Key Aspect of Smart Farm Concept in Almond Production: Precision Irrigation[1]

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Smart Farm at UC Davis is an innovative concept and an university sponsored **BIG IDEA** that aims to develop superior plants, smart machines, and more efficient farming methods for crops and animals alike to provide a path towards food security in the year 2050 and beyond (- personal communication with Dr. David Slaughter, Professor and Director of Smart Farm, Biological and Agricultural Engineering Department, UC Davis). It envisions the development of technological and knowledge based solutions at individual plant and animal level to optimize on-farm management and resource utilization, and maximize production in harmony with the natural environment. It includes the development of smart machines that integrate adaptive and precision technologies, on-farm wireless data networks, new smart sensors and control systems, drones, robotics, phenotyping, and data analytics to rapidly acquire and interpret plant and animal responses to environmental conditions and provide information needed to make critical management decisions. It seeks to achieve a new paradigm in plant and animal production by optimizing resource utilization and minimizing agriculture's environmental footprint leading to a more sustainable agricultural production system worldwide. In this presentation, one key aspect of Smart Farm - Precision Irrigation – in producing "Most Crop per Drop" to conserve water resources while preserving quality and quantity of almond production is described.

Precision irrigation or **Variable Rate Irrigation (VRI)** has the potential to conserve water by increasing water use efficiency and water productivity. For orchard and vineyard crops, which have extensive root systems, soil moisture content measured at shallow depths may not adequately represent total water available to the plants. Plant Water Status (PWS) is believed to be a good indicator of irrigation needs of trees and vines (Dhillon et al., 2014). A pressure chamber is often used to measure plant water status. While this device is considered as the standard to measure plant water status, it is time consuming and tedious to use and measurements must be done around solar noon, when California's Central valley temperature can exceed about 38° C. Udompetaikul (2012) and Dhillon et al. (2014) developed a sensor suite to measure PWS using a suite of sensors that included a thermal IR sensor to measure leaf temperature, and sensors to measure air temperature, relative humidity, incident radiation, and wind speed. They conducted extensive field tests in almond, walnut and grape crops and showed that this sensor suite can successfully predict PWS. Dhillon (2015) and Dhillon et al. (2017 and 2018) further developed this system to continuously monitor PWS and interfaced it to a wireless mesh network so that data can be uploaded to the web and made available on a personal computer or a handheld device. This version of the sensor was called a continuous leaf monitor. This system could not only monitor the system, but also control latching solenoid valves through the same wireless mesh network to implement precision irrigation. The objective of this research was to irrigate almond crop based on real-time PWS as estimated by a wireless network of these continuous leaf monitors. To accomplish this objective, two management zones were created based on spatial variability in soil (texture, electrical conductivity (EC) at two different depths, and digital elevation) and plant (light interception and canopy temperature) characteristics in an almond orchard in Arbuckle, CA (Nickels Soil Lab) (Bazzi et. al., 2018, Kizer, 2017, Kizer et al., 2017 and 2018, Upadhyaya et al., 2017). These management zones are considered stable over the years as they are primarily based on static characteristics of the soil. Within each management zone, both conventional grower treatment and PWS based precision irrigation management were implemented.

The continuous leaf monitors, soil moisture sensors, pressure sensors (to detect the pressure in irrigation lines), and latching solenoid valves (to turn on and off irrigation lines) were all connected to nodes which formed a wireless network. The sensor information was accessed remotely through PCs or mobile devices. Plant water status was estimated using information derived from leaf temperatures and environmental conditions. Precision irrigation management based on PWS was implemented throughout the 2016 and 2017 growing seasons. Attempts

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were made to control Stem Water Potential (SWP) level at about -13 bar during the pre- as well as post- hull split period and at about -16 bar during the hull split period. According to Plant Physiologists, this approach minimizes hull rot disease in almonds and promotes uniform maturity to assist in mechanical harvesting. During the 2016 growing season sensor derived PWS values were used as the indicator for stress management. However, when PWS indicated high stress levels, actual SWP measurements were taken (just to be sure) before irrigation management decisions were implemented. During an irrigation event, each management zone of the treatment received a fixed percentage of evapotranspiration (ET_c) at regular time intervals to maintain the stress within the desired range. However, when stress levels exceeded desired levels, irrigation amount was increased at intervals of 5% of ET_c until the PWS returned to normal. In 2017, a similar approach was followed, except irrigation management was implemented whenever sensors indicated that plants were stressed without checking the actual SWP values. SWP measurement was done on a regular time interval throughout the growing season (Kizer et. al., 2018).

