

Chapter 2

Adapting Irrigated Agriculture to Drought in the San Joaquin Valley of California

James E. Ayars

Abstract *Webster's* dictionary defines drought as a continuous state of dryness but does not define a cause for that dryness, just the existence. Irrigated agriculture is in a continuous state of drought by definition, simply because water is supplied by stored surface or groundwater supplies. This results in agriculture being in constant competition for that supply with municipal, industrial, and environmental uses—any one of which may have a higher right to the water supply than agriculture. Thus, even in times of plentiful water supply, a drought condition still could exist in irrigated agriculture. The challenge for agriculture is how to improve water productivity to compensate for any potential losses to competing demands. This chapter presents options for improved water productivity; including changing irrigation systems, improving use of water and fertilizer, and employing irrigation water management strategies, including deficit irrigation. Alternative water management strategies will be discussed, including defining production goals based on the available water supply, integrated water management of irrigation and drainage systems, cropping alternatives, and physical management of crops (e.g., pruning and thinning).

2.1 Introduction

Climate change and global warming are currently among the most discussed and researched environmental concerns throughout world. The effect of these phenomena on the hydrologic cycle is not well understood and, thus, the impact on future water supplies is unknown. Sustained drought is certainly one scenario resulting from global warming, and those areas of the world relying on stored

J. E. Ayars (✉)

USDA-ARS, San Joaquin Valley Agricultural Sciences Center, Parlier, CA, USA
e-mail: James.Ayars@ARS.USDA.GOV

water from rainfall runoff and snowmelt as the principal supply are facing an uncertain future (www.epa.gov/climatechange/basicinfo.html).

Drought is simply a prolonged period of dryness with no causal relationship, with potential causes being physical, regulatory, or any combination of these. In arid areas when water supply derives from melting snowpack, below-average snowpack over several years will result in reduced runoff and storage and, subsequently, reduced or no allocations to municipal and agricultural uses. In addition to the lack of water, regulatory restriction on the removal of water from a region or mandates to allocate more water to meet environmental demands can result in reduced or severely limited quantities of water for alternative uses.

California experiences intense competition for water among its urban, agricultural, and environmental interests because the state's water supply depends on the Sierra Nevada snowpack and a series of reservoirs to store the runoff from snow melt. Urban areas in Southern California rely on water transported the length of the state from reservoirs in Northern California. Other users of water stored in Northern California include agriculture on the west side of the San Joaquin Valley (SJV) and the Sacramento-San Joaquin River Delta, recently identified as the most significant estuary on the West Coast of the United States. The delta has a significant water demand for agriculture, recreation, and environmental restoration. The delta is also a critical component in the north to the south transport of water in California, and environmental regulations control the flow through the delta (CVPIA 1992). These regulations determine the volume required to flow through the delta for environmental purposes and the allowable pumping of water from the delta to the San Luis canal that carries water to Southern California. This multiple-use doctrine results in an on-going conflict between the water users with regard to the allocation of water (www.water.ca.gov/swp/delta.cfm).

Drought is an existing condition in California and will become a larger problem as the population of the state increases to more than 50 million people by 2050. In the past century, California has experienced four drought periods prior to the current drought from 2007 to 2009: 1929 to 1934, 1976 to 1977, 1987 to 1992, and 1999 to 2002. There have been several instances of a one-year below-average snowpack but only a few with multiple-year deficits. The drought extending from 1976 to 1977 resulted in less than 37 % of the average Sacramento Valley runoff for the period 1901–1996. The average runoff for this period in the San Joaquin Valley was 26 % of the average for the period 1901–1996.

In 2009, after three years of below-average snowpack in the Sierra Nevada in Northern California, the reservoir levels in the Central Valley Project (CVP) were reduced to critical levels and water supply to agriculture on the west side of the San Joaquin Valley was curtailed, due in part to pumping restrictions and in part to low water supply. The pumping restrictions were a result of the finding that the Delta smelt, an endangered species, was being harmed by the pumping of water from the delta to the San Luis canal for transport to agricultural users in the San Joaquin Valley and to municipal users in Southern California (WSJ 2009). In total, more than 200,000 ha of irrigated land in several irrigation districts were impacted by the lower water supplies from the Central Valley Project. Most of this area is

planted with annual crops but there are significant areas of trees and vines located in the affected irrigation districts.

While much attention was given to the plight of farmers on the west side of the valley, the east side farmers experienced little or no restriction in water use. There were adequate supplies from the dams in the state water project that supply water to east side water districts. Also, east side farmers rely heavily on groundwater as either the primary or supplemental supply and are thus not affected by the reduced snowpack or environmental constraints. Agriculture on the east side is dominated by perennial crops, which, as mentioned above, were not affected by water shortages in 2009.

