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

PROJECT LEADERS:

Bruce Linquist
Professional Researcher
University of California
One Shields Avenue
Department of Plant Sciences
Davis, California 95616-8627
(530) 752-3450
balinquist@ucdavis.edu

Robert Hijmans
Assistant Professor
Environmental Science and Policy

Richard Snyder
UCCE Specialist-Biometeorology
Land, Air and Water Resources

Richard Plant
Professor
Plant Sciences

Chris van Kessel, Professor
Department Chair
Plant Sciences

Jim Hill,
UCCE Specialist-Rice
Plant Sciences

COOPERATORS: Randall Mutters, UCCE Farm Advisor
Butte County

Chris Greer, UCCE Farm Advisor
Sutter, Placer and Yuba Counties

Luis Espino, UCCE Farm Advisor
Colusa, Glenn and Yolo Counties

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CONCISE GENERAL SUMMARY OF CURRENT YEAR'S RESULTS:

1. A data base has largely been developed from statewide wide variety trails that contain information on all major varieties, yields, planting dates and days to heading. Data on all varieties is available for 1994 to 2009 and for the major varieties from 1978 to 2009.
2. A crop development model was developed for M-202 based on the growing degree day concept. This model, while an improvement on simply counting days to heading, could be improved by accounting for accounting for photoperiod sensitivity.
3. For M202, it appears that time to heading is largely driven by photoperiod sensitivity when rice is planted before May 21. For planting dates later in May, time to heading appears to be driven by temperature. The other eight CA varieties tested in 2011 appear to follow this same pattern.
4. In 2011, we also collected two other growth stages that are of interest to growers. These were panicle initiation (green ring) and time to physiological maturity (grain at 28% moisture). These data were collected for 8 varieties common to California (M104, M105, M202, M205, M206, L206, CM101, S102). Within any given location, the time from planting to PI was similar for the 8 varieties we evaluated in 2011. The main difference between varieties (that affected crop duration) was between PI and 50% heading. The time from 50% heading to physiological maturity was similar for the 8 varieties we evaluated in 2011 except for the long grain variety tested (L206) which had a shorter time from heading to maturity than the other varieties possibly due to the narrow grain drying out faster.
5. Using the preliminary degree day model, we tested two options that could potentially reduce ET in rice systems. These were to (1) reduce crop duration by planting later in the season when it is warmer and (2) reduce crop duration by planting a shorter duration variety (M-206 versus M-202). For both M-202 and M-206 a later planting date would reduce ET by about 1 inch between planting to heading. The days to 50% heading for M-206 were 6 and 8 days less than for M-202 for planting dates of May 1 and June 1, respectively. Shorter duration translated into reduced ET by 1.6 inches (about an 8% reduction) between planting and heading. This difference comes without a reduction in yield as yields of M-206 are comparable to M-202. However, this data needs to be interpreted with caution for a couple of reasons. First, the model is still in its development stages and we know it needs improvement. Second, we do not know how varieties differ between heading and maturity. For example, does a 6 to 8 day difference in time to heading also translate into a 6 to 8 day difference in time to maturity?
6. We summarized 3 years of data on water use in wet and dry seeded systems. Preliminary results show that seasonal evapo-transpiration and water use are similar for the two systems.

BACKGROUND

Water is scarce in California and there are efforts to conserve water in all sectors of the economy. Identifying opportunities to conserve water and increase water use efficiency (WUE) will be increasingly important for the rice industry as well.

To discuss options for improving rice WUE, identifying where water losses are occurring is essential. In brief, water is lost through **evaporation** (E - water vapor loss from water surfaces), **transpiration** (T - water vapor loss from plant surfaces), **percolation and seepage** (water loss downward through the soil) and **drainage** (D - surface water loss from drain outlet). Evaporation and transpiration are often combined and referred to as **evapotranspiration** (ET). In California, total annual (growing season) water use in rice systems is estimated at between 3.6 and 7.7 ac ft/ac (Table 1). Of this amount, 3.1 to 3.7 ac ft/ac go to ET, 0.5 to 2.0 ac ft are lost via percolation, and 0 to 2.0 ac ft are drained from the field. Separating losses due to E and T indicate that both E and T losses are significant and roughly equal in magnitude.

