Project No. RM-11

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. Field and greenhouse studies evaluating 9 CA varieties (M104, M105, M202, M205, M206, L206, S102, CM101, and M401) reinforced our last year findings (2012) that regardless of planting date all varieties had similar times to PI. Varietal differences, with respect to duration, primarily occurred between PI and heading and to a lesser extent between heading and maturity.
2. The greenhouse study on rice photoperiod sensitivity (with temperature controlled) was conducted similar to 2012 with the aforementioned varieties, including five planting dates with two weeks intervals from April 17 to June 12. Work is going on to analyze the data and cluster varieties base on their respond to photoperiod sensitivity.
3. For the photoperiod non-sensitive varieties (S102 and L206), the main driver in terms of crop development is temperature. We developed a degree-day model for these two varieties and were able to accurately predict time to 50% heading.
4. The result from greenhouse study in 2012 and 2013 indicated that the other varieties are moderately photoperiod sensitive (M-401 is highly sensitive). A preliminary photo-thermal model was developed that predicts time to 50% heading for M202. This model accounts for both temperature and photoperiod sensitivity. The primary objective for 2014 is to develop this model for other varieties.
5. Field trials was conducted to determine the effect of water temperature in three different irrigation management schemes on crop development: (1) wet-seeded continuous flood, (2) wet-seeded with intermittent wet and dry periods following canopy closure, and (3) drill seeded with intermittent wet and dry periods throughout the season. The data has not been analyzed yet but will also be used in model development.

BACKGROUND

Abbreviated background

The background section is long and similar to the background provided for this report in previous years. In brief, the main point we are making is that initially this project started out trying to identify options for conserving water in CA rice systems. We looked at drill vs. wet seeding, effect of different planting dates, and varieties of different duration. While gains are possible through some of these practices – they are small (roughly 1-2 inch). In doing this research, we found that it was not possible to predict with accuracy crop duration (based on degree day calculations) and hence the amount of time a field is irrigated. On problem is that all information on the duration of CA varieties is limited to "days to heading"; however varieties also differ in their time from heading to maturity. When considering water use and other management practices we also need to know days to other critical stages such as panicle initiation (PI) or maturity. Little to no information exists on this. When we attempted to predict days to heading using degree day (DD) models, the predictions were poor. One reason for this is that some varieties may be moderately photoperiod sensitive. This research has then shifted focus (for the time being) to developing a good predictive crop development model that can predict days to PI, heading and maturity based on planting date. The model will account for both temperature and photoperiod sensitivity. We anticipate that this model will be valuable in aiding growers plan their management decisions and in addressing the original issue related to water use.

Full 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. 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. Analysis of three years of data comparing the two systems shows that ET is similar for both systems (Table 2).
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.

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. 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 FOR 2013

As the previous discussion indicates, reducing water use in rice systems is not straight forward and involves complex interactions which are costly and time consuming to test in the field. 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). While we have examined some options (described in previous years) our primary objective now is to develop a model that accurately predicts various stages of crop development (PI, heading and maturity) based on temperature and the degree a variety is photoperiod sensitive. Building on previous years efforts, our specific objectives for 2013 were:

1. Continue monitoring 8 varieties common to California (M104, M202, M205, M206, L206, M401, CM101, S102) to determine time to PI, heading and maturity in each of the statewide variety trials.
2. Determine degree of photoperiod sensitivity for these same varieties in a controlled temperature greenhouse setting with multiple planting dates.
3. Based on data obtained from Objectives 1 and 2, develop a model that is able to predict the timing of PI, heading and maturity.
4. Quantify the importance of either water temperature or air temperature in degree day calculations

EXPERIMENTAL PROCEDURE AND RESULTS TO ACCOMPLISH OBJECTIVES:

Objective 1: In 2013, 8 varieties common to California (M104, M401, M202, M205, M206, L206, CM101, S102) were selected for observation. Each of these varieties were planted in separate plots outside each of the statewide rice variety trails. Throughout the season plots were regularly visited and stages of growth determined. We determined green ring (PI), heading (50%) and maturity (R7-Counce et al., 2000).