A major difference in the water supply situation between the east and west sides of the San Joaquin Valley is the quality of the groundwater. The groundwater on the east side has a low electrical conductivity ($EC < 0.1$ dS/m) and is within 100 m of the ground surface. Water of this quality is suitable for all crops and does not present a hazard for soil salination. This is in contrast to the wells on the west side of the San Joaquin Valley that are typically in excess of 500 m deep with groundwater having an electrical conductivity of 1.0–1.5 dS/m and a boron content of 5–10 mg/L. This poor-quality water limits the crops that can be grown and the amount that can be used to simply sustain crop growth, albeit with negative impacts. Perennial crops are generally sensitive to salt and boron, and the groundwater found on the west side can only be used for a limited time to sustain crop production. As a result, good-quality surface water is critical to sustain irrigated agriculture on the west side of the San Joaquin Valley.

The situation in the San Joaquin Valley is unique. That is, while the drought is regional, only a relatively small area is impacted compared to the typical scenario that includes extensive land areas suffering from the lack of water. Yet while the area is small geographically, the impact is significant because of the high agricultural productivity of the affected region. Economic losses in the Central Valley due to the drought were estimated to be \$710 million in 2009 (RMN 2009).

The objective of this chapter is to highlight the management alternatives to sustain water productivity in semi-arid irrigated areas, e.g., the San Joaquin Valley, both in times of adequate water supply and during periods of drought.

2.2 Coping with Reduced Water Supply

A critical part of developing water management strategies is to understand the reality of crop production from the standpoint of the water requirement to meet production goals for a particular crop (e.g., with a forage crop the goal will be biomass, while in tree and vine crops it would be individual fruit). A reduction in applied water for alfalfa, for instance, will result in reduced yield, while a similar percentage reduction in water applied to peaches may result in the complete loss of yield.

The yield—evapotranspiration relationship (Eq. 2.1) has been characterized by many researchers as:

$$1 - (Y_c/Y_m) = K_y(Et_c/Et_m) \quad (2.1)$$

where Y_c is the crop yield resulting from crop evapotranspiration (Et_c). Y_m is the maximum yield related to the maximum evapotranspiration (Et_m) for a given crop cultivar, climate and conditions of the experiment; K_y is a regression coefficient. The relationship has been further refined to consider yield responses resulting from deficit irrigation at strategic periods in the growth cycle. This basic relationship can be further modified when salinity tolerance is considered. The Maas-Hoffman equation (Maas 1990) has been used to describe the relative yield response of plants to uniform salinity in the root zone, and is given as

$$Y/Y_m = 1 - B(EC_e - A_s) \quad (2.2)$$

where Y is the yield, Y_m is the maximum yield, EC_e is the average salinity in the root zone, B is the slope of the yield reduction with a 1 dS/m increase in the average soil salinity in the root zone, and A_s is the threshold where yield begins to decrease with increased salinity in the root zone.

Passioura (2006) discusses the objectives of water management with limited water supply in the context of grain crops grown in rain-fed agriculture. The goals are to transpire more of the limited water supply (Eq. 2.1); improve exchange of transpired water and CO_2 ; more effectively produce biomass; and convert biomass into grain or other harvestable material. To do this, he suggests several approaches that are applicable to irrigated agriculture as well. In regions with winter rainfall, soil and crop residue management will be important to improve infiltration and provide soil water storage. Timeliness of operation, ensuring evenness of establishment, and nutrient management will contribute to improved yield potential. Water supply management to reduce evaporation and surface runoff, and deep percolation losses is another important consideration.

Irrigation water management depends on the crop selection, the irrigation system, and the production goals. The importance of each of the components will be determined by the available water supply. When water is plentiful, any crop can be selected and the type of irrigation system used and its management are not given much consideration. As the water supply dwindles, crop selection is more focused and irrigation system efficiency is a prime concern. With abundant water, the production goal may be to maximize yield; conversely, with limited water it may be to break even or make some amount of profit. The challenge is to weigh the factors to determine the appropriate mix of cropping, irrigation system selection, and management to achieve the desired production goal. The following sections will discuss the water management implications relative to the selection and management of both crops and irrigation systems.

2.2.1 Crop Selection

Factors included in crop selection include the water requirement, the salt tolerance, and the seasonal growth period. The total crop water requirement will be an easy selection criterion (e.g., does it require 500 or 750 mm of water to be productive). Another consideration will be whether the total water supply can be met in part by rainfall. In the SJV, rainfall occurs primarily during the late fall, winter, and early spring, which means that crops grown using rainfall to supplement irrigation have to be suited to cool weather. The crop selection then is focused on vegetable crops (e.g., lettuce, broccoli, onion, all of which are short-season and cool-weather tolerant).

