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Crop yield response to water

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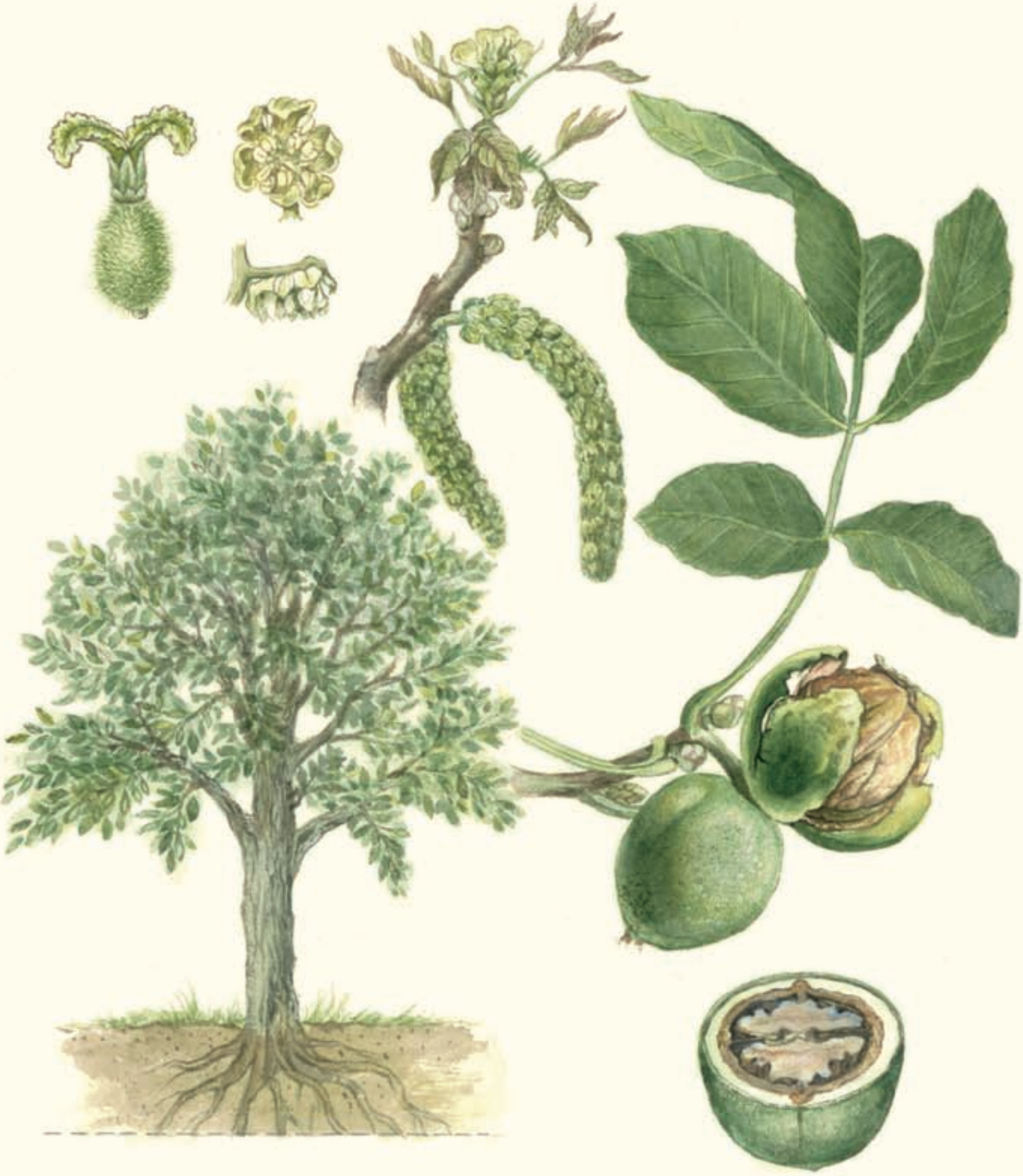