Objective 2: The controlled temperature environment of the greenhouse was used to quantify the effect of photoperiod on rice growth and development. Nine major California rice varieties were evaluated in this study (M104, M105, M202, M205, M206, L206, S102, CM101, and M401). All varieties were planted at two-week intervals in pots from the beginning of April to mid-June. Two pots (standard #3 regular nursery pots) per variety were planted at each planting date and submerged in 20 ^{x} 3 ^{x} 1 ft basins filled with water such that the height of water was 2” over the tops of the pots. All varieties were randomly assigned to the pots in each basin and planting dates were randomized between basins. Crop growth stages were closely monitored and recorded for all varieties and planting dates. While temperature effects were minimized across planting dates, the air and water temperatures were recorded throughout the experiment in order to account for any temperature variation. Panicle initiation, flowering, and physiological maturity were identified as follows: Panicle initiation was tested using four random destructive samples per sampling; when 2 or more of the 4 sampled plants show panicle initiation (internodes elongation between node 5-6 and green ring formation), the crop was designated as having reached 50% panicle initiation. 50% flowering of each plot is determined by visual observation. To test for physiological maturity, grain color was used as described by Counce et al. 2000. When at least one grain on the main stem panicle has a yellow hull, the crop was said to have reached physiological maturity.

Objective 3: These data are being used to develop a crop development model. While work has begun in this area it is very preliminary.

Objective 4: To initially quantify effect of water and air temperature on degree day calculations, we did two things. First, in the green house trails we measured and recorded water as well as air temperature. Using this data we will test to determine if by using water temperatures we can improve the accuracy of our model. Second, at the RES we measure air, water and within canopy temperature in three systems that differed in terms of water management. We have observed that drill seeded rice often takes 7 to 10 days longer to mature than water-seeded rice. This may be due to lower temperatures within the drill seeded system. At the RES we have three systems (described in detail in RM-4 report) that differ in water management from systems that are continuously flooded (conventional) to those where there is drill seeding and the soil is allowed to dry out between irrigation events. Temperature loggers were placed at various intervals from below the soil to above the canopy to measure water and air temperatures at these locations throughout the year. Differences in degree day accumulation depending on where the temperature is being measured will be quantified.

RESULTS

The student that is doing this research had his qualifying exams this past year. Therefore, while he was able to set up experiments and collect the data as planned; he had limited time to conduct an in-depth analysis.

Objective 1:

In 2013 planting dates for the statewide variety trails ranged from April 29 (Glenn county) to May 23 (RES) (Table 1). As we have found in previous years the time to PI for all varieties is relatively similar (average of 52 days). This holds true even for M401 – considered a late maturing photoperiod sensitive variety. The real difference between varieties is the time between PI and heading and to a lesser extent between heading and maturity.

These data, along with those from 2011 and 2012, are being compiled into a date base, which will be used to develop a crop development model for each of these varieties.

Objective 2:

Rice varieties were planted in the greenhouse at five different dates from April 17 to June 12 in order to access how sensitive they are to photoperiod. Average daily temperatures were warmer in the greenhouse so the plants developed faster than would normally be observed in the field.

Days to PI was very similar for all varieties and planting dates and averaged 37 days. As we noted in the field trial, the real difference among varieties occurred between PI – heading and heading to maturity.

Base on the data from 2012, using a degree day (DD) model to account for differences in temperature between the different planting times we identified three groupings of varieties (Fig. 1): photoperiod sensitive (M401), moderately photoperiod sensitive (CM101,M104, M105, M202, M205, M206) and photoperiod non-sensitive varieties (S102 and L206). In these graphs 11 DD is about 1 day. For example, the photoperiod non-sensitive varieties all required the same amount of DD to reach heading regardless of planting time. For all the other varieties the number of DD required to reach PI was high for late April/early May planting dates and then decreased. In the moderately sensitive varieties (with the exception of M105), late planting (in June) also resulted in a longer period from planting to PI. For these varieties the shortest time from planting to PI would be for mid-May plantings.

Objective 3:
Based on our greenhouse study that suggest varieties differ in their response to photoperiod sensitivity, we developed a photo-thermal model for M202, which predicts days to 50% heading base on temperature and photoperiod effect. And also a DD model for L206 and S102, which predicts day to 50%heading base on degree-day accumulation.

In Figure 2 and 3 we show result of how DD and photo-thermal models predict days to heading for S102, L206 and M202. In such figures you want your slope to be close to 1.0 as this means that there is a 1:1 relationship between predicted and observed values. Furthermore you want the R2 to be as high as possible (the higher the number the less variability in results-max number is 1). The data for M202 is relatively poor (as discussed earlier). The slope of the relationship between observed and predicted is 0.48 and the R2 is 0.16. This poor relationship is because M202 is also photoperiod sensitive. Therefore, photo-thermal model better predicts heading for M202 with slope of 1.003 and the R2 is 0.439. In contrast, for S102 and L206 the slope of the line is 1.07 and 1.02, respectively and the R2 values are 0.58 and 0.71, respectively. This model predicted fairly accurately time to flowering for photo-period non-sensitive varieties.

