Examination of SWAT Protocol Utilizing a Performance Analysis of Weather-based Irrigation Controllers: Update with Extended Data

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Final Report

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Table of Contents

Executive Summary

The previous Florida SWAT test occurred over mostly a winter period with low ET_O and little rainfall. Thus, the reported results were generally inconclusive in many areas of analysis such as the transferability of the SWAT results to many different climates and the effects of rainfall on controller performance. The objective of this report is to analyze the results of the Florida SWAT test during variable weather conditions such as frequent/infrequent rainfall and high/low ET_O that occurred since the end of the original analysis. In addition, this study examined the following changes to the protocol that WaterSense considered making based on the 2009 Final Report:

- at least one irrigation event for every zone for a reportable score,
- three minute minimum runtimes per irrigation event,
- thresholds for passing irrigation adequacy and scheduling efficiency scores,
- missing weather data occurring less than two consecutive days or three days during the test period, and
- re-assessment of the potential rainfall penalty.

Three brands of ET controllers previously tested under the SWAT protocol by the Center for Irrigation Technology (CIT) in Fresno, California, were selected for study where two controllers were signal-based systems and one was a standalone controller. Duplicates of the signal-based controllers consisted of a controller with an additional Mini-Clik rain sensor (Hunter Industries, Inc., San Marcos, CA) set at a 0.25 inch threshold. Controller brands were anonymously identified as ET-A, ET-B, and ET-C, while duplicate controllers were denoted with a rain sensor (WRS) or without a rain sensor (WORS).

The most influential weather conditions concerning SWAT scores were during frequent rainfall and high ET_O periods where scheduling efficiency scores were generally lower than scores calculated for the other periods. The declaration of a minimum number of rainfall events would benefit SWAT scores so that they are transferable from rainy to dry conditions. It is likely that a controller that is efficient at scheduling irrigation under unpredictable rainfall conditions will also have high scheduling efficiency results during periods of less rainfall.

In general, the addition of a rain sensor increased or did not affect the SWAT scores obtained in any of the study periods. Generally, a rain sensor resulted in decreased irrigation but there were several instances of increased irrigation due to a combination of the effect a rain sensor has on individual controller soil water balance, the variability inherent in the rain sensors, and differences in weather data from signal based controllers to onsite conditions. These findings indicate that the requirement of an on-site rain shut off device such as a rain sensor would be justified as part of the WaterSense program if a controller does not already contain a means of on-site rainfall detection.

Requiring irrigation to occur by every zone severely cut down the number of reportable scores throughout the year by as much as 66%. Additionally, it was found that irrigation was not theoretically required for all zones, even during the high ET_O period. As a compromise, it would be acceptable that the test would still be valid without an irrigation event as long as deficit conditions are not created as a result of the lack of irrigation occurring in the 30-day period.

The removal of any runtime less than three minutes long did not affect the number of reportable scores and only minimally affected the values of the scores by as much as a few percentile points. Though it may not have made a large difference for these study periods, requiring a minimum runtime would create a more realistic test that would encourage more efficient irrigation practices.

The controllers met the proposed minimum score threshold of 80% for irrigation adequacy, but generally failed to meet the 95% threshold for scheduling efficiency throughout all

of the study periods when using the minimum score of the six zones. Over-irrigation was a frequent occurrence as evidenced by low scheduling efficiency and high irrigation adequacy. Additionally, there were slight increases in the percentage of scores above the proposed thresholds when using the average of the scores from all six zones compared to requiring that all zones are above the threshold. The effects of using an average may increase the passing rate of the test, at the cost of some over-irrigation. The implementation of an ET controller that could not achieve the thresholds at a minimum for all types of landscapes could increase outdoor water use despite being labeled a WaterSense product.

Missing weather data is dependent on the quality of maintenance to ensure the functionality of the weather station. There were no instances of missing weather data from the station managed by the University of Florida, but there were 13 days of missing data from the publically available FAWN weather station. Allowing no more than two consecutive days or three total days of missing data throughout the 30-day period would be appropriate as a data quality control measure.

Accounting for rainfall before irrigation on a daily basis resulted in decreased scheduling efficiency scores in all of the study periods, but was most prominent in the frequent rainfall period and during the periods of frequent rainfall in the high and low ET_O periods.

Below is a summary of key findings from this work:

- The impact of a rain sensor on scheduling efficiency scores varied throughout all of the periods where the maximum increase in average scores from using a rain sensor was 28 percentile points for the ET-A controllers during the Low ET_O period and 37 percentile points for the ET-B controllers during the frequent rainfall period. Additionally, the rain sensor addition resulted in less irrigation for many site specific instances.
- When determining if a controller exceeds the passing threshold, using the average score resulted in increased passing rates compared to using the minimum score across all zones.
- The combination of averaging scores across all zones to get the final score and changing the order of calculations to the order of ET_C, irrigation, and rainfall ensured the highest rate of passing. Using the minimum score across all zones to get the final score instead of the average and changing the order of calculations increased the passing rate to a lesser extent while encouraging appropriate scheduling techniques for all landscapes.
- Two consecutive days or three total days of missing weather data by the controller or from the weather station during a single 30-day test period should not significantly impact final results.

The following are recommendations for EPA WaterSense based on this research:

- The EPA WaterSense program should consider requiring at least one irrigation event for every zone to have a valid test with reportable results. The only exception occurs when each zone without irrigation does not experience any level of deficit with an irrigation adequacy score of 100%. Final scheduling efficiency scores are calculated from only the zones that applied irrigation during the test.
- Each irrigation event must exceed three minutes in length as recorded by the datalogger to be counted as a valid event. Irrigation events totaling three minutes or less are removed from the test as if those events were never applied. Removed irrigation events (cycles) within an incomplete cycle/soak schedule are converted to soak time and consolidated with the soak times occurring before and after the converted event. The removal of irrigation due to the minimum runtime requirement of less than or equal to three minutes does not invalidate the test.

- In accordance with typical irrigation scheduling techniques and rainfall patterns, the order of operations for the daily soil water balance should be updated from the SWAT protocol to be in the order of ET_C, irrigation, and rainfall. The specified order of calculations will eliminate the penalty for irrigation occurring prior to rainfall on the same day.
- A minimum number of rain events for a valid test should be considered based on regional climate norms.

Introduction

The increased demand for conservative irrigation practices has created a market for irrigation technologies that control water application based on prevailing climate conditions. One such technology, an evapotranspiration (ET) irrigation controller, is defined as a controller that estimates depletion of available plant soil moisture to schedule irrigation as needed while minimizing excess water use. The Irrigation Association has developed the smart water application technologies (SWAT) testing protocol for ET controllers that describes a procedure for testing the efficacy of ET controllers (Irrigation Association [IA], 2008). It is anticipated that the SWAT testing protocol will be adopted by WaterSense and implemented by independent testing labs.

From October 2008 through February 2009, the University of Florida performed the SWAT test independently of the official SWAT testing lab at the Center for Irrigation Technology at California State University (Fresno, CA) (Dukes and Davis, 2009). The objectives of the 2009 Florida SWAT test were to: A) determine the reproducibility and B) transferability of the SWAT climatologically-based controller testing protocol; C) analyze the test requirements such as rainfall, ET_O, and test length minimums; and D) determine the significance of the penalty for rainfall and irrigation occurring on the same day. Transferability is an assessment of the SWAT test in different climates. Ideally the test could be conducted in a range of climates with identical results. Reproducibility refers to identifying any deficiencies in the protocol in terms of adoption by an independent lab.

During implementation of the SWAT protocol, it was found that the documentation is sometimes unclear making the test difficult to independently reproduce by testing labs (Dukes and Davis, 2009). As written, all of the calculations need to be pieced together from the summary table of equations and the written description. The EPA and the University of Florida responded to this conclusion during the 2009 Florida SWAT test by creating a spreadsheet that can be used by the testing labs to perform the SWAT analysis. Additionally, a training course was developed to ensure the testing labs understand the SWAT testing procedures and the proper use of the spreadsheet.

Unfortunately, the Florida testing conditions were unusually dry from October 2008 through February 2009, resulting in similar rainfall amounts as testing in California to date (Dukes and Davis, 2009). Thus, the test results did not fully show the effect of controller performance in a rainy climate despite satisfying the minimum testing requirements of ET_O and rainfall. Consequently, no definitive conclusions were drawn in regards to transferability. Additionally, the rainfall penalty due to rainfall and irrigation occurring on the same day was not sufficiently assessed. Based on past experience, it was suggested by the University of Florida that increasing the length of the test and increasing the ET_O and rainfall thresholds would better define controller performance under changing conditions. For example, partial growing season ET_O might range from 15-20 inches for a minimum 90 day period and rainfall of 5 inches in a minimum of 10 events would be reasonable limits for the eastern U.S.

Controller programming is important for receiving good SWAT results. Controllers for the 2009 Florida SWAT test were programmed by manufacturers or according to their instructions with settings that do not necessarily describe the landscape specified in the protocol to create a smaller RZWWS than specified for the zone resulting in unrealistic runtimes of just a few minutes per cycle in some cases (Dukes and Davis, 2009). It was recommended that minimum runtimes be established to alleviate this problem. The program settings used by the controller to achieve the published scores should also be included in the published report as they would be helpful in applying the results to different landscapes when using the controllers in the field.

The objective of this report is to analyze the results of the 2010 Florida SWAT test during rainy and dry as well as high and low ET_O weather conditions that have occurred since the 2009 Final Report (Dukes and Davis, 2009). Also, the EPA suggested updates to the WaterSense testing procedures based on the conclusions of the 2009 Final Report. Updates addressed in this current work include requiring on-site rain shutoff devices during testing, at least one irrigation event for every zone for a score to be valid, the effects of requiring a three minute minimum runtimes per irrigation event, thresholds for passing irrigation adequacy and scheduling efficiency scores, missing data occurring less than two consecutive days or three days during the test period, and reassessment of the rainfall penalty.

Materials and Methods

Three brands of ET controllers previously tested under the SWAT protocol by the Center for Irrigation Technology (CIT) in Fresno, California, were installed at the Agricultural and Biological Engineering turfgrass research facility in Gainesville, FL. Two brands of selected controllers were classified as signal-based and one brand was classified as a standalone controller. There were a total of five controllers installed. Duplicates of the signal-based controllers consisted of a controller with an additional Mini-Clik rain sensor (Hunter Industries, Inc., San Marcos, CA) set at a 0.25 inch threshold. Controller brands were anonymously identified as ET-A, ET-B, and ET-C, while duplicate controllers were denoted with a rain sensor (WRS) or without a rain sensor (WORS). These controllers were selected based on their previous SWAT testing by CIT as well as previous testing by University of Florida. Results from a bench test using three controllers of each brand being tested in the 2010 Florida SWAT Test showed that there was little variability between replications (Davis et al., 2009). Thus, performance results of these brands are likely to be similar to any controller of the same brand being utilized in the real world but may not be representative of all controller brands. More details on the controllers and project description can be found in the 2009 Final Report (Dukes and Davis, 2009).

Data collection included irrigation application by the ET controllers and weather data collected from a weather station located on-site. Irrigation run times were collected from all six zones where each zone represents one of the six landscapes described in the SWAT protocol (IA, 2008). Reference evapotranspiration was calculated using the ASCE standardized reference evapotranspiration equation as specified in the SWAT protocol (ASCE-EWRI, 2005). Calculated ET_O and measured rainfall from the on-site weather station were used directly in the soil water balance model in association with all controllers. Though not used in the SWAT analysis, data was also obtained from the Citra weather station belonging to the Florida Automated Weather Network (FAWN) to determine the impact of missing weather data. This FAWN station was used in the 2009 Florida SWAT test and is described in more detail in the 2009 Final Report (Dukes and Davis, 2009).

The 8th draft of the SWAT protocol was used to calculate irrigation adequacy and scheduling efficiency results to quantify under and over irrigation by ET controllers, respectively (IA, 2008). The SWAT protocol specifies that testing should occur over a minimum of 30 consecutive days (IA, 2008). This test was performed for each ET controller over a minimum of

60 days to obtain at least thirty 30-day periods for each seasonal variation. For each 60-day period, scores were calculated in 30-day rolling increments so that a new 30-day score was calculated by shifting the test dates by one day. The 30-day results were reported only if they met the minimum requirements of 2.50 inches of ET_O and 0.40 inches of rainfall (IA, 2008).

The SWAT protocol calculations were used to determine the amount of irrigation that was theoretically required for each zone during the period of study. This irrigation calculation, termed the theoretical irrigation requirement, occurred when the root zone working water storage (RZWWS) was fully depleted. The amount of irrigation equaled the depth required to replenish the soil water level to the RZWWS. The theoretical irrigation requirement would be considered the ideal irrigation scheduling technique according to the design of the SWAT protocol. The 2009 Final Report contains detailed descriptions of the SWAT calculations used to determine irrigation adequacy and scheduling efficiency (Dukes and Davis, 2009).

Similar to the 2009 Final Report, this report focuses on the zones that required extreme irrigation scheduling techniques. These zones were identified as Zone 2, with a high irrigation demand combined with a small RZWWS, and Zone 4, with a low irrigation demand combined with a large RZWWS. Results from the other tested zones can be found in the tables at the end of the report.

Results

Study Period Weather

There were four unique weather conditions selected for analysis to determine their effects on the irrigation adequacy and scheduling efficiency scores when performing the SWAT test. The weather conditions were frequent rainfall, infrequent rainfall, low ET_O, and high ET_O. Each period was selected by comparing the rainfall and ET_O amount over the 60-day period with the historical averages over the same 60 days determined from 37 years of Gainesville Regional Airport weather data occurring from 1970 through 2006 (National Climatic Data Center, 2007).

The frequent rainfall period was selected as 28 July through 25 September 2009, with a total of 10.6 inches occurring over 60 days (Table 1). This amount of rainfall was less than the historical average by 17%, totaling 12.7 inches. However, the number of rain events during the period was similar with 28 events compared to an average of 27 events. The 30-day totals of rainfall and ET_O indicate that each 30-day period had more than 4.8 inches of rainfall, in comparison to the 0.4 inch requirement, and between 4.14 inches and 5.24 inches of ET_O, compared to the 2.5 inch requirement (Fig. 1).

The infrequent rainfall period totaled only 1.8 inches over 10 rainfall events that occurred from 26 September through 24 November 2009. This period had 64% less rainfall than the historical average of 5.0 inches. Over the 30-day periods, rainfall ranged from 0.57 inches to 1.06 inches (Fig. 2). Thirty-day ET_O ranged from 3.93 inches to 2.29 inches. The ET_O did not meet the 2.5 inch minimum requirement for three 30-day periods at the end of the season.

The low ET_O period occurred from 27 January through 26 March 2010. The ET_O for the 60-day period totaled 6.4 inches, with a daily average of 0.11 inches, compared to the historical average of 8.2 inches and a daily average of 0.14 inches. Thirty-day ET_O increased over time from 2.83 inches to 3.74 inches (Fig. 3). Rainfall was consistently greater than the minimum requirement of 0.4 inches, with a minimum rainfall total of 2.48 inches.

The high ET_O period had the highest 60-day ET_O, totaling 11.3 inches and averaging 0.19 inches daily, occurring from 7 April through 5 June 2010. The total ET_O was 14% less than the historical average that totaled 13.1 inches. Rainfall was also less than its historical average by 22%, totaling 4.9 inches. Thirty-day ET_O steadily increased over the period from 4.79 inches to

7.71 inches (Fig. 4). Rainfall was also greater than the minimum requirement, ranging from 2.13 inches to 3.91 inches.

Frequent Rainfall Period

Theoretically, 4.2 inches of irrigation were required for zone 2 despite the frequent rainfall over this period due to the small RZWWS resulting in only 35% of the rainfall effective (Table 2). Irrigation application over the 60-day period by the ET-B controllers was the highest with 7.1 inches and 5.9 inches for the WORS and WRS, respectively. The ET-A controllers irrigated similarly to each other with the WRS irrigating 5.2 inches and the WORS irrigating 4.8 inches. The ET-C controller irrigated less than the theoretical requirement, applying 2.9 inches.

Irrigation adequacy results reflected the way the controllers irrigated compared to what was theoretically required for zone 2 (Table 3). The irrigation adequacy scores of the ET-A and ET-B controllers were 100% throughout the entire frequent rainfall period while consistently irrigating more than the theoretical requirement. The ET-C controller had less than perfect irrigation adequacy scores, averaging 88% and reaching a minimum score of 85%, due to irrigating less than the theoretical requirement.

