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Modelling Plum (*Prunus domestica*) Yield in Norway

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Summary

Climate effects on plum yield and prediction of yield in commercial plum production were studied. Data were collected from fruit co-operations in three regions in the fjord district of western Norway. Relative yield levels as percentage of a moving average for the years 1962–2002 were compared to meteorological data. In the northernmost region yield level varied more than in the two other regions. Yield level was positively correlated to several climatic parameters the year previous to the fruiting year; one hour more sun in July gave 0.3 % higher yield the next year in Hardanger. Yield level was negatively correlated to high temperatures in January and February; in the Sogn region 1 °C higher February maximum temperature gave 6.9 % lower yield. In the northernmost region warm and dry weather in May was crucial for high yield. For all districts climate factors before June 1 had a large influence on yield level, making it possible to develop models for predicting yield levels. Multiple regression models with meteorological variables as predictors were developed for predicting yield per June 1, and for explaining yield after harvesting. When predicting relative yield level as a percentage of an average, the models can be applicable for the growing and the marketing of fruit.

Key words. climate – meteorological – regression – prediction – temperature – precipitation

Introduction

Modelling and predicting fruit yields have been of great interest for the fruit industry. Plum is an important fruit world wide. Especially under northern climate plum yield can vary greatly from year to year. Modelling yield can make more precise predictions possible and can explain the causes of variation. The weather at certain phenological stages can be crucial for the plum yield. Fruit species are more or less susceptible to winter damage. Also blossom frost might cause severe yield loss. The weather conditions at these periods of development are possible explanaitions for yield variation (Måge 1975, 1976). Sekse (2007) suggested that winter damage and blossom frost in plum are rare in the fjord district near the west coast of Norway. Måge (1976) described the plum yield variations in an orchard in Hardanger 1934–1974. Several authors have developed regression models with climate data as variables to predict the yield for various fruit crops; 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). Jimenez and Diaz (2003a, b) developed prediction models for peaches and pears with several parameters for tree size as variables. Måge and Grønnerød (2007) discussed growth of plum fruitlets in relation to time in the growing season and climatic conditions. Multiple regression models have also been developed for the analysis of potential cultivation areas for plums (Rumayor-Rodríguez 1995). Yield level also influences fruit quality; Vangdal et al. (2007) reported a negative correlation between yield and fruit soluble solids content for all tested cultivars. It can be of great value to get early and precise yield prediction. The purpose of the present work was to develop better models for predicting and explaining the plum yield. Through these models the effect of climate on yield can be explained and thus making it possible to improve yield levels.

Materials and Methods

Data on plum yield were collected from eight small growers' co-operations in the fjord district of western Norway. The years 1961–2002 are included for Hardanger (Folgefonn Fruktlager 1966–2001; Hardanger Frukt Og Bær 1947–2002; Hardanger Fruktsamsal 1960–2001; Kvam Fruktlager 1961–2002; Nå Fruktlager 1952–2002; Ullensvang Fruktlager 1955–2002), 1960–2005 for Sogn (Leikanger Fruktlager/Sognafrukt 1960–2005) and 1954–2004 for Nordfjord (Gartnerhallen Møre 1954–1997). The data were sorted according to climate zones in three regions; Hardanger 60° N, Sogn 61° N and Nordfjord 62° N. There were six co-operations in Hardanger, one in Sogn and one in Nordfjord. Data about area or number of trees were not available, and consequently the yield per hectare or tree could not be calculated. Therefore relative yield as % of a moving average were used. The total yield includes a large number of cultivars, but by using an eight years moving average the effect of cul-

tivars was smoothed out. This is an accepted procedure when working with this type of data.

The meteorological data for Hardanger were obtained from the Norwegian Meteorological Institute (1954–2005) for the stations in Ullensvang, Kvam and Bergen for Hardanger. The station in Vangsnes was used for Sogn and Tafjord for Nordfjord. For most of the calculations for Hardanger meteorological data from Kvam were used as this meteorological station had the longest time series. The meteorological station in Vangsnes is close to the fruit growing areas in Sogn. The co-operation in Nordfjord collects small quantities of plums from a large district; however the variations in climate in Tafjord are representative for this district. The topography is variable in all regions, the climates in the growing regions and in the meteorological stations are not identical, but the variations are very similar.