Objective 4:
To initially quantify effect of water and air temperature on degree day calculations, we did two things. First, in the green house trails we measured and recorded water as well as air temperature. Using this data we will test to determine if by using water temperatures we can improve the accuracy of our model. Second, at the RES we measure air, water and within canopy temperature in three systems that differed in terms of water management. We have observed that drill seeded rice often takes 7 to 10 days longer to mature than water-seeded rice. This may be due to lower temperatures within the drill seeded system. At the RES we have three systems (described in detail in RM-4 report) that differ in water management from systems that are continuously flooded (conventional) to those where there is drill seeding and the soil is allowed to dry out between irrigation events. Temperature loggers were placed at various intervals from below the soil to above the canopy to measure water and air temperatures at these locations throughout the year. The data has not yet been analyzed; however, we will be looking at differences in degree day accumulation depending on where the temperature is being measured.

Future Research

2013 research results are very encouraging in that we were able to quantitatively determine how photoperiod sensitive a variety is. We were able to develop a model that predicts relatively accurately days to heading for S102 and L206 which are not photoperiod sensitive. We have also made good advances in developing the photo-thermal model. Our future work will be to finish the photo-thermal model development for all tested varieties. Furthermore, in 2014 we plan to have the model predict PI and maturity stages. This is important as the main CA varieties are all moderately sensitive to photoperiod. In 2015, our goal will be to develop an on-line application that will allow growers to determine the stage of crop development based on planting date and variety.

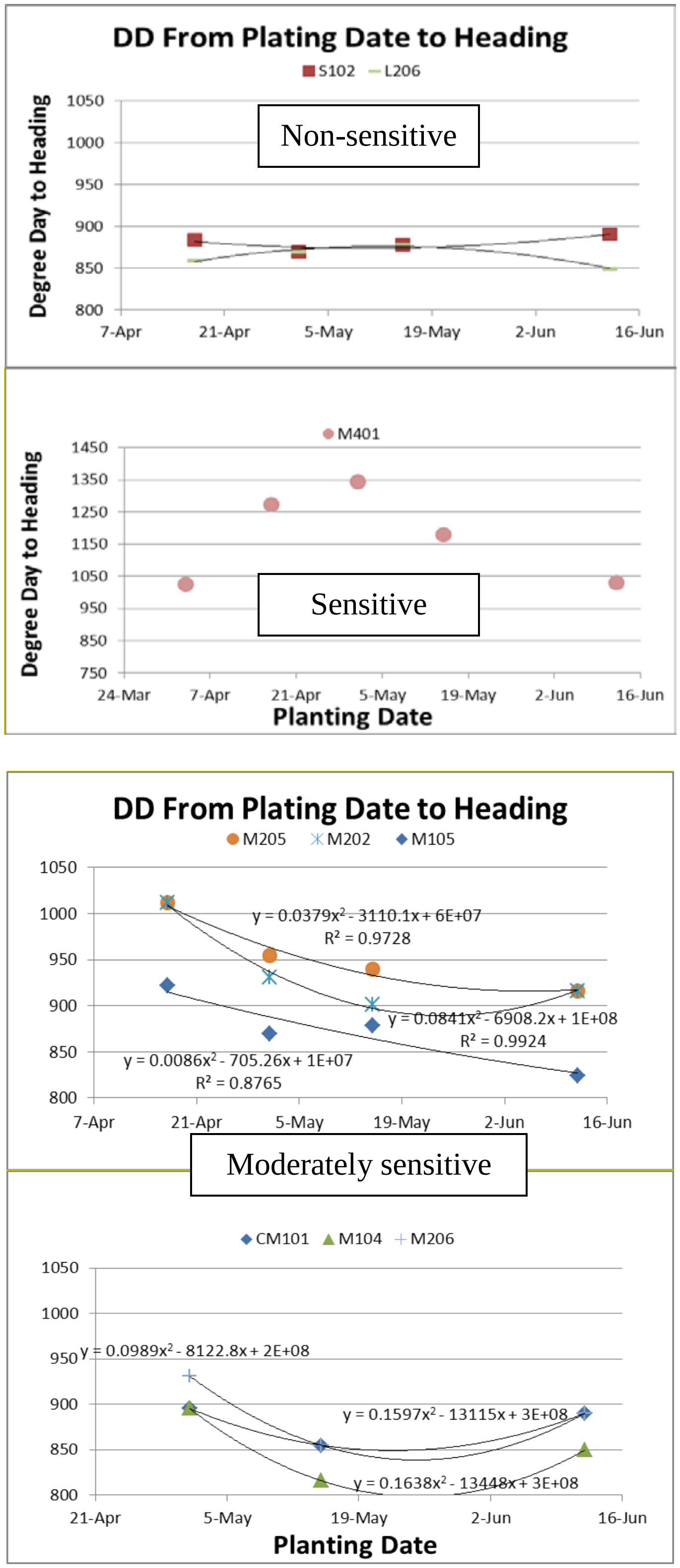

Figure 1. Relationship between planting date and degree days (DD) to heading. Varieties that are not sensitive to photoperiod (non-sensitive) should require a similar amount of DD to reach heading regardless of planting date as we see with S102 and L206.

