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1 **Research Article**

Evaluation of the Concord Crop Load Response for Current Commercial Production in New York

Terry Bates,[1,3]* Rhiann Jakubowski,[1] and James A. Taylor[2]

[1]Cornell University, School of Integrative Plant Science, Horticulture Section, Cornell Lake Erie Research and Extension Laboratory, Portland, NY; [2]ITAP, University of Montpellier, INRAE, Institut Agro, Montpellier, France; and [3]Current address: Cornell Lake Erie Research and Extension Laboratory, 6592 West Main Road, Portland, New York, 14769.

*Corresponding author (trb7@cornell.edu)

Abstract: Economic pressures in the NY Concord grape industry over the past 30 years have driven crop management practices toward less severe pruning to achieve larger crops. The purpose of this study was to investigate the effect of crop load on juice soluble solids and the seasonal change in vine pruning weight in NY Concord grapevines. Over a four-year period, vines were balanced pruned at two levels or fixed node pruned at two levels to give four pruning severities. For balanced pruning, vines were pruned to leave 33 or 66 fruiting nodes for the first 500 g pruning weight and an additional 11 nodes for each additional 500 g pruning weight. For fixed node pruning, vines were pruned to 100 or 120 fruiting nodes per vine. The 120 node vines were also manually cluster thinned at 30 days after bloom to target 0, 25, or 50% crop removal. In a second

31   study, the 120 node pruning with mid-season fruit thinning was repeated over 11 years to assess

32   seasonal differences on the crop load response. Crop load was measured as the yield to pruning

33   weight ratio (Y:PW) and ranged from 1 to 40 in this study. On average, the industry standard of

34   16 Brix was achieved at a Y:PW of 20 and no seasonal pruning weight change was observed at

35   Y:PW of 17.5. There was a positive linear relationship between seasonal GDD and the Y:PW

36   needed to reach 16 Brix as well as between seasonal precipitation and the Y:PW required to

37   observe no seasonal pruning weight change. The results from this study were used to improve crop

38   load management recommendations for NY Concord vineyards under current practices.

39   **Key words:** fruit thinning, pruning, Ravaz index, *Vitis labruscana*, yield management

Introduction

41   Commercial Concord (*Vitis labruscana* Bailey) grape production in the Lake Erie AVA

42   aims to consistently grow the largest possible crop size that meets an obligate quality standard in

43   any given season. Achieving this goal requires the understanding and management of vine crop

44   load in a cool and relatively short growing region (Howell 2001). "'Crop load' is the crop size

45   relative to vine size (estimated as pruning weight or leaf area) and is a measure of the sink:source

46   ratio" (Keller 2010, pg 169). In cool-climate Concord production, the dormant cane pruning mass

47   of one-year-old wood, commonly referred to as pruning weight, is directly related to vine total leaf

48   area (unpublished data derived from Bates 2008, equ. Total Leaf Area (m^2/m) = 8.31 * Pruning

49   Weight (kg/m) + 5.10, R^2 = 0.90). Pruning weight is often used to represent leaf area in crop load

50   calculations. The most common usage is in the Ravaz Index, which is calculated as the yield to

51   pruning weight ratio (Y:PW) (Ravaz 1911), and used to indicate if vines are "subjectively"

52   overcropped, undercropped, or balanced. Crop load has also been measured more directly as the

53   exposed leaf area to fruit weight ratio, rather than Y:PW. This is particularly true in studies that

54   investigate additional canopy management, such as canopy division, with a need to account for

55   changes in exposed, rather than total leaf area (Shaulis et al. 1966, Smart and Robinson 1991,

56   Kliewer and Dokoozlian 2005, Bates 2008). Therefore, Y:PW or leaf area:fruit yield are

57   quantitative measurements of vine crop load; however, what constitutes "vine balance" is

58   qualitative based on region, variety, viticulture production goals, and grape market destination

59   (Howell 2001, Taylor et al. 2019).

60   Crop load management in commercial Concord vineyards is a function of manipulating

61   crop size through practices such as pruning level and fruit thinning or by influencing vine size

62   through water and nutrient availability and uptake. This paper deals primarily with the former by

63   investigating crop size management over a range of vine sizes; however, the importance of the

64   latter in commercial Concord production cannot be understated. Water, nutrient, and rootstock

65   management options have been addressed in other Concord studies and all show how increasing

66   vine size supports larger crop size while maintaining fruit quality due to the importance of vine

67   size in the crop load ratio (Pool 2004). Crop size management has been long studied in NY

68   Concord vineyards, and practices have evolved in response to the economic pressures for

69   maximum yield at a minimum acceptable juice soluble solids and the lowest production costs (see

70   Bates and Morris 2009 for summary).

71   The effect of crop load, measured by Y:PW, on fruit quality and vine size has been

72   characterized with mixed results in *Vitis vinifera* cultivars. A Carignane crop load study with an

73   8.0 to 19.6 Y:PW range, under warm climate conditions, showed delayed fruit maturity and

74   reduction in vine size when Y:PW > 10. Below a Y:PW of 10, yield was not a factor in wine

75   quality (Bravdo et al. 1984). Crop load studies with Cabernet sauvignon in Oakville, CA (Y:PW

76   range of 3 to 14) also supported Y:PW between 5-10 as being indicative of vines with balanced

77   vegetative and reproductive growth (Kliewer and Dokoozlian 2005). Crop load values < 5 were

78   considered undercropped, did not respond to additional crop reduction, and were at risk of

79   excessive canopy growth and cluster zone shading. Crop load values > 10 were considered

80   overcropped with delayed fruit maturation and retarded vegetative growth.

81   Several cool-climate crop load studies have questioned the appropriateness of these crop

82   load indicators in regions where more leaf area per unit fruit may be needed to achieve optimum

83   fruit maturity and vegetative growth (Howell 2001); however, these studies have provided little

84   evidence to deviate from the general crop load response. Fruit thinning studies with Pinot noir in

85   Oregon and Merlot in Hawkes Bay, New Zealand (Y:PW ranges 0.5 to 3.7 and 3.4 to 9.0,

86   respectively) indicated excessive vegetative growth and canopy density in the fruiting zone as

87   having a larger impact on fruit composition than crop load and questioned the need for fruit

88   thinning at these values (King et al. 2015, Reeve et al. 2018). Riesling crop load studies in NY and

89   WA (Y:PW ranges 2.9 to 9.9 and 8.2 to 11.4, respectively) both showed slight delays in fruit

90   ripeness at the highest crop load levels but questioned if the minor improvement in fruit quality

91   from fruit thinning justified the economic cost in labor and crop loss (Keller et al. 2005, Preszler

92   et al. 2013). Furthermore, differences in fruit composition and wine quality in these studies were

93   attributed more to seasonal differences than crop load at Y:PW between 5 and 10. Higher crop

94   loads than those recommended (Y:PW > 12) have been reported for some cool-climate *V. vinifera*

95   and French-American hybrids without detrimental effects on fruit quality; however, these required

96   canopy division to optimize leaf area exposure (Reynolds et al. 2009). This is similar for Concord

97   on Geneva Double Curtain training but only on excessively large vines, which is not the norm for

98   commercial Concord vineyards (Shaulis et al. 1966)

99   In New York Concord production studies, which evaluated different balanced pruning

100 formulas or fruit thinning to manipulate crop size in response to vine size, Y:PW ranged from 5 to

101 20 (Shaulis and Steele 1969, Shaulis 1980, Poni et al. 1994). Crop loads > 10 had lower juice

102 soluble solids than the maximum, eventually leading to the pruning severity recommendation that

103 maintained crop loads between 7 and 10. These crop loads in NY Concord ensured acceptable

104 fruit maturity in any given season and tended to increase vine size over time. Under current

105 production costs and market value for juice processing Concord, the economic breakeven point for

106 producers is roughly 13.5 t/ha (6 tons/acre) and conservative balanced pruning only reaches those

107 yields at large vine sizes, which is why historical recommendations for managing 'Concord' vine

108 size have targeted PW > 1.2 kg/vine (~0.5 kg/m of trellis, Shaulis 1956). Commercial Concord

109 producers, under current market conditions, consider Y:PW < 10 as uneconomically sustainable

110 because of low yields; however, consistently pushing high crop loads results in low, and possibly

111 unmarketable, fruit quality while reducing vine size and return crop potential.

