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in

Kodad O. (ed.), López-Francos A. (ed.), Rovira M. (ed.), Socias i Company R. (ed.). XVI GREMPA Meeting on Almonds and Pistachios

Zaragoza : CIHEAM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 119

2016
pages 247-251

Climate change and vulnerability of the pistachio and almond crops in the Mediterranean arid areas

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Abstract. Almond and Pistachio are the most important nut crops in Tunisia. The main production areas are located in the central and southern part of the country, characterized by scarce precipitations and harsh environments. Low and highly variable yields are commonly observed under those conditions. Nut crops are reported to be vulnerable to temperature fluctuations and decreasing water availability. In this study, yield response of almond and pistachio to global warming is evaluated under the arid conditions of Tunisia. The approach is focussing on chilling and its incidence on yield, using various chilling accumulation models. On the basis of 35 years of daily climatic data (1980-2014), results show a declining trend in winter chill units. Pistachio yields varied between 0 and 35 kg/tree and were affected by chill accumulation. Yields for three almond cvs varied within similar ranges but seemed to be less affected by warm winters, whereas one variety seemed to be non responsive to chill conditions, probably because of high sensitivity to rainfall variations. With the prospects of global warming, increasing temperatures are expected to be detrimental to nut cultivation in arid Tunisia; unless efforts are deployed to grow the appropriate cultivars.

Keywords. Almond – Pistachio – Dry area – Winter chill – Precipitation.

Changement climatique et vulnérabilité des cultures d'amandier et du pistachier dans la région aride Méditerranéenne

Résumé. *Les cultures d'amandier et du pistachier occupent une place importante dans le système de production du centre et du sud tunisiens. Elles sont conduites en pluvial sous climat aride. Des rendements faibles et très variables ont été réalisés sous ces conditions sévères. Ces cultures ont été signalés être vulnérables aux fluctuations de température et à la diminution de la disponibilité en eau. L'évaluation des risques imposés par le changement climatique en particulier pour les cultures des régions marginales de la Tunisie centrale est d'un grand intérêt. Les rendements de l'amandier et du pistachier ont été évaluées par rapport aux variations de température et de précipitation. L'impact du froid hivernal a été analysé et différent modèles d'estimation du froid ont été utilisés. Les résultats d'analyses des données climatiques sur 35 ans (1980-2014) ont révélé une tendance décroissante de l'accumulation du froid. Les rendements du pistachier ont varié entre 0 et 35 kg/arbre et ont été affectés par le manque du froid. Les performances des variétés d'amandier ont varié dans les mêmes ordres de grandeur et semblaient peu affectées par les hivers doux, alors qu'une variété paraissait plutôt sensible aux variations des précipitations que des accumulations du froid. Avec les perspectives du réchauffement climatique, la hausse des températures pourrait limiter le développement des cultures des fruits secs; moins que des efforts seront déployés pour valoriser les ressources génétiques appropriées.*

Mots-clés. *Amandier – Pistachier – Région aride – Froid hivernal – Précipitation.*

I – Introduction

Observed increases in temperature and in precipitation variability, induced by global warming, are expected to have harmful effects on fruit trees, particularly in rain-fed agro-systems. Nut crops such as almond and pistachio are among the most important fruit species used to make important parts of dry lands productive. For instance these species are largely grown in the central and southern areas of Tunisia, where climate variability, drought and heat spells represent major constraints to developing intensive cropping systems.

Drought is known to be a significant environmental stress in agriculture, and many efforts are deployed to improve crop productivity under water scarcity. However, impacts of warm winter temperatures on fruit species in arid areas are less documented. Lack of chilling affects flowering and fruiting of many species (Campoy *et al*., 2011). Various models were developed to quantify the chilling accumulation and requirements (Weinberger, 1950; Crossa-Raynaud, 1955; Richardson *et al*., 1974; Fishman *et al*., 1987). Chilling hours (CH) under +7.2°C method was conventionally used to measure chilling for fruit trees (Weinberger, 1950; Crossa-Raynaud, 1955). Recently, the Dynamic model is considered to be suitable for warm areas (Elloumi *et al*., 2013; Ghrab *et al*., 2014).

In this study, attempts are made to assess risks imposed by global warming on the main nut crops grown in central part of Tunisia. The analysis concerns primarily the actual trends in winter chill accumulation and the impact on the yield of almond and pistachio cultivars.