An alternative would be to develop a dry land production strategy that uses stored soil water and rainfall to produce a crop. This is typically done with a grain crop planted in the early winter that relies on winter rain for production. A decision can be made in the spring to provide irrigation to complete the crop or to accept yield losses and let the crop mature on existing soil water. This provides a money-making opportunity with little expenditure. Depending on the outcome from rainfall and the projected water supply, spring and summer cropping can be developed.

The salt tolerance of the crop will also be a factor in the crop selection. Many of the vegetable crops are salt sensitive and require good-quality (low-salinity) water for germination and growth. Field crops may be more salt tolerant than vegetable crops but have longer growing seasons and higher water demands. If both good- and poor-quality water are available, cropping pattern and irrigation management can be developed to incorporate both supplies (Rhoades 1989; Rhoades et al. 1989). When using saline water for irrigation, salt management in the soil profile is critical to limit salt accumulation in the root zone. While this may not be a problem the first year, over a period of extended drought surface salt accumulation may impact germination of subsequent crops. Future salinity management will require additional good-quality water for leaching.

Another factor in the cropping selection is the total economic return and its relationship to productivity. The concept of crop-water production function needs to be included in the discussion of crop selection and management. The crop-water production function is described as the crop yield and the applied water used to produce it. The shape of the curve will reflect the over or under irrigation of the crop. As noted previously, yield is nearly a linear function of the evapotranspiration—when the yield is related to the applied water, the deviation of applied water to the crop requirement results in a non-linear response. Singh et al. (1987) substituted evapotranspiration for applied water and obtained a non-linear response for wheat that is demonstrated in Fig. 2.1. Crop water production curves are also impacted by water quality as well as the depth of applied water. As the electrical conductivity increases, additional water is applied to provide a leaching fraction to control soil salinity. The additional water does not provide a proportional increase in yield, which results in a non-linear response.

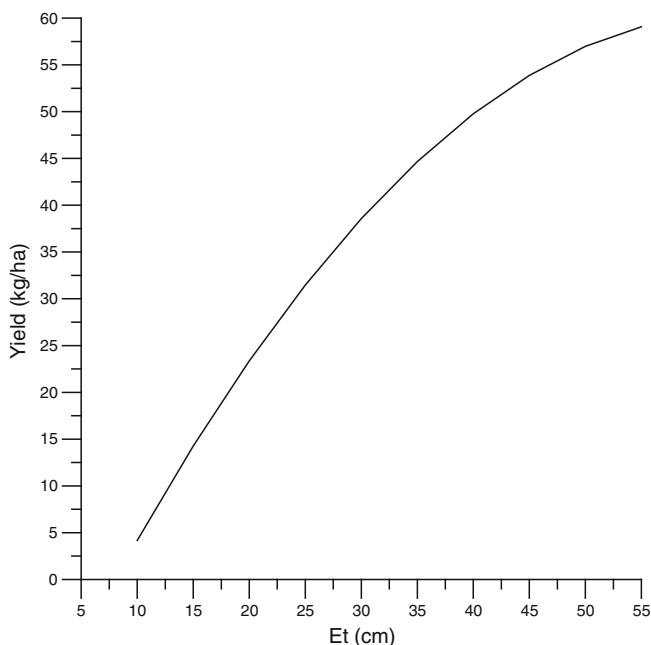


Fig. 2.1 Typical crop-water production function after Singh et al. (1987)

The term water productivity and water use efficiency are used to describe yield as a function of applied water. In the case of deficit irrigation, the water productivity or efficiency can be high because of deficit irrigation. High water productivity does not necessarily correspond to maximum yield, since the yield function is not linear in relation to applied water. As yields are maximized, the return on applied water is reduced, so the maximum water productivity may not be at maximum yield. Most farmers do not operate with that set of criteria, since the yield response curves may not be well defined and this requires an additional level of management.

The interactions of water and fertilizer on yield are not well researched. Phene et al. (1986) demonstrated significant increases in water productivity of tomatoes when nitrogen, phosphorous, and potassium were added to the irrigation water and the crop water requirement was met. These increases were a result of the fertilization, not additional applied water. Thus, in a water-short year, fertilization may be used with a deficit-irrigation strategy to maintain production sufficiently to remain economically viable. Knapp and Schwabe (2008) demonstrated how efficient nitrogen management varies with water applications and irrigation efficiencies in the case of corn within a spatial dynamic model.

It is possible to develop a cropping sequence that effectively uses the available water supply to produce crops at less than maximum or even optimum yields, but results in a better net return than can be achieved by using the total supply on a

single crop. This strategy requires the manager to develop a yield and input strategy that optimizes the inputs of seed material, fertilizer, applied water, soil water, and labor. It can be very effective if rainfall is included as part of the strategy. This concept needs additional research.

