Optimization of Water and Nitrate Use Efficiencies for Almonds Under Micro Irrigation

Project No.: **10-HORT15-Hopmans**

Project Leader: Jan W Hopmans
Department of Land, and, Air and Water Resources
UC Davis
One Shields Ave.
Davis, CA 95616
(530) 752-3060
jwhopmans@ucdavis.edu

Project Cooperators and Personnel:
Maziar M. Kandelous and Blaine R. Hanson, Department of Land, Air and Water Resources, UC Davis
Patrick Brown, Department of Plant Science, UC Davis
David R. Smart, Department of Viticulture and Enology, UC Davis

Objectives:

The proposed modeling study provides critical information on the movement of water and nutrients through the soil under drought and wet conditions, and provides insight into the interactions of irrigation, fertilizer, soil, and crop root growth on nutrient use efficiency, minimizing losses of water (leaching and evaporation) and nitrogen (leaching and denitrification), and crop yield by water and salinity stress. Implications of the results do not only apply for almonds to California, but are worldwide.

The goal of this research project is to field validate, optimize and refine the HYDRUS model under a variety of fertigation regimes and two fertilizer sources using the on-going nutrient study in almonds implemented by P Brown et al.. Results will be used to optimize the management of irrigation and fertigation in an almond orchard. The specific objectives of this project are:

1. To evaluate the results of the HYDRUS model using extensive field data for specific treatments, and refine it if so needed;
2. To determine optimal irrigation and fertigation practices for micro-irrigation (drip and micro-sprinkler) systems for almond using HYDRUS, to improve water and nutrient use efficiencies, and to reduce leaching and gaseous losses of nitrates, using a wide range of possible management scenarios (water, fertigation, salinity) and 2 fertilizer sources.

The objectives are achieved by collecting new field data such as soil hydraulic and textural properties, monitoring of soil moisture, temperature variation and nitrate concentration for selected treatments, in addition to data already being collected as part of the larger nutrient management project. A final optimization model will provide best management practices for various relevant micro-irrigation layouts with corresponding optimum irrigation and fertigation scheduling for a range of soil types.

Interpretive Summary:

Micro-irrigation methods have proven to be highly effective in achieving the desired crop yields, but there is increasing evidence suggesting the need for the optimization of scheduling and management of localized irrigation (drip/microsprinkler), thereby achieving sustainable agricultural practices, while minimizing losses of applied water and nutrients.

To optimize irrigation/fertigation of almonds, it is essential that irrigation and fertilizers are applied at the optimal concentration, place, and time to ensure maximum root uptake. Moreover, sound and sustainable irrigation systems must maintain a long-term salt balance that minimizes both salinity impacts on crop production and salt leaching to the groundwater. The applied irrigation water and dissolved fertilizer, as well as root growth and associated nutrient and water uptake, interact with soil properties and fertilizer source(s) in a complex manner that cannot easily be resolved with ‘experience’ and field experimentation alone.

The goal of this research project is to optimize management practices for various micro-irrigation systems for almond, minimizing losses of water (leaching and evaporation), nitrogen (leaching and denitrification), and crop yields by water and salinity stress (droughts). In addition, the applied HYDRUS[1] model with associated root water and nutrient uptake will be evaluated using extensive datasets as acquired from an ongoing nutrient management field project. Therefore, the research project consists of two main components: (a) evaluation of the results of the HYDRUS model using extensive field data for specific treatments, and to refine it if needed, and (b) determining the optimal irrigation and fertigation practices for micro-irrigation (drip and micro-sprinkler) systems for almond using the HYDRUS modeling results, to improve water and nutrient use efficiencies, and to reduce leaching and gaseous losses of nitrates, using a wide range of possible management scenarios (water, fertigation, salinity) and two fertilizer sources.