The long time series make a good basis for statistical calculations, which is necessary when working with climate variables. The yield variations were large during this period. In Nordfjord the total yield varied from 2 to 46, in Sogn from 12 to 161 and in Hardanger from 47 to 399 t year^{-1}. The large variation is due to climate, cultivar and cultural practise. Better pruning and thinning have reduced the yield variations the last decades. 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. Due to outlier tests and evaluation of plots two years for Sogn were regarded as outliers and excluded from the dataset.

The selection of predictors for the models were based on correlation matrix and on plum biology. From the biological point of view, winter and blossom were regarded as critical periods for plum growth and development. The method for selecting variables was a combination of forward selection and stepwise. 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 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. This is a normal method for estimating regression models.

Results

A tendency to biannual bearing can be seen (Fig. 4), but it was not statistically significant. The yield variations were strongly correlated between the three districts. The plum yield varied more in the northernmost district Nordfjord than farther south, probably because it is on the northern border for plum growing and has a more changing weather (Table 1). The meteorological data were 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.

Plum yield as related to climate

In Sogn and Hardanger the plum yield was positively correlated with high temperatures and many sun hours in July in the year previous to the fruiting year (Tables 2, 3), and interactions increased this effect. In Nordfjord which is more to the north there was a positive effect of high temperatures and negative effect of rain in August the year before fruiting (Table 2, Fig. 3). Relatively high temperatures in January and February were negatively correlated with yield in all three districts; in Sogn 1 °C higher mean temperature in February resulted in more than 9 % lower yield (Table 2). Also maximum temperatures in the winter are negatively correlated with yield; 1 °C higher maximum temperature in January reduces yield by 7.7 %, which means that a warm period in January might cause severe yield loss. In Sogn the interaction between low maximum and low minimum temperatures in February gave the highest yields in Sogn (Fig. 2). The winter is not very cold in these three regions; the minimum temperatures are seldom under −10 °C. The lowest recorded temperature this period was −14.6 in Hardanger, −14.4 in Sogn and −15.5 °C in Nordfjord. The maximum temperature in January and February has been 14.5, 11.4 and 16.9 °C respectively. The northernmost region had a very large variation in winter temperature and also the largest yield variation. In Nordfjord the 15 years with the lowest average maximum temperature in January and February had an average relative yield of 124 %, while in the 15 years with highest maximum temperatures in January and February the average yield was only 82 %. The results for the two other regions, Hardanger and Sogn, were similar, but less significant. Years with high temperatures and low precipitation in May resulted in high yield levels in the northernmost district (Table 2, Fig. 1). Yield was positively correlated to minimum temperature in May for Nordfjord, indicating that blossom frost can reduce yield in this region. In the two other regions there were no correlation between May minimum temperature and yield (Table 2). High September temperatures had a negative effect on yield, a great part of the plums were ripening and harvested in September, so climate effects on yield were probably a result of influence on fruit size and quality (Table 2).

Predicting plum yield per June 1st

Regression models were developed to predict the relative plum yield per June 1st (Table 3). The predicted yield showed good agreement with observed yield for Hardanger and Sogn. The R^2 was lower for Nordfjord, indicating a greater variation because the cooperation in Nordfjord

Table 1. Minimum, maximum and standard deviation for relative plum yield for three districts in Norway, average = 100.

District	Minimum	Maximum	Standard deviation
Hardanger	23	167	36
Sogn	30	164	36
Nordfjord	11	251	62

Table 2. Effect of climate on plum fruit yield in three districts of Norway, Hardanger, Sogn and Nordfjord 1960–2002. The effects shown as % change in relative yield per °C, mm precipitation, number of days with precipitation, number of days with clear weather or number of sun hours per month. Only significant effects are shown.