Identifying potential improvements in terms of WUE and crop productivity are important issues that will address the current efficiency of WUE in the rice industry as well as address various options for reducing water use. We will briefly consider each loss and the possibilities for reducing those losses and how a reduction in those losses may affect rice system sustainability.

Transpiration is the amount of water lost as water vapor as the crop takes up water through its roots and the water exits the plant through stomata in the stems and leaves. A plant must take up water to survive as water is used in the transport of nutrients, in photosynthesis, to provide cell rigor, to cool the plant, etc. The amount of water required to produce a certain amount of biomass, i.e. the transpiration efficiency (TE), is relatively constant for each crop. For rice the TE is lower than other C3 cereal grains. Rice produces 1.47 g biomass/kg water compared to the other C3 cereal crops which average 1.84 g biomass/kg water (25% more). Alfalfa (1.33 g biomass/kg water) is one of the major crops in California, and rice has a higher TE. While TE varies considerably between crops it does not vary much between varieties of the same crop. For example, extensive breeding efforts over the last century have not changed the TE of maize. What has changed in maize (and in other grains) is the partitioning efficiency of maize so that more of the biomass is grain (Loomis and Conner, 1992). Thus, it is not likely in the near term that research efforts will be able to change the TE of rice.

Evaporation (E), or the water loss from water surfaces, is a significant form of water loss from fields. During the early part of the growing season in California's wet-seeded systems, most of the water lost from the systems occurs via E because the plants are small and T is minimal. As the season progress, T contributes increasingly to water loss as the canopy develops which increases transpiration and reduces E by shading the surface of the water. Evaporation losses can be reduced by reducing the amount of water exposed to sunlight and surface air. This is part of the rationale behind dry seeding. In dry-seeded rice systems, water is flushed across the field but standing water is not maintained. This practice may reduce E losses during the first month before a flooded paddy is maintained.

Percolation and seepage losses vary tremendously between fields and even within a field. Such losses are very difficult to quantify and are usually estimated based on the difference between total water loss and losses due to ET and D. Generally, in California, due to the high clay content and hardpan soils where rice is cultivated, percolation losses are low. However percolation losses can be high in newly developed rice fields where hardpans are broken or when sand streaks are present within a field. Management of percolation losses is impractical because it is often difficult to determine where the losses are occurring within the field. Seepage losses are more easily identified and controlled but they are generally a minor component of the water balance.

Drainage losses also vary tremendously and range from 0 to 2.0 ac ft (and higher). Drainage events are common in rice fields either as a complete drain or to as part of maintenance flow operations (continual flow of water through a field). Growers prefer to have the option to drain water as part of their herbicide management programs and to control water height in the field. Furthermore, some soils are saline and require maintenance flow of fresh water to avoid salinity problems which may reduce rice yields. However, we have observed that a number of growers do not drain water from their fields and have maintained good rice yields. This suggests that at least in some fields, farms or districts no water outflow may be an option to reduce D.

Finally, it is important to consider the losses not only at a field scale but also a regional scale. Water lost from a field due to percolation, seepage and D eventually ends up in the Sacramento River either via surface drain water canals or underground lateral movement of water. In contrast, water lost via ET is lost from the system at both field and regional scales.

Some proposed options for reducing water use

Table 3 provides some options to reduce water use in rice. The table identifies where these savings might be realized as well as some possible counter effects. These options are discussed in more detail below.

