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Subsurface drip irrigation in California—Here to stay?

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ABSTRACT

Subsurface drip irrigation (SDI) has been used in California for over 30 years. Adoption occurred first in high value annual row crops. Over the years as drip irrigation materials, installation equipment, and irrigation scheduling tools have evolved, SDI has gained wider acceptance and is now being used in perennial crops as well on a limited basis. We discuss the early research on SDI in California and provide examples of the current commercial practices in both annual and perennial crops. These examples demonstrate how research preceded on-farm adoption and contributed to the implementation of SDI in California's production agriculture. SDI is being implemented throughout the world and these examples of implementation in production agriculture will be of interest in countries adopting the technology. Significant benefits are identified in terms of increased yield, improved crop quality, reduction in applied water and reduced agronomic costs for weed control, fertilization, and tillage. Improved water management is crucial for a sustainable future and SDI will be one tool that is available to improve water productivity.

1. Introduction

The competition for water between agriculture, municipal supplies, and the environment is now and will become more intense in the future, as the world population increases and the effects of climate change are felt. Since agriculture uses from 70 to 90% of the developed water supply (Postel, 1999), it will be the first source exploited to meet the competing demands for water. It is important to remember that nearly 40% of the world food supply comes from irrigated agriculture (Postel, 1999) and there will be additional pressure in the future to meet increased food demands. To meet the twin challenges of conserving water and increasing the food supply, irrigated agriculture will have to improve water productivity, e.g. “more crop per drop”.

California has nearly 2.8 million ha of irrigated land that is irrigated primarily with surface irrigation. The irrigation efficiency in California is generally higher than the world average (DWR, 2009), however, recent drought (2014) and environmental requirements have limited the availability of water to nearly 240,000 ha of land primarily in the Central Valley (San Joaquin and Sacramento Valleys) with nearly 100,000 ha being idled in 2014. Areas outside the Central Valley (Imperial, Coachella, Salinas, Napa, and Sonoma Valleys) are also water limited and rely extensively on groundwater as a significant supplemental supply to surface water and rainfall. Currently, treated wastewater is also being used as a supplemental source of irrigation on a limited basis. Over the past 25 years there has been a significant shift in irrigation technology in California from surface to pressurized irrigation with a significant component being microirrigation including mini-sprinklers, micro-sprays, surface drip, and subsurface drip (SDI).

SDI is the smallest component of microirrigation but is gradually gaining wider acceptance. Excellent reviews of subsurface drip irrigation research are provided by Lamm et al. (2007) and Camp (1998) and the following discussion relies heavily on those references.

The major advantages of SDI in the soil–water environment include: more efficient water use since surface evaporation, surface runoff, and deep percolation losses can be reduced or nearly eliminated. Subsurface drip facilitates the use of degraded quality water (Palacios-Díaz et al., 2009), by increasing irrigation frequency thus minimizing the matric and osmotic stress, and in cases of treated wastewater reducing pathogen movement, odors, and animal and human contact. The advantages related to cropping and cultural practices include: enhanced plant growth, yield, and quality of produce due to the timing and placement of water and nutrients in the crop root zone.

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Plant health is improved because of reduced fungal pathogens due to lower humidity within the plant canopy and reduced surface wetting of planting beds. SDI can also be used effectively for soil fumigation (Woodrow et al., 2008). SDI has the advantage of concise and timely application of pesticides and fertilizers which also increases efficiency and guards against non-point pollution because of reduced deep percolation losses.

Since the SDI system is buried, there is a significant reduction in the weed germination and growth particularly in the area between rows. Options for double cropping in some areas are improved in comparison to surface drip irrigation as there is no need to remove the drip lines at harvest and reinstall before planting. Farming operations and management are facilitated since the drip laterals are buried and damage due to farm equipment and field labor is minimized. Additionally, there should be no vehicle traffic over the drip tubes/tapes at any time.

Infrastructure advantages include: the ability to automate the system and have a closed loop system between a system controller and various field sensors that are ideally suited for water and nutrient efficiency. The energy costs are decreased due to lower operating pressures compared to sprinkler irrigation. An SDI system has fewer mechanized parts than an automated center pivot or linear move sprinkler systems and it is made of plastic and corrosion resistant materials.

There is significant design flexibility to match the shape of fields and sizes compared to center pivots and linear move systems. The effect of sprinkler operation on reduced infiltration due to droplet impact is eliminated, as is wetting of plant surfaces that may induce foliar diseases or salt toxicity when poor quality water is used. The lateral spacing is flexible for widely spaced crops which optimizes water and nutrient placement. When properly designed and operated they have long lives that permit amortization over longer periods and potential for use on lower value crops. There is also reduced damage from pests.