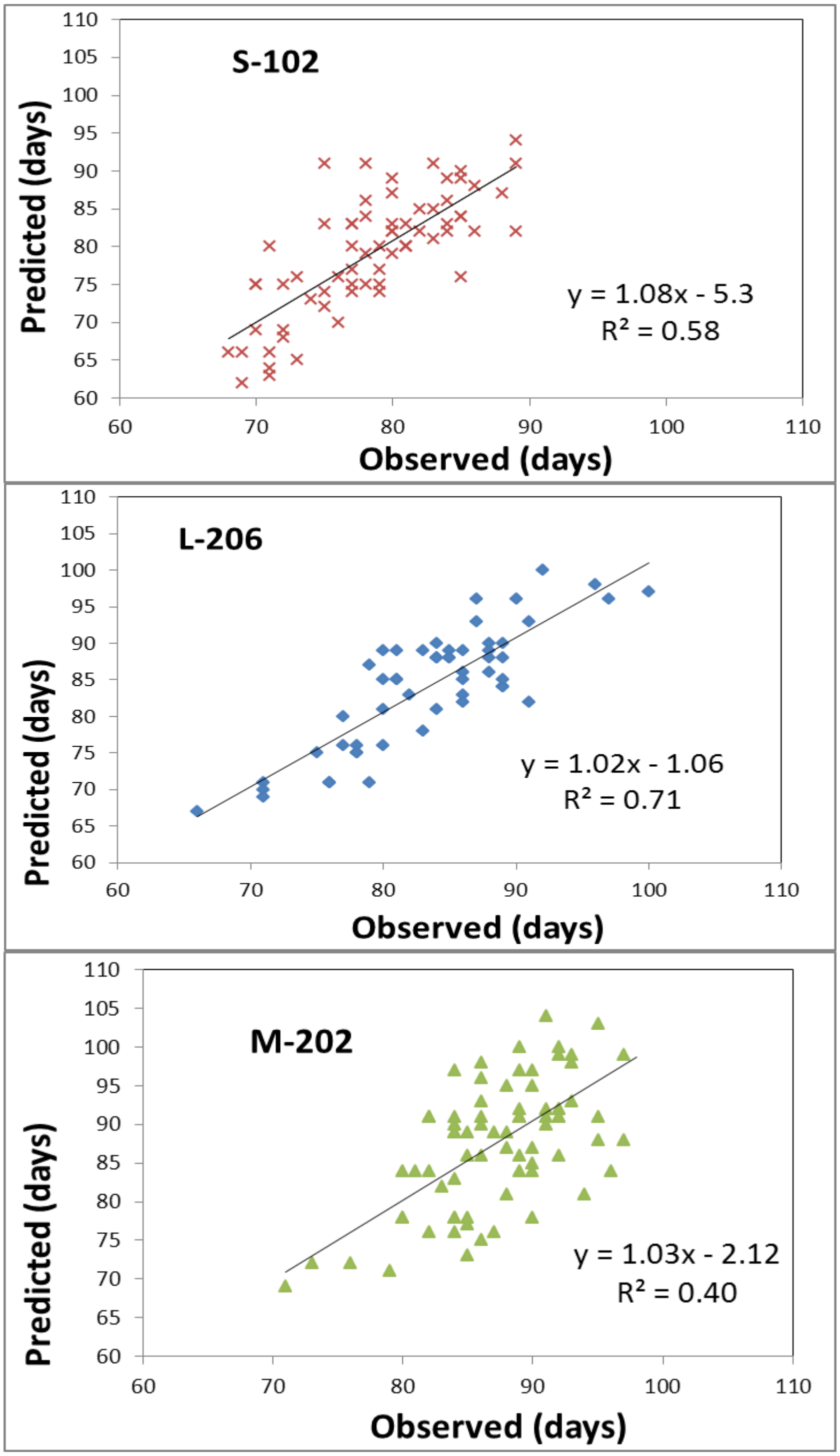

Figure 2. Degree-day model predictioin (observed vs. predicted) for days to heading comparing L206 and S102 with M202.Notice that the degree-day model does a better job of predicting heading for L20 and S102 which are both photo-period insensitive. In contrast, M202 is moderatly photoperiod sensitive and the model does a poorer job in predicition(r^2=0.40).