Table 1. *A summary of various management options and our assumptions on if they reduce evaporation (E), transpiration (T) and drainage (D).*

	Reduce			
Management option	E	T	D	Comment
Use shorter duration varieties	Y	Y	Y	Shorter duration varieties may yield less
Reduce crop duration by planting later in season when it is warmer	Y	Y	Y	May not be an option for large growers. planting too late may reduce yield.
Drill seeded rice	Y	N	?	Dry seeded rice extends crop duration by 7-10 days so savings in E may be lost in T and D
Aerobic rice (not flooded but irrigated like wheat)	Y	N	Y	Aerobic rice extends crop duration by up to 2 wk based on observations in 2009. Increased risk of water stress.
Early final drain	N	?	Y	Thompson and Mutters have show that there may be potential to drain rice fields a few days to a week earlier than normal.
No outlet flow	N	N	Y	In some fields, salinity may be an issue

Options for reducing ET (net water use)

1. <u>Reduce crop duration by growing shorter duration varieties:</u> Shorter duration require less water because the crop grows for a shorter period of time thus lowering transpiration (T) and evaporation (E) if the initial growth period is shortened. As mentioned earlier, shorter duration varieties typically have lower yields than longer maturing varieties due to a reduction in photosynthesis.
2. <u>Reduce crop duration by planting later in the season:</u> Planting later ensures planting in warmer weather (and water) which accelerates canopy closure thus reducing E during the

early part of the season. Since planting occurs during the warmer part of the season, degree days will accumulate faster and the initial growth is more rapid. Since water is a better absorber of sunlight, the faster canopy growth reduces net radiation and, hence, the energy available to evaporate water. Thus, faster growth reduces the rice ET relative to ETo. This is the opposite of other field crops which tend to having increasing ET relative to ETo as the crop grows. Later planting dates, however, may be an option only for growers with relatively low acreage.

3. <u>Dry seeded rice systems:</u> Possibly requires less water early in the growing season by reducing E, however, drill seeding extends the duration of the crop. Gains made in savings to E may be lost by having to irrigate the crop longer. We estimate that dry seeding extends crop duration by 7 to 10 days. Analysis of three years of data comparing the two systems shows that ET is similar for both systems (Table 2).
4. <u>Aerobic rice production:</u> Aerobic rice production would involve irrigating the crop like wheat. There would be savings to E during early crop establishment until canopy coverage. Savings due to reduced E will also depend on the type of irrigation (flood versus sprinkler). However, like dry-seeded rice, irrigating the crop in this manner extends crop duration. In a 2009 trial at the Rice Experiment Station (RES) aerobic rice systems headed two weeks later than conventional water-seeded systems. Thus, savings to E may be lost by needing to irrigate longer. Additionally, the risk of water stress is increased due to the possibility of untimely irrigations.

Table 2. *Net water use (water applied – drainage water), ET and percolation/seepage (net water use – ET) for wet and dry seeded rice systems across three years. In each study year, the wet and dry seeded fields were adjacent to each other.*

Year	**Wet seeded**			**Dry seeded**		
	Net water use	ET	Percolation / seepage	Net water use	ET	Percolation/ seepage
	Acre feet/acre					
2007	3.04	2.95	0.09	3.96	2.97	0.99
2008	3.47	3.0	0.47	4.12	2.78	1.34
2009	4.37	2.8	1.57	2.63	2.8	0
Mean	**3.63**	**2.92**	**0.71**	**3.57**	**2.85**	**0.78**

Options for reducing drainage (D) and gross water use:

1. <u>Reduce tailwater drainage:</u> Some growers and irrigation districts have had success in either reducing or eliminating tailwater outflow. This does not directly affect ET but it reduces D and hence the amount of water delivered to a field. The main problem is with salinity in some fields (see Scardaci et al., 2002).

2. Early final drain: Thompson and Mutters in recent research funded by the Rice Research Board (RRB) have suggested that, with the use of certain varieties, there is the possibility of draining the fields by up to a week earlier. This would require a week less of delivery to a field and reduce D.

OBJECTIVES

As the previous discussion indicates, reducing water use in rice systems is not a straight forward task. Water saved in one area may require more in another. These are complex interactions and very costly and time consuming to test in the field. Instead, a more cost effective way is to narrow the possible options using existing data and crop simulation models. This would determine which of the many options are most likely to yield positive results in field trails. With this in mind, our overall objective of this project is to identify options for improving WUE for California rice systems while maintaining productivity and soil quality. Importantly we want to maximize our productivity for every unit of water used (more crop per drop). Our specific objectives are:

1. Develop a model that can accurately predict crop development and duration.
2. Use model and existing data to predict how various management options reduce water use.