2.2.2 Irrigation System Selection

A goal in irrigation management is to achieve a high value of irrigation efficiency, which is a performance parameter that describes the ratio of the beneficially used water and the water applied to a field. Beneficial uses include evapotranspiration, cooling, frost protection, and salt management—not just Et_c. This means that there will be some losses to deep percolation needed for salinity control to maintain productivity. The objective of the system design and operation is to control the losses to what is needed and to distribute the losses uniformly across the field. The distribution uniformity (DU) is the measure used to describe the water lost to deep percolation from irrigation. Typically, surface systems, (furrow, border) are assumed to have the poorest DU's because the infiltration is controlled by the soil surface and the length of time water is on the soil surface. With surface irrigation, there is potentially a large difference in infiltration opportunity time between the head and tail ends of the field. Aggressive management can minimize the differences. This type of distribution non-uniformity is generally not present in properly designed and operated pressurized systems since water is delivered across the field in a pipe.

Improved irrigation efficiency is generally assumed to be associated with selection of advanced irrigation equipment, e.g., switching from surface irrigation methods to pressurized systems. This is true to some extent, but simply buying a new sophisticated irrigation system does not lead to improved water management unless significant effort is made to use this system properly. An often overlooked factor in irrigation system design and management is the selection and design of a system to fit the conditions, e.g., the soil type, field size, source of water, available water supply, management skill, and crops. Unless these factors are considered, there is no guarantee of improved irrigation efficiency and productivity.

In the SJV, the majority of the cropping is field crops (e.g., tomato, cotton, melons), which have typically been irrigated using surface irrigation that is ideally suited for the valley conditions due to the existing clay loam soils with gentle slopes. The lower cost of the system has made the existing cropping profitable. Irrigation efficiency ranges from 75 to 85 % with good management. Hand-move sprinkler systems are also used for germination and some seasonal irrigation (Ayars 2003). These systems are capable of better irrigation efficiency than surface irrigation (Hanson and Ayars 2002). However, labor costs are a limitation with using hand-move sprinklers.

A shift from either surface or sprinkler system to micro-irrigation systems was generally not considered because of the additional cost of the micro-irrigation system. The cost of surface irrigation is in the range of \$185 to \$370 per ha, while

a micro-irrigation system can cost up to \$3,700 per ha. Also, micro-irrigation systems were not generally suited to field crops. The transition from surface to pressurized systems has been driven by reduced water availability and reduced labor availability.

There has been extensive adoption of subsurface drip irrigation (SDI) on tomatoes and vegetable crops (lettuce, peppers, broccoli) being grown on the west side of the SJV. Tomato yields were improved by nearly 20T/ha when converting from surface to SDI. This was a result of being able to match the crop water demand and to apply fertilization to meet crop requirements. The adoption also has been facilitated by improvements in the drip tape size that permitted longer lateral lengths (300 m) and development of equipment to install and retrieve drip tape. Additionally, the use of differential global positioning systems to guide the tractor during the installation of the drip tubing has enabled improved cultivation in fields with permanently installed tubing.

Labor constraints along with reduced water supplies have resulted in a reconsideration of the use of center pivot sprinklers in the SJV. Center pivots and linear move irrigation systems were tried in the 1980s and 1990s with very little success. The soils on the west side of SJV are clay and clay loam soils with low-infiltration rates; consequently, the early machines were not designed to keep water off the wheel tracks so that ponding occurred which resulted in machines getting stuck (Ayars et al. 1991). Current designs are using spray packages that reduce application rates and also keep the wheel tracks dry.

Well-managed micro-irrigation and sprinkler systems have the capability to match crop water use and fertilizer requirements at high levels of irrigation efficiency. The added benefit is that deep percolation losses are significantly reduced, which reduces the drainage disposal problem found on the west side of the SJV (Ayars 1996). SDI has been demonstrated to be effectively used in crop production in the presence of shallow groundwater without the need for subsurface drainage (Ayars et al. 2001; Hanson et al. 2006).

2.2.3 Water Management

Water management will be a critical component in coping with reduced water supply. The first step in improved water management is to implement irrigation scheduling to provide water when and in the quantities needed by the plant. This is routinely done using an evapotranspiration-based approach where the crop water use is determined based on the climate and stage of plant development. The equation is

$$Et_c = K_c * Et_o \quad (2.3)$$

where Et_c is the crop evapotranspiration, Et_o is the reference crop potential evapotranspiration, and K_c is the crop coefficient that is a function of the plant

development. The product of E_{t_0} and K_c is the crop evapotranspiration E_{tc} or the crop water use during a specified time. The irrigation schedule is constructed by accumulating the water use (E_{tc}) until a predetermined threshold value of water lost is reached at which time irrigation is initiated to replace the lost water. The threshold is developed based on the age of the crop, and the soil's water-holding capacity, and the allowable depletion of the soil water. An alternative method is to operate on a high-frequency schedule in which the goal is to supply water on a nearly daily basis. In this case, soil water storage is not a critical component in the scheduling methodology and an accurate measure of the water loss is required.

