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專題演講

國外果樹栽培面對氣候變遷之調適與緩和作為

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摘要

人為加劇溫室氣體釋放加速氣候變遷。本文綜述氣候變遷對重要國外產區果樹生育之影響及其適應與緩和策略。藉由各種氣候情境與生育模型，闡明或預測暖化已經或將改變果樹物候、果樹產量與果實品質等。暖化造成暖溫帶地區落葉果樹冬天低溫累積不足，芽體較難萌發或花期拉長；而春季熱累積加速，芽體提早萌芽，增加晚霜為害；果實多提早採收，但著色較差。暖化與乾旱不利南歐葡萄生產，預測高品質釀酒葡萄將向北推移。涼溫和土壤適度乾旱裨益常綠果樹花芽形成，若氣溫或雨量失常，則無法開花或調節產期；面對暖化，預計熱帶地區果樹罹害程度較溫帶地區嚴重。設法提高果樹的韌性以適應或減緩氣候變遷，其策略如下：(1) 利用適當模式預測和評估氣候變遷對果樹可能影響；(2) 研討遺傳與環境因子對物候的影響，闡明與利用抗逆境機制，協助果樹理想品種選育；(3) 落葉果樹選育低需冷性品種，常綠果樹促進開花；(4) 強化氣象預報，降低高溫、強光、乾旱等逆境，減少低溫、霜害等傷害；(5) 整合改善果樹栽培方式，如修飾樹冠架構、改變果園微氣候、採用設施栽培等；(6) 藉精準與智慧農業有效管理、利用再生性與非再生性資源；(7) 以農業生態原則經營果園，促進養分循環，防止土壤流失；(8) 經由再生型農耕提高土壤有機質含量、加強果園碳儲匯功能；(9) 測量與減緩果園溫室氣體釋放量，評

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估碳足跡與水、能源等生態效率；(10) 依據適地適種原則，進行果樹產區遷移規劃。

關鍵詞：氣候變遷、暖化、適應、緩和、落葉果樹、常綠果樹、物候、休眠、低溫、開花、土壤碳儲匯、碳足跡

前言

氣候變遷包含長期與短期極端天氣變化，其乃因人為加劇溫室氣體 (如 CO_2) 釋放導致。長期氣候變化含暖化、乾旱、沙漠化、土壤鹽化、海平面上升等，而短期極端天氣變化則有寒流、早霜、晚霜、冰雹、焚風、熱浪、颶風 (颱風)、水災、旱災等。大氣 CO_2 濃度增高雖能提高 C3 型植物光合作用，提高產量 (Kimball *et al*., 2007)，但其對氣候產生的效應可能抵消增產之效果 (Raza *et al*., 2019)。蘋果、葡萄、柑橘和香蕉等果樹對氣候變遷的反應曾有綜述 (Glenn *et al*., 2014)。本文試著說明氣候變遷對國外落葉與常綠果樹生育栽培造成的影響，進而陳述適應與緩和作為。

如何預測氣候變遷對果樹栽培的影響？

1. 基於科學數據的管理。
   - 1.1. 過去：收集、整理、分析、研判數據。
   - 1.2. 未來：援用或創建適當模型 (modeling)(含氣候模型)，探討和過去狀況與數據符合度；選用各種情境，預測爾後可能反應；並依據將來實際狀況，不斷修飾模型，重新預測，持續精進。
   - 1.3. 基於需要，雖果樹生育過程較複雜，但仍可參考農藝作物生長模型研究成果，進行相關研究 (van Diepen *et al*., 1989; Luedeling *et al*., 2009; White *et al*., 2011; Yao *et al*., 2011; Ramirez-Villegas *et al*., 2013; Fraga *et al*., 2016; Iizumi *et al*., 2018; DeJong, 2019; Bai *et al*., 2019; Das and Sharma, 2020)。

2. 學門整合、科技整合，經由電腦普及，借助大數據與機械學習，加速模型運算。

氣候變遷對果樹生育的影響

1. 氣候變暖或有利農業生產，其地帶多屬高緯度地區，如歐洲北部，但南部則風險增加，尤其高溫和缺水逆境；但也必須考慮探討的尺度及地域 (Iglesias *et al*., 2012; Ponti *et al*., 2014)。
2. 不同時期之氣候逆境對於果樹不同生育階段有不同意義，尤其是高溫逆境，又會對病 - 蟲 - 雜草產生複雜效應。因此需投資於氣候與環境之監測，闡明逆境對果樹生育的影響，開發中國家更需如此 (Thornton *et al*., 2014)。
3. 暖化改變多種果樹物候期，造成落葉果樹低溫需求不足、果樹產量降低、果實品質變劣與病蟲害威脅增加等。應加強區域性調適研究以盡量降低高溫和熱浪風險，提升對缺水與乾旱的適應，鼓勵多方面利益關係人的參與、對話和資訊推廣等 (Pathak *et al*., 2018)。果樹為長年性作物，如美國加州利用適當的氣候與作物模式預估氣候對果樹生產的影響，進而結合氣候學與相關農業科技設法因應 (Lobell *et al*., 2006)。
4. 日本果樹栽培已受到暖化影響，如提早萌芽、提早採收、延遲著色，改變病蟲害狀態、增加或減少凍害、增加晚霜危害、果實酸度和澀度降低和果肉較軟等 (Sugiura, 2010; Sugiura *et al*., 2012; Sugiura *et al*., 2013; Shinomiya *et al*., 2015; Sugiura, 2019)。
5. 澳洲仁果類產區將因日漸升溫而轉到較涼產區，目前遭遇熱浪高溫導致果實日燒，需要降溫保護果實 (Thomson *et al*., 2014)。
6. 南非蘋果和梨在 1973-2009 年間，氣溫每 10 年增加 0.45℃，盛花期也提早 1.6 天 (Grab and Craparo, 2011)；Western Cape 地區溫度已漸升，預測未來 30 年會再升 1-2℃，冬雨減少。將影響低溫需求，干擾生殖過程，增加果實日燒，著色不良，乾旱逆境風險提高 (Wand *et al*., 2008)。
7. 智利落葉果樹低溫需求，北部地區將漸不足，南部尚可，中部地區預計 2050

年代減少 10-15 chilling portions。另外，晚霜將減少。目前北部栽培低需冷的鮮食葡萄和杏仁生產將受影響 (Fernandez *et al*., 2020)。

