

## **Climatic Warming and Soil Respiration in Horticulture**

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### **Abstract**

Soil respiration rates under pear, apple and citrus were recorded in South Africa and Germany to investigate the effect of temperature and study the differences between deciduous and evergreen fruit trees. Girdling was performed on a set of pears to assess the interactions between assimilate supply by the tree and CO<sub>2</sub> release from the soil. The experiments revealed that a temperature increase due to global warming will probably not stimulate soil respiration significantly in temperate and subtropical regions. However, it may affect orchard ecosystems especially in the temperate regions by enabling the introduction of evergreen citrus. In citrus rows, soil respiration was comparatively stable but low, whereas pear and apple rows were characterised by a marked respiration maximum in summer.

*Keywords: apple, pear, citrus, CO<sub>2</sub>, deciduous, evergreen*

### **Introduction**

Apart from the increase of atmospheric CO<sub>2</sub> concentration, the rise in temperature is probably the most important factor of the predicted global climate change. Milder winters may increase carbon assimilation of plants and allow the expansion of new foliage earlier in spring than today, but may shorten the life expectancy of leaves. Higher temperatures in summer may intensify the already existing summer stress, viz. heat, light, and drought stress. Soil respiration, a process by which CO<sub>2</sub> from soil organisms and plant roots is released at the soil surface, is coupled with the climate. Root respiration generally accounts for approximately 30% to 84% of total soil respiration with the balance being largely microbial respiration. The latter depends on the organic matter, which is released into the soil either as decayed plant organs such as roots or leaves or leaching of carbohydrates from the roots. Root and soil respiration is predicted to increase, if CO<sub>2</sub> and temperature

increase and enhance photoassimilate translocation to the roots (Ceulemans and Mousseau, 1994). Soil respiration rates can vary considerably during the year and show a clear temperature dependency. As soil respiration provides some of the CO<sub>2</sub> essential for photosynthesis, it also contributes to the CO<sub>2</sub> balance of the orchard ecosystem.

The objective of the present research was to predict effects of climatic warming by comparing soil respiration under deciduous trees grown in South Africa (Stellenbosch) and Germany (Ahrweiler). Moreover, the effect of pear stem girdling, a treatment gaining popularity to induce early bearing in young, vigorous trees, increase fruit set and reduce vegetative vigour, was studied to quantify the contribution of recently fixed photoassimilates to soil respiration. Finally, differences in soil respiration between deciduous (pear) and evergreen (citrus) trees growing in adjacent orchards were investigated to work out principal differences between these tree types.

## **Materials and Methods**

In 1997/98 soil respiration rates of an Oakleaf soil under 7-year-old 'Rosemarie' pear (*Pyrus communis* L.) trees on 'BP3' rootstock and 'Miho Wase Satsuma' citrus (*Citrus unshiu* Marc.) trees on 'Troyer citrange' rootstock and also of a fluviatile soil type under 25-year-old 'Granny Smith' apple (*Malus domestica* Borkh.) trees on seedling rootstock grown in Stellenbosch (Welgevallen Experimental Farm, South Africa) were compared with soil respiration rates under 8-year old 'Pinova' and 'Elstar' apple trees on 'M9' rootstock grown on a sandy loam in Ahrweiler (Experimental Station SLVA) near Bonn, Germany. One set of pear trees was girdled in the South African spring using a pruning saw and a 6 mm strip of bark around the trunk was removed to minimize photoassimilate translocation from the canopy to the root system. Soil respiration measurements were conducted below the trees, about 10-40 cm from the trunk, on days without irrigation or rainfall 24 hours before the measurement. A CPY-2 canopy assimilation chamber covered with cardboard or a SRS soil respiration system connected to the CIRAS-1 or EGM portable infrared CO<sub>2</sub> analyser from PP Systems

were used (cf. Blanke, 1996). The CIRAS-1 or EGM software calculates respiration rates from increases in the CO<sub>2</sub> concentration and the chamber volume in a closed gas circulating system using a quadratic equation. Soil temperature was measured with a thermometer inserted to a depth of ca. 20 mm.

