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Improving forage crop water productivity through innovation irrigation management

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Project Summary

Decreased and more variable water supplies are expected in California's San Joaquin Valley (SJV) in the future and are likely to hit the region's forage production sector particularly hard. Improving crop water productivity through innovative irrigation management and drought-resilient tillage and residue management techniques will be increasingly imperative in this region if producers are to avoid uneconomic and unsustainable reductions in production due to shrinking water availability. Recent technological advances in precision overhead irrigation systems that can be readily coupled with water-use-efficient tillage and residue management techniques and regulated deficit irrigation approaches may be a 'cropping systems' means for sustaining productivity and preserving the competitive agricultural capacity of the region.

Two important SJV forage crops that may particularly lend themselves to these 'drought-proofing' strategies are sorghum and alfalfa. In this project, a team of UC and CSU Fresno research and extension, farmer, private sector, and NRCS partners will work together to develop best irrigation and crop management practices by comparing full and regulated deficit irrigation strategies for apportioning limited water for production of these forages.

Our objectives are 1) to determine the water use and economic efficiencies of forage alfalfa and sorghum under full ET, a moderate regulated deficit (75% ET), a severe deficit 50% ET), and a 'seasonal drydown' approach for restricting water applications during a 'reduced risk' period of vegetative growth for sorghum and late summer for alfalfa, 2) to measure crop responses and water productivity of these crops under limited water supplies, and 3) to have these evaluations of overhead irrigation for these forages serve as the basis for intensive public extension education programs for precision crop management technologies through our CASI (Conservation Agriculture Systems Innovation) Center outreach networks.

We will use a state-of-the-art 'E-2' ('Electrogator,' Reinke Mfg.) center pivot system at the UC West Side Research and Extension Center in Five Points, CA that is equipped with drop hoses at 40" spacing, advance speed and water application control and in-line flow meters to impose these deficit irrigation regimes based on CIMIS and ETGage daily ET estimates. We will generate soil water balance data based on profile water content sensing instrumentation (neutron probe and TDR volumetric soil water content and granular matrix soil water tension). We will provide three public extension education field days annually, real-time project data summaries at our CASI website http://casi.ucanr.edu/, and both video and peer-reviewed article summaries of the project's findings before its termination in 2016.

By using highly uniform center pivot irrigation technology to apply small, precise amounts of water particularly during the vegetative growth stage for sorghum and both immediately before and after monthly harvests and during the mid- to late-summer period for alfalfa when SJV productivity typically is reduced under flood irrigation, we expect to produce marketable and economic yields for sorghum using 25% less water as has been achieved under pivots in TX and similar increases in crop water productivity for alfalfa. This work will inform and improve future water management strategies in CA's critically-important $7B dairy industry.

Research Program

Average agricultural water allocations throughout the Westlands Water District, the SJV's largest irrigation district, in the 8-year period from 2007 – 2013 were 38% of historical contracts (Bureau of Reclamation, 2013). Farmers throughout the SJV, as in other regions of irrigated cropping, thus face critical questions on how to adapt under persistent water shortages: invest in more efficient irrigation technologies and machinery, change crops, alter agronomic and/or irrigation strategies, or fallow more land (Gaydon et al., 2012).

There is thus now interest and indeed a very strong need not only for technologies that apply water to crops more efficiently and uniformly, but also for the need to understand and use deficit-irrigation strategies for certain crops when water shortages occur. (Colaizzi et al., 2004, O'Shaughnessy et al., 2012a, b). Coupling overhead irrigation with deficit irrigation scheduling may thus be a useful means for taking advantage of the higher application efficiencies or uniformities of overhead systems (Lascano and Sojka, 2007; Hanson et al., 2007) and thereby reducing actual water application requirements relative to surface systems and also for using the systems to very precisely apply small water volumes at carefully-designed periods within a cropping season to 'stretch' productivity, or to in effect, 'get more with less.' Overhead irrigation may in theory, also provide for more diversity and flexibility in crop rotations since a farmer is not saddled by fixed drip tape spacing and for enabling uniform salt leaching out of the crop rootzone.

