ANNUAL REPORT COMPREHENSIVE RESEARCH ON RICE
January 1, 2017 - December 31, 2017

PROJECT TITLE:
Identifying opportunities for improving water use efficiency in California rice systems.

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OBJECTIVES AND EXPERIMENTS CONDUCTED, BY LOCATION, TO ACCOMPLISH OBJECTIVES:

The specific objectives addressed in 2017 were:

1. Summarize our analysis of the salinity study and make that information available on-line to assist growers in managing fields with salinity issues.
2. Publish papers related to salinity, and effects of water temperature on crop development.
3. Quantify percolation and seepage losses in rice fields across the valley. In this study we will determine if percolation rates are affected by the height of the ground water table in relation to the perched water table. We will also assess how seepage is affected by the type and position of levees relative to irrigation or drain ditches and to other flooded fields.

SUMMARY OF 2017 RESEARCH (major accomplishments), BY OBJECTIVE:

Objective 1: Summarize our analysis of the salinity study and make that information available on-line to assist growers in managing fields with salinity issues.

This research has been finalized and results have been recently published:

> Marcos, M, H. Sharifi, S.R. Grattan, B.A. Linquist (2018). Spatio-temporal salinity dynamics and yield response of rice in water-seeded rice fields. Agricultural Water Management. 195:37-46.

Information from this research is being developed into a handout for growers and should be available on-line in a couple of months.

Objective 2: Publish papers related to salinity, and effects of water temperature on crop development.

The salinity paper has been published (see above) and the research from the study examining water temperature affects on crop development has been submitted for publication in Paddy, Water and Environment.

Objective 3: Quantify percolation and seepage losses in rice fields across the valley.

Part 1: Direct field measurements of percolation

Direct measurements of percolation losses were made in 8 rice fields spread throughout the Central Valley (Figure 1). In order to measure *in situ* percolation rates, we adapted established protocols to ensure that we were actually measuring vertical percolation rather than the horizontal exchange of water between the percolation ring and the field. Percolation rings made of 12-inch diameter PVC were installed to 8-10 inches below the soil surface and covered with vented lids to eliminate evaporation while preventing air pressure differences between the ring and the field. Rings were also equipped with flexible plastic bags that allowed water to flow into or out of the bag to equilibrate the field and ring water heights, but did not allow the “ring water” inside the bag to mix with the “field water” outside the bag. The bag was completely emptied into the ring for each ring water height measurement (done with a high-precision caliper), so any difference in ring water height from the last measurement could be attributed to percolation. Water temperature was also measured to account for any fluctuations in ring water height due to thermal expansion and contraction of water.

Percolation rates at all sites indicated that percolation is a small percentage of either evapotranspiration or applied water. Percolation rates ranged from 0.004 mm day^{-1} (one ten-thousandth of an inch per day) to 0.6 mm day^{-1} (two hundredths of an inch per day), which converts to a range of 0.02 inches per season to 3 inches per season assuming 120 flooded days (Figure 2). The average percolation rate across all sites was 0.2 mm day^{-1} (0.8 hundredths of an inch per day) or 1 inch per season. Two important caveats to this data must be stated. First, reliable percolation rate measurements were not obtained early in the season due to technical challenges and the inability of the methodology to function with a widely fluctuating field water height (such as during drains for Leather’s, herbicide applications, etc. at the beginning of the season). The first reliable measurements were therefore obtained in mid-June, and it is quite possible that early-season percolation rates differ from the rest of the season. However, high initial percolation rates are contributing to an increase in soil moisture early in the season and thus may appropriately be accounted for elsewhere. Second, spatial variability in percolation rates almost certainly exists, and it is possible that a large amount of the total percolation occurs in a relatively small area, which may have been missed by this methodology. However, the small error bars representing the average of 3 percolation rings per field (filled points in Figure 2) indicate that the spatial variability was minimal in the areas measured.