## Results

### *Temperature coefficients $Q_{10}$*

Soil respiration under apple grown in Ahrweiler (Germany) resulted in a CO<sub>2</sub> release from the soil between 250 and 1250 mg CO<sub>2</sub> m<sup>-2</sup> h<sup>-1</sup>, depending on time of year. The different temperature ranges during the season were used to calculate temperature coefficients ( $Q_{10}$ ), which are defined as factors describing the increase in respiration rate for a temperature rise of 10 °C. For a mean soil temperature above 20 °C,  $Q_{10}$  remained quite similar (at 1.3), but it rose considerably, when soil temperature decreased below 5 to 10 °C (Fig 1).

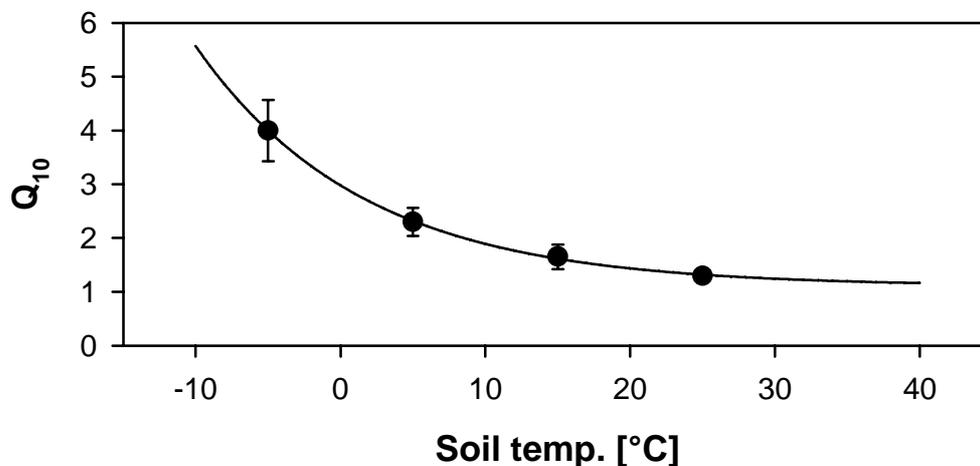


Figure 1. Average temperature coefficients  $Q_{10}$  and resulting curve fit for soil respiration of a sandy loam under apple in Ahrweiler (Germany).

Similar measurements under apple, pear, and citrus in South Africa revealed comparable temperature coefficients, but temperature did not drop below 10 °C during the measuring period.

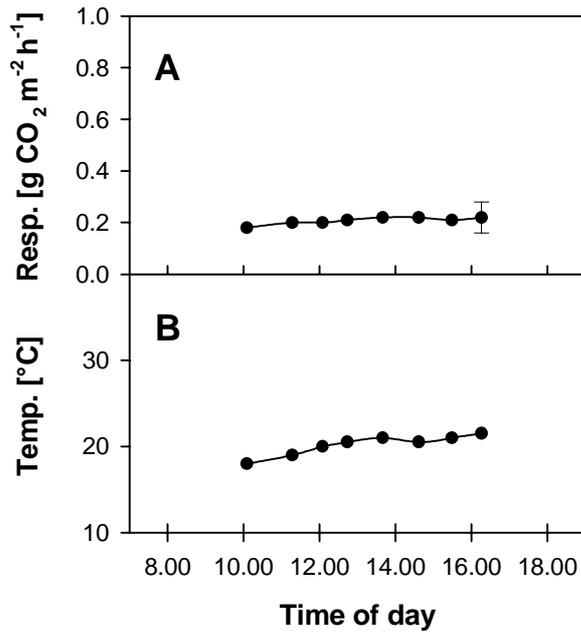


Figure 2. (A) Soil respiration and (B) soil temperature 20 mm below the soil surface under apple in Stellenbosch (South Africa) measured on 7<sup>th</sup> November 1997.

Under 'Granny Smith' apple trees grown in South Africa, soil respiration was quite low, about 200 mg CO<sub>2</sub> m<sup>-2</sup> h<sup>-1</sup>, but the calculated Q<sub>10</sub> of about 1.7 for a temperature range of 18 to 22 °C was comparable with the data from Germany (Fig. 2).