Overhead irrigation is currently the most prevalent form of irrigation nationwide (NASS, 2010), and recent surveys in Nebraska, a region similar to California in terms of the general need for irrigation for crop production, indicate that precision overhead systems and recent technological advances in overhead equipment are now rapidly and completely replacing gravity irrigation because of the ability that these systems provide to apply precise water amounts and to increase productivity (Pfeiffer and Lin, 2009). Perhaps surprisingly, however, overhead irrigation is currently estimated to be used on less than 1% of CA's cropland (NASS, 2010). While there are over 80,000 pivots in NE, fewer than 350 are in use today in CA (NASS, 2010). The possible benefits of overhead for SJV systems have been recognized by a number of farmers in recent years throughout the area (Warnert, 2011) as a means for sustaining profitability, increasing competitiveness, and preserving the productive capacity of the region, however, no locally-derived information has been developed to guide and inform forage producers on how to use overhead systems to achieve greatest advantage.

Two SJV crops that may particularly lend themselves to overhead deficit irrigation are alfalfa and sorghum. Alfalfa is currently the single largest agricultural water user in California due to its large acreage and long growing season (Hanson et al., 2007). While there has been some movement toward drip in alfalfa, it is still a largely surface-irrigated crop (Personal communications, D. Munk and D. Putnam). However, no work is being done currently and locally to develop information on the potential beneficial applicability of overhead deficit irrigation for these crops and farmers have expressed to us difficulties in conducting this sort of investigation at their farms for a variety of reasons. In the studies outlined here, we therefore propose to carry out relatively large-scale evaluations at the West Side Research and Extension Center of deficit irrigation strategies under overhead irrigation as a means for increasing the water use efficiency and return-on-investment characteristics of SJV forage production systems. This proposed work also provides a unique opportunity for the UC West Side Research and Extension Center and indeed the region to showcase state-of-the-art irrigation and other precision irrigation management instrumentation and as well, to forge a high-impacting, broad-based, and diverse research and extension education team that will conduct the study and provide extensive, high-visibility outreach.

Deficit irrigation of alfalfa as a strategy for saving water has been reviewed by Lindenmayer et al., (2011) and reported by Hanson et al. (2007) in northern California using flood irrigation. In 1991, Frate et al. found that reducing or terminating irrigation on established alfalfa during late-summer reduced yields, but did not cause the crop to die also under flood irrigation. Putnam (Personal communication, 2011 and Putnam, 2012) provided the deficit irrigation strategy and rationale that we propose to use in this study based on his work and experience in the SJV and in Southern Desert Valleys. A comparison of subsurface drip, LEPA, 'scheduled' furrow and conventional furrow irrigation systems was conducted in 1989 by Smith et al. for cotton indicating the drip provided the highest net returns, but that both drip and the LEPA systems resulted in 'significant water conservation.'

Our group's own work in recent years at the WSREC has demonstrated the ability to produce no-till corn and wheat with overhead irrigation with yields similar to those achieved with furrow irrigation using standard tillage (Mitchell et al., In preparation) and onions and cotton (Hollingsworth et al., Submitted) with yields similar to those achieved with drip. Munk and Wroble on our project team have conducted field trials with deficit irrigated cotton during the past two years, but not under overhead irrigation. Local partner farmers, Schmidt and Diener, have also produced both cotton and alfalfa under overhead irrigation. There is no study, report or farm experience that has coupled overhead irrigation with the deficit irrigation strategy in the SJV.

The objectives of this proposed project are:

a. to determine the water use efficiency and economic efficiency of a forage production system of alfalfa and sorghum under full ET, moderate deficit (≈ 75% ET), and severe deficit (≈ 50% ET) center pivot irrigation,
b. to measure crop responses and water productivity of these crops under limited water supplies, and
c. to have these evaluations of overhead irrigation for these forages serve as the basis for intensive public extension education programming for precision crop management technologies at the WSREC.