112   In a New York Concord study, which measured the effect of pruning severity and yield on

113 the harvest date for 16 Brix fruit, the industry standard, the harvest date was delayed at crop loads

114 > 11 but only by one week at crop loads as high as 20 (Bates 2008). Arguably, this is an acceptable

115 harvest delay for higher crop returns. In a Concord mechanization study, which investigated

116 mechanical shoot and fruit thinning practices (Y:PW range 4 to 27), Y:PW values as high as 22

117 produced fruit with 16 Brix but reduced vine size. However, crop loads between 11 and 14 have

118 produced acceptable juice soluble solids and maintained vine size (Bates 2017). Recent spatial

119 crop load mapping and variable-rate fruit thinning studies in commercial NY Concord observed

120 Y:PW from 15 to 45 in unthinned blocks. Mechanical fruit thinning reduced mean Y:PW in

121 separate management classifications from 30.1 to 19.8 and produced fruit above 16 Brix for the

122 whole vineyard block (Bates et al. 2018, Taylor et al. 2019). The high crop load values, considered

123 as substantial overcropping in other studies, and the wide range in crop load values under

124 commercial Concord production illustrates the impact of market pressures on vineyard

125 management.

126   Subjectively, vine balance for Lake Erie AVA Concord grown for the juice grape market

127 is defined as growing the largest possible crop reaching 16 Brix by commercial harvest (30 to 40

128 days after veraison) and having no net change in vine size. Grower experience with crop thinning

129 also indicates a seasonal influence on the thinning level decision. The purpose of this study was to

130 (a) identify the Y:PW in Lake Erie Concord that matches a commercial definition of vine balance,

131 (b) determine if the method of crop size management (pruning or fruit thinning) effects the crop

132 load response on Brix and the seasonal change in PW, and (c) understand how seasonal conditions

133 change the target Y:PW for vine balance. Results will be used to improve seasonal pruning and

134 fruit thinning recommendations and give validation to spatial crop load vineyard maps.

Materials and Methods

136   This research investigated the response of Concord grapevines to crop load in two different

137 but related studies. The first study compared the crop load response of Concord vines pruned to

138 various levels against vines pruned to a relatively high node number and then fruit thinned mid-

139   season over a four-year period (2001-2004). The second study investigated the crop load response

140   of mid-season fruit thinning over an 11-year period (1999-2009). These will be referred to as the

141   "Pruning vs. Thinning" and the "Thinning Response" studies, respectively.

142   **Vineyard Description.** These studies were conducted in two neighboring 0.41 ha Concord

143   vineyards planted in 1956 and separated by less than 70 m at Cornell's Taschenberg Vineyard

144   Laboratory in Fredonia, NY (42°27'00"N, 79°18'42"W). The experimental block elevation was

145   231 m above sea level with a 1 to 2% slope and a southeast aspect. The soil was well drained

146   Chenango gravel-loam (USDA 1994) with a surface soil pH of 5.5 and 2% organic matter.

147   The Lake Erie grape production region is characterized by cool and humid conditions. The

148   92-year (1926 to 2018) average GDD accumulation (base 10 °C) from 1 April to 31 October

149   recorded at the experiment site was 1532 GDD (Table 1). Average precipitation accumulation for

150   the same time period was 630 mm, with rainfall being evenly distributed throughout the growing

151   season. Supplemental irrigation was not used in these vineyards because it is rarely used for

152   commercial Concord production in NY. The 39-year average bud break was 3rd May, and the 53-

153   year bloom and veraison phenology dates were 13th Jun and 22nd Aug, respectively. The seasonal

154   GDD accumulations (1 April to 31 October, base 10°C) for the course of the 1999-2009 experiment

155   ranged from 1343-1811. The warm 2005 season was the only year to be more than two standard

156   deviations from the long-term GDD mean. The seasonal precipitation accumulation (1 April to 31

157   October) over the same period ranged from 390-950 mm. The dry 2007 season was the only year

158   to be more than two standard deviations from the 92-year mean. Bloom and veraison were

159   relatively consistent in 10 of the 11 years and were within six days of the long-term average. The

160   exception to this was in 2003, when bloom and veraison were 11 and 10 days later than the long-

161   term mean, respectively.

162   The own-rooted Concord vines in both blocks were 43 years old at the beginning of the

163   experiment and planted at a row-by-vine spacing of 2.7 x 2.4 m, with rows oriented in an east-west

164   direction. Vines were cordon-trained to a trellis wire at 1.8 m. Floor, nutrient, pest and disease

165   management were done according to commercial standards for western NY Concord vineyards

166   (Jordan et al. 1980). No-till weed management was used by maintaining a 1.2 m-wide weed-free

167   zone under the vines with pre- and post-emergence herbicides and treating row centers with one

168   glyphosate application at bloom. Ammonium nitrate fertilizer was surface broadcasted at a rate of

169   56 kg per ha of actual N across the block in a single application near bud break. Fungicide and

170   insecticide materials and application rates were done according to the New York and Pennsylvania

171   Pest Management Guidelines for Grapes (Weigle 2006) and varied annually depending on seasonal

172   weather conditions.

173   **Pruning vs. thinning study.** For pruning treatments, two balanced pruning levels, 33 + 11

174   and 66 + 11, and one 100 node pruning level, were used to achieve a range of crop levels over a

175   range of vine sizes. For balanced pruning, vines were rough pruned to approximately 100 nodes,

176   and the weight of one-year-old canes was recorded using a spring scale. The number of retained

177   nodes was then adjusted to retain 33 or 66 nodes for the first 500g of pruning weight and 11

178   additional retained nodes for each additional 500g of pruning weight (imperial units = 30 + 10 or

179   60 + 10 per pound pruning weight). For the 100 node pruning treatment, vines were pruned to 100

180   retained nodes regardless of vine pruning weight. There were 36 count vines per pruning treatment

181   grouped in six-vine plots in six randomized complete blocks; however, for this crop load response

182   investigation, the individual vine measurements were used and the vine data regrouped for analysis

183   based on crop load values rather than spatial location. The same vines received the same treatments

184   for each of the four years.

185   For thinning treatments, 100 vines each year were pruned to have 120 retained nodes per

186   vine, regardless of vine pruning weight. This was chosen to achieve a relatively high crop potential

187   across a range of vine size classes. At 30 days after bloom, 25 individual vines were randomly

188   selected from the original 100 vine population each year, and the fruit was removed and weighed.

189   The mean crop size was used to calculate the weight of fruit needed to be removed to achieve 0,

190   25, and 50% crop reduction on the remaining 75 vines. On the vines to receive 25 or 50% crop

191   removal, clusters were randomly removed at 30 days after bloom from individual vines and

192   weighed until the target weight was achieved (Pool et al. 1993, Fendinger et al. 1996). Thinning

193   treatments were assigned randomly to the vine population.

194   Different from the pruning treatments, the thinning treatments were applied on a new vine

195   population each year. For example, vines pruned to 120 nodes and fruit thinned in 2001 were again

196   pruned to 120 nodes but not thinned in 2002 to investigate the effect of altering crop load by fruit

197   thinning in year one on vine growth and the return crop size in year two. A new set of vines, which

198   were untreated in 2001, were pruned to 120 nodes and subjected to the thinning treatments in 2002.

199   This process continued on a new vine population for each of the 11 experiment years.

200   **Thinning response study.** The 120 nodes/vine pruning with mid-season manual fruit

201   (random cluster) thinning procedure described above was applied from 1999 to 2009. The number

202   of vines used each year varied from season to season based on labor availability. From 1999 to

203   2004 and then again in 2006 and 2010, 100 vines (25 per crop level treatment) were used. In 2005,

204   the vine number dropped to 24 (six vines per crop level treatment). From 2007 to 2009, 56 vines

205   (14 vines per crop level treatment) were used in each year.

206   **Vine measurements.** Dormant vine pruning weight was measured on individual vines each

207   year. Harvest date was determined when the juice soluble solids in the lower yielding treatments

208   were between 16 and 17 Brix (Table 1). On average, this occurred at approximately 40 days after

209   veraison and coincided with the first or second week of the commercial Concord harvest in the

210   region. A 100-berry pre-harvest sample was randomly collected from two vertical planes

211   transecting the east and west side of each vine. Juice soluble solids were measured with a hand-

212   held refractometer (Leica model no.10423, Leica, Inc., Buffalo, NY), and the clusters from each

213   vine were manually harvested and weighed. Crop load was calculated as vine fruit weight divided

214   by vine pruning weight at the end of a season (Y:PW).

