ANNUAL REPORT
COMPREHENSIVE RESEARCH ON RICE
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PROJECT TITLE: Identifying opportunities for improving water use efficiency in California rice systems.

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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 growing degree concept. This model predicts time to heading with reasonable accuracy; however, accuracy could be improved by accounting for photoperiod sensitivity that may exist in the varieties. We plan to continue to improve this model in 2011.
3. 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 (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?

BACKGROUND

Water is increasingly scarce in California and there are renewed 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. Too late planting 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. Reduce crop duration by growing shorter duration varieties: 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. Reduce crop duration by planting later in the season: 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. Dry seeded rice systems: 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.
4. Aerobic rice production: 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.

Options for reducing D and gross water use:

1. Reduce tailwater drainage: 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). In specific,

1. Develop a model that can accurately predict crop growth, crop duration, evapo-transpiration (ET) and yields.
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, water use, and productivity for different varieties and the climatic zones for rice 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 and biomass production for different varieties, and under different climatic conditions (locations, years, planting dates). We will also use soils and climate data for the different rice growing areas. In 2010 we were able to:

1. Develop a data base
2. Develop a preliminary crop development model using a degree day concept
3. 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.

Data base development

There is a large body of existing data available for California rice systems, including:

1. Rice variety trials: Data are currently available from 1973 and electronically from 1994 through 2009 from the rice variety trials that have been conducted around the state at six to nine locations per year. The trials include very early, early and intermediate to late varieties.
2. Every year the RES has two planting dates for the statewide variety trial. These data will be used to assess the affect of planting date on crop duration and productivity.
3. Water use data in dry and wet seeded systems. A three year project was recently completed evaluating water use (E, T, percolation and D) in wet- and dry-seeded systems.
4. An earlier study (R.L. Snyder and J. Williams - funded by the RRB) on rice ET was conducted during 2000 and 2001 near Nicholaus.
5. Climate data from CIMIS and other weather stations around Sacramento Valley.
6. Soils data from the USDA.

In 2010, we pulled together data from all of the variety trails into a single data base. Most of this work has been completed but the data base still needs some refinement and checking. We had electronically available data from 1994 through 2009. In addition for the major varieties (i.e. M-202) we went back as far as 1978 and manually entered data.

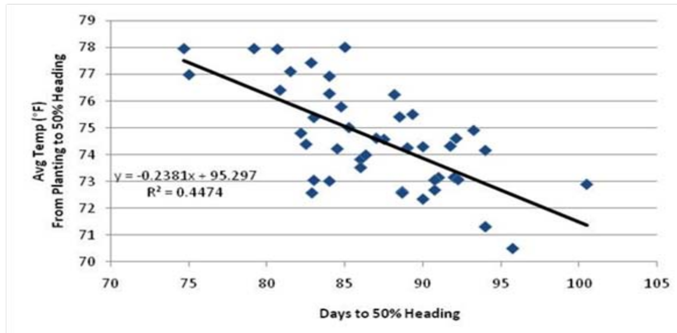
Crop Development Model

A predictive degree day model (CalDD) that estimates days from planting to 50% heading (D50%H) 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.

Degree day (DD) accumulations can be used by growers to monitor and predict the development of biological processes, and thus DD programs have informed management of various crops. Several rice growing states, such as Arkansas, Louisiana, Texas, and Missouri, have developed such programs. Typically called DD50, due to using a base temperature of 50°F, the programs improve timeliness of rice management decisions by utilizing temperature data from different weather station networks (Wilson et al.). The heat unit accumulations are estimated by measuring the area contained within threshold temperatures, maximum (Max), minimum (Min) and base (Tb). Thus, the key factor in the development of such a program is to determine the best temperature thresholds for the accumulation of DD. These thresholds will directly depend on the properties of the local cultivars and the regional climatic conditions.

Planting and 50% heading dates were extracted from UCCE rice variety evaluation tests conducted at the Biggs RES between 1984 and 2009. Daily maximum and minimum temperatures for this period were downloaded from the California Department of Water Resources CIMIS weather station at Durham.
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.