Information Transfer/Outreach Program

Methods

This two-year study will develop information on management options for sustaining forage production in California's Central SJV using less water. It will test the hypotheses that the water use efficiency for a forage rotation of alfalfa and sorghum can be increased using carefully-designed deficit irrigation strategies relative to full ET irrigation under overhead precision irrigation, that economically competitive yields can be achieved and finally, that rootzone salinity can be effectively managed using overhead irrigation within forage rotations.

Irrigation System:
A three-span 'E-2' ('Electrogator') center pivot system with drop hoses at 80" spacing and a touchscreen control panel that allows variable advance speed and water application control has recently been provided to the Center by Reinke Manufacturing Company, Inc. Pressure regulators and water application packages for each drop hose have been provided by Senninger Irrigation Inc. An electronic SeaMetrics flow meter will be installed at the pivot point to permit recording of precise water application volumes.

Experimental Procedures:
The proposed experimental field will be divided in half in the north-south direction providing two 7.5-acre study areas. A forage rotation consisting of alfalfa and sorghum will be pursued with each crop occupying half of the study field (Figure 1).
The forage deficit irrigation study will be laid out as a circular randomized complete block design with twelve different 'pie-shaped' sector plots. Each of these sectors consists of 117' at the outside diameter. The following four irrigation regimes will be established by programming the pivot's speed so as to apply different amounts of water as indicated below.

a. full ET irrigation
b. moderate deficit irrigation (≈ 75% ET)
c. severe deficit irrigation (≈ 50% ET)
d. 'seasonal drydown' (late-summer for alfalfa and during early vegetative growth for sorghum)

These irrigation treatments will be imposed over the course of the entire year by using a predominantly 'cold turkey' strategy in which late-season (July onward) irrigations are either cut-down (as in the severe treatment) or significantly curtailed (as in the moderate deficit system), rather than using the so-called 'starvation diet' mode for generating season-long deficits during all irrigations. This strategy has been tested and developed to address the 'sub-economic' productivity of late-season alfalfa crops in high ET regions such as the SJV and the Southern California Desert Valleys that is thought to result from high heat impacts on alfalfa that lead to early flowering and lower tonnage (Personal communication, D. Putnam).

We hypothesize that 'system benefits' of the center pivot including higher water application efficiencies as well as the ability to apply very small amounts of water very precisely and thereby effectively ‘ramp down’ applications before harvest and to then ‘ramp back up’ following harvest may result in increased production under the deficit irrigation treatments relative to the full ET system and thus that annual productivity may not be as negatively impacted by deficit irrigation as has been previously reported for flood-irrigated alfalfa (Frate et al., 1991). The two deficit irrigation treatments will thus be achieved over the course of an annual cycle by curtailing water applications either by turning drop nozzles off during the late-summer, or by reducing application volumes by changing nozzle packages or run time. In alfalfa, observations and, if warranted, ratings will be taken to evaluate presence/level of alfalfa leaf diseases which may be affected by sprinkler irrigation. Also root health (longevity of stand) will be evaluated to determine if cracking soils in the summer cut-off treatments increase crown and root disease by injuring roots and thereby providing entry for pathogens.

Our approach for sorghum is modeled after extensive deficit-irrigation work conducted at the USDA ARS Bushland, TX facility over several years (Colaizzi et al., 2004; O’Shaughnessy et al., 2012a, b). This work suggests that sorghum is actually a crop that ‘benefits’ from some moderate early-season stress. Thus, once the crop has been established, we will impose the irrigation deficit treatments during the vegetative period and later once seed set has occurred, but not during the early reproductive period.

Goals of this study will be to develop management information on both the potential to use the precision and application efficiency (uniformity) of the pivot to effectively be able to apply less water than would be applied in a surface irrigation context to meet ET demand across an entire field. We illustrate this by the following example. If the water application efficiency of an irrigation system is, for instance, 75%, which is common for some surface systems, and the seasonal ET demand is 28,” then a total of about 37” of water would be needed to irrigate the entire field. Whereas, if the application efficiency is assumed to be 93%, as we have measured in previous overhead work and as has been commonly reported (Lascano and Sojka, 2007), then the water requirement would be 30,” – a potential savings of 23%).

