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Climate change and its potential impacts on the future of apple cultivation¹

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What ‘climate change’ means?

As stated by the Intergovernmental Panel on Climate Change (IPCC) in 2013, “since the 1950s, many of the observed [climate] changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased”. Also, and may be more important because less predictable, these changes go along with an increase in the frequency of extreme weather and climate events such as warm days and nights, and heat waves.

These phenomena are well identified in many fruit-tree growing areas such as South Africa where “higher mean, maximum and minimum temperatures with more frequent and warmer hot days and less frequent cold days” are observed (Lötze et al., 2015). Temperature appears as a main environmental variable that is affected by climate change.

How the temperature regime in winter and spring impacts apple tree biology

During its growth the apple tree develops three main types of buds: vegetative buds that establish tree architecture, flower buds that ensure fruiting, and latent buds that do not develop in the usual course of growth but that typically burst after pruning (Schmitz et al., 2014). Floral induction and initiation occurs several months (up to 10 months) prior to actual flowering. For example, in Brazil, flowering in September - October indicates a floral initiation likely between January and March of the same civil year. Petri et al. (2012) observed apple flower buds with a stereomicroscope from January 15th onwards in the conditions of Southern Brazil.

Except in the case of syllepsis where the bud grows very soon after it is initiated (Schmitz et al., 2014) producing a vigorous shoot competing with the parent branch, vegetative and flowering buds undergo a dormancy period when the bud does not grow. Three consecutive phases of dormancy are usually defined: para-, endo- and eco-dormancy, where budburst inhibition results from relations with other plant parts also called “correlative inhibition” (e.g., acrotony), lies within the bud itself or is imposed by the environment, respectively (Lang et al., 1987).

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For both vegetative and flowering buds, in this latter case after flower induction, endodormancy is strongly affected by temperature: the dormant bud requires exposure to low temperatures (phase of chill accumulation, CA) in order to overcome the endodormancy phase, followed by exposure to heat temperatures (phase of heat accumulation, HA) to resume organogenesis and growth during ecodormancy (Legave et al., 2015). High temperatures during the endodormancy phase, i.e., in winter, delay the time at which the tree becomes receptive to heat temperatures (Luedeling et al., 2013). However, actual budburst results from the interplay of both CA and HA. In their study on flowering in 10 locations in Western Europe, North Africa and Southern Brazil, Legave et al. (2015) showed contrasted results depending on the site. In Western Europe, the higher the HA is the earlier the flowering date will be, whereas the CA was not related to flowering time. In Southern Brazil, the lower the CA is the later the flowering time will be, emphasizing the importance of too high temperatures during winter time.

Cultural operations and the long-term interest of apple breeding as levers to overcome insufficient chilling

Breeding for lack of chilling is surely a main aspect of the long term strategy to adapt apple growing to climate change. Among countries that are already facing the negative effects of climate change on apple phenology and productivity, Brazil is likely a leader in this domain (Leite et al., 2008; Pommer and Barbosa, 2009). However, breeding for low chilling requirement alone may not suffice if the objective is to reach good fruit quality and regular fruiting. The challenge for the future is also to integrate in the 'apple tree ideotype for mild winter climate' other characters such as resistance or tolerance to main pests and diseases to reduce as much as possible the use of chemicals, and regular fruiting which is tightly related to well identified tree architecture traits (Lauri and Corelli-Grappadelli, 2014). Such breeding program should include the search for more rusticity of both the cultivar and the rootstock (Parisi et al., 2014).

Apart from genetics and breeding, a panel of cultural management options also exists. Rest breaking chemicals are still the main means to stimulate and group vegetative and flowering at spring in commercial orchards from mild winter regions all over the world (Erez, 1995; Leite et al., 2013). These chemicals are effective in different ways but the most used are mineral oils that decrease bud respiration and hydrogen cyanamid (dormex®) that acts on hormonal balance. Apart from toxicity of some of these chemicals (e.g., dormex®; Sheshadri et al., 2011), the use and effects of rest breaking agents are well documented, especially in Brazil (Leite et al., 2013, 2014) and South Africa (Midgley and Lötze, 2011). However, their effectiveness depends on the physiological status of the tree and also on the climatic conditions that often leads to irregular results in commercial orchards.