8. 美國東南地區之不同低溫需求桃子品種，低溫需求高者預計在 21 世紀中期已無法滿足，如喬治亞州有 40% 品種不適宜 (Parker and Abatzoglou, 2019)。加州中央谷地果樹產區 1950-2010 年間，每 10 年減少 40 低溫小時 (chilling hours)，到 21 世紀末，僅剩 500 低溫小時，將不利落葉果樹生產 (Baldocchi and Wong, 2008)。不過，德國之較高緯度地區，利用各種低溫模型預測多種溫帶果樹將提前萌芽、展葉 (Chmielewski *et al*., 2012)。
9. 英國喬木性果樹可能因低溫需求不足而限制生產；而漿果類除此外，尚缺水源，必須限水灌溉 (Else and Atkinson, 2010)。
10. 西班牙果樹產區 21 世紀後期無法滿足落葉果樹低溫需求 (Funes *et al*., 2016; Rodríguez *et al*., 2021)。升溫 (模擬 21 世紀末，提高 6℃) 情境下，西班牙之草莓將提早生產，但作物生產週期縮短，總產量也降低 (Palencia *et al*., 2009)。
11. 葡萄牙分析 1981-2015 年與預測 2041-2070 年之 growing degree hours 與 chilling portions。大部分地區熱累積 (heat accumulation) 增加而低溫累積 (chill accumulation) 降低，進而評估對 8 種果樹分布的影響，希望有助於對氣候變遷之因應 (Santos *et al*., 2017)。
12. 落葉果樹萌芽、開花時間受到低溫累積與熱累積的影響。該等果樹一旦進入休眠 (所謂內生休眠 endodormancy)，須經歷足夠的低溫累積，才能於春天萌芽。又縱使已經滿足低溫需求，該芽體可能仍處於氣溫較低、不利萌芽的內生休眠狀態，必須獲得足夠的熱累積 (或所謂的 forcing) 後才能發芽或開花。暖化可能造成低溫累積降低、熱累積增加，調查蘋果在西歐 (7 處) 與 3 個較溫和地區 (北摩洛哥 1 處、南巴西 2 處) 物候期。開花日期 (flowering date) 在大部分西歐及摩洛哥都提前，而巴西與法國則維持不變。雖然無論何地，其開花期間 (flowering duration) 都維持不變，但暖溫帶地區均較溫帶地區為長。顯示隨著暖化，相對於溫帶，暖溫帶地區低溫需求漸漸不足，導

致開花較晚，花期也較長 (Legave *et al*., 2015)。面對暖化，位在寒冷冬天的中國大陸北京，其低溫累積可滿足打破休眠的低溫需求，而春天之熱累積可能因暖化而受到促進，因此，板栗開花早晚受制於熱累積速率；位在溫帶氣候的德國 Klein-Altendorf 地區，櫻桃開花早晚則受制於低溫累積與熱累積兩者的速率；相反地，位於溫和冬天的美國加州，核桃之展葉則較受制於低溫的累積速率 (Luedeling *et al*., 2013)。

13. 中國大陸陝西咸陽蘋果產區溫度升高、降水與日照時數減少，物候期提前，暖冬導致病害孢子、蟲卵越冬基數提高；降水減少造成旱災發生頻繁，高溫果實熱害，低溫霜凍不利開花著果及幼果生長 (馬等，2011)。
14. 中國大陸為桃子原產地，約有 600 個品系 (俞等，2019)，低溫需求介於 200-1,200 小時，大部分品種介於 200-900 小時。河南鄭州 1983-2012 年間每 10 年減少 85 冷單位 (CU)，每升 1℃，冬天減少 121 CU。鄭州春季提早來到，而秋季延遲結束，導致生長季延長。過去 30 年間，桃子開花日期提早 11.1 天，落葉延遲 8.7 天，導致生長季延長 19.8 天。每 10 年溫度升 0.67℃。相對地，若冬季低溫不足，則開花日期推遲 (Li *et al*., 2016b)；冬天低溫不足，桃子延緩開花，而且果實較長、較尖 (Li *et al*., 2016a)。
15. 釀酒葡萄注重風土 (Terroir)。法國 Alsace 地區 ‘Riesling’ 品種在過去 70 年來，各物候期提早日數 : 萌芽 10 天，開花 23 天，果實變換期 39 天，採收 25 天 (van Leeuwen *et al*., 2019)。波爾多地區 1952-1997 年間各物候期都提前，物候期間多縮短，但生長期延長。‘Merlot’ 和 ‘Cabernet Sauvignon’ 糖酸比提高 (酸度降低顯著)，果重增加，釀酒品質提高 (Jones and Davis, 2000)。以 1600-2007 年較長期觀察，法國、瑞士等西歐地區釀酒葡萄在過去較早年代若提早採收，均為春夏高溫伴隨乾旱；但 1981-2007 年提早採收，卻僅由溫室氣體濃度提升所引發的高溫即可達成，顯示近年早收原因，乾旱已和升溫脫鉤 (Cook and Wolkovich, 2016)。歐洲地區推估萌芽、開花、果實成熟、採收等物候期均提早；南部地區缺水乾旱將日益嚴重，勢必降低產量，又提早成熟，品質降低；相反地，北部地區則可能因暖化提高產量 (Fraga *et al*., 2016)。

西歐和中歐之高品質釀酒葡萄將向北推移 (Cardel *et al*., 2019)。澳洲釀酒葡萄一些栽培地區的低溫需求不足，萌芽延遲；從萌芽到採收日數縮短，進而影響品質 (Webb *et al*., 2007)。

16. 印度之仁果類與核果類提早萌芽開花，溫度提高，柑橘、葡萄提早成熟，草莓走莖增加，果實減少，高溫多濕促進蘋果、杏子、櫻桃日燒或裂果，高溫促進荔枝裂果，缺水、高溫不利香蕉生長；蘋果生產總產量雖增加，但每公頃產量卻由 10.8 降到 5.8 公噸 (Datta, 2013)。喜馬拉雅山脈暖化速率較全球高 2-3 倍，冰河退縮，季風雨季 (monsoon) 前乾旱將更嚴重。遺憾當地居民排碳量不高，卻須承受高碳暖化之害 (Singh and Gumber, 2018)。印度之蘋果多栽於喜馬拉雅山脈之 Himachal Pradesh 1,500-3,000 公尺海拔山區，為排名第 6 果樹，1963-2007 年間，降雪少了，最高溫和最低溫分別增加 0.58℃和 2.75℃。多數品種需要 1,000-1,600 小時低溫，低溫需求不足，面積減少，單產降低；灌溉水缺乏，蒸發散速率提高，樹體致死率增加 (Singh *et al*., 2016)。
17. 低溫和土壤適度乾旱裨益常綠果樹花芽形成，若氣溫或雨量失常，則無法開花或調節產期；開花期遭遇寒流或陰雨不利昆蟲授粉，著果不良；幼果生長期遭遇乾旱容易落果，或果實生長不佳。芒果低於 17℃，花粉發育不良，低溫不利兩性花形成；氣溫影響營養抽梢頻率，高溫多雨助於抽梢，而不利花芽形成 (Rajan, 2012)。
18. 二氧化碳濃度增加，柑橘光合作用增強，可以部分抵消其他逆境的不良反應，不過，適當質、量的灌溉水將是柑橘業發展的瓶頸。選育耐乾旱、鹽化、淹水、高溫、低溫和能有效利用二氧化碳的品系 (Vincent *et al*., 2020)。為了因應未來增加的灌溉需要，西班牙安達盧西亞柑橘產區利用土壤、水分、大氣條件和植物模型，模擬 2008 年調節限水灌溉園，進而預估氣候變遷 2050 年和 2080 年之需水增加量，分別增加 6% 和 16%(Martínez-Ferri *et al*., 2013)。
19. 美國佛羅里達州曾為世界最大甜橙濃縮汁產區，因接連凍害與颶風導致該產