This plant-based irrigation scheme required about 70% of estimated crop evapo-transpiration (ET). With respect to the grower practice that used soil moisture sensors only, the water savings was about 15%. Similarly, the PWS based irrigation scheduling resulted in greater water productivity (0.776 ± 0.111 kg/m^3) as compared to that obtained by the grower (0.689 ± 0.070 kg/m^3). Despite the water use differences, there was no difference between grower yield (1.330 ± 0.112 kg/m^2) and stress treatment yield (1.299 ± 0.126 kg/m^2). Additionally, there was no significant difference in yield between zones. Kernel yield followed similar trends. Kernel yield was not significantly affected by treatment (grower treatment = 0.353 ± 0.050 kg/m^2, stress treatment = 0.331 ± 0.056 kg/m^2). Moreover, the PWS based irrigation management did not significantly impact nut quality (number of moldy almonds, kernel volume measurements, and kernel mass). Thus management zone based precision irrigation that utilized continuous leaf monitors not only indicated plant water status in real-time to manage irrigation but also enhanced crop productivity (crop per drop) without impacting quality and quantity of yield.

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Udompetaikul, V. 2012. Development of a sensor suite for plant water status determination for irrigation management in specialty crops. Unpublished PhD dissertation submitted to the Office of Graduate Studies, University of California at Davis. 177pp.
Upadhyaya, S. K, E. Kizer, C. Ko-Madden, F. Rojo, K. Drechsler, and J. Meyers. 2017. Precision irrigation in orchard crops based on plant water status. May/June 2017. Progressive Crop Consultant. P24-29.

Biography
Shrini K. Upadhyaya

Education

Ph.D. in Agricultural Engineering (1979): Cornell University, Ithaca, NY, USA
MS in Agricultural Engineering (1975): University of Manitoba, Winnipeg, Canada
B. Tech (Hons) in Agricultural Engineering (1972): Indian Institute of Technology, Kharagpur, India.

Employment History

1992-present	Professor, University of California, Davis
1987-1992	Associate Professor, University of California, Davis
1983-1987	Assistant Professor, University of California, Davis
1981-1983	Assistant Professor, Univ. Delaware, Newark, Delaware
1979-1981	Research Associate, Cornell University, Ithaca, NY

Professional Activities

Scientific and Professional Societies: American Society of Biological and Agricultural Engineers, International Society for Soil and Tillage Research, International Society for Terrain Vehicle systems.

Summary of Grants Received

A total of over 4.5 million dollars in funding in the last ten years from various agencies such as Almond Board of California, California Tomato Research Institute, California Energy Commission, Department of Water Resources, USDA-NRI, Binational Agricultural Research and Development Agency, Deere and Co., Caterpillar Inc., Trimble Navigation Ltd., Digital Media Innovation, Morning Star, Chevron, E & J Gallo Wineries, National Institute of Food and Agriculture (NIFA, USDA), and California Department of Food and Agriculture CDFA).