The accumulated plant water use from soil water is then replenished to sustain the plant development with minimum stress. The depth of irrigation will be equal to the lost water. This value will be adjusted to account for the efficiency of the irrigation system. The adjustment for efficiency will attempt to minimize the yield lost to deficit irrigation in parts of the field due to distribution non-uniformity. The irrigation frequency will depend on the soil type, the irrigation system, the crop growth stage, and the susceptibility of yield loss to water stress.

Soil type affects the amount of stored soil water, with sand having a lower storage potential than loams and clay soils. With reduced storage, irrigation frequency will have to be increased to limit water stress. The irrigation system operational characteristics determine how frequently irrigation can occur. Surface systems typically apply 75–100 mm of water during each irrigation event, while pressurized systems can apply as little as 10 mm per event. As a result, the pressurized systems are used for high-frequency irrigation (daily), while surface systems are used for weekly or longer irrigation intervals. The effectiveness of this approach relies on a good understanding of the crop water requirements during the growth cycle and adequate climate information.

Extensive work has been done in California to determine the crop water requirements and the development of the crop coefficients needed for irrigation scheduling for a wide variety of crops (Ayars et al. 2003; Ayars and Hutmacher 1994; Grattan et al. 1998; Hanson et al. 2003). The California Irrigation Management Information System (CIMIS) has weather stations located throughout the state that can be used to determine the potential evapotranspiration needed to determine crop water use. In addition to California, Arizona, Kansas, Texas, and Washington State operate weather networks for irrigation scheduling.

One solution for annual crops during water shortages is to forgo planting a crop or, alternatively, attempt dryland agriculture and rely solely on rainfall (e.g., cereal crops). If some water is available, a survival strategy needs to be developed that depends on the total available water. Approaches include production on limited acreage for crops with high-water demand or switching to short-season crops with lower water demand, and use in conjunction with rainfall and stored soil water.

Perennial crops that are currently in production create a different problem because irrigation is necessary. The decision is further complicated by the type of crop, i.e., whether it is a tree or vine crop. The selected strategy will depend on the volume of available water. One strategy will be to opt for an economic level of

production on a portion of the acreage and restrict irrigation or stress the remaining acreage.

For tree crops, the time of fruit maturity will also provide some opportunities for water savings. An early maturing crop can be nearly fully irrigated prior to harvest and stressed after harvest with limited impact on subsequent crops. In the San Joaquin Valley, the greatest portion of the E_t for an early maturing peach crop occurs after harvest (Johnson et al. 1992, 1994).

Two water management strategies have been proposed for controlling plant water stress during reduced irrigation. The first is regulated deficit irrigation (RDI). The concept is that there are periods of growth when the plant can be put under stress without significantly impacting yields, which allows economic levels of production with reduced water requirement. It has been successfully demonstrated on fruit and nut crops (Chalmers et al. 1981, 1986; Johnson et al. 1992; Goldhamer et al. 2006). The RDI strategy as currently practiced provides full water supply during periods of fruit growth development and significantly reduced supply during other periods.

An alternative strategy would be to decrease the water supply over the entire growing season. Implementation of this strategy requires knowledge of the crop water requirement which may not be well defined. Williams et al. (2010) demonstrated that the yield of Thompson Seedless grapes was not affected when grown with a sustained deficit of 80 % of crop water use, measured with a weighing lysimeter. In either case, the water requirements during the production cycles are not well known for most crops.

The second water management strategy is known as partial root zone drying (PRD) (Costa et al. 2007; Kang et al. 2002). This method dries down a portion of the crop root zone while maintaining soil water in the remainder of the root zone and then switches to another section of the root zone. The concept is to induce stress in a portion of the plant supplied by the stressed portion of the root zone, resulting in a chemical signal being sent to the stomata which close and reduce plant transpiration and, thus, total water requirement. This has been implemented using two drip irrigation laterals that were placed on each side of a grape vine, and the irrigation is alternated between each side of the vine. This results in the alternate wetting and drying of the soil with induced stress in part of the root zone. A drawback in this approach is the additional cost due to the extra irrigation equipment. The success of the approach depends on the crop being responsive to the drying down. In soils with large water-holding capacity, there may not be an advantage over regulated deficit irrigation, since there may be inadequate drying of the soil and stress development (Sadras 2009).

Shallow groundwater represents an alternative supply in many arid and semi-arid irrigated areas. When the groundwater is a result of poor irrigation practice, the supply may be limited; there may be situations, however, in which the groundwater is a result of lateral flow from another water source. In this instance, there may be enough supply to develop management practices to use this water (Christen and Ayars 2001). If the area requires subsurface drainage, the drains can be managed to control the water table position to facilitate in situ use by the crop

(Ayars et al. 2007). Crops have the potential to get up to 50 % of the water requirement from shallow groundwater, depending on the groundwater salinity, crop salt tolerance, and depth to groundwater (Ayars et al. 2006). Such an option makes the groundwater a potential valuable resource during droughts.