215   **Data analysis.** The four-year relationship between pruning weight and yield at each

216   pruning severity was done by binning observations for each year and pruning severity into groups

217   at an interval of 0.1 kg/vine and then calculating the mean for each year. Linear and exponential

218   regression models were fitted in JMP (JMP Pro v13.1, SAS Institute Inc, 2016). For the four-year

219   Pruning vs Thinning crop load analysis, multiple linear regression was performed using standard

220   least squares to investigate the effect of treatment (pruning or thinning), year, and Y:PW on juice

221   soluble solids and the seasonal change in pruning weight. In both cases, year had an effect (p value

222   <0.0001); therefore, within year effects of treatment and Y:PW were further analyzed.   To

223   investigate the crop load response in each year, observations were binned into groups at intervals

224   of Y:PW = 2, and linear regression was performed against harvest juice soluble solids and the

225   seasonal change in pruning weight. The general crop load response was generated by calculating

226   the mean for each bin (n = 4 years) and then performing linear regression analysis on the combined

227   pruning and thinning data. Combining the data was done to understand the crop load response,

228   regardless of whether it is achieved via altering the source (leaf) or sink (fruit) components.

229   Different trials were plotted with different markers although, as hypothesized, the thinning and

230   pruning treatments showed similar crop load response. For the crop load – juice soluble solids

231   relationship, a segment linear regression (broken-stick) model was fitted. Observations from the

232   11-year thinning were similarly binned in intervals of Y:PW = 2 and the same linear and broken-

233   stick regression fitting was performed for the general crop load responses (n = 11 years). The linear

234   response equations for each year were used to investigate the effect of seasonal GDD and

235   precipitation on the annual crop load response. Multivariate regression using standard least squares

236   in JMP was used to investigate the effect of GDD and precipitation on the Y:PW to achieve 16

237   Brix or no seasonal change in pruning weight. To investigate the effect of year-one Y:PW on year-

238   two yield, the 11-year thinning observations, also binned in intervals of Y:PW = 2, were further

239   grouped into small (0-0.6 kg/vine), medium (0.6-1.2 kg/vine), and large (1.2-1.8 kg/vine) vine size

240   classes (roughly representing one-, two-, and three-pound vines, a common industry reference on

241   standard commercial spacing) and subject to linear regression.

242   **Results**

243   Pruning weight in the own-rooted Concord vines from 2001-2004 ranged from 0.2 to 1.8

244   kg/vine across all pruning levels (Figure 1). As expected, crop size increased as vine size increased,

245   but the response was not linear and differed depending on pruning severity. Severe balanced

246   pruning (33 + 11) had the lowest yield across all vine sizes because there were fewer retained

247   nodes at any given vine size compared to the other pruning treatments. Balanced pruning retained

248   more fruiting buds as vine size increased; therefore, shoot number, cluster number, and total fruit

249   yield increased as vine size increased (data not shown). This was observed with 33 + 11 pruning;

250   however, crop size did not fully plateau at the largest vine size, indicating that pruning had limited

251   yield potential in this treatment. Balanced pruning at 66 + 11 had a similar vine size to yield

252   response as the 33 + 11 treatment but with higher yields because of the less severe pruning formula.

253   The 66 + 11 treatment also did not fully plateau but approached the same yield as the 100 node

254   pruning at the highest vines size.

255   Less severe pruning at either 100 or 120 nodes/vine had higher yields than either of the

256   balanced pruning treatments across the range of vine size. The shape of the vine size to yield

257   response was slightly different for the fixed node treatments compared to the balanced treatments.

258   In the fixed node treatments, there was a stronger positive response of yield to vine size at low

259   pruning weight up to approximately 0.6 kg PW/vine. For both fixed node treatments, the response

260   plateaued at approximately 1 kg PW/vine at a yield value of 13.6 kg fruit/vine and 17.6 kg

261   fruit/vine for the 100 and 120 node pruning treatments, respectively.

262   **Pruning vs. thinning study.** The range of pruning severity and vine size created a

263   population of Concord vines with crop loads (Y:PW) from 2 to 50 (Figure 2). Severe balanced

264   pruning (33 + 11) tended to have the lowest crop load values, while 120 node pruning tended to

265   have the highest crop load values. In addition to the pruning treatments described, 120 node vines

266   were fruit thinned at multiple levels to adjust the crop load down and increase the crop load range.

267   For comparison, the 33 + 11, 66 + 11, and 100 node pruned treatments were grouped to give a

268   range of crop loads achieved through pruning severity. The 120 node pruned vines with and

269   without fruit thinning were grouped to give a range of crop loads achieved through fruit thinning.

270   There was a negative linear relationship between crop load and juice soluble solids for both

271   pruning and thinning treatments in each year, except for thinned vines in 2001 (Figure 2). The

272   mean gradient, excluding 2001 thinned vines, was -0.076, indicating that an increase in crop load

273   by 13 decreased juice soluble solids by 1 Brix at harvest. There was an effect of Y:PW on juice

274   soluble solids in every year, an effect of treatment in 3 of 4 years, and an interaction effect in 2001

275   and 2003 (Table 2). In 2001, the thinned vines had lower average yield and higher average pruning

276   weight than the other three years, which compressed the crop load values to the lower end of the

277   scale. In 2003, the response of juice soluble solids to crop load was greater for pruned vines than

278   thinned vines. For the general response over four years, there was an effect of Y:PW on juice

279   soluble solids but not a treatment effect nor an interaction effect on juice soluble solids (Table 2).

280   Similarly, there was a negative linear relationship between crop load and the seasonal

281   change in vine pruning weight (Figure 3). The mean gradient for all years and treatments was -

282   0.014, indicating an increase in crop load by 7.1 decreased vine pruning weight by 0.1 kg. There

283   was an effect of crop load on the change in pruning weight for each year and smaller effect of

284   treatment in 2002 and 2004, where thinned vines had a greater increase in pruning weight (Table

285   2). There was not a treatment effect nor an interaction effect on delta pruning weight when all

286   years were combined.

287   The four-year pruning and thinning data were combined to characterize a general Concord

288   crop load response. A segmented regression (broken-stick) model was fitted to the Y:PW by

289   harvest juice soluble solids relationship to capture the plateau at the lower Y:PW values (Figure

290   4A) as described by Equation 1. The general response indicated that maximum possible juice

291   soluble solids occurred at or below a Y:PW of 7.2. The crop load to reach the industry standard of

292   16 Brix, however, occurred at a Y:PW of 20, on average.

293    $$\left. \begin{array}{ll} If & Y\!:\!PW < 7.2 \; then \; \text{Brix} = 17.2 \\ else & \text{Brix} = 17.8 - 0.085 * (Y\!:\!PW) \end{array} \right\}$$ Equation 1

294    $$R^2 = 0.92, \text{F ratio} = 384.8, \text{Prob} > \text{F}; <0.0001$$

295   The Y:PW by seasonal change in vine pruning weight did not plateau but exhibited a linear

296   response across the full range of crop load values (Figure 4B) as described by Equation 2. On

297   average, a Y:PW of 17.5 resulted in no net seasonal change in vine pruning weight.

298    $$\Delta PW(kg) = 0.21 - 0.012 * (Y\!:\!PW)$$ Equation 2

299    $$R^2 = 0.68, \text{F ratio} = 70.97, \text{Prob} > \text{F}; <0.0001$$

300   The crop load response was very similar whether the crop loads were achieved through pruning or

301   through thinning treatments (Figure 4).

302   **Thinning response study.** From 1999-2009, crop load was calculated on vines pruned to

303   120 nodes and fruit thinned to different crop levels. In each season, there was a negative linear

304   relationship between crop load and juice soluble solids and between crop load and the seasonal

305   change in pruning weight (Figure 5). The mean gradient for the crop load to juice soluble solids

306   response was -0.07 and the mean gradient for the crop load to pruning weight change was -0.016,

307   both similar to the four-year pruning vs thinning study.

308   Using the average linear regression equations from the crop load vs. juice soluble solids

309   and vs. pruning weight change (Figure 5), the Y:PW that achieved 16 Brix or no PW change in

310   each season was calculated. The effect of seasonal growing degree days and precipitation on the

311 predicted Y:PW to achieve 16 Brix or no seasonal change in PW was investigated by multivariate

312 regression. There was an effect of GDD on the Y:PW to achieve 16 Brix, but no effect of

313 precipitation or an interaction effect (Table 3). In contrast, the main effect in the multivariate model

314 to predict the seasonal change in PW was precipitation, and GDD had no direct predictive power

315 for the seasonal change in PW (Table 3). The univariate relationships between Y:PW for 16 Brix,

316 Y:PW for no PW change, GDD and precipitation are plotted in Figure 6. In general, in warmer

317 seasons, 16 Brix could be achieved at a higher crop load (Figure 6A). The two warmest seasons,

318 2005 and 2007 achieved 16 Brix at Y:PW > 40. In contrast, for the seasonal change in pruning

319 weight, wetter seasons were able to attain no seasonal change in PW at higher crop loads (Figure

320 6D).