業競爭力降低 (Miller and Glantz, 1988 ; Ferrarezi *et al*., 2020)。

20. 鳳果 (mangosteen) 須一段乾旱助於花芽形成，而裨益產期調節，但泰國南部 2010 年經長期乾旱後緊接於夏季 6-7 月降雨，導致抽梢而無法產調，即氣候變遷影響鳳果物候期與開花 (Apiratikorn *et al*., 2012)。
21. 泰國之龍眼產期調節，在新梢或花穗生長初期碰到「熱風」，新梢生長受阻，爾後花芽形成率減少 80%；所形成的花穗亦無法順利開花 (Pichakum *et al*., 2020)。
22. 高溫、淹水、颶風、冰雹與霜害造成澳洲芒果、鳳梨和荔枝的中度減產 (Haque *et al*., 2020)。中國大陸熱帶果樹遭遇氣候異常，如氣溫和雨量變動懸殊、乾旱或颱風頻率高、暖冬、寒冬或寒春等 (Chen, 2012)。
23. 分析 27 個國家 (佔 86% 世界總產量) 自 1986 年以來之香蕉產量變化。每年平均增產 1.37 $ton·ha^{-1}$，爾後則依不同氣候變化情境，預測 2050 年將降至 0.59 與 0.19 $ton·ha^{-1}$。其中馬來西亞、巴拿馬、尼加拉瓜、巴西和哥倫比亞為高風險區，而印度、中國、拉丁美洲、澳洲、印尼和菲律賓為「可適應」區，大部分非洲、厄瓜多爾與宏都拉斯則為「得利」區。但本分析並未考慮極端天氣或所導致引發的病害 (Varma and Bebber, 2019)。因變得較熱、較乾，中美洲及南美洲之西北地區預測 2060 年將有 50% 土地不再適合栽培香蕉，香蕉栽培預計減少 19%，但墨西哥栽培面積將增加 (Machovina and Feeley, 2013)。印度之香蕉產業也將遭遇缺水和高溫問題，葉斑病將更嚴重 (Ravi and Mustaffa, 2013)。以 Global Environmental Stratification(GEnS) 分析預測尼泊爾地區香蕉栽培，隨氣溫提升，2050 年適宜栽培面積增加 40%，並希望能和咖啡混合栽培 (Ranjitkar *et al*., 2016)。
24. 隨氣候變遷，紅龍果在中美洲生可望增加生產 (Sosa *et al*., 2020)。
25. 病害：氣候變遷不僅改變病原菌發育階段與速率，也改變寄主抗病性，進而改變病原菌和寄主間交互作用之生理 (Coakley *et al*., 1999)。無可避免地，氣候變遷影響植物病害導致的損失、病害管理策略和病原的地理分佈 (Chakraborty *et al*., 2000)。

26. 氣候變遷影響土壤有機質含量，尤以表層土壤為然；必須設法提高農田碳儲匯，尤其是較底層土壤 (Albaladejo *et al*., 2013)。

果樹栽培對氣候變遷之適應(adaptation)方式-容忍

1. 妥善利用 BBCH(Biologische Bundesanstalt, Bundessortenamt and CHemische Industrie) 調查因氣候變遷造成果樹物候期的改變 (Rajan *et al*., 2013)。
2. 加強配合長期氣候變遷與極端天氣變化研究與相關災害風險評估，闡明上述變化或災害對果樹生育的可能影響 (Thornton *et al*., 2014)。
3. 果樹物候期隨著暖化而變化，必須研發適當模型並加以長期追蹤，進而研討遺傳與環境因子對於物候表現的影響 (Atauri *et al*., 2017)。亦即研發適當的影響評估模擬模型 (simulation models for impact assessment)，預測和推估氣候變遷對果樹生育可能影響，進而就地策劃氣候智慧 (climate-smart) 果樹栽培。果樹近年來雖開始有相關物候模型研究，但仍少有將打破休眠模型整合成果樹作物模型，而此乃果樹如何面對氣候變遷所亟需 (DeJong, 2019)。作物生長模型 (crop modeling) 主要從一年生作物發展出來，並已融合於氣象變遷研究 (Fodor *et al*., 2017)。其中 WOFOST(van Diepen *et al*., 1989) 已使用 30 年，最近試用於棗子不同灌溉量的生長研究 (Bai *et al*., 2019)。總之，藉由人工智慧、大數據和機械學習，有效整合作物遺傳、生理和對環境的複雜性，冀能妥善因應氣候變遷 (Langensiepen *et al*., 2020)。
4. 利用作物模擬模型，聯結基因型和在不同環境下之表現型，進而協助果樹理想品種的選育 (Parent and Tardieu, 2014; Rötter *et al*., 2015)；面對暖化，為正確時間打破休眠與開花，整合物候、遺傳、分子與氣候資訊等進行理想型 (ideotype) 設計與標誌輔助 (marker-assisted) 作物品種選育 (Wenden and Mariadassou, 2017)。利用生理生態之作物模型幫助理想型品種選育，即將基因或數量性狀基因座 (quantitative trait locus, QTL) 納入生理生態模型，評估在多種不同環境下之表現 (Martres *et al*., 2015)。為了選育適應高溫、缺水與生物逆境品種，首須鑑定出關鍵基因，進而利用標誌輔助選種與育種