2.2.4 Agronomy

One approach proposed for crop drought management in perennials is to engage in severe pruning of the tree or vine and lose production for that year. Implementing this strategy with a vine crop may result in just a one-year loss, since vines are heavily pruned every year. Severe pruning of a tree crop may result in a two- to three-year loss of production, since the entire scaffold may be eliminated and it will take several years to regain the structure needed for production.

As Passioura (2006) has indicated, the role of agronomy will be to conserve water and produce the maximum yield possible with the stored supply. One practice is to capture rainfall with tillage to incorporate stubble to improve infiltration and to produce a mulch that minimizes evaporation losses. Precision agriculture will play a role in this system by insuring uniform stand establishment and precision application of fertilizers. Fertilization strategies will be required to manage plant growth and yield based on existing water supplies. The goal would be to prevent luxurious use of fertilizer that would result in vigorous plants that cannot be sustained with the stored soil water and the available irrigation supply. Weed management will also be a part of the strategy, since weeds are a non-beneficial user of water and need to be eliminated.

Surface water management will also be required. The field should be prepared to insure infiltration of rain and to minimize water lost to surface runoff. In irrigated areas, tailwater return pits and other water conservation structures can be used for storage and recycling surface runoff.

Cultivar selection will be important in a drought strategy, since each cultivar will have its own characteristics for water productivity. The harvest index (HI) is a measure of the yield of the crop to the biomass created and is often used to characterize the productivity of a crop (Howell 1990). The higher the index, the greater is the yield relative to the biomass. This demonstrates a partitioning of the transpired water to the fruit and not the biomass, which is a desirable characteristic for the crop.

2.2.5 Alternative Water Supply

In the San Joaquin Valley, the surface water supply is high quality (low salinity) and has no restrictions on use while the ground water quality varies from high quality on the east side to saline (1–15 dS/m) on the west side. In water-short

periods alternative supplies will need to be considered, including saline ground-water and treated municipal effluents. A major problem will be in the delivery of this water to the farm. There may be some opportunities for poor-quality water in one area to be mixed into the good supply for transport to another region for use. However, this is limited since this might be part of a municipal supply as well.

Treated municipal wastewater also represents an alternative supply for agricultural use. Extensive research has demonstrated the feasibility of this approach (Angin et al. 2005; Carr 2005; Dugan and Lau 1981; Koo and Zekri 1989). Regulations allow the application of treated waste water to feedstuff for animals and prohibit the direct application to food that will not be processed prior to consumption. One limitation on this supply is access. The infrastructure needed to supply water is generally not in place and, hence, mixing with existing surface supplies for transport via a canal will not be a viable alternative, since that water may also be a municipal supply.

Treated wastewater is currently being used in California for irrigating highway landscape, control of salt water intrusion and in some agricultural enterprises located near cities. The Irvine Ranch Water District (IRWD) in Orange County, California, is currently using treated wastewater on approximately 400 ha of crops. Water produced by IRWD carries an Unrestricted Use Permit from the California Department of Health Services and thus meets the requirements of Title 22 of the State Health Code, which is of high enough quality to be used in swimming pools. The treated wastewater is just one component of the total water supply for the IRWD.

2.2.6 Future Concepts

In the future, irrigated agriculture will have to make every drop of water count and will rely increasingly on poorer-quality water as part of the supply, thereby requiring increased levels of management. Farmers may also be faced with a smaller labor pool, which increases the need for sophisticated technology to control the irrigation systems and the determination of water requirements. Much of the data to accomplish this task has yet to be collected.

The interaction of irrigation and fertilizer management is one area that needs extensive research. Past research has shown the need and effect of fertilizer on crop productivity when fully irrigated, but additional research is needed to determine the effects of fertilization on yield at less than full irrigation. In addition, work needs to continue to define the crop water requirements, since new cultivars are being developed continually.

Decision support systems will need to be developed for crop production based on water productivity. This requires a determination of the crop water production function curve for a range of water management strategies (e.g., sustained deficit irrigation or deficit during particular growth stages). This support system will need real-time feedback of soil water status and plant water use to assist in the irrigation schedule.

Water quality and the effects on soil quality and plant growth and quality will be another area of concern. Traditionally, water quality has been related to salinity and the osmotic effect of increased soil water salinity on plant growth and yield; however, as treated wastewater becomes a potential supply, additional contaminants will have to be considered. Municipal wastewater includes the traditional salts but also the potential for heavy metals and a wide range of pharmaceutical compounds that may have a significant impact on the soil flora and fauna with yet-to-be determined effects on plant growth and quality.