Walnut

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Walnut

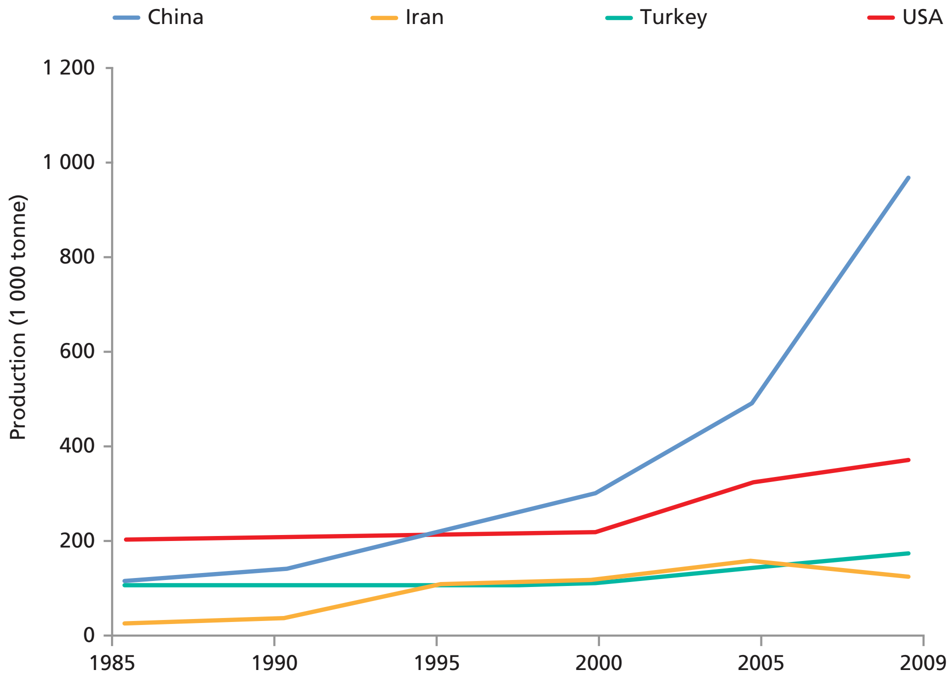
INTRODUCTION AND BACKGROUND

Walnuts *(Juglans regia* L.*)* are large trees that are cultivated in temperate climates for their nuts, rich in oil, and for their wood. Plantations are relatively widely spaced as this species does not tolerate mutual shading well. Common spacing of vigorous varieties varies between 8 x 8 and 10 x 10 m, while the less vigorous cultivars may be planted at 7 x 7 m spacing. Experiments that have increased tree density above the spacing mentioned have resulted in higher yields during the first years of the orchard but this may be at the expense of reduced orchard longevity. In 2009, world acreage was 843 000 ha and average global yield (with shell) was 2.7 tonne/ha (FAO, 2011). Figure 1 presents the production trends of the main producing countries. China and the United States are the two main world producers, followed by Iran, Turkey, and Ukraine. France is the main European producer and Chile is now an important producer in the Southern Hemisphere.

VEGETATIVE AND REPRODUCTIVE DEVELOPMENT

Commercial varieties of walnut trees break dormancy and begin to leaf out in the Northern Hemisphere between mid-March and mid-April, depending on the environmental conditions and the cultivar. This is followed by flowering, both the emergence of pollen-producing male flowers and the female flowers that evolve into the nut after pollination. Normally, flowering is completed by late April and is followed by rapid fruit expansive growth with concomitant rapid shoot growth. Bud formation occurs from leaf out through June on mature trees. By early June, the fruit has reached its full size and this is followed immediately by the internal development of the nut. At this time, shoot growth slows. The internal nut development sequence begins with shell expansion and hardening and dry matter accumulation in the kernel that continues through harvest. The indicator for physiological maturity is the development of 'packing tissue brown' which occurs before hull split. This can be identified by cracking open the nuts and observing the colour of the tissue surrounding the kernel inside the shell. If this tissue is white, the nuts have not reached maturity and there will likely be continued dry matter accumulation in the kernel. A brown colour indicates the nuts have matured and kernel development has ceased. Hull split generally follows closely after walnuts have reached physiological maturity. After splitting, the hulls break down rapidly. During the postharvest period, some shoot growth and carbohydrate storage are the primary sinks of photosynthesis products.

FIGURE 1 Production trends of walnuts in the principal countries (FAO, 2011).



EFFECTS OF WATER DEFICITS

Water stress can decrease nut size and quality (kernel colour and shrivel). Stress-related reductions in shoot growth can reduce fruiting wood for the following season(s). There is some evidence that not only are the number of reproductive buds less because of lower vegetative growth but that some flower buds are not viable, resulting in fewer flowers and ultimately less fruit. Further, the reduction of shoot growth causes higher fruit temperatures as a result of both more sunlight penetration into the canopy and thus, more direct solar radiation on a higher percentage of the fruit, and higher canopy temperatures because of less transpiration, that can darken kernel colour, reducing crop value. This temperature effect is very cultivar dependent.