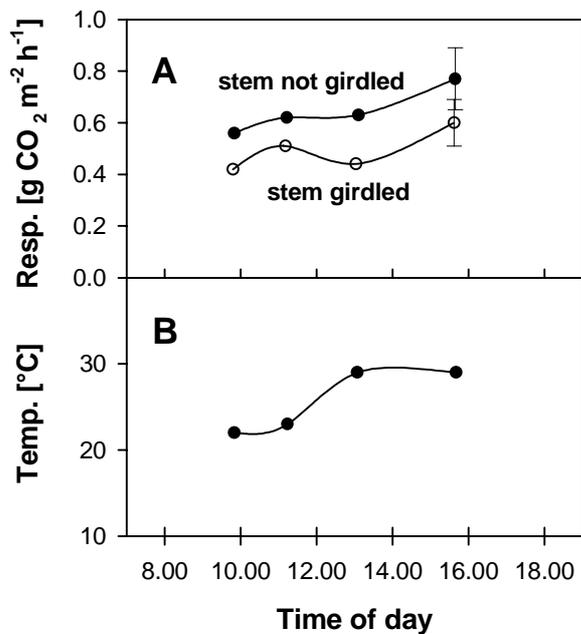


Figure 3. (A) Soil respiration and (B) soil temperature 20 mm below the soil surface under pear in Stellenbosch (South Africa) measured on 11<sup>th</sup> December 1997.

Under pear, soil respiration ranged between 250 and 780 mg CO<sub>2</sub> m<sup>-2</sup> h<sup>-1</sup>, depending on time of year. Temperature coefficients Q<sub>10</sub> were found to be quite stable about 1.3 between temperatures of 22 and 36 °C. Noteworthy, Q<sub>10</sub> under stem-girdled and non-girdled trees did not differ significantly, also soil respiration under girdled trees was always smaller (Fig. 3).

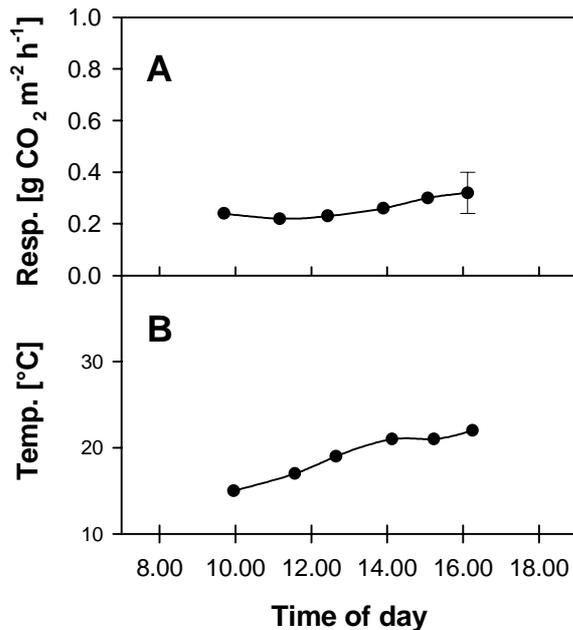


Figure 4. (A) Soil respiration and (B) soil temperature 20 mm below the soil surface under citrus in Stellenbosch (South Africa) measured on 19<sup>th</sup> November 1997.

Under evergreen citrus trees the CO<sub>2</sub> release from the soil was lower than under pear and varied between 170 and 280 mg CO<sub>2</sub> m<sup>-2</sup> h<sup>-1</sup>. The fluctuation of soil respiration was only slightly affected by the time of year (September to February). Temperature coefficients Q<sub>10</sub> were about 1.6 or 1.2 below or above 20 °C, respectively (Fig. 4). When compared with the relationship of soil temperature to Q<sub>10</sub> observed under apple in Ahrweiler (Germany), the relationships found in Stellenbosch (South Africa) under apple, pear and also citrus were quite similar (Fig. 5). However, the absolute values for CO<sub>2</sub> released at the soil surface were different and might be attributed to the soil type, viz. sandy loam in Ahrweiler and Oakleaf soil or fluviatile soil type in Stellenbosch, respectively.