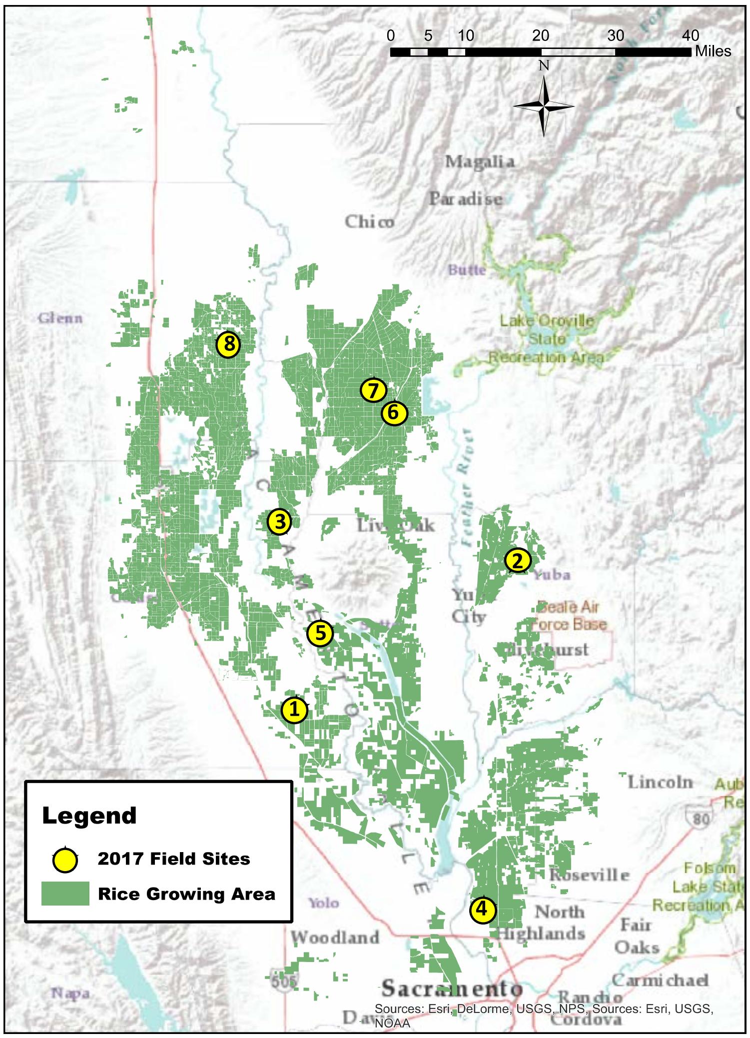

Figure 1: Field sites for direct measurement of percolation rates (numbered yellow circles). The rice-growing area in the Sacramento Valley is shown in green.

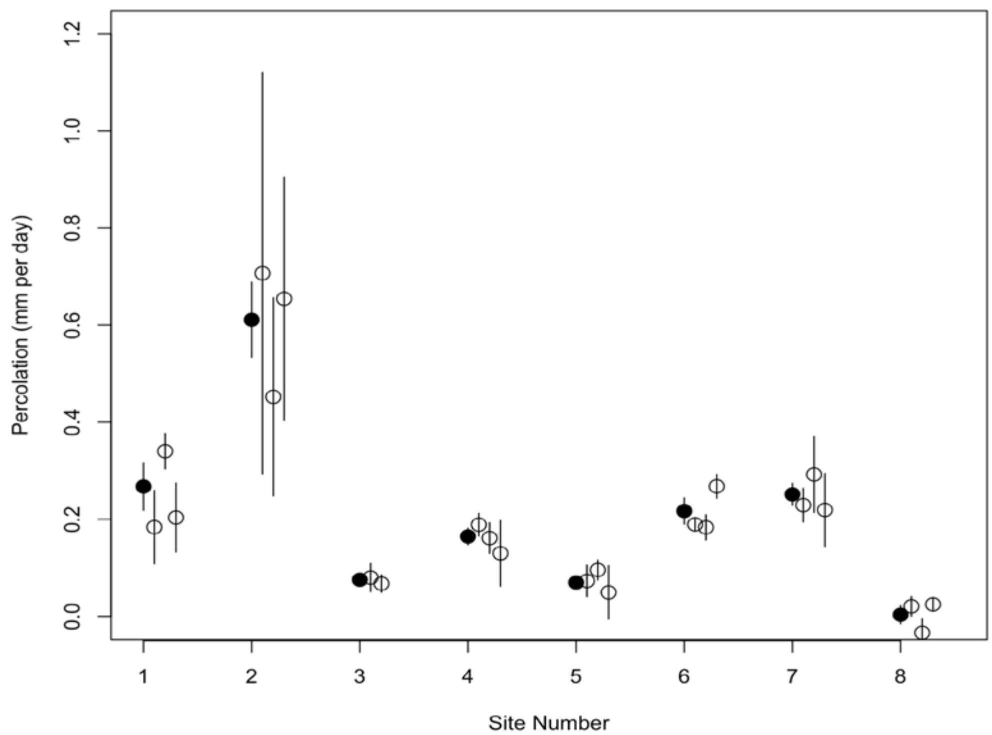

Figure 2: Percolation rates measured directly in eight Sacramento Valley rice fields. Each filled point represents the mean (± standard error) of 3 percolation rings in each field. Each open point represents the mean (± standard error) of all measurements for a single percolation ring.