EXPERIMENTAL PROCEDURE AND RESULTS TO ACCOMPLISH OBJECTIVES:

A crop growth model will be developed to predict crop growth and duration for different varieties in California. We will build on existing rice growth models that were developed elsewhere, and adjust these for California conditions. Key data required are measurements of crop development for different varieties, and under different climatic conditions (locations, years, planting dates). In 2011 we were able to:

1. Develop a preliminary crop development model using degree days and photoperiod sensitivity as major drivers of development.
2. Use this model to determine water saving benefits from planting later in the season and using shorter duration varieties.

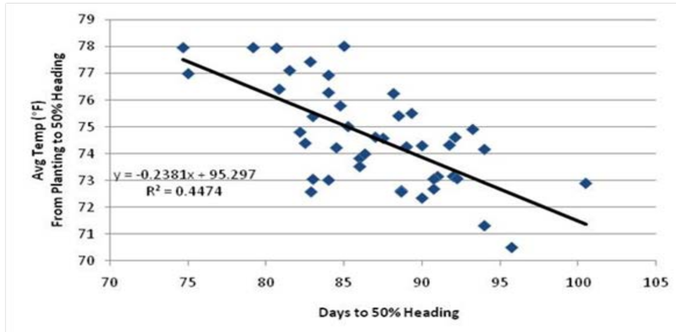
We will discuss each of these outcomes below.

Crop Development Model

Based on research in 2010 (reported in in more detail in the RRB 2010 Annual Report) a predictive degree day model (CalDD) that estimates days from planting to 50% heading for M-202 was developed from historical data collected from 1984-2009 as part of the UC Cooperative Extension (UCCE) Rice Variety Evaluation at Rice Experiment Station (RES) in Biggs, CA as well as other locations.

The relationship between the observed days to 50% heading (D50%H) and the average daily temperature, 1984-2009, indicates the clear effect of temperature on the rice growth cycle during the study period (Fig. 1).

Figure 1. Observed days from M-202 planting to 50% heading as related to average air temperature during the growing period. 1984-2009 – UCCE Rice Variety Evaluation at Biggs RES.



Using the CalDD model we predicted days to heading for M202 in two locations: the RES and Natomas-Sutter (a cooler location). Natomas-Sutter predicted and observed D50%H overlay with the ones used to develop the model at Biggs-RES (Figure 3) but generally take longer to heading due to cooler weather.

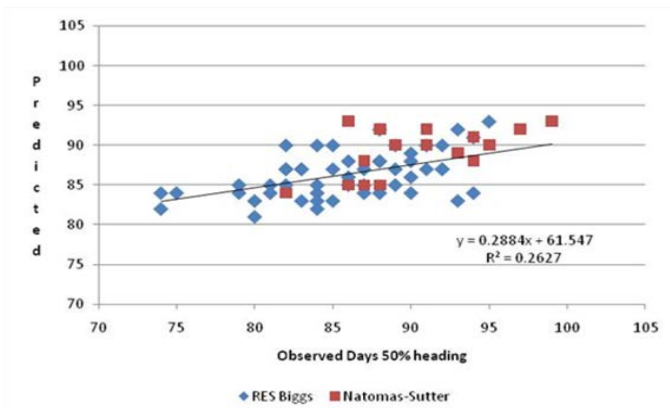


Figure 3. Observed Vs. Predicted days to 50% heading (at 1944DD) using CALDD (Tmax>93°F, Tmin>70°F; Tb = 32°F) for Biggs RES and Natomas-Sutter. 1984-2009 – UCCE rice variety evaluation.

While the model that has been developed does a reasonable job at predicting time to heading based on temperature, it consistently underestimates long duration years and overestimates short duration years (Fig. 3). One reason for this may be that the varieties we are using are photoperiod sensitive. So, in addition, to responding to temperature, they also respond to day length. Therefore, in 2011, we further explored this issue using the current data base.