Scheduling efficiency results were similar between ET-A and ET-B controllers for zone 2, with WORS and WRS averages of 77% and 77% for ET-A and 71% and 75% for ET-B, respectively (Table 3). Additionally, the range of scores was small for all of the controllers with maximum and minimum scores were only 17 percentile points in difference at the most (Fig. 5). Decreased scores would be expected due to the consistent over-irrigation compared to the theoretical requirement. The ET-C controller cumulatively irrigated less than the irrigation requirement and applied irrigation in short and frequent events allowing scheduling efficiency results of 100% for all 30-day periods.

According to the theoretical requirement, irrigation wasn't required for zone 4 during this period due to the combination of frequent rainfall and a large RZWWS (Table 2). Both ET-A controllers also determined that irrigation wasn't required and did not irrigate over the 60 days. The ET-B controllers applied the most irrigation, totaling 3.1 inches and 4.7 inches for the WORS and WRS, respectively. The ET-C controller also irrigated during this period, applying 1.3 inches.

Since irrigation was not necessary for zone 4, all irrigation adequacy results were 100% for all controllers (Table 3). Additionally, the ET-A controllers did not apply irrigation so they could not receive scheduling efficiency scores. The ET-B controllers had very low scheduling efficiency scores, averaging 15% and 31% for the WORS and WRS, respectively, due to the large depth of irrigation applied per event that wasn't required according to the SWAT water level calculations. Despite ET-B WORS cumulatively applying less irrigation compared to the ET-B WRS controller, the average scheduling efficiency scores were lower for the WORS than the WRS. This occurred due to differences in timing of irrigation application where these two controllers applied irrigation on different days while following separate soil water balances. Differences in soil water balances were a product of the addition of a rain sensor and the way the controller handles rainfall as indicated by the rain sensor as well as signal data. The ET-C controller applied irrigation in such small amounts that the events never increased the soil water level above RZWWS. As a result, scheduling efficiency results for this controller were 100% during these 30-day periods.

When averaging the six scores for each 30-day period, all controllers performed well in irrigation adequacy with all scores above 95% and only the ET-C did not have consistent perfect scores (Table 3). The slight deficit that decreased the irrigation adequacy scores for the ET-C meant that irrigation application was more effective thus resulting in perfect scheduling efficiency scores. However, the other controllers had lower scheduling efficiency scores with averages of 91% for the ET-A controllers, 50% for the ET-B WORS, and 64% for the ET-B

WRS. These controllers would have had higher scheduling efficiency results if they had allowed short periods of deficit as the ET-C controller had.

Infrequent Rainfall Period

Irrigation application by the ET-B controllers was the highest, applying 6.4 inches by the WORS and 5.4 inches by the WRS, for zone 2 in the infrequent rainfall period (Table 2). Respectively, these controllers applied 68% and 42% more than the theoretical requirement. The ET-A controllers applied the least amount of irrigation, both totaling 3.7 inches. In general, these controllers followed the irrigation scheduling trend of the theoretical irrigation requirement, but did apply less irrigation per event over a few more events than the requirement. The ET-C controller applied 5.0 inches of irrigation over many short and frequent irrigation events, applying 32% more than the theoretical requirement.

Irrigation adequacy results for the ET-B and ET-C controllers were perfect over the 60-day period due to frequent irrigation for zone 2 (Table 4). However, irrigation adequacy results for the ET-A controllers were less than perfect, averaging 89% for both controllers. Though cumulative irrigation by these controllers was very similar to the theoretical requirement, there were many times along the 60-day period where deficit conditions occurred. Both controllers had a range of scores from 84% to 96%.

Opposite of the irrigation adequacy results for zone 2, the ET-A controllers had perfect scheduling efficiency scores while the ET-B controllers had less than perfect scores (Table 4). The ET-B WORS had slightly decreased results, averaging 86%, compared to the ET-B WRS that averaged 95%. The ET-C controller consistently scored either 98% or 99% throughout the period due to short, frequent irrigation events.

Similarly to the frequent rainfall period, irrigation wasn't required during this 60-day period for zone 4 (Table 2). However, all five controllers applied irrigation. Once again, the ET-B controllers applied the most irrigation, totaling 3.6 inches for the WORS and 4.6 inches for the WRS. The ET-A controllers applied the least amount of irrigation with an irrigation total of 1.0 inches and 1.3 inches for the WORS and the WRS, respectively. The ET-C controller cumulatively applied 2.9 inches.

Irrigation adequacy scores for all of the controllers were perfect due to irrigation being unnecessary for zone 4 (Table 4). The scheduling efficiency scores for the ET-A controllers were also perfect. The ET-A controllers were not punished for applying irrigation when unnecessary because the irrigation events were timed so that they occurred prior to a rainfall event. This allowed the irrigation event to fill the soil water level to RZWWS and decrease the amount of effective rainfall. The ET-B controllers had much lower scores, averaging 60% and 65% for the WORS and WRS, respectively. Low scores would be expected considering such a large amount of irrigation applied by these controllers. The ET-B WORS had a much wider range of scheduling efficiency scores for this period, totaling 19 percentile points, compared to the ET-B WRS that had a range of only 8 percentile points (Fig. 6). The ET-C controller generally had high scheduling efficiency scores despite the cumulative irrigation total due to short and frequent irrigation events, averaging 97%.

The overall irrigation adequacy and scheduling efficiency scores calculated by averaging across all six zones were high for both ET-A controllers and the ET-C controller (Table 4). The ET-A controllers allowed small amounts of deficit with minimum irrigation adequacy scores of 95% and 94% for WORS and WRS, respectively, while the ET-C had perfect scores. On average, both controllers over-irrigated slightly but received minimum scheduling efficiency scores of 99% for the ET-A controllers and 97% for the ET-C controller. Once again, the ET-B controllers over-irrigated thus creating lower scheduling efficiency scores, averaging 76% and 87% for WORS and WRS, respectively. Despite ET-B WORS cumulatively applying less irrigation compared to the ET-B WRS controller, the average scheduling efficiency scores were lower for the WORS than the WRS due to differences in soil water balances as a result of the way the controller handles rainfall with an added rain sensor that is not standard equipment.

Low ET_O Period

It was estimated that 3.0 inches of irrigation were required for zone 2 over this 60-day period to supplement rainfall (Table 2). The ET-A controllers irrigated slightly more than the theoretical amount, totaling 3.2 inches and 3.3 inches for the WORS and WRS, respectively. In contrast, the ET-B controllers irrigated slightly less than the theoretical requirement by applying 2.8 inches for the WORS and 2.7 inches for the WRS. Results were not reported for the ET-C controller due to equipment malfunction.

Irrigation adequacy results for zone 2 ranged from 93% to 100%, averaging 95%, for the ET-A controllers (Table 5). The ET-B WORS had similar results where the irrigation adequacy scores ranged from 94% to 98%, averaging 96%. The ET-B WRS also had acceptable irrigation adequacy scores, but were slightly lower than its WORS counterpart, averaging 92%.

Scheduling efficiency results for zone 2 were also less than perfect for all four controllers being tested (Table 5). Additionally, the average scores were similar, frequenting 87% across the controllers though their ranges varied. The ET-A WORS controller had the smallest variation in scores, ranging from 79% to 100%. The ET-B WORS had the largest variation in scores, ranging from 62% to 100% with two instances of 44% occurring at the beginning of the 30-day periods.

Similar to the other periods of study, irrigation wasn't required for zone 4 over this 60-day period (Table 2). The ET-A controllers did not schedule irrigation during this period, thus scheduled irrigation appropriately. The ET-B controllers irrigated 1.8 inches and 1.6 inches for the WORS and WRS, respectively.

Zone 4 irrigation adequacy results were 100% for all controllers being tested (Table 5). Scheduling efficiency scores can only be reported for the ET-B controllers because they were the only controllers to irrigate over this 60-day period. The ET-B WORS averaged 54% with a small range of 52% to 61%. On the other hand, the ET-B WRS had a higher average of 57%, but also a larger range of scores from 41% to 62%. The scores from both controllers would be considered low compared to the average scheduling efficiency scores calculated for the other zones.

There were only small amounts of deficit allowed by all of the controllers when looking at overall irrigation adequacy scores averaged from all six zones with minimum scores only as low as 97% (Table 5). All controllers also had a wide range of scheduling efficiency results with the ET-A WORS having the most variation of all the controllers, ranging from 67% to 100% over thirty 30-day periods. The ET-B controllers only reached a maximum of 91% whereas the ET-A controllers achieved perfect scores at some point during the study period.

For zone 3, there was a large difference between average scheduling efficiency scores for the ET-B controllers, calculated as 60 percentile points where WORS had a higher score, but the controllers had similar irrigation totals. However, irrigation was applied at different times throughout the 60-day period where the WORS applied smaller amounts spread throughout the season and the WRS applied larger amounts toward the end of the season. There were higher scheduling losses for the WRS thus decreasing the average scheduling efficiency results.

High ET_O Period

The combination of high ET_O, rainfall that was less than the historical average, and a small RZWWS created a high demand for irrigation during this time period for zone 2. It was determined that the theoretical amount of irrigation required equaled 9.1 inches (Table 2). Both WORS controllers applied 10.7 inches of irrigation, 18% more than the theoretical requirement.

The ET-A WRS also applied more than the theoretical requirement by 13%, applying 10.3 inches. The ET-B WRS applied the most similar amount of irrigation to the theoretical requirement, totaling 9.3 inches. The ET-C controller was the only controller to apply less than what was required, totaling 7.3 inches, 20% less than the theoretical requirement.

Irrigation adequacy scores were less than perfect for all five controllers at some point for zone 2 (Table 6). The ET-A controllers had the smallest difference between scores, ranging from 91% to 99%. The ET-B WORS had the next smallest difference with a range of scores from 85% to 100%. The ET-B WRS and ET-C controllers had similar irrigation adequacy results where both controllers averaged 82%. These results indicate that all of the controllers had periods of deficit occurring throughout the 60-day period.

Scheduling efficiency results also tended to be less than perfect for zone 2 (Table 6). The ET-A controllers had scheduling efficiency results ranging from 78% to 91% for WORS and 80% to 96% for WRS. A majority of the scores were in the 80% to 82% range for the ET-A WORS while a majority of the scores were in the 82% to 88% range for the ET-A WRS. The ET-B controllers had slightly higher but similar results ranging from 88% to 97% and 87% to 100% for WORS and WRS, respectively. The ET-C controller had the best range, from 93% to 100%, and highest average of 95% out of any of the controllers.

Despite the high ET_O and less than average rainfall conditions, irrigation was not required for zone 4 due to the significantly larger RZWWS compared to zone 2 (Table 2). However, all five ET controllers irrigated during this period. The most irrigation was applied by the ET-B WRS controller, applying 7.2 inches. The ET-B WORS and ET-C controllers irrigated the same cumulative amount, totaling 4.5 inches. However, the controllers scheduled irrigation differently where the ET-C controller irrigated in much smaller events more frequently than the ET-B WORS. The ET-A controllers irrigated the least of the controllers by applying 1.5 inches and 2.1 inches for the WORS and WRS, respectively.

Irrigation adequacy results for zone 4 were 100% across all controllers (Table 6). Scheduling efficiency scores were not as good except for the ET-C controller that averaged 99% for this period. The ET-A controllers had the lowest scores, starting at a minimum of 11%, but increased through the 30-day periods to reach 100% during the last few 30-day periods. However, a majority of scheduling efficiency scores for the ET-A controllers occurred in the 11% to 41% range for the WORS and 11% to 55% for the WRS. Average scheduling efficiency scores were higher for the WRS than the WORS even though the WRS applied more cumulative irrigation over the season. This occurred due to the WRS applying irrigation over two events with one at the beginning and one at the end of the season whereas the WORS applied only one event in the middle of the season. The timing of the events created the same amount of scheduling losses but twice the amount of irrigation for the WRS thus increasing the average scheduling efficiency results. The ET-B controllers began at much higher scheduling efficiency results compared to the ET-A controllers, with minimum scores of 54% for WORS and 45% for WRS. However, the ET-B controllers increased their scores much more slowly, reaching a maximum score of 75% and 62% for the WORS and WRS, respectively.

Averaging across the six zones, irrigation adequacy only reached a minimum of 90% for the ET-C whereas all other controller adequacy scores were higher (Table 6). Scheduling efficiency results were less than perfect for all controllers most of the time with averages ranging from 73% by the ET-A WORS to 93% by the ET-C. These results indicate that the controllers generally over-irrigated compared to what the soil can theoretically hold on a regular basis.

Discussion

Rain Sensor Requirement

During the frequent rainfall period, the addition of a rain sensor generally resulted in less irrigation application across most zones with exceptions occurring by the ET-A controllers for zone 2 and by the ET-B controllers for zone 4 (Table 2). Reductions in water use averaged 8% for the ET-B controllers with as much as 40% during a single 60-day period having frequent rainfall. The ET-A controllers were also duplicated to determine the effect of a rain sensor, but were identical in irrigation application with only an increase in irrigation application by 8% for zone 2.

Similar results were seen in the other seasonal variation periods. In the infrequent rainfall period, reductions in irrigation application were seen in the ET-B controllers for every zone except zone 4 by as much as 23%, averaging 6%. Irrigation application by the ET-A controllers was identical except for zone 3 that had a 17% reduction and zone 4 that had a 30% increase. For the low ET_O period, there was an increase of 3% for zone 2 and 7% for zone 6 for the ET-A controllers and 13% increase for zone 3 by the ET-B controllers. Zones 1 and 4 had increases of 2% and 40%, respectively, for the ET-A controllers and zone 4 had an increase of 60% for the ET-B controllers for the high ET_O period. Across all seasons, there were no water reductions on zone 4 except an 11% reduction in the low ET_O period by the ET-B controllers. The amount of irrigation applied per event varied between the controllers.

Scheduling efficiency results were consistently higher for the ET-B WRS compared to the ET-B WORS within the same testing period. There were some zones for the ET-B where the scores were minimally or negatively impacted by the addition of a rain sensor with three instances occurring in the high ET_O period (zones 1, 4, and 5). Additionally, zone 3 in the low ET_O period had a 30 percentile decrease in average scheduling efficiency with the WRS. Otherwise, the rest of the zones in all of the periods had higher scheduling efficiency scores with the addition of a rain sensor by as much as 37 percentile points for zone 3 in the frequent rainfall period. Thus, the addition of a rain sensor positively affected the scheduling efficiency results of the ET-B controller.

The addition of a rain sensor to the ET-A controller didn't necessarily affect the scheduling efficiency scores. There were only six zones where scores were different by more than one percentile point. The rain sensor addition negatively affected the scores for zones 2 and 6 during the low ET_O period by 5 percentile points each. However, zone 3 of the low ET_O period with a 28 percentile point increase and zones 2, 4, and 6 of the high ET_O period with 4, 5, and 8 percentile point increases, respectively, were the only zones that were positively impacted by the rain sensor. In general, the ET-A controllers applied similar irrigation amounts consistently and thus there were rarely differences in scheduling efficiency scores.

Theoretically, the addition of a rain sensor cannot increase irrigation application because the only function of a rain sensor is to bypass irrigation events. However, rain sensors were wired into sensor ports labeled on the ET controllers as recommended by the respective user manuals. The way the controller processes the rain sensor interruption due to rainfall is proprietary information and is uncertain in reference to this study. It is likely that the addition of a rain sensor altered the soil water balance of the controller and resulted in increased irrigation. Additionally, other research has shown that there is significant variability inherent in rain sensors where rain sensor replicates bypassed at different times and for different amounts of rainfall after being installed for only three months (Cardenas-Lailhacar and Dukes, 2008). Additional variability in the replicates included failure to bypass for rainfall events at least five times greater than the threshold and switching to bypass mode many hours after the rainfall event had stopped. Any combination of rain sensor variability, differences in the scheduling algorithms of the controller, and a different rainfall data feed as compared to the weather station at the test site may have resulted in more irrigation application by the controllers using rain sensors.

Though savings are not guaranteed by including a rain sensor in the installation of the ET controller, the addition generally increases the likelihood for water savings and increased scheduling efficiency. Thus, testing these units with rain sensors would be an appropriate requirement for the WaterSense program considering the concept of the program is to reduce water use without compromising performance.

Impact of Rainfall

In general, scheduling efficiency scores were significantly higher during the infrequent rainfall period compared to the frequent rainfall period zone 2 (Fig. 5). More specifically, the ET-B controllers increased their average 30-day scores from the frequent rainfall period to the infrequent rainfall period for zone 2 by 15 percentile points and 20 percentile points for the WORS and WRS, respectively. Zone 4 also had a significant increase in scores by 45 percentile points for the WORS and 34 percentile points for the WRS (Fig. 6). The ET-A controllers had perfect scheduling efficiency scores for zone 4 during both periods, but had increased scores from frequent rainfall to infrequent rainfall by a minimum of 23 percentile points across both controllers. In a study by Davis and Dukes (2010) where the same models of controllers were tested on field plots, it was found that rainfall negatively impacted the SWAT scores by 20 percentile points, on average, which is consistent with the results presented in this report. This indicates that the ways the controllers handle rainfall are important to efficient irrigation.

