TOOLS TO ADVANCE ROW CROP BEST MANAGEMENT PRACTICE (BMP) IMPLEMENTATION IN FLORIDA'S LOWER SUWANNEE RIVER BASIN

By

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To my elementary school science teacher, Marcia Cremer, who led me to the love of science I have today; and to my brother, Oren, because he said so.

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LIST OF ABBREVIATIONS

AWC	Available water capacity
B	Boron
BMP	Best management practice
Ca	Calcium
CEC	Cation exchange capacity
DAP	Days after planting
ET	Evapotranspiration
FAWN	Florida Automated Weather Network
FC	Feild capacity
FD	Frequency domain
FDACS	Florida Department of Agriculture and Consumer Services
FDEP	Florida Department of Environmental Protection
FDR	Frequency domain reflectometry
GMS	Granular matrix sensor
K	Potassium
LSRB	Lower Suwannee River Basin
N	Nitrogen
NO_3 –N	Nitrate-nitrogen
P	Phosphorus
PWP	Permanent wilting point
SM	Soil moisture
TDR	Time domain reflectometry
TL	Transmission line
TSWV	Tomato Spotted Wilt Virus
UF-IFAS	University of Florida – Institute of Food and Agricultural Sciences
V6	Vegetative stage 6
V10	Vegetative stage 10

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Water resources in Florida's Lower Suwannee River Basin (LSRB) must be protected from excessive consumption and nitrate contamination to preserve the unique springs habitat. Thus, agricultural producers must make more efficient use of irrigation water and N fertilizer. New tools are available to help better manage these resources. This project tested a chlorophyll meter on corn (*Zea mays* L.) because many producers apply N at rates greater than the UF-IFAS recommendation, and tested soil moisture sensors on peanut (*Arachis hypogaea*) because producers have reported large discrepancies in efficacy of peanut irrigation that have been traced to irrigation scheduling. Silage corn and no-till peanut were grown for two seasons under center pivot irrigation at the North Florida Research and Education Center-Suwannee Valley in Live Oak, FL. In 2007, the corn field was divided into 20 plots that received five replications of four N fertilizer rate treatments (168, 235, 280, and 325 kg/ha). In 2008, N rates of 67, 134, 202, 269, and 302 kg/ha were replicated five times. There were also non-irrigated corn plots that received the four lowest N rates in 2008. Irrigated corn silage yield reached 90% of absolute maximum around 200 kg N/ha in 2007 and around 150 kg N/ha in 2008. Non-irrigated corn yielded less than half of irrigated corn. Chlorophyll (SPAD 502 meter) measurements taken before tasseling,

at tassel, and at the kernel blister stage were divided by corresponding SPAD measurements from non-limiting N plots to produce a relative SPAD reading. In both growing seasons, a relative SPAD reading of at least 95% indicated that the crop contained sufficient N for maximum yield. The peanut field was divided into three large plots that in 2007 received either full irrigation (100% of crop ET demand), limited irrigation (roughly half of full irrigation), or no irrigation, and in 2008 received either ET-based, soil sensor-based, or no irrigation. In 2007, limited (84 mm) and full (154 mm) irrigation produced significantly greater yields (4081 and 4716 kg/ha, respectively) compared with the non-irrigation yield (2840 kg/ha) during a relatively dry growing season (296 mm rainfall). The 2007 season was much wetter (515 mm rainfall); there was no response to irrigation, and peanut yields exceeded 5000 kg/ha. Time domain reflectometry (TDR), frequency domain reflectometry (FDR), and tensiometric sensors measured root zone soil moisture status throughout both growing seasons. The two most reliable and accurate soil moisture sensors, evaluated by their response to rainfall and irrigation, were the EasyAG and the AquaSpy devices. Critical instrument output ranges to trigger irrigation for avoidance of peanut water stress were determined to be 11 to 15 percent soil moisture for the EasyAG and 47 to 49 output units for the AquaSpy.

CHAPTER 1
INTRODUCTION

Best Management Practices (BMPs) are voluntary practices that farmers can choose to implement in order to comply with Florida water quality standards and meet the intent of the Federal Clean Water Act and other subsequent acts and regulations in the state of Florida. There are many different BMPs, and many ways in which to implement them. In north-central Florida, many BMPs are aimed at spring protection, specifically to prevent nitrates and other agricultural chemicals from entering the groundwater and spring conduits. Of particular concern in Florida's Lower Suwannee River Basin (LSRB) is nitrate leaching, which is exacerbated by over-irrigation of crops. Nitrate concentrations in the springs and rivers of the LSRB in north-central Florida have created concerns about water pollution and associated ecosystem change. Some of the region's row crops, such as corn and peanuts, require intensive irrigation and fertilization due to droughty soil conditions and the low nutrient-holding capacity of the soils. Increasing both water use efficiency and the efficiency of nitrogen (N) fertilization will help decrease N losses to both surface and ground water.

The main problem in the LSRB is limited use of quantitative measures to determine irrigation or in-season N fertilization needs. This situation leads to over-application of N fertilizer and excessive irrigation, both of which can lead to an increase of nitrate to the springs and rivers. There are new tools available that can alleviate some of these problems, but they have not been sufficiently evaluated in the LSRB to determine their effectiveness. Once reliability of these instruments is established, farmers will feel more comfortable investing in them and following the BMPs relating to their use.

Tissue testing is one BMP that can be implemented in order to improve nutrient management. Traditional tissue testing methods are expensive, time-consuming, and destructive.

Sometimes the results are not returned in a timely fashion, which makes it difficult to make rapid fertilization decisions. The use of an instrument that measures leaf chlorophyll content (e.g., a SPAD meter) may be a quick and non-destructive way to indirectly determine how much N is in the plant in order to make appropriate fertilization decisions. A SPAD meter measures the intensity of the green color of a plant leaf, which can be used to determine whether or not an additional application of N fertilizer is necessary. SPAD meters have been used on corn in the Midwest, but they have not been used for this particular application in north Florida.

Proper irrigation management techniques can help prevent excessive water application. Irrigation can be managed in multiple fashions, such as using soil moisture-measuring devices or an evapotranspiration (ET) based irrigation schedule. Soil moisture devices show the effect of water application to the soil and the effect of water uptake by plants. They also show how deep water percolates during each irrigation or rainfall event. This information should allow farmers to better manage their irrigation systems. There is a large selection of soil moisture devices; many farmers are wary of such technologies and do not know how to properly use them. It is unclear what the output data provided by many of these soil moisture sensors actually mean, and what type of measurements the farmer should be looking for in order to know when and how much to irrigate.

There are several questions that need answers in order to determine 1) if the SPAD meter can be used as a type of tissue testing for corn in the LSRB; 2) which type of soil moisture devices work best in the region; and 3) if managing irrigation using soil moisture devices conserves more water than an ET-based method.

- **Research Question 1:** Can the SPAD meter predict silage corn yield?
- **Research Question 2:** Can the SPAD meter be used to determine whether or not nitrogen fertilization is required?

- **Research Question 3:** Does the SPAD meter reading correlate with the concentration of N present in the tissue?
- **Research Question 4:** Which soil moisture devices work best in the LSRB region of Florida?
- **Research Question 5:** What does sensor output data mean with regard to irrigation scheduling?
- **Research Question 6:** Does using soil moisture devices conserve more water than using the ET method?
- **Objective 1:** Determine if the SPAD meter readings correlate with plant tissue N, silage yield, and/or protein yield,
- **Objective 2:** Determine if the SPAD meter can be used as a tool to determine the need for in-season N fertilization,
- **Objective 3:** Determine which soil moisture devices are the easiest to use and most reliable in the LSRB, and
- **Objective 4:** Determine if soil moisture devices can be used as a tool to improve irrigation management.
- **Hypothesis 1:** SPAD meter readings will correlate with a) plant tissue nitrogen, b) silage corn yield, and c) protein yield.
- **Hypothesis 2:** SPAD readings will be able to be used in order to determine whether or not supplemental N fertilizer application is needed at tasseling.
- **Hypothesis 3:** Certain soil moisture devices will prove to be more effective and easier to install and use than others.
- **Hypothesis 4:** Soil moisture equipment can be used as a tool for effective irrigation scheduling to avoid water stress.

The practical purposes of this study are to determine the utility of the SPAD meter and soil moisture devices, and to demonstrate the effectiveness of BMP implementation tools to farmers.

CHAPTER 2
LITERATURE REVIEW

Best Management Practices

BMPs are a practice, or combination of practices, that have been determined to be effective and practicable means for improving water quality in agricultural discharges based on research, field experiments, and expert review. They include both structural and nonstructural practices that have been determined to reduce or prevent pollution. BMPs are technically feasible, economically viable, socially acceptable, and based on sound science. BMPs evolved from the 1972 Federal Clean Water Act where states were required to assess the impacts of point and nonpoint sources of pollution within their boundaries. In Florida, the 1999 Florida Watershed Restoration Act specified BMPs as the primary method to minimize agricultural nonpoint source pollution through voluntary measures. Producers who enact BMPs that have been officially adopted by t he Florida Department of Agriculture and Consumer Services (FDACS) and verified by the Florida Department of Environmental Protection (FDEP) receive a presumption of compliance with state water quality standards. Enrolled producers may also become eligible for cost-share funds in order to implement eligible BMPs (FDACS, 2005).

The springs of north-central Florida are valuable natural resources in need of protection from contamination by excess nutrients, particularly nitrate-N. In order to protect springsheds, BMPs have been developed that can decrease the potential for nutrient losses in agricultural runoff from fertilizer applications. Irrigation management BMPs can protect the springs by preventing over–irrigation, which can leach nutrients into the groundwater and into spring conduits (FDACS, 2005).

Efficient fertilizer management is very important to farmers by reducing costs and to the environment by reducing environmental impacts and conserving natural resources. Tissue testing is a potential BMP that can improve fertilizer management (FDACS, 2005). There are several types of tissue testing, both direct and indirect. A device that measures leaf chlorophyll content like the Minolta SPAD 502 meter may be an effective tool for tissue testing since it gives immediate results and is a nondestructive method of testing.

Irrigation scheduling is consists of forecasting of timing and amount of irrigation required by a specific crop. Information needed for good irrigation management includes: crop water requirements, soil physical and chemical properties, current weather data and forecast weather conditions, method of irrigation, and management objectives. Irrigation is usually scheduled based on either monitoring the soil or crop water status, or creating a soil water budget that estimates irrigation based on water addition to and depletion from the root zone. Irrigation scheduling is complicated in Florida due to the fact that many of the soils are sandy with low water holding capacity and cannot store more than a few hours or days worth of the water required by crops (FDACS, 2005). Proper irrigation scheduling is important to protect the springs in the area since excessive irrigating causes leaching of nutrients into the groundwater and spring conduits. Fertilization and irrigation should be managed together in order to best prevent leaching, and increase the utility of both the fertilizer and the water applications.

Corn Production

Best resource management for corn production includes yield, economic considerations, and environmental considerations in order to fertilize at rates that will provide the greatest economic return while minimizing environmental impacts (Gascho and Lee, 2002). A challenge continually being faced by researchers is to make appropriate N fertilization recommendations while keeping field losses of NO_3 -N to a minimum (Costa et al., 2001) and maintaining high yields. Inadequate fertilization can lead to reduced grain yields and reduced profit (Bullock and

Anderson, 1998). In sandy soils, split applications of N are recommended in order to prevent leaching (Gascho and Lee, 2002).

Plant Nitrogen Status Measurements

The most common forms of plant N status assessment are destructive, time consuming, and based on either soil or plant tissue analysis (Costa et al., 2001). Tissue testing of corn leaves has been useful in predicting corn N requirements, but due to time required for sampling and analysis, it does not allow for proper response to determined deficiencies (Wood et al., 1992).

SPAD meters provide for a quick, easy, inexpensive and nondestructive method to provide real-time measurements of leaf chlorophyll (Sunderman et al., 1997). One of the main goals of using a SPAD meter in this context is to determine when a crop will respond to N fertilization versus when the crop contains sufficient N and does not require fertilization (Shapiro, 1999). It can be used as a tool for early detection of N deficiency in corn and fertigation management (Costa et al., 2001). Data from a SPAD meter allows farmers to minimize applications of "insurance N" with only a minimal risk of reducing yield (Blackmer and Schepers, 1995). This technique can also be used near the end of the growing season to evaluate the N status of corn in order to make more informed decisions for the upcoming growing seasons (Piekiekek et al., 1995). It may also be an effective way to make fertilizer recommendations for sidedressed N (Zebarth et al., 2002). One problem with using this as an assessment tool is the cost of purchasing a SPAD meter (approximately $1500), which may be prohibitive to many farmers (Feil et al., 1997).

Grain yield can be correlated with leaf chlorophyll measurements from the SPAD meter (Sunderman et al., 1997). There is a strong correlation between leaf chlorophyll and leaf N concentration (Costa et al., 2001), particularly at the silking growth stage (Bullock and Anderson, 1998). Therefore, it should follow that leaf chlorophyll concentrations can reflect the

N status of a crop (Blackmer and Schepers, 1995). SPAD readings have been found to be correlated with leaf N concentration, N fertilizer rate, and yield (Bullock and Anderson, 1998). The SPAD meter is more sensitive to N deficiency than yield (Shapiro, 1999).

The SPAD meter measures leaf chlorophyll by measuring light transmittance through the leaves (Costa et al., 2001). More specifically, it uses two light-emitting diodes of 650 nm and 940 nm along with a photodiode detector to measure the transmission of red and infrared light through leaves (Markwell et al., 1995). These wavelengths are associated with chlorophyll activity (Blackmer et al., 1994). Atypical leaves should not be sampled for chlorophyll meter readings, as they skew the data and may make it unrepresentative of the entire sample. This problem is larger with the SPAD meter than it is with tissue testing (Blackmer et al., 1993).

It has not been clearly determined how many leaf samples are required in order to achieve a certain level of precision with a SPAD meter. This number has been estimated to be between 3 and 30, with more research necessary. Insufficient sample size does not allow for the detection of important, small variations between treatments, and an overly large sample size wastes time and resources (Costa et al., 2003). According to one study, the required sampling size for precision of 5% in plots of 9.1 m x 61 m is 30 tissue samples, which is the maximum stored by the SPAD meter (Blackmer et al., 1993). Ten leaves are considered to be a satisfactory representative sample for a plot of 8 rows with row dimensions of 0.9 x 15.2 m (Blackmer et al., 1994). Another study in plots 4.6 x 6 m, containing six rows spaced 0.76 m apart showed that the required sample size for a 5% level of precision varied between 13 and 18 leaves, and four or five leaves at a precision of 10% at $\alpha = 0.05$ (Costa et al., 2003).

The relationship between SPAD readings and leaf chlorophyll is exponential. The exponential model was chosen because it most consistently represents the appropriate relationship between the two parameters (SPAD readings and leaf chlorophyll) (Markwell et al., 1995). Another potential model for SPAD reading as a function of N fertilization is a quadratic-plus-plateau function (Bullock and Anderson, 1998). The relationship between leaf N concentration and SPAD meter readings differs depending on a multitude of factors, such as developmental stage of the plant, position of the measurement taken on the leaf, and genotype of the plant (Costa et al., 2001). Generally, SPAD readings increase from the vegetative stage to the reproductive stage, where it reaches a maximum, followed by a gradual decrease in SPAD values (Costa et al., 2001).

One problem with taking tissue reading samples is that the base of younger corn leaves usually have lower readings than near the leaf tip, and this variation continues until the leaf collar is fully exposed. After the leaf collar is fully exposed, this variation within the leaf and between leaves is minimized (Schepers et al., 1992). SPAD readings are usually taken on the most recently matured leaf (MRML), which is the newest fully expanded leaf with an exposed collar (Costa et al., 2003). After tasseling, the ear leaf is measured (Costa et al., 2003).

Chlorophyll meter readings in the early season relate to the N status of the plants (Piekiekek et al., 1995). In addition to this, there is a strong relationship between SPAD readings and N concentrations in plant tissue at V10 and at the mid-silk stages of plant growth (Wood et al., 1992). Through comparing yield response with N fertilization and leaf chlorophyll content, the SPAD 502 chlorophyll meter may provide a better estimate of potential yield (Schepers et al., 1992). Nitrogen deficiency can also be indicated by the SPAD meter (Szeles, 2007), although it cannot be used to make fertilizer N recommendations where the index is lower than the critical value (Zebarth et al., 2002).

