Water Management and Plant Performance in a Changing Climate: Introduction to Colloquium

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Climate change refers to any significant shift or variability in temperature, precipitation, humidity, light, or wind. These changes may be of relatively short duration or last for an extended period that could be decades or longer [Intergovernmental Panel on Climate Change (IPCC), 2007]. Throughout history, earth's climate has been changing naturally. However, the rapid warming we have been witnessing in the past several decades is not solely the result of natural processes. Some are attributed to an increase in anthropogenic activities such as burning fossil fuels for the production of personal and commercial transportation, deforestation, and various agricultural and industrial practices (U.S. Environmental Protection Agency, 2010). With the increase in the world population from 1.25 billion in 1850 to 6.5 billion in 2005, world energy consumption has increased ≈ 40 times (Lal, 2007). The earth's atmospheric carbon dioxide (CO_2) concentration was $\approx 280 \mu\text{mol}\cdot\text{mol}^{-1}$ until the 1800s. It increased exponentially during the industrial era reaching $315 \mu\text{mol}\cdot\text{mol}^{-1}$ in 1957 and $362 \mu\text{mol}\cdot\text{mol}^{-1}$ in 1994 (Schimel et al., 1994). Human activities have increased atmospheric concentrations of greenhouse gases such as CO_2 , methane (CH_4), and nitrous oxide (N_2O), which occur naturally in the atmosphere (IPCC, 2007) resulting in a 0.74°C rise in the global average surface temperature to approximately over the past 100 years (Trenberth et al., 2007). As of 2010, the atmospheric CO_2 concentration is $388 \mu\text{mol}\cdot\text{mol}^{-1}$ and it is expected to increase to $\approx 450 \mu\text{mol}\cdot\text{mol}^{-1}$ by 2030 and $700 \mu\text{mol}\cdot\text{mol}^{-1}$ by 2050 (IPCC, 2001) as the world's population approaches nine billion (United Nations, Department of Economic and Social Affairs Population Division, 2009).

A number of studies have shown positive effects on plant growth and productivity from an increase in atmospheric CO_2 concentration (Kimball et al., 2002). An increase in CO_2 concentration (from $330 \mu\text{mol}\cdot\text{mol}^{-1}$ to $660 \mu\text{mol}\cdot\text{mol}^{-1}$) increases yields of C_3 crops [e.g., soybeans (*Glycine max* L.), cotton (*Gossypium* spp. L.), alfalfa (*Medicago sativa* L.), wheat (*Triticum aestivum* L.), rice (*Oryza sativa* L.), barley (*Hordeum vulgare* L.), and potatoes (*Solanum tuberosum* L.)] by 33% and yields of

C_4 crops [e.g., corn [*Zea mays*] and sorghum [*Sorghum bicolor* (L.) Moench.}] by 10% (Kimball, 1983; Long et al., 2006; Pinter et al., 2000; U.S. Climate Change Science Program, 2008). In addition, studies showed that CO_2 enrichment alone could boost water use efficiency and increase yield of water-limited crops (e.g., grains) (Drake et al., 1997; Idso and Idso, 1994). For example, in addition to increases in yield, CO_2 enrichment increases water use efficiency (WUE) in wheat (Hunsaker et al., 1996), soybean (Jones et al., 1985a, 1985b), and rice (*Oryza sativa* L.) (Baker et al., 1990). Similar observations reported by Conley et al. (2001) indicted that cumulative evapotranspiration of sorghum was reduced without a loss in yield. Other beneficial effects were documented by Wechsung et al. (1999) on the increase of root growth and biomass of wheat under dry conditions and that of cotton (Rogers et al., 1992) as a result of CO_2 enrichment.