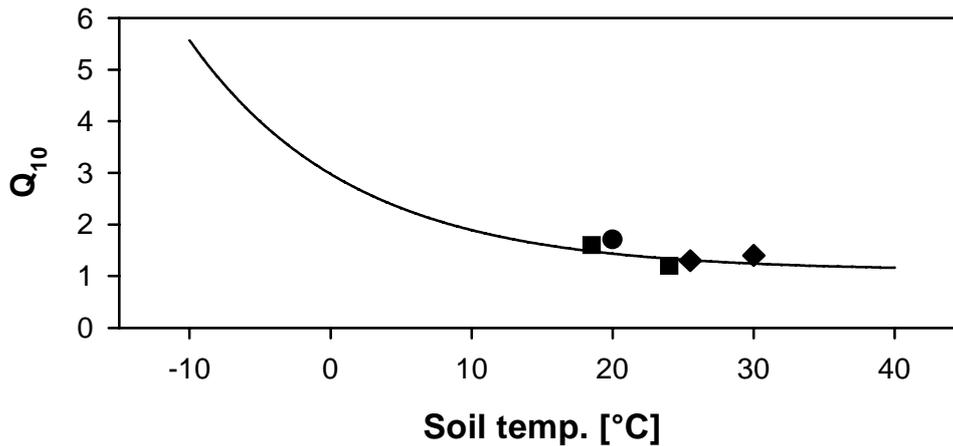


Figure 5. Temperature coefficients  $Q_{10}$  calculated for soil respiration under apple (●), pear (◆), and citrus (■) in South Africa compared with the soil respiration data measured under apple in Germany (for the regression line cf. Fig. 1).

#### *Variation of soil respiration during the growing season*

From end-September to end-February, soil respiration under citrus grown in Stellenbosch remained almost stable at about  $240 \text{ mg CO}_2 \text{ m}^{-2} \text{ h}^{-1}$ . Under pear, however, soil respiration in the same soil and climate varied considerably during the growing season (Fig. 6). A distinct peak was detectable in mid-December. Daytime mean soil temperature varied between 17 and 30 °C, and was always higher in the pear block due to the fact that the trees were trained to a more open shape (vase) than the citrus trees (hedge), thereby reducing shading of the soil (data not shown). However, the temperature changes could not account for the summer respiration peak in pear because of the small  $Q_{10}$  values. Noteworthy, the  $\text{CO}_2$  release from the soil under pear could be reduced up to 40% by girdling the trees and thus limiting assimilate supply from the tree canopy to the root/soil system.

Under apple, soil respiration was also variable. Changes during the season were to a certain extent similar to the  $\text{CO}_2$  release from the soil under pear (Fig. 6). In the apple rows, soil respiration ranged from less than  $250 \text{ mg CO}_2 \text{ m}^{-2} \text{ h}^{-1}$  in the frosty, cold winter, 300 to  $800 \text{ mg CO}_2 \text{ m}^{-2} \text{ h}^{-1}$  in spring and autumn to up to  $1250 \text{ mg CO}_2 \text{ m}^{-2} \text{ h}^{-1}$  in summer. In comparison with pear grown in South Africa, large respiration values were measured for a distinctly longer period of time in the summer and autumn under apple grown in Germany, viz. five compared to two months.

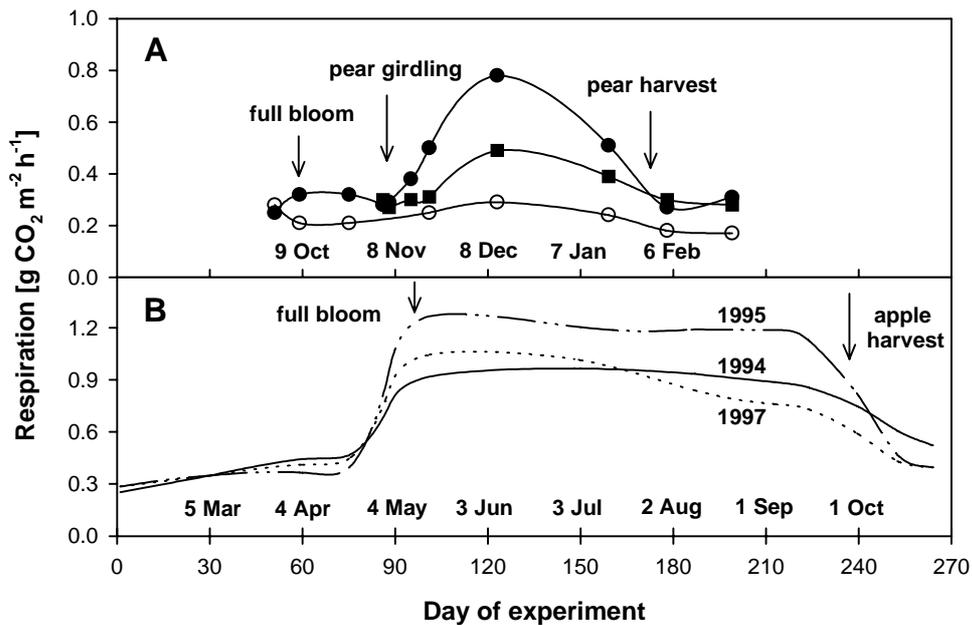


Fig. 6: Mean soil respiration rates (A) under pear (non-girdled: ●; girdled: ■) and citrus (○) in Stellenbosch, South Africa, in 1997/98 and (B) under apple in Ahrweiler, Germany, in 1994, 1995 and 1997.