Correlations between grain yield and leaf chlorophyll measurements are non-significant based on data collected at different growth stages and combined data from multiple years, which falls in line with results from previous experiments (Sunderman et al., 1997). Early season SPAD readings do not correlate well with yield (Bullock and Anderson, 1998) unless the readings can be adjusted to take other environmental factors into consideration. During midseason, there is also only a limited potential for the use of SPAD meters to predict yield responses to N fertilization unless the readings are interpreted for a specific location (Blackmer and Schepers, 1995). In addition, SPAD readings are not reliable at low chlorophyll concentrations, such as at senescence (Costa et al., 2001). SPAD readings are also not always well related to leaf N or the quantity of N applied (Gascho and Lee, 2002). Timing of N fertilization also influences the chlorophyll concentrations and readings of the SPAD meter, and different types of fertilizers influence the SPAD meter readings to varying extents (Schepers et al., 1992). Leaf thickness influences SPAD readings, so anything that can influence the thickness of the leaves being measured can influence the readings of the SPAD meter, including water stress or nutrient deficiencies (Blackmer et al., 1994).

SPAD meter readings increase when one of two things occurs: within-row plant spacing is increased or N rate is increased (Blackmer et al., 1993). Plant spacing within a specific N treatment rate did not influence leaf N concentrations significantly, yet plant spacing seems to influence SPAD meter readings more than it influences leaf N concentration. This effect may be due to the extensive root system of corn that minimizes the benefits of spacing between plants (Blackmer et al., 1993).

Research with SPAD meters is conflicted. Certain studies find inconsistent relationships between SPAD and leaf N concentrations, and other studies find that readings only relate well to corn N status late in the growth cycle, when correcting for N deficiency is not possible. Yet other research finds that SPAD meters can be useful in making sidedress decisions, and that there is a meaningful relationship between SPAD readings and N status as early as the V6 growth stage (Gascho and Lee, 2002). Knowing the SPAD value, the grain yield of corn could be predicted with an accuracy of 1 tonne/ha (Szeles, 2007).

There is a significant interaction between plant hybrid variety and planting date with respect to SPAD readings. Leaf greenness increases the later in the year the corn is planted (Jemison and Lytle, 1996). In corn, critical SPAD values vary depending on the hybrid used. SPAD values also depend on stage of growth and cultural practices used throughout the growing season (Debaeke et al., 2006). Another factor in measurable chlorophyll content is the crop water status (Schepers et al., 1992). There are significant differences in leaf chlorophyll measurements among hybrids and during varying growth stages, but not for reproductive stages (Sunderman et al., 1997).

It is difficult to determine a critical level for maximum yield that is accurate for multiple sites or multiple years (Piekiekek et al., 1995). The critical value determined by Wood et al. (1992) for a Norfolk sandy loam soil is a SPAD reading of 56.4. A critical value of 54 SPAD units was determined, with a range of 52 – 56 units as a sufficiency range (Piekiekek et al., 1995). Another suggested value is 52 at anthesis, and 43.4 is suggested to be the critical level of separation between N-responsive and nonresponsive sites (Costa et al., 2001). In 2002, a critical value of 43.7 was determined using the Cate-Nelson procedure, and a value of 47.1 using the curve-fitting approach (Zebarth et al., 2002.). Other studies have found the critical point to be 41 (Rashid et al., 2005).

The normalized SPAD index, also called the sufficiency index, is calculated by dividing SPAD readings by the maximal value of the reference strip (Debaeke et al., 2006). This technique is one of the suggested methods to correct for the variations within hybrid species (Gascho and Lee, 2002) and to take into account seasonal climactic variations. A critical level for relative SPAD readings is 0.93 (Piekiekek et al., 1995). In 2002, the critical value was determined to be 0.96 (Zebarth et al., 2002). Tests that are not normalized should be done at specific growth stages and specific maturity of plants, and only compared with the same growth and maturity stage for accurate results (Piekiekek et al., 1995).

As N fertilization rates increase, chlorophyll meter readings approach a plateau and N leaf concentrations no longer reflect the increase in N applied (Schepers et al., 1992). Another way of describing this effect is that luxury consumption of N does not increase SPAD meter readings (Sunderman et al., 1997), which makes it ideal for detecting N deficiency (Rashid et al., 2005). Thus, if optimal yield is not being obtained but optimal SPAD readings have been reached, it may indicate that other nutrients are the limiting factor in plant growth and production (Blackmer and Schepers, 1995).

Peanut Production

Peanuts require coarse-textured soils with good drainage and moderately low amounts of organic matter (Putnam, 1991). The soils in the LSRB area are categorized into three soil orders: Entisols, Ultisols, and Spodosols. These three cannot be differentiated by their top A horizon because this horizon is very similar in all three orders. The A horizons are usually comprised of sand or fine sand and make up the root zone for row crop agriculture. Based on this sandy composition, these soils have poor water retention capability and also have a low nutrient holding capacity (low CEC and low organic matter). Entisols are the most vulnerable to leaching of chemicals and nutrients because there is no layer of clay (as in an Ultisol) or accumulated organic matter, iron, and aluminum (as found in a Spodosol) to prevent this leaching.

Peanuts are one of the major agricultural products in the LSRB (Obreza and Means, 2006). Peanuts are a high management and high input crop. In order for farmers to remain competitive, they must find ways to improve crop production and yield (Wright et al., 2006b). Peanut yields respond to rotation with other crops, and do best when planted after perennial grasses. Rotation is recommended in order to reduce the effects of pests (e.g., nematodes and insects), weeds, and diseases (Wright et al., 2006a). In addition to these benefits, there is also residual fertility and better weed control when peanuts are planted in rotation with other crops (Wright et al., 2006b). Rotations produce more profit and reduce the amount of management necessary. Management considerations are driven by tomato spotted wilt virus (TSWV) (Wright et al., 2006a). Planting cover crops can help reduce the disease pressure of TSWV when compared with the plow/plant method of peanut production. Cover crops are killed by herbicides before the peanuts are planted (Wright et al., 2006b). Another way of preventing or minimizing disease is by planting multiple varieties of peanuts on a farm, especially if more than 40 ha are planted. This practice helps minimize the risk of losses from both weather and diseases (Tillman et al., 2006).

Peanuts grow best at a soil pH of 6.2 or greater (Wright et al., 2006b), and lime should be applied if soil pH is below 5.8 such that the target pH of 6.2 to 7.0 is reached. If necessary, lime should be applied in the fall in order to provide a sufficient amount of reaction time to raise soil pH. If the crop grown prior to the peanut crop was well-fertilized, the peanuts may not require fertilization due to the fact that there may be enough residual nutrients within the soil for the peanuts to flourish. Boron (B) is normally a deficient nutrient in peanuts, especially in sandy soils. Phosphorus (P) and potassium (K) may also be low and should be applied based on soil tests (Wright et al., 2006a). Adding P or K in a successive cropping system is usually unnecessary because peanuts are very good at utilizing nutrients left over from previous crops (Wright et al., 2006b). Calcium (Ca) application may also be required because a large quantity of this nutrient is needed for peanut plants to form seeds. A deficiency in Ca will result in pod rot and unfilled pods. Calcium is typically applied as gypsum (Wright et al., 2006a). In addition, peanuts are somewhat unresponsive to direct fertilizer applications, so it is recommended that they be grown in rotation with other well-fertilized crops (Cope, 1984).

The variety of peanut selected for planting should be based on yield potential, grade, and pest resistance, while taking into consideration the maturity that best fits the farming operation (Wright et al., 2006b). Pod yields and grades should be considered first, followed by disease resistance, maturity, and seed supply. Anticipated planting date should be considered in order to get the best yield from the selected peanut variety (Tillman et al., 2007). Depending on the variety, peanuts require a minimum of 100 to 150 days from planting to reach maturity (Putnam, 1991).

Runner peanuts are most commonly grown in Florida and they generally mature 135 to 155 days after planting. Peanut is usually planted between May 11 and May 25 in north Florida. They can grow well if planted through the first week of June, but will suffer if planted later. Planting too early, such as in April, can cause a serious yield loss due to TSWV. Twin rows and strip tillage have been useful management tools to suppress TSWV (Wright et al., 2006a).

Peanuts flower above ground, followed by growth of a reproductive stem called a peg down into the ground where the peanuts form. Peanuts are harvested by digging the entire plant with a digger-shaker-inverter, letting the peanuts partially dry in the field, and then combining them (Wright et al., 2006a).

Peanuts are considered to be drought resistant because they can withdraw water from greater depths than other plants (Wright et al., 2006a). For example, peanuts can extract water from depths greater than 60 cm after 75 days. Plant water demand starts off low, and increases to a maximum around pegging and pod formation, which occurs during midseason. Water use decreases again afterwards. Flowering and pegging are the two most critical growth periods for peanuts, so water availability during these stages is critical to plant growth and development (Rocheseter et al., 1984). Also, the number of seeds produced by peanuts depends on conditions over a relatively long period of time, so the crop is not as affected by short-term water stress as other plants (Whitty and Chambliss, 2005). This fact is important because non-irrigated peanuts are likely to experience water stress for at least a short period of time (Ferreyra et al., 2003).

Whether or not to irrigate peanuts is a major decision. Irrigation has been reported to increase peanut yield and improve peanut quality (Paz et al., 2007), and can be used to stabilize yield (Rocheseter et al., 1984). High yields cannot be produced during dry seasons without irrigation, but for small farmers, the cost of irrigation equipment may be prohibitive. Also, if irrigation does occur, excessive irrigation may be a problem. White mold and pod rot are diseases that can be made more severe with poor irrigation management compared with a non-irrigated condition (Wright et al., 2006a). Over-irrigation can also affect the availability of oxygen to plant roots (Kahn et al., 2002). In addition to potentially exacerbating plant damage, water, a valuable resource, is also wasted when improper irrigation occurs (Bandyopadhyay et al., 2005).

Irrigation Water Management

What type of peanut to plant and on how many acres, or what type of inputs to purchase before planting, or even whether or not to grow peanuts as dryland crops or irrigated crops for the growing season are all climate-based decisions. Irrigation itself (when and how much) is a weather-based decision, based on the current day-to-day conditions throughout the growing season (Fraisse et al., 2004).

Sixty-nine percent of crop failures in the USA are due to either drought or excess water (Fraisse et al., 2005). Crop models can be used in order to help best determine the irrigation requirements of crops such as peanuts and can help prevent crop failure (Fraisse et al., 2005). Of course, if the peanut crop experiences stress during its essential growth period, the models may not be accurate (Ferreyra et al., 2003). In Florida, most crops are irrigated due to sandy soils and non-uniform rainfall distribution that result in soil moisture that is lower than optimum for plant growth (Smajstrla and Haman, 2005).

Florida ranks 9th in total irrigated acreage in the USA, and 2nd east of the Mississippi River. Florida ranks 11th in sprinkler irrigation (Smajstrla and Haman, 2005), which is the type of irrigation used in north Florida peanut fields. Irrigation systems provide available water to plants in sufficient volume in order to ensure that water is not a limiting factor during crop growth. Water is considered available to plants only within the root zone. Water existing deeper in the soil profile is not useful to the plants and is not considered to be plant available, no matter how much water there is. When water is depleted from the root zone, nutrient uptake within the plant is reduced (Zazueta, 2006). Irrigation should be scheduled in a manner that only applies water to the soil when it is needed, and only in the necessary quantity. Sprinkler irrigation uniformity is also important because when water application is not uniform, excess water is applied in certain areas while not enough water is applied in others (Smajstrla et al., 2006).

During sprinkler irrigation, water evaporates from the droplets sprayed into the air. The amount of evaporation depends on climatic demand, the time available for evaporation to occur, and the surface area of the drops of water. Climatic demand refers to how much water vapor the surrounding air is able to absorb. For example, dry air has a greater capacity to add moisture, thus evaporation will more readily occur when air is dry as opposed to moist. The time available for evaporation to occur is equal to the time between the drops of water leaving the sprinkler and contacting the ground or vegetative surface. The surface area of the drop of water is significant because evaporation increases as surface area decreases. There is also wind drift loss, which occurs when water droplets are carried by wind away from the irrigated crop area (Smajstrla and Zazueta, 2003).

Sprinkler irrigation evaporative loss can be estimated from air temperature, relative humidity, and wind speed data. Based on the general climactic conditions in Florida, it is unlikely that water loss due to sprinkler irrigation is greater than 5%. The reason is that even though Florida has relatively high temperatures, there is also high humidity in the air and low wind speeds that negate the effects of high temperature. During phases of low temperature, the vapor deficit is low, and therefore there will not be a great loss of water to evaporation. The same is true during periods of relatively high humidity, no matter what the temperature (Smajstrla and Zazueta, 2003).

There are ways to minimize the loss of water from sprinkler irrigation. Two of these methods include increasing the nozzle diameter and decrease the operating pressure, both of which will increase the amount of larger water droplets (decreasing the surface area so less evaporation will occur). Loss of water to evaporation can also be prevented by only watering when climate demand is low. For example, relative humidity is high and both air temperature and wind speeds are low at night, early morning, and late evening in Florida, so these are prime times for irrigation with minimal water loss (Smajstrla and Zazueta, 2003). Of course, some of the water that is lost to evaporation helps cool the crop canopy and reduces transpiration, so it slightly compensates for the loss of water to evaporation (Smajstrla et al., 2002).

The issue of water loss during irrigation to evaporation is of concern when determining irrigation efficiency. Irrigation efficiency is the measure of the effectiveness of an irrigation system in delivering water to a crop, and the effectiveness of irrigation at increasing crop yield. It provides a platform to compare different irrigation systems from a water use/waste standpoint on the basis of yield. More specifically, irrigation efficiency refers to the ratio of the volume of water delivered by an irrigation system to the volume that is input to the system. One way of increasing irrigation efficiency is the recovery and reuse of surface runoff and subsurface water (Smajstrla et al., 2002). In order to obtain high efficiency, uniform discharge is required from the irrigation system (Zazueta, 2006).

Application efficiency is always less than 100% because of the factors mentioned previously: evaporation, wind drift, and non-uniform applications. However, these factors can be minimized, which improves the efficiency of the irrigation system. Managing water for effective irrigation starts with having an accurate way to measure the water being used. Flow rates can be measured in order to determine how much water was applied and to ensure that the system is operating appropriately (Boman and Shukla, 2006).

Irrigation Scheduling

Plants themselves are good indicators of the need for irrigation. The amount of water available to a plant can change the plants visual appearance. Of course, yield reduction has likely occurred when the plant reaches the point where its appearance (e.g., wilting) indicates the need for irrigation. With many crops, growth stops before signs of wilting appear, and yield reduction sometimes occurs before this point as well (Smajstrla et al., 2006).

Due to limitations of irrigation scheduling based on plant indicators, other methods have been developed that can be used to estimate soil water content and the need for irrigation. For example, a water budget procedure can be used. This procedure is based on an estimate of the water used by the crop coupled with the soil's ability to store water. In order to use a water budget, several measurements are needed (Smajstrla et al., 2006). Evapotransipration (ET) includes water that is lost to the air due to evaporation and water lost due to transpiration by plants. This includes the water evaporating from moist or wet surfaces including soil, water, plants, and other surfaces. Transpiration is specifically the evaporation of water through the stomata of plant leaves. (Smajstrla and Zazueta, 2002). ET can be closely estimated either using a computer model or by using a physical method such as pan evaporation. For example, the Florida Automated Weather Network (FAWN) website (http://fawn.ifas.ufl.edu) provides daily evapotranspiration, rainfall, and temperature data for locations across Florida (Smajstrla et al., 2006). Individuals can estimate ET by measuring evaporation from a standard pan. This measurement requires some extra work since the pan must be checked and measurements must be taken every day around the same time. In order to determine ET, the pan measurement must first be multiplied by a correction factor (pan coefficient) to convert it to potential ET, and then by a crop coefficient in order to take into account the specific crop and growth stage. ET varies by crop due to differences in water uptake and due to the soil and climactic conditions (Smajstrla et al., 2000).

Additional necessary information for a water budget are the upper limit of water storage (field capacity, FC), the lower limit of water storage (permanent wilting point, PWP), and the volume of water that is allowed to deplete from the soil before irrigation is necessary (allowable soil water depletion). The difference between FC and PWP is considered to be the available water capacity (AWC). Irrigation should occur before ET is restricted by lack of available water held in the soil. In order to use the water budget procedure, ET is subtracted from the available soil water every day until the soil water storage has been reduced to the critical level (the level where ET becomes restricted). At this point, the crop should be irrigated to replace the net amount of water lost to ET since the last irrigation. If rainfall is predicted to occur around the same day as irrigation, irrigate to less than field capacity in order to leave room for the potential rain. This procedure minimizes irrigation and increases the effectiveness of rainfall (Smajstrla et al., 2006). When using the water budget method, irrigation should occur once one-third to one-half of the available water is depleted (Whitty and Chambliss, 2005).