The deficit irrigation strategy that will be implemented will target the ‘moderate’ (≈ 75% ET) and more ‘severe’ (≈ 50% ET) application constraints and will be designed on a weekly basis by a team consisting of Dan Munk, Bob Hutmacher, Jon Wroble, and Jeff Mitchell, based on the related research Hutmacher and Munk have previously conducted locally for surface and drip irrigation. We successfully used this ‘weekly decision’ approach to manage our 2011 – 2012 drip and overhead cotton crop at the Center in which we applied 24” within the season when it was deemed most necessary. We see this weekly decision-making process, - which will be largely facilitated by email communication, - to be a highly effective and productive strategy that we believe will lead to successful implementation of the experimental goals of this proposed work.

Crop management:

Alfalfa will be seeded in early 2014 to achieve a strong stand (Figure 2). Cutting and harvesting will be conducted on a roughly 28-day cycle during the peak production period as is common in the Central SJV. The capability of the center pivot system to apply quite small volumes of water very precisely will be used to advantage to ‘ramp down’ application amounts prior to harvest thus permitting timely access to the field by harvesting equipment, and then to 'ramp back up' again with small, quickly-applied water volumes following harvest. Yield determinations will be made using the 'Carter" forage harvester that will be provided by Putnam. Following these yield determinations that will be made in circular fashion under each irrigation treatment and over a minimum of about 200 ft^2 (except under the inner span where a shorter harvest distance will be secured). The remainder of the field will then be harvested using commercial equipment provided by John Diener of Red Rock Ranch. We recognize that because the inner span on pivot systems often applies more water than other exterior spans, that we may end up using the two outer spans for experimental data collection. A dual-purpose sorghum such as NK300 will seeded using the UC ANR Conservation Tillage and Cropping Systems Workgroup's John Deere 1730 6-row seeder in straight-line across the field. Yield determinations and bulk harvests will be determined using commercially-provided equipment by Mike Danel, Hanford, CA.

Monitoring system performance and data collection:

Economic analysis: A calendar of operations will be maintained for each of the systems and the equipment used and materials applied will be recorded. The cost of each operation for each system will be estimated using a model of a hypothetical farm under each of the four systems. The time required for each operation, fuel, lube, and repairs will be generated using agricultural engineering equations. The input costs for seed, fertilizer and pesticides will be obtained from local input suppliers and entered into the model. The water use for each system will be measured as part of the experiment and input into the model.

Water costs per acre foot will reflect local irrigation district charges. The cost or production and resource use for each of the systems will be compared. In particular, the model will summarize the labor requirements for both tractor operators and irrigation labor as well as fuel use. Finally, the yield data will be used to calculate the expected gross returns using local market information. From this, the economic feasibility of each system will be estimated and the relative profitability determined. Project partner, Karen Klonsky, has already begun to compile information on center pivot systems and will be developing production cost and return-on-investment analyses for each of the irrigation treatments.

Irrigation water applications: Careful records will be kept of all irrigations by recording daily flow meter and run-time data. Weekly summaries of cumulative applied water data will be provided to all project partners as a means for us all to keep on track of progress and so that the irrigation treatments are being implemented properly. Soil water storage and crop water use: A very straightforward monitoring approach will be pursued in this proposed study to determine soil water storage throughout each annual crop cycle. Weekly readings using a hydroprobe (Campbell Pacific Nuclear, Martinez, CA) of PVC tubes installed to a depth of 270 cm along a single transect in the center of each of the twelve forage plots and each of the twelve cotton plots will be conducted throughout the entire course of the study. Based on previously-published work at the Center (Islam et al., 2006) and ongoing work by our project team, this monitoring approach should be both adequate and quite revealing in terms of season-long trends in soil water storage and water availability.