The disadvantages often mirror the described advantages. The SDI systems tend to have smaller wetting patterns than surface drip which is particularly important when used on coarse textured soils since it results in a reduced wetting zone. The reduced storage capacity of coarse soil may have a significant impact due to limited stored soil water when faced with system shutdowns. One of the most difficult aspects is that the SDI system is not visible. Thus, it is difficult to evaluate system operation and application uniformity and without careful monitoring, the potential for mismanagement is significant. The interaction between soil infiltration rates and application rate is/or can be a significant problem. Improper system design and installation can result in poor distribution around the dripper or water forcing its way to the soil surface if not buried deep enough. Germination may be a significant problem with use of SDI because of the minimal upward movement of water particularly in coarse textured soils. Salt accumulation at the edge of the wetted zone that envelops the dripper and salt management in the root zone are potential concerns. Proper design of the irrigation system must be based on the anticipated radius or distance of wetting front (r) from the dripper which is dependent on the soil texture, structure, and the hydraulic conductivity of the soil and discharge rate of drippers (q). The wetting front is the location of the largest accumulation of salts so the wetting fronts from neighboring drippers must overlap in the main mass of roots to more evenly redistribute and leach root zone salinity and prevent excess salt accumulation… On the basis of these considerations the designer will suggest drip line (lateral) placement, i.e. distance between two adjacent drip lines (laterals) and the distance between drippers within a single drip line. The optimum planting bed configuration for row crops will be based upon these soil and SDI design considerations. The row spacing is then based on the lateral spacing.

Cropping and cultural practices are impacted by potentially different or fewer tillage operations because of the drip line placement. Conventional tillage methods such as ripping, plowing, or disking to eliminate compacted layers at a depth of 0.3 m or deeper may no longer be possible or necessary with SDI. It may still be possible to provide some precisely guided ripping between the laterals providing the system was installed using GPS guidance equipment. New tillage equipment and approaches to cultivation using permanent or semi-permanent planting beds and different harvest methods may be needed. However, after the initial purchase of new equipment for SDI installation, tillage, planting and harvest, the reduction in draft requirements and energy for less tillage and production is likely to reduce farming costs in the long run and change this from a disadvantage to an advantage.

Plant root development may be restricted because the operation of the drip system limits movement of water. Changes in planting configurations from season to season should be avoided or limited due to the permanent design of drip laterals and drippers within each lateral line. If this is not adhered to, then the potential exists for poorly performing SDI systems and damage to the drip lines from wheel traffic (Ayars et al., 1999).

Issues related to infrastructure include: a higher initial investment for SDI compared to other systems and very little resale or salvage value. Filtration is critical to ensure the SDI drippers do not become clogged. It is difficult to confirm that emission rates are restored once clogged because the SDI emitters are hidden from view. Use of flow meters and routine recordkeeping of applied water are necessary to troubleshoot clogging problems. A clogged SDI system will apply less water than designed. Careful attention for visual clues (plant stress, water on the soil surface) or direct measurements of crop stress help ensure successful SDI operation.

One critical facet of the operation of an SDI system is the frequency of irrigation. Surface and sprinkler irrigation systems typically apply more water in a single irrigation and have irrigation schedules that provide water on a weekly or even longer time frame. However, both surface and subsurface drip systems are generally operated such that the irrigation frequency is increased to daily or near daily operation. This is a significant departure from other irrigation methods and requires constant monitoring and data input to describe the total applied water for a given irrigation. The implementation of higher frequency irrigation has resulted in improved yields and reduced percolation losses compared to surface and sprinkler pipe systems. This requires a major management commitment and usually requires a change or enhancement of management skills when the decision is made to implement SDI.

As the scarcity of water has intensified in California and greater attention is placed upon irrigated agriculture to manage it, interest in SDI has also drawn attention from the fruit and nut, and alfalfa forage industries. Over 550,000 ha fruit and nuts primarily, almond, walnut, pistachio, and stone fruits and approximately 405,000 ha of alfalfa are grown statewide. Fruit, nut, and berry farms account for 47% of all farms in California and they produce 40% of the farm sales ($17 billion).

Additional incentives for SDI include: improved orchard access for timely disease and insect control; reduced orchard humidity and incidence of diseases; less damage to above ground irrigation lines from coyotes and other vertebrate pests; decreased applications and costs for gypsum and other amendments used with above ground systems to enhance water infiltration; more efficient fertilizer use; reduced weed control cost for orchard floor and maintenance of an orchard floor that is conducive to efficient harvest.

The objective of this paper is to characterize the current state of implementation of SDI in commercial irrigated agriculture in California and discuss its future potential. We will highlight previous research in California and how it has contributed to the