Several methods have been proposed to determine the best temperature thresholds; for the purpose of this project two methods were compared. The first method, proposed by Arnold (1960) and then refined by Baskerville and Emin (1965), is based on a least variability approach to determine the best base temperature (t_b) by using standard deviation in days (S_d) from the following equation: $S_d = (S_{dd})/(X_{bar}t - t_b)$, where $X_{bar}t$ is the mean temperature and S_{dd} is the standard deviation in degree days.

In the second method, a Microsoft Excel Solver DD Application, developed by R.L. Snyder (2010), was modified to optimize the combination of temperature thresholds (Tmax, Tmin, and Tb), until the slope of the regression equation between mean temperature (independent variable) and DD accumulation was minimized and the minimum root mean square error (RMSE) between observed and predicted D50%H was obtained. From our thresholds evaluation the modified Snyder DD model was optimal when the following threshold were set (subsequently referred to as CalDD):

$$CalDD = \left(\frac{Tmax + Tmin}{2}\right) - Tb$$

If Tmax>93°F, then 93°F; If Tmin>70°F, then 70°F; Where Tb = 32°F

With these thresholds the minimal slope between mean temperature (independent variable) and degree days (°D) was 10.14 (°D/°C) and the root mean square error between observed and predicted D50%H was minimized to 4.3 days (Figures 2a and b). From our thresholds evaluation there was a total average accumulation of 1944 Degree Days (°D).

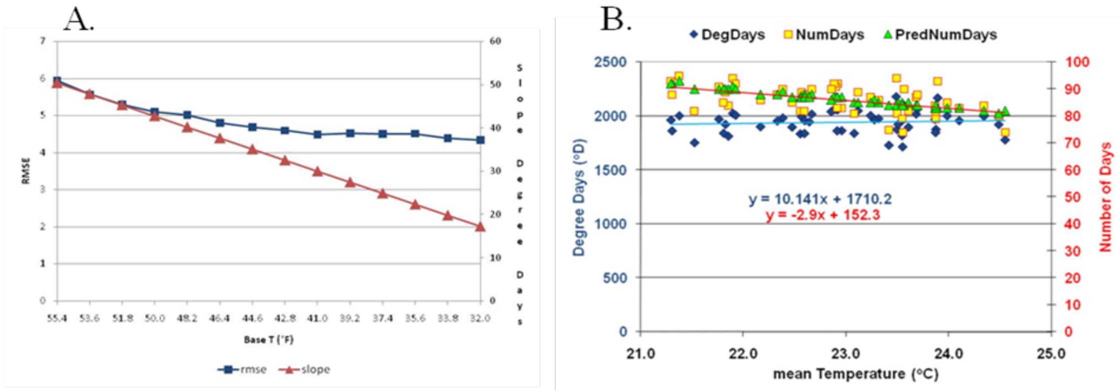


Figure2a. Slope values generated by the relationship between accumulatedDD to 50% heading and different base temperatures and the corresponding root mean square error of the relationship between observed and predicted days. M202. 1984-2009 – UCCE rice variety evaluation at Biggs RES.

Figure 2b. Relationship among accumulatedDD, average air temperature, and numbers of days to 50% heading. Using CALDD (Tmax>93˚F, Tmin>70˚F; Tb = 32˚F) for M-202. 1984-2009 – UCCE rice variety evaluation at Biggs RES.

In order to test the model a southern rice growing region was selected (Natomas, Sutter County) and CalDD was computed using daily Max and Min temperatures from the CIMIS Nicholaus weather station. Natomas-Sutter predicted and observed D50%H overlay with the ones used to develop the model at Biggs-RES (Figure 3).