Other irrigation scheduling methods involve the use of instrumentation to measure the amount of water in the soil (Smajstrla et al., 2006). There are two general methods by which the amount of water in soil can be measured: direct and indirect. Direct methods include gravimetric and volumetric techniques, while indirect methods include volumetric and tensiometric methods. Gravimetric water content is expressed as the weight of water divided by the weight of dry soil, while volumetric water content is expressed as the volume of water that is held within a specific volume of undisturbed soil. While these direct methods are accurate and inexpensive, they are also destructive, meaning there is no possibility for replication in the same location. They are also labor intensive and time intensive. Indirect methods estimate soil moisture by utilizing relationships with other measured variables. Depending on the method and variables used, these indirect methods are classified as volumetric and tensiometric. Volumetric methods are methods that estimate the volume of water within a certain volume of undisturbed soil, while tensiometric methods estimate the soil water matric potential. Matric potential takes into account both adsorption and capillary effects of the soil (Munoz-Carpena et al., 2006).

Soil Moisture Sensing Devices

Determining which method of soil moisture monitoring should be used should be based on the following factors: soil properties, application, plant type, accuracy, depth, necessary moisture range, cost, skill level required for operation, and maintenance (Munoz-Carpena et al., 2006). One soil property that needs to be considered is soil texture. Water is held strongly by fine-textured soils, so knowing soil texture is an important factor in determining water available to plants. Even if the volumetric water content in a fine-textured soil is high, the water may not be available due to the fact that the water is held strongly. Suction may be a more useful measurement since it measures the amount of energy a plant must exert in order to obtain water from the soil (Munoz-Carpena et al., 2006). Monitoring soil moisture helps farmers ensure that their crops have enough plant available water in order to grow and mature properly, while allowing the farmer to conserve water. This practice also prevents leaching of fertilizers and chemicals due to the fact that excess water is not applied (Munoz-Carpena et al., 2006).

Irrigation of peanuts works well when tensiometers (an indirect method of measuring soil water content) are placed with the sensing cup at a depth of 15 cm. In this case, a reading between 20 and 25 cb is typically used to trigger irrigation in sandy soils. If tensiometers are placed at a depth of 30 cm, then a reading of 30 cb indicates when irrigation is necessary. Previous research has found that the use of 15 and 30 cm tensiometers to trigger irrigation resulted in over irrigation with no increase in peanut yield, while the use of 30 cm tensiometers was inappropriate due to the difficulties of sufficiently wetting the soil to that depth (Rochester et al., 1984). The accounting method of a water budget scheduling procedure is the most practical way to determine when to irrigate compared with tensiometers or other soil moisture sensing devices: they not only indicate when to irrigate, but also how much water to apply (Whitty and Chambliss, 2005).

The tensiometer consists of a sealed water-filled plastic tube with a ceramic cup at one end and a negative pressure gauge at the other. When a sealed water-filled tube is placed in contact with the soil through a permeable and saturated porous material, such as a ceramic cup, the water inside the tube comes into equilibrium with the soil solution. Therefore the soil water matric potential is equal to the vacuum or suction created inside the tube. Typically the measurement range is 0 to 80 cb, although there are low-tension versions (0 to 40 cb) designed for coarse soils (Munoz-Carpena et al., 2006).

Advantages of using tensiometers include direct readings, a 10 cm radius of detection, continuous readings when using a pressure transducer, electronics and power consumption are not necessary, they are well-suited for high frequency sampling or irrigation schedules, minimal skill is required for maintenance, they are not affected by soil salinity, and they are inexpensive. Disadvantages of using tensiometers include a limited soil suction range of less than 1 bar, they have a relatively slow response time, they require manual readings unless using extra equipment, they require intimate contact with the soil around the ceramic cup for accurate and consistent readings, and they require frequent maintenance/refilling, especially in hot and dry weather (Munoz-Carpena et al., 2006).

Time Domain Reflectometry (TDR) instruments, such as the EasyAG®, the Portable TDR, and the CS625 use a device capable of producing a series of electrical pulses with a wide range of high frequencies. These electrical pulses travel along a transmission line (TL) that is built with a coaxial cable and a probe. In addition, a TDR uses a device for measuring and digitizing the energy (voltage) level of the TL. When the electromagnetic pulse traveling along the TL finds a discontinuity, part of the pulse is reflected, producing a change in the energy level of the TL. The travel time is determined by analyzing the digitized energy levels (Munoz-Carpena et al., 2006).

Advantages of using TDR probes is that they are accurate, they do not require soil-specific calibration, they cause minimal soil disturbance, they are relatively unaffected by normal soil salinity levels, and they can provide simultaneous measurements of soil electrical conductivity. The disadvantages include the fact that they are relatively expensive due to the complex electronics involved, they are potentially limited in their application under highly saline conditions or in areas with highly conductive heavy clay soils, soil-specific calibration is required for soils with large amounts of bound water, and they have a relatively small sensing volume (Munoz-Carpena et al., 2006).

Probes such as the AquaSpy™, ECHO Probe, and Aqua Pro are capacitance and Frequency Domain Reflectometry (FDR) probes. The electrical capacitance of a capacitor that uses the soil as a dielectric depends on the soil water content. When connecting this capacitor (made of metal plates or rods imbedded in the soil) together with an oscillator to form an electrical circuit, changes in soil moisture can be detected by changes in the circuit operating frequency. This measurement is the basis of the Frequency Domain (FD) technique used in capacitance and FDR sensors. These probes usually consist of two or more electrodes (i.e., plates, rods, or metal rings around a cylinder) that are inserted into the soil. On the ring configuration, such as the Aqua Pro, the probe is introduced into an access tube installed in the field. Thus, when an electrical field is applied, the soil around the electrodes (or around the tube) forms the dielectric of the capacitor that completes the oscillating circuit. The use of an access tube allows for multiple sensors to take measurements at different depths. Soil-specific calibration is recommended due to the low operating frequency of these devices. At these low frequencies the estimation is more affected by temperature, salinity, bulk density and clay content (Munoz-Carpena et al., 2006).

Advantages of Capacitance/FDR probes is that they are accurate after soil-specific calibration, they can be used in high salinity soils, they have better resolution than the TDR, they can be connected to conventional loggers, and they are relatively inexpensive. Disadvantages include a small sensing sphere of influence, good contact between the sensor and soil is critical for good data measurements, careful installation is necessary to avoid air gaps, these sensors tend to be more sensitive to temperature, bulk density, clay content, and air gaps, and soil-specific calibration is required (Munoz-Carpena et al., 2006).

The Watermark sensor is a Granular Matrix Sensor (GMS). The sensor consists of electrodes embedded in a granular quartz material, surrounded by a synthetic membrane and a protective stainless steel mesh. Inside, gypsum is used as a buffer against the effects of salinity on the measurements. This kind of porous medium allows for measuring in wetter soil conditions and lasts longer than the gypsum blocks. However, even with good sensor-soil contact, GMS have rewetting problems when they have desiccated. This is because of the reduced ability of water films to re-enter the coarse medium of the GMS from a fine soil. The GMS material allows for measurements closer to saturation. The measurement range of this instrument is 10 to 200 cb (Munoz-Carpena et al., 2006), which provides for a much larger measurement range than the tensiometer.

Advantages of GMS include the reduction of problems that are associated with gypsum blocks, such as loss of contact with the soil and inconsistent pore size distribution, no maintenance is required, they are simple and inexpensive, salinity effects are buffered, and they are suited to regulated-deficit irrigation. Disadvantages of the GMS system include low resolution, slow reaction time, they do not work well in sandy soils or swelling soils, and if the sensor becomes too dry it must be removed, re-saturated and re-installed (Munoz-Carpena et al., 2006).

CHAPTER 3
MATERIALS AND METHODS

Experiments were conducted at the North Florida Research and Education Center in Live Oak, Florida. Based on the 2006 soil survey of Suwannee County, both the SPAD meter experiments and the soil moisture experiments were conducted on Hurricane, Albany and Chipley soils with 0-3 percent slopes. The Hurricane Series soils are sandy, siliceous, thermic Oxyaquic Alorthods; the Albany series soils are classified as loamy, siliceous, subactive, thermic Grossarenic Paleudults; the Chipley series is classified as a thermic, coated Aquic Quartzipsamment.

SPAD Measurements with Corn

The experiments using the SPAD meter were conducted throughout the 2007 and 2008 spring/summer growing seasons in a corn field irrigated with a center pivot system. On March 9, 2007, corn seed (Pioneer 31Y42, a variety bred for silage production) was planted in single rows 76 cm apart at a rate of 69,189 seeds/ha. Six-row plots (4.6 m wide by 8.8 m long) were demarcated in the field (Figure 3-1). The corn was irrigated on a schedule that was based on measurements of soil water content using an EasyAG® sensor system. The entire field received equal irrigation; 1.7 cm of water was applied when the EasyAG® read 11% soil moisture at the 30 cm depth. The field was irrigated every other day during dry periods (Figure 3-2).

The experiment was a completely randomized design with five replications of four N fertilizer rate treatments (Table 3-1):

A. 168 kg N/ha, with 33% applied at planting, followed by one sidedress and one broadcast application.

B. The UF-IFAS recommended rate of 235 kg N/ha, with 25% applied at planting, followed by one sidedress and two broadcast applications.

C. The UF-IFAS recommended rate, but instead of one sidedress and two broadcast applications, there were three broadcast applications. (This treatment is presented here for clarity in understanding the field plot diagram, but it was not used in the data analysis).

D. 280 kg N/ha, with 25% applied at planting, followed by one sidedress and two broadcast applications.

E. Non-limited nutrient benchmark of 324 kg N/ha, with 18% applied at planting, followed by one sidedress and four broadcast applications.

In addition to the N fertilization, all plots were fertilized with 22 kg/ha of P_2O_5 (10 kg P/ha) and 247 kg/ha of K_2O (205 kg K/ha).

A Minolta SPAD 502 meter was used to take chlorophyll readings in all N fertilizer rate plots. Ten most recently matured leaves were removed from the four inner rows of each plot, and meter readings were taken two-thirds of the way from the tip of the leaf in direct sunlight. The individual reading was recorded, along with the average of the ten readings. These leaf samples were then sent to a laboratory to measure total N. Samples were collected at 66, 76, and 89 DAP, which correlated with before tassel, at first tassel, and the blister stage.

Harvesting of silage corn occurred on July 5, 2007. Plots were harvested by hand by cutting the center four rows of each plot 15 cm above ground. The harvested plant material was weighed, and subsamples were fed into a chopper and collected for further analysis of moisture and protein concentrations. N response data including silage and protein yields, leaf N concentration, and SPAD readings were analyzed using standard analysis of variance (one-way ANOVA) for a completely randomized design. Linear and/or non-linear regression was used to describe the nature of significant relationships. The Cate-Nelson procedure (Cate and Nelson, 1971) was used to determine the critical value of N fertilization required to produce the maximum response. Cate-Nelson analysis divides a data set into two populations and calculates an R^2 value based on the differences between sums of squares. The independent variable value at the point with the highest R^2 value is deemed the critical value separating a responsive population from a non-responsive population.

The 2008 experiment was again grown under a center pivot irrigation system, where the previous crops were 2007 soybeans and peanuts. On March 11, 2008, Pioneer 31Y42 corn seed was planted into a killed rye cover crop in single rows 76 cm apart at a rate of 80,275 seeds/ha. As in 2007, six-row plots (4.6 m wide by 8.8 m long) were demarcated in the field. The corn was irrigated according to ET estimates and soil moisture content data acquired from an EasyAG® probe. Irrigation was triggered when available soil moisture reached 50% depletion at the 30 cm depth. Typical irrigation was 15 mm every 2 days during peak crop ET (Figure 3-2).
In 2008, a section of non-irrigated corn was planted adjacent (west) of the irrigated field, and similar field plots were established to evaluate use of the SPAD meter under a dryland condition.

The experiment was a completely randomized design with five replications of six N fertilizer rate treatments (Table 3-2):

A. 67 kg N/ha, with half applied at planting followed by one sidedress application.
B. 134 kg N/ha, with 25% applied at planting followed by two sidedress applications.
C. 202 kg N/ha, with one-sixth applied at planting followed by two sidedress and one broadcast application.
D. 269 kg N/ha, with one-eighth applied at planting, followed by two sidedress and two broadcast applications.
E. Non-limited nutrient benchmark of 302 kg N/ha, with one-ninth applied at planting, followed by two sidedress and three broadcast applications.

In addition to the N fertilization, all plots were fertilized with 224 kg/ha of K_2O (186 kg K/ha). Herbicides used during the growing season included glyphosate for pre-plant weed burn-down, glyphosate and atrazine post-emergence, and Sandea® and glyphosate to spot-spray nutsedge and bermudagrass.

The procedures to take SPAD meter chlorophyll readings and leaf N measurements were the same as those used in 2007. Samples were collected at 51, 59, 70, and 77 DAP, which correlated with two before tassel, followed by first tassel, and then the blister stage. Harvesting of silage corn occurred on July 3, 2008 using the same methods as in 2007. Methods to analyze corn response to N and SPAD readings were also similar to 2007.

Soil Moisture Measurements with Peanuts

The soil moisture experiments were conducted in a two-acre 'Georgia Green' peanut field irrigated with the same center pivot system used to irrigate the silage corn. The field did not have any history of peanut production. Peanut seed was no-till planted into a burned-down rye cover crop on May 10, 2007 at a target spacing of 20 seeds/m of row with 76 cm between rows. The actual plant population after germination was 13 to 16 plants/m of row. The two acres of peanuts were divided into three pie-shaped wedges in order to accommodate three irrigation treatments using a center pivot and allow for management with farm equipment (Figure 3-3).

Dry 0N-3P-23K fertilizer was broadcast at 448 kg/ha before planting (providing 14 kg P/ha and 104 kg K/ha), along with 0.56 kg/ha of B. Gypsum was applied at a rate of 2.24 tonnes/ha at 35 DAP. A 14 day spray schedule was followed, including chlorothalonil and Provost® applications. TSWV was prevalent during the growing season, which was probably influenced by the low plant population, previous crop history of tobacco and vegetable production, and a susceptible variety.

The three irrigation treatments were non-irrigated, limited irrigation, and full irrigation based on ET. Treatments were based on a soil water holding capacity of 38 mm within a 60-cm deep root zone:

1. Non-irrigated – Irrigation water was applied only within the first 40 DAP to encourage seed germination and to activate herbicide and insecticide.

2. Limited irrigation – Treatment began with soil moisture brought to field capacity by rainfall. When crop ET reduced available soil moisture to 7.5 mm, an irrigation amount of 10 mm was added. This prescription theoretically maintained soil moisture below 50% plant-available water. Using this method, irrigation was initiated prior to plant wilting.

3. Full irrigation – Treatment began with soil moisture brought to field capacity by rainfall. When crop ET reduced available soil moisture to 19 mm, an irrigation amount of 19 mm was added. This scheduling was based on a checkbook method using reference ET, percentage groundcover of the peanut plants as a crop coefficient, and water applied. The prescription essentially maintained soil moisture above 50% plant-available water.

Commercially-available soil moisture status measuring devices were placed in each treatment in order to determine their efficacy in differentiating between potential plant water stress. Examples of these devices are shown in Figure 3-6. Specifically, the instruments used were:

1. Continuous monitoring devices –
    a. Sentek EasyAG® (Sentek Sensor Technologies, Stepney, South Australia, Australia) – Instruments were installed to a depth of 51 cm in each treatment. Soil moisture measurements were recorded at depths of 10, 20, 30, and 51 cm.
    b. Campbell Scientific CS625 (Campbell Scientific, Inc., Logan, UT) – The sensors were installed at depths of 10 and 30 cm in the full irrigation treatment.
    c. Spectrum ECHO probe (Spectrum Technologies, Inc., Plainfield, IL) – All instruments were installed in the full irrigation treatment at depths of 10 and 30 cm.
    d. AquaSpy™ (Agrilink Florida, Inc., Ft. Denaud, FL) – The instrument was installed in the full irrigation treatment to a depth of 51 cm. Soil moisture measurements were recorded at 10, 20, 30, 40, and 51 cm depths.
    e. Watermark (Spectrum Technologies, Inc., Plainfield, IL) – The sensor was installed in the full irrigation treatment at depths of 10 and 30 cm.
2. Non-continuous (“snapshot”) devices –
    a. AquaPro (AquaPro Sensors, California) – Instrument access tubes were installed in two locations within each treatment to measure soil moisture at 15, 22.5, 30, 45, 60, and 75 cm depths.
    b. Tensiometers (Irrometer Co., Riverside, CA) – One instrument was installed in each treatment, with sensing cup at the 30-cm depth.

c. Spectrum Portable TDR (Spectrum Technologies, Inc., Plainfield, IL) – The portable instrument was used in 10 locations within each treatment to measure soil moisture to the 25 cm depth. The average of the 10 readings was recorded.