Our results show that the effect of temperature and photoperiod sensitivity may be dependent on when the rice was planted. For planting dates before May 21 there was no effect of temperature on days to heading (Fig. 4). However, temperature did appear to have an effect for planting dates after May 25 such that an average 1 degree increase in temperature decreased time to heading by 6 days (Fig. 4).

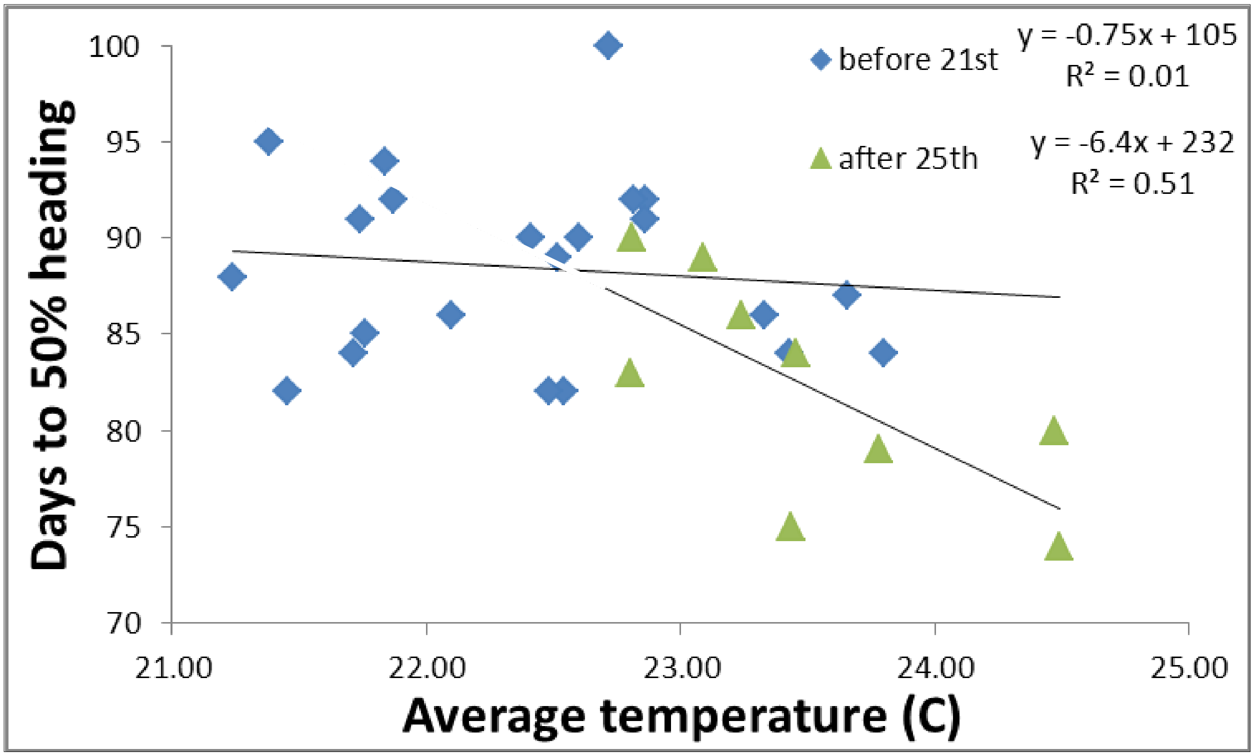


Figure 4. *Time to heading as affected by average temperature for planting dates before May 21 and planting dates after May 25.*