To achieve this goal additional field data such as soil hydraulic properties, soil texture, and soil layering are needed, and continued monitoring of soil moisture, temperature, salinity, and nitrate concentration must be done for selected irrigation type treatments. Therefore, for this first year of the study we installed various soil sensors to evaluate and calibrate the HYDRUS model. For each of the two irrigation treatments, soil profiles were analyzed to identify soil layers and the textural properties for each layer were measured. In addition, undisturbed soil samples were collected from each soil layer and were analyzed for soil hydraulic properties, such as the soil water retention curve. A set of 34 ECHO-TE soil moisture sensors (Decagon, Inc.) were installed in the almond tree root zone of two irrigation types (fan jet and drip) to monitor the spatial and temporal changes of soil water content, soil salinity, and temperature. A tensiometer is being designed to monitor deep percolation of applied irrigation water, as well

[1] In HYDRUS, using computational mathematics, a set of mathematical equations is solved to compute the movement of applied irrigation water and dissolved solutes (e.g. salt and nitrate) through the soil, computing soil water content, soil solution nitrate concentration, root water and nitrate uptake, and soil leaching rates, at each pre-defined time interval (minutes to hours) at every point below the soil surface, at every day of the year.

as to assess nitrate leaching below the root zone. For that purpose, soil solution extractors were developed, to be installed soon, for monitoring of soil solution nitrate in the root zone. Finally, a first version of a modeling and optimization framework was developed, to be used for analysis of various irrigation system designs.

Materials and Methods:

The presented methods were used for two micro-irrigation systems, drip and fanjet. For each irrigation system, one tree was selected for detailed instrumentation for the purpose of real-time monitoring of soil- water and tree status. The study is part of an ongoing project at Paramount Farms in Lost Hills (near Bakersfield).

1. Soil textural analysis

Among the most important information is an evaluation of the presence of soil layers, and the textural/hydraulic properties of each individual layer for typical soil profiles. For that purpose, a single soil core (down to 9 feet) was taken in each site (drip and fanjet) using a Geoprobe (Geoprobe Systems). At each location three 3-feet long soil cores were collected to the nine feet soil depth (i.e., 0-3, 3-6, and 6-9 feet) and were analyzed for soil layering and soil texture. First, soil layers were identified visually (soil color and structure). Subsequently, soil samples were taken from one-foot increments of each layer, and were analyzed for soil texture. In addition, undisturbed soil samples (8-cm diameter and 6-cm tall) were taken from each layer, and will be used for measurement of soil hydraulic properties (soil water retention and unsaturated hydraulic conductivity) and soil bulk density.

2. Sensor installation

2.1. Soil moisture and soil water potential

A total of 34 ECHO-5TE (Decagon Inc) soil moisture sensors were installed in the rooting zone of each of the two tree locations in a grid pattern (**Figure 1**), thereby instrumenting one quarter of the tree root zone, using depths of 30, 60, 120, and 180 cm for 8 locations. Two additional sensors were installed at the 10 cm depth in the berm along the center line (Y-direction). The sensor installation grid is designed such that measurements provide soil information halfway between trees (Y direction), and up to the radius of the fanjet wetting pattern perpendicular to the trees row (in X direction). The distance between sensors in the X direction is different between the two sites, because of their differences in wetting patterns. The ECHO-5TE provides for measurement of volumetric soil water content, as well as for soil salinity (Electrical Conductivity or EC), and soil temperature. For the purpose of installation, holes were dug with a 5” hand auger. In addition, we installed four MPS1 sensors around each tree, at the 30 and 60 cm soil depth in the single transect of the center line between almond trees, to monitor temporal changes in soil water matric potential in the root zone. Sensors were provided and installed by PureSense Environmental Inc.

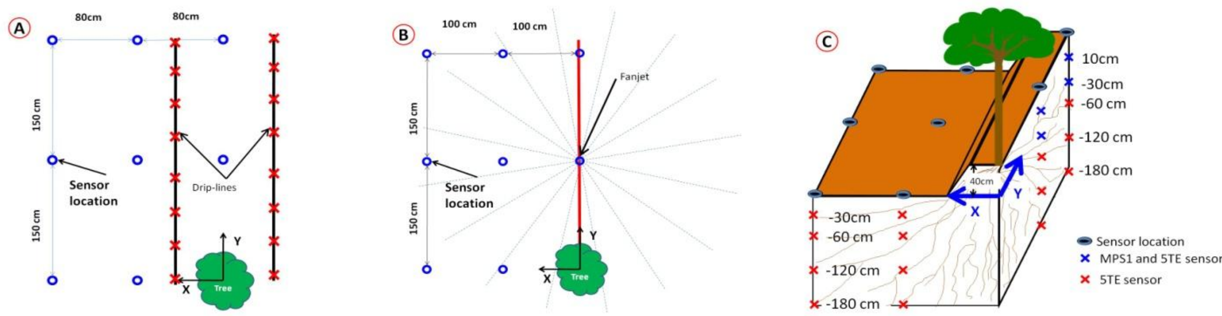

Figure 1. A schematic top view of the installed soil moisture sensors in (A) Drip and (B) Fanjet. The schematic in (C) shows the installation depths.