As walnut fruit load is very dependent on the previous year's shoot growth, the impact of water deficits is much more severe in the season following the imposition of water deficits. The primary impact in the year that stress is imposed is on fruit size and quality while in the following season, the impact is on fruit load, regardless of the irrigation regime used in the following season. One California study found that hedgerow walnuts (cv. Chico) irrigated at 33 and 66 percent ET_c suffered marketable nut yield reductions of 32 and 50 percent, respectively, after three years because of reduced nut size, fruit load, and crop quality (Goldhamer, 1997). Upon returning these trees to full irrigation, tree growth and gas exchange immediately recovered but yields were little changed the first recovery year, even though shoot growth dramatically increased. It wasn't until the second recovery year that harvest yields completely recovered as a result of the fruiting positions created by the first recovery year's shoot growth. Similar stress impacts and recovery results have been obtained from other studies in California (cv. Chandler) (Lampinen *et al.*, 2004). The rapid production recovery from severe water stress was possible because of the absence of stress-induced disease or insect pressures. Trunk diseases such as deep bark canker that often occur in water stressed orchards were not evident in these studies.

WATER USE

Walnut orchards have high water use rates as because of the high leaf, tall tree stature, and near full ground cover when the trees are fully mature. Table 1 provides the crop coefficients for mature walnut orchards obtained from studies in California (Goldhamer, 1997).

TABLE 1 Crop coefficients for mature walnut trees (Goldhamer, 1997).

Date	Crop coefficient (K_c)
Mar. 16-31	0.12
Apr. 1-15	0.53
Apr. 16-30	0.68
May 1-15	0.79
May 16-31	0.86
June 1-15	0.93
June 16-30	1.00
July 1-15	1.14
July 16-31	1.14
Aug. 1-15	1.14
Aug. 16-31	1.14
Sept. 1-15	1.08
Sept. 16-30	0.97
Oct. 1-15	0.88
Oct. 16-31	0.51
Nov. 1-15	0.28

DEFICIT IRRIGATION STRATEGIES

The general strategy followed experimentally for reducing irrigation in walnut orchards has been to limit water deficits during early stages of tree and crop development in favour of imposing them during mid and late season. One study in northern California used midday stem-water potential to impose the 'low' and 'moderate' stress treatments. The target midday stem-water potential values were -0.5 to -0.7 MPa and -1.2 to -1.4 MPa during the bulk of the season for these two regimes with corresponding reductions in applied water of 30 and 50 percent of potential ET_c, respectively (Fulton *et al.*, 2002). It should be noted that the water potential values of fully irrigated walnut trees are much less negative then the two primary nut crops, almond and pistachio. Walnut predawn leaf water potential values for fully irrigated trees range between -0.15 and -0.2 MPa and midday stem-water potential between -0.40 to -0.60 MPa. After three seasons, yields in these stress treatments had declined by 26 and 40 percent, respectively, relative to fully irrigated trees (Lampinen *et al.*, 2004). Full recovery was achieved after two years of full irrigation. A companion study was conducted on deeper soils with older trees with a lower tree density. Yield reductions were appreciably lower at this site, which was attributed to the stress development being relatively slow because of the larger soil moisture reservoir and possibly the larger carbohydrate reserves of the bigger trees.

To simulate a one-year drought with a water supply of 400 mm where potential ET_c was

1 100 mm, a team in California applied 85 percent of ET_c through April to mature cv. Chico trees and then progressively lower percentages of ET_c as the season progressed (25 percent was the minimum from early July through the early September harvest) and no postharvest irrigation (Goldhamer *et al.*, 1989). Fruit yields in the drought year were about 10 percent lower than the fully irrigated control (not statistically significant). However in the following recovery year, when full irrigation was applied to all trees, the drought year trees had about 80 percent lower yields almost entirely the result of a lower fruit load. Yields returned to near full levels during the second recovery year (Goldhamer *et al.*, 1990).

It appears that walnut trees do not respond well to water deficits, regardless of the deficit irrigation strategy, in terms of nut yield. This is probably because of the high sensitivity of shoot growth to water deficits and, in turn, to the heavy dependence of fruit load on the shoot growth of the previous year in walnuts.

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