The results of this study indicate that an ET controller's ability to handle rainfall is still one of the most important influences over the SWAT scores. Consequently, the dependence of SWAT scores on weather patterns indicates that the SWAT test is not transferable throughout the United States. An improvement to this problem would be to declare a minimum number of rainfall events within the 30-day period. This would benefit the transferability of the SWAT scores by increasing the potential for a higher amount of rainfall. It is likely that a controller that performs well in a frequent rainfall environment will be able to adequately and efficiently schedule irrigation in an infrequent rainfall environment.

Irrigation Event for Every Zone

If irrigation is never applied by a zone, then it is impossible to determine if the controller applies irrigation at the right time and in an acceptable amount. The EPA WaterSense program was considering adding a requirement that each zone should apply at least one irrigation event so that all zones were subjected to the scheduling efficiency calculation. The ET-A and ET-B controllers were tested over 120 30-day periods and the ET-C controller was tested for 90 30-day periods where all 30-day periods met the minimum ET_O and rainfall requirements (Table 7). By requiring at least one irrigation event on every zone, a significant portion of the reportable scores are no longer valid. For the ET-A WORS and ET-A WRS, only 34% and 47% of the scores were reportable, respectively. The ET-B WORS and ET-B WRS also experienced a decrease in scores, though less substantial, where the number of scores decreased by 9% and 10%, respectively. Because of the way the ET-C schedules irrigation, there was no decline in the number of reportable scores for this controller.

Zone 4 was the zone with the least amount of reportable scores for the ET-A controllers while zone 5 was the limiting zone for the ET-B controllers (Table 8). The ET-C had an equipment failure where zones 5 and 6 were not functioning during one of the 60-day periods. As a result, a reduction in 34% of the scores occurred for the rest of the zones. However if the equipment failure had not occurred, all of the scores from the 90 30-day periods would have been reportable for this controller.

It was found that irrigation was not theoretically required for zone 4 during any testing period, even during the high ET_O period (Table 2). Irrigation that occurs when not actually required would encourage unnecessary irrigation and inefficient scheduling practices just to have a viable 30-day test. Instead, it is recommended that that the test would still be considered valid without an irrigation event as long as deficit conditions are not created. The test would only be acceptable if irrigation adequacy scores were 100% for all zones that did not apply irrigation. Irrigation adequacy scores by all controllers and for all of the 30-day periods where no irrigation occurred were 100%. Thus, the controllers would not be limited in reportable test scores by this requirement for any of the testing periods.

Minimum Runtime Length Per Event

In previous work, it was recommended that runtimes less than or equal to three minutes in length would be inefficient due to practical irrigation system hydraulic considerations. For example, it may take at least three minutes for the pipes to fill with water and build enough pressure to activate the irrigation nozzles. The effects of removing irrigation application resulting in runtimes of less than three minutes were unknown. An analysis was performed on the same five periods suggested previously where any runtime less than or equal to three minutes was removed as if it was never scheduled by the controller.

The ET-A controllers were not affected by the removal of runtimes less than three minutes (Table 9). These controllers always applied more irrigation than three minutes in length even during the periods of low ET_O. The ET-B controllers were affected in every period effecting primarily zone 2 with low runtimes for zone 3 occurring only in the low ET_O period. Anywhere from 6% to 23% of the total irrigation applied was removed due to being less than or equal to three minutes per event.

The ET-C controller also had irrigation events less than or equal to three minutes that were removed from every period. Removed irrigation was less than 5% for the frequent rainfall and high ET_O periods. The infrequent rainfall period had four zones with irrigation less than three minutes. Zone 2 had the most irrigation removed, totaling 30%.

Over the 2009-2010 winter period, there was a 60-day period occurring from 25 November 2009 through 23 January 2010 that would also be considered a low ET_O period, averaging 0.07 inches/day. During this period, 30-day ET_O reached a maximum of only 2.27 inches, thus not meeting the minimum ET_O requirement for irrigation adequacy and scheduling efficiency. However, ET-C had five out of the six zones with irrigation less than three minutes during this period. More specifically, all of the irrigation scheduled for zone 2 was removed due to being less than or equal to three minutes and zones 1 and 4 had 28% and 26%, respectively, of irrigation removed during this period. According to the theoretical irrigation requirement over this 60-day period, irrigation wasn't necessary for any zone and the removal of irrigation less than or equal to three minutes would have only benefited the scheduling efficiency scores if the ET_O would have met the minimum requirements.

Despite the irrigation loss to so many zones throughout the study periods, the removal of irrigation if less than or equal to three minutes in length did not significantly affect the irrigation adequacy or scheduling efficiency scores. As a result, these irrigation events were not required and only affect the potential water savings of these controllers. On the other hand, if an irrigation event greater than three minutes run time was required for a valid test, the results here would have been substantially impacted.

Soil water levels would be most affected by the lack of irrigation during non-rainy periods where irrigation is the primary water source for landscapes. Though the infrequent rainfall period had significantly less rainfall than the frequent rainfall period, the infrequent rainfall period would still be considered rainy in a predominantly dry climate such as the climate conditions at the current SWAT testing facility in Fresno, CA. The 2009 Florida SWAT test was conducted over a much drier time period, totaling 7.37 inches over 26 events in a 142 day period, where runtimes of three minutes or less could potentially impact the SWAT test scores (Dukes and Davis, 2009).

The ET-A controllers did not have runtimes less than or equal to three minutes resulting in no impact on SWAT scores (Table 10). Both ET-B controllers had some irrigation events that were three minutes or less for zone 2 resulting in 14% less cumulative irrigation over the 142 day period. Irrigation adequacy was only minimally impacted for the ET-B controllers due to slight increases in deficit of 0.04 inches and 0.13 inches for the WORS and WRS, respectively. The ET-C controller was most influenced by the removal of irrigation events less than or equal to three minutes with the removal of 77% of the irrigation application for zone 2. This drastic decrease in irrigation application caused an increase in deficit conditions and an associated decrease in irrigation adequacy (Fig. 7). The 30-day irrigation adequacy scores were consistently perfect for the original test, however, scores dropped to a range of 39% occurring during the drier periods to 88% occurring after large rainfall events. Scheduling efficiency scores could not be calculated after 17 November 2008 due to all irrigation being removed resulting in a 69% decline in reportable scores due to no scheduling efficiency score and less than perfect irrigation adequacy. Additionally, there would be a 40% decline in passing scores compared to the original test.

Minimum Score Requirements

It was proposed by the EPA that an ET controller would earn a WaterSense label when the lowest scores achieved by any zone were above 80% for irrigation adequacy and 95% for scheduling efficiency. These limits were chosen to encourage irrigation scheduling practices by the ET controllers that create short periods of deficit that do not impact the landscape negatively, but will provide an opportunity for more effective rainfall and thus lead to water conservation.

Irrigation adequacy scores were always above the acceptable limit, with many instances of constant 100% scores, for every zone in every 30-day period of study except for the ET-C during the high ET_O period. The ET-C controller had some scores below the 80% cutoff for both zones 2 and 6, reaching minimums of 75% and 71%, respectively (Table 6). As a result, this controller had only 42% of scores where all zones exceeded the 80% threshold (Table 11). Zones 2 and 6 have the shallowest RZWWS out of the landscapes described in the SWAT protocol. During the high ET_O period, the RZWWS for these zones can be depleted in as little as two days without rainfall. As a result, periods of high ET_O such as during the growing season would be ideal in determining how well ET controllers can maintain soil water levels with the assumption of good landscape quality above an 80% irrigation adequacy score.

The ET-A and ET-B controllers did not have many passing scheduling efficiency scores over all of the testing periods (Table 11). The ET-A controllers had no passing scores during the frequent rainfall period and a maximum of 10% of passing scores during the high and low ET_O periods. However, ET-A WRS had 100% passing scores during the infrequent rainfall period while the ET-A WORS had 58% of passing scores. The ET-B controllers had less than 10% of passing scores for all periods indicating consistent over-irrigation. The ET-C had many scores that were above the thresholds including 100% of scores passed for the frequent rainfall period and 94% of scores passed for the infrequent rainfall period, however, there were no passing scores for the high ET_O period.

Such low scheduling efficiency scores from the Florida SWAT test were very different than the scores reported from the official SWAT test. There are many possible reasons for the decrease in performance. As was discussed in the 2009 Final Report, controller programming was generally chosen to maximize performance over 30 days and not necessarily over a longer term such as the ongoing testing for this study (Dukes and Davis, 2009). Additionally, the controllers did not have access to the on-site weather data used for the SWAT calculations and had to rely on their own methods of obtaining accurate weather data. The weather data source would be critical during periods of frequent convective rainfall.

Decreasing the scheduling efficiency threshold to 90% would increase the percentage of passing scores on some occasions throughout all of the study periods (Table 12). When using the minimum score of the six zones, significant increases in scheduling efficiency occurred during the infrequent rainfall period for ET-A WORS and during the high ET_O period for ET-C, both increasing by 42 percentile points. There were many more increases in passing scores when an average of the six zones was used to obtain the final score. The largest increase occurred during the frequent rainfall period where the ET-A controllers increased by 77 percentile points for the WORS and 71 percentile points for the WRS. Decreasing the threshold may have increased the passing rate in some cases, but did not generally indicate that the controllers performed better overall than when evaluated using the 95% threshold. It would be advisable to maintain a higher standard to minimize over-irrigation.

In general, there were slight increases in the percentage of passing scores when using the average of the scores from all six zones compared to requiring that all zones are above the threshold (Table 11). The most dramatic increases occurred for the ET-A WORS where the passing rate increased from 58% to 100% during the infrequent rainfall period. This occurred because zone 3 had 42% of the scheduling efficiency scores less than 95%, but were not low enough to decrease the zone average scheduling efficiency score below the threshold. Additionally, there were increases in the passing rate for all five controllers during the high ET_O period. The effects of using an average may increase the passing rate of the test, but it would be at the cost of encouraging over-irrigation. The implementation of an ET controller that could not achieve the thresholds at a minimum for all types of landscapes could increase outdoor water use despite being labeled a WaterSense product. The threshold that is critical to the passing score is scheduling efficiency. Because none of the controllers allowed deficit conditions, there were many opportunities for over-irrigation in all of the testing periods exhibited by scheduling efficiency scores ranging from as low as 11% to as high as 100% (Tables 3-6). Unless the controller had consistently perfect scheduling efficiency scores, which only occurred a handful of times spread across the ET-A and ET-C controllers, average scores were much less than the 95% acceptable limit.

Missing Data Requirements

Currently, there is not a standard outlined in the SWAT protocol for handling missing weather data from the weather station or the controller being tested. The EPA WaterSense program was considering adding the requirement that there should be no more than three days of missing data in any 30-day period. Additionally, there will be no more than two consecutive days of missing weather data in the 30-day period.

The weather data used for this report was maintained regularly by the University of Florida irrigation research team and therefore did not have any occurrences of missing weather data. In the 2009 Final Report, the FAWN weather station located in Citra, FL was used for the signal-based controllers (Dukes and Davis, 2009). This weather station was originally used due to its easy access of weather data by the signal providers but was not used for the report update due to its large distance from the testing site as well as its use of the IFAS Penman ET_O equation instead of the ASCE-EWRI standardized ET_O equation specified in the SWAT protocol. According to its records, ET_O was not available from the weather station for 13 consecutive days occurring from 5 May through 17 May 2010. This missing data would have completely eliminated all scores for the high ET_O period.

The controllers also experienced some weather data loss from their ET_O and rainfall collection methods. The controllers were closely monitored daily for a six week period from 10 May through 26 June 2010 to determine if they were prone to data loss. The ET-A controllers consistently updated the weather data daily. There was one instance where two consecutive days of ET signal was lost to the ET-B WRS. Otherwise, the ET-B controllers only had a few instances where the signal was lost for over 24 hours. The ET-C also had a period where the weather information was not available due to battery failure. It is likely that this problem would not happen for a certifying lab because the units will be new whereas the dead battery can be attributed to the ET-C being in the field since 2008 when testing began.

Accounting For Rainfall

Currently, the SWAT protocol specifies that rainfall occurs first, followed by irrigation in the daily soil water budget when determining effective rainfall and effective irrigation. This can be problematic due to irrigation usually being scheduled for the morning hours if rainfall occurs later in the day. As a result, the controllers can be penalized for not accurately predicting rainfall that may occur in the future. During the 2009 Florida SWAT Test, the importance of the order of calculations was inconclusive due to generally non-rainy conditions (Dukes and Davis, 2009). The testing periods for this report, however, had significantly more rainfall and so the analysis was repeated to determine the impact of accounting for rainfall in the daily water balance.

The rainfall penalty was most prevalent in the frequent rainfall period where average scheduling efficiency scores were increased by as much as 9 percentile points for the ET-A WORS (Fig. 8A), 10 percentile points for the ET-A WRS (Fig. 9A), 28 percentile points for the ET-B WORS (Fig. 10A), and 18 percentile points for the ET-B WRS (Fig. 11A). The ET-A controllers had the least amount of increase in scheduling efficiency with scores generally ranging in difference from 5 to 9 percentile points. The ET-C had perfect scheduling efficiency during the frequent rainfall period and was not affected by the order of calculations (Fig. 12A-B).

There were no significant effects from changing the order of calculations during the infrequent rainfall period (Figs. 8C-11C). The ET-B WORS had the most effect with a maximum percentile difference of 6 points using the scheduling efficiency scores averaged across all zones. A minimal response to the calculation order would be expected for the infrequent rainfall period considering less rainfall would make irrigation the primary input to the soil water level calculation.

The differences in average scores due to calculation order during the low ET_O period and the high ET_O period were similar with maximum increases in average scores by as much as 23 percentile points (ET-B WORS) and 10 percentile points (ET-A WORS), respectively (Figs. 13-17). Rainfall totals for these two periods fell between the rainfall totals of the frequent rainfall period and the infrequent rainfall period, thus score increases due to calculation order also fell in the middle.

Overall, the largest increases in scheduling efficiency due to switching the order of operations occurred in zones where controllers originally scored poorly indicating that they were penalized for rainfall occurring after irrigation on the same day. During the frequent rainfall period, the ET-A controllers were most affected by this penalty where the percentage of scores above the 95% threshold increased from 0% to 77% of scores passing for the WORS and 100% of scores passing for the WRS when using the average score across the zones (Table 13). The passing rate also increased in the infrequent rainfall period for the ET-A WORS from 58% to 100% when considering the minimum score across all zones. The ET-C had increased scores during the high ET_O period where passing rates increased by 48 percentile points using the minimum score and by 67 percentile points using the average score where 90% of the scores were above the 95% threshold.

The order of calculations in the current SWAT protocol decreases scheduling efficiency scores during periods of frequent rainfall. Though it may not be problematic when testing in an arid climate, it is possible that WaterSense testing could occur in more humid climates where this would occur more frequently.

Conclusions

The most influential weather conditions concerning SWAT scores were during frequent rainfall and high ET_O periods where scheduling efficiency scores were generally lower than scores calculated for the other periods. These weather conditions would be indicative of a typical growing season in the eastern United States and were not similar to weather in western U.S. Though the west does have high ET_O during many times of the year, there was still almost five inches of rainfall occurring over 16 events during the high ET_O period that is uncharacteristic of western rainfall patterns. The results of this study indicated that an ET controller's ability to handle rainfall is still one of the most important influences over the SWAT scores. Consequently, the dependence of SWAT scores on weather patterns indicates that the SWAT test is not transferable throughout the United States. An improvement to this problem would be to declare a minimum number of rainfall events within the 30-day period. This would benefit the transferability of the SWAT scores by increasing the potential for a higher amount of rainfall. It is likely that a controller that performs well in a frequent rainfall environment will be able to adequately and efficiently schedule irrigation in an infrequent rainfall environment.

In general, the addition of a rain sensor increased or did not affect the SWAT scores obtained in any of the study periods. Maximum increases in average scheduling efficiency scores were 28 percentile points by the ET-A controllers and 37 percentile points by ET-B controllers as a result of the rain sensor. Maximum decreases in average scheduling efficiency occurred during the low ETO period for both controller brands totaling 5 percentile points by the ET-A controllers and 30 percentile points by the ET-B controllers. Also, the rain sensor addition generally decreased the amount of irrigation applied by the ET-B controller, averaging 6% during the infrequent rainfall period. These findings indicate that the requirement of an on-site rain shut off device such as a rain sensor would be justified as part of the WaterSense program. However, there were instances where the controller with a rain sensor applied more irrigation, especially for zone 4, due to variations in the amount of irrigation per event that was applied. Thus, the way the controller handles the rain sensor within the soil water balance should be further explored for these types of controllers.