(Gogorcena *et al*., 2020)。如利用簡單重複序列 (simple sequence repeat, SSR) 標誌檢定 14 個東方李子地方品系，從偵測的 118 個基因中至少有 26 個基因與果實品質、植物生育和逆境抗性有關，有助於抗逆境育種 (Acuña *et al*., 2019)。最近出版之 Genomic Designing of Climate-Smart Fruit Crops 一書，針對杏仁、蘋果、杏子、香蕉、櫻桃、柑橘、可可椰子、葡萄、桃子及薔薇科漿果類等果樹，說明藉由分子輔助育種或基因體設計，冀能對變遷的氣候智慧應對或富韌性 (climate-smart or climte-resilient)(Kole, 2020)。

5. 落葉果樹低溫需求不足。

5.1. 如何評估果樹低溫需求？在人為控溫環境如何評估低溫需求？雖一般多用 50% 萌芽，但建議如甜櫻桃高達 90% 萌芽才不至於低估 (Campoy *et al*., 2019)。美國加州中央谷地利用 4 種模型 (Chilling Hours, Utah, Positive Utah 與 Dynamic models)，依據 1950 年與 2000 年低溫時數預測 2041-2060 年低溫狀況，依模型的不同，低溫時數減少 14-33% 間，不過，強調選別適當低溫模型的重要性 (Luedeling *et al*., 2009)。澳洲利用 4 種低溫需求累積計算模型探討溫帶果樹主要產區過去 100 年低溫累積之趨勢，顯示均減少。強調須利用多種模型估算，以免失準 (Darbyshire *et al*., 2011)。各模型間無法換算；若使用的低溫模型不準確，則預測失準，建議比較全球使用的各種冬天低溫模型 (chill models) 相容性 (Luedeling and Brown, 2011)，又應共同研擬較佳能讓大家普遍接受的低溫累積與休眠模型 (chilling accumulation and dormancy models)，俾利由數量上探討因應計畫 (Luedeling, 2012)。亦即如仁果類利用不同的開花模型預測盛花期，所選用的低溫需求預測應更符合所對應的生理過程 (Darbyshire *et al*., 2014)。

5.2. 落葉果樹休眠低溫需求不足，萌芽延遲、萌芽率低、開花和展葉不整齊及花芽脫落等。可採用熱帶或亞熱帶地區栽培落葉果樹的作法，如選用低需冷性品種、利用化學藥劑打破休眠、冬季灌溉干擾、除葉及雙遍修剪等 (Pio *et al*., 2019)。不過，最好能選育較低低溫需求品種。若高日溫

阻礙萌芽，可用樹頂噴水及遮陰之栽培技術；或利用化學藥劑：硝酸鉀、hydrogen cyanamide、thidiazuron([TDZ] N-phenyl-N-1,2,3-thiodiazol-5-yl-urea) 與礦物油混施等。另外，熱帶地區栽培低需冷性品種，可配合休眠逃避 (dormancy avoidance)，在尚未進入內生休眠前，予以完全除葉，促進萌芽而持續生長。隨氣候暖化，落葉果樹分佈雖可往較高緯度或海拔地區移動，但對於現有產區 (尤其是暖溫帶) 不利，花期不一，導致授粉樹授粉困難。對暖溫帶地區，選育較低低溫需求品種配合休眠打破藥劑乃是上策 (Campoy *et al*., 2011)。

5.3. 以櫻桃為例，首次利用碳水化合物、水分狀態、溫度及低溫時數區分休眠不同階段 (Kaufmann and Blanke, 2017)。*Prunus* 屬中桃子、杏子與甜櫻桃之開花和果實成熟期由遺傳決定，覓得數個 QTL，它們不受氣候變異影響，因此可用來選育適應爾後氣候變遷理想型之選育 (Dirlewanger *et al*., 2012)。如甜櫻桃開花日期之物候特性受到低溫需求和熱需求的影響，其中低溫需求受遺傳基因控制，而熱需求則呈現遺傳 × 環境作用，經由此研究可進而研發適應氣候變遷之理想型 (Castède *et al*., 2014)。希望能覓得耐逆境之關鍵基因，進而利用標誌桃子選種與育種 (Gogorcena *et al*., 2020)。

6. 設法闡明熱帶和亞熱帶果樹低溫、乾旱促進開花的機制，進而促進開花：如設法闡明乾旱與低溫促進荔枝開花的分子學機制 (Shen *et al*., 2016; Lu *et al*., 2017; Wang *et al*., 2017)。

7. 設法減少高溫、強光、乾旱等逆境。

7.1. 日本果樹產業適應策略：第一階段忍受高溫 (如疏果、環刻、遮網)；第二階段選擇品種與育種 (‘Kinshu’ 和 ‘Beniminori’ 蘋果，‘Morinokagayaki’ 黃蘋果，無著色問題；‘Queen Nina’ 和 ‘Gross Krone’ 葡萄；‘ 不知火 ’、‘ 瀨戶香 ’；‘Harehime’ 和 ‘Mihaya’ 柑橘品種)；第三階段栽培地區遷移 (蘋果、桶柑) (Sugiura, 2019)。

7.2. 美國加州果樹遭受熱或高溫之害：灌溉、栽培地管理 (如草生栽培、遮

陰網、葡萄園東北 - 西南走向和改變園籬式樣增加遮陰、重找栽培地)、品種選育 (低需冷、抗旱鹽根砧、野生品種收集分類與利用如美國農部農業研究服務網的種源庫 (USDA Agricultural Research Service germplasm repositories, USDA ARS)(Parker *et al*., 2020)。

7.3. 澳洲仁果類產區將遭遇熱浪高溫導致果實日燒，需要降溫並保護果實。如考慮栽培行向、設法增加保護果實的葉片、遮網、噴灑黏土基質材料、樹冠頂端噴水等 (Thomson *et al*., 2014)。

7.4. 釀酒葡萄：高溫，建議選用促進晚熟的砧木、選用晚熟性品種或品系，改變栽培方式如增加主幹高度、減少葉 / 果比、拖延修剪時間、遷移到較高緯度產區等，俾確保如往常季節採收。乾旱：耐旱植物材料，改變整枝系統 (如 goblet or bush vines，園籬式整枝系統行間加大)，選用含水量較高的土壤、採限水滴灌等 (van Leeuwen *et al*., 2019)。

7.5. 熱帶果樹 (如芒果)：溫度可能升到灼熱程度，乾旱也較嚴重，淹水、鹽害加重，颶風增多；高溫促進間歇性抽梢，頻率提高，枝梢停止延緩；果實生長速率提高。可移往較適宜地區生產，研究逆境生理如高溫、乾旱、光和鹽害，品種選育，耐高溫、乾旱及強光等，並可在較高溫度開花，根砧篩選，加速研發初期表現型方法 (early phenotyping methods)；果園管理改善，如灌溉、調控樹冠和開花、創造適合生育的微氣候等，研發芒果作物模型 (mango crop model) 等 (Normand *et al*., 2015)。