Awards

1. 2018 Outstanding Engineering Teaching faculty Award. College of Engineering, University of California Davis.
2. 2014 European Society of Agricultural Engineering Outstanding Paper Award for the publication Tractor-based Real-time kinematic-Global Positioning System (RTK-GPS) guidance system for geospatial mapping of row crop transplant. Biosystems Engineering 111(1):64-71.
3. 2013. John Deere Gold Medal for Advances in Soil Dynamics by American Society of Agricultural Engineers.
4. 2011. Elected Fellow of American Society of Agricultural and Biological Engineers.
5. Awarded 2009 Japanese Society for Agricultural Machinery International Award on March 27, 2009.
6. 2009. Paper award for the paper Development and field evaluation of a field-ready soil compaction profile sensor for real-time applications. Applied Engineering in Agriculture. 24(6): 743-750.
7. 2005 Honorable mention award for the paper “Experimental verification of an inverse solution technique for determining physical properties of soil” American Society of Agricultural Engineers, St. Joseph, MI 49085.
8. 1997. Honored at the 3rd International Conference on Soil Dynamics by planting 10 trees in the Jerusalem Forest for my contribution to the field of Soil Dynamics.
9. 1995 Paper award by the American Society of Agricultural Engineers for the paper entitled, "Encapsulation of Seeds in Gel by Impact".
10. 1993. Recipient of JSPS (Japan Society for Promotion of Science) award to visit Tokyo University of Agriculture and Technology.
11. 1990 Honorable mention for the paper "Hydro-Pneumatic Singulation of Gel-Encapsulated Propagules". American Society of Agricultural Engineers, St. Joseph, MI 49085.

12. 1982 Paper Award by the American Society of Agricultural Engineers for the paper "Dynamics of Fruit Tree Trunk Impact."

Honors and Recognitions:

1. 2013. Invited Special presentation on "Soil Compaction: Its Measurement and Management." XLII Brazillian Congress of Agricultural Engineering (CONBEA 2013). Fortaleza, Brazil.
2. 2009. Invited presentation on "Precision Agriculture" during the International Conference on Food Sustainability and Environmental Sustainability held at IIT Kharagpur, India. December 2009.
3. 2007. Invited to make a special presentation on "Precision Agriculture" at the Engineering input for specialty crops workshop in Washington DC. April 7, 2007.
4. 2004. Invited to make a keynote presentation at the on Precision Agriculture at the First International Conference on Emerging Technologies in Agricultural and Food Engineering. December 13-17, 2004, Indian Institute of Technology, Kharagpur, India.
5. 1997. Keynote speaker on the topic "Prediction of traction and soil compaction" at the 3rd International Soil Dynamics Conference in Israel, August 1997.
6. 1996. Invited to make Special presentations on "Precision Agriculture" and "Agricultural Engineering Education in the United States" by UNSEP, SBEA, and ALIA at the XXV Congresso Brasileiro de Engenharia Agricola and II Congreso Latinoamericano de Ingenieria Agricola at Baru, Brazil. July 22 –26, 1996.
7. 1993. Invited to make a special presentation on Precision Agriculture at the Tokyo University of Agriculture and Technology, Japan. July 1993.

SELECTED RECENT PUBLICATIONS *(Total peer reviewed and conference papers over 300)*

Dhillon, R., V. Udompetaikul, F. Rojo, J. Roach, S. Upadhyaya, D. Slaughter, B. Lampinen, and K. Shackel. 2014. Detection of plant water stress using leaf temperature and microclimatic measurements in almond, walnut, and grape crops. Trans. ASABE. 57(1):297-304.

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PATENTs: 1. Hydro-Pneumatic Seed Singulation for Plant Propagules US Patent 4917029.

2. Method and apparatus for ultra precise GPS based mapping of seeds or vegetation during planting – Patent No: US 6516271B2.

3. Upadhyaya, S. K., M. Ehsani, and M. L. Mattson. 2003. Method and apparatus for ultra precise GPS-based mapping of seeds or vegetation during planting. US patent No. **6,553, 31**2 **B2.**

4. Upadhyaya, S. K. and P. Andrade. 2004. Development of a soil compaction profile senor. US Patent No. 6,834,550.

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7. Upadhyaya, S. K., R Dhillon, J. Roach, and F. Rojo. 2016. Systems and methods for monitoring leaf temperature for prediction of plant water status. US Patent No. 9, 374,950 B2