2.2. <u>Sensor installation device</u>

Whereas the sensors at the 30 and 60 cm depths were installed manually, no commercial tool was available for sensor installation at the larger soil depths. We note that the sensor must be installed in undisturbed soil with good soil-sensor contact; otherwise the soil moisture measurements will not be accurate. For that purpose, we designed an installation device, using a hand-operated horizontal jack, in conjunction with a miniature camera to monitor installation progress. **Figure 2** shows the newly made installation device.

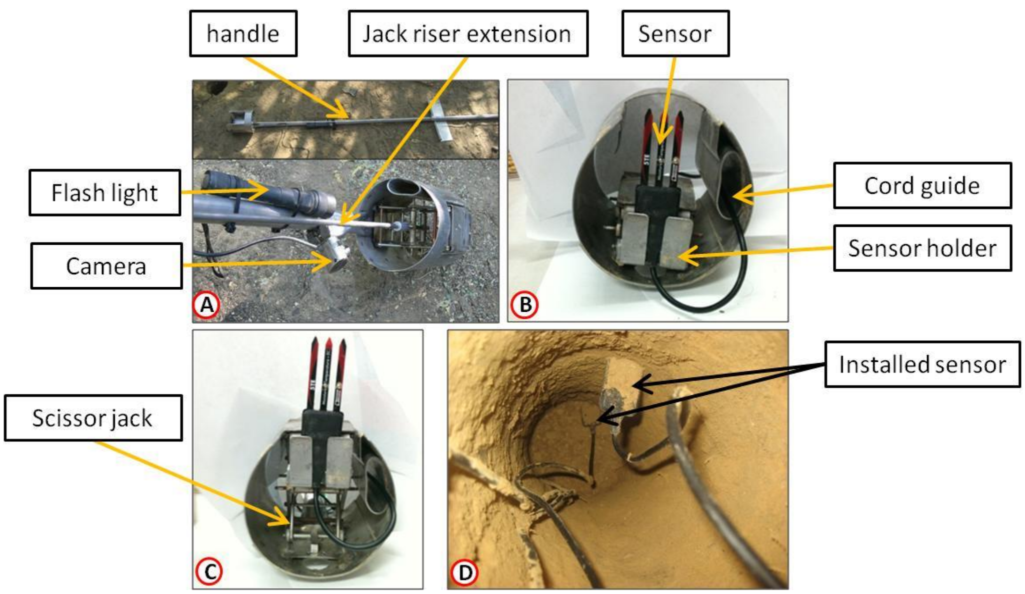

Figure 2. (A) Sensor installation device, (B) sensor placement in the device with the hand-driven jack closed and ready for the sensor to be installed, (C) sensor positioned in the device with jack fully opened and the sensor is completely inserted into the soil, and (D) installed sensor at different depths with the new installation device**.**

3. HYDRUS modeling
We have built a modeling framework for computer simulation of the soil-plant-atmosphere continuum using HYDRUS (Simunek et al., 1999). In this framework an efficient optimization model (Vrugt and Robinson, 2007) is linked with the HYDRUS model, optimizing irrigation system design and irrigation scheduling management. We applied this model for subsurface drip irrigation of alfalfa (Kandelous et al., 2011) to minimize irrigation system installation and equipment costs, and applied irrigation water while maximizing yield and profit. This framework will be used for optimizing the irrigation/fertigation scheduling in almonds.