An analysis of potential explanatory variables indicated that the site (each field) and the date had a significant correlation with the percolation rate, although the influence of the date disappeared if one of the sites was removed (Site 2 in Yuba County). Interestingly, water height did not show a significant relationship with the percolation rate. Other potential explanatory variables are also being explored, such as soil texture, bulk density, and saturated hydraulic conductivity. Due to the difficulty in determining the exact elevation of the groundwater table in a flooded rice field, we cannot conclusively say to what degree percolation rates are affected by the elevation of the groundwater table. We used nested piezometers (spaced every 4 inches from 8–20 inches) to monitor head gradients and the presence of unsaturated zones in the soil profile (the absence of water in one or more piezometers indicated an unsaturated zone). An unsaturated zone was unequivocally present between the floodwater and the groundwater table in only one of the eight sites (Site 2), and although the percolation rate was also highest in this site, the site's soil differed dramatically from all of the other sites. Given the presence of confined aquifers at some of the sites (e.g. Sites 2, 6, 7, and 8) and other data that suggest a limited interaction between the floodwater and the groundwater (such as electrical conductivity and stable isotope data not shown here), it seems unlikely that the elevation of the groundwater table would have a very significant effect on percolation rates.

Part 2: Direct field measurements of lateral seepage

Direct measurements of lateral seepage were also made using three-sided steel frames that were driven into the field borders (almost exclusively levee roads) at the interface between the water and the levee soil. Evaporation from the frames was minimized with reflective insulation, and percolation rates were generally small enough to not result in any appreciable water loss from the frames (see Part 1). Therefore, any water loss from the frames (measured as the water loss from a reservoir designed to maintain a constant water height in the frame) could be attributed to lateral seepage. Measurements as described above were taken in 6 Sacramento Valley rice fields at a minimum of four locations per field (all sites except for Sites 4 and 5). Representative measurements (focusing on all field borders) were only taken at 3 of the sites, so lateral seepage losses could only be estimated for the whole field at these sites (Table 1). In general, lateral seepage losses were small but highly variable (varying over 3 orders of magnitude). Our ongoing work is looking at the influence of various explanatory variables, such as levee type (Figure 3), levee dimensions, field water height, soil texture, bulk density, and more on lateral seepage.