Month	Climate	% Effect on yield		
		Hardanger	Sogn	Nordfjord
In the year before fruiting				
July	mean temp		16.30*	
	day degrees		0.53*	
	mean max. temp.	6.48*	13.90*	
	max. temp.		10.40**	
	sun hours	0.31***		
	days with clear weather		8.32**	
	precipitation	−0.14*	−0.53**	
	rain days	−3.00**		
August	mean temp.			15.00*
	mean max. temp.			10.40*
	mean min. temp.			14.10*
	day degrees			0.46*
	rain days			−3.66*
October	rain days			2.98*
	precipitation	0.07*		
In the fruiting year				
January	max. temp.		−7.67*	
February	mean temp.		−9.29*	
	mean min. temp.		−9.48*	
	max temp.		−6.89**	
	mean max. temp.		−9.36*	
April	precipitation			−0.50*
	rain days			−3.56*
	days with clear weather		4.33*	
May	mean temp.			24.40***
	minimum temp.			18.80**
	mean max. temp.			16.70**
	mean min. temp.			26.50***
	max. temp.			7.76*
	day degrees			0.79***
	precipitation			−1.00**
June	mean temp.			13.60*
	mean min. temp.			18.90*
July	rain days			3.94*
September	mean min. temp.	−9.30*	−14.00*	−12.80*
	mean temp.		−12.40*	
	minimum temp.	−8.32**	−11.90**	
	day degrees	−0.29*		

* 5 % significance; ** 1 % significance; *** 0.1% significance.

receives small quantities of plums from a large district. Prediction and validation showed good agreement with the observed yield (Fig. 4). The correlations between observed yield and predicted yield, and between observed yield and validated yield are high for all three districts. The regression model showed similar effect and with related variables as in simple regressions (Tables 2 and 3). High temperatures and many sun hours in July–August

Table 3. Prediction of plum fruit yield per June 1st and modelling plum fruit yield after harvest for three districts of Norway.

District	Regression model	R^2	SEE Rel. yield (%)
Prediction of plum fruit yield per June 1st			
Hardanger	Y = 23.3 + 0.268pJul sun + 6.73pDec max – 11.3Feb Txm + 1.12Mar Dd – 0.140May prec	58.9	24.3
Sogn	Y = 123 + 9.12pJul clear – 9.22Feb Txm – 4.04Feb diff + 2.76Apr clear	71.4	21.1
Nordfjord	Y = – 69.8 + 13.7pAug Tmean – 4.33Jan max – 5.36AprRd – 6.69Apr clear + 19.4MayTnm	43.3	43.9
Modelling plum fruit yield after harvest			
Hardanger	Y = 84.0 + 0.303pJul sun + 6.54pDec Tmax – 6.55Feb Txm – 0.104May prec – 1.74Aug Rd – 5.36Sep Tnm	63.2	23.3
Sogn	Y = 177 + 6.67pJul clear – 9.07Feb Txm – 4.10Feb Tdiff + 1.92Apr clear – 5.96Sep Tmin – 0.792Sep Rd	81.9	17.9
Nordfjord	Y = – 18.4 + 14.1pAug Tmean – 3.99Jan Tmax – 4.51Apr Rd – 5.06Apr clear + 19.4May Tnm – 1.89Sep Rd – 7.34Sep Tmean	48.0	43.1

SEE = standard error of estimate; Y = relative yield %; p... = month in the previous year; Dd = degree days (temperature sum) per month with 5 °C base temperature; prec = accumulated precipitation in mm per month; Rd = number of days with precipitation > 0.1 mm per month; Feb diff = the difference between maximum and minimum temperature in February; Tnm = mean minimum temperature per month; Tmean = mean temperature per month; Txm = mean maximum temperature per month; Tmax = maximum temperature per month; Tmin = minimum temperature per month; clear = number of clear days per month; sun = number of sun hours per month.

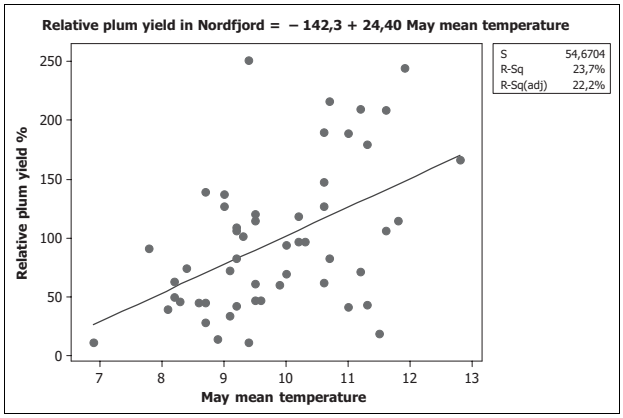


Fig. 1. Relative plum yield as related to May mean temperature in Nordfjord Norway 1954–2005.

were positively correlated to yield the following year. Years with high temperatures in the winter had relatively low yield levels. Low temperatures and much rain in May appeared to have negative effects on yield (Tables 2 and 3, Fig. 1).

