School of Agriculture, Policy and Development

University of Reading

Apples in a Warmer World ®: Productivity, Fruit Quality and Climate Change

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Introduction and Methodology

IPCC climate change temperature rise scenarios of +2.1 to +3.5°C will alter the growth, physiology and production of apple trees. Warming climate effects on phenological acceleration over the past 50 years are already apparent (Figure 1). Strong market competition from imported fruit has raised fruit quality standards over recent years. The UK fruit industry requires research on climate change impacts on yield and fruit quality to ensure produce can remain competitive in a warming world. Between 2017-22, a 0.6 ha modified environment orchard at the National Fruit Collection, Brogdale, Kent, was established to evaluate the effect of varied climate regimes on apple production. Three separate triple-span polythene tunnels housed 20 unique cultivars under nine climate regimes that reflect uncertainty amongst climate change scenarios (Figure 2). These comprised of three temperature (ambient, +2°C, and +4°C [nominal values]) and three rainfall (ambient, +20%, and -20%) regimes. The cultivars grown differed in commercial importance (e.g. 'Gala'), seasonality (early to late), or specific phenotypic traits (e.g. low chill requirements).

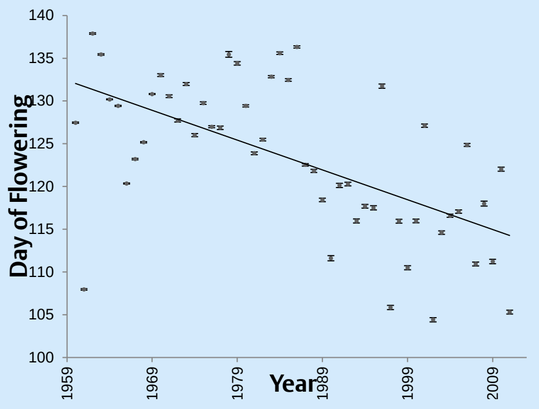

Figure 1: *Average 'full flowering' date of apple varieties (1959 – 2011) at the National Fruit Collection, Brogdale, Kent (1st Jan = Day 1).*

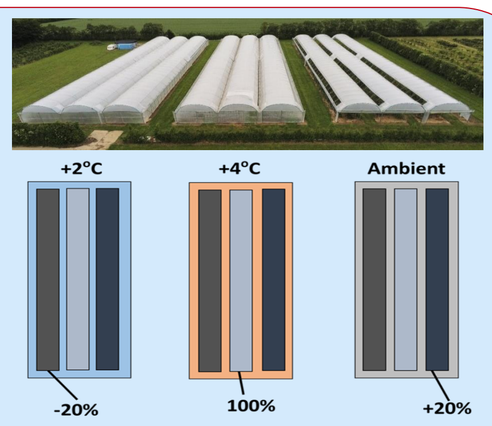

Figure 2: *Aerial overview of the facility housing field-cultivated apple trees under nine climate regimes.*

Results: Impacts of Warmer Seasonal Weather on Apple Production

The effects of the temperature treatments on apple fruit yield and quality often varied among cultivars and also among years. Nevertheless, several trends were apparent as a consequence of increased seasonal temperature:

Altered biennial floral bud production

Warmer growing season weather was associated with enhanced alternate bearing patterns. Fewest flower clusters were produced under the warmest treatment (+4°C) in 2022 (Figure 3). Negative relationships between temperature and fruit yield were found during fruit bud initiation (May-June) and tree endodormancy (Nov-Jan) (Figure 4). Crop load was also found to be negatively associated with yield in the subsequent season.

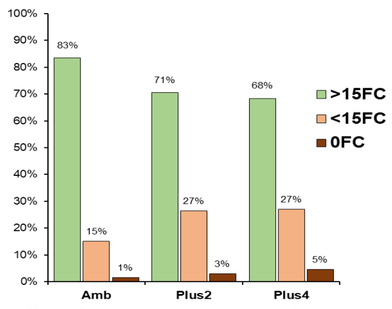

Figure 3*: Percentage of trees producing more >15, <15 and 0 flower clusters (FC) in* ***2022****.*

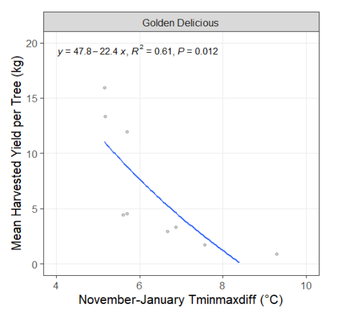

Figure 4*: Logarithmic relationship between Nov-Jan Tminmaxdiff and yield for 'Golden Delicious'.*