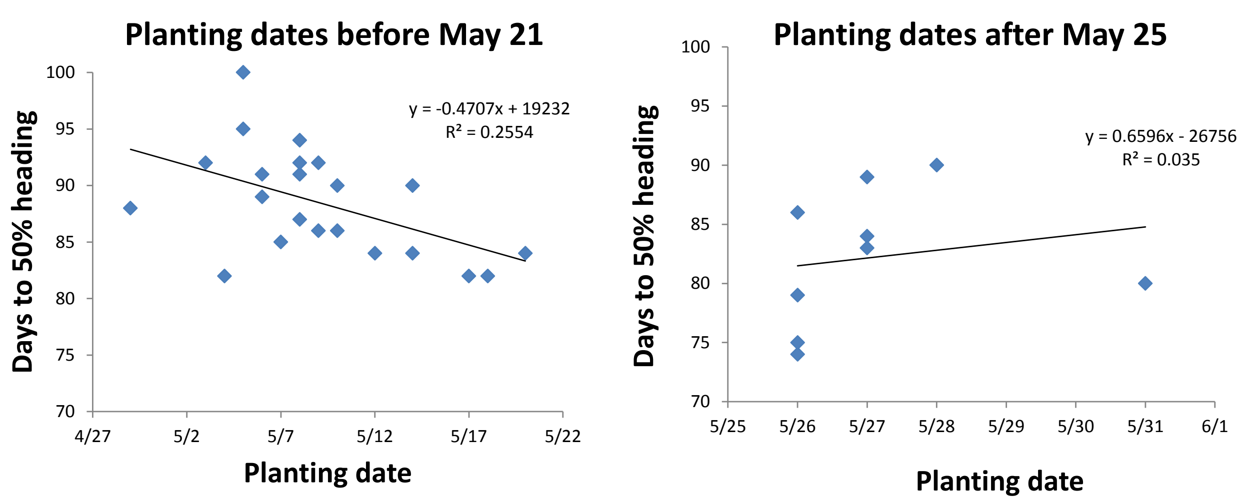


Figure 5. *Time to heading as a function of planting date for two planting periods: before May 21 and after May 25.*

To determine the effect of photoperiod sensitivity on days to heading we examined the same planting periods relative to planting date (instead of temperature). The data suggest that for planting dates before May 21, photoperiod sensitivity was a factor in determining time to heading (Fig. 5). In general, for every 2 days earlier that rice is planted the heading date will be one day earlier - suggesting that these varieties are slightly photoperiod sensitive. If they were strongly photoperiod sensitive the heading date would remain the same with earlier planting dates. If they were not at all photoperiod sensitive then planting two days early would have no effect on time to heading and, all else being equal, the heading date would also be two days earlier.

A second issue with the model is that it only accounts for the time between planting and heading. The time to panicle initiation and to maturity is also important, and should be accounted for in the model in order to make it more useful for growers. In addition this information should be available for other varieties as well.

In 2011, we collected this data for 8 major CA varieties (M104, M105, M202, M205, M206, L206, CM101, S102) from the statewide variety trials. Time to panicle initiation was determined by green ring and physiological maturity was determined at 28% grain moisture. Time to 50% heading was collected as normal for these trails.

Results for M202 show that time to heading and PI (Fig. 6) as affected by planting date, are similar to those we found across many years at the RES (Fig. 5). That is, M202 appears to be driven by photoperiod sensitivity. In 2011 we also found that planting 2 days earlier reduces the heading date by about 1 day.

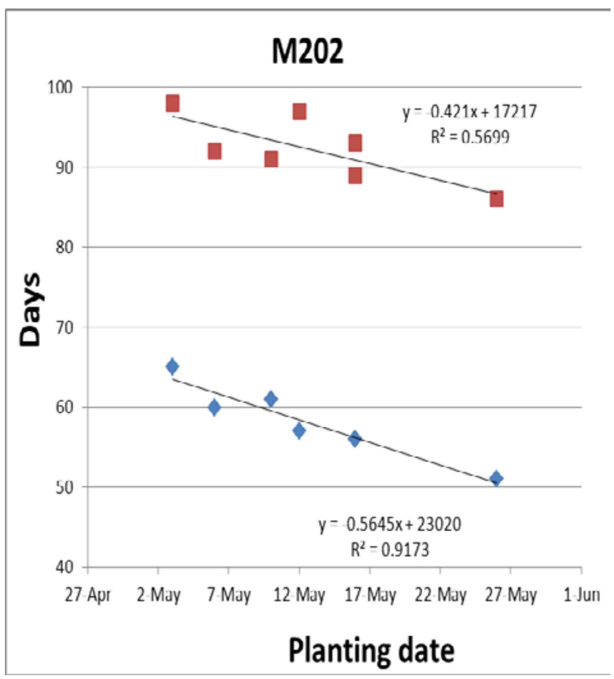


Figure 6. *Time to PI (blue diamonds) and heading (red squares) for M202 across 7 variety trials in 2011.*