Results and Discussion:

1. Soil textural analysis
The analysis of soil texture for both the fanjet and drip sites showed that the soil profile of the studied almond orchard is highly heterogeneous and layered. **Figure 3** shows representative soil layers and differences of soil profiles between the drip and fanjet site. The top one meter of soil profile at the fanjet site consists of coarse soil material, allowing quick infiltration of applied irrigation water. The profile includes two 10 cm thick fine-textured soil layers at approximate depths of 130 and 200 cm. These layers will prevent and/or delay of downward water movement below the root zone. Though slightly different, the soil textures and layering are similar for the drip site.

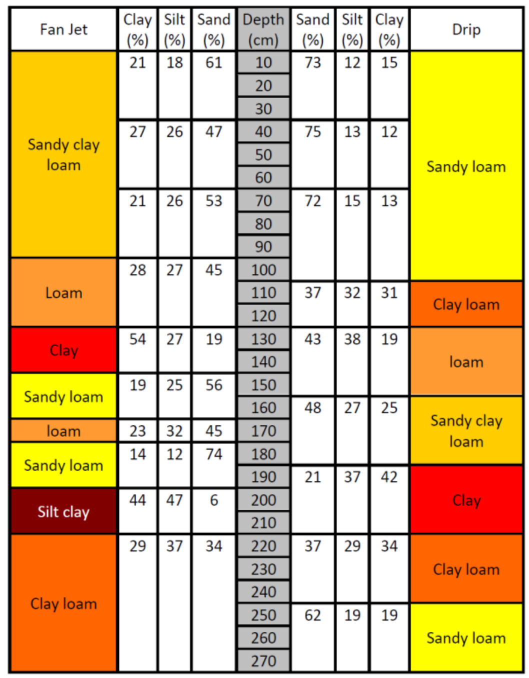

Figure 3. A schematic with soil layers and soil texture for the drip and fanjet sites.

2. Soil moisture measurements.
Figure 4 shows the spatial and temporal variation of soil water content in the root zone for the drip site. The black and red arrows indicate the irrigation and rain events during the presented time period, respectively. The (X, Y) notation represents the Cartesian coordinate system, with both X and Y, representing distances (cm) from the tree trunk. For example, the panel with the (0,150) notation presents soil water content data that is exactly along the tree row (X = 0 cm) and midway between the trees (Y = 150). First, we notice differences in soil water content variations with time between the wet (winter and early spring), and dry (summer and fall) seasons. After each infiltration event in winter, the infiltrated water moves through the sandy loam layer until reaching the clayey loam layer, after which deeper wetting is stagnated and delayed by the finer-textured soil layers by a few weeks. During this time of redistribution, soil water content above the restricted soil layer decreases to field capacity, whereas the deeper soil layers increase their water content gradually. For the summer period, evapotranspiration

demand is high and the trees require frequent irrigation. These irrigations result in much larger variation of soil water content at the shallower soil depths where most of the tree roots are located. The near constant water content values at the larger depths below the finer-textured layers are an indication of little or no leaching. **Figure 4** also shows that the soil water content at the shallow depths below the berm at panels (0,150) and (0,300) did only increase after rainfall, but not during irrigation events. Instead of infiltrating along the drip line, much of the applied irrigation water would flow downhill over the berm surface towards the berm edge and infiltrate there instead.

Figure 5 shows the spatial and temporal variation of soil water content in the root zone for the fanjet irrigation site. The same pattern of deep percolation during the wet period was observed for the fanjet site. Although patterns are similar, the changes in water content at deeper depths are slightly different. Specifically, we note that the 180-cm deep water content readings are much lower for the fanjet than for the drip site (**Figure 4**), likely because of the coarser soil