Increased biennial fruit yield variation at harvest

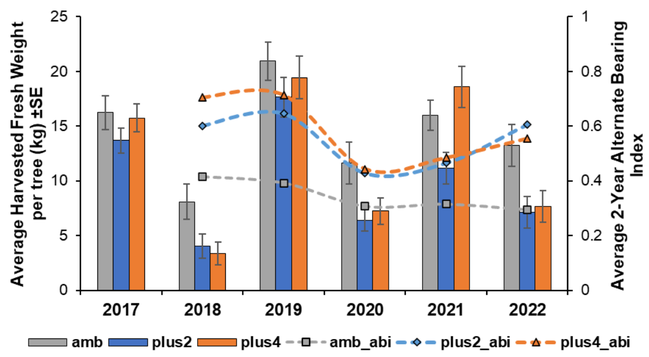

Figure 5*: Mean fruit fresh weight (kg) per tree and alternate bearing index across 12-13 cultivars.*

Trends in biennial bearing were consistent throughout the study with a high yielding year (2017,-19,-21) followed by a low yielding year (2018,-20,-22) across all treatments (Figure 5). However, the scale of variation differed. Biennial yield variation was more pronounced in the warmer treatments, despite identical management practices. Overall, mean +4°C fruit yield was lower than Ambient for many of the study cultivars.

Altered fruit quality characteristics

Analyses showed associations between seasonal temperature and fruit quality response: Soluble Solids Content (SSC) and Dry Matter Content were positively influenced, red colour coverage (RCC) (Figure 6) and fruit weight were negatively influenced, and firmness showed mixed influence. However, variable importance in projection model analysis suggests that temperature was less influential than other factors, such as precipitation, pruning, and fruit yield parameters (Figure 7).

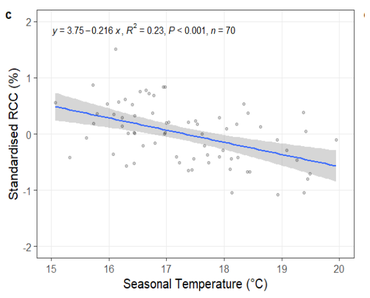

Figure 6*: Linear regression relationship between seasonal temperature and cross-cultivar SSC.*

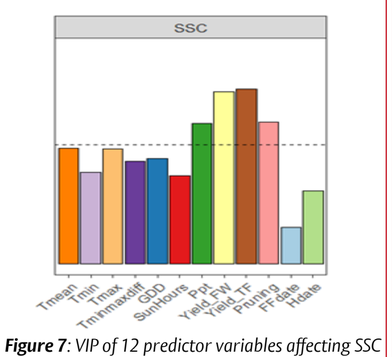

Figure 7*: VIP of 12 predictor variables affecting SSC based on a PLSR model. Score >1 = high influence.*

Altered fruit storability

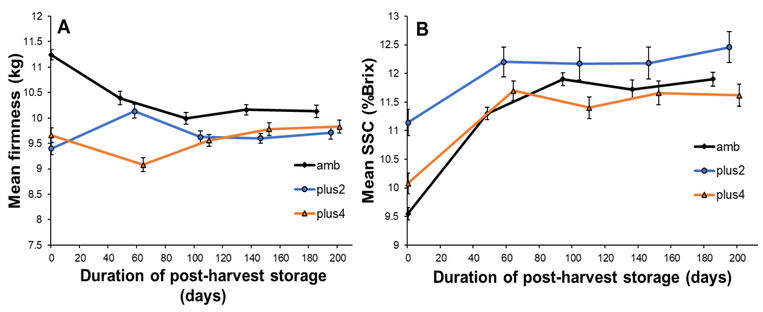

Figure 8*: Change in mean firmness (A) and SSC (B) with duration of storage for 'Gala' fruit.*

The treatments had mixed direct and indirect effects on 'Gala' fruit storability in controlled atmosphere (CA) conditions (1.5°C, 1% O_2, 5% CO_2). +4°C accelerated harvest date by 16-22 days. Differences in firmness and SSC between temperature treatments were present at harvest, but reduced over time (Figure 8). After 6 months in CA storage, there was little difference in overall 'Gala' fruit marketability between temperature treatments.