8. 降低低溫、霜害等低溫傷害。

8.1. 蘋果園為防晚霜，樹冠上部噴灌，試著利用野生蜂協助授粉，雖殺草劑仍盛行，但試著利用鋸木屑或植物性堆肥覆蓋，頂覆防冰雹之細網，因細網遮陰，不利著色，披覆反光材料 (Solomakhin and Blanke, 2007; Blanke, 2008)。在防冰雹網之蘋果園內，採收前 4-5 週地面鋪設反光材料，促進果實著色 (Meinhold *et al*., 2011)。'Jonathan' 蘋果採後，經 450 nm 波長藍光照射 4 天，花青素顯著提高，而 ' 富士 ' 效果低 (Arakawa *et al*., 2016)。

8.2. 加拿大東部果樹產區於 21 世紀中期預計升溫 2-6℃。秋天早霜將遲緩降臨約 16 天，春天最後一次晚霜將提早 15 天結束；早霜減少，仲冬凍害亦較少；雖然仍會碰到冬天融雪，導致耐寒性降低易罹極端冷凍之害。暖化，不僅可在目前產區添加新品種或種類，也可往北推進 (Rochette *et al*., 2004)。

8.3. 美國加州杏仁、酪梨、甜橙因暖化降低霜害頻率，進而減少防霜噴灌所需用水 (Parker *et al*., 2021)。

9. 探討氣候智慧型作物 (Climate-smart crops)：如印度建議 phalsa、pumello、bael、wood apple、aonla、karonda、barbados cherry、紅龍果、石榴與無花果等可適應變遷氣候環境 (Mani and Suresh, 2018)，西班牙乾旱或半乾旱地區建議栽培刺梨 (*Opuntia*)(Andreu-Coll *et al*., 2020)。

10. 改變果樹栽培方式如更換整枝修剪模式，改善樹冠架構、設施栽培、混合栽培、高密度栽培等，藉以改變果園微氣候；果園覆蓋、草生栽培、施用有機肥、土壤保育等，俾減少土壤流失並增加土壤有機質。

11. 草莓除了原有短日 ‘June bearing’ 品種外，經由中日性終年結果、低需冷性品種選育、利用穴植苗木、塑膠棚架及溫室等手段，在變遷氣候挑戰下，仍能滿足歐洲全年需求 (Neri *et al*., 2012)。

12. 就地貯存降雨或開發水源 (Pandey *et al*., 2003)，循環利用都市廢水。計算果園水足跡 (Bazrafshan *et al*., 2019)，改善灌溉系統，進行節水灌溉或限水灌溉 (Dichio *et al*., 2011; Campi *et al*., 2020)。儀器測量水勢配合電腦控制，調節性限水灌溉 (regulated deficit irrigation, RDI) 能有效控制營養生長但不影響果實產量 (Fereres and Soriano, 2007)，釀酒葡萄效果明顯 (Chaves *et al*., 2010)。除了 RDI，更因地理資訊系統 (geographic information system, GIS) 與全球定位系統 (global positioning system, GPS) 的發展，研發精準灌溉 (precision irrigation)；加上物聯網 (Internet of Things, IoT) 的推廣，可進行遠端遙控。但須先明瞭作物水分狀態，方能決定灌溉時程，但量測植物水分狀態 (如莖部水勢、樹幹汁液流動、樹幹伸縮、葉片膨壓等) 儀器昂貴，果

農難負擔 (Fernández *et al.*, 2019)。不過，蘋果園嘗試利用水平衡方程式配合導電容量型土壤水分感測器自動校準程式 (an automated algorithm of water balance tuned by capacitance-type soil moisture sensors)，能達到滿意自動排程灌溉效果 (Domínguez-Niño *et al.*, 2020)。

13. 進行果園綜合營養管理：如水和氮肥為柑橘產量之二個限制因子，分析 11 個國家 55 個研究，中位數 (median) 產量 30-60 ton·ha^{-1}，全球平均產量 10-30 ton·ha^{-1}；中位數之水分利用率 (WUE) 2.5-5 kg·m^{-3}，中位數之氮利用率 (NUE) 150-350 kg·kg^{-1}。分析若減少超用水量，仍能提升產量 20%、WUE30%、NUE15%，同樣地，減少施用過量氮肥，仍能提升產量 10%、WUE15%、NUE40%。亦即經由經由精準肥灌，同時考慮水和氮肥施用的最佳化，仍能增加產量、WUE 和 NUE(Qin *et al.*, 2016)。
14. 依據適地適種原則，進行果樹產區遷移規劃。隨氣候暖化，如 'Hayward' 奇異果在紐西蘭主要產區 Te Puke，預計於 21 世紀末期冬天低溫已不敷需求，但其他地區可漸符合所需 (Tait *et al.*, 2018)。21 世紀中期，美國加州中央谷地不利杏仁果實生長，可轉往奧勒岡州西部之 Willamette 谷地 (Parker and Abatzoglou, 2018)。厄瓜多爾到 21 世紀末期氣溫可能提升 3.3℃，雨量增加，冰河緩衝降低，可能造成洪災，須移往約高 500 公尺山地栽培，屆時勢必伐林，而原來不適合栽培地點必須造林，以緩和氣候變遷 (FAO, 2016)。
15. 普遍設立即時、準確氣候 (天災) 預報系統服務農民。如 USDA Climate Hubs (https://www.climatehubs.usda.gov/) 設立數個地區性 Climate Hubs，提供及時相關氣象災害預警，提供農民因應氣候變遷之相關決策，希能減少損失。
16. 開辦合理可行之作物或農業保險，降低農民災害損失等。

    氣候變遷加劇，作物保險愈顯需要；保險可減少災害風險；不過，農場作物多樣化可減少災害風險，甚可取代保險 (Falco *et. al.*, 2014)。依據聯合國氣候變遷綱要公約 (the United Nations Framework Convention on Climate Change) 條款 4.8，建議成員國考慮利用保險作為適應氣候變遷的工具，如

開發中國家，不僅須設立保險機構或組織，也須設立可信的災害風險管理制度 (Linnerooth-Bayer and Mechler, 2006)。擬籌措該保險制度之開發中國家可能遭遇各種挑戰 (Alam *et al*., 2020)。印度農業保險雖已開辦近 20 年，但運作仍受訾議，因其利益未讓多數農民均霑 (Singh *et al*., 2020)。