Modelling plum yield after harvest

Models for explaining plum yield after harvest may also include climate variables during fruit development, ripening and harvest (Table 3). These gave only a slightly higher R^2 and lower SEE, which means the most important factors influencing yield came before June 1. Average and minimum temperatures in September had negative coefficients, suggesting that high temperatures in September decreases plum yield. Years with many rain days in August or September had relatively low yield levels (Table 3).

Discussion

Norway is located on the northern border for plum growing and the variable weather might have strong impact on yield and quality of plums. Meteorological factors are more or less interrelated and in open field it is impossible to change one variable while others are kept constant. In spite of that it is interesting to look at the effect of single variables on plum yield (Table 2). The results of the present work indicate that warm and sunny weather in July–August the year before fruiting had a positive effect on yield levels, Måge (1976) found similar results. The temperature in August had the strongest effect in the northernmost region, Nordfjord. Also Rumayor-Rodríguez (1995) suggested that relatively high summer temperatures in the previous year formed stronger flowers in Japanese plums (*Prunus salicina*) grown in Mexico. Williams (1965) reported similar results for apples.

The present study suggests a negative effect of high maximum temperatures in January and February, like Måge found in 1976. In our study there was a tendency that high temperatures in December were positively correlated to high yields. It is possible that dormancy and hardening are both strong in December, while the dormancy might be more completed later in the winter and high temperatures then can cause a dehardening. High temperatures in January and February reduced yields; while years with stable low temperatures had the highest yields. This was significant only for Sogn, but the tendency was similar for the two other regions (Table 2, Fig. 2). Also low minimum temperatures are positively correlated with high yields. Logically low temperature damage should be expected during the winter, but the highest yields were achieved when both maximum and minimum temperatures were low during the winter (Fig. 2). It is possible that the egg cell starts to develop during a warm

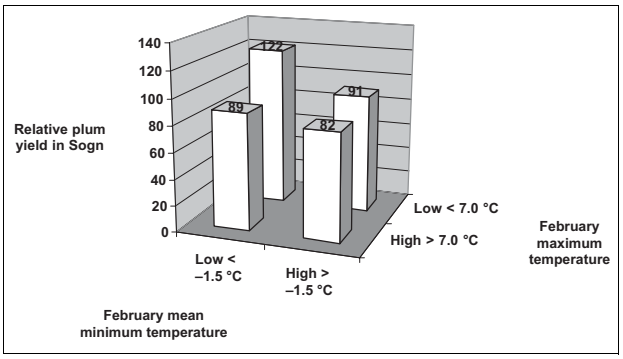


Fig. 2. Effects of the interaction between February maximum and mean minimum temperature effects on plum yield in Sogn Norway 1961–2001.

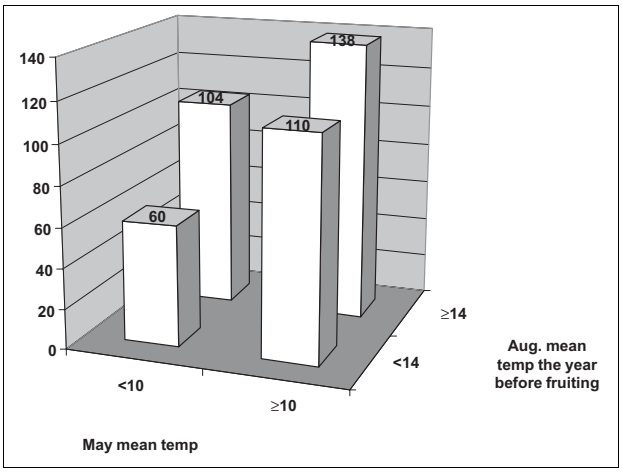


Fig. 3. Effects of the interaction between the mean temperature in August the year before fruiting and the mean temperature in May in the fruiting year on plum yield in Nordfjord Norway 1954–2002.

period in the winter, and that it will later be destroyed, thus it can not be fertilized during flowering season. On the other hand the difference between maximum and minimum temperatures in February had negative coefficients in the regression models (Table 3). The winter temperatures are not very low in these regions; they are seldom under −10 °C, while other authors write about winter damage at temperatures from −20 to −35 °C (DUCHOVSKIS et al. 2007).