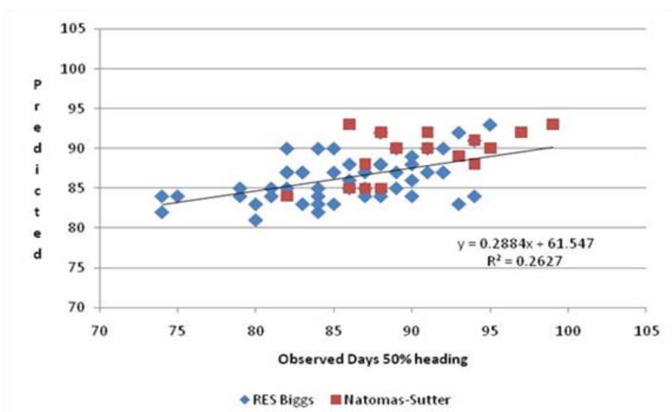


Figure 3. Observed Vs. Predicted days to 50% heading (at 1944DD) using CALDD (Tmax>93˚F, Tmin>70˚F; Tb = 32˚F) for Biggs RES and Natomas-Sutter. 1984-2009 – UCCE rice variety evaluation.

The 2010 rice growing season has been particularly cold (Figure 4), approximately 70% of days between April 1 and July 31 were below the 25 years historical average. CalDD was used to estimate D50%H for 2010 and compare it to the average days using the historical 25 years daily maximum and minimum temperatures for planting dates varying from early May to late June (Figure 5). There is a clear delay in D50%H during the 2010 growing season, with the greatest predicted difference (7 days) for planting on May 1. It is important to note that these are average estimated D50%H values, therefore the predictions are “conservative” and larger deviation may occur.

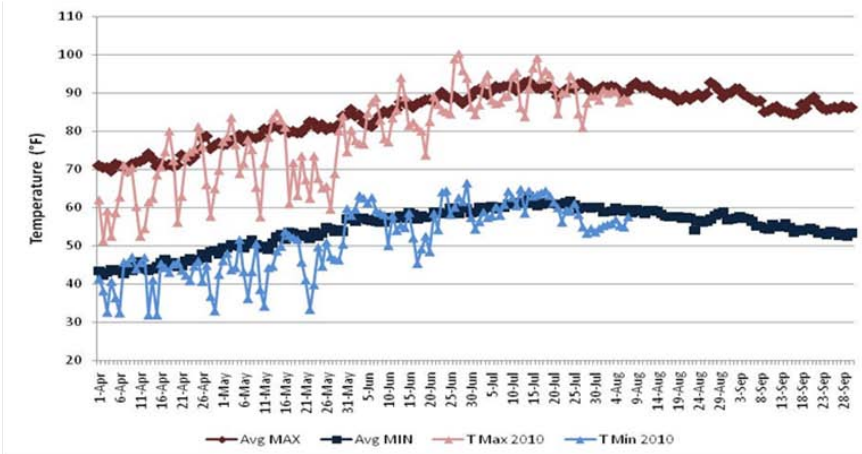
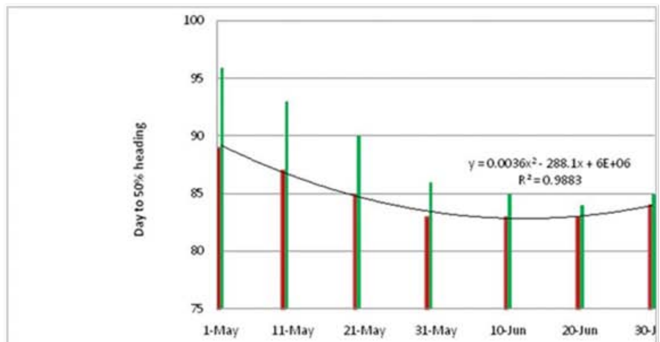


Figure 4. Comparison of 2010 and Historical Average Maximum & Minimum Temperature (°F) at Durham CIMIS Weather Station



	1-May	10-May	20-May	30-May	10-Jun	20-Jun	30-Jun
Day50% heading Historical	89	87	85	83	83	83	84
Day50% heading Predicted 2010	96	93	90	86	85	84	85

Figure 5. D50%H (at 1944 DD) based on historical average temperature (1984-2009, CIMIS Durham) and predicted for 2010 growing season using CALDD0. For the 2010 growing season prediction temperatures were used up to August 9 and historical average temperatures data after that.