保險制度若設計得宜，當可提升對氣候變遷的韌性。不過，應將保險當做適應策略之一，而非與適應分離或甚至取代適應；對各種災害風險予以詳細、確實評估，實施公正而有效，否則保險形同補助，喪失降低風險的本意，反而減弱農民適應氣候變遷的能力 (Surminski *et al*., 2016) 或同時降低創新的原動力 (Miao, 2020)。有建議農業保險乃是針對全場，而不僅單對作物 (Ames and Dufour, 2014)。另外，氣候變遷帶來的災害日增，雖增加保險業者機會，但也增加如荷蘭保險公司對淹水與強降雨引起的經濟損失 (Botzen *et al*., 2010)。

果樹栽培對氣候變遷之緩和(mitigation)方式-防止或延緩

1. 有效管理與利用自然資源，果園操作節能減碳：配合機械化、自動化和智慧農業，合理、精準使用非再生能源，充分使用再生性能源，資源盡可能循環利用。
2. 土壤保育，加強果園碳儲匯功能。

果園具有緩和氣候變遷的功能，以西洋橄欖為例，每年果樹生質固定 0.36-2.78 $tonCO_2 \cdot ha^{-1}$，土壤約 8.5 公噸。土壤碳復可提升增加孔隙度、滲水能力與減少土壤沖蝕 (Montanaro *et al*., 2018)。為因應氣候變遷，土壤成為全球性碳循環之重要議題 (Amelung *et al*., 2020)。由於水文循環隨氣候變遷將更為劇烈，預測全世界土壤被水沖蝕增加 30-66%(Borrelli *et al*., 2020)。土壤沖蝕對全球碳循環產生很大衝擊，並成為大氣 CO_2、CH_4、N_2O 來源；應防止土壤衝蝕，並予以保育 (Lal, 2019)。利用再生型農業模式增加土壤有機質含量，促進養分循環，俾增加土壤對氣候變遷的韌性 (Lal, 2014; Lal, 2020a; Lal, 2020b)。

地中海地區受氣候變遷衝擊高 (Cramer *et al.*, 2018)，發生季節性乾旱，土壤有機質含量低；保育性耕犁與外加有機質可增加土壤碳儲匯 (Aguilera *et al.*, 2013; Morugán-Coronado *et al.*, 2020)。西班牙地中海氣候區之果園進行草生栽培，最初 20 年可增 0.44 百萬 $gC \cdot yr^{-1} \cdot ha^{-1}$，外部添加都市有機廢棄物可增 0.09 百萬 $gC \cdot yr^{-1} \cdot ha^{-1}$，外部添加都市有機廢物和農業有機堆肥可增 0.13 百萬 $gC \cdot yr^{-1} \cdot ha^{-1}$；動物廄肥進行沼氣無氧發酵或製作堆肥，可減少 4.3(無氧) 與 1.1(堆肥化) $TgCO_2 \cdot yr^{-1}$ 相當等量之排放 (Pardo *et al.*, 2017)。地中海地區果園經由減少或不耕犁、草生栽培、枝條回田、增施有機肥等提升土壤有機碳存量 (Montanaro *et al.*, 2017)。希臘之西洋橄欖園添加有機堆肥、枝條與榨油後果渣回田可提升土壤碳儲匯，減少碳足跡；合理每年修剪，可調控營養和生殖生長 (Michalopoulos *et al.*, 2020)。義大利 (地中海氣候) 桃子園嘗試利用零耕犁、割草、保留地上部殘留與添加有機物等較永續性管理，雖增加土壤 CO_2 釋放量，但提升土壤有機碳量 (Montanaro *et al.*, 2012)，有效增加碳帳 (730 $gC \cdot m^{-2} \cdot yr^{-1}$ 對 90 $gC \cdot m^{-2} \cdot yr^{-1}$) (Montanaro *et al.*, 2017)。中國大陸廣州亞熱帶果園種草 10 年，地表 1 公尺土壤碳儲匯增加 2.85 $ton \cdot ha^{-1}$(Liu *et al.*, 2013)。柑橘園種草覆蓋有效減少強降雨對土壤的沖刷 (Duan *et al.*, 2020)。美國農部設立草生栽培與土壤健康 (Cover Crops and Soil Health) 服務網站供參 (https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/climatechange/?cid=stelprdb1077238)。

3. 以農業生態原則設計對氣候變遷具有韌性的農業生產系統 (climate-resilient farming systems)。縱使改變單一栽培 (monoculture)，也僅能短暫治標，根本之道乃在設法建立農民和農村的韌性。方法：建立農業生態系統的多樣性，如多樣化栽培、農林栽培 (agroforestry)、種養結合等，並結合土壤有機管理、水源保育及匯集與農業生物多樣性等 (Altieri *et al.*, 2015)。中國大陸陝西渭北高原澄城縣東馬店村的五配套生態果園模式 - 沼氣子系統、太陽能暖圈子系統、集水貯水子系統、節灌保墒子系統以及蘋果種植子系統 (張等，2018)。熱帶地區糊口農業 (subsistence agriculture) 之小農對氣候變遷適應力低，而農

林栽培值得採用 (Verchot *et al.*, 2007)；因其可更有效利用水資源，改善微氣候，提升養分循環與土壤生產力，控制病蟲害，改善農場生產力，在儲匯碳同時，也助於農場財務收入和多樣化 (Lasco *et al.*, 2014)。氣候變遷下，越南穀類生產威脅大，可鼓勵多用途家庭農林混種園 (Nguyen *et al.*, 2013)。農林混種又可增加碳源，改善土壤肥力和當地氣候 (Mbow *et al.*, 2014)。縱使單一栽培園相普遍如歐洲者，仍鼓勵農林栽培 (Eichhor *et al.*, 2006)。不過，初建農林混合栽培制度，需重新考量園相，以蘋果為例，其樹形原多以單一作物高密度果園設計，一旦擬成混合體系，必須在植物種類、樹體結構等重新思量 (Lauri, 2019)。有關農業生態設計，可參考聯合國糧農組織的 Agroecology Knowledge Hub(http://www.fao.org/climate-change/programmes-and-projects/detail/en/c/461247/)，或 Climate-Smart Agriculture(http://www.fao.org/climate-smart-agriculture/en/)。