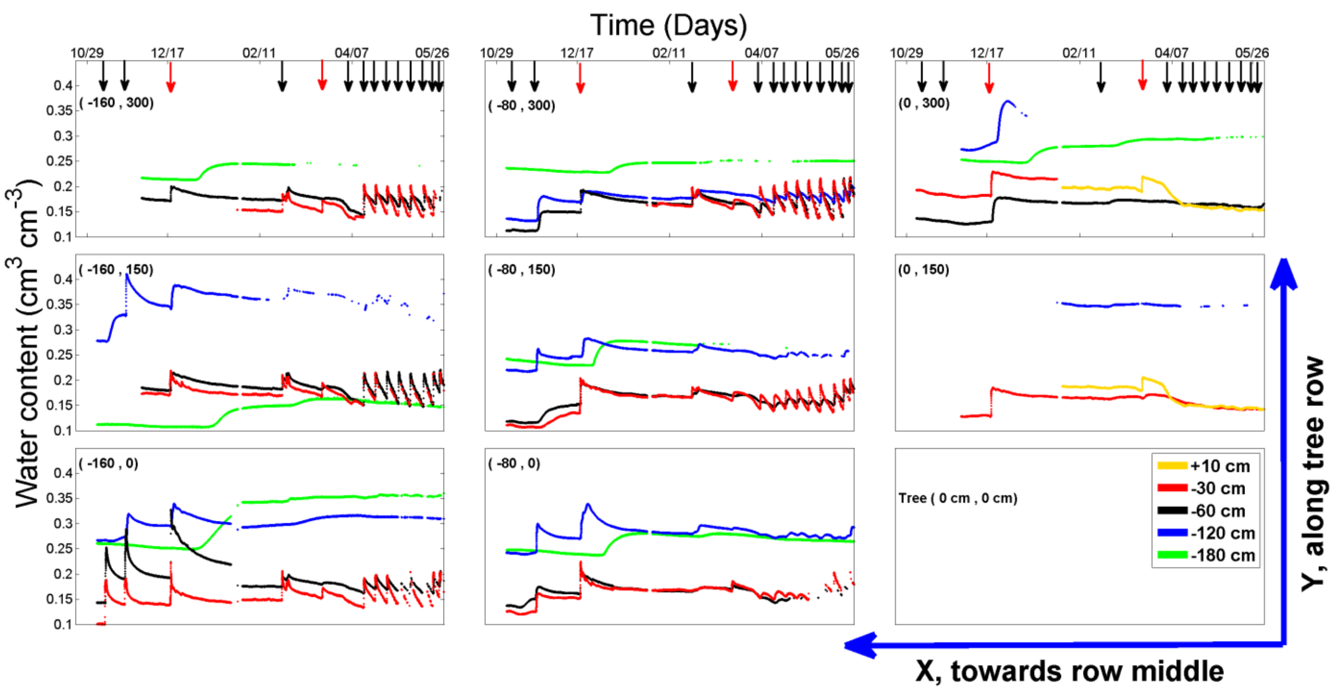

Figure 4. Spatial and temporal variations of soil water content in the root zone under drip irrigation system. The black arrows indicate the irrigation events and the red arrows denote the precipitation events.

texture of the fanjet site at that depth (compare soil layering between sites in **Figure 3**). Also, because of the larger wetted area of the fanjet system, wetting patterns were different between sites, and shallow sensors responding to infiltrating applied irrigation water in the berm for panels (0, 150) and (0,300).

Unfortunately, many data were lost because of malfunctioning of sensors and data collection issues, explaining significant data gaps in **Figures 4 and 5**. We are planning for additional sensor installation with data collection procedures using our own expertise as developed for soil moisture monitoring purposes at other experimental sites.

3. HYDRUS modeling

An irrigation design-management modeling tool was developed to simultaneously optimize subsurface drip irrigation system design and management, for using subsurface drip irrigation in alfalfa. In this approach, we coupled a robust optimization algorithm with the HYDRUS model, and developed irrigation system design parameters that minimize installation costs and maximize irrigation water use efficiency. The analysis of this study showed the importance of a priori knowledge of root distribution in irrigation system design and water management, as it dictates potential available soil water and storage capacity, relative to water application distribution (both in space and time), and deep percolation losses. Analysis of soil texture effects showed major differences between soil types, because of variations in water holding capacity, capillary forces, and drainage rates between soil types. We plan to apply a similar sensitivity analysis for almonds in the coming year(s), to minimize drainage water and nitrogen losses across irrigation system, scheduling, and soil parameters.