Salinity management has always been a component of water management in irrigated agriculture; however, salt has been approached as something to be eliminated from the soil profile. This is not a viable approach any longer because of the potential for significant environmental damage from the discharge of salt from subsurface drains (Ayars et al. 2007). Salt management in the past required excess amounts of water to remove salt from the crop root zone. Future management must be focused on maintaining the salt in the root zone at a level that will not negatively impact crop production that will require improved monitoring capability and a better understanding of crop salt tolerance.

Salt management also will be impacted by drainage system design and management (Ayars et al. 1997). Implementing new drainage system designs with controls will reduce the total salt load from the system and improve the water management by increasing in situ crop water use. This will require additional technologies for real-time control of the drainage system and development of equipment to retrofit existing drainage systems.

Precision agriculture will play a significant role in the future. The ability to match the crop demand for water and fertilizer and to selectively manage the salt across the field may have a significant impact on productivity and the conservation of resources.

2.3 Conclusions

The population of California is projected to increase from the current approximately 35 million people to 50 million people by 2050. Decisions will need to be made on how to accommodate the water supply needs for this population. In addition to the population, there will be demands for industrial water supply and environmental uses, and the role of agriculture will be questioned. Since agriculture is the single largest water user in the state, it will be the first source to be considered for supply reductions, and questions will have to be answered as to the volume of supply that will be made available. Potential supply reductions will depend on many of the factors discussed above, but also include consideration of the state's ability to develop additional water storage and the type of storage. The options are to build additional reservoirs, increase the size of existing structures when possible and/or conjunctive use (groundwater recharge). Any solution will require a large investment; the investment will depend on the water demand and

what policy decisions are made with regard to the extent of the agricultural enterprise in California.

Another factor in the decision is the impact of California agriculture in the food supply system within the United States and the world. California supplies nearly 100 % of the production of several commodities in the United States, and loss of this production will have implications with regard to food security and food costs. Economists argue that water will provide a larger return when used in production of silicon chips and thus that may be a better use of water from an economic view. However, economics cannot be the single consideration in this instance.

If a decision is made to sustain agriculture, it will probably be with a mixture of high-quality water and impaired water from saline groundwater and municipal sources. In this instance, there will need to be infrastructure developed to implement this strategy. This will require transporting water from a municipal site to a storage and distribution facility that is accessible to the agricultural community. Another alternative may be the “toilet to tap” concept where municipal water is treated to a level that makes it suitable as water supply. While technically feasible, this is an alternative that is not currently politically acceptable.

References

- Angin I, Yaganoglu AV, Turan M (2005) Effects of long-term wastewater irrigation on soil properties. *J Sustain Agric* 26:31–42
- Ayars JE (1996) Managing irrigation and drainage systems in arid areas in the presence of shallow groundwater: case studies. *Irrig Drainage Syst* 10:227–244
- Ayars JE (2003) Field crop production in areas with saline soils and shallow saline groundwater in the San Joaquin Valley of California. *J Crop Prod* 7:353–386
- Ayars JE, Hutmacher RB (1994) Crop coefficients for irrigating cotton in the presence of groundwater. *Irrig Sci* 15(1):45–52
- Ayars JE, Hutmacher RB, Schoneman RA, Dettinger DA (1991) Influence of cotton canopy on sprinkler irrigation uniformity. *Trans ASAE* 34:890–896
- Ayars JE, Grismer ME, Guitjens JC (1997) Water quality as design criterion in drainage water management system. *J Irrig Drainage Eng* 123:148–153
- Ayars JE, Christen EW, Soppe RWO, Meyer WS (2006) Resource potential of shallow groundwater for crop water use. *Irrig Sci* 24:147–160
- Ayars JE, Johnson RS, Phene CJ, Trout TJ, Clark DA, Mead RM (2003) Crop water use by late season drip irrigated peaches. *Irrig Sci* 22:194
- Ayars JE, Christen EW, Hornbuckle JW (2007) Managing irrigation and drainage in saline environments. *CAB Rev: Perspect Agric Vet Sci Nutr Nat Resour* 2:13
- Ayars JE, Schoneman RA, Dale F, Meso B, Shouse P (2001) Managing subsurface drip irrigation in the presence of shallow groundwater. *Agric Water Manag* 47:243–264
- Carr R (2005) WHO guideline for safe wastewater use—more than just numbers. *Irrig Drainage* 54:103–111
- Chalmers DJ, Mitchell PD, van Heek L (1981) Control of peach tree growth and productivity by regulated water supply, tree density, and summer pruning. *J Am Soc Hortic Sci* 106:307–312
- Chalmers DJ, Burge G, Jerie PH, Mitchell PD (1986) The mechanism of regulation of “Bartlett” pear fruit and vegetative growth by irrigation withholding and regulated deficit irrigation. *J Am Soc Hortic Sci* 111:904–907