An accurate account of an ET controller's scheduling efficiency would require irrigation to occur by every zone. However, this requirement severely cut down the number of reportable scores throughout the year by as much as 66%. Additionally, it was found that irrigation was not theoretically required for zone 4 during any testing period, even during the high ET_O period. By mandating irrigation to occur when not actually required, it would encourage irrigation when not required. As a compromise, it would be acceptable that the test would still be valid without an irrigation event as long as deficit conditions are not created as a result of the lack of irrigation occurring in the 30-day period. The test would only be acceptable if irrigation adequacy scores were 100% for all zones that did not apply irrigation.

The removal of any runtime less than three minutes did not affect the number of reportable scores and only minimally affected the values of the scores by as much as a few percentile points. Though it may not have made a large difference for these study periods, requiring a minimum runtime would create a more realistic test that would encourage more efficient irrigation practices.

The controllers met the proposed minimum score threshold of 80% for irrigation adequacy, but generally failed to meet the 95% threshold for scheduling efficiency throughout all of the study periods when using the minimum score of the six zones. This indicates that the scheduling efficiency score is critical to passing the SWAT test. Because none of the controllers allowed deficit conditions, there were many opportunities for over-irrigation in all of the testing periods exhibited by low scheduling efficiency scores. Unless the controller had consistently perfect scheduling efficiency scores, which only occurred a handful of times spread across the ET-A and ET-C controllers, average scores were less than 95%. The low scores from the Florida SWAT test were in contrast to the scores reported from the official SWAT test that were nearly 100% for these controller brands.

Additionally, there were slight increases in the percentage of scores above the thresholds for WaterSense labeling when using the average of the scores from all six zones compared to requiring that all zones are above the threshold. The effects of using an average may increase the passing rate of the test, but it would be at the cost of encouraging over-irrigation. The implementation of an ET controller that could not achieve the thresholds at a minimum for all types of landscapes could increase outdoor water use despite being labeled a WaterSense product.

Missing weather data is dependent on the quality of maintenance to ensure the functionality of the weather station. There were no instances of missing weather data from the station managed by the University of Florida, but there were 13 days of missing data from the FAWN weather station. If a testing lab chooses to use a local weather station the risk increases that there may be occasional missing data. Allowing no more than two consecutive days or three total days of missing data throughout the 30-day period, as suggested, may be appropriate as a data quality control measure.

Accounting for rainfall before irrigation on a daily basis resulted in decreased scheduling efficiency scores in all of the study periods, but was most prominent in the frequent rainfall period and during the periods of frequent rainfall in the high and low ET_O periods. The combination of using the average score across all zones and changing the order of calculations to the order of ET_C, irrigation, and rainfall ensured the highest rate of passing scores whereas using the minimum score across all zones and changing the order of calculations increased the passing rate to a lesser extent while encouraging appropriate scheduling techniques for all landscapes.

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Table 1. Cumulative ET_O, cumulative rainfall, and number of rainfall events in each 60-day period of study from 2009 through 2010 compared to the historical averages.

Period	Dates	ET_O (in)		Rainfall (in)		Rainfall Events (#)	
		Obs.	Historical	Obs.	Historical	Obs.	Historical
Freq. rain	28 Jul – 25 Sep 2009	9.4	10.6	10.6	12.7	28	27
Infreq. rain	26 Sep – 24 Nov 2009	6.2	8.0	1.8	5.0	10	12
Low ET_O	27 Jan – 26 Mar 2010	6.4	8.2	7.8	7.3	17	14
High ET_O	7 Apr – 5 Jun 2010	11.3	13.1	4.9	6.3	16	13

Table 2. The ET controllers applied irrigation (inches, cumulative basis) for each of the 60-day periods.

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
			Frequent rainfall			
ET-A WORS	2.9	4.8	3.0	0.0	1.0	4.4
ET-A WRS	2.9	5.2	3.0	0.0	1.0	4.4
ET-B WORS	6.4	7.1	4.5	3.1	5.7	6.5
ET-B WRS	5.8	5.9	2.7	4.7	4.5	5.8
ET-C	2.0	2.9	1.9	1.3	NA	NA
Theoretical	3.4	4.2	2.6	0.0	0.0	3.9
			Infrequent rainfall			
ET-A WORS	2.9	3.7	3.6	1.0	2.0	3.4
ET-A WRS	2.9	3.7	3.0	1.3	2.0	3.4
ET-B WORS	6.2	6.4	4.8	3.6	3.6	5.8
ET-B WRS	5.4	5.4	3.7	4.6	3.6	5.0
ET-C	4.8	5.0	4.4	2.9	2.6	2.9
Theoretical	3.2	3.8	2.7	0.0	2.8	3.5
			Low ET_O			
ET-A WORS	2.2	3.2	2.4	0.0	0.0	2.9
ET-A WRS	1.4	3.3	1.8	0.0	0.0	3.1
ET-B WORS	2.0	2.8	1.6	1.8	1.2	2.6
ET-B WRS	2.0	2.7	1.8	1.6	1.2	2.5
ET-C	NA	NA	NA	NA	NA	NA
Theoretical	0.0	3.0	1.3	0.0	0.0	2.7
			High ET_O			
ET-A WORS	9.4	10.7	7.3	1.5	3.9	10.3
ET-A WRS	9.6	10.3	7.3	2.1	3.9	9.4
ET-B WORS	12.0	10.7	7.1	4.5	6.8	10.0
ET-B WRS	10.4	9.3	4.5	7.2	5.9	8.7
ET-C	7.3	7.3	7.0	4.5	5.2	5.9
Theoretical	9.9	9.1	5.4	0.0	5.7	8.4

[1]NA refers to periods where data could not be collected due to controller equipment failure.

Table 3. Irrigation adequacy and scheduling efficiency for each SWAT zone over 30 consecutive 30-day periods where the average, maximum, and minimum scores were reported for the **frequent rainfall period**.

	Irrigation Adequacy			Scheduling Efficiency		
	Average	Maximum	Minimum	Average	Maximum	Minimum
Zone 1						
ET-A WORS	100	100	100	96	100	91
ET-A WRS	100	100	100	96	100	91
ET-B WORS	100	100	100	57	64	48
ET-B WRS	100	100	100	65	73	60
ET-C	96	100	95	100	100	100
Zone 2						
ET-A WORS	100	100	100	77	80	67
ET-A WRS	100	100	100	76	80	70
ET-B WORS	100	100	100	71	78	61
ET-B WRS	100	100	100	75	81	70
ET-C	88	100	85	100	100	100
Zone 3						
ET-A WORS	100	100	100	91	100	89
ET-A WRS	100	100	100	92	100	90
ET-B WORS	100	100	100	52	69	36
ET-B WRS	100	100	100	89	100	71
ET-C	100	100	100	100	100	100
Zone 4						
ET-A WORS[1]	100	100	100	NS	NS	NS
ET-A WRS[1]	100	100	100	NS	NS	NS
ET-B WORS	100	100	100	15	31	13
ET-B WRS	100	100	100	31	40	25
ET-C	100	100	100	100	100	100
Zone 5						
ET-A WORS	100	100	100	95	95	95
ET-A WRS	100	100	100	96	96	96
ET-B WORS	100	100	100	33	48	22
ET-B WRS	100	100	100	50	60	44
ET-C[2]	NA	NA	NA	NA	NA	NA
Zone 6						
ET-A WORS	100	100	100	96	100	80
ET-A WRS	100	100	100	95	100	80
ET-B WORS	100	100	100	72	80	62
ET-B WRS	100	100	100	74	80	68
ET-C[2]	NA	NA	NA	NA	NA	NA
Overall						
ET-A WORS	100	100	100	91	94	86
ET-A WRS	100	100	100	91	94	87
ET-B WORS	100	100	100	50	55	46
ET-B WRS	100	100	100	64	67	60
ET-C	96	100	95	100	100	100

[1]NS, no score. Scheduling efficiency scores could not be calculated because an irrigation event did not occur during any of the 30-day periods.

[2]Scores were not reported due to malfunction in controller equipment.

Table 4. Irrigation adequacy and scheduling efficiency for each SWAT zone over 30 consecutive 30-day periods where the average, maximum, and minimum scores were reported for the **infrequent rainfall period**.

	Irrigation Adequacy			Scheduling Efficiency		
	Average	Maximum	Minimum	Average	Maximum	Minimum
			Zone 1			
ET-A WORS	99	100	99	100	100	100
ET-A WRS	99	100	98	100	100	100
ET-B WORS	100	100	100	71	91	58
ET-B WRS	100	100	100	83	92	76
ET-C	100	100	100	99	100	95
			Zone 2			
ET-A WORS	89	96	84	100	100	100
ET-A WRS	89	96	84	100	100	100
ET-B WORS	100	100	100	86	95	76
ET-B WRS	100	100	100	95	100	88
ET-C	100	100	100	99	99	98
			Zone 3			
ET-A WORS	100	100	100	96	100	94
ET-A WRS	100	100	100	97	100	95
ET-B WORS	100	100	100	74	81	68
ET-B WRS	100	100	100	100	100	100
ET-C	100	100	100	98	100	93
			Zone 4			
ET-A WORS	100	100	100	100	100	100
ET-A WRS	100	100	100	100	100	100
ET-B WORS	100	100	100	60	72	53
ET-B WRS	100	100	100	65	68	60
ET-C	100	100	100	97	100	93
			Zone 5			
ET-A WORS	100	100	100	100	100	100
ET-A WRS	100	100	100	100	100	100
ET-B WORS	100	100	100	82	100	62
ET-B WRS	100	100	100	86	100	63
ET-C	100	100	100	100	100	100
			Zone 6			
ET-A WORS	100	100	100	100	100	100
ET-A WRS	100	100	100	100	100	100
ET-B WORS	100	100	100	86	96	76
ET-B WRS	100	100	100	95	100	88
ET-C	100	100	100	100	100	100
			Overall			
ET-A WORS	96	99	95	99	100	99
ET-A WRS	96	99	94	99	100	99
ET-B WORS	100	100	100	76	85	67
ET-B WRS	100	100	100	87	93	81
ET-C	100	100	100	98	100	97

Table 5. Irrigation adequacy and scheduling efficiency for each SWAT zone over 30 consecutive 30-day periods where the average, maximum, and minimum scores were reported for the **low ET_O period**.

	Irrigation Adequacy			Scheduling Efficiency		
	Average	Maximum	Minimum	Average	Maximum	Minimum
Zone 1						
ET-A WORS	100	100	100	100	100	100
ET-A WRS	100	100	100	100	100	100
ET-B WORS	100	100	100	100	100	100
ET-B WRS	100	100	100	100	100	100
ET-C[1]	NA	NA	NA	NA	NA	NA
Zone 2						
ET-A WORS	95	100	93	87	100	79
ET-A WRS	95	100	93	82	100	70
ET-B WORS	96	98	94	86	100	44
ET-B WRS	92	98	90	87	100	75
ET-C[1]	NA	NA	NA	NA	NA	NA
Zone 3						
ET-A WORS	100	100	100	70	100	47
ET-A WRS	100	100	100	98	100	78
ET-B WORS	100	100	100	90	96	64
ET-B WRS	100	100	100	60	62	59
ET-C[1]	NA	NA	NA	NA	NA	NA
Zone 4						
ET-A WORS[2]	100	100	100	NS	NS	NS
ET-A WRS[2]	100	100	100	NS	NS	NS
ET-B WORS	100	100	100	54	61	52
ET-B WRS	100	100	100	57	62	41
ET-C[1]	NA	NA	NA	NA	NA	NA
Zone 5						
ET-A WORS[2]	100	100	100	NS	NS	NS
ET-A WRS[2]	100	100	100	NS	NS	NS
ET-B WORS	100	100	100	100	100	100
ET-B WRS	100	100	100	100	100	100
ET-C[1]	NA	NA	NA	NA	NA	NA
Zone 6						
ET-A WORS	95	100	93	87	100	78
ET-A WRS	95	100	93	82	100	70
ET-B WORS	98	99	97	85	100	43
ET-B WRS	93	97	90	87	100	75
ET-C[1]	NA	NA	NA	NA	NA	NA
Overall						
ET-A WORS	98	100	98	80	100	67
ET-A WRS	98	100	98	91	100	85
ET-B WORS	99	100	99	85	91	67
ET-B WRS	98	99	97	81	91	75
ET-C[1]	NA	NA	NA	NA	NA	NA

[1]Scores were not reported due to malfunction in controller equipment.
[2]Scheduling efficiency scores could not be calculated because an irrigation event did not occur during any of

the 30-day periods.

Table 6. Irrigation adequacy and scheduling efficiency for each SWAT zone over 30 consecutive 30-day periods where the average, maximum, and minimum scores were reported for the **high ET_O period**.

	Irrigation Adequacy (%)			Scheduling Efficiency (%)		
	Average	Maximum	Minimum	Average	Maximum	Minimum
			Zone 1			
ET-A WORS	100	100	100	84	95	70
ET-A WRS	100	100	100	84	95	70
ET-B WORS	100	100	100	80	90	66
ET-B WRS	100	100	100	79	100	58
ET-C	95	100	93	88	100	78
			Zone 2			
ET-A WORS	94	99	91	82	91	78
ET-A WRS	94	99	91	86	96	80
ET-B WORS	99	100	97	92	97	88
ET-B WRS	93	100	87	93	100	87
ET-C	82	100	75	95	100	93
			Zone 3			
ET-A WORS	100	100	100	73	100	59
ET-A WRS	100	100	100	72	100	58
ET-B WORS	100	100	100	87	93	83
ET-B WRS	97	100	94	100	100	99
ET-C	100	100	100	83	100	61
			Zone 4			
ET-A WORS	100	100	100	39	100	11
ET-A WRS	100	100	100	44	100	11
ET-B WORS	100	100	100	64	75	54
ET-B WRS	100	100	100	53	62	45
ET-C	100	100	100	99	99	98
			Zone 5			
ET-A WORS	100	100	100	66	100	17
ET-A WRS	100	100	100	66	100	16
ET-B WORS	100	100	100	81	91	70
ET-B WRS	100	100	100	66	100	48
ET-C	100	100	100	100	100	100
			Zone 6			
ET-A WORS	95	99	92	82	91	79
ET-A WRS	93	99	90	90	98	86
ET-B WORS	99	100	97	92	97	88
ET-B WRS	95	100	89	93	100	88
ET-C	81	100	71	95	100	93
			Overall			
ET-A WORS	98	100	97	73	95	59
ET-A WRS	98	100	97	74	98	57
ET-B WORS	100	100	99	83	89	77
ET-B WRS	98	100	95	81	94	73
ET-C	93	100	90	93	100	88

Table 7. The cumulative number of valid scores that could be reported when requiring at least one irrigation event on every SWAT irrigation zone within a 30 day test period compared to without the requirement.

	Test Periods Meeting Minimum Rainfall and ET_O Requirements (#)	Viable Test Periods Irrigation Event Requirement (#)[1]	Percent Difference (%)
ET-A WORS	120	41	-66
ET-A WRS	120	57	-53
ET-B WORS	120	109	-9
ET-B WRS	120	108	-10
ET-C	90	90	0

[1]Implementing the recommendation that irrigation is not required for zones with 100% irrigation adequacy scores would increase the number of viable test periods to the maximum amount.

Table 8. The cumulative number of viable scores that could be reported when requiring at least one irrigation event within a 30 day test period compared to without the requirement for each zone.

	Test Periods With Irrigation and Meeting Minimum Rainfall and ET_O Requirements (#)	Viable Test Periods Irrigation Event Requirement (#)[1]	Percent Difference (%)
Zone 1			
ET-A WORS	120	41	-66
ET-A WRS	120	57	-53
ET-B WORS	120	109	-9
ET-B WRS	120	109	-9
ET-C	90	59	-34
Zone 2			
ET-A WORS	120	41	-66
ET-A WRS	120	57	-53
ET-B WORS	120	109	-9
ET-B WRS	120	109	-9
ET-C	90	60	-34
Zone 3			
ET-A WORS	120	41	-66
ET-A WRS	120	57	-53
ET-B WORS	120	109	-9
ET-B WRS	115	109	-5
ET-C	90	60	-34
Zone 4			
ET-A WORS	41	41	0
ET-A WRS	57	57	0
ET-B WORS	120	109	-9
ET-B WRS	120	109	-9
ET-C	90	60	-34
Zone 5			
ET-A WORS	84	41	-51
ET-A WRS	84	57	-32
ET-B WORS	109	109	0
ET-B WRS	109	109	0
ET-C[2]	90	60	0
Zone 6			
ET-A WORS	120	41	-66
ET-A WRS	120	57	-53
ET-B WORS	120	109	-9
ET-B WRS	120	109	-9
ET-C[2]	90	60	0

[1]Implementing the recommendation that irrigation is not required for zones with 100% irrigation adequacy scores would increase the number of viable test periods to the maximum amount.
[2]Scores were less than the maximum value due to malfunction in controller equipment.