We believe that this is a simple, inexpensive, yet quite useful data generation approach for this study. Monitoring protocols will be implemented to assure consistency of measurements (Hanson and Dickey, 1993). Local ETo data will be accessed weekly using CIMIS daily weather information (http://wwwcimis/water/ca/gov/cimis/welcome.jsp). "24/7" real-time soil water content data will be compiled with Watermark granular matrix sensors and Acclima remote TDR dataloggers (Personal communication, R. Schwartz) to measure soil matric potential and to use this information as a guide for irrigation scheduling.

Crop growth, development and yield determinations: We will also pursue a straightforward and inexpensive monitoring approach for determining crop performance under each irrigation treatment by weekly estimates of % crop canopy cover using a DYCAM Agricultural Digital Camera (Chatsworth, CA) that relies on distinguishing crop canopy from soil and residue background using red and near-infrared wave band ratioing (Hanson et al., 2002). Crop yields will be determined for alfalfa by cutting, drying, and weighing a minimum 200 ft^2 length of treatment plot in each replication for all harvests using the "Carter" small-plot harvester of Putnam and protocols he has currently in place for his other alfalfa work at the Center. Sorghum yields will be determined by a combination of small-plot weighing and the use of large-scale commercial drive-on scales as we have done in the past for our wheat and corn harvests at the Center.

Irrigation system performance: We will conduct a series of four catch-can determinations during the first year of the proposed study by putting out #10 cans at a uniform height every 5 ft. across a linear transect under the entire four-span pivot system. Water in each can will be collected and measured and Christiansen's coefficients of uniformity (CU's) will be calculated (Hanson et al., 1988). Planning meetings will be held in advance of the project initiation with irrigation company and local farmer partners to determine the optimal nozzle, pressure regulator and run-time configurations that will be used.

Soil salinity monitoring: Soil salinity will be determined at the beginning of the study and then in March of each subsequent year by sampling soil at 0 – 30 cm, 30 – 60 cm, and 60 – 90 cm depths and conducting ECe laboratory determinations.