321   To investigate the effect of crop adjustment on return crop potential, vines in the thinning

322 study were pruned to 120 nodes, fruit thinned in year one, again pruned to 120 nodes, and received

323 no other crop adjustment in year two. Vines from the thinning study were further grouped into

324 small (0-0.6 kg/vine), medium (0.6-1.2 kg/vine), and large (1.2-1.8 kg/vine) vine size classes to

325 investigate the effect of year-1 crop load on year-2 crop yield. Within a vine size class, there was

326 no effect of year-1 crop load on return crop yield over a wide range of crop load values (Figure 7).

327 Year-1 crop load influenced the change in vine pruning weight in year-1 (Figures 3, 4 and 5), but

328 it was the absolute vine pruning weight at the beginning of year 2 which influenced yield potential

329 in year 2.

330   **Discussion**

331   The main objectives of this study were to characterize the crop load response in NY

332 Concord, determine if the crop load response was influenced by pruning or fruit thinning, and

15

333   understand seasonal impacts on crop load targets. The results from this study support the general

334   Y:PW reported in accepted crop load theory (Bravdo et al. 1985, Kliewer and Dokoozlian 2005),

335   but add details specific for Concord production for the juice grape industry in NY and PA.

336   Maximum juice soluble solids were achieved at Y:PW of approximately 7.2. Crop loads below 7.2

337   did not result in an increase in juice soluble solids but did continue to increase vine size. This is

338   consistent with other fruit thinning studies that showed little response of fruit maturation to crop

339   load at Y:PW values below 10 and attribute fruit quality differences in this range to regional

340   climatic conditions or seasonal variation (Keller M et al. 2005, Preszler et al. 2013, Reeve et al.

341   2018). The crop load – Brix inflection point of 7.2 in this cool-climate study was slightly lower

342   than the 10-12 reported in warmer climate studies (Kliewer and Dokoozlian 2005), supporting the

343   theory that cool-climate grapevines need relatively more leaf area per unit fruit to reach maximum

344   maturity. Given the wide range of Y:PW values, this slight difference does not practically change

345   the accepted industry standard crop load range of 5 – 10 for high fruit maturity.

346   This study also supports the theory that vines become fruit sink limited at very low crop

347   loads and extra vine photosynthates are diverted to vegetative structures. Conservative balanced

348   pruning (33 + 11) consistently undercropped the vines (mean Y:PW = 7 and quartile range = 4.6

349   to 8.6) by limiting yields, even at large vine sizes. This is a possible pruning strategy for building

350   vine size and improving the long-term productivity potential of young or stressed vineyards, but it

351   is not a viable option for sustainable economic production. It is also consistent with other cool

352   climate crop load studies which describe excessive canopy growth and the need for canopy

353   management at Y:PW below 5.

354   The conservative to moderate balanced pruning formulas used by Shaulis (Shaulis and

355   Steele 1969) promoted Concord crop loads that increased vine size each year. Since both

356   vegetative and reproductive growth increased with vine size, the annual increase in vine size led

357   to excessively large vines with increased leaf area, canopy density, and fruit zone shading. This

358   led to the development and success of the Geneva Double Curtain divided canopy training and

359   shoot positioning system to expose excessive leaf area to sunlight (Shaulis et al. 1966). However,

360   the current economic pressures in the Concord industry has, in general, led to chronic overcropping

361   and a reduction in vine size below the point where canopy division is beneficial.

362   Crop loads above 7.2 had a negative linear relationship with harvest juice soluble solids

363   and seasonal change in vine size. In most other viticulture situations, where high fruit maturation

364   is desired, this would be considered overcropping with incremental increases in Y:PW leading to

365   greater reductions in juice soluble solids or later harvest dates and decreases in vine size and return

366   crop potential. Liberal balanced pruning (66 + 11) had a mean Y:PW of 11 (quartile range = 8.3

367   to 13.0) with juice soluble solids between 16.6 and 17.0 and a seasonal increase in vine size. This

368   pruning management is appropriate for conservative producers who want to ensure a ripe crop in

369   any given season and do not want to adopt fruit thinning as a crop control strategy. Since retained

370   nodes and yield increased with increasing vine size under this treatment, economic revenue is

371   maximized at high vine size > 1.2 kg/vine (0.5 kg/m of canopy).

372   Fixed node pruning at 100 nodes/vine without additional crop adjustment had a mean crop

373   load of 17 (quartile range = 12.0 to 20.0) and tended to be on the high end with small vines and

374   the low end with large vines. In commercial Concord operations in NY, the term "grower pruning"

375   typically refers to pruning standard spaced vines (2.7 m row x 2.4 m vine) to between 80 nodes on

376   small vines and 100 nodes on large vines. This study indicated that 100-node pruning management

377   reasonably satisfies the crop load goal for achieving 16 Brix fruit while maintaining vine size in

378   NY Concord. The disadvantage of high node number "pruning only" crop management is that the

379   crop potential is set during the dormant season and does not allow for in-season crop load

380   adjustments. In the event of frost or poor fruit set, limiting bud number limits potential yield by

381   limiting the number of secondary shoots, thereby undercropping the vines and limiting revenue.

382   In contrast, high fruit set combined with a cool growing season, as experienced in 2003, results in

383   overcropped vines with low juice soluble solids and a reduction in vine size. In this case, mid-

384   season fruit thinning is an option to bring vines into balance.

385   Managing vines to a relatively high level of crop stress together with the physical stress of

386   fruit thinning makes high node number pruning a questionable treatment. In two of the four pruning

387   vs thinning comparison years, and in eight of the eleven thinning study years, vines pruned to 120

388   nodes without additional crop adjustment had Y:PW values > 20 with reductions in juice soluble

389   solids and vine size. In Lake Erie Concord production, there is a trend to retaining relatively high

390   node numbers as a result of mechanized pruning and frost risk mitigation. Mechanized pruning

391   reduces production costs but is less precise in managing retained node quantity and quality;

392   therefore, producers err on the side of retaining too many buds. In this study, fruit thinning one

393   month after bloom reduced Y:PW, increasing harvest juice soluble solids and the seasonal change

394   in pruning weight. The Concord crop load response was the same whether a given Y:PW was

395   achieved through pruning severity or by retaining additional fruiting nodes followed by mid-

396   season fruit thinning.

397   In practice, Concord crop estimation and adjustment are done by mechanical fruit thinning

398   with a harvester at approximately one month after bloom. The decision to fruit thin is primarily

399   dictated by an assessment of vine crop load and vineyard goals for balance, as described in this

400   study. Deciding how much fruit to thin, or retain, can be additionally adjusted by seasonal climatic

401   conditions. The thinning data in this study indicated that warmer than average seasons achieved

402   16 Brix at higher Y:PW than cooler than average seasons. Assuming GDD accumulation one-

403   month after bloom is reflective of total season GDD, high GDD accumulation at fruit thinning

404   means the vineyard can be managed to higher crop load levels and may require less thinning or no

405   thinning at all. Low GDD accumulation at fruit thinning would warrant more fruit thinning to

406   maintain higher sugar accumulation rates from veraison to harvest.

407   There was also an effect of seasonal precipitation on the change in vine pruning weight.

408   Holding everything else equal, it is common to observe higher vine size in wet years and lower

409   vine size in dry years. It raises an interesting question concerning the error associated with using

410   pruning weight to estimate vine capacity. If a vine with a Y:PW of 17.5 has a vine size of 1.0 kg

411   in an average precipitation year, 1.2 kg in a wet year, and 0.8 kg in a dry year, is the vine capacity

412   different, possibly as a result of decreased photosynthetic capacity in dry years, or an artifact of

413   growth habit, such as longer internode lengths in wet years?

414   On a broader scale, vine size did influence fruit yield potential at all pruning levels, as

415   expected (Figure 2), but the return crop analysis in this study also showed that it did not matter

416   how the vine size was achieved (Figure 7). For example, overcropping large vines in year 1,

417   undercropping small vines in year 1, and balancing medium size vines in year 1, all resulted in

418   medium size vines having the same yield potential in year 2 at a given pruning level. This illustrates

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419   the continual management interaction between crop load and the vine size-yield response, two

420   concepts often confused. Crop load, managed as the Y:PW, influences if a vine will gain or lose

421   pruning weight during a season; however, it is the absolute vine size (or vine capacity) during the

422   dormant season which determines the next season's yield potential.