Projected increases in CO_2 and air temperature will continue to contribute to climate warming in the next century (Alcamo et al., 1996; IPCC, 2001). The northern high latitudes have warmed by $\approx 0.8^\circ\text{C}$ since the early 1970s (Hansen et al., 1999). Warming is predicted to be greatest at high northern latitudes during fall and winter (IPCC, 2007) with reduced rainfall in the subtropics and increased precipitation in eastern America, northern Europe, and parts of Asia. Such changes appear to have a profound effect on plant periodicity as has been found in Europe (Menzel and Fabian, 1999), and plant phenology (IPCC, 2001), especially for plants that depend on accumulation of degree-days to reach flowering or fruiting (Peñuelas and Filella, 2001). The increase in temperature may extend the growing season (longer crop cycle), i.e., early planting and late harvest time will be anticipated (Porter, 2005). It has been documented that flowering had been ≈ 1 week earlier in the Mediterranean plant species for 1952–2000 (Peñuelas et al., 2002), in Hungary for 1851–1994 (Walkovszky, 1998), in Wisconsin for 1936–1998 (Bradley et al., 1999), and in Washington, DC, for 1970–1999 (Abu-Asab et al., 2001).

It is expected that the production of certain crops may shift across regions as a result of climate change. Increases in temperature will cause the optimum crop growth latitude to move northward. For example, yields of some agronomic crops such as soybean are expected to decrease in southern U.S. states (U.S. Climate Change Science Program, 2008) and increase in the Midwest (Boote et al., 1996, 1997). Similarly, warming temperatures will cause production of many cool-season vegetable crops [such as potato, lettuce (*Lactuca sativa* L.), broccoli (*Brassica oleracea* L.), and spinach (*Spinacea oleracea* L.)] to decline. In addition,

it will negatively impact fruit trees such as apples [*Malus $\times$ sylvestris* (L.) Mill. *domestica* (Borkh.) Mansf.] that require a certain amount of chilling (Hartfield et al., 2008). In northern temperate areas, heat-demanding warm-season crops [e.g., corn and sunflower (*Helianthus annuus*)] are projected to replace many of the present grain cereals and oilseed crops (Olesen and Bindi, 2002). Thus, the impact of climate change on agriculture will lead to intensified production in northern Europe and less in southern Europe exacerbated by a reduction in water use for irrigation resulting from increased water scarcity (Alcamo et al., 2007; Olesen and Bindi, 2002).

The effect of high temperature may surpass the impact of water availability for plants. For example, under well-watered conditions, when increases in temperature exceed the temperature threshold for pollination, grains may not produce seed and the quality of vegetable crops (e.g., tomato, *Lycopersicon esculentum* Mill.) may decrease (Kunkel et al., 2008). The impact of night temperature on plant growth and yield is as important as that of day temperature. Warmer nights increase plant respiration rates, resulting in further depletion of carbohydrates and yield reduction of fruits and vegetables [e.g., snap beans (*Phaseolus vulgaris* L.)] (Arevalo, 2008). Bud, flower, and fruitlet abscission is commonly found in tomato plants grown under high night temperatures, especially because tomatoes require lower night than day temperatures (Peet et al., 1998; Sato et al., 2004).

Increases in the average global air temperature will likely lead to changes in precipitation and atmospheric moisture and such changes may vary from region to region (IPCC, 2007). Although some regions (e.g., tropics) will experience more frequent and intense precipitation events, precipitation is expected to decrease in other regions (e.g., the Mediterranean, northern Africa, northern Sahara, Central America, the American Southwest, and southwestern Australia during winter).

Water scarcity, as a result of changes in precipitation patterns and intensity and decreases in natural water storage capacity from glacier or snowmelt-fed river basins, will increase the competition between agricultural and urban users as population growth increases. Under climate change, water and its availability and quality will create bigger challenges than energy security (IPCC, 2008). Agriculture is the dominant user of fresh water (Gleick, 2003a, 2003b), and demand for water will continue to increase with increases in population and economic growth (Rosegrant et al., 2009). It is anticipated that the world's population will approach nine billion by 2050 (United Nations, Department of Economic and Social