- Christen EW, Ayars JE (2001) Subsurface drainage system design and management in irrigated agriculture: best management practices for reducing drainage volume and salt load. CSIRO Land and Water Australia, Technical Report 38-01:130
- Costa JM, Ortuno MF, Chaves MM (2007) Deficit irrigation as a strategy to save water: physiology and potential application to horticulture. *J Integr Plant Biol* 49:1421–1434
- CVPIA (1992) Public law 102–575 Central Valley Project Improvement Act
- Dugan GL, Lau LS (1981) Sewage irrigation and recharge consequences, Oahu. *J Environ Eng Div* 107:699–711
- Goldhamer DA, Viveros M, Salinas M (2006) Regulated deficit irrigation in almonds: effects of variations in applied water and stress timing on yield and yield components. *Irrig Sci* 24:101–114
- Grattan SR, Bowers W, Dong A, Snyder RL, Carroll JJ (1998) New crop coefficients estimate water use of vegetables, row crops. *Calif Agric* 52:16–21
- Hanson B, May D, Voss R, Cantwell M, Rice R (2003) Response of garlic to irrigation water. *Agric Water Manag* 58:29–43
- Hanson BR, Ayars JE (2002) Strategies for reducing deep percolation in irrigated agriculture. *Irrig Drainage Syst* 16:261–277
- Hanson BR, Hutnacher RB, May DM (2006) Drip irrigation of tomato and cotton under shallow saline groundwater conditions. *Irrig Drainage Syst* 20:155–175
- Howell TA (1990) Water use by crops and vegetation. In: Stewart BA, Nielsen DR (eds) *Irrigation of agricultural crops, agronomy no, 30th edn*. American Society of Agronomy, Madison, pp 391–434
- Johnson RS, Handley DF, DeJong TM (1992) Long-term response to early maturing peach trees to postharvest water deficits. *J Am Soc Hortic Sci* 117:881–886
- Johnson RS, Handley DE, Day KR (1994) Postharvest water stress of an early maturing plum. *J Hortic Sci* 69:1035–1041
- Kang S, Hu X, Goodwin I, Jerie P (2002) Soil water distribution, water use, and yield response to partial root zone drying under a shallow groundwater table condition in a pear orchard. *Sci Hortic* 92:277–291
- Knapp K, Schwabe K (2008) Spatial dynamics of water and nitrogen management in irrigated agriculture. *Am J Agric Econ* 90(2):524–539
- Koo RCJ, Zekri M (1989) Citrus irrigation with reclaimed municipal wastewater. *Proc Florida State Hortic Soc* 102:51–56
- Maas EV (1990) Crop salt tolerance. In: Tanji KK (ed) *Agricultural salinity assessment and management*. American Society of Civil Engineers, New York, pp 262–304
- Passioura J (2006) Increasing crop productivity when water is scarce—from breeding to field management. *Agric Water Manag* 80:176–196
- Phene CJ, Bar-Yosef B, Hutnacher RB, Patton SH, Davis KR, McCormick RL (1986) Fertilization of high-yielding subsurface trickle irrigated tomatoes. In: *Proceedings of the fertilizer conference and trade exhibit, Fresno, CA*, pp 33–43
- Rhoades JD (1989) Intercepting, isolating and reusing drainage waters for irrigation to conserve water and protect water quality. *Agric Water Manag* 16:37–52
- Rhoades JD, Bingham FT, Letey J, Hoffman GJ, Dedrick AR, Pinter PJ, Replogle JA (1989) Use of saline drainage water for irrigation: imperial valley study. *Agric Water Manag* 16:25–36
- RMN (2009) California drought and jobs: budget. *Rural Migr News* 15:1
- Sadras VO (2009) Does partial root-zone drying improve irrigation water productivity in the field? A meta-analysis. *Irrig Sci* 27:183–190
- Singh P, Wolkewitz H, Kumar R (1987) Comparative performance of different crop production functions for wheat (*Triticum aestivum* L.). *Irrig Sci* 8:273–290
- Williams L, Grimes DW, Phene CJ (2010) The effects of applied water amounts at various fractions of measured evapotranspiration on reproductive growth and water productivity of Thompson seedless grapevines. *Irrig Sci* 28:233–243
- WSJ (2009) California's man-made drought. Opinion page Wall Street J 2 Sept, Online wsj.com

Drought in Arid and Semi-Arid Regions

A Multi-Disciplinary and Cross-Country Perspective

Schwabe, K.; Albiac Murillo, J.; Connor, J.D.; Hassan, R.;

Meza González, L. (Eds.)

2013, XXI, 507 p., Hardcover

ISBN: 978-94-007-6635-8