Manual readings were taken from the tensiometers, portable TDR, and the AquaPro every Monday, Wednesday, and Friday at 2 PM. Data from the other sensors were recorded using dataloggers and downloaded to a computer each month. The EasyAG®, AquaSpy™, CS625, and Watermark devices were connected to their own data loggers. The ECHO probe was connected to a Watchdog® data logger (Spectrum Technologies, Inc., Plainfield, IL).

The output of each device and units of measurement were as follows:

1. The EasyAG® output value (X) was converted to soil water content (% by volume, Y) using the equation: $Y = 33.51X^2 + 7.825X + 0.32$ ($R^2 = 0.93$) (K. T. Morgan, unpublished EasyAG® calibration curve for Florida sandy soils.)
2. Output from the CS625 was volumetric soil water content (cm^3 water/cm^3 soil) calculated using an internal factory calibration.
3. Output from the ECHO probe was volumetric soil water content calculated using an internal factory calibration.
4. Output from the AquaSpy™ was a "scaled frequency" that had no direct physical meaning.
5. Output from the Watermark sensor was soil water tension in centibars.
6. Output from the tensiometers was soil water tension in centibars.
7. Output from the portable TDR was volumetric soil water content calculated using an internal factory calibration.

Peanut plants were dug and inverted using a standard tractor-pulled peanut digger on September 19, 2007. After 2 days of drying, nine plots measuring two rows wide by 9.1 m long in each treatment were harvested by removing all plants and running them through a threshing machine. The separated peanuts were weighed in the field. Peanut yield in 2007 is reported at 7% moisture. Peanut yield response to irrigation was analyzed using standard analysis of variance (one-way ANOVA) for a completely randomized design, and the nature of the response was determined with linear regression.

Soil moisture status measurements were plotted as a function of time to evaluate the behavior and suitability of each for scheduling irrigation. The readouts from each instrument were compared with the recorded rainfall and irrigation events in order to determine responsiveness to changes in soil moisture. Readouts were also analyzed for erroneous changes in soil moisture content. The data were also analyzed in order to determine the range of readings under which water stress occurred. Since the EasyAG® was installed in all three treatments, the data from the three treatments were compared in order to determine a more precise reading of the percent moisture at which plants begin to experience water stress.

The 2008 soil moisture experiments were conducted in a 2-acre 'Georgia Green' peanut field as in the previous year. On May 10, 2008, peanut seed was no-till planted into a burned-down rye cover crop at a target spacing of 20 seeds/m of row with 76 cm between rows. The actual plant population after germination was 13 to 16 plants/m of row. Gypsum and fertilizer rates and applications were the same as in 2007. A 14-day pest management schedule was followed, including chlorothalonil and Provost applications.

The experimental design was altered in 2008 to compare an ET-based water budget schedule to a soil moisture sensor-based schedule. The water budget irrigation schedule was determined as follows: after the crop was established and pesticides were activated, the soil was brought to field capacity (38 mm of water in the root zone), which is where the water budget was initiated. Each day, ET was determined from FAWN data, and was multiplied by the percentage of the ground surface covered by the peanut plant canopy. This value was subtracted from the previous-day water budget. Rain and irrigation were measured and added to the previous-day budget. When the available soil water reached 50% depletion (19 mm), the field section receiving this treatment was irrigated to bring the soil back to field capacity. An example of the spreadsheet used to track the water budget is shown in Figure 3-7.

The soil moisture sensor based irrigation schedule was based on EasyAG® sensors. Based on previous field work, field capacity (FC) was estimated to be 14% soil moisture, and peanuts do not remove soil moisture if water content is below 8%. Based on this information, 50% depletion was assumed to be 11%, and the 30 cm sensor was used as the indicative sensor to determine depletion. Once the EasyAG® sensors read 11% soil moisture, the plot was irrigated with 1.9 cm in order to bring the profile back up to FC.

In 2008, soil moisture devices were placed in the soil moisture-based irrigation treatment only. The devices used were:

1. Three EasyAG® units with sensors at 10, 20, 30, and 51 cm depths.
2. Three CS625 units with sensor placed at 30 cm.
3. Three ECHO Probe units with sensor placed at 30 cm.
4. Three tensiometers installed with sensing cup at 30 cm.
5. One AquaSpy™ with sensors at 10, 20, 30, 40, and 51 cm depths.

Manual readings were taken from the tensiometers every few days throughout the growing season. Data from the other sensors were recorded using dataloggers and downloaded to a computer on a monthly basis.

Peanut plants were dug and inverted with commercial field equipment on September 19, 2008. After 3 days of drying, ten plots measuring two rows wide (one double row) by 7.6 m long in each treatment were harvested by removing all plants and running them through a threshing machine. The separated peanuts were weighed in the field. A subsample was removed and used to measure field moisture. Yields were reported on a standard 7% moisture basis. Yield response to irrigation was analyzed using standard analysis of variance (one-way ANOVA) for a completely randomized design.

Table 3-1. Schedule of N fertilizer treatments applied to irrigated corn in 2007. Fertilizer was banded next to the row unless otherwise indicated. SPAD meter readings were taken 66, 76, and 89 DAP, which corresponded to pre-tassel, tassel, and blister growth stages.

	Treatment				
Fertilization timing	A	B	C	D	E
	---------------------- kg N/ha ----------------------				
Starter – 3/10/2007 (1 DAP)	22	22	22	22	22
Sidedress – 4/6/2007 (28 DAP)	56	56	56[z]	56	56
Sidedress – 4/23/2007 (45 DAP)	45	45	45	45	67
Sidedress – 5/3/2007 (55 DAP)	45	67	67	67	67
Sidedress – 5/14/2007 (66 DAP)	0	45	45	45	67
Sidedress – 5/24/2007 (Silking–76 DAP)	0	0	0	45	45
Total N rate applied	168	235	235	280	325

[z]Broadcast application.

Table 3-2. Schedule of N fertilizer treatments applied to irrigated corn in 2008. Non-irrigated corn received treatments A through D only. Fertilizer was banded next to the row unless otherwise indicated. SPAD meter readings were taken 59, 70, and 77 DAP, which corresponded to pre-tassel, tassel, and blister growth stages.

	Treatment				
Fertilization timing	A	B	C	D	E
	---------------------- kg N/ha ----------------------				
Starter – 3/11/2008 (0 DAP)	34	34	34	34	34
Sidedress – 4/3/2008 (23 DAP)	0	67	67	67	67
Sidedress – 4/8/2008 (28 DAP)[z]	34	34	34	34	34
Broadcast – 4/20/2008 (40 DAP)	0	0	67	67	67
Broadcast – 4/30/2008 (50 DAP)	0	0	0	67	67
Broadcast – 5/10/2008 (Silking–60 DAP)	0	0	0	0	34
Total N rate applied	67	134	202	269	302

[z]Applied 34 kg N/ha to all treatments due to a 91-mm rainfall on April 5 that was assumed to leach N from the root zone.

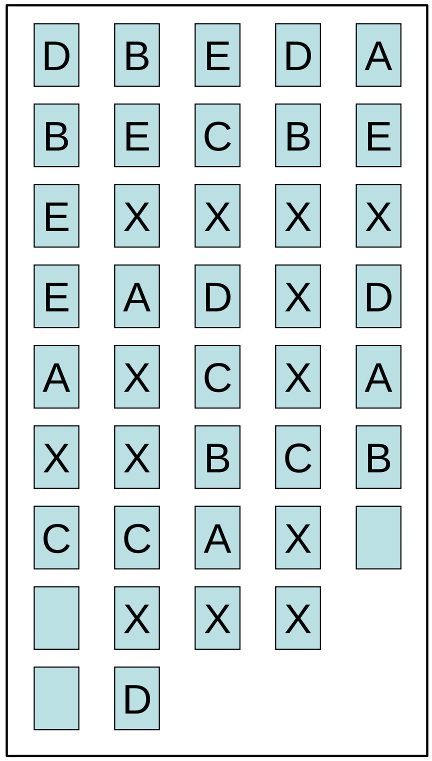

Figure 3-1. Corn plot layout in 2007. Each rectangle represents a plot that measured 4.57 m wide (six rows) by 8.84 m long. Letters of the alphabet correspond to the treatments described in Table 1. 'X' and blank boxes designate no treatment was applied.

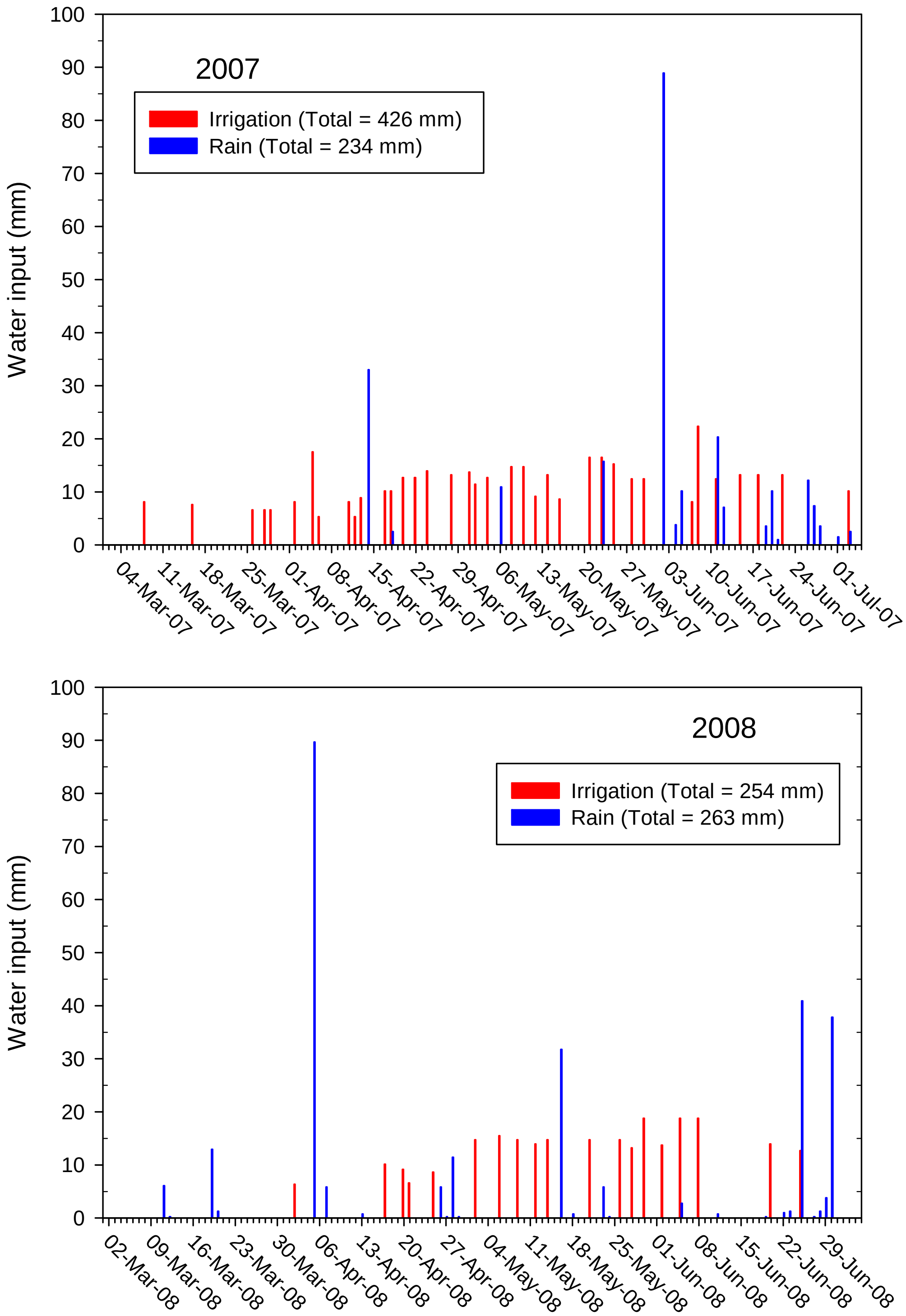

Figure 3-2. Rainfall distribution and irrigation applied to silage corn in 2007 and 2008.

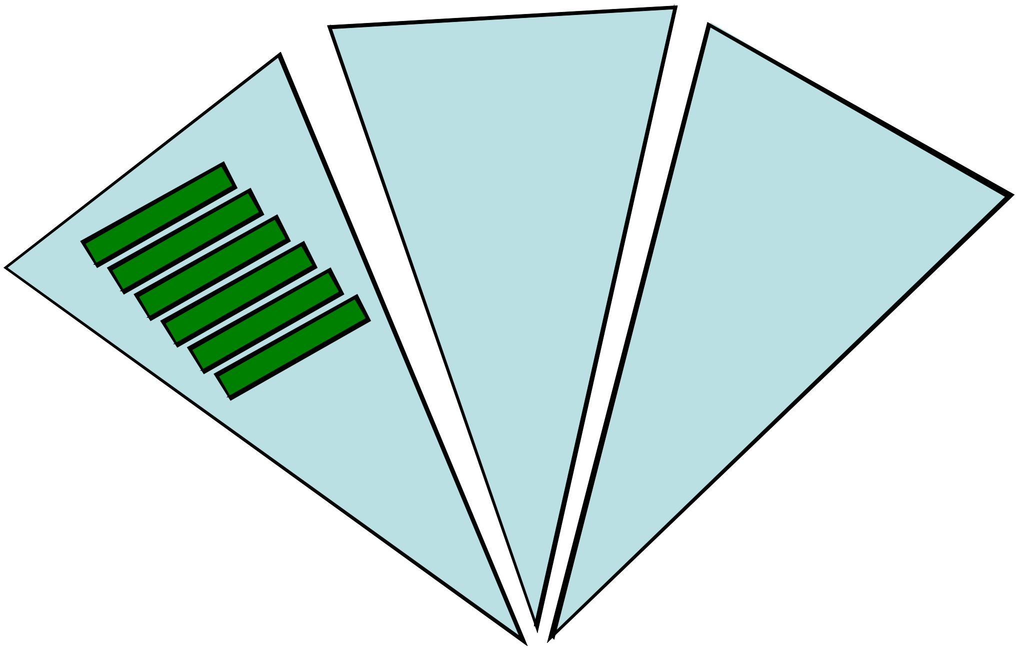

Figure 3-3. Wedge-shaped peanut plots used to apply differential irrigation treatments. The triangle-shaped areas represent the whole plots. Smaller rectangular areas represent areas from which peanut yield was measured.