4. 提升與強調果園之生態系統服務 (ecosystem service) 功能：農業本身就具有碳匯功能，而不是源 (劉，1998)。果園本身充當碳儲匯、氣體交換和營養分之緩衝與過濾 (Clothier *et al.*, 2013)。蘋果樹體本身也為碳儲匯容器，中國大陸蘋果栽培面積 199 萬公頃，1990-2010 年間其所有蘋果園淨碳匯 (sink) 為 14-32 Tg，而碳以生質儲存者為 230-475 Tg，相當於中國大陸陸生生態系統淨碳總值之 4.5% (Wu *et al.*, 2012)。印度之所有芒果果園儲匯 285.005 百萬公噸碳 (Ganeshamurthy *et al.*, 2019)。地中海型氣候區的西洋橄欖果園一年碳交換淨值為 11.60-13.45 ton·ha^{-1}(Nardino *et al.*, 2013)。紐西蘭嘗試利用生命週期評估 (life cycle assessment, LCA) 進行碳足跡計算，以評估果園管理模式對溫室氣體的排放或儲匯的影響 (Page *et al.*, 2011)。園內多樣草生栽培 (10 種) 能減少土壤流失，並增加節肢動物族群和害蟲天敵 (Gómez *et al.*, 2018)。或認為僅添加有機肥無法長期展現土壤有機質功能，而主張變換成整合型土壤肥力管理 (Integrated Soil Fertility Management, ISFM))，包括微生物製劑 (生物肥料)、無機肥料與有機肥等，利用微生物之協同作用 (synergism) 形成微生物之集團 (consortium)，可以促進土壤健康，接近對氣候具有韌性之土壤肥

力管理 (Srivastava *et al.*, 2021)。總之，果園具有生態系統服務功能，如果實生產、氣候調節、土壤氮肥有效性、水文調節、病蟲害控制和授粉等，主要可以儲匯碳 2.4-12.5 tonC·ha^{-1}·yr^{-1}，也可維護生物多樣性，吾人需隨時檢視各種農業操作對該服務功能的影響 (Demestihas *et al.*, 2017)。

5. 有機栽培、生態栽培：西班牙地中海氣候區果園 (柑橘、葡萄、西洋橄欖等) 進行有機栽培，因草生栽培及修剪枝條回田，土壤碳儲匯增加；與慣行農法比較，溫室氣體釋放量以面積計，減少 56%，以產品計，減少 39%(Aguilera *et al.*, 2015)。降低滴灌頻率和覆蓋碎樹皮減少加拿大半乾旱地區蘋果園 N_2O 釋放量 (Fentabil *et al.*, 2016)。不過，與其選擇何種對環境健全的農耕系統，倒不如探討該系統對環境產生的影響來得重要，例如較低能源投入，水質生態中毒或污染、水質優氧化等 (Mouron *et al.*, 2006)。如在防冰雹蘋果園，為促進果實著色，以可重複利用的鋁箔或白色紡織品取代塑膠布，可減低溫室氣體釋放量 (Hess *et al.*, 2021)。
6. 計算果園生態效率 (eco-efficiency)、碳足跡等：提升果園生產生態效率，不僅減少對環境衝擊，還能獲利 (Müller *et al.*, 2015)。利用 ISO 14067:2018(Greenhouse gases -Carbon footprint of products - Requirements and guidelines for quantification) 計算與比較永續性與慣行農法經營果園之碳足跡 (Lardo *et al.*, 2018)。在杏子及桃子園施行不耕犁、修剪枝條覆蓋地面、草生栽培機械除草，每年施用 10 公噸堆肥。每年可減少 2.7 tonCO$_2$eq·ha^{-1}·yr^{-1}，大部分歸功於土壤碳儲存，建議可在義大利果園推廣，尤其堆肥製作 (Fiore *et al.*, 2018)。以 LCA 計算不同果實 (蘋果、梨、桃、橘子、香蕉) 生產過程碳足跡，投入方面，化學合成氮肥佔比超過 50% 之溫室氣體排放量 (Yan *et al.*, 2016)。另外，可用 LCA 計算果實從生產、運銷、消費到廢棄物處理過程之碳足跡 (Kilian *et al.*, 2012; Vinyes *et al.*, 2017)，並以之作為減少果園碳排 (Guo *et al.*, 2018) 或綠色行銷 (Peano *et al.*, 2015) 的依據。總之，計有 4 種常用的果園環境影響評估方式，即 LCA 評估、生態足跡分析 (Ecological Footprint Analysis)、能值分析 (Emergy Analysis) 及能量均衡 (Energy Balance)(Cerutti *et al.*, 2011)。美國農

業部 (USDA) 也公布碳管理評估工具 (Carbon Management Evaluation Tool, COMET-FARM)(http://comet-farm.com/)，希望幫助農民計算他們農地中的土壤和植被可移除多少大氣中的碳。為何如此費心於土壤碳儲匯或計算碳足跡？答曰：監測土壤碳量，將有助農友應付可能到來的「碳交易系統」(carbon trading system)(Suddick *et al.*, 2013)。無論是碳總量管制與交易制度 (cap and trade) 或是課徵碳稅 (carbon tax)，可能成為減緩全球暖化的有效工具（諾德豪斯，2019)。

國外相關作爲對臺灣果樹栽培的啓示

1. 臺灣地區過去 100 年暖化 1.0-1.4℃ (Hsu and Chen, 2002)，暖化速率遠高於全球同期平均之 0.3-0.6℃ (Weng, 2010)；若 CO_2 濃度提升到 1961-1990 年之 1.9 倍，相對於同期平均溫，預計氣溫提升 0.9-2.7℃ (Hsu and Chen, 2002)。另外，自 1901 年，臺灣地區的平均日照時數下降，日平均最高溫卻增加；而日較差 (diurnal temperature range, DTR) 則逐漸下降。所謂日較差係指白天最高溫 (T_{max}) 與夜晚最低溫 (T_{min}) 的差 (黃和翁，2011)。DTR 降低原因係 T_{min} 上升趨勢大於 T_{max} 上升趨勢 (Liu *et al.*, 2002；黃和翁，2011)。預測臺灣熱浪來襲頻率增多；熱浪期間，不僅 DTR 大、T_{min} 高，整個夜間溫度也高 (Kueh *et al.*, 2017)。
2. 過去 100 年間，臺灣中部 (Yu *et al.*, 2006)、南部 (Hsu and Chen, 2002; Yu *et al.*, 2006) 雨量漸減。1960-2010 年間，年總降雨量，臺灣西半部由北而南減少，而東部則由南往北呈現減少趨勢（鍾等，2009）。臺灣一年總降雨時數減少，但降雨強度增加，洪災嚴重 (Liu *et al.*, 2002)。亦即全臺年降雨天數逐年降低，導致降雨延時縮短、降雨集中、強度更強，使得瞬時暴雨量增大，而乾旱也將逐年嚴重 (鍾等，2009)。小雨發生頻率漸減而強降雨漸增；強降雨頻率增加，其降雨強度增加，延期亦較長，尤以颱風期為然 (Tu and Chou, 2013)。總之，預期臺灣洪災、逕流、土壤衝蝕、乾旱等將日益嚴重。
3. 臺灣跨處亞熱與熱帶氣候區，又山岳垂直高度懸殊，溫差大，熱帶、亞熱帶