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Affairs Population Division, 2009). However, sharp increases in water demands are expected from industrial, commercial, and urban users in the next 50 years (Kondratyev et al., 2003). Thus, heightened demand for water will have major political and economic impacts for maintaining food security throughout the world (Rosegrant and Cai, 2001). By the end of this century, agricultural users are expected to have less fresh water and more access to low-quality water sources for irrigation. Shannon and Grieve (2000) reported that low-quality water can be used during specific growth stages of plants and the potential water use may be higher for crops with higher yield potentials such as pac choy [*New Zealand spinach (Tetragonia tetragonoides* Pall.) O. Kuntze] vs. orach [*Atriplex hortensis* L.]. It is documented that the use of low-quality water with high-quality water in successive applications improves the quality of many fruits and vegetables, for example, by increasing sugar content in cantaloupe (*Cucumis melo* L.) (Shannon and Francois, 1978), amount of fatty acids in safflower (*Carthamus tinctorius* L.) (Irving et al., 1988), and soluble solids content (Pasternak et al., 1986) in processing tomato (Grattan et al., 1987) and asparagus spears (*Asparagus officinalis* L.) (Francois, 1987).

Research pertaining to the effects of climate change on water management and its impact on plant response is the need of the hour. Efforts must be taken to assess the challenges faced by the agricultural sector taking into account the fast-growing population and economic development in a changing climate. The impacts of climate change on agriculture and water resources are of great concern to scientists and policymakers. In view of these challenges, the American Society for Horticultural Science Water Utilization and Management working group convened a colloquium titled "Water Management and Plant Performance in a Changing Climate" in 2010 to address the: 1) general aspects of water security and plant performance under increased concentration of atmospheric CO₂ and temperature; 2) selection of drought-tolerant plant species; and 3) practical techniques and tools that can be used to detect stress in various crops. The six presentations that follow examine and discuss the challenges inherent in impact of climate change on availability of water and its impact on agricultural production in various regions and offering a series of priority targets for future research. O'Neill and Dobrowolski (2011) outline some of the scientific and educational challenges of water resource management in agriculture and emphasize six possible intervention opportunities to achieve agricultural water security. The increase in water demand for irrigating agricultural crops in some areas might be partially offset by more efficient use of water by plants as a result of rising atmospheric carbon dioxide. Prior et al. (2011) report that plants can be stimulated by the rising level of atmospheric CO₂ as reflected by increased photosynthesis, growth, and WUE. They discuss priority research areas in horticulture such as identifying drought-tolerant species, soil carbon storage potential, green-

house gas emissions, and potential pest problems to help the horticulture industry develop best management practices for meeting the challenges of a changing environment. Increases in CO₂ levels increase plant growth and elevated temperatures increase plant transpiration and the water requirement of plants. Leaves are key factors in the global water exchange cycle. Bauerle and Bowden (2011) address the effects of leaf width on transpiration, boundary layer conductance, and leaf temperature in red maple (*Acer rubrum* L.) genotypes. Kjølgren et al. (2011) present an overview of tropical urban forestry in Southeast Asia and focus on the response of tropical tree species that successfully tolerate the urban heat island and droughty urban soils in a changing climate. Ecological models of climate change impacts on tropical forest type distribution can yield insights into selection of tree species better suited to urban conditions in tropical cities. Shackel (2011) demonstrates the use of midday stem water potential as a reliable and practical measure of stress in woody fruit trees and vines and gives an example of its usefulness in applying regulated deficit irrigation for the purpose of increasing the field-scale uniformity of hull split in almonds (*Prunus dulcis* Mill.). Complementing such a technique is the use of sensors in the field to improve irrigation scheduling of vegetable crops. Shock and Wang (2011) discuss the use of soil moisture tension as a powerful measurement to improve crop productivity and elaborate on the pros and cons of using various sensors for irrigation scheduling.

As the climate continues to change in the next few decades or century, water availability (quantity and quality) and water management will continue to be important components for both agricultural production and urban landscapes. To cope with climate change, the implementation of adaptive strategies for resolving water stress in many agricultural regions becomes an imminent need. These strategies may include 1) the development and use of drought-tolerant and drought-resistant crops; 2) changes in agricultural land use and management, soil cultivation, fertilization, planting and harvesting times; 3) the implementation of WUE measures; 4) increase in the use of recycled and low-quality water for irrigation; and 5) the development of practical tools for irrigation scheduling and measuring plant water stress.

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