When historical data is used CalDD estimates 50% heading on July 29, for a May 1 planting date. When a combination of historical and 2010 actual temperature data (through August 9) is used 50% heading is estimated on August 5. For later planting dates these difference are smaller. However one reason for these smaller differences is that on later planting dates the amount of days used in the calculations from the historical data are larger and therefore is less influenced by actual conditions (Table1).

Planting Date	Day 50% heading Historical Average	Day 50% heading Predicted 2010	Date 50% heading Historical Average	Date 50% heading Predicted 2010
1-May	89	96	29-Jul	5-Aug
10-May	87	93	5-Aug	11-Aug
20-May	85	90	13-Aug	18-Aug
30-May	83	86	21-Aug	24-Aug
10-Jun	83	85	1-Sep	3-Sep
20-Jun	83	84	11-Sep	12-Sep
30-Jun	84	85	22-Sep	23-Sep

Table 1. Estimated number of days and dates to 50% heading (at 1944 degree days) using CALDD (T Max > 93°F, T Min > 70°F and Tb = 32°F) for different planting dates based on historical average temperature 1984-2009 and for 2010 growing season (CIMIS Durham).

Model Problems

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 slightly photoperiod sensitive. So in addition to responding to temperature, they also respond to day length. Therefore, in the upcoming year, we plan to address this issue and account for photoperiod sensitivity in the model which should allow the model to be more accurate. A second issue with the model is that it only accounts for the time between planting and heading. The time from heading to maturity is also affected by temperature and this needs to be accounted for in the model in order to make it more useful for growers.

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 (M-206 versus M-202).

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 (Figure 6). 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. Importantly 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 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?

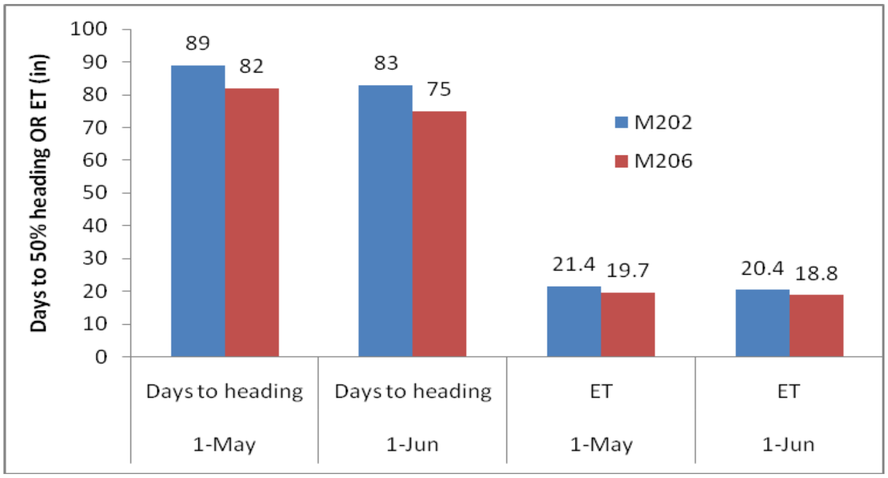


Figure 6. Results of model showing effect of variety and planting date on days to heading and water use (ET) from planting to heading.

Future Research

From our threshold evaluation, CalDD accumulation was found to predict 50% heading dates for the variety M-202 relatively reliably but this could be improved by accounting for photoperiod sensitivity. This will be a key task in 2011. Secondly, we need to develop a more complete understanding of crop development by also accounting for time to PI and time to maturity for different varieties. This information is currently not available will need to be collected. We plan to collect such information from some of the major varieties in 2011.