II – Materials and methods

The almond and pistachio orchards used in the study belong to the experimental station of the Olive Institute, Taous (34°94'11", 10°60'82"). Located in Central Tunisia, the production area is characterized by deep sandy soils; annual precipitations of 204 mm and reference evapotranspiration (ET_o) of 1340 mm. The experimental orchards have been conducted during the experimental period (1980-2014) under rain-fed conditions without any supply of irrigation water or fertilizers. For pistachio, the most common local cultivar Mateur grafted on *Pistacia vera* rootstock and planted on a wide spacing (12 m x 12 m) is used. Whereas for almond, the local genotype Fekhfekh and three introduced cultivars 'Ferragnes', 'Ferraduel' and 'Tuono' are included in this work. Measurements of flowering and nut yield per individual trees were carried out routinely on all cultivars.

Climatic data, in terms of daily records of air temperature and precipitation, were obtained from a local weather station. Our calculations of chilling accumulation used an hourly interpolation function applied to daily maximum-minimum temperature data (Darbyshire *et al*., 2011). The Crossa-Raynaud's method (Crossa-Raynaud, 1955), the Utah model (Richardson *et al*., 1974) and Dynamic model (Fishman *et al*., 1987) were used to estimate chilling accumulation as chilling hours (CH_{CR}), chill unit (CU) and chilling portions (CP), respectively. The summation periods correspond to October 1st – March 31st for pistachio and October 1st to January 31st for almond. Annual precipitations were computed from September to August.

III – Results and discussion

Based on 35 years of climatic data, the amount of winter chill occurring in central Tunisia shows an important decline over the period 1980-2014 (Fig. 1). This trend is expected to continue since most climate change scenarios are forecasting major increases of winter temperature in the Mediterranean areas. All chill accumulation models used in the analysis are concordant in showing the decline in winter chill over the last three decades and bring additional evidence to statements on how decline in winter chill became apparent in different parts of the globe (Baldocchi and Wong, 2008; Luedeling *et al*., 2011; Darbyshire *et al*., 2011). Similarly, high variability in annual precipitations was observed over the same period, but the decreasing tendency occurred with less evidence.

The analysis also revealed that almond and pistachio trees in the centre of Tunisia are increasingly subjected to lack of chilling, since warm winters are becoming more frequent. During the last period, a winter with severe lack of chilling occurred every three-four years (1997, 2001, 2007 and 2010). Such conditions are known to impact on the adaptability of deciduous fruit crops (Darbyshire *et al*., 2011). In a previous work, the beginning of flowering of pistachio was found to be highly related to winter thermal regimes (Elloumi *et al*., 2013). The correlation indicated that the severe lack of chilling delays the flowering of pistachio cv. Mateur by about one month. Almond cultivar Fekhfefk was similarly affected with a flowering delay of 15 days.

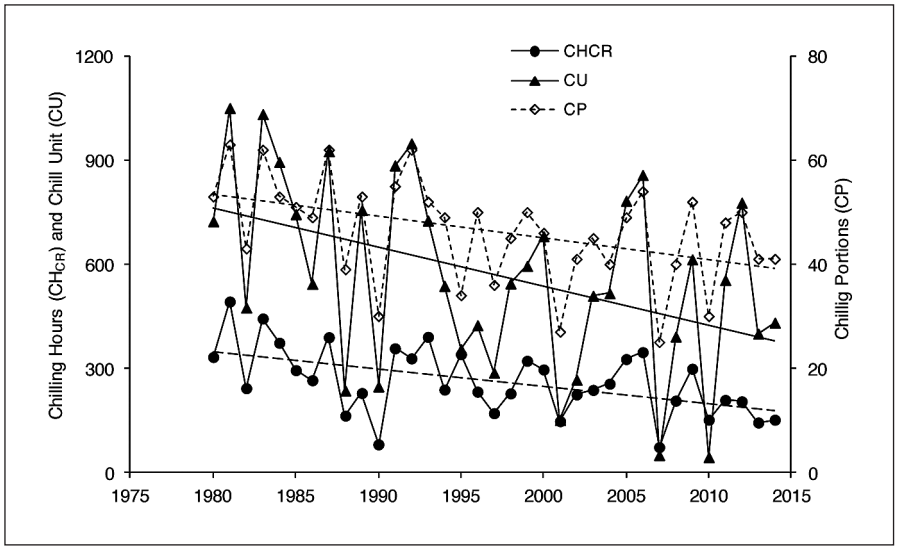

Fig. 1. Declining of chilling accumulation measured as chilling hours (CH_{CR}), chill units (CU) and chilling portions (CP) over the period of 1980-2014 in a warm production area.