Several cultural operations are also used such as bending (Erez, 1995) and scoring or notching (Leite et al., 2014). Other methods can be applied at larger scales such as leaf removal after harvest in mountains in Java (Indonesia) during a dry period that induces bud dormancy followed by synchronous budburst a few weeks later with the beginning of the rainy season. Taking the opportunity of the two dry and rainy seasons typical of the equatorial climate, this strategy permits two harvests per year (Janick 1974). In regions where water availability is not an issue, another method consists in over-tree irrigation to decrease temperature during winter (Lötze et al., 2015).

Other options include the redesign of the orchard system as a whole to increase its sustainability. A great amount of research works have been developed in past years on the interest to develop agroforestry to optimize land productivity per unit area (land equivalent ratio, LER, stating that mixing two or more cultures on a same land area usually increases on the long term the global productivity of the system)(Lovell et al., 2017). Many works developed in the tropics show that agroforestry systems may also mitigate climate change avoiding the negative effects of extreme high temperature and radiation events (Lin, 2007). Interestingly, other works, more oriented to agroecology, show that the management of plant biodiversity may be an efficient means to foster both plant-mediated (e.g., bottom-up) and natural enemy-mediated (e.g., top-down) processes in the foodweb to reduce pest and disease pressure and, as a consequence, the use of chemicals (Simon et al., 2017). How apple tree-based agroforestry systems may help mitigating climate change negative effects while also reducing pest infestation and disease infection remains an open field for research (Lauri et al., 2016; Lauri, 2018).

Altitudinal shifts in apple cultivation in Brazil: description and interpretation

In many parts of the world the potential impacts of climate change on shifting of production areas are discussed. Changes in apple production areas in Santa Catarina/Brazil is a reality, where in the past few years production area has dramatically migrated from areas of lower altitudes to areas of higher altitudes. However the 'climate change' interpretation should be considered with caution. Massignam and Pandolfo (2016) show a clear shift in the harvested area from the region of Joaçaba (lower altitude) to Campos de Lages (higher altitude). The city of Fraiburgo is the most representative in apple production for the first region whereas São Joaquim is the most representative for the latter.

The average minimum and maximum temperatures during the colder two months (June and July) from 1984 to 2016 and for both places are shown in Figure 1. Fraiburgo is represented by Caçador (nearby city) where the weather station is located. One might speculate that the migration shifting observed between the two regions is a direct effect of climate change. Indeed, if we observe the data shown in Figure 1, there is only a slight trend, not statistically significant, of increasing minimum temperatures in Caçador in June (Figure 1A), and for both regions in July (Figure 1B). However, differences between the two sites are more likely due to the differences in maximum temperatures in winter, which may negatively affect dormancy completion. Indeed, maximum temperatures in June and July are approximately 4°C higher in Caçador, relative to São Joaquim, while the difference in the minimum is approximately 1°C. Legave et al. (2015) showed that the warmer the temperatures during winter the later the flower will occur in the conditions of Southern Brazil. Actually, this is observed in the field where apple orchards in São Joaquim usually bloom before Fraiburgo and with a shorter flowering duration. In areas of lower altitude, with insufficient chilling accumulation, a more prolonged bloom period is observed (Petri et al., 2012). Moreover, a delayed and heterogeneous budburst is also noted in apple trees subjected to insufficient cold exposure, relative to trees having adequate chilling accumulation, as shown by Schmitz et al. (2014).