In this study high temperatures in March and May were positively correlated to high yields, which is in agreement with MÅGE and GRØNNERØD (2007) who found a positive correlation between fruit size and temperatures in March, April and May. MÅGE (1975) also reported a positive correlation between May temperature and sweet cherry yields. In the present study there was a negative correlation between yield and May precipitation in Hardanger. The flowering normally occurs in May, and dry and warm weather is probably favourable for the pollination. Especially for the northernmost district the correlations between yield and May temperatures were strongly positive, the average temperatures are lower in this district and the weather in May is important for the pollination. Climate in August and September might be important for the plum quality, and thus for marketable yield. In this study many rain days in August and September had a negative effect on the plum yield in all the three regions, it is suggested that rain causes cracking and rot (Table 3) and that high temperatures might increase this effect (Table 2).

The regression model showed good agreement with the observed yields (Fig. 4), but not as good as a model developed for predicting strawberry yields (DØVING and MÅGE 2001). In some years there was a deviation between predicted and observed yields (Fig. 4), especially in the years 1965, 1973, 1980 and 1988 the observed yield levels were lower than the model for Hardanger. In some years there were severe damages from bullfinch (*Pyrrhula pyrrhula*) eating the fruit buds of the plum trees. It was difficult to find exact information about the bird attacks, but 1988 is known as a year with a lot of damage, and this can explain why 1988 is a negative outlier (Fig. 4). In 1973 May was very cold and wet, and in 1980 there was

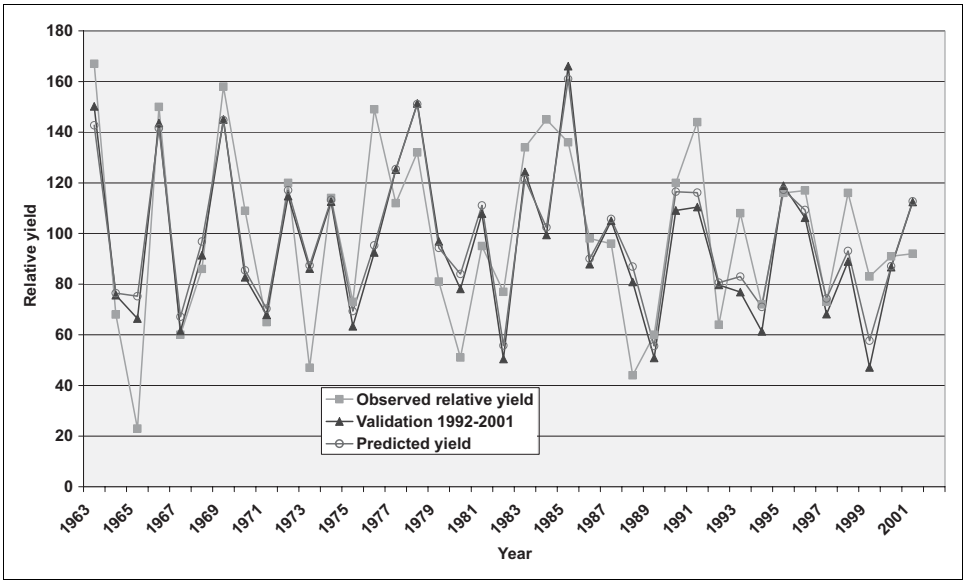


Fig. 4. Observed yield, predicted yield and validation of the model for relative plum yield in Hardanger Norway per June 1. Equation in Table 2.

some winter damage (Folgefonn Fruktlager 1966–2001; Hardanger Frukt Og Bær 1947–2002; Hardanger Fruktsamsal 1960–2001; Kvam Fruktlager 1961–2002; Nå Fruktlager 1952–2002; Ullensvang Fruktlager 1955–2002). For Sogn the years 1973 and 1986 were negative outliers. In 1973 it was warm in January, cold and wet during the flowering, and also relatively cold during the summer. For 1986 some winter damage was reported. For Nordfjord the years 1960 and 1971 were negative outliers, for both years the low plum yields could be explained by severe attacks from bullfinch, in 1960 there also was some winter damage (Fylkesmannen I Sogn Og Fjordane 1959–2005).