Looking at all of the varieties, the data suggest that all of them behave similarly with respect to time to PI. That is that for planting dates before May 21 time to PI (or heading) is driven by photoperiod sensitivity (Fig 7). We found in 2011 that green ring (PI) occurred between July 8 and 13 for most varieties, planting times (before May 21) and locations. 2011 data also show that planting dates after May 25 (in 2011 the planning date was May 26) do not follow the same trend and may be affected more by temperature as seen in Figure 5.

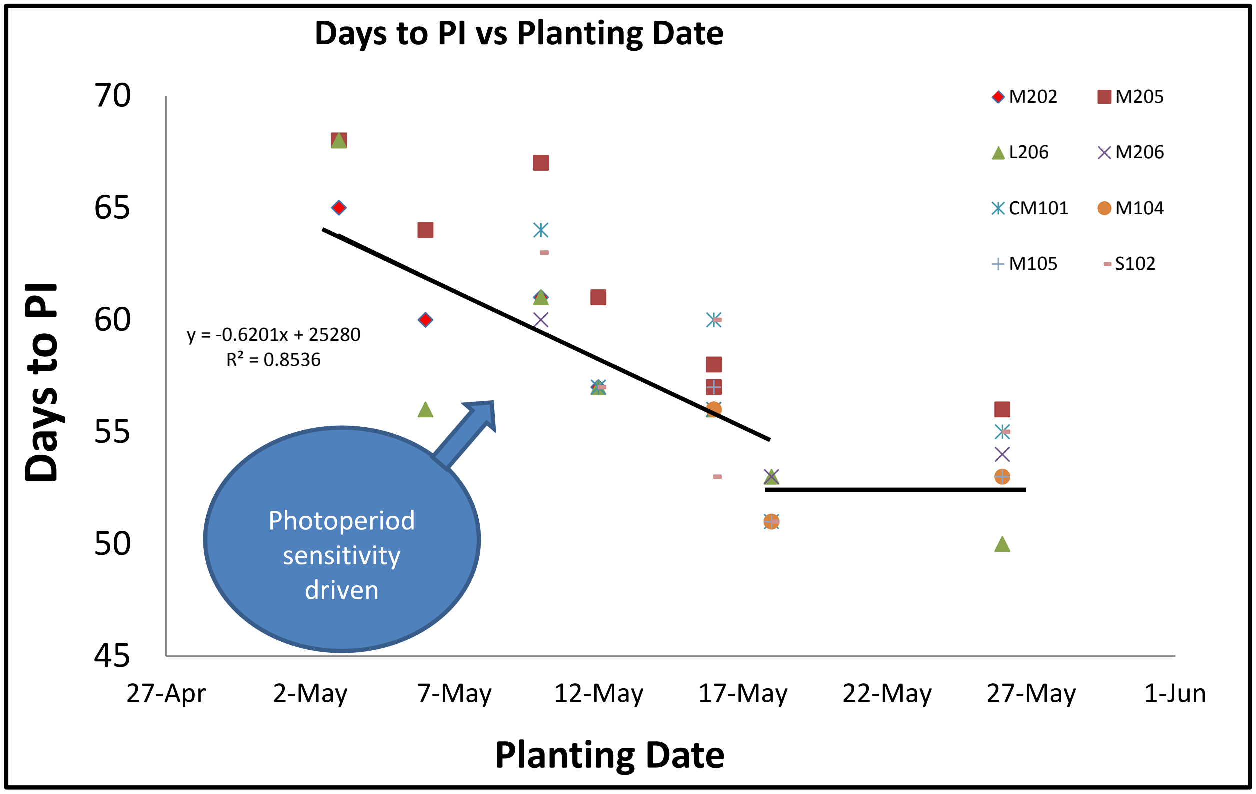


Figure 7. *Days to panicle initiation (PI) for different varieties, locations and planting dates in 2011.*