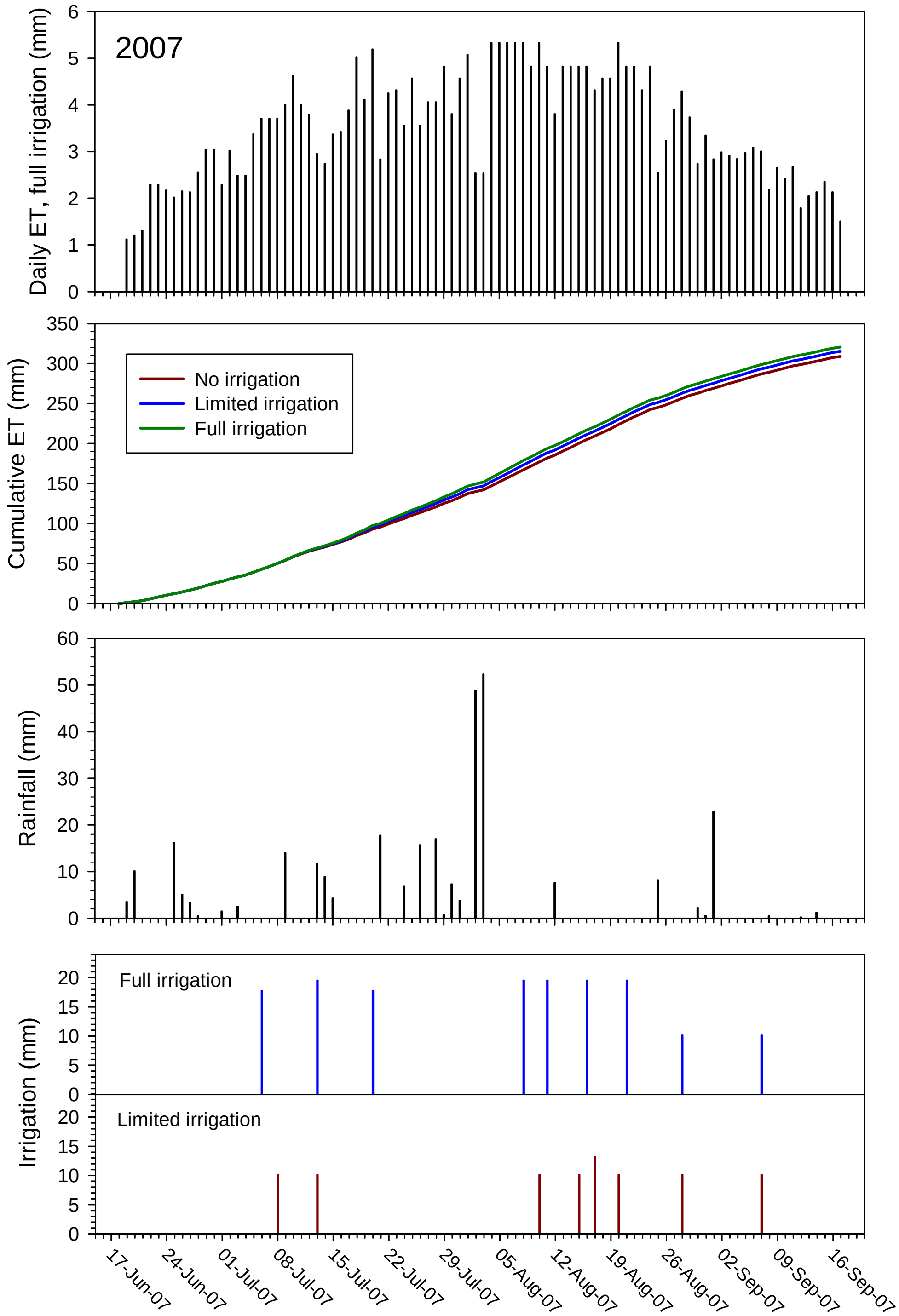

Figure 3-4. Daily ET, cumulative ET, rainfall, and irrigation volumes for the 2007 peanut season. Rainfall = 296 mm; Full irrigation = 154 mm; Limited irrigation = 84 mm.

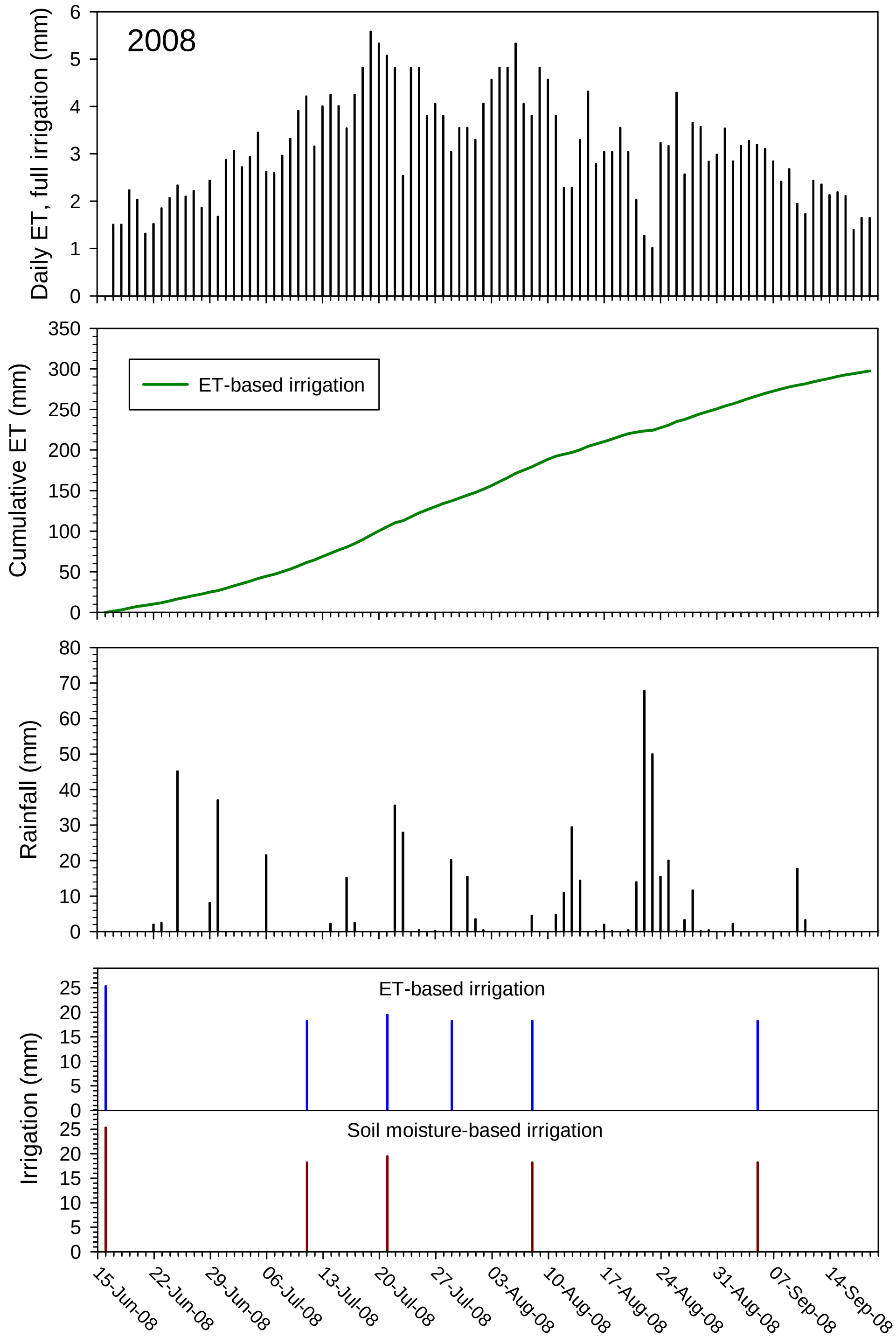

Figure 3-5. Daily ET, cumulative ET, rainfall, and irrigation volumes for the 2008 peanut season. Rainfall = 515 mm; ET based irrigation = 118 mm; Soil moisture based irrigation = 100 mm

Figure 3-6. Example of some of the soil moisture sensing devices used in the peanut field. A) EasyAG®; B) CS625; C) ECHO probe; D) AquaSpy™; E) Tensiometer; F) Portable TDR.

	A	B	C	D	E	F	G	H	I	J
3	**Date**	**% cover**	**ET**	**Crop ET**	**rain**	**irrigation**	**Total**	**Water MAX**	**Available Moisture**	
4		Measured	FAWN	Calculated			1.5		**Irrigate 0.72" at 0.72"**	
31	15-Jul	0.83	0.16	0.13	0.17		1.54	1.5	1.5	**OK**
32	16-Jul	0.9	0.15	0.14			1.37	1.37	1.37	**OK**
33	17-Jul	0.9	0.17	0.15			1.21	1.21	1.21	**OK**
34	18-Jul	0.9	0.22	0.20			1.01	1.01	1.01	**OK**
35	19-Jul	0.9	0.18	0.16			0.85	0.85	0.85	**OK**
36	20-Jul	0.93	0.22	0.20		0.7	1.35	1.35	1.35	**OK**
37	21-Jul	0.93	0.12	0.11	0.7		1.94	1.5	1.5	**OK**
38	22-Jul	0.93	0.18	0.17			1.33	1.33	1.33	**OK**
39	23-Jul	1	0.17	0.17			1.16	1.16	1.16	**OK**
40	24-Jul	1	0.14	0.14	0.27		1.29	1.29	1.29	**OK**
41	25-Jul	1	0.18	0.18			1.11	1.11	1.11	**OK**
42	26-Jul	1	0.14	0.14	0.62		1.59	1.5	1.5	**OK**
43	27-Jul	1	0.16	0.16			1.34	1.34	1.34	**OK**
44	28-Jul	1	0.16	0.16	0.67		1.85	1.5	1.5	**OK**
45	29-Jul	1	0.19	0.19	0.03		1.34	1.34	1.34	**OK**
46	30-Jul	1	0.15	0.15	0.29		1.48	1.48	1.48	**OK**
47	31-Jul	1	0.18	0.18	0.15		1.45	1.45	1.45	**OK**
48	1-Aug	1	0.2	0.20			1.25	1.25	1.25	**OK**
49	2-Aug	1	0.1	0.10	1.92		3.07	1.5	1.5	**OK**
50	3-Aug	1	0.1	0.10	2.06		3.46	1.5	1.5	**OK**
51	4-Aug	1	0.21	0.21			1.29	1.29	1.29	**OK**
52	5-Aug	1	0.21	0.21			1.08	1.08	1.08	**OK**
53	6-Aug	1	0.21	0.21			0.87	0.87	0.87	**OK**
54	7-Aug	1	0.21	0.21			0.66	0.66	0.66	**Irrigate**
55	8-Aug	1	0.21	0.21		0.77	1.22	1.22	1.22	**OK**
56	9-Aug	1	0.19	0.19			1.03	1.03	1.03	**OK**
57	10-Aug	1	0.21	0.21			0.82	0.82	0.82	**OK**
58	11-Aug	1	0.19	0.19		0.77	1.40	1.40	1.40	**OK**
59	12-Aug	1	0.15	0.15	0.3		1.55	1.5	1.5	**OK**
60	13-Aug	1	0.19	0.19			1.31	1.31	1.31	**OK**
61	14-Aug	1	0.19	0.19			1.12	1.12	1.12	**OK**
62	15-Aug	1	0.19	0.19			0.93	0.93	0.93	**OK**
63	16-Aug	1	0.19	0.19		0.77	1.51	1.5	1.5	**OK**
64	17-Aug	1	0.17	0.17			1.33	1.33	1.33	**OK**
65	18-Aug	1	0.18	0.18			1.15	1.15	1.15	**OK**
66	19-Aug	1	0.18	0.18			0.97	0.97	0.97	**OK**
67	20-Aug	1	0.21	0.21			0.76	0.76	0.76	**OK**
68	21-Aug	1	0.19	0.19		0.77	1.34	1.34	1.34	**OK**
69	22-Aug	1	0.19	0.19			1.15	1.15	1.15	**OK**
70	23-Aug	1	0.17	0.17			0.98	0.98	0.98	**OK**
71	24-Aug	1	0.19	0.19			0.79	0.79	0.79	**OK**

Figure 3-7. Example of spreadsheet used for water budget calculations.

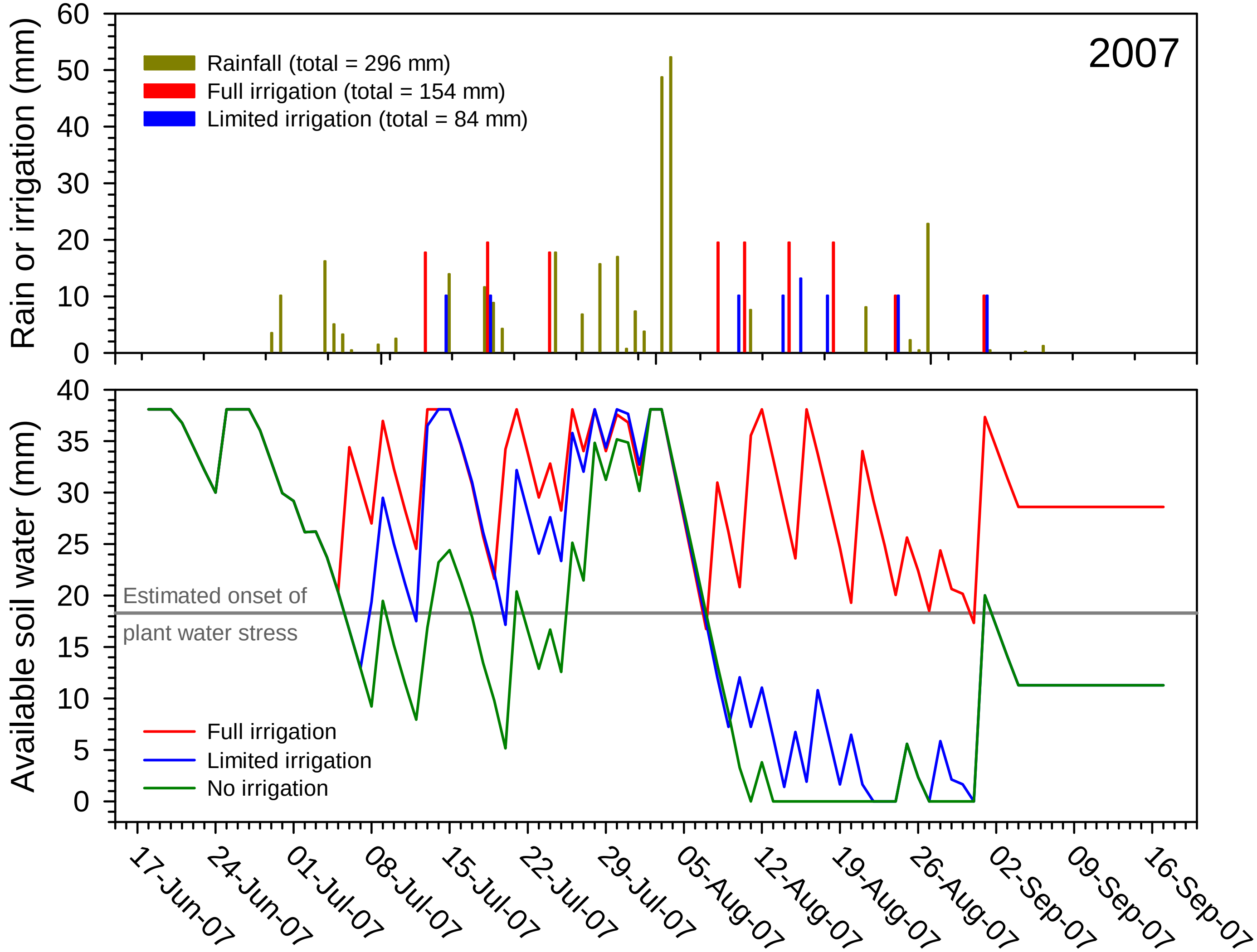

Figure 3-8. Rainfall, full irrigation, limited irrigation, available soil water within each treatment, and the point at which water stress occurred in 2007.

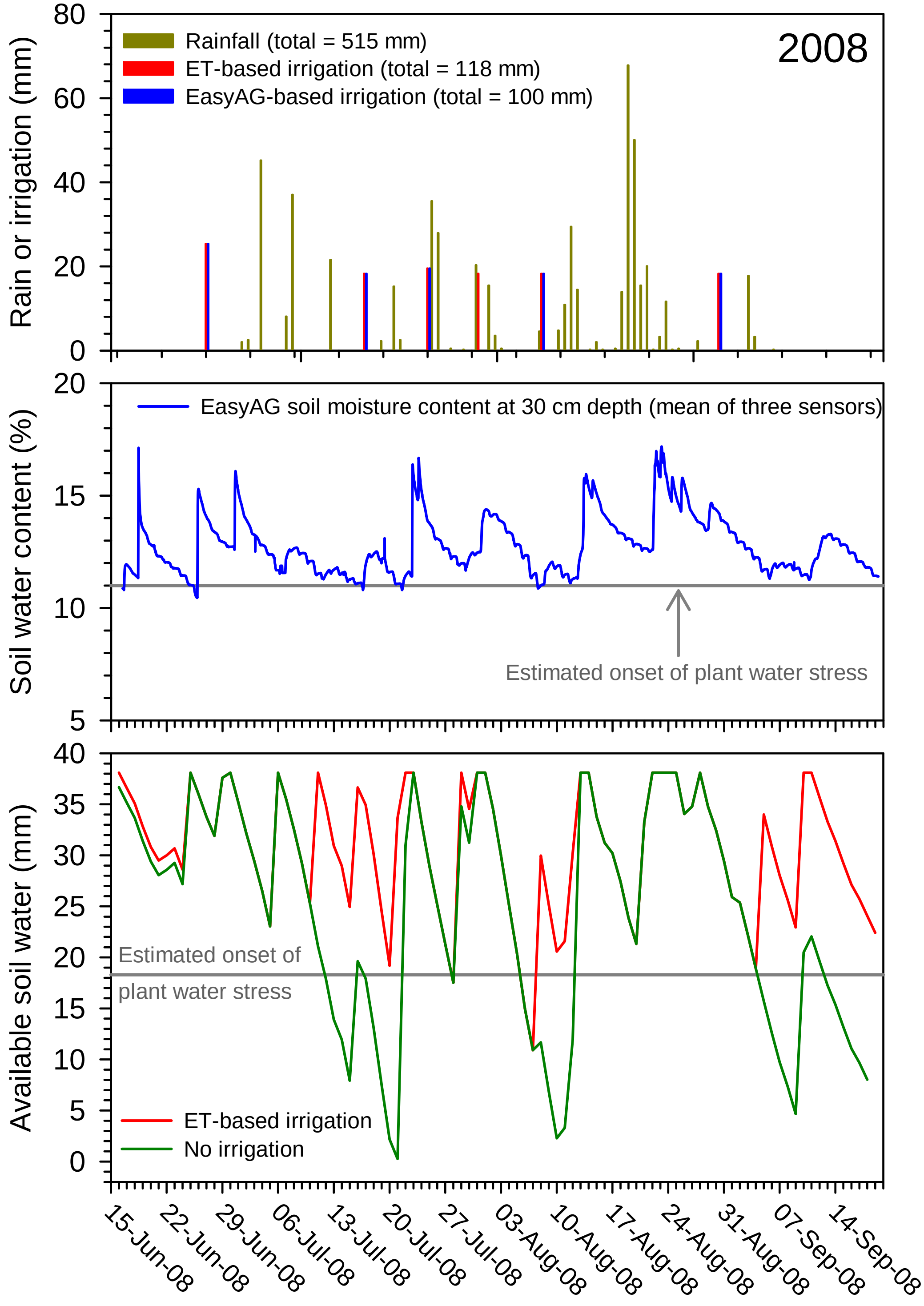

Figure 3-9. Rainfall, ET based irrigation, SM based irrigation, soil water content based on the EasyAG® device at 30 cm with an estimate as to when plant water stress occurred, and available soil water for the ET based treatment and the non-irrigated treatment along with an estimate of when plant water stress occurred.