Table 9. The differences in total irrigation applied (%) for each zone was calculated after taking into account a minimum runtime requirement of three minutes.

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
			Frequent rainfall			
ET-A WORS	0	0	0	0	0	0
ET-A WRS	0	0	0	0	0	0
ET-B WORS	0	-22	0	0	0	0
ET-B WRS	8	-22	0	0	0	0
ET-C	-5	0	-1	0	0	0
			Infrequent rainfall			
ET-A WORS	0	0	0	0	0	0
ET-A WRS	0	0	0	0	0	0
ET-B WORS	0	-6	0	0	0	0
ET-B WRS	0	-13	0	0	0	0
ET-C	-4	-30	-1	-2	0	0
			Low ET_O			
ET-A WORS	0	0	0	0	0	0
ET-A WRS	0	0	0	0	0	0
ET-B WORS	0	-17	0	0	0	0
ET-B WRS	0	-16	-3	0	0	0
ET-C[1]	NA	NA	NA	NA	NA	NA
			High ET_O			
ET-A WORS	0	0	0	0	0	0
ET-A WRS	0	0	0	0	0	0
ET-B WORS	0	-22	0	0	0	0
ET-B WRS	0	-23	0	0	0	0
ET-C	-4	0	-3	-1	0	0

[1]Scores were not reported due to malfunction in controller equipment.

Table 10. The percentage of removed irrigation due to the minimum runtime requirement of greater than three minutes was calculated using the ratio of cumulative depth removed (in.) per cumulative depth without removed data (in.) from the time period presented in the 2009 Florida SWAT Test (September 2008 – February 2009).

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
ET-A WORS	0	0	0	0	0	0
ET-A WRS	0	0	0	0	0	0
ET-B WORS	0	14	0	0	0	0
ET-B WRS	0	14	0	0	0	0
ET-C	3	77	1	2	0	0

[1]Scores were not reported due to malfunction in controller equipment.

Table 11. The percentage of scores that was greater than the acceptable score thresholds of 80% for irrigation adequacy and 95% for scheduling efficiency.

Controller	Percent Passing Using Minimum Score Across All Zones (%)			Percent Passing Using Average Score (%)		
	Irrigation Adequacy	Scheduling Efficiency	Both	Irrigation Adequacy	Scheduling Efficiency	Both
Frequent rainfall						
ET-A WORS	100	0	0	100	0	0
ET-A WRS	100	0	0	100	0	0
ET-B WORS	100	0	0	100	0	0
ET-B WRS	100	3	3	100	3	3
ET-C	100	100	100	100	100	100
Infrequent rainfall						
ET-A WORS	100	58	58	100	100	100
ET-A WRS	100	100	100	100	100	100
ET-B WORS	100	10	10	100	10	10
ET-B WRS	100	10	10	100	13	13
ET-C	100	94	94	100	100	100
Low ET_O						
ET-A WORS	100	10	10	100	7	7
ET-A WRS	100	10	10	100	10	10
ET-B WORS	100	0	0	100	0	0
ET-B WRS	100	0	0	100	3	3
ET-C[1]	NA	NA	NA	NA	NA	NA
High ET_O						
ET-A WORS	100	0	0	100	6	6
ET-A WRS	100	10	10	100	19	19
ET-B WORS	100	0	0	100	0	0
ET-B WRS	100	0	0	100	3	3
ET-C	42	0	0	100	23	23

[1]Scores were not reported due to malfunction in controller equipment.

Table 12. The percentage of scores that was greater than the acceptable score thresholds of 95% and 90% for scheduling efficiency.

Controller	Percent Passing Using Minimum Score Across All Zones (%)		Percent Passing Using Average Score (%)	
	95% Threshold	90% Threshold	95% Threshold	90% Threshold
Frequent rainfall				
ET-A WORS	0	0	0	77
ET-A WRS	0	0	0	71
ET-B WORS	0	0	0	0
ET-B WRS	3	3	3	3
ET-C	100	100	100	100
Infrequent rainfall				
ET-A WORS	58	100	100	100
ET-A WRS	100	100	100	100
ET-B WORS	10	10	10	10
ET-B WRS	10	10	13	29
ET-C	94	100	100	100
Low ET_O				
ET-A WORS	10	17	7	21
ET-A WRS	10	10	10	38
ET-B WORS	0	0	0	10
ET-B WRS	0	0	3	21
ET-C[1]	NA	NA	NA	NA
High ET_O				
ET-A WORS	0	6	6	10
ET-A WRS	10	10	19	19
ET-B WORS	0	0	0	0
ET-B WRS	0	0	3	13
ET-C	0	42	23	74

[1]Scores were not reported due to malfunction in controller equipment.

Table 13. The percentage of scores that was greater than the acceptable score threshold of 95% for scheduling efficiency assuming irrigation occurs before rainfall in the soil water balance.

Controller	Percent Passing Using Minimum Score Across All Zones (%)		Percent Passing Using Average Score (%)	
	Original Scheduling Efficiency	New Scheduling Efficiency	Original Scheduling Efficiency	New Scheduling Efficiency
		Frequent rainfall		
ET-A WORS	0	26	0	77
ET-A WRS	0	10	0	100
ET-B WORS	0	0	0	0
ET-B WRS	3	3	3	3
ET-C	100	100	100	100
		Infrequent rainfall		
ET-A WORS	58	100	100	100
ET-A WRS	100	100	100	100
ET-B WORS	10	10	10	10
ET-B WRS	10	10	13	13
ET-C	94	94	100	100
		Low ET_O		
ET-A WORS	10	10	7	10
ET-A WRS	10	10	10	10
ET-B WORS	0	0	0	0
ET-B WRS	0	0	3	3
ET-C[1]	NA	NA	NA	NA
		High ET_O		
ET-A WORS	0	6	6	19
ET-A WRS	10	19	19	19
ET-B WORS	0	0	0	0
ET-B WRS	0	0	3	3
ET-C	0	48	23	90

[1]Scores were not reported due to malfunction in controller equipment.

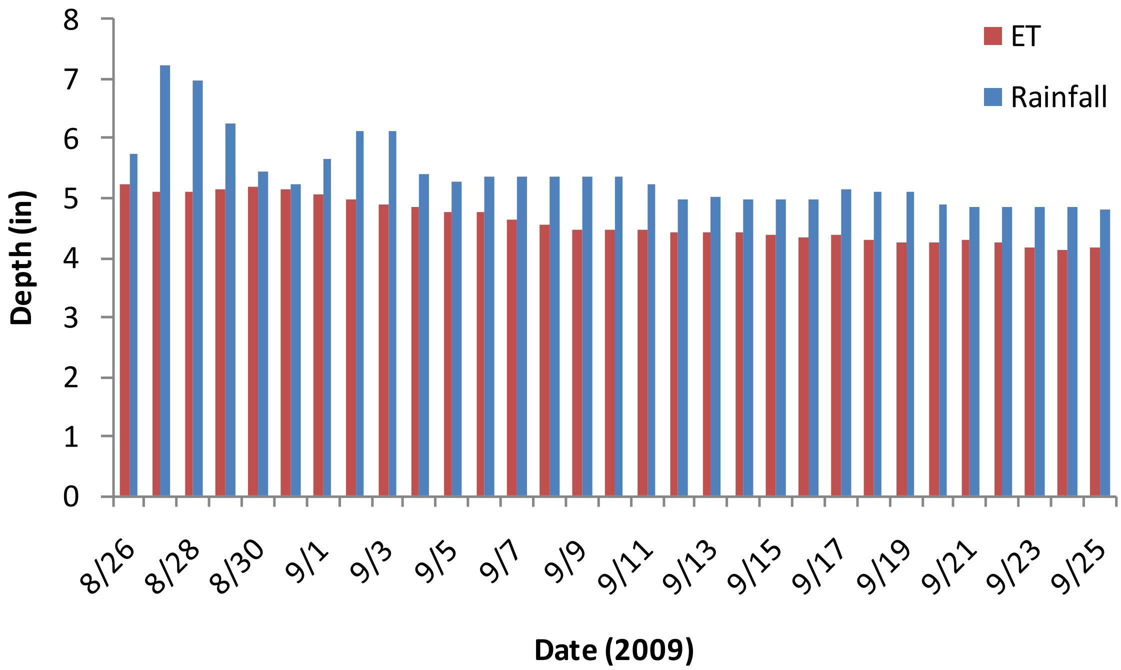

Figure 1. Rainfall and ET_O were summed for each 30-day period reported for the **frequent rainfall period**, 28 July through 25 September 2009.

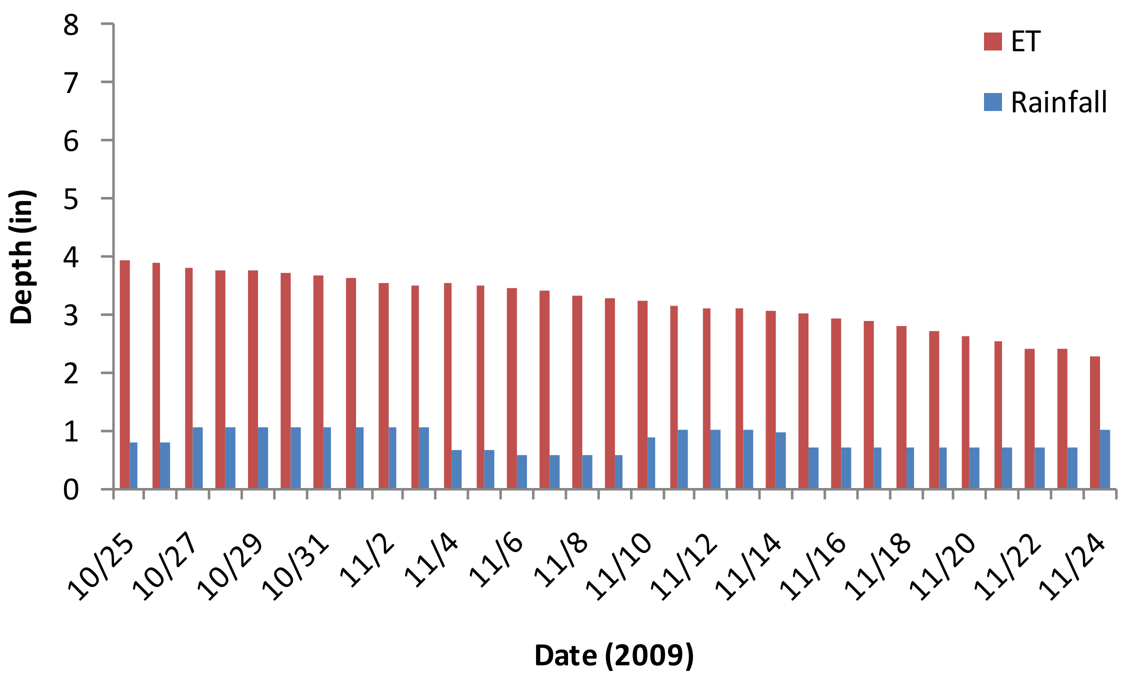

Figure 2. Rainfall and ET_O were summed for each 30-day period reported for the **infrequent rainfall period**, 26 September through 24 November 2009.

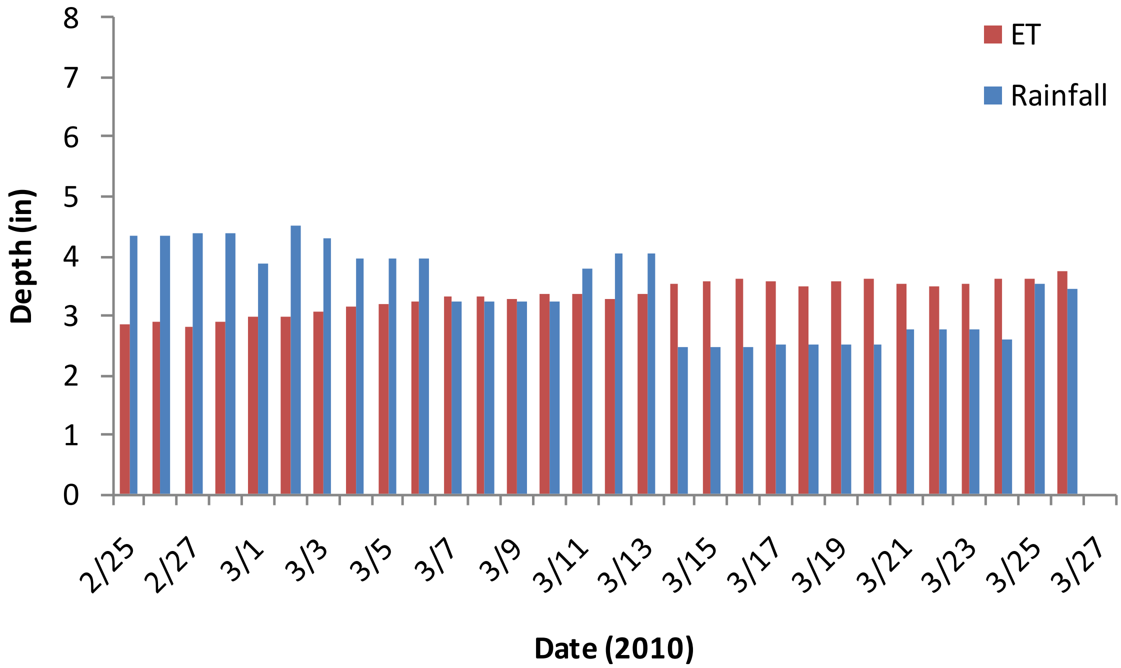

Figure 3. Rainfall and ET_O were summed for each 30-day period reported for the **low ET_O period**, 27 January through 27 March 2010.

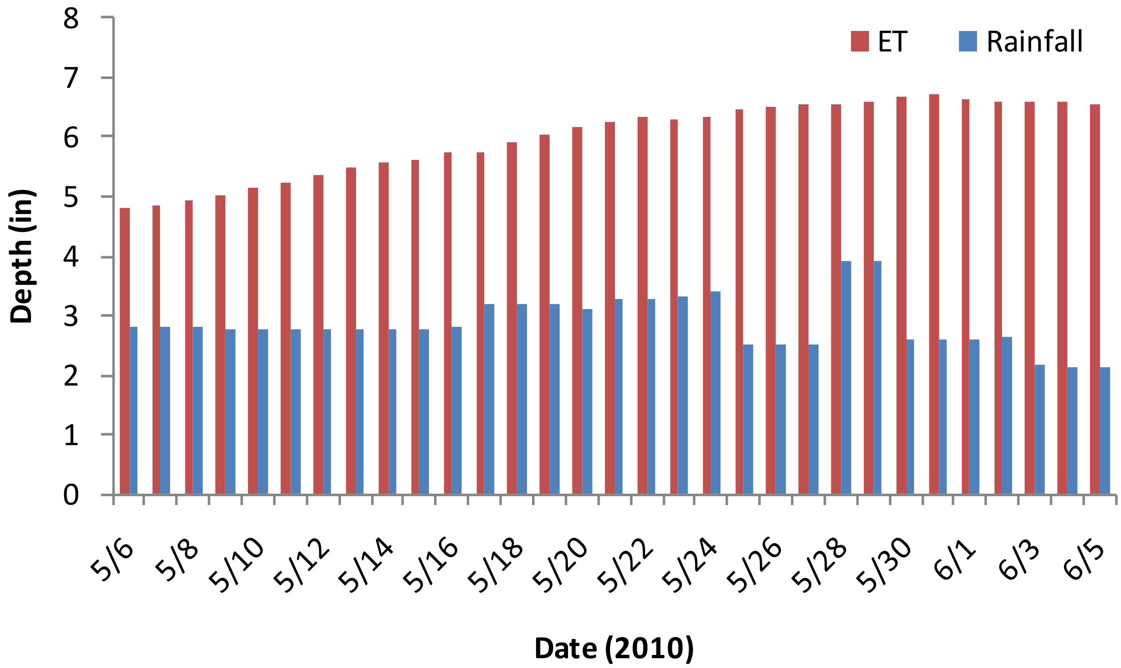

Figure 4. Rainfall and ET_O were summed for each 30-day period reported for the **high ET_O period**, 7 April through 5 June 2010.