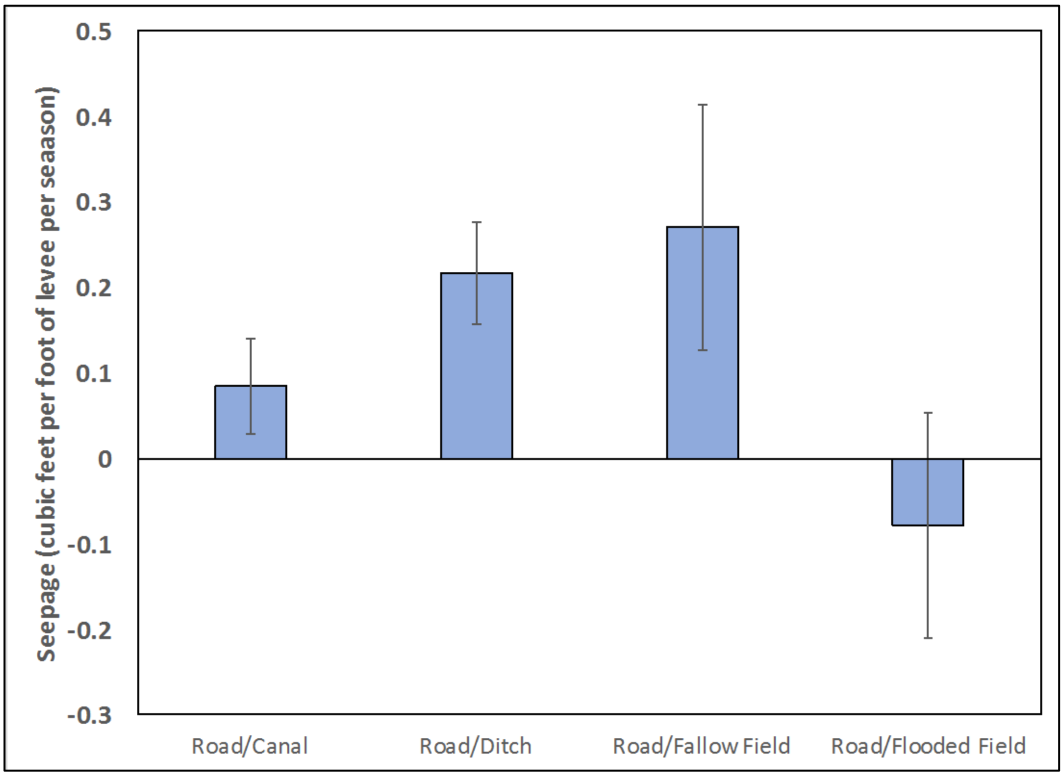

Figure 3: Mean (± standard error) lateral seepage rates for different arrangements of rice field border levees (whether they are neighbored by an irrigation canal, drainage ditch, fallow field, or flooded field).

Part 3: Complete water balance

A complete water balance was calculated for 3 of the sites in Figure 1 (Sites 1, 3, and 7). Applied water was measured by each irrigation district (Reclamation District 108, Reclamation District 1004, and Richvale Irrigation District), rainfall was obtained from the nearest CIMIS (California Irrigation Management Information System) weather station, and evapotranspiration

(ET) was calculated from the CIMIS data and recently developed crop coefficients for California rice (Montazar et al., 2016). Tailwater drainage was measured with an outlet weir and data loggers that recorded the height of water above the weir crest, except when rapid drains required the removal of outlet boards; in these cases, water height measurements were made in 70–80 locations throughout the field immediately prior to the drain, and it was assumed that all of this water was removed from the field during the drain. Changes in soil moisture were determined by soil sampling immediately prior to the initial flood and prior to harvest. Percolation and lateral seepage were measured as described above in Parts 1 and 2.

Table 1: Water balances for three commercial rice fields in the Sacramento Valley. All values are in inches unless otherwise noted (e.g. for "Field size" and "Outputs as a % of inputs").

	Site 1	Site 3	Site 7
Description			
County	Colusa	Colusa	Butte
Field size (acres)	89.8	112.5	35.5
Inputs			
Irrigation	59.47	46.86	44.89
Rainfall	0.51	0.72	0.72
Outputs			
Evapotranspiration	30.89	32.91	31.81
Tailwater drainage*	25.2	6.99	3.71
Lateral seepage	0.55	0.85	0.63
Percolation	1.06	0.36	1.11
Soil moisture change	2.63	2.75	1.04
Balance			
Outputs as % of inputs	100.7	92.2	84.0

* Tailwater drainage includes maintenance flow drainage, Leather's drains, herbicide application drains, and the final drains for harvest.

The calculated outflows for the water balances accounted for 100.7%, 92.2%, and 84.0% of the water inputs for Sites 1, 3, and 7, respectively. Evapotranspiration accounted for approximately half to two-thirds of the applied water, with tailwater drainage representing the second largest outflow. Lateral seepage accounted for only 0.9%, 1.8%, and 1.4% of applied water (irrigation) or 1.8%, 2.6%, and 2.0% of ET in Sites 1, 3, and 7, respectively. Similarly, percolation accounted for only 1.8%, 0.8%, and 2.5% of applied water or 3.4%, 1.1%, and 3.5% of ET in Sites 1, 3, and 7, respectively. It is important to note that we were unable to account for 100% of the water inputs in some of the sites. This discrepancy could be due to spatial heterogeneity in lateral seepage and percolation (discussed briefly in Part 1). However, it could also be due to errors associated with measuring the other terms of the water balance or leaks caused by poor contact between the soil and the outlet boxes, crayfish holes, etc. The water balance approach is perhaps used most commonly to estimate the magnitude of one term (e.g. percolation) by measuring all of the other terms and assuming that the remaining term is the difference between inputs and outputs. This approach can yield valuable information, but any errors in the measurement or estimation of the other terms can give an inaccurate value for the remaining term, especially when some of the terms (e.g. irrigation) and their associated error are much greater than the remaining term (e.g. percolation). For example, if we had measured all of the terms except for percolation in Site 3, we would have accounted for 91.4% of the water inputs and percolation could be assumed to make up the difference (4.1 inches rather than the 0.36 inches measured). Leaks through levees or around the outlets could be erroneously lumped in with seepage and percolation (which occur through the soil matrix), but really should be considered a separate term since the management considerations are different. Two of our three water balance fields in 2016 had significant leaks around the outlet boxes. It is therefore important to consider the relative weaknesses of each approach for any given situation (errors in other terms of the water balance v. unaccounted for spatial heterogeneity with direct measurement).