CHAPTER 4
RESULTS AND DISCUSSION

SPAD Measurements with Corn

Weather conditions. During the 2007 and 2008 silage corn growing seasons, rainfall plus irrigation totaled 660 and 517 mm, respectively (Figure 3-2). Crop ET for the 2007 and 2008 seasons totaled 222 mm in 2007 and 284 mm in 2008. Drought conditions were fairly severe during the early portion of the 2007 season, but the center pivot system was able to keep the corn out of moisture stress. Rainfall was more evenly distributed during the 2008 season. Each season had one rainfall event that could be considered a "leaching rain." This event took place early in the 2008 season, which triggered the application of extra N fertilizer (Table 3-2). In 2007, the event occurred later in the season and did not affect the fertilization schedule.

Nitrogen fertilizer response. During the 2007 season, the pre-tassel, tassel, and blister growth stages for silage corn corresponded to 66, 76, and 89 DAP, respectively. In 2008, these stages corresponded to 59, 70, and 77 DAP. Both years, there was no visually-discernable leaf color difference between the lower and higher N rate treatments until tassel. At that point, the lower N rate treatments began to appear more yellow than corn fertilized with a higher N rate. The corn at higher N rates stayed green the entire season. At the highest N rate, the leaves showed fertilizer burn.

Irrigated corn silage and protein yields responded to N fertilizer rate both years, although the response was more pronounced in 2008 due to a wider range of N rates applied (Table 4-Table 4-1). The yield values measured at maximum response were comparable to the upper end of irrigated corn yields obtained by north Florida producers in commercial fields. Crude protein was affected by N rate in 2008, but not 2007. In general, N rate had a strong influence on leaf N concentration and SPAD meter reading, particularly in 2008 (Table 4-Table 4-1).

Non-irrigated corn silage and protein yields did not respond well to N fertilizer, although there was a significant response of leaf N and SPAD reading at the pre-tassel growth stage (Table 4-2). Non-irrigated corn was much shorter than the irrigated corn throughout the growing season; it never grew much taller than knee high (~ 50 cm). The non-irrigated corn also showed N deficiency early in the growing season, and suffered from frost damage more than the irrigated corn.

Nature of the observed N responses. Irrigated corn silage yield responded quadratically both years (Figure 4-1). The points of maximum response (vertex of the parabola) were 277 kg N/ha in 2007 and 243 kg N/ha in 2008. However, both quadratic relationships were relatively "flat": 90% of maximum yield corresponded to around 200 kg N/ha in 2007 and 150 kg N/ha in 2008. The poor response of non-irrigated corn to N fertilizer rate is evident by the nearly flat linear regression line (Figure 4-1).

The nature of the irrigated corn protein yield response was similar to the silage response (Figure 4-2). The major difference was a change in the shape of the quadratic model in 2008 to a steeper curve, reflecting the positive response of crude protein concentration we observed that year (Table 4-1). Therefore, considering that protein is the most important output from silage production to feed dairy cattle, N fertilizer response was more pronounced in 2008 compared with 2007. Whereas protein production in 2007 was maximized around 277 kg N/ha, protein production in 2008 was still on the increase at the highest N rate of 302 kg N/ha.

Influence of N rate on leaf N concentration. Leaf tissue analysis data provided evidence that corn plant N uptake increased as fertilizer rate increased (Figure 4-3). The response of total leaf N concentration to N rate was mostly quadratic in nature. Whereas leaf N decreased with leaf age in 2007, it tended to increase with age in 2008. It is possible that this effect occurred due to dilution since the plants grew larger (increased in mass) in 2007 compared with 2008.

Influence of N rate on actual and relative SPAD meter readings. Both actual and relative SPAD meter readings increased as N rate increased (Figures 4-4 and 4-5), mostly following a quadratic model. Overall, actual SPAD readings were higher in 2007 compared with 2008, even though the corn variety, irrigation management, soil type, and N fertilizer rates were similar between years. This difference emphasizes the importance of using relative SPAD readings to interpret plant N status because the relative value normalizes the data with respect to external factors that can cause the actual readings to vary up and down from year to year.

Relative SPAD reading decreased as stage of plant growth increased (Figure 4-5). The range of relative SPAD values was about five times greater in 2008 (roughly 75 to 100 on average) compared with 2007 (roughly 95 to 100 on average) due to the wider range of N rates the second year. Relative SPAD was related to leaf N concentration in a linear fashion (Figure 4-6), although coefficient of determination was fairly low. It is apparent that N in corn leaves is not all partitioned into chlorophyll or the relationship would likely be stronger.

Relationship of corn leaf N concentration to relative silage yield. It was clear that leaf N concentration was positively correlated to relative silage yield in a linear fashion (Figure 4-7). The sensitivity of the relationship measured by the slope of the regression line increased with the stage of plant growth.

Relationship of relative SPAD reading to relative corn silage and protein yields. Relative SPAD reading measured at pre-tassel is related to relative yield in a quadratic manner (Figures 4-8 and 4-9). At later plant growth stages, the relationship became linear. These relationships were slightly stronger for relative protein yield compared with relative silage yield, as evidenced by the larger linear slopes.

Determining the critical value of relative SPAD reading. The Cate-Nelson procedure indicated that critical values for relative SPAD reading were 86, 94, and 82 for the pre-tassel, tassel, and blister growth stages, respectively, when relative silage yield was considered (Figure 4-8). When relative protein yield was the response variable, the critical SPAD numbers were 85, 94, and 96 for the same three growth stages (Figure 4-9). This also emphasizes the stronger relationship between SPAD and protein yield when compared to silage yield. Based on this information, if, at pre-tassel, the SPAD reading is at least 85% of the maximum, additional fertilization is not necessary in order to obtain maximum yields. At tassel, if the SPAD readings are at least 94% of the maximum, there is no need to fertilize at this time. This can also be used as a general rule since it encompasses all of the determined critical values; if the SPAD readings are above 95% of the maximum, there is enough N present for optimal protein and silage yields, and fertilization is not necessary.

Soil Moisture Measurements with Peanuts

2007 weather conditions. During the 2007 peanut growing season, rainfall totaled 296 mm (Figure 3-4). In 2007, the peanuts reached full groundcover on July 23rd (62 DAP), reaching about knee high (~50 cm). Total estimated crop ET for the season was 320 mm in the full irrigation treatment, 315 mm in the limited irrigation treatment, and 308 mm in the non-irrigated treatment. Rainfall was fairly well distributed during July, but dry periods occurred during June and August where the ET-based soil water model predicted water stress (Fig 3.8). During dry periods a total of 154 mm of irrigation was applied to the full treatment and 84 mm to the limited treatment.

Peanut response to irrigation. There was a significant response of peanut yield to irrigation in 2007 (Table 4-3). The limited irrigation treatment provided 148 kg/ha additional yield per cm of irrigation applied. The full irrigation treatment added an additional 91 kg/ha of yield per additional cm of irrigation applied. It was apparent that the two dry periods caused enough plant water stress to limit yield even in a crop that is fairly resistant to low soil moisture conditions.

Evaluation of soil moisture sensors. The AquaPro access tube and sensor were difficult to use. There were two access tubes installed in each treatment, and readings varied greatly within treatments. Two locations stopped producing readings in the middle of the season, and even after re-installation, they did not work. Also, the caps were apparently easily blown off or removed by animals, as occurred with one of the access tubes. When readings were to be taken, the tube was full of water and needed to be uninstalled, dried, and reinstalled. Overall, this was one of the most problematic tools we tested, thus they are not recommended for use in the LSRB. Data from this instrument are not presented.

The portable TDR was difficult to use, especially in the dryer sections of the field. The TDR was difficult to get into the ground at times, and the prongs bent together at some points and bent apart at others. The prongs constantly needed readjusting in order to obtain accurate field measurements. In the full irrigation treatment, portable TDR measurements ranged from 4.3 to 15.5% soil moisture. In the limited irrigation treatment, the range fell between 2.2 and 12.4%, and in the non-irrigated treatment, the percentage soil moisture ranged from 0 to 12.6 (Figure 4-10).

The ECHO Probe sensors were easy to install to depths of 10 and 30 cm. The shallow probe readings fell between 1.7 and 19.2% soil moisture, while the deeper readings ranged from

2.7 to 12% (Figure 4-11). The CS625 probes were also easy to install to 10 and 30 cm depths. The shallow sensor recorded measurements ranging from 17.7 to 24.6% soil moisture, while the deeper sensor ranged between 17.7 and 22.3% (Figure 4-12).

Easy Ag sensors were easy to install, and previous research experience indicated that they worked very well in sandy Florida. In the full irrigation treatment, the 10 cm sensor read between 10.8 and 31.3% soil moisture, the 20 cm sensor percentage soil moisture readings fell between 12.4 and 29.4%, the 30 cm sensor recorded readings ranging from 12.0 to 27.2%, the 40 cm sensor read from 10.5 to 25.7%, and the 51 cm sensor readings fell between 11.6 and 24.6% (Figures 4-13 to 4-17). In the limited irrigation treatment, the 10 cm sensor read from 9.1 to 28.4% soil moisture, the 20.3 cm sensor readings ranged from 6.4 to 25.6%, the 30 cm sensor readings fell between 6.2 and 24.8%, the 40 cm sensor read from 9.7 to 26.1%, and the 51 cm sensor percentage soil moisture readings were between 10.6 and 21.6 (Figures 4-13 to 4-17). In the non-irrigated treatment, the 10 cm sensor read from 8.7 to 33.2% soil moisture, the 20 cm sensor readings fell between 9.0 and 28.2%, the 30 cm sensor read a percent moisture between 8.6 and 27.0, the 40 cm sensor readings ranged between 8.2 and 47.4%, and the 51 cm sensor read 8.6 to 20.4% (Figures 4-13 to 4-17).

Tensiometers were installed easily in all three treatments. Minimum/maximum tensiometer readings in the full irrigation treatment were 6 and 40 cb; in the limited irrigation treatment they were 6 and 70 cb; and in the non-irrigated treatment they were 6 and 66 cb (Figure 4-18). Since the efficacy of tensiometers has already been proven, they were used as a basis for comparison for the Watermark sensor. Watermark sensors placed at 10 cm did not read properly for the first week after installation, but then started working. The watermark sensor is typically assumed to not to function well in sandy soils like those found in the LSRB. At the 10 cm depth, readings ranged from 3.6 to 114.5 cb, and at the 30 cm depth they ranged from 3.4 to 87.3 cb (Figure 4-19).

The AquaSpy™ probe was easy to install. Part of this research was to determine if the "unknown" units in which this instrument reads correlated with a certain soil moisture content, or if a correlation with soil water tension existed. The AquaSpy™ measured soil moisture at five depths, similar to the EasyAG®. The readings at 10 cm ranged from 7.3 to 80.6, the 20 cm sensor read between 10.9 and 84.4, the 30 cm readings fell between 12.6 and 80.3, the 40 cm sensor read from 10.9 to 87.0, and the 51 cm sensor read between 10.8 and 83 (Figure 4-20).

Comparison of readout ranges between instruments. In the irrigated treatments, the CS625 had the narrowest output range of instruments measuring soil water content, followed by the portable TDR and the ECHO Probe. The Easy Ag had the widest range of output data. The instruments tended to group into two categories by maximum, low maximum, and high maximum readings. A low maximum reading fell below 20% soil moisture, as with the portable TDR and the ECHO Probe. High maximum readings fell between 20 and 31% soil moisture, which included the CS625 and the Easy Ag. The same grouping occurred when observing the minimum readings recorded. Low minimum readings of less than 10% soil moisture occurred with the portable TDR and the ECHO Probes, whereas high minimum readings between 10 and 20% soil moisture occurred with the CS625 and the Easy Ag.

When the soil water tension-measuring instruments were compared, output values from tensiometers and the Watermark sensors were not closely related. The tensiometer readings ranged from 6 to 40 cb, while the Watermark ranged from 3 to 115 cb.

Another way to compare instruments is to base the comparison on depth. Even when considering depth as the main factor, instrument output was still not close in terms of absolute values. Each sensor (ECHO, CS625, and EasyAG® at 10 cm, and ECHO, CS625, EasyAG®, and Portable TDR at 30 cm) detected soil moisture differently, and thus produced a different numerical output value. For example, in both the limited and non-irrigated treatments, the portable TDR read lower than the EasyAG®, both in minimum and maximum readings. This result was most likely due to differences in factory calibration curves.

Determining instrument accuracy for detecting potential crop water stress. During the 2007 irrigation dates in the full irrigation treatment (July 6, 13, 20; August 8, 11, 16, 21, 28; September 7), AquaSpy™ readings ranged from 44 to 53 units, Watermark readings ranged from 29 to 82 cb, ECHO probe readings ranged from 2.8 to 3.9% soil moisture, CS625 ranged from 17 to 18% soil moisture, and EasyAG® ranged from 12 to 17% soil moisture (for individual date readings, see Table 4-4). In the limited irrigation treatment, EasyAG® readings ranged from 9 to 15% soil moisture when 1) irrigation was based on ET, 2) the crop was either experiencing water stress or needed to be irrigated, or both (Table 4-5). In the non-irrigated treatment, EasyAG® readings ranged from 8 to 15% soil moisture when, according to the ET-based scheduling method, the plant began to experience water stress (Table 4-6). It appeared that the higher the range of numbers the device is able to output, the larger the range for the numerical representation of water stress.

Based on irrigation and rainfall event dates, the accuracy of each instrument was calculated based on the frequency of agreement between the instrument reading and the recorded event (Tables 4-7, 4-8, and 4-9). While the EasyAG® responded to 100% of the irrigation events the Watermark responded to 89%, the ECHO Probe responded to 40%, and the CS625 only responded to 33% of the events. The AquaSpy™ responded to 82% of rainfall events, the EasyAG®, WaterMark, and ECHO Probe responded to 72%, while the CS625 responded to 66%

of rain events. Overall, based not only on recorded rainfall and irrigation, but also extraneous measurements of increased soil moisture, the EasyAG® performed the best, with an agreement rate of 83%. Next was the AquaSpy™ at 72%, followed by the ECHO probe at 65% and the CS625 at 63%. The Watermark sensor had an agreement rate of 51%. The data obtained from the Watermark was so varied that no conclusions could be drawn from it. Thus, the Watermark is not recommended for use in the LSRB.

The TDR measurements did not provide enough data on irrigation dates or dates of water stress in order to fully analyze the instruments utility. Based on this result and difficulties with its use, it is not recommended for use in the LSRB.