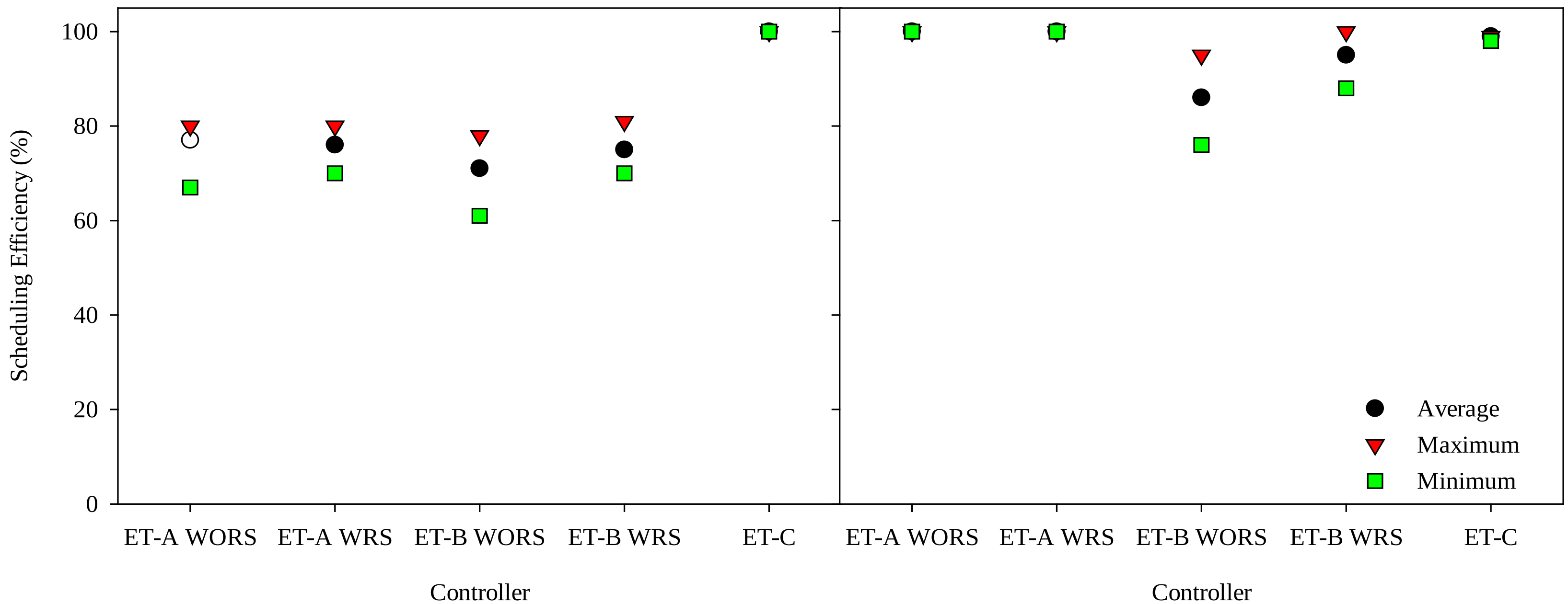

Figure 5. Scheduling efficiency results for Zone 2 were calculated for the various 30-day periods occurring during the **frequent rainfall period** (left) and **infrequent rainfall period** (right).

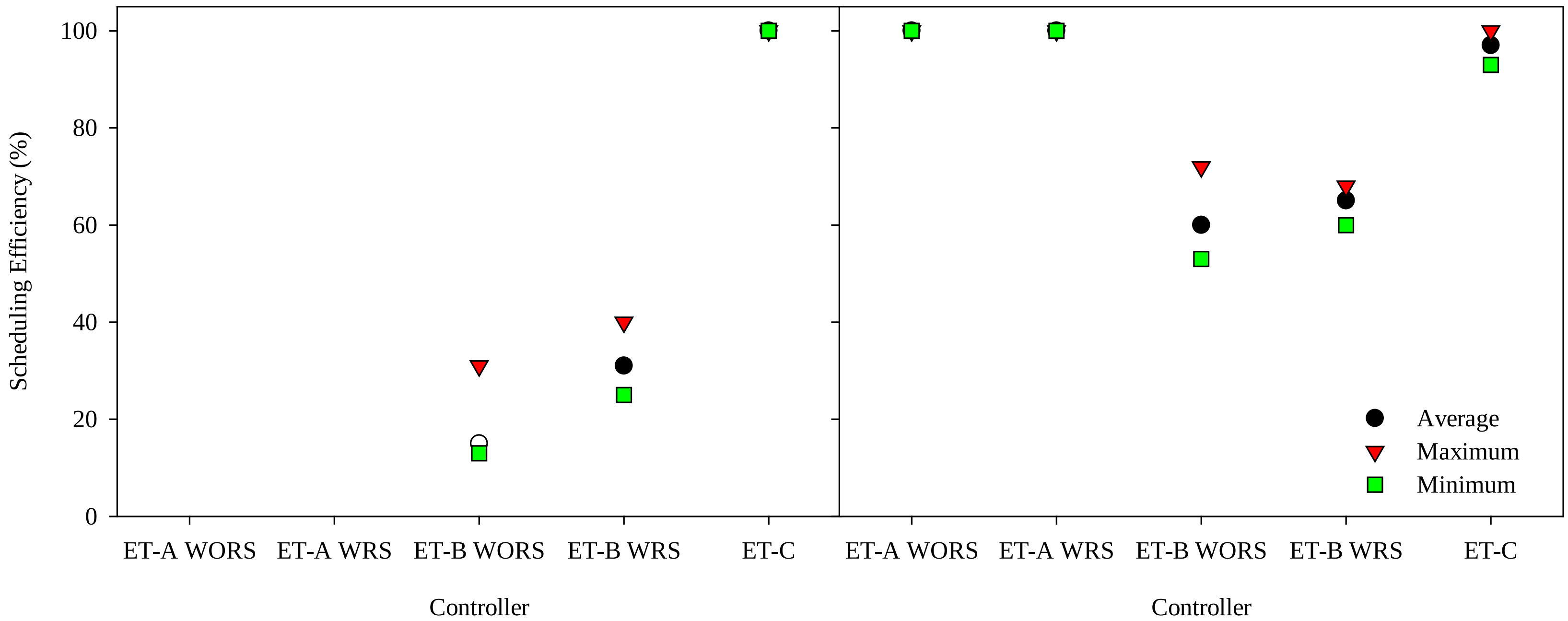

Figure 6. Scheduling efficiency results for Zone 4 were calculated for the various 30-day periods occurring during the **frequent rainfall period** (left) and the **infrequent rainfall period** (right).

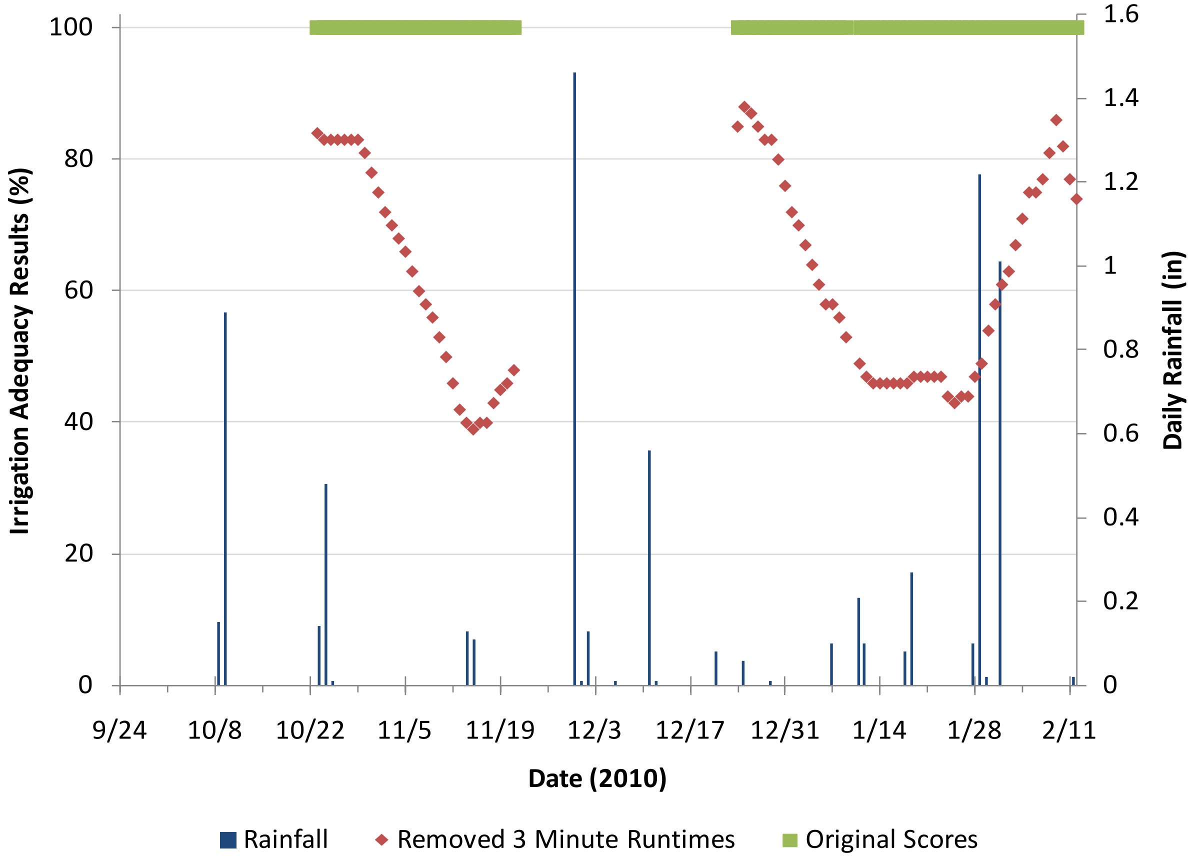

Figure 7. Rolling irrigation adequacy results for zone 2 were compared to determine the effects of requiring a minimum runtime of three minutes or less for the ET-C controller from the 2009 Florida SWAT Test, 24 September 2008 through 12 February 2009.

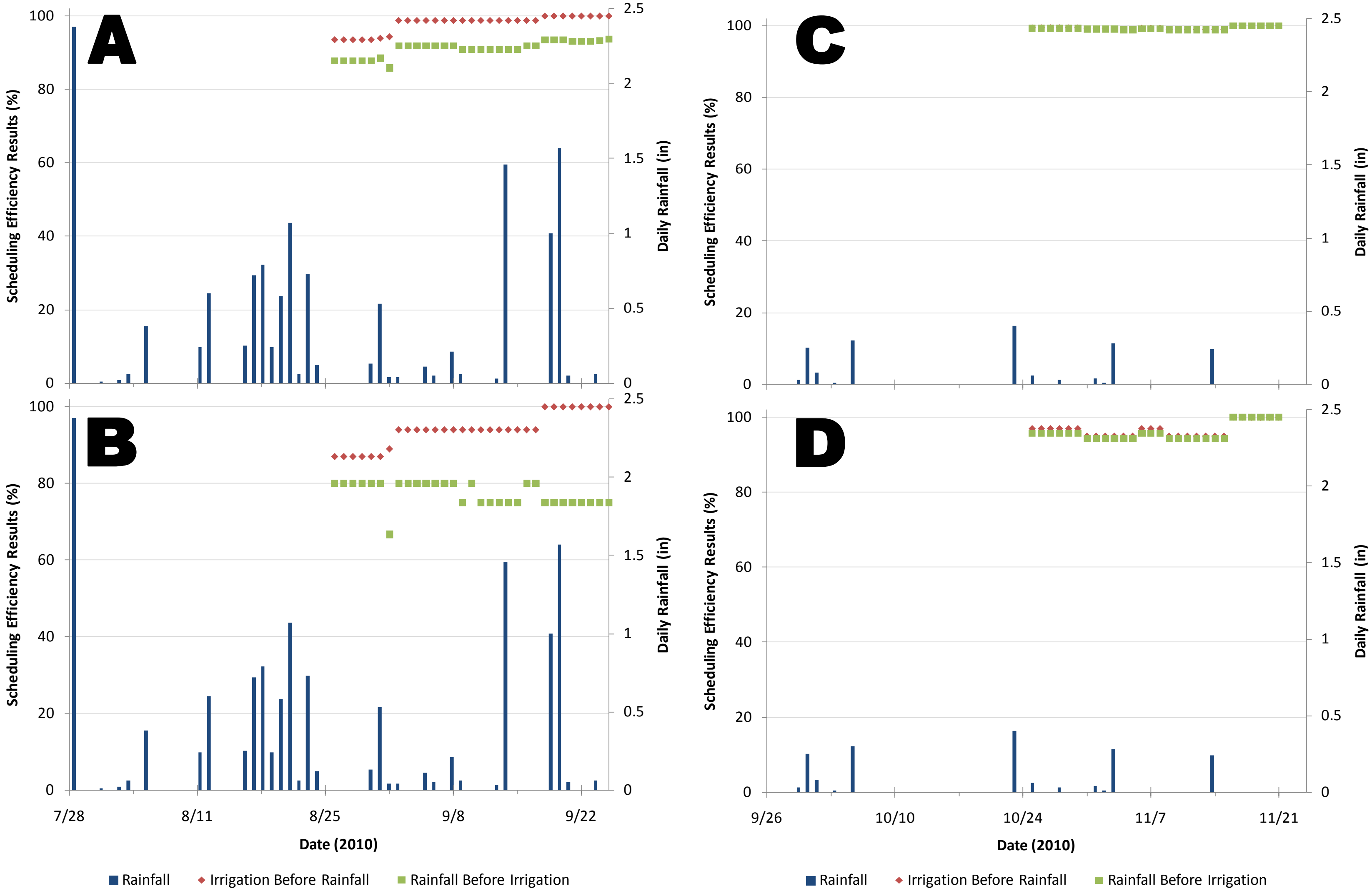

Figure 8. Scheduling efficiency scores for the ET-A WORS during the **frequent rainfall period** using A.) the average score of the six zones and B.) the minimum score of the six zones and the **infrequent rainfall period** using C.) the average score of the six zones and D.) the minimum score of the six zones.

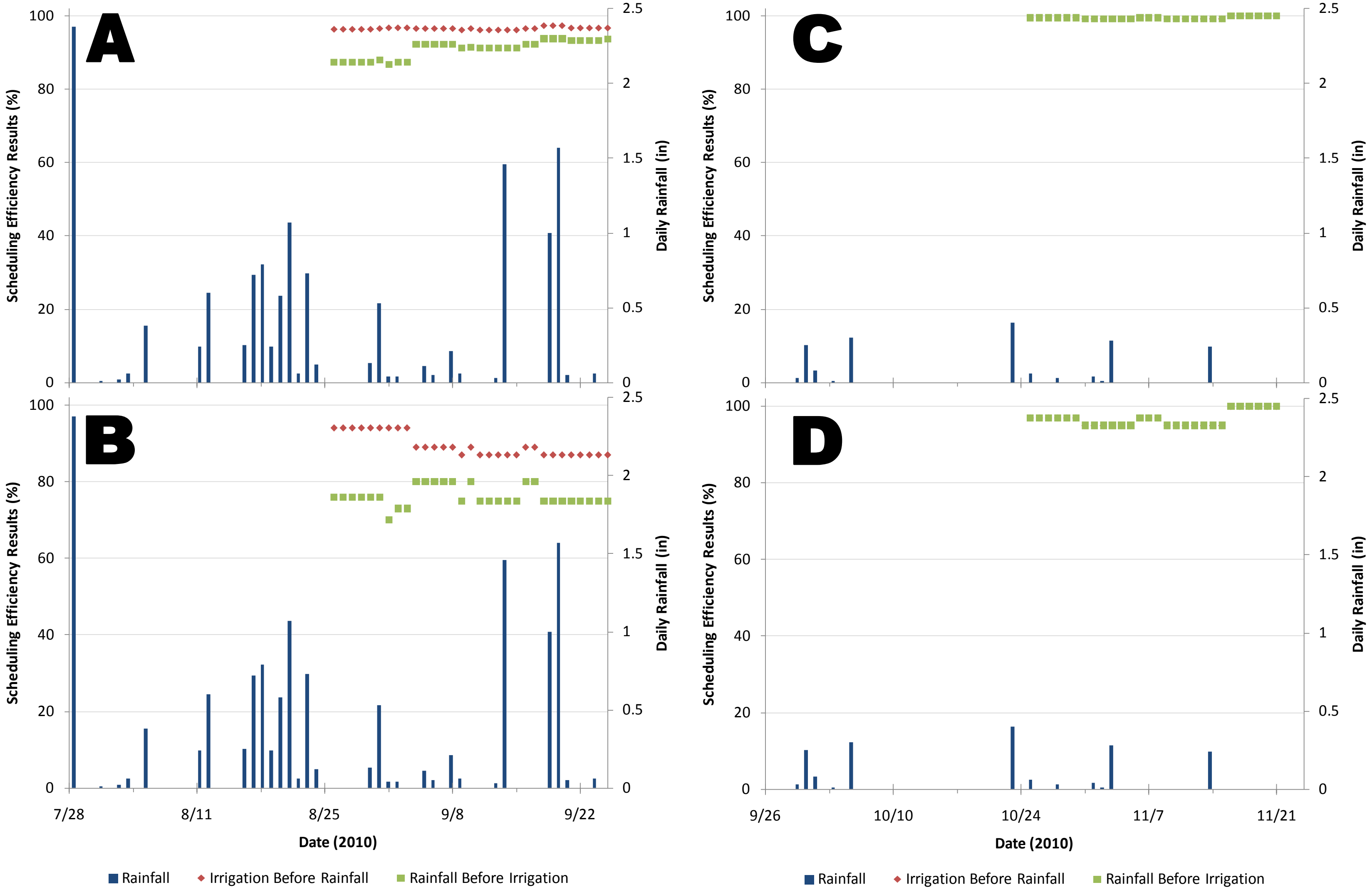

Figure 9. Scheduling efficiency scores for the ET-A WRS during the **frequent rainfall period** using A.) the average score of the six zones and B.) the minimum score of the six zones and the **infrequent rainfall period** using C.) the average score of the six zones and D.) the minimum score of the six zones.