423   Based on the crop load relationships and seasonal responses in this study, crop load ranges

424   and recommendations were developed for NY Concord vine balance (Table 4). Climate change

425   predictions for the northeast US point toward warmer and longer growing seasons, longer spring

426   frost windows, increased spring precipitation, and more frequent water shortages in the growing

427   season (Wolfe et al. 2018). If managed properly, both warmer and wetter conditions indicate an

428   opportunity to produce Concord grapes in the future at higher crop loads while maintaining high

429   juice soluble solids and vine size. The potential increase in spring frost events is a risk which can

430   be partially mitigated by retaining high node numbers, either manually or mechanically, and then

431   adopting mid-season fruit thinning to balance vines if needed.

432   **Conclusions**

433   The response of Concord in New York to crop load, measured as Y:PW, was similar to

434   previously reported studies with respect to harvest juice soluble solids and the seasonal change in

435   vine pruning weight. There was a negative relationship between crop load and juice soluble solids,

436   which reached a maximum at a Y:PW of 7.2, and with no further increase below 7.2. The seasonal

437   change in vine pruning weight also increased with decreasing crop load but did not plateau. The

438   crop load response to juice soluble solids and vine size was the same whether the crop load was

439   adjusted through changes in pruning severity or by light pruning followed by mid-season fruit

440 thinking. There was a positive linear relationship between seasonal GDD and the Y:PW needed to

441 reach 16 Brix, as well as between seasonal precipitation and the Y:PW required to observe no

442 seasonal pruning weight change. The results of this study were used to develop a crop load

443 management model for NY Concord which integrates the juice grape industry parameters for 16

444 Brix fruit, sustainable vine size and production, spring frost mitigation, seasonal environmental

445 variation, and possible climate change impacts. Annually, the CLEREL research group tracks

446 weather, Concord phenology, and Concord fresh berry weight on a set of sentinel vines and

447 provides this information to the growers for crop estimation and management through the Lake

448 Erie Regional Grape Program. The Concord crop load model developed here will integrate with

449 this information to assist growers with mid-season crop estimation and fruit thinning management.

450 The crop load response information from this study can also be used to provide viticulture context

451 to spatial vineyard crop load mapping where NDVI and Yield monitor spatial sensor data can be

452 used to calculate spatial vineyard crop load maps.

453 **Literature Cited**

454 Bates T, Morris J. 2009. Mechanical cane pruning and crop adjustment decreases labor costs and
455   maintaines fruit quality in New York "Concord" grape production. Horttechnology 19:247–
456   253.

457 Bates T, Dresser J, Eckstrom R, Badr G, Betts T, Taylor J. 2018. Variable-rate mechanical crop
458   adjustment for crop load balance in "Concord" vineyards. 2018 IoT Vert Top Summit Agric
459   - Tuscany, IOT Tuscany 2018:1–4.

460 Bates TR. 2008. Pruning level affects growth and yield of New York Concord on two training
461   systems. Am J Enol Vitic 59:276–286.

462 Bates TR. 2017. Mechanical crop control in New York "Concord" vineyards target desirable
463   crop load levels. *In* Acta Horticulturae. pp. 259–264. International Society for Horticultural
464   Science (ISHS), Leuven, Belgium.

465 Bravdo B, Hepner Y, Loinger C, Cohen S, Tabacman H. 1984. Effect of crop level on growth,
466   yield, and wine quality of a high yielding Carignane vineyard. Am J Enol Vitic 35:247–251.

467 Bravdo B, Hepner Y, Loinger C, Cohen S, Tabacman H. 1985. Effect of irrigation and crop level
468   on growth, yield and wine quality of Cabernet Sauvignon. Am J Enol Vitic 36:132–139.

469 Fendinger AG, Pool RM, Dunst RM, Smith R. 1996. Effect of mechanical thinning minimally-
470   pruned "Concord" grapevines on fruit composition. *In* Proc. 4th Intl. Symp. Cool Climate
471   Viticult. p. IV/13--17.

472 Howell GS. 2001. Sustainable grape productivity and the growth-yield relationship: a review.
473   Am J Enol Vitic 52:165–174.

474 Jordan TD, Pool RM, Zabadal TJ, Tomkins JP. 1980. Cultural practices for commercial
475   vineyards. *In* Misc. Bul. 111. pp. 29–30. New York State College of Agriculture and Life
476   Sciences, Cornell University, Ithaca.

477 Keller M. 2010. The Science of Grapevines – Anatomy and Physiology. Elsevier: Academic
478   Press, Burlington, MA.

479 Keller M, Mills L, Wample R, Spayd S. 2005. Cluster Thinning Effects on Deficit-Irrigated
480   Winegrapes. Am J Enol Vitic 2:91–103.

481 King PD, Smart RE, McClellan DJ. 2015. Timing of Crop Removal Has Limited Effect on
482   Merlot Grape and Wine Composition. Agric Sci 06:456–465.

483 Kliewer WM, Dokoozlian NK. 2005. Leaf area/crop weight ratios of grapevines: influence on
484   fruit composition and wine quality. Am J Enol Vitic 56:170–181.

485 Poni S, Lakso AN, Turner JR, Melious RE. 1994. Interactions of crop level and late season water
486   stress on growth and physiology of field-grown concord grapevines. Am J Enol Vitic
487   45:252–258.

488 Pool RM. 2004. Vineyard balance -what is it? Can it be achieved? Acta Hortic 640:285–302.

489 Pool RM, Dunst RE, Crowe DC, Hubbard H, Howard GE, DeGolier G. 1993. Predicting and
490   controlling crop on machine or minimal pruned grapevines. *In* Proc. N.J. Shaulis Grape
491   Symposium: Pruning mechanization and crop control. RM Pool (ed.), pp. 31–45. Fredonia,
492   NY.

493 Preszler T, Schmit TM, Vanden Heuvel JE. 2013. Cluster thinning reduces the economic
494   sustainability of Riesling production. Am J Enol Vitic 64:333–341.

495 Ravaz M. 1911. L'effeuellage de la vigne. Ann d L'Ecole Natl d'agriculture Montpellier 11:216–
496   241.

497 Reeve AL, Skinkis PA, Vance AJ, McLaughlin KR, Tomasino E, Lee J, Tarara JM. 2018.
498   Vineyard floor management and cluster thinning inconsistently affect 'Pinot noir' crop load,
499   berry composition, and wine quality. HortScience 53:318–328.

500 Reynolds AG, Vanden Heuvel JE, Heuvel JE v. 2009. Influence of grapevine training systems on
501   vine growth and fruit composition: a review. Am J Enol Vitic 60:251–267.

502 Shaulis N. 1980. Responses of the grapevines and the grapes to the spacing of and within
503   canopies. pp. 353–361.

504 Shaulis N, Steele RD. 1969. The interaction of resistant rootstock to the nitrogen, weed control,
505   pruning, and thinning on the productivity of Concord grapevines. J Am Soc Hortic Sci
506   91:122–129.

507 Shaulis N, Amberg H, Crowe D. 1966. Response of concord grapes to light, exposure and
508   geneva double curtain training. Proc Am Soc Hortic Sci 89:268–280.

509 Shaulis NJ. 1956. Looking ahead with grape growers. *In* N. Y. State Hort. Soc. Proc. pp. 126–
510   132.

511 Smart RE, Robinson M. 1991. Sunlight into Wine: A Handbook for Winegrape Canopy
512   Management. Winetitles, Adelaide.

513 Taylor J, Dresser J, Hickey C, Nuske S, Bates T. 2019. Considerations on spatial crop load
514   mapping. Aust J Grape Wine Res 25:144–155.

515 USDA. 1994. Soil survey of Chautauqua county, New York. National Cooperative Soil Survey.

516 Weigle TH. 2006. 2006 New York and Pennsylvania Pest Management Guidelines for Grapes.
517   WF Wilcox, G English-Loeb, RM Dunst, and A Landers (eds.). Cornell University.

518 Wolfe DW, DeGaetano AT, Peck GM, Carey M, Ziska LH, Lea-Cox J, Kemanian AR,
519   Hoffmann MP, Hollinger DY. 2018. Unique challenges and opportunities for northeastern
520   US crop production in a changing climate. Clim Change 146:231–245.

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Table 1 Weather and phenology from Cornell's Taschenberg Vineyard Laboratory, Fredonia, NY, from 1999-2009.

