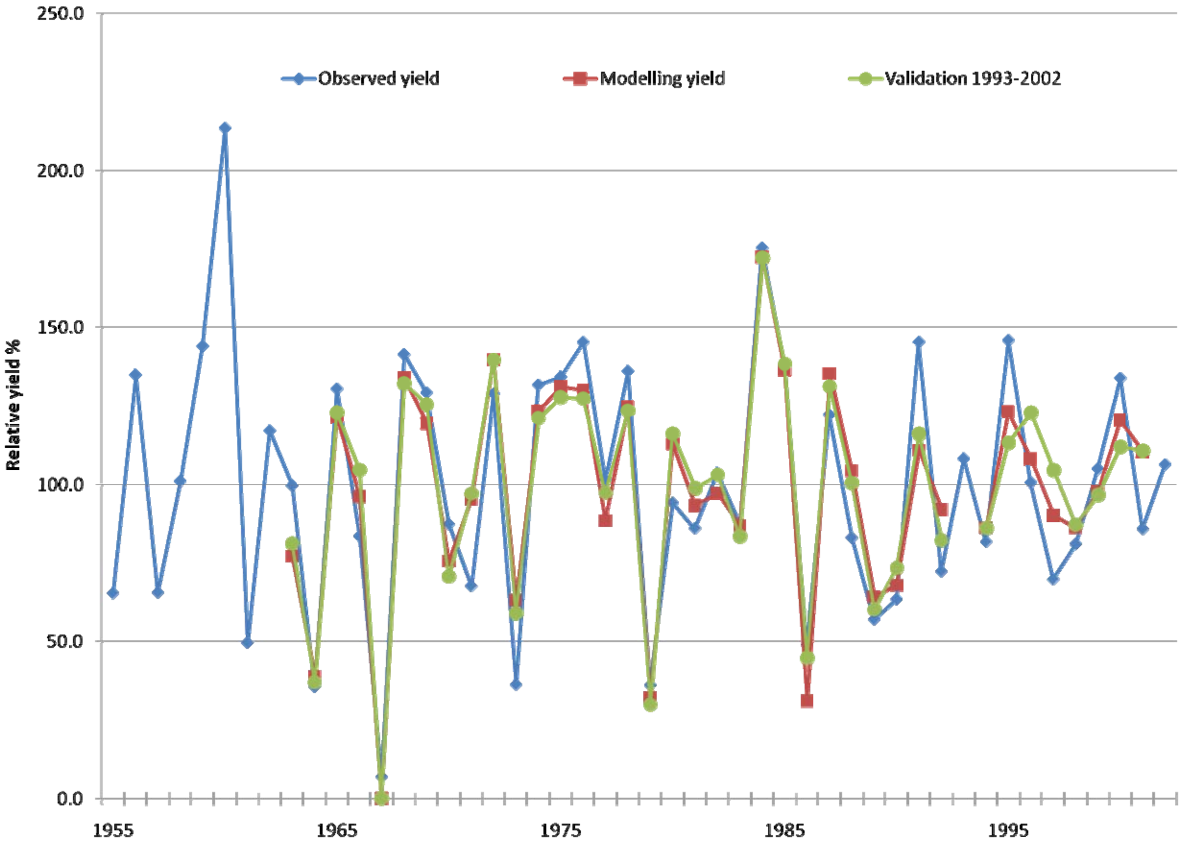

Fig. 3 Sweet cherry yield. Relationship between sweet cherry yield observed, modelling, and validation in Ullensvang. Corresponding with the regression model in **Table 2** for the three packing houses in Ullensvang 1955-2002. For the validation the same variables as in **Table 2** were used, data from the years 1963-1992 were used to develop a new model, which was used to predict yield for the years 1993-2001.

regression models are consistent and not overfitted. For the first dataset from Ullensvang a regression equation with eight variables was selected, this gave a somewhat higher R^2 than the second dataset, but the R^2-predicted was about the same. For the dataset from Gartnerhallen a regression equation with only four variables was chosen, but also with a high R^2 and a low standard error of estimate. All four variables had a p=0.000. The results for the model in the first column in **Table 2** are visualized in **Fig. 3**. The three lines show a good conformity for Ullensvang. The regression model for predicting yield in Valldal was a bit less precise; R^2 was quite low and the difference between the R^2, R^2-adjusted and R^2-predicted was too large. The standard error of estimate for Valldal is about 45% which is quite much compared to the results for Ullensvang.

DISCUSSION

Fruit growing under northern climate is marginal and subject to yield variation, and the variable weather can boost this effect. Climate variables are more or less interrelated and in open field they will never be totally independent. In spite of that it might be useful to look at the effect of single variables on sweet cherry yield. Warm weather in July-September the year before fruiting had in this study a positive effect on yield level; the effects were similar for the three datasets, but not always significant. Måge (1975, 1976) indicated similar results for cherry and plum. Kühn (2003) suggested that low temperatures in October-November reduced sour cherry yield in Denmark. In the present study high number of sun hours in November and December was negatively correlated with yield level in Ullensvang, and similarly high temperatures in January and February were negatively correlated to yield. Also in plums there was a negative correlation between winter temperatures and yield (Døving 2009); similar effects were observed by Måge (1975, 1976) and Kühn (2003). It is possible that much sunshine in November-December or high temperatures in January-February can cause a dehardening, making the buds more vulnerable for low temperature damage.

Warm and dry weather in May was positively correlated with high yield level; weather that favours pollination increased yield. Also Måge (1975) reported a positive correlation between May temperatures and sweet cherry yield. Måge and Grønnerød (2007) found a positive correlation between plum fruit size and temperatures in March, April and May. Kühn (2003) discussed the relationship between weather unfavourable for pollination and low sour cherry yield. In the present study there is not found any significant correlation between yield and minimum temperatures in April or May, indicating that there has not been any frost damage in the spring. This is in agreement with Måge (2007) and Sekse (2007) who reported that blossom frost is very rare in this district. Måge (2007) suggested that earlier flowering through global warming might increase the risk of blossom frost in eastern Norway. There is no indication of similar results in the present study for western Norway.

In the present study an interaction between June and July precipitation caused a yield reduction of 26-29%. The lowest column in **Fig. 2** represents the eight years with highest precipitation in June and July. A year with maximum precipitation in both months would result in more than 50% yield reduction compared to years with low precipitation in both months (data not shown). Børve and Meland (1997) compared the marketable sweet cherry yield with and without rain cover, and they reported a difference of 48% the first year and 25% the second year; this is on the same level as in the present study.

The regression models for Ullensvang showed good agreement between observed yield, modelling and validation (**Fig. 3**), it is about as precise as models developed for strawberries (Døving and Måge 2001) and better than those for plums (Døving 2009). This model (**Fig. 3**) has a tendency to show less variation than the observed yield. In the two datasets from Ullensvang there were no typical outliers. The dataset from Valldal contains a few extreme values that could possibly be called outliers, both positive and negative deviations compared to the model. These outliers have not been excluded from the calculations.

The climate before June 1st in the fruiting year has a strong impact on the sweet cherry yield, making it possible to develop regression models for predicting the yield (**Table 2, Fig. 3**). When reliable data and long time series are available, regression models can be used to predict yield with good accuracy. Reliable prediction may be a useful tool in production and marketing of sweet cherries. Better prediction and more knowledge about the effect of the climate can help growers in their management decisions about pest control, fertilization, and irrigation, with the aim to get higher and more predictable yield.

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