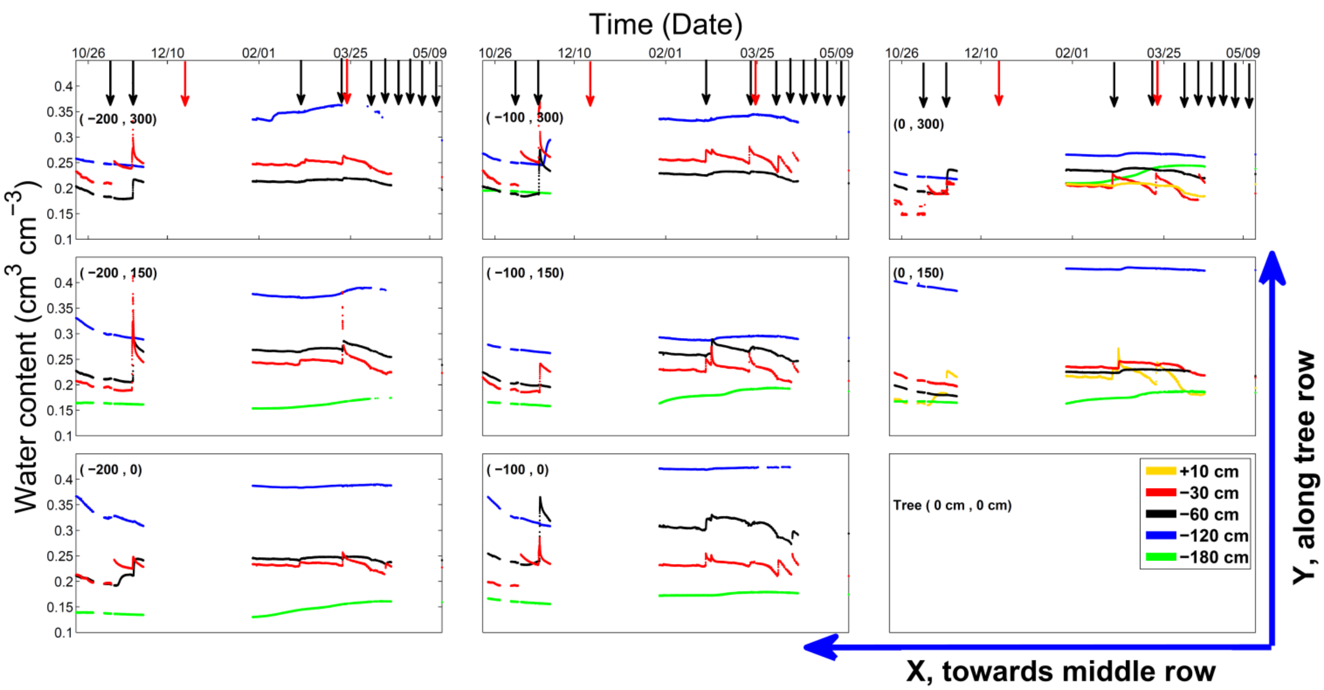

Figure 5. Spatial and temporal variations of soil water content in the root zone under Fanjet irrigation system. The black arrows indicate the irrigation events and the red arrows denote the precipitation events.

Research Effort Recent Publications:

Kandelous, M.M, T. Kamai, J.A. Vrugt, J. Simunek, B.R. Hanson and J.W. Hopmans. 2010. An optimization model to design and manage subsurface drip irrigation system for alfalfa. AGU Fall meeting, San Francisco, CA.

Hopmans, J.W., M.M. Kandelous, A. Olivos, B.R. Hanson and P. Brown. 2010. Optimization of water use and nitrate use for almonds under micro-irrigation. Almond Industry Conference, Modesto, CA.

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Kandelous, M.M, T. Kamai, J.A. Vrugt, J. Simunek, B.R. Hanson and J.W. Hopmans. A multi-criteria optimization approach for efficient design and management of subsurface drip irrigation systems: Application to alfalfa. In preparation.

Šimůnek, J., M. Šejna, M.T. van Genuchten. 1999. The HYDRUS-2D software package for simulating two-dimensional movement of water, heat, and multiple solutes in variable saturated media. Version 2.0, IGWMC-TPS-53, International Ground Water Modeling Center, Colorado School of Mines, Golden, Colorado: 1-251.

Vrugt, J.A., and B.A. Robinson. 2007. Improvement evolutionary optimization from genetically adaptive multi-method search. Proc. Natl Acad. Sci USA., 104(3):708-711.