The climate before June 1st in the fruiting year is important for the plum yield, making it possible to develop regression models for predicting the yield (Table 3). The most crucial periods for the plum yield have been July–August the year before the fruiting year, January–February, the flowering season which normally comes in May, and also the ripening season in August–September. 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 plums. Better prediction and more knowledge about the effect of the climate can help growers in their management decisions about pest control, fertilization, thinning and irrigation, with the aim to get higher and more predictable yield.

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References

Beattie, B.B. and R.R.W. Folley 1978: Production variability in apple crops. II. The long term behaviour of the English crop. Sci. Hort. **8**, 325–332.

Duchovskis, P., V. Stanys, A. Sasnauskas and C. Bobinas 2007: Cold Resistance of *Prunus domestica* L. and *Prunus cerasifera* Ehrh. In Lithuania. Acta Hort. **734**, 299–303.

Døving, A. and F. Måge 2001: Prediction of strawberry yield. Acta Agric. Scand., Sect. B, Soil and Plant Sci. **51**, 35–42.

Folgefonn Fruktlager 1966–2001: Årsmelding. (Annual Report).

Fylkesmannen I Sogn Og Fjordane 1959–2005: Årsmelding landbruksavdelinga. (County Council. Annual Report Agricultural Department.)

Gartnerhallen Møre 1954–1997: Årsmelding. (Annual Report).

Hardanger Fruktsamsal 1960–2001: Årsmelding. (Annual Report).

Hardanger Frukt Og Bær/Børve Fruktlager 1947–2002: Årsmelding. (Annual Report).

Jimenez, C.M. and J.B.R. Diaz 2003a: A statistical model to estimate potential yields in peach before bloom. J. Amer. Soc. Hort. Sci. **128**, 297–301.

Jimenez, C.M. and J.B.R. Diaz 2003b: Statistical model estimates potential yields in pear cultivars 'Blanquilla' and 'Conference' before bloom. J. Amer. Soc. Hort. Sci. **128**, 452–457.

Kvam Fruktlager 1961–2002: Årsmelding. (Annual Report).

Leikanger Fruktlager 1960–2005: Årsmelding. (Annual Report).

Måge, F. 1975: Variasjon i avlingar og prisar i søtkirsebærdyrkinga hos ein produsent i Hardanger. Frukt og Bær, 50–59 (in Norwegian).

Måge, F. 1976: Plommeproduksjon på ein gard i Hardanger i åra 1934–1974. Frukt og Bær, 51–61 (in Norwegian).

Måge, F. and K. Grønnerød 2007: Growth of plum fruitlets in relation to time and climatic conditions. Acta Hort. **734**, 201–207.

Måge, F., A. Døving and Ø. Vangdal 2007: Prediction of plum yield in Ullensvang, Norway. Acta Hort. **734**, 249–254.

Mimoun, M.B. and T.M. Dejong 1999: Using the relation between growing degree hours and harvest date to estimate run-times for peach. A tree growth and yield simulation model. Acta Hort. **499**, 107–114.

Norwegian Meteorological Institute 1954–2005: Climatic Reports.

Nå Fruktlager 1952–2002: Årsmelding (Annual Report).

Rudolph, V. 1983: Untersuchungen zur Ertragsplanung bei *Fragaria ananassa* Duch. Dissertation Humboldt-Universität zu Berlin. pp.128.

Rumayor-Rodríguez, A. 1995: Multiple regression models for the analysis of potential cultivation areas for Japanese plums. HortScience **30**, 605–610.

Sekse, L. 2007: Plum production in Norway. Acta Hort. **734**, 23–28.

Stanley, C.J., D.S. Tustin, G.B. Lupton, S. McCartney, W.M. Cashmore and H.N. Desilva 2000: Towards understanding the role of temperature in apple fruit growth responses in three geographical regions within New Zealand. J. Hort. Sci Biotechn. **75**, 413–422.

Stanley, C.J., J.R. Stokes and D.S. Tustin 2001: Early prediction of apple fruit size using environmental indicators. Acta Hort. **557**, 441–446.

Ullensvang Fruktlager 1955–2002: Årsmelding (Annual Report).

Vangdal, E., A. Døving and F. Måge 2007: The Fruit Quality of Plums (*Prunus domestica* L.) as Related to Yield and Climate Conditions. Acta Hort. **734**, 425–429.

Williams, R.R. 1965: The effect of summer nitrogen applications on the quality of apple blossoms. J. Hort. Sci. **40**, 31–41.

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