Determining critical instrument output values. Based on both the average and mode for each soil moisture device, a “critical number” was determined to be the point at which the plant reaches the edge of water stress and should be irrigated. For the AquaSpy™, this critical number is 47 to 49. With the ECHO Probe, the critical number at which the plant begins to experience water stress is 2.9% soil moisture. For the CS625, the critical number is 18. For the EasyAG®, the critical value falls between 14 and 17% soil moisture, but when this range is compared with the EasyAG® critical values in the limited (Table 4-5) and non-irrigated (Table 4-6) treatments, these numbers seem to be high. In the limited treatment, the critical water stress value is 10 to 12% soil moisture, and in the non-irrigated treatment, this value falls between 9 and 11% soil moisture. It is possible that the ET method of irrigation over-irrigates, thus producing slightly higher critical numbers for plant water stress, thus a critical value closer to 10 to 12% soil moisture may be more accurate. More research is needed to verify this speculation.

2008 weather conditions. The 2008 peanut season was much wetter than the 2007 season, with rainfall totaling 515 mm (Figure 3-5). In 2008, the peanuts reached full groundcover on July 18th (57 DAP), reaching about knee high. Total estimated crop ET for the season in the ET-based irrigation treatment was 299 mm. Rainfall was fairly well distributed throughout the growing season (Fig 3.9). During the short dry periods that occurred, a total of 118 mm of irrigation was applied to the ET-based treatment and 100 mm was applied to the soil moisture-based treatment.

Peanut response to irrigation. In 2008, the yield produced in the ET-based irrigation treatment was significantly lower than yields in the soil moisture-based irrigation treatment and the non-irrigated treatment (Table 4-3). This result is likely due to a factor other than irrigation since ET-based irrigation applied only 18 mm more water than soil moisture-based irrigation. Since the experimental treatments could not be placed in a randomized design due to the limitations of irrigation using a center pivot, there was likely another issue that occurred in the main ET-based irrigation plot that influenced yield. Reduced plant stand is the most likely reason. It is possible, however, that since peanuts are not only drought tolerant but also flood tolerant, over-irrigation in the soil moisture-based irrigated treatment was just within the flood-tolerance threshold. The extra 18 mm could have crossed that threshold to the point where the peanuts were not able to tolerate the excess water.

The flood scenario seems more likely when yield and water applied (rainfall plus irrigation) data for both years is combined (Figure 4-21). There was an increase in yield as water applied increases, but the curve plateaus and then turned downward around 600 mm of applied water. More research is needed in order to test this hypothesis. Whether to irrigate peanuts or grow them as a dryland crop is a climactic decision that needs to be made at the beginning of the growing season based on the predictions for the entirety of the season. If a wet season is predicted, then there is no need to plan irrigation, but if a dry season is anticipated then irrigation will increase yield, as seen in the 2007 growing season. Since soil moisture sensors actually measure the moisture in the soil instead of estimating it based on external factors, they should be able to provide a more accurate determination of irrigation scheduling. More research is needed in order to confirm this, since there was no response to irrigation in the 2008 season.

Evaluation of soil moisture sensors. The ECHO Probe sensors were very problematic during the 2008 season. Between technical difficulties with the data logger and the sensors not responding to changes in soil moisture, no data set was assembled that could be discussed.

Seasonal behavior of the AquaSpy™, CS625, EasyAG®, and tensiometers are shown graphically in Figures 4-22 to 4-25. The AquaSpy™ readings ranged from 36 to 42 units, the CS625 readings ranged from 19 to 21% soil moisture, and the EasyAG® readings ranged from 9 to 11% soil moisture (Table 4-10). Since the soil moisture-based treatment was irrigated when at least two of the EasyAG®s reached a reading of 11%, it follows that both the average and mode of the readings is 11%. The AquaSpy™ averaged 39.7 while the CS625 averaged 20.3% soil moisture. The average of the AquaSpy™ readings was almost 10 units lower than in 2007, while the average of the CS625 was higher than it was in 2007. However, the accuracy of all three instruments was lower than it was in 2007. The accuracy of the EasyAG® for responding to irrigation was only 47%, similar to the accuracy of the CS625, while the accuracy of the AquaSpy™ was slightly higher at 60% (Table 4-10). With regard to rainfall response, the accuracy of both the AquaSpy™ and EasyAG® was 71.4%, while the accuracy of the CS625 was 57.1% (Table 4-11).

The overall accuracy, which was based on not only response to irrigation and rainfall events, but also based on extraneous soil moisture increases, was determined to be highest for the CS625, at 70.8%. The overall accuracies of the AquaSpy™ and EasyAG® were 67.5% and

63.3%, respectively (Table 4-12). There are multiple reasons to explain why the accuracies of these instruments were so much lower in 2008 compared with 2007. First, there were many rainfall events in 2008 that made it more difficult to distinguish between each individual event. Also, many of the rainfall events were relatively small, so it was difficult to tell the difference between the instruments responding to the change in soil moisture versus fluctuations in measurement. In order to try to account for this, we only evaluated rainfall events larger than 6mm in order to increase the likelihood that the water from the rain events would percolate to a depth of 30 cm. In addition to this, in 2007 response was determined by the shallowest sensor (10 cm), and the reading at 30 cm was recorded. In 2008, only the 30 cm data was used to determine response to irrigation since not all instruments recorded at 10 cm. When irrigation or rainfall occurred later in the evening, it is possible that at 30 cm, the response was not recorded until the next day, which can lead to false negatives when determining response to change in soil moisture for a given day.

Table 4-1. Response of irrigated silage corn and protein yields, leaf N concentration, and SPAD meter reading to N fertilizer rate in 2007 and 2008.

N rate	Silage yield at 65% moisture	Crude protein	Protein yield	Leaf N concentration			SPAD meter reading		
				Pre-tassel	Tassel	Blister	Pre-Tassel	Tassel	Blister
kg/ha	tonnes/ha	%	kg/ha	-------------------- % --------------------					
2007									
168	51.9	7.09	1.35	3.15	2.76	2.55	49.5	59.7	59.1
235	65.6	7.70	1.76	3.28	3.00	2.72	51.0	60.7	61.8
280	68.9	7.65	1.95	3.42	2.95	2.78	50.1	61.5	61.5
325	66.3	7.73	1.80	---	2.84	2.87	---	61.7	62.1
P value	0.101	0.275	0.114	0.031	0.285	<0.001	0.819	0.374	0.003
2008									
67	36.1	6.43	0.76	1.72	2.63	1.95	46.7	40.4	44.7
134	53.5	6.86	1.24	2.08	2.88	2.06	53.3	47.6	52.2
202	55.7	7.19	1.34	2.26	3.14	2.73	56.8	49.3	58.1
269	64.7	8.97	1.79	3.75	3.27	2.86	56.2	51.6	59.5
302	59.4	9.53	1.81	---	3.30	2.69	---	50.6	59.0
P value	0.015	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001

Table 4-2. Response of non-irrigated silage corn and protein yields, leaf N concentration, and SPAD meter reading to N fertilizer rate in 2008.

				Leaf N concentration			SPAD meter reading		
N rate	Silage yield at 65% moisture	Crude protein	Protein yield	Pre-tassel	Tassel	Blister	Pre-Tassel	Tassel	Blister
kg/ha	tonnes/ha	%	kg/ha	--------------------	%	--------------------			
67	17.0	9.32	0.54	2.17	2.89	---	43.0	43.4	---
134	22.3	9.79	0.71	2.31	2.95	---	49.1	43.3	---
202	19.6	10.69	0.68	2.24	3.16	---	51.4	43.6	---
269	27.6	9.60	0.85	2.87	3.19	---	51.5	45.4	---
P value	0.163	0.290	0.164	0.019	0.148	---	0.049	0.573	---

Table 4-3. Peanut yield response to irrigation treatments in 2007 and 2008.

Treatment	Irrigation volume	Total water applied (rain + irrigation)	Peanut yield[z]
	mm	mm	kg/ha
	2007		
No irrigation	0	296	2840
Limited irrigation	84	380	4081
Full irrigation	154	450	4716
P value			<0.001
	2008		
No irrigation	0	515	5036
Soil moisture-based irrigation	100	615	5115
ET-based irrigation	118	633	4286
P value			<0.001

[z]7% moisture content.

Table 4-4. Full irrigation 2007 data for each day the plot was irrigated; what each sensor was reading before it registered a change in soil moisture.

Date	AquaSpy™	Watermark	ECHO	CS625	EasyAG®
	frequency	cb	------------- soil water content (%) -------------		
6-Jul	44-45	34	N/A	N/A	14
13-Jul	45	77-82	2.8-2.9	17	12
20-Jul	51-52	29-35	N/A	N/A	16
8-Aug	49-50	N/A	N/A	N/A	16
11-Aug	49-52	43-44	3.7-3.9	N/A	16-17
16-Aug	53	N/A	N/A	N/A	17
21-Aug	46-48	N/A	N/A	N/A	15-16
28-Aug	47-48	N/A	N/A	17	14
31-Aug	46-47	N/A	N/A	17	13
7-Sep	45-47	N/A	N/A	18	13-14
13-Sep	51-53	N/A	N/A	17	12
Range	44-53	29-82	2.8-3.9	17-18	12-17
Average	48.9	49	2.9	18	14.6
Mode	47.3	34.7	2.9	N/A	16.7

Table 4-5. Limited irrigation 2007 data for each day the plot was irrigated or under water stress, or both; what each sensor was reading before it registered a change in soil moisture.

Date	Soil water content (%)	Condition
6-Jul	12-13	Stress
8-Jul	n/a	Irrigated
12-Jul	12	Stress
13-Jul	11-12	Irrigated
20-Jul	12-14	Stress
7-Aug	14-15	Stress
10-Aug	11-12	Irrigated
15-Aug	10-11	Irrigated
17-Aug	10	Irrigated
20-Aug	11	Irrigated
25-Aug	10	Stress
28-Aug	9-10	Stress and irrigated
2-Sep	10-11	Stress
7-Sep	10	Irrigated
Range	9-15	
Average	11.9	
Mode	10.1	

Table 4-6. Non-irrigated 2007 data for each day the plot soil moisture reached a level of water stress; what each sensor was reading.

Date	EasyAG®
	Soil water content (%)
6-Jul	9-10
10-Jul	9
17-Jul	12-13
22-Jul	9-10
7-Aug	14-15
12-Aug	10
2-Sep	8-9
Range	8-15
Average	11.1
Mode	9.2

Table 4-7. Device response to irrigation in the full irrigation treatment using the shallowest sensor as an indicator of response in 2007.

	Device response to irrigation				
Date	AquaSpy™	Watermark	ECHO	CS625	EasyAG®
6-Jul	Y	Y	N	N	Y
13-Jul	Y	Y	Y	Y	Y
20-Jul	Y	Y	N	N	Y
8-Aug	Y	N	N	N	Y
11-Aug	Y	Y	Y	N	Y
16-Aug	Y	Y	N/A	N	Y
21-Aug	Y	Y	N/A	N	Y
28-Aug	Y	Y	N/A	Y	Y
7-Sep	Y	Y	N/A	Y	Y
Total	9	9	5	9	9
Accuracy (%)	100	89	40	33	100

Table 4-8: Device response to rain events in the full irrigation treatment using the shallowest sensor as an indicator of response in 2007.

	Device response to rain events				
Date	AquaSpy™	Watermark	ECHO	CS625	EasyAG®
19-Jun	Y	N/A	N/A	N	N
20-Jun	Y	N/A	N/A	Y	Y
25-Jun	Y	N/A	N/A	Y	Y
26-Jun	Y	N/A	N/A	Y	Y
27-Jun	Y	Y	Y	Y	Y
28-Jun	Y	Y	N	N	N
1-Jul	Y	N	N	N	N
3-Jul	Y	N	N	N	N
9-Jul	Y	Y	Y	Y	Y
13-Jul	Y	Y	Y	Y	Y
14-Jul	Y	Y	Y	Y	Y
15-Jul	Y	Y	Y	Y	Y
21-Jul	Y	Y	Y	Y	Y
24-Jul	Y	Y	N	Y	Y
26-Jul	Y	Y	Y	Y	Y
28-Jul	Y	Y	Y	Y	Y
29-Jul	N	N	N	N	N
30-Jul	Y	Y	Y	Y	Y
31-Jul	Y	Y	Y	Y	Y
2-Aug	Y	Y	Y	Y	Y
3-Aug	Y	N	Y	Y	Y
12-Aug	N/A	N	Y	Y	Y
25-Aug	Y	N/A	N/A	Y	Y
30-Aug	Y	N/A	N/A	N	Y
31-Aug	N	N/A	N/A	N	N
1-Sep	Y	N/A	N/A	Y	Y
8-Sep	N	N/A	N/A	N	Y
12-Sep	N	N/A	N/A	N	N
14-Sep	Y	N/A	N/A	N	N
Total	28	18	18	29	29
Accuracy (%)	82	72	72	66	72

Table 4-9: Overall device accuracy at recording rain events, irrigation events, and extraneous events using the shallowest sensor as an indicator of response in 2007.

	AquaSpy™	Watermark	ECHO	CS625	EasyAG®
Correct	41	19	24	38	50
Incorrect	16	18	13	22	10
Total	57	37	37	60	60
Accuracy (%)	72	51	65	63	83

Table 4-10: Irrigation accuracy in 2008.

Date	AquaSpy™	CS625 1	CS625 2	CS625 3	EasyAG® 1	EasyAG® 2	EasyAG® 3
16-Jun	N/A	21	21	20	11	10	N/A
11-Jul	40-42	N/A	N/A	N/A	N/A	9,10	11
21-Jul	38-40	20	19-20	N/A	N/A	N/A	11
8-Aug	36-37	20	19	N/A	N/A	N/A	11
5-Sep	N/A	N/A	N/A	N/A	N/A	N/A	11
Range	36-42	20-21	19-21	20	11	9-10	11
Individual mean	40	21	20	21	11	10	12
Group mean	40		20			10	
Mode	41.3	N/A	20	20.6	11.2	10.4	11.1
Correct	3	3	3	1	1	2	4
Incorrect	2	2	2	4	4	3	1
Total	5	5	5	5	5	5	5
Accuracy (%)	60	60	60	20	20	40	80
Mean accuracy (%)	60		47			47	

Table 4-11: Rainfall accuracy in 2008.

	AquaSpy™	CS625 1	CS625 2	CS625 3	EasyAG® 1	EasyAG® 2	EasyAG® 3
Correct	15	14	12	10	15	15	15
Incorrect	6	7	9	11	6	6	6
Total	21	21	21	21	21	21	21
Accuracy (%)	71.4	66.7	57.1	47.6	71.4	71.4	71.4
Mean accuracy (%)	71.4		57.1			71.4	

Table 4-12. Overall device accuracy in 2008.

	AquaSpy™	CS625 1	CS625 2	CS625 3	EasyAG® 1	EasyAG® 2	EasyAG® 3
Correct	27	32	29	26	26	19	31
Incorrect	13	8	11	16	14	21	9
Total	40	40	40	40	40	40	40
Accuracy (%)	67.5	80	72.5	60	65	47.5	77.5
Mean accuracy (%)	67.5		70.8			63.3	

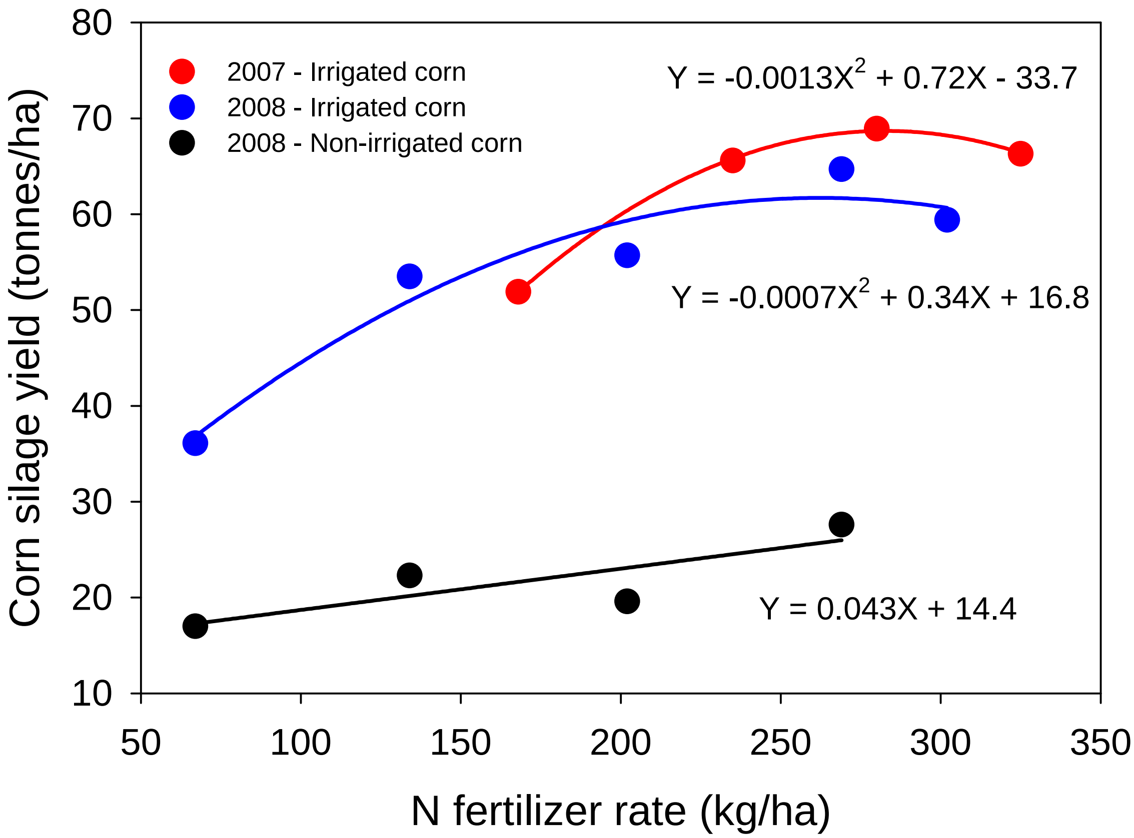

Figure 4-1. Corn silage yield as a response to N fertilization rate for irrigated corn in 2007 and 2008, and non-irrigated corn in 2008.