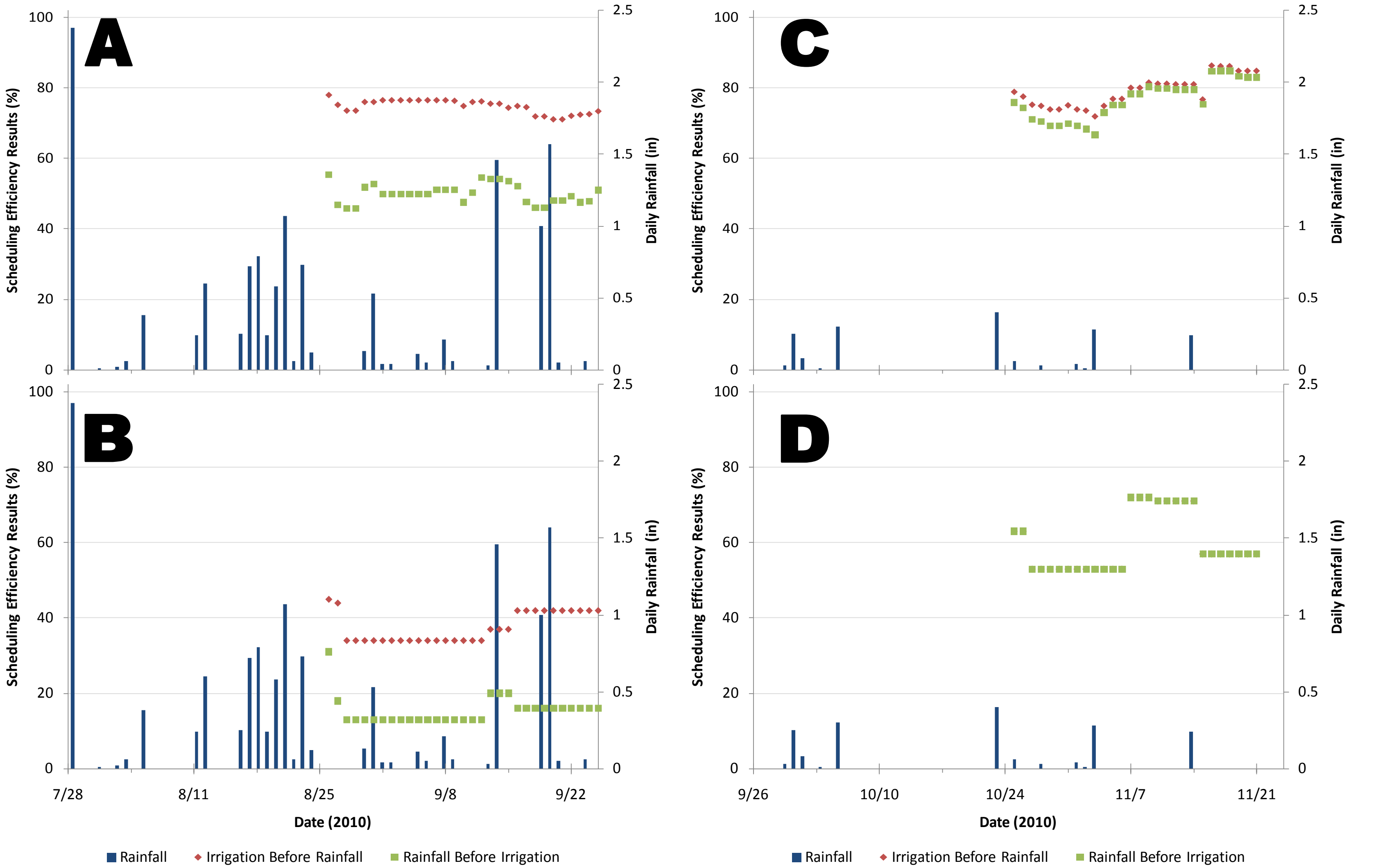

Figure 10. Scheduling Efficiency scores for the ET-B WORS during the **frequent rainfall period** using A.) the average score of the six zones and B.) the minimum score of the six zones and the **infrequent rainfall period** using C.) the average score of the six zones and D.) the minimum score of the six zones.

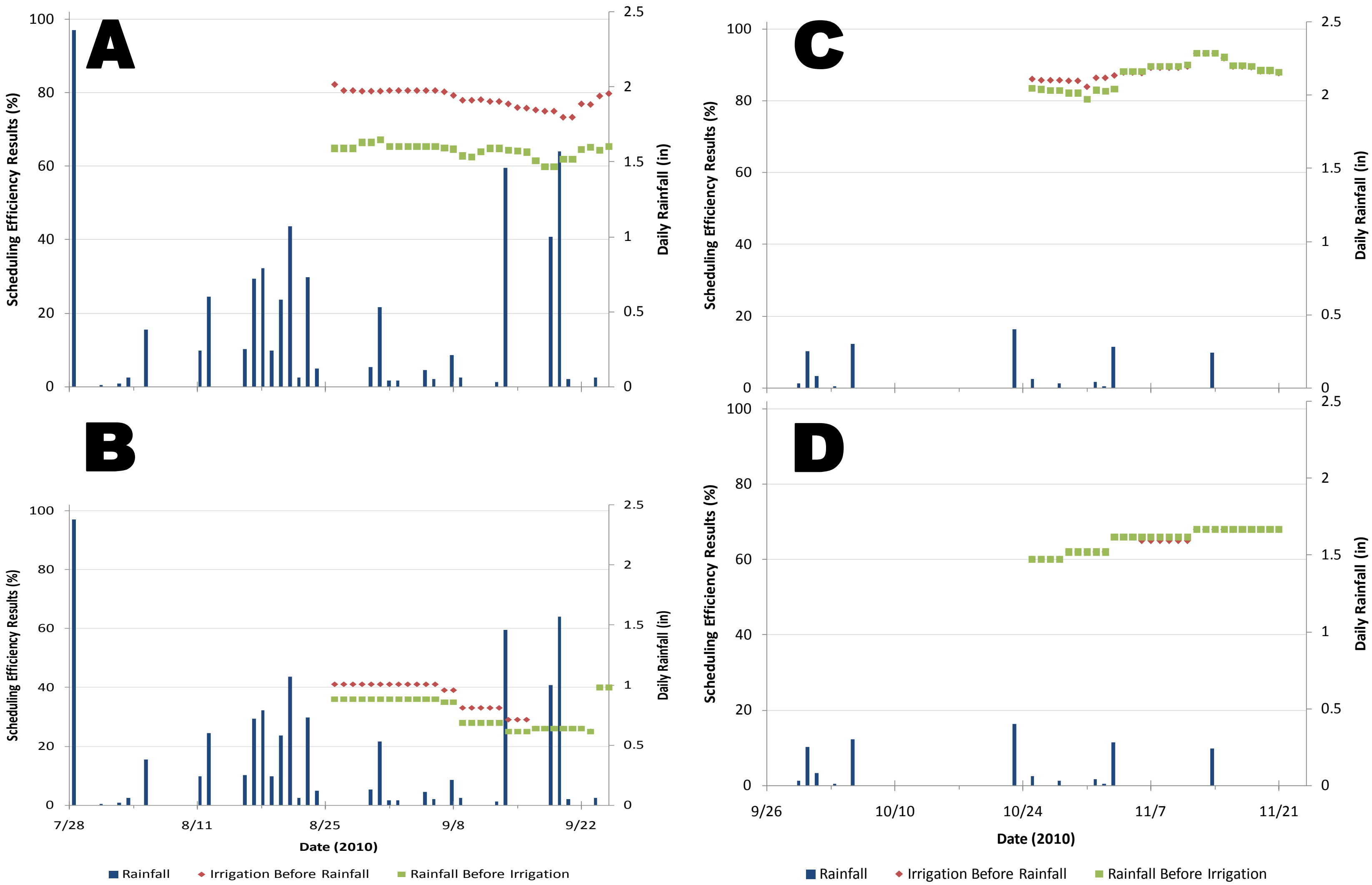

Figure 11. Scheduling Efficiency scores for the ET-B WRS during the **frequent rainfall period** using A.) the average score of the six zones and B.) the minimum score of the six zones and the **infrequent rainfall period** using C.) the average score of the six zones and D.) the minimum score of the six zones.

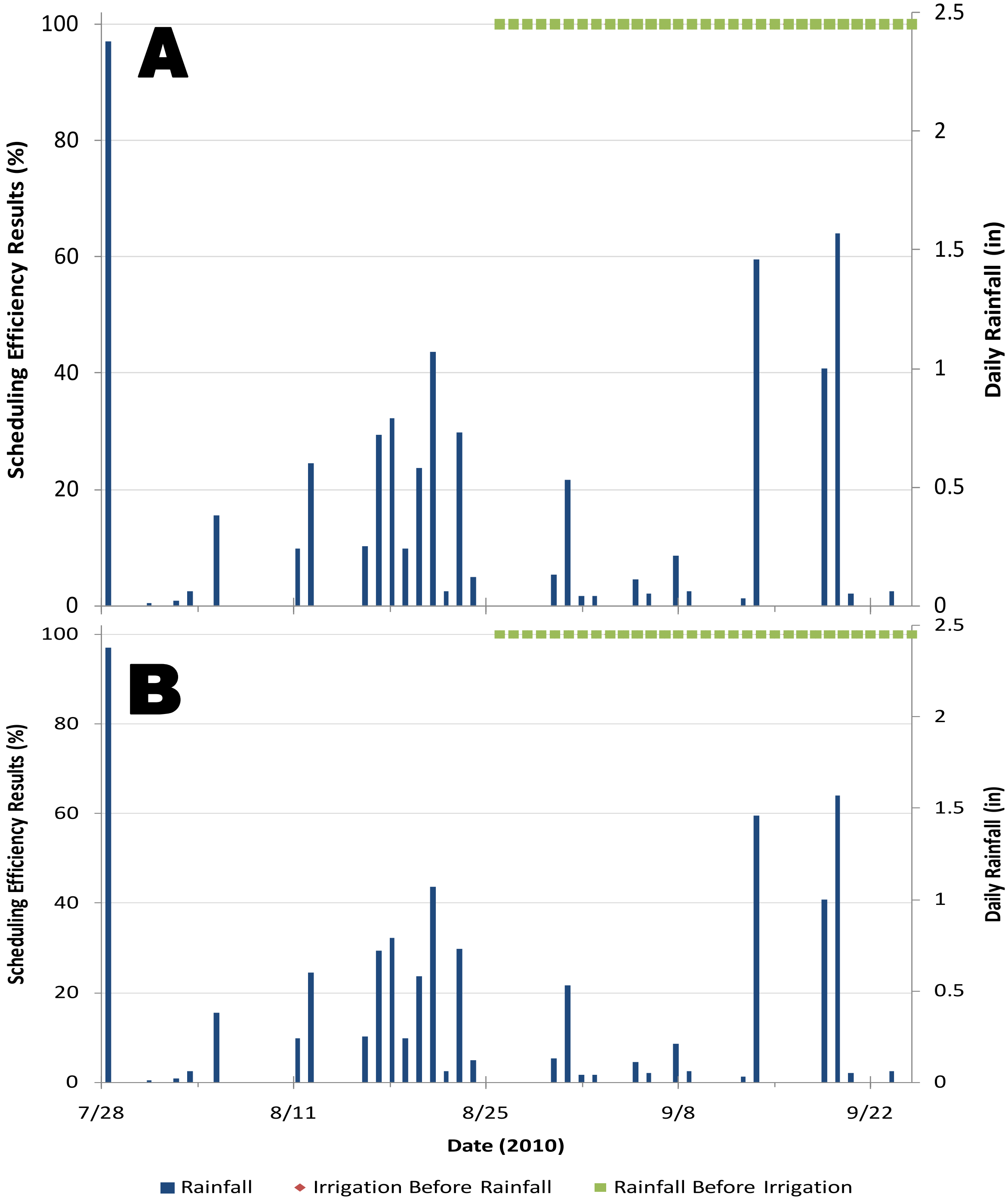

Figure 12. Scheduling Efficiency scores for the ET-C during the **frequent rainfall period** using A.) the average score of the six zones and B.) the minimum score of the six zones.

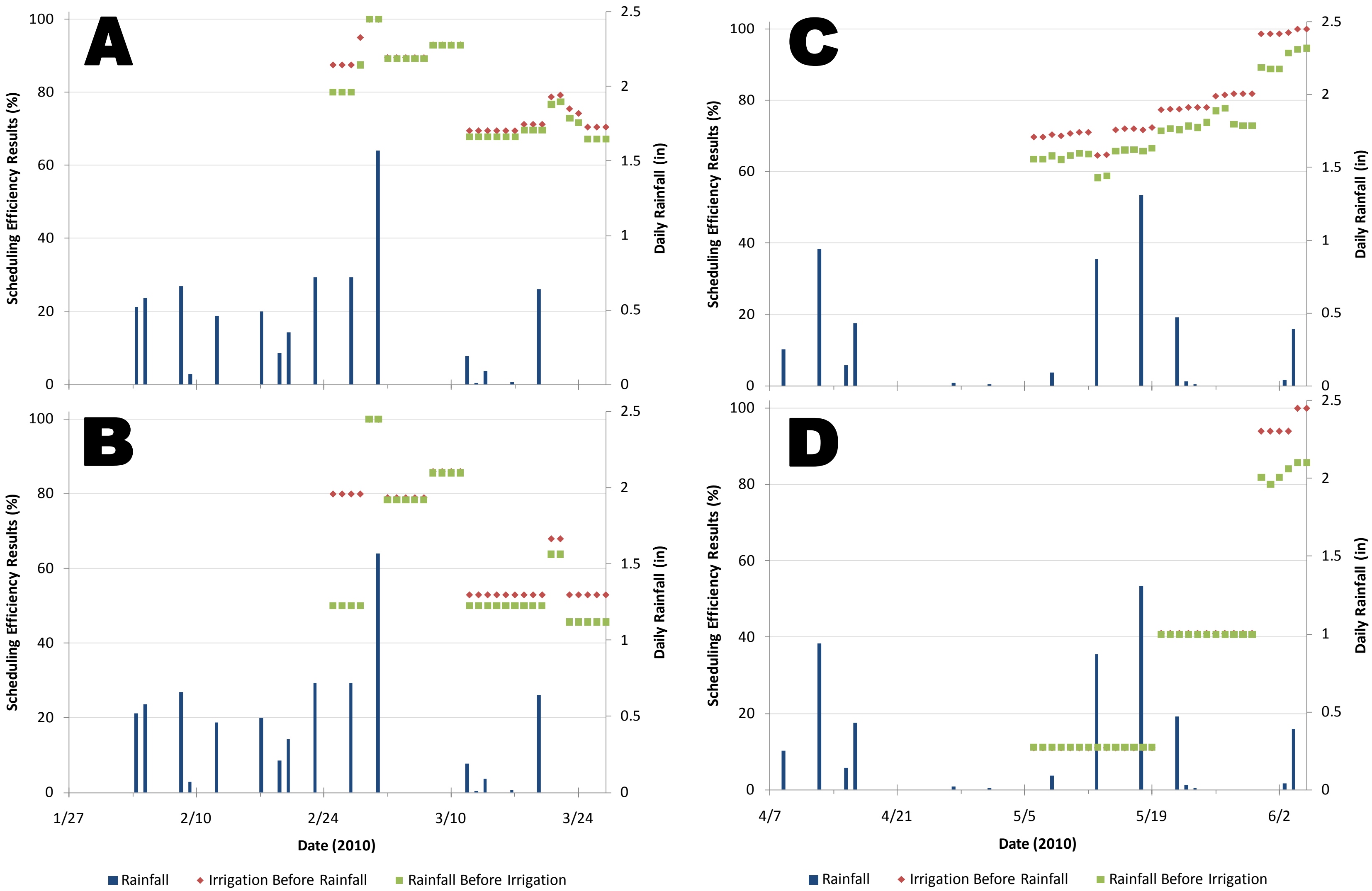

Figure 13. Scheduling efficiency scores for the ET-A WORS during the **low ET_O period** using A.) the average score of the six zones and B.) the minimum score of the six zones and the **high ET_O period** using C.) the average score of the six zones and D.) the minimum score of the six zones.