PUBLICATIONS OR REPORTS:

Linquist, B.A., R. Snyder, F. Anderson, L. Espino, G. Inglese, S. Marras, R. Moratiel, R. Mutters, P. Nicolosi, H. Rejmanek, A. Russo, T. Shapland, Z. Song, A. Swelam, G. Tindula, and J. Hill. (2015) Water balances and evapotranspiration in water- and dry-seeded rice systems. Irrigation Science 33:375-385.

Montazar, A., Rejmanek, H., Tindula, G.N., Little, C., Shapland, T.M., Anderson, F.E., Inglese, G., Mutters, R.G., Linquist, B., Greer, C.A., Hill, J.E., Snyder, R.L. (In Press) A crop coefficient curve for paddy rice from residual of the energy balance calculations. Journal of Irrigation and Drainage Engineering 10.1061/(ASCE)IR.1943-4774.0001117 , 04016076.

Marcos, M, H. Sharifi, S.R. Grattan, B.A. Linquist (2018). Spatio-temporal salinity dynamics and yield response of rice in water-seeded rice fields. Agricultural Water Management. 195:37-46.

LaHue, G.T., and Linquist, B.A., 2017. Subsurface water losses: Seepage and percolation in California rice fields. Rice Field Day. August 30th, 2017. Biggs, CA.

LaHue G.T., Sandoval-Solis S., and B.A. Linquist. 2016. The influence of the recent California drought on water table levels in the Sacramento Valley. Poster presented at the Toward Sustainable Groundwater in Agriculture conference in Burlingame, California. June 29th, 2016.

LaHue G.T., Dahlke H.E., and B.A. Linquist. "Elucidating the interactions between rice cultivation and groundwater in California". Oral presentation at the American Society of Agronomy, Crops Science Society of America and Soil Science Society of America annual meeting. Phoenix, AZ. November 9th, 2016.

Mathias Marcos , Hussain Sharifi , Stephen R. Grattan , Bruce A. Linquist. 2016. The distribution and build-up of salinity in rice fields and its effect on yield. Oral presentation at the Rice Technical Working Group. March 1-4th, 2016.

Mathias Marcos , Hussain Sharifi , Stephen R. Grattan , Bruce A. Linquist. 2016. Spatial and Temporal Water Salinity Dynamics in Flooded Rice Systems. Oral presentation at the American Society of Agronomy, Crops Science Society of America and Soil Science Society of America annual meeting. Phoenix, AZ. November 9th, 2016.

LaHue G.T., Dahlke H.E., Sandoval-Solis S., and B.A. Linquist. "Elucidating the interactions between rice cultivation and groundwater in California". Poster at the Annual Rice Field Day. August 31 2016. Biggs, CA

Mathias Marcos , Hussain Sharifi , Stephen R. Grattan , Bruce A. Linquist. "Water Salinity Dynamics in California Rice Fields." Poster at the Annual Rice Field Day. August 31 2016. Biggs, CA

CONCISE GENERAL SUMMARY OF CURRENT YEAR'S RESULTS:

1. Results from salinity research published. From these were are developing extension pamphlets on how best to manage salinity if it is a problem.
2. Direct measurements of percolation losses were made in 8 rice fields spread throughout the Central Valley. Percolation rates ranged from 0.004 mm day^{-1} (one ten-thousandth of an inch per day) to 0.6 mm day^{-1} (two hundredths of an inch per day), which converts to a range of 0.02 to 3 inches per season assuming 120 flooded days. The average percolation rate across all sites was 0.2 mm day^{-1} (0.8 hundredths of an inch per day) or 1 inch per season.
3. Direct measurements of lateral seepage were also made in 6 Sacramento Valley rice fields at a minimum of four locations per field. Representative measurements (focusing on all field borders) were only taken at 3 of the sites, so lateral seepage losses could only be estimated for the whole field at these sites. In general, lateral seepage losses were small but highly variable (varying over 3 orders of magnitude). Seepage was greatest in fields where the levee bordered a fallow field, followed by when it bordered a drain ditch, when it bordered an irrigation supply channel and when it boarded another fallow field.
4. A complete water balance was calculated for 3 of the sites. Irrigation inputs ranged from 4 to 5 ft., while evapotranspiration (ET) averaged 2.5 to 2.75 ft. Tail water drainage ranged from 4 to 25 inches. Lateral seepage and percolation together were about 2 inches or about 6% of ET.