Year	GDD accumulation (°C)	Precipitation accumulation (mm)	Bud break	Bloom	Veraison	Harvest
	1 April - 31 Oct		Date			
1999	1658	621	3-May	8-Jun	13-Aug	17-Sep
2000	1461	692	2-May	11-Jun	21-Aug	30-Sep
2001	1615	548	30-Apr	12-Jun	18-Aug	25-Sep
2002	1680	677	18-Apr	19-Jun	24-Aug	25-Sep
2003	1435	584	4-May	24-Jun	1-Sep	13-Oct
2004	1578	841	1-May	7-Jun	22-Aug	7-Oct
2005	1811	646	9-May	12-Jun	20-Aug	3-Oct
2006	1554	772	29-Apr	13-Jun	21-Aug	3-Oct
2007	1732	389	7-May	9-Jun	17-Aug	2-Oct
2008	1511	797	23-Apr	13-Jun	22-Aug	29-Sep
2009	1343	947	2-May	13-Jun	31-Aug	5-Oct
Mean	1532[a]	683[a]	3-May[b]	13-Jun[c]	22-Aug[c]	
St. Dev.	140	153	7	6	6	

[a]92-year mean (1926-2018).
[b]39-year mean (1979-2018).
[c]53-year mean (1965-2018).

Table 2 Multivariate analysis of Yield:Pruning weight (Y:PW) and Treatment (pruning or thinning) on harvest juice soluble solids or the seasonal change in pruning weight in New York Concord from 2001-2004. Model used standard least squares and effect tests (Prob > F) are shown.

	Year				
	2001	2002	2003	2004	All Years
Juice soluble solids					
Y:PW	*[a]	***	***	**	***
Experiment	***	***	*	NS	NS
Y:PW * Experiment	*	NS	***	NS	NS
Seasonal PW change					
Y:PW	*	***	***	***	***
Experiment	NS[b]	**	NS	*	NS
Y:PW * Experiment	NS	NS	NS	NS	NS

[a] *, **, *** indicate significance at $p < 0.01$, < 0.001, and < 0.0001, respectively.
[b] NS = not significant ($p > 0.01$).

Table 3 Multivariate regression effect tests of seasonal growing degree days or precipitation on the Yield:Pruning weight (Y:PW) needed to reach harvest juice soluble solids of 16 Brix or no seasonal change in vine pruning weight in New York grown Concord from 1999-2009.

	Y:PW for 16 Brix		Y:PW for no PW change	
	F Ratio	Prob > F	F Ratio	Prob > F
GDD	13.8	**0.0099**	0.1591	0.7019
Precipitation	2.4	0.1700	10.66	**0.0138**
GDD * Precip	0.04	0.8574	2.63	0.1483

Table 4 General crop load descriptions and management recommendations for Concord production in the Lake Erie AVA.

Y:PW	Category	Predicted Brix[a]	Management
0-5	Severely undercropped	17.2	Juice soluble solids (JSS) maximized and vine size increased by 0.15-0.20 kg/vine. Severe undercropping, generally only observed in frost damaged vineyards, can be managed to increase overall vine size and crop potential for the following season.
5-10	Undercropped	17.0-17.2	JSS > 1.0 Brix above the 16.0 standard and vine size increased by 0.10-0.15 kg/vine. This crop load is not economically viable for long-term Concord production in NY and recommended only when attempting to build vine size in young or stressed vineyards.
10-15	Slightly undercropped *Balanced in cool season*	16.5-17.0	JSS 0.5 to 1.0 Brix above the 16.0 standard and vine size slightly increased by 0.03-0.09 kg/vine. This conservative crop load can be achieved with moderate balanced pruning, does not require fruit thinning, and will still mature to 16 Brix in cooler than average seasons.
15-20	**Balanced in average season[b]**	**16.1-16.5**	**JSS at or slightly above the 16 Brix standard and vine size maintained +/- 0.03 kg/vine**
20-25	Slightly overcropped *Balanced in warm season*	15.7-16.0	JSS below the 16 Brix standard and vine size reduced by 0.03-0.09 kg/vine in an average season. Harvest delays and reduced crop potential for the following season are expected; however, vines will maintain balance in warmer and wetter than average seasons. This crop load recommended if mid-season fruit thinning is part of the management strategy. In cool and average seasons, the crop can be moderately thinned to maintain balance. In warm seasons, no thinning would be necessary.
> 25	Severely overcropped	<15.7	JSS well below the 16 Brix standard and, if left unthinned, will still require a significant period of ripening after harvest has started. Vine size will be reduced by > 0.1 kg/vine (0.25 lbs/vine) with a lower future yield potential and a lower return crop. It requires excessive fruit thinning to achieve vine balance mid-season, which has been shown to cause canopy damage in Concord and negates the positive effects of fruit thinning on vine size/health. This level of crop load stress is not recommended.

[a]Predicted Brix in an average season at a standard harvest of 30 - 40 days after veraison. The given ranges reflect this spread of time.
[b]An average season = 1455-1723 GDD (+/- 1 st. dev. from the 11 -year GDD mean). Cool season < 1455 GDD, Warm season > 1723 GDD.
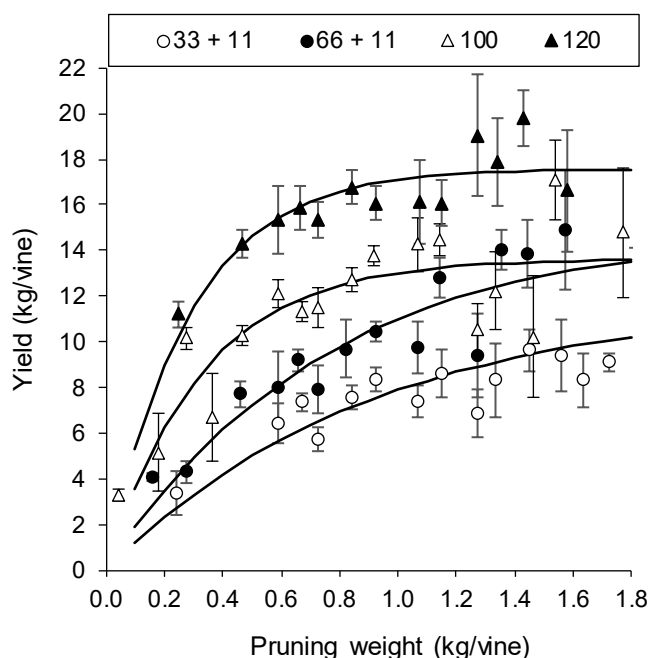
Figure 1 The effect of Concord pruning weight (PW) on fresh fruit yield at two variable node and two fixed node pruning severities. Vines were balanced pruned to retain 33 (open circles) or 66 (closed circles) nodes for the first 500g pruning weight plus an additional 11 nodes for each additional 500g or pruned to retain 100 (open triangles) or 120 (closed triangles) nodes per vine, regardless of pruning weight. Individual vine observations (n = 36 per year) from 2001-2004 were combined by pruning treatment and binned by 0.1 kg pruning weight (bars = ±SE). Fitted curves for 33 + 11: Yield = 11.8 - ((11.8) * EXP(-1.1 * PW)), R^2 = 0.91; 66 +11: Yield = 14.9 - ((14.9) * EXP(-1.3 * PW)), R^2 = 0.94; 100 nodes: Yield = 13.6 - ((13.6) * EXP(-3.1 * PW)), R^2 = 0.87; 120 nodes: Yield = 17.6 - ((17.6) * EXP(-3.6 * PW)), R^2 = 0.88.
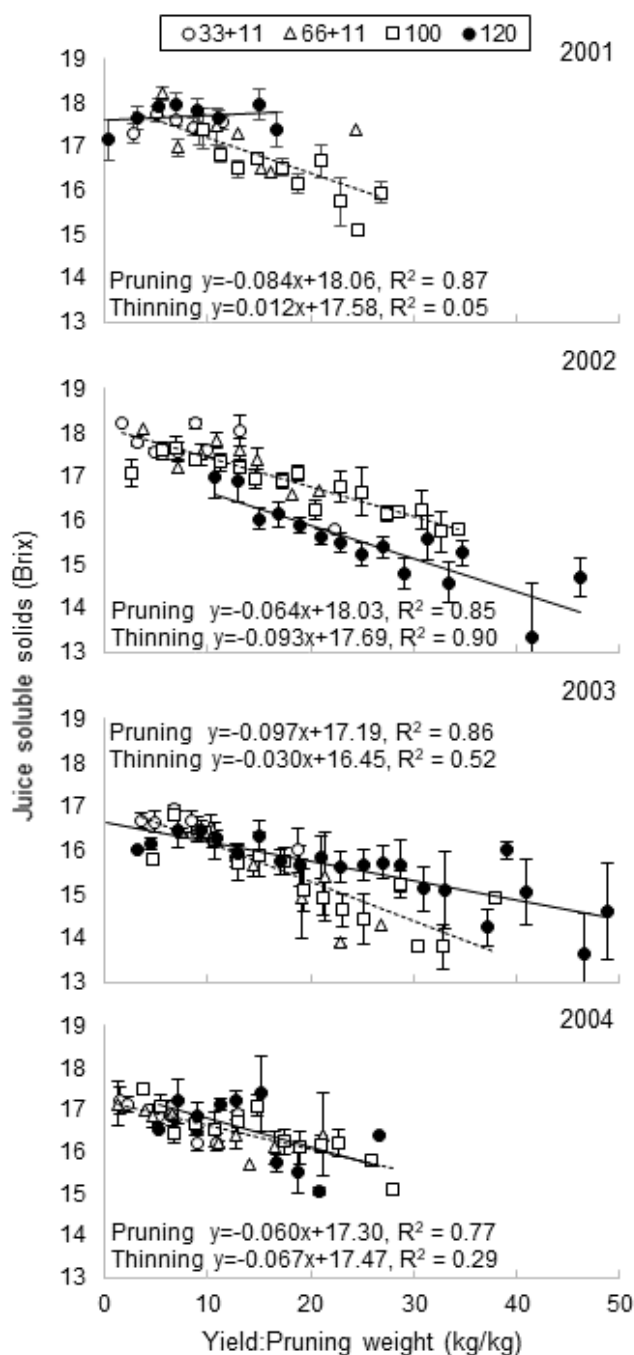
Figure 2 The effect of Concord Yield:Pruning weight (Y:PW) on harvest juice soluble solids from 2001-2004. Vines were grouped by pruning severity (33 + 11, 66 + 11, or 100 nodes: open symbols) or by 120 node pruning with mid-season fruit thinning (closed symbols). There were 108 pruning observations per year (36 per pruning level) and 75 thinning observations per year. Data was binned by crop load in intervals of 2 Y:PW. (bars = ±SE).
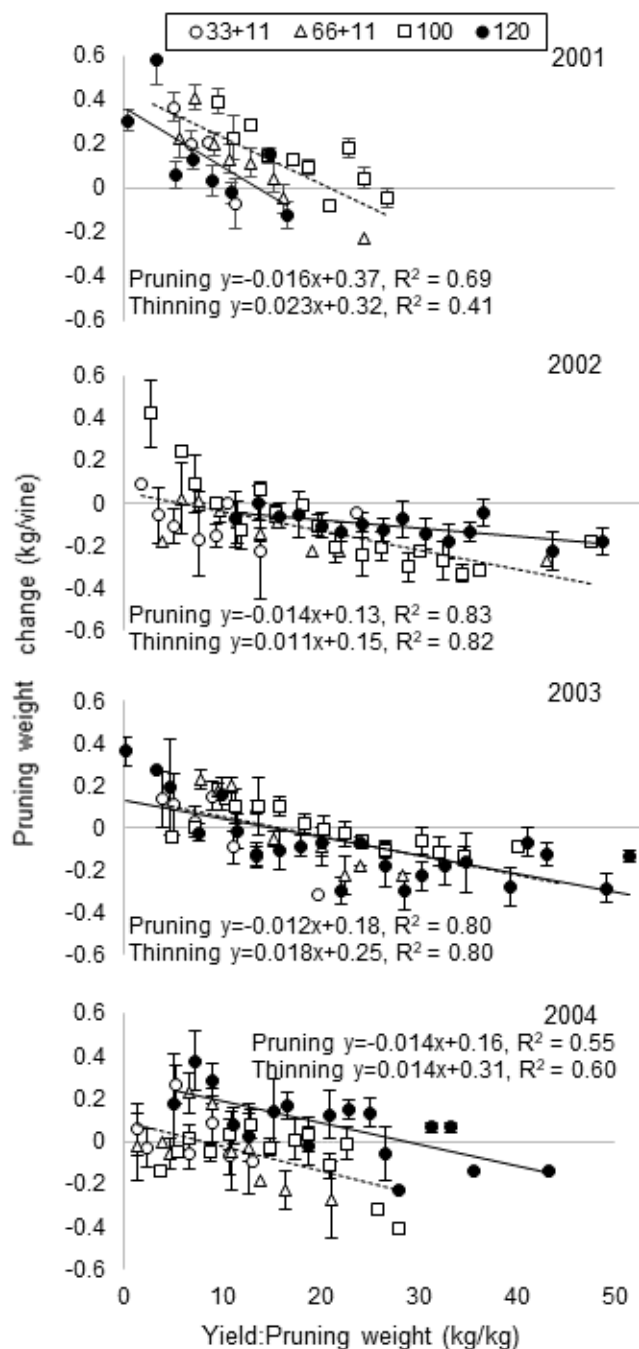
Figure 3 The effect of Concord Yield:Pruning weight (Y:PW) on the seasonal change in pruning weight from 2001-2004. Vines were grouped by pruning severity (33 + 11, 66 + 11, or 100 nodes: open symbols) or by 120 node pruning with mid-season fruit thinning (closed symbols). There were 108 pruning observations per year (36 per pruning level) and 75 thinning observations per year. Data was binned by crop load in intervals of 2 Y:PW. (bars = ±SE).
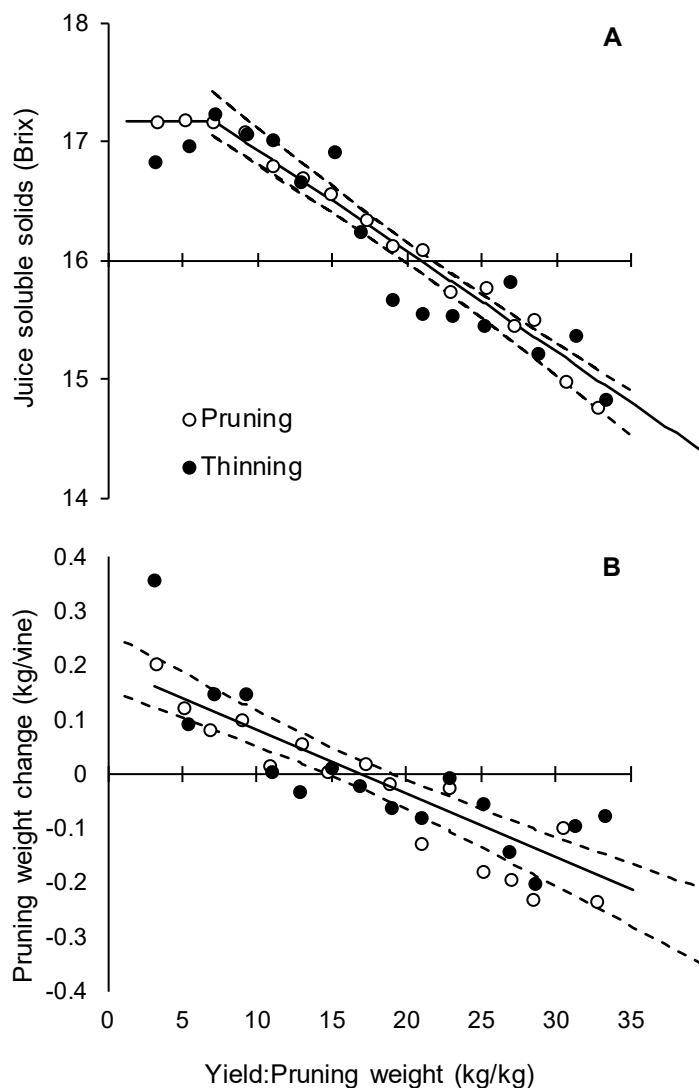
Figure 4 The general 4-year Concord crop load response on harvest juice soluble solids (**A**) and seasonal change in vine pruning weight (**B**). Pruning severity (open circles) or mid-season fruit thinning (closed circles) was used to generate a range of Y:PW. Each point is the mean of four years (n = 4). Pruning and thinning data were combined for the mean response. A broken stick model was fitted to illustrate the inflection point on the juice soluble solids response (see Equation 1). For the pruning weight response, a linear model was used (see Equation 2). Dashed lines indicate 95 % mean confidence limits.
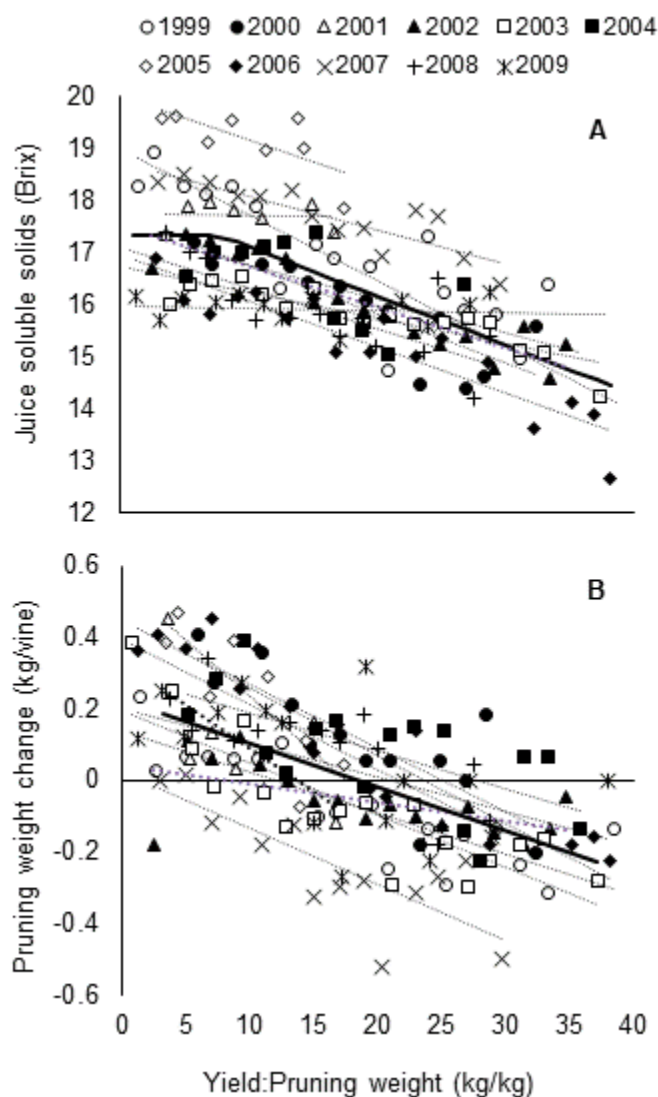
Figure 5 The effect of Concord Yield:Pruning weight on harvest juice soluble solids (**A**) and the seasonal change in vine pruning weight (**B**) from 1999 to 2009. Dashed lines are individual year trend lines and the solid lines are the mean response for all years. (n = 75 for 1999-2004, 2006, and 2010; 18 for 2005; and 42 for 2007-2009). The solid lines are the mean response (n = 11 years).
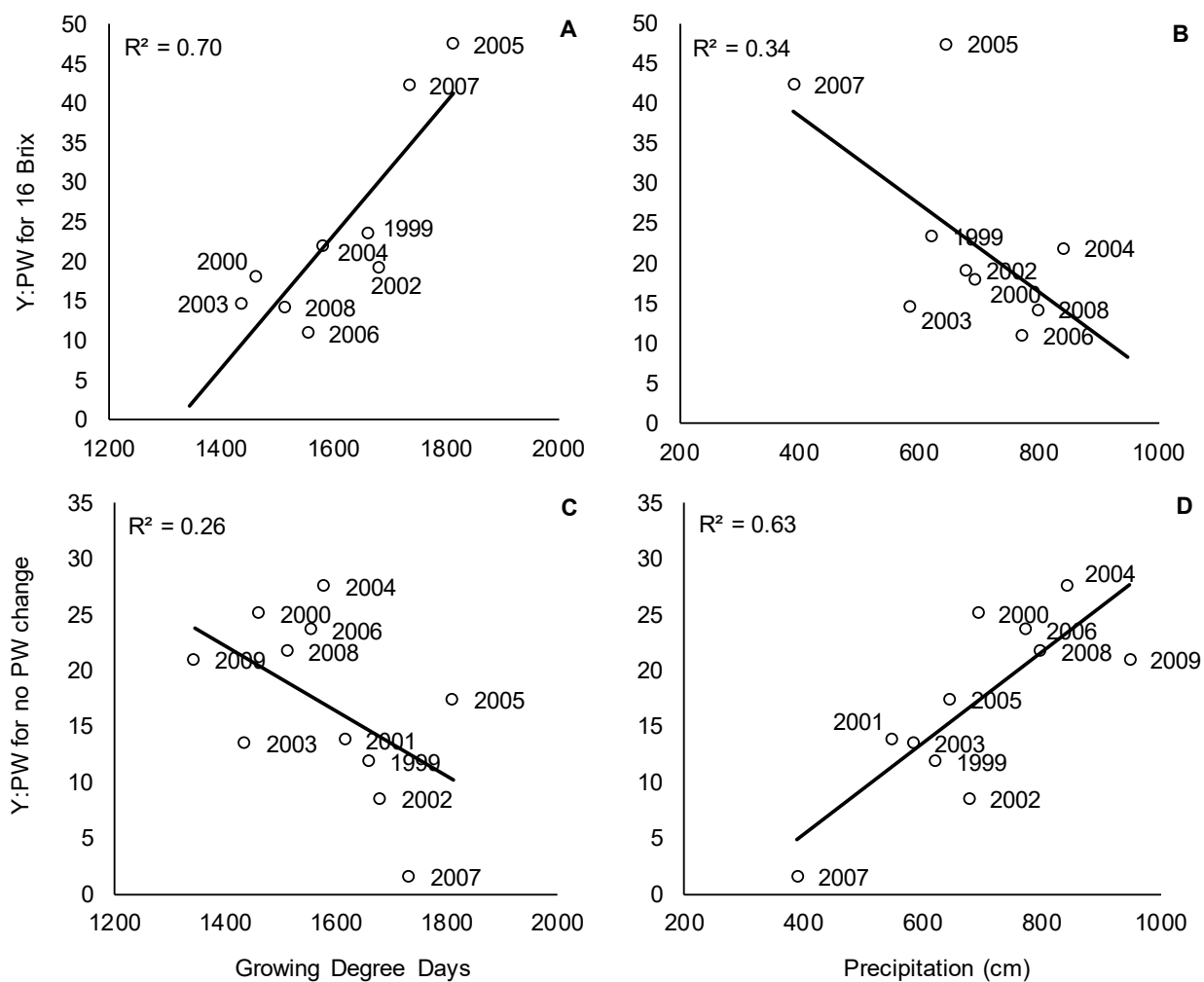
Figure 6 The effect of growing degree day (base 10°C) and precipitation (mm) accumulation on the Yield:Pruning weight (Y:PW) needed to achieve 16 Brix at harvest (**A** and **B**) or no seasonal pruning weight change (**C** and **D**) in NY Concord from 1999-2009. Data labels indicate year.
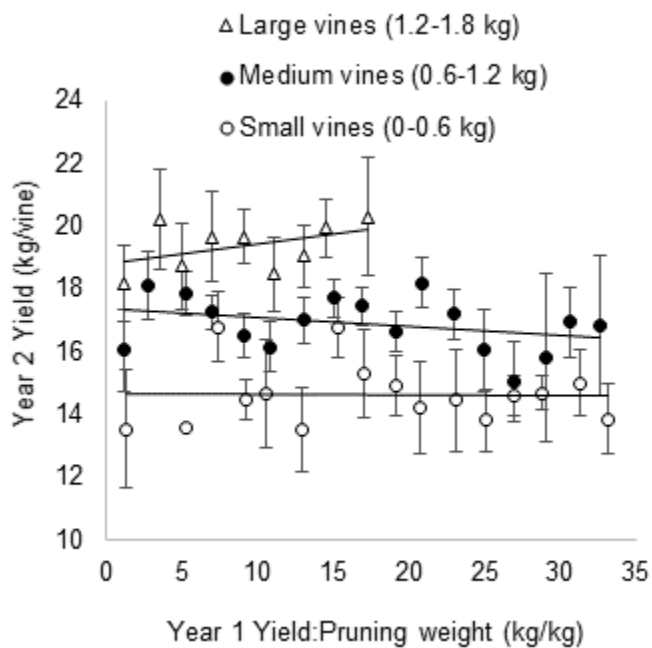
Figure 7 The relationship of year-1 Yield:Pruning Weight on year-2 yield on small (0-0.6 kg), medium (0.6-1.2 kg), and large (1.2-1.8 kg) vine size classes in Concord grapevines. Data was pooled from a 11-year fruit thinning study, grouped by vine size class, and binned in intervals of Y:PW = 2 (each point n = 10, bars = ±SE).