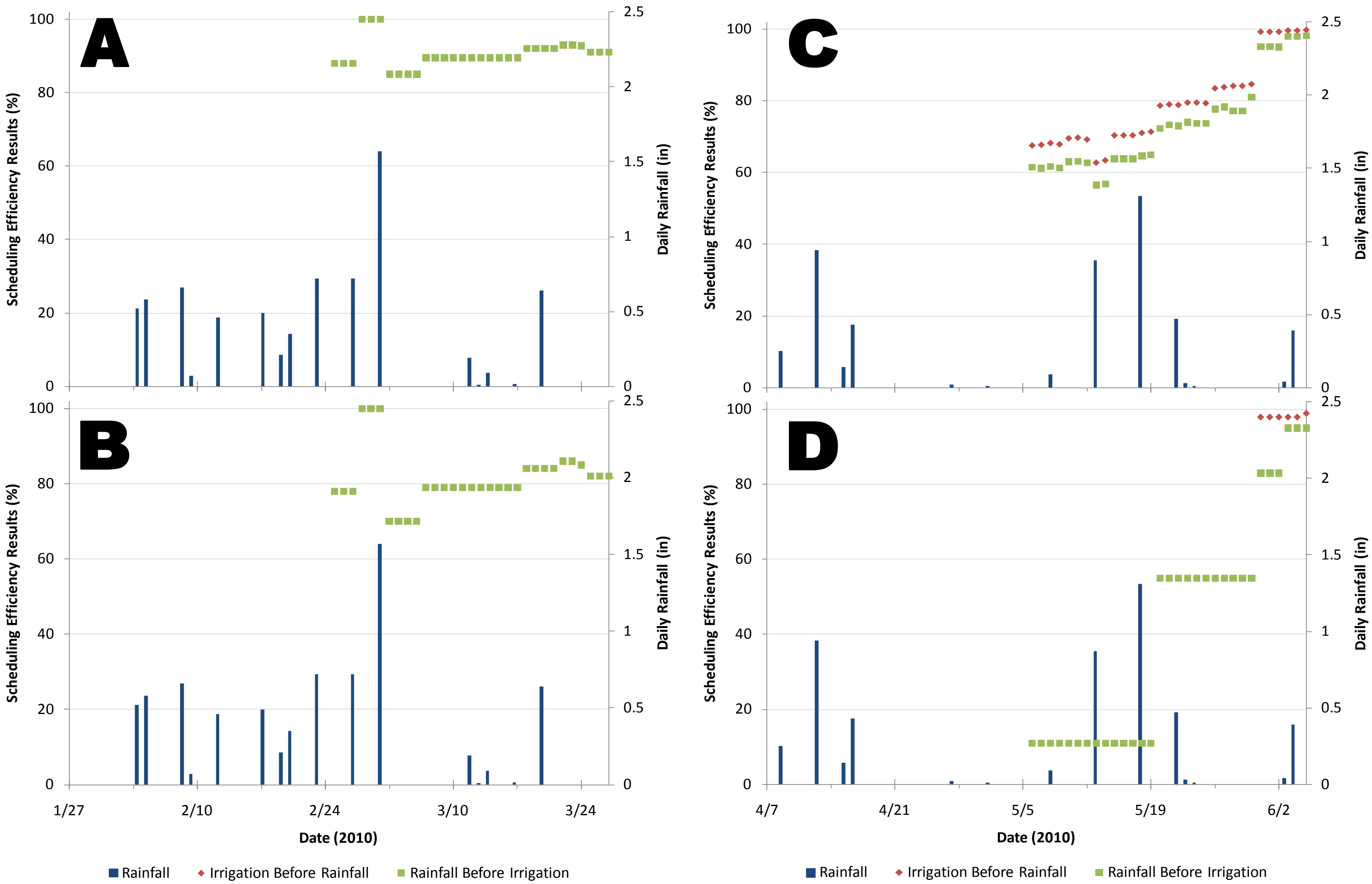

Figure 14. Scheduling Efficiency scores for the ET-A WRS during the **low ET_O period** using A.) the average score of the six zones and B.) the minimum score of the six zones and the **high ET_O period** using C.) the average score of the six zones and D.) the minimum score of the six zones.

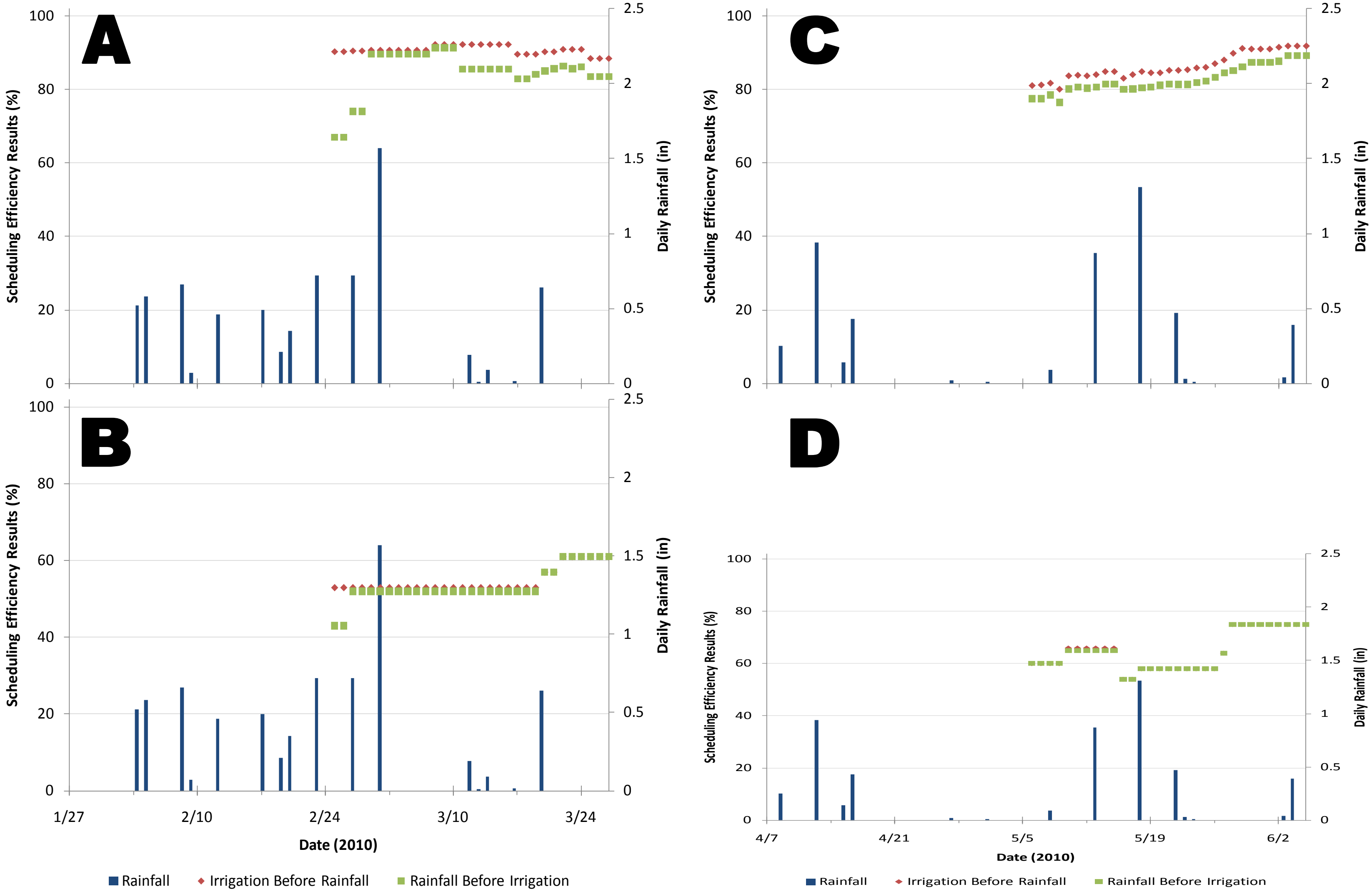

Figure 15. Scheduling Efficiency scores for the ET-B WORS during the **low ET$_O$ period** using A.) the average score of the six zones and B.) the minimum score of the six zones and the **high ET$_O$ period** using C.) the average score of the six zones and D.) the minimum score of the six zones.

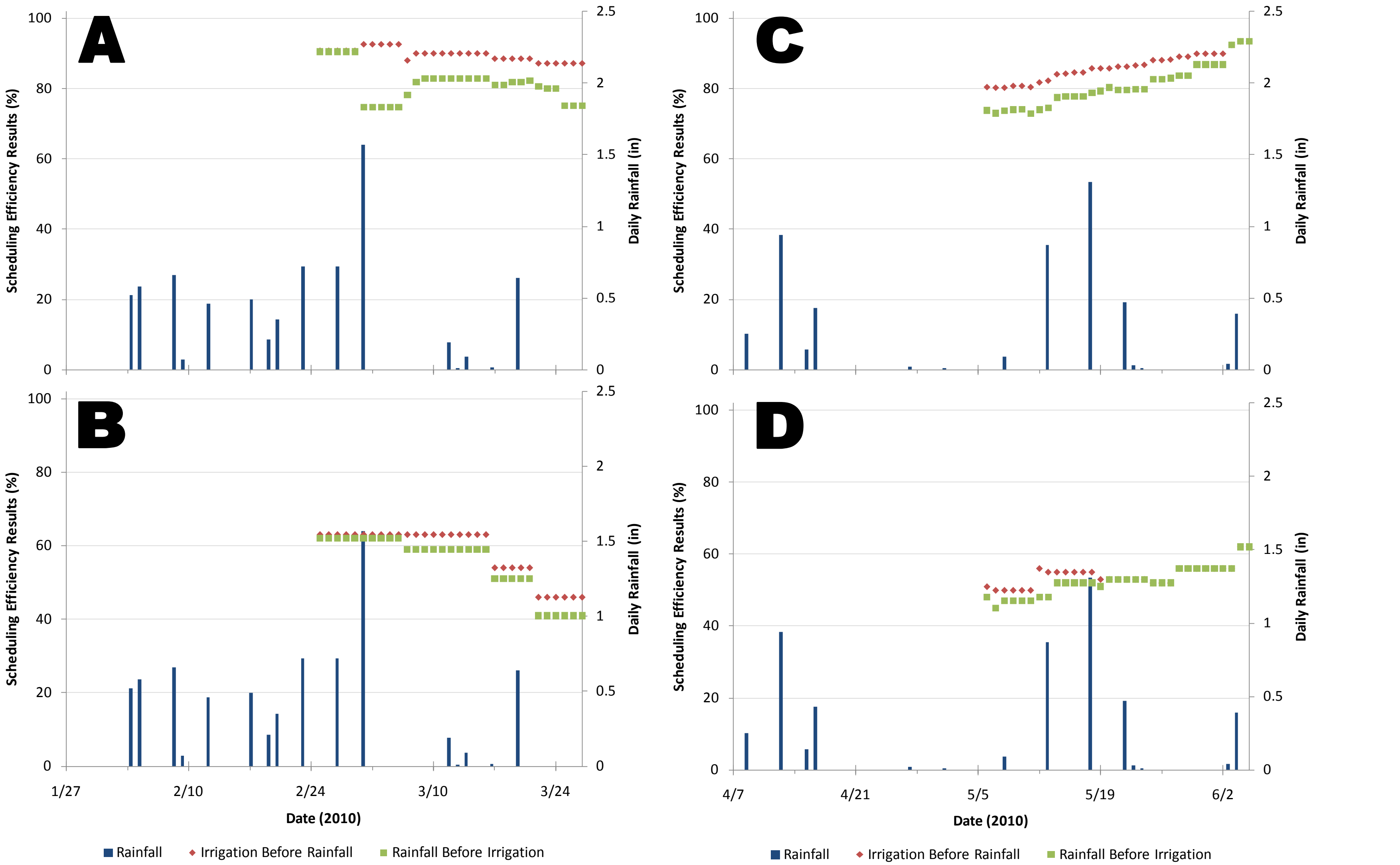

Figure 16. Scheduling Efficiency scores for the ET-B WRS during the **low ET_O period** using A.) the average score of the six zones and B.) the minimum score of the six zones and the **high ET_O period** using C.) the average score of the six zones and D.) the minimum score of the six zones.

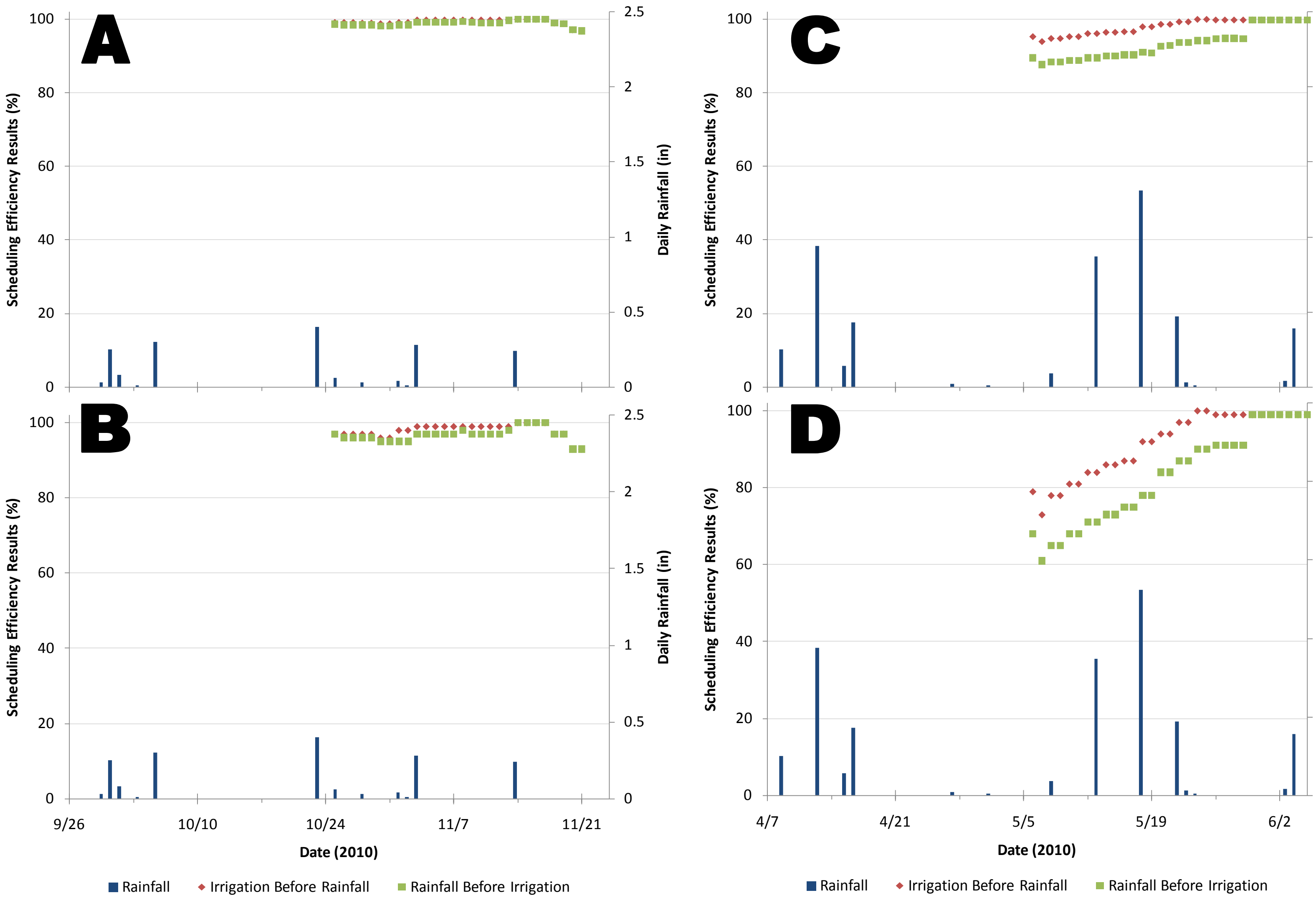

Figure 17. Scheduling Efficiency scores for the ET-C during the **low ET_O period** using A.) the average score of the six zones and B.) the minimum score of the six zones and the **high ET_O period** using C.) the average score of the six zones and D.) the minimum score of the six zones.