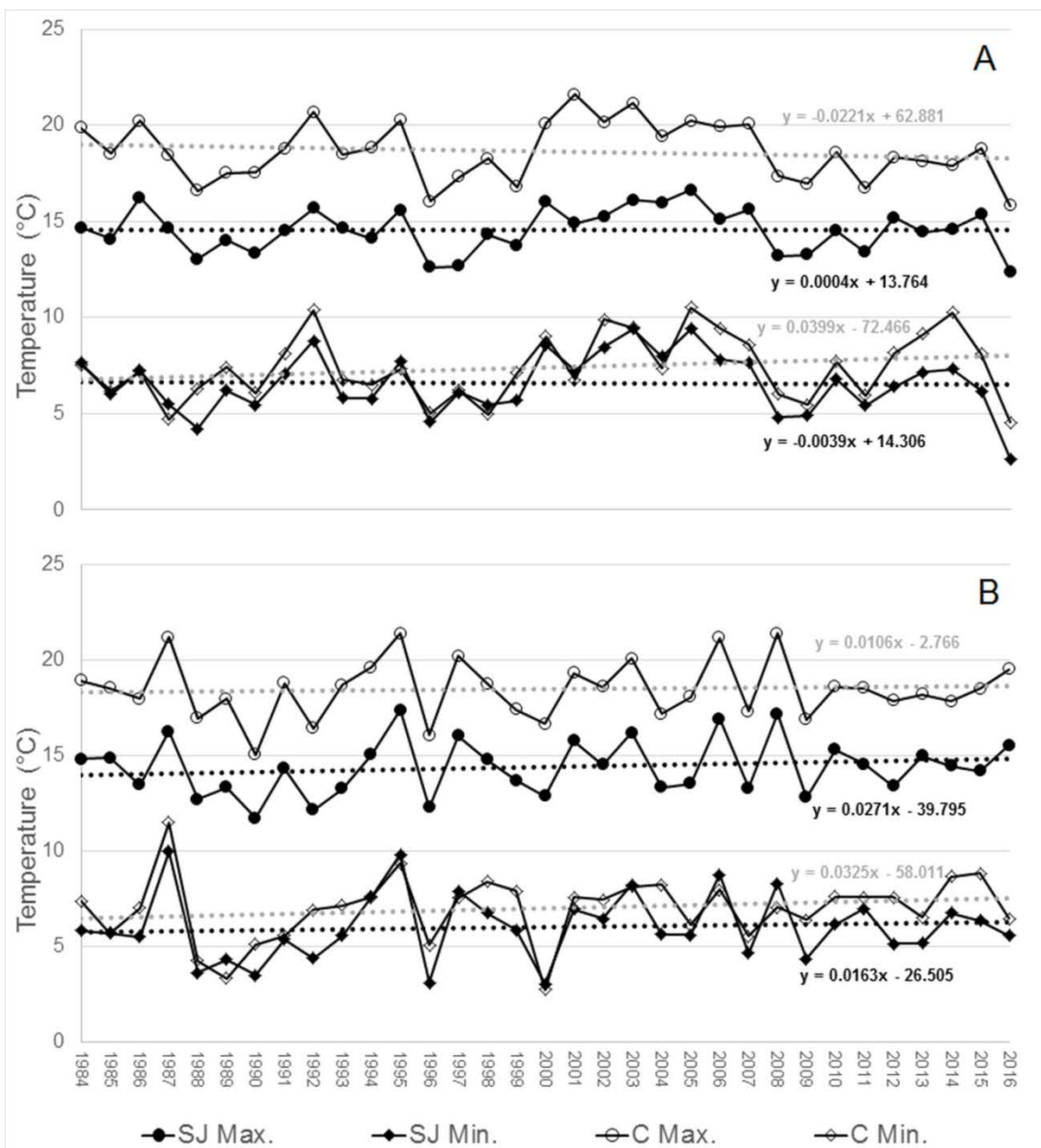


Figure 1. Monthly average of minimum (Min.) and maximum (Max.) temperatures in June (A) and July (B) in São Joaquim (SJ) and Caçador (C), Santa Catarina, Brazil, from 1984 to 2016. Source: EPAGRI/CIRAM. Altitude of weather stations: SJ = 1376 m; C = 945 m.

Discussion and conclusion

As well documented, climate change is characterized by a syndrome of phenomena among which temperature plays a crucial role. However, other aspects have to be better taken into account in the studies on the effects of climate change on apple cultivation, especially total rain water amount and distribution along the growing season.

The shift in apple production areas in Santa Catarina from areas of lower to higher altitudes is a reality. This shift does not seem to be directly related to climate change itself, as variations in temperatures over the years in both regions are subtle, but more related to production migrating to areas with climate more suitable for apple production, i.e., to higher altitudes with colder climate like São Joaquim. However,

climate may become an issue in the future in Santa Catarina. Growing apples in warmer areas is more difficult due to lower chilling accumulation entailing lower and irregular fruit-set and fruit quality (mainly poorer red color) and stronger vegetative growth, among other effects. Genetic knowledge of dormancy mechanisms and breeding for lack of chilling, with an already existing panel of very interesting released cultivars in Brazil, is surely a major issue in the medium and long term. On existing cultivars, cultural operations, such as chemical treatments or technical operations to induce a more uniform budburst and flowering, are still mandatory.

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