## Discussion

Based on the present results, it can be concluded that soil respiration under apple and pear trees in Germany and South Africa is comparable, also the CO<sub>2</sub> emission under pear was 10% to 20% less than under apple. This slight difference is well within a range that could be due to the different soil types. When soil respiration in apple orchards was compared, the rates measured in South Africa were about 35% less than in Germany. Here, differences in tree age have to be considered in addition to effects of soil type and cultivar. However, Miremadi (1963) and Proctor et al. (1976) published soil respiration rates under apple between 100 and 400 mg CO<sub>2</sub> m<sup>-2</sup> h<sup>-1</sup>, which is well within the range for apple and pear rows in South Africa.

In contrast to the evergreen citrus, soil respiration peaked in pear and apple rows in summer. This peak under deciduous trees can be attributed to an increased root respiration, because Ebert and Lenz (1991) reported that root respiration of apple trees proceeds at a much greater rate in summer than in winter. Soil respiration rate under citrus remained stable, which is in accordance with Bouma et al. (1997), who observed that citrus is able to adapt to different soil temperatures and to

maintain a certain root respiration level. It is yet uncertain, whether pear and apple also show this kind of adaptation, but it is possible that their marked seasonal change of root respiratory activity represents a difference between evergreen and deciduous tree species.

Soil respiration under pear was generally higher than under citrus, also both species were grown in adjacent orchards in Stellenbosch. Hence, differences of the soil type influencing soil respiration were limited. The different CO<sub>2</sub> release rates can only partly be attributed to the soil temperature, which was about 2-5 °C higher under pear. Presumably, the lower soil respiration rates in citrus rows indicate a reduced supply of photoassimilate from the tree canopy to the roots. This hypothesis is favoured by the observation that soil respiration below girdled pear trees remained low when assimilate transport to the roots was limited, but rose under non-girdled trees. Citrus stores a considerable amount of carbohydrates in leaves, apple in the trunk and roots (Wibbe and Blanke, 1995). In deciduous tree species, assimilate transport to the roots should strongly depend on the time of year and stage of the tree, whereas in evergreen species such as citrus assimilate partitioning to the root should depend less on the season. The stable and low soil respiration in citrus rows could thus reflect a comparatively low but stable assimilate translocation to the roots.

Although many short-term studies on the decomposition of organic matter in the soil have shown that decomposition rates increased with temperature, a transient rise of soil respiration is unlikely to represent the long-term response to global warming. Increasing soil respiration rates due to a temperature rise indicate either the depletion of a very small, active pool of organic matter or - because soils are under nearly steady-state conditions - a return to the pre-disturbance situation (Giardina and Ryan, 2000). Moreover, effects to increasing temperatures are small in excess of 15 °C (Q<sub>10</sub> values between 1.2 and 1.7). Taken together, these data suggest that a temperature-related significant increase in soil respiration rate due to global warming should not be expected.

Decomposition of organic matter by the root system and especially by micro-organisms in the soil is performed by enzymes, and enzyme activity is limited by temperature only when the supply of substrate

exceeds its reaction rate. Seemingly, soil respiration is more limited by assimilate supplied from the tree canopy or covering vegetation, soil moisture, and soil clay content than by temperature (Keutgen and Huysamer, 1998; Giardina and Ryan, 2000). The present data suggest that soil respiration is not controlled by temperature limitations above 15 °C. Consequently a rise in temperature alone will not stimulate CO<sub>2</sub> release from the soil in fruit tree orchards. On the other hand, if the amount of assimilates translocated to the root/soil system rises due to the predicted CO<sub>2</sub> and temperature increase, soil respiration rates may indirectly be changed. In addition, it can be assumed that cultivation of subtropical fruit trees such as citrus instead of apple or pear will affect the CO<sub>2</sub> evolution of the orchard ecosystem, because the course of soil respiration during the year is different. Taking into account the changing selection of tree species due to climatic warming, the long-term adaptation of the orchard ecosystem becomes rather complex, because interactions between vegetation, fertilisation and soil development have to be considered.

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