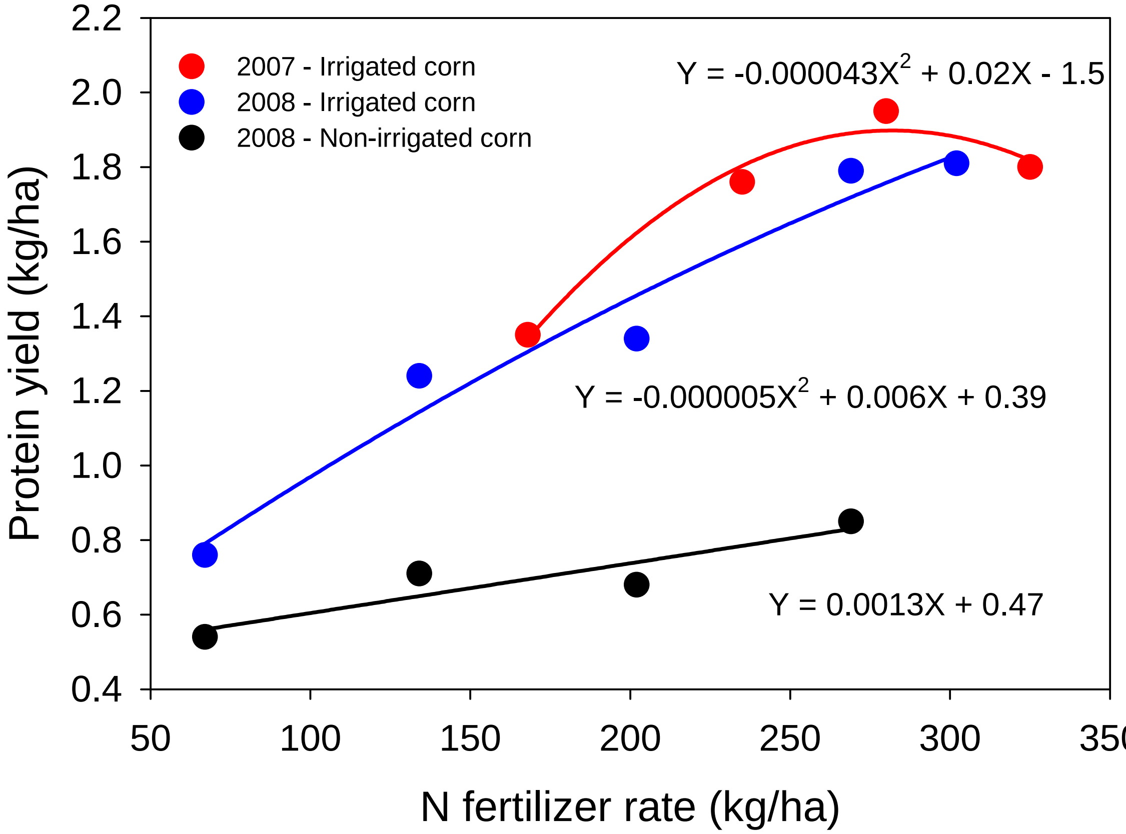

Figure 4-2. Protein yield as a response to N fertilization rate for irrigated corn in 2007 and 2008, and non-irrigated corn in 2008.

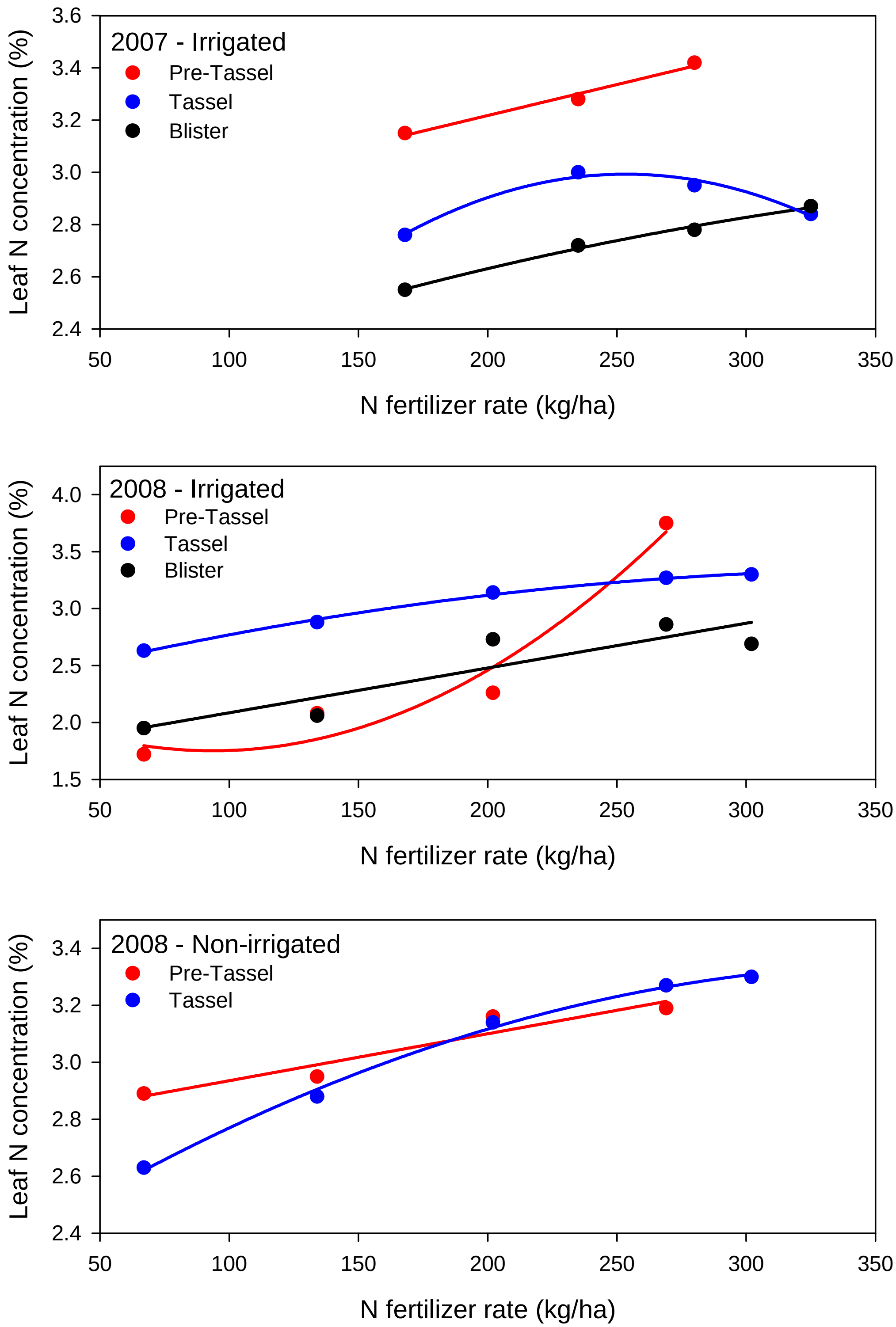

Figure 4-3. Leaf N concentration as a response to N fertilization rate for 2007 and 2008 irrigated corn at Pre-Tassel, Tassel, and Blister, and for 2008 Non-irrigated corn at Pre-Tassel and Tassel.

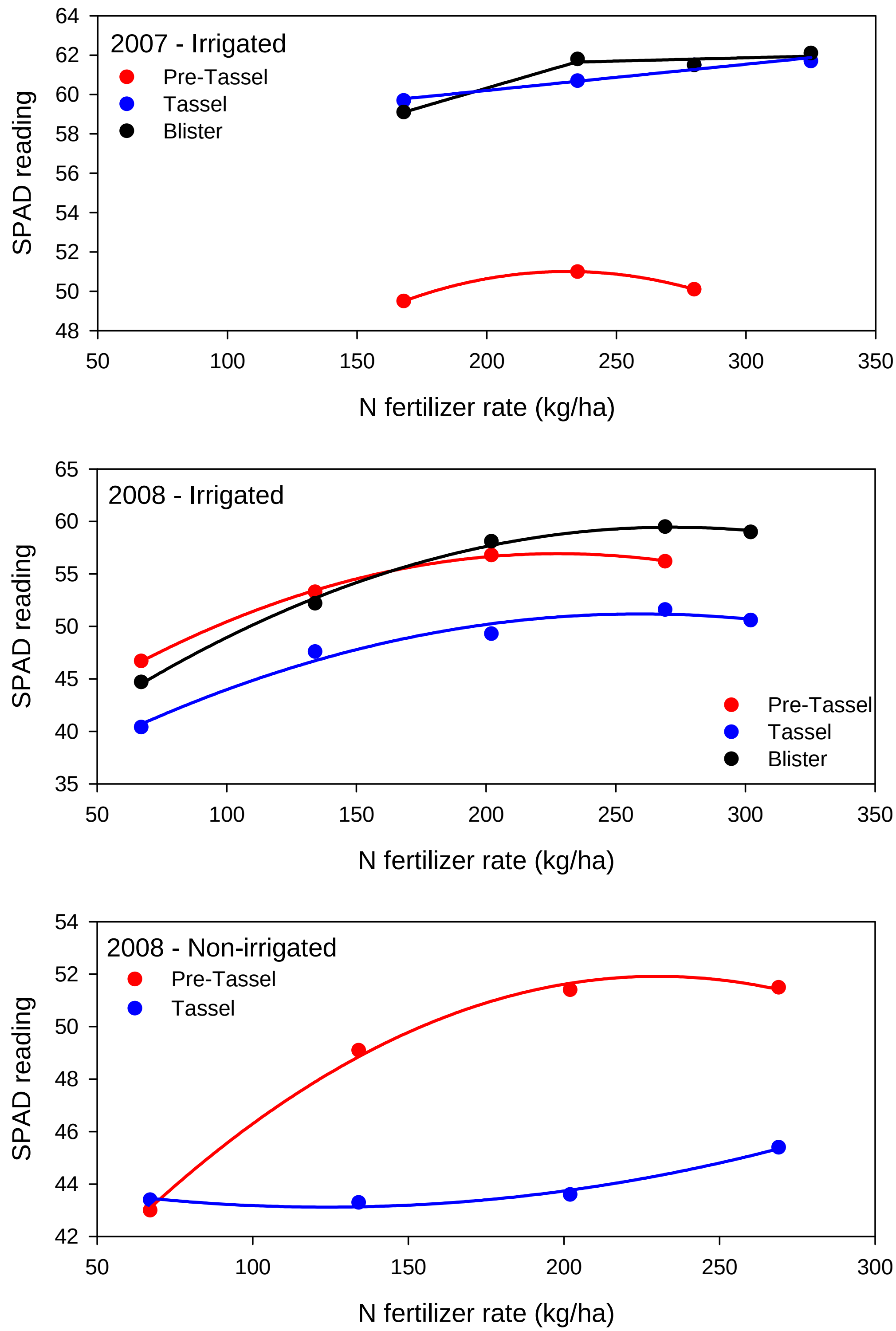

Figure 4-4. SPAD reading as a response to N fertilization rate for 2007 and 2008 irrigated corn at Pre-Tassel, Tassel, and Blister, and for 2008 Non-irrigated corn at Pre-Tassel and Tassel.

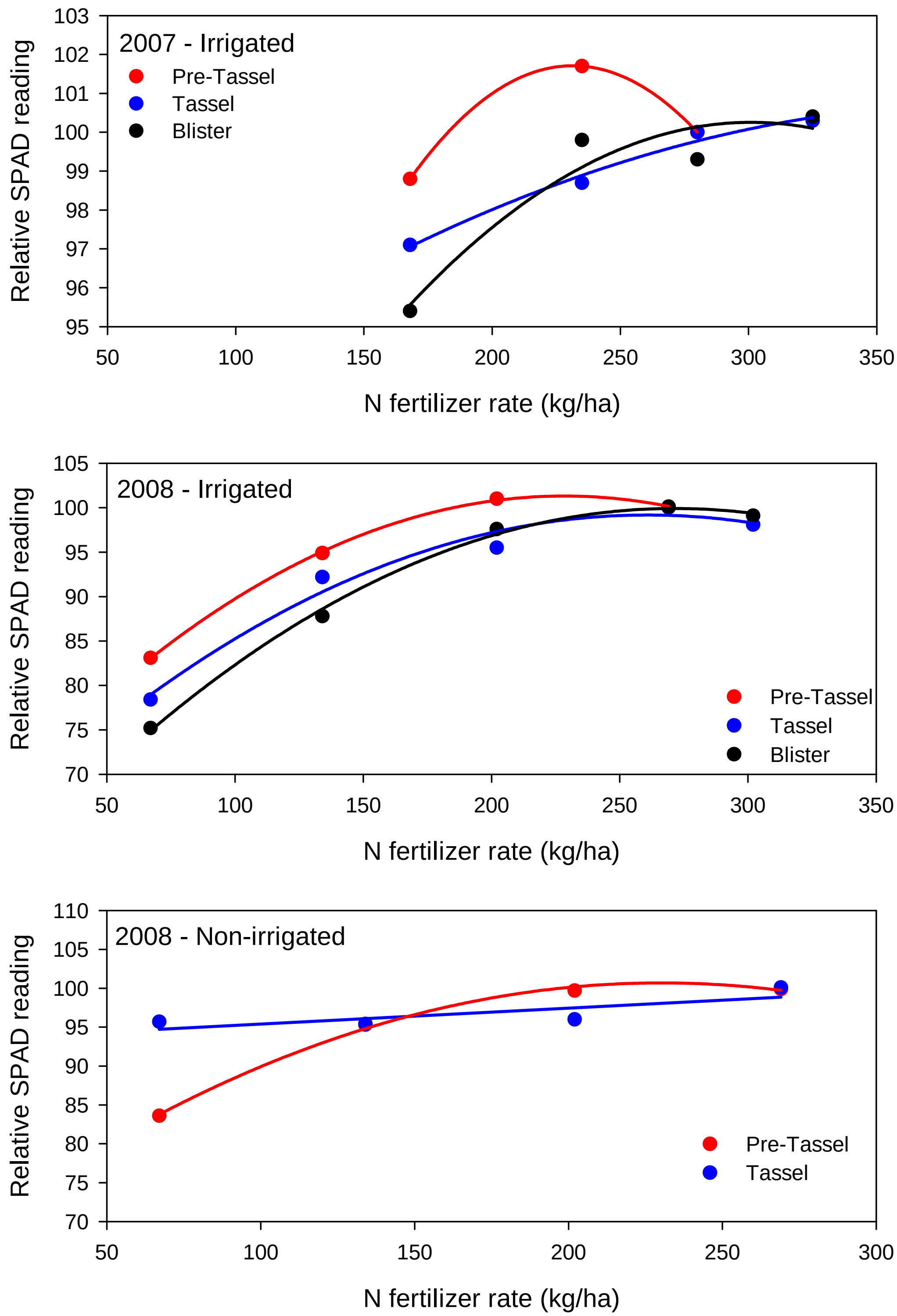

Figure 4-5. Relative SPAD reading as a response to N fertilization rate for 2007 and 2008 irrigated corn at Pre-Tassel, Tassel, and Blister, and for 2008 Non-irrigated corn at Pre-Tassel and Tassel.