Notable Achievements

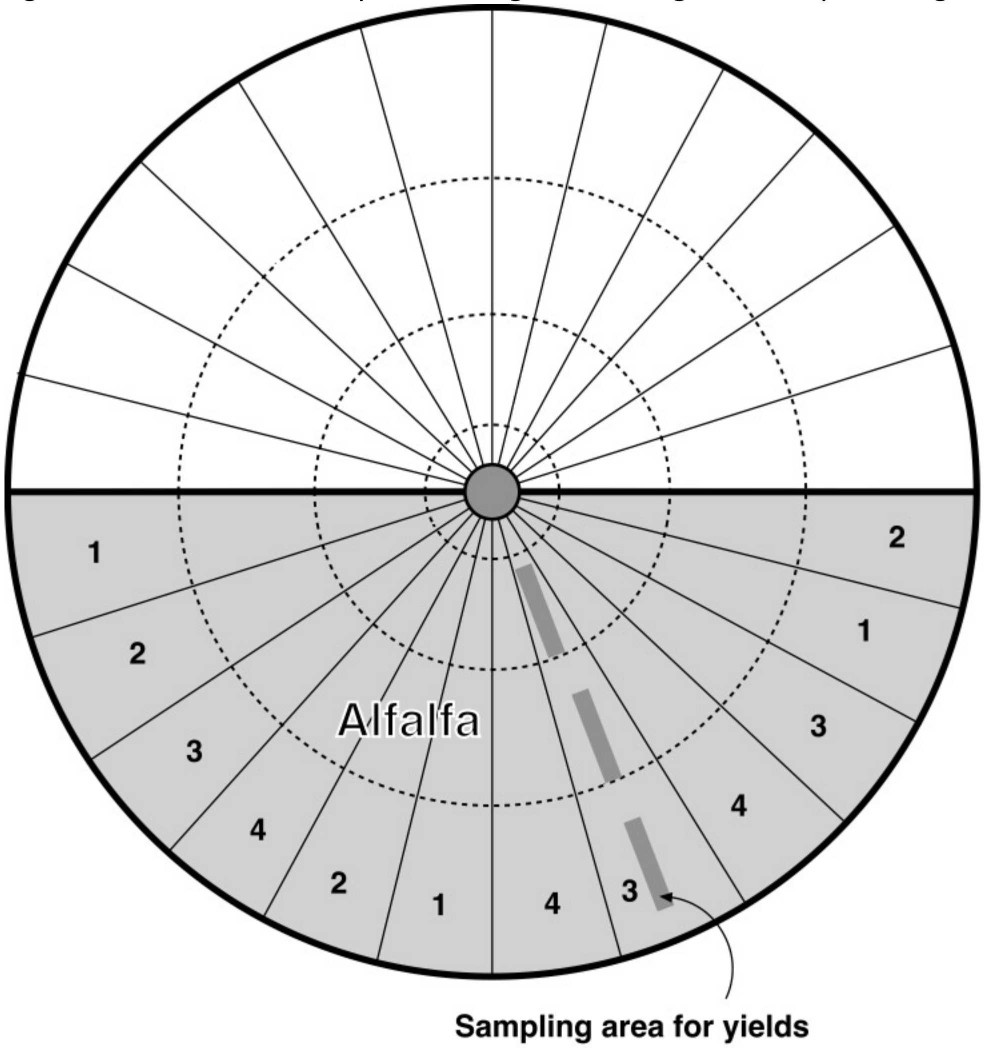
Note that we are in no way suggesting that overhead irrigation can or will somehow overcome the fundamental relationship of the crop water production function which shows particularly for crops such as alfalfa, a relatively linear relationship between ET (applied water) and crop biomass production. The research we are proposing here, however, seeks to develop information within a larger-scale experimental context on the possible extent to which the expected efficiencies and uniformities of the overhead system may be potentially used to advantage to, in essence, reduce the water application requirements of a given crop.

Also, we seek to evaluate potential additional advantages the precision overhead irrigation system may have under decidedly 'water-short' scenarios, which have been and are likely to continue to be common throughout the Central SJV. Furthermore, for a crop such as alfalfa, we will test the extent these potential benefits of the overhead system may have in actually increasing the annual water use efficiency of the crop.

We further expect that potential problems that have been associated with overhead irrigation in the past in California (Hanson et al., 1988; McKnight, 1983), such as the discharge rate from drop tubes or LEPA systems being much higher than the soil's intake rate, - resulting in ponding and surface water movement, may to a large extent be controlled or minimized by three factors. First, we will attempt to very carefully match the water application rate with the soil's intake characteristics. This is something that our research team now has considerable experience with and it is something that we believe we can now effectively mitigate by careful selection of nozzle flow rates and run-times of the pivot machine. Secondly, it is our team's long-term goal to use our crop and residue management practices to preserve and increase surface residues over time so as to further contribute to increased irrigation water application efficiency.

Our team has also recently documented benefits of these surface residues themselves in terms of reducing soil water evaporation which may account for a net 'savings' of 13% of overhead applied water over the course of a summer annual crop season (Mitchell et al., 2012; Singh et al., 2011). The costs and benefits of the adoption of the irrigation systems for forage crops and alfalfa at the varying levels of ET will be quantified and projected for the life of the equipment, between 15 and 20 years. The analysis will take into account the cost and quantities of labor, water, and capital. We expect that water use will be reduced without compromising yield or quality and that the systems will show a favorable return on investment.

Figure 1. Schematic layout of forage deficit irrigation study showing alfalfa half of the field.



Irrigation Treatments

1. Full irrigation (100% ET)
2. Deficit 1 (75% ET)
3. Deficit 2 (50% ET)
4. Deficit 3 ('Seasonal Drydown')

Figure 2. Drawing of proposed overhead irrigation system for flat-planted forages