與溫帶諸多果樹薈萃寶島。因應氣候暖化，或位移往更高海拔山區栽培；但山地土壤瘠薄，涵養肥水差，不僅不耐乾旱，若疏忽保育，反加速暴雨侵蝕土壤，得不償失。

4. 溫帶果樹休眠打破，亞熱帶或甚至熱帶果樹營養梢或花芽形成，均深受氣溫影響；建議妥善利用國際通用的 BBCH(Biologische Bundesanstalt, Bundessortenamt und CHemische Industrie)，逐年詳細調查因氣候變遷或暖化造成臺灣各類果樹物候期的改變，唯有如此，方能進一步思考因應策略。
5. 高溫雖可促進果實生長，果實較大，但果實酸度可能較低，而可溶性固形物不見得提高。日夜溫差大，助於果實成熟期碳水化合物之累積；高夜溫反而促進呼吸作用，加速有機酸代謝，不利可溶性固形物累積。高溫若加上土壤高濕、高肥，植株營養生長旺盛，果實品質易劣；又高溫加上強光，果實日燒可能較嚴重，上述推論有待在臺灣地區論證與確認，並予以改善。
6. 臺灣地區高溫、暴雨、乾旱、缺水等頻率將日益增加，唯有設法提高果樹的韌性才能克服該等逆境，除選育抗逆境品種外，應鼓勵果園土壤保育，阻止土壤流失，「有土斯有財」。草生栽培，果園生質回土，增施有機肥，提高土壤碳儲匯功能，改善土壤物理性、化學性和生物性。不僅減緩氣候變遷，還因增加土壤有機質，土壤孔隙度隨之提高，進而增加換氣率、滲水率，提高保水、保肥力。另外，增加貯水設施，改善節水灌溉等。如此，果樹根群生長不僅密度高，而且廣而深，當可提高韌性。
7. 果樹栽培或果園經營是一種系統性的管理科技，除了陸續選育抗逆境優良品種外，希能了解果樹在各種生態環境的生理活性，整合改善栽培管理，藉以適應或緩和氣候變遷。

結語與建議

1. 國外關於氣候變遷對果樹栽培影響之研究雖已進行多年，但氣候變遷隨經濟發展，仍如影隨形，影響層次將愈來愈廣而深。我們宜加強與改善逐一果樹產業對氣候變遷管理所需的知識和能力，就如澳洲對鳳梨釋迦 (custard apple)

產業的分析那般 (Deuter, 2011)。

2. 一般而言，愈靠近熱帶地區，氣候變遷對農業的衝擊將較廣、較深。但臺灣農業或水果產值佔全部經濟發展總值比例不高，面對氣候變遷衝擊，預計可撥用財力、物力不豐，勢必須集中有限資源做最有效運用。
3. 建議加強援用或創建適當作物生長模型，結合氣候預測模型，預測和推估氣候變遷對果樹生育可能影響，進而策劃因應措施。
4. 氣候變遷挑戰才剛開始，氣候變遷是動態的，而且還有太多的未知數，唯有抱著學習的態度，針對問題，依據數據、實證解決問題，估計機會與社會成本，提升投入效率與精確度，少做無謂的浪費 (Zilberman, 2018)，但應提升全民 (含果樹從業者) 因應氣候變遷的意識與準備。
5. 參照美國北加州釀酒葡萄園應對氣候變遷，或依個人經驗做短期或立即性調整，如改變栽培或釀酒方法，較容易操作而達成目標；但對較廣層次者，如品種改變，則須群策群力、個人和政府長期投入，以建立較可行的策略俾降低對氣候變遷的衝擊 (Nicholas and Durham, 2012)。
6. 因應氣候變遷，除考慮果樹育種、栽培等技術層面外，建議同時綜合各種社經因素做全面考量 (Jackson *et al*., 2011)。

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Climate change adaptation and mitigation on fruit production in foreign countries- a review

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Abstract

Increased emission of anthropogenic greenhouse gases hastens climate changes or global warming. Phenology, fruit yield and quality of various fruit crops in many foreign countries are affected or will be altered based on past studies and models of tree growth and climate with various scenario. For deciduous fruit trees in mild temperate regions, the dormant buds sprout unfavorably or exhibit extended flowering duration due to insufficient chilling accumulation. However, some other buds, once their chilling requirements are fulfilled, accelerate bursting in the early spring but may subject to late-frost injury owing to faster heat accumulation. Fruits generally mature earlier with inferior pigmentation. Wine grapes may be moved northward from southern Europe due to the detrimental effect of warming on prime wine quality. Cool temperature and drying soil are beneficial for the flower initiation of evergreen fruit crops. If not so, it is destined to the absence of flowers and futile for cropping-season adjustment. Confronting the warming climate it is anticipated that the tropical area will be more disastrous than the temperate region. It is imperative to enhance the resilience of fruit trees to adapt or mitigate climate change. The following strategies have been adopted: 1) Devising suitable models to predict and assess the possible impact of climate change on fruit crops; 2) Elucidating the roles of genetic and environmental factors on phenology, and the mechanism of tolerance to various stresses for facilitating ideotype selection; 3) Breeding low-chilling-requirement varieties for deciduous fruit crops and enhancing flower initiation for evergreen ones; 4) Improving meteorological

forecast system, reducing stresses to high temperature, strong light, and drought, alleviating injury to low temperature and frost; 5) Integrating cultivation methods such as modifying canopy structure or orchard microclimate, or cultivation under protection; 6) Adopting techniques of precision agriculture or artificial intelligence to manage and utilize renewable and nonrenewable resources more wisely; 7) Implementing orchards based on agricultural ecosystem to facilitate nutrient cycling and to protect soil from erosion; 8) Strengthening soil carbon sequestration by regenerative conservation farming; 9) Trying to mitigate and assessing greenhouse gas emission through carbon and water footprint and energy analysis; and 10) Re-evaluating the allocation of each fruit crop based on the principle of befitting place for befitting species or varieties.

Key words: Climate change, Warming, Adaptation, Mitigation, Deciduous fruit trees, Evergreen fruit trees, Phenology, Dormancy, Chilling, Flowering, Soil carbon Sequestration, Carbon footprint

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