The yearly variations of pistachio yields are closely related to climatic conditions (Fig. 3). Results show a positive correlation between nut yield and chilling accumulation. It appears that an exponential increase of nut yield occurred with winter chill accumulation until reaching the chilling requirement. After that nut yield seemed to be unaffected by chilling accumulation but rather by other factors such as precipitation.

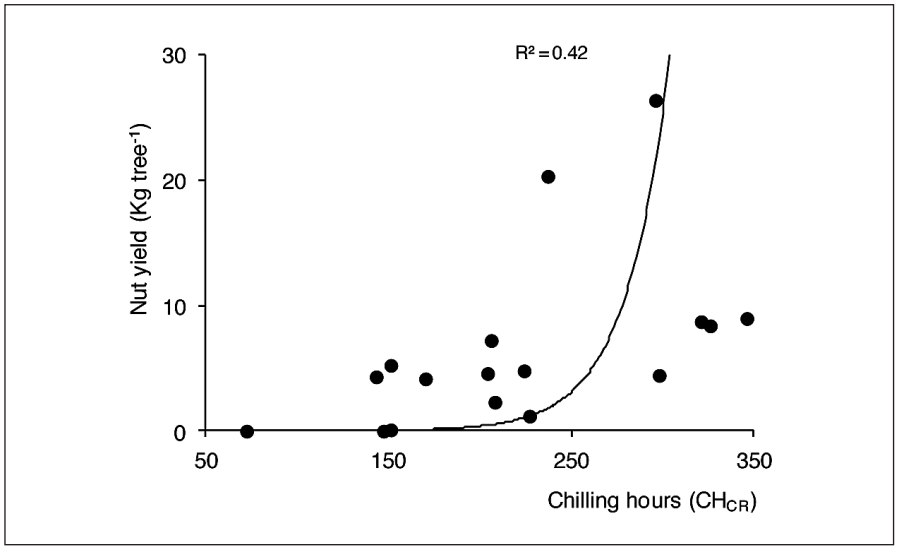

Fig. 2. Relationship between nut yield (kg $tree^{-1}$) of pistachio trees cv. Mateur and chilling accumulation as chilling hours (CH_{CR}) for data collected over the period 1997-2013.

Chilling had a lower impact on almond varieties and there is no strong relationship between chilling trends and nut yield (Fig. 3). There may have been sufficient chilling during much of the analysis period ensuring little yield influence. However, some of the recent reductions in yields of almond were attributed to a decline in winter chill and/or drought, depending on the cultivar. Hence, nut yield of Fekhfekh, Ferragnes and Ferraduel seemed to be related to chilling accumulation, whereas Tuono appeared to be not as affected.

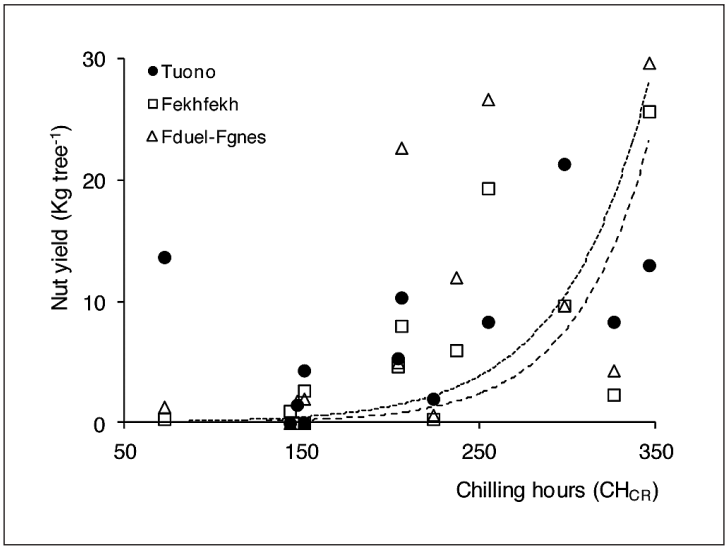

Fig. 3. Relationship between nut yield (kg tree^{-1}) of almond cultivars and chilling hours (CH_{CR}).

IV – Conclusions

Analysis of daily climatic data revealed important decline in winter chill over the 1980-2014 period in Central Tunisia. Chilling accumulation models were used effectively to study the impact of increasing winter temperature on fruit production. Warm winters impacted strongly yields of the pistachio crop cv. Mateur but only within some limits those of three almond cultivars 'Fekhfekh', 'Ferragnes' and 'Ferraduel', whereas cv. Tuono appeared to be more sensitive to drought. In the future, it will be interesting to consider the important genetic diversity of the almond and pistachio species to mitigate the harmful effect of global warming.

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