The data are still being analysed; however some other factors that were noted with respect to varietal differences can be summarized as follows:

1. Time from planting to PI was similar (varied by 4 days) for all varieties within any given location.
2. Time from PI to 50% heading varied among varieties.
3. The period from 50% heading to maturity was similar for all varieties except L206 which was earlier. It may be earlier due to the slenderness of the grain which allows for more rapid drying.
4. Some varieties may be earlier to heading but have similar times to maturity. An example of this is M202 which is takes longer to 50% heading than M206 but is much closer to M206 at physiological maturity.

These data highlight the need to examine the entire cropping cycling in order to accurately predict various growth stages as well as to determine the period which the crop may need to be flooded.

Using model to predict potential water savings strategies

Using this preliminary model, we tested two options that could potentially reduce ET in rice systems. These were to (1) reduce crop duration by planting later in the season when it is warmer and (2) reduce crop duration by planting a shorter duration variety (M206 versus M202).

The effect of Et on the potential trade-off between having a shorter crop duration during a warmer period was estimated. CIMIS cumulative 25 years historical daily reference evapotranspiration (Eto) between planting date and 50% heading was compared, based on CalDD D50%H estimations for a May1 and June 1 planting dates (Fig 8). For both M202 and M206 a later planting date would reduce ET by about 1 inch between planting to heading. The days to 50% heading for M206 were 6 and 8 days less than for M202 for planting dates of May 1 and June 1, respectively. Shorter duration translated into reduced ET by 1.6 inches (about an 8% reduction) between planting and heading. Importantly this difference comes without a reduction in yield as yields of M206 are comparable to M202. However, this data needs to be interpreted with caution for a couple of reasons. First, the model is still in its development stages and we know it needs improvement. Second, we do not how varieties differ between heading and maturity. For example, does a 6 to 8 day difference in time to heading also translate into a 6 to 8 day difference in time to maturity?

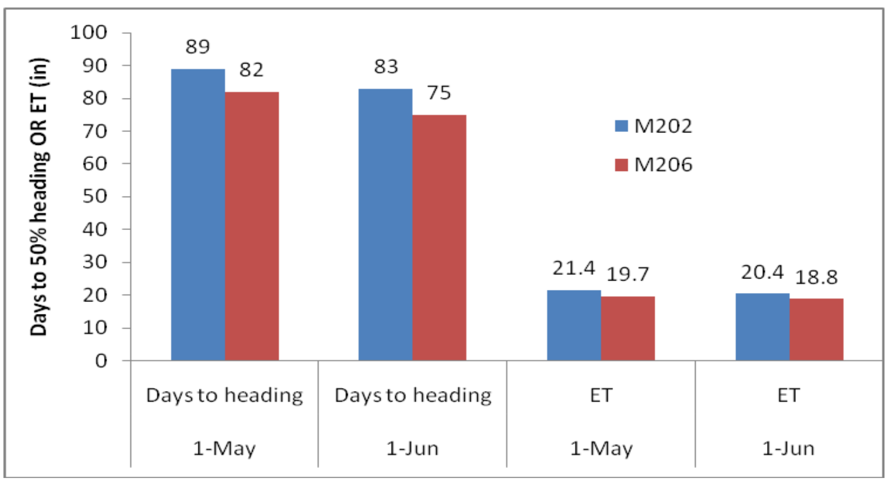


Figure 8. *Results of model showing effect of variety and planting date on days to heading and water use (ET) from planting to heading.*

Future Research

We have shown the importance of considering both temperature and photoperiod sensitivity for crop development. These factors now need to be used in a M202 crop development model which will be a key task for 2012. In addition, we will continue to collect PI and physiological maturity dates of the eight varieties at the state wide variety trials. This will allow us to have the data necessary to develop a model for all of major CA varieties. Finally, we will conduct a greenhouse study for the same 8 varieties with a broader range of planting dates to better determine the effect of photoperiod sensitivity in a greenhouse where temperature can be controlled.