Conclusions and Recommendations

Six years of investigation has shown how the three unique modified field temperature regimes had both direct and indirect effects on a wide range of apple production variables across diverse cultivars. Generally, warmer seasonal temperature caused greater variation in apple fruit production output. Combining evidence from several foci presents a possible sequence of events that explains the variation identified by the investigation (Figure 9).

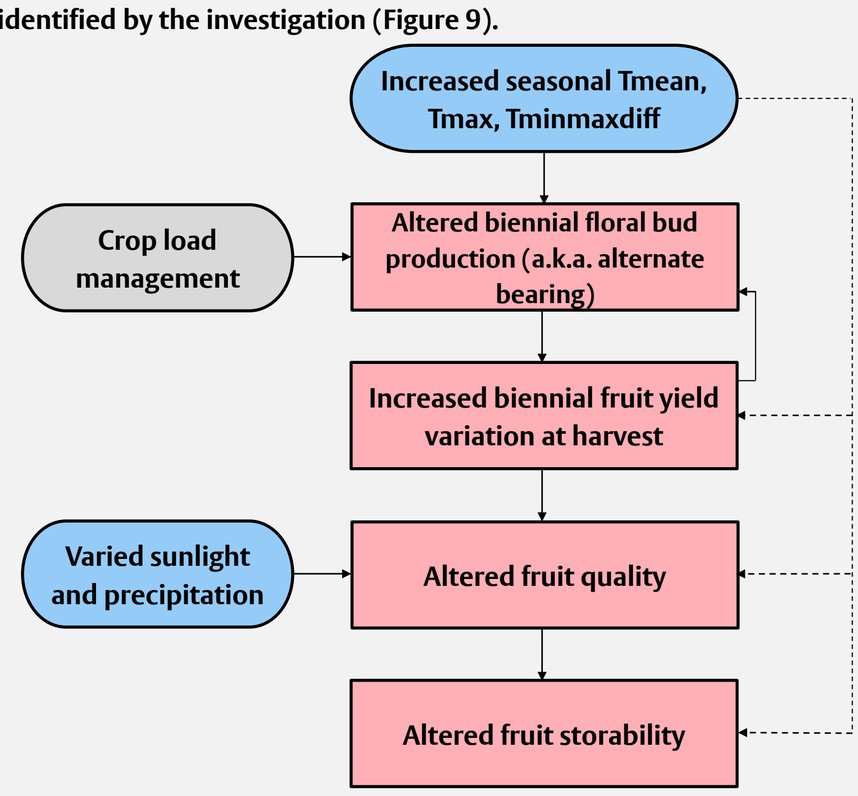

Figure 9: *Simplified flowchart on how key variables (red = production, blue = meteorological, grey = crop management) influenced apple fruit yield and quality over the six years (2017-22) of the NFCT's 'Apples in a Warmer World'® investigation. Solid lines indicate strong direct influences; dotted lines weaker direct or indirect influence.*

Based on the results, growers seeking to mitigate the effects of a warming climate might consider the following actions:

- *Appropriate cultivar selection for the geographic environment and end use*
- *Possible irrigation measures for projected drier summers*
- *Implementation of frost protection measures*
- *Enhanced crop protection measures for increased pest and disease presence*
- *Increased pruning activity to remove excess vegetative growth*
- *Earlier reproductive bud thinning to reduce biennial bearing*
- *Earlier harvesting activity caused by advanced fruit maturity*
- *Enhanced fruit quality checks to ensure fruit is marketable at harvest*

Overall, results show that commercial production of apple will remain possible within Kent as the UK warms over the remainder of this century. Even though apple is a perennial crop, the dominant use of 'Gala' by industry and its characteristics suggest that management practices can evolve with the expected time scale of changes to the environment. Research to support growers might use facilities similar to that developed at Brogdale, albeit with fewer cultivars (those of commercial interest). Similar facilities are suggested in the light of the challenge posed by bienniality and the need to study tree management (e.g. the effect of fruit thinning and tree pruning at different times of the year) over several consecutive years to support reliable fruit production to produce high-quality, high yield fruit crops every year.

Acknowledgements

We thank the Perry Foundation, The Worshipful Company of Fruiterers, and the University of Reading for their generous funding of the PhD research programme; FAST for managing the experimental facilities; and the National Fruit Collections Trust for providing the 'Apples in a Warmer World"® research facility. The 2017-20 results are from the PhD Thesis of Dr Tobias Lane. The National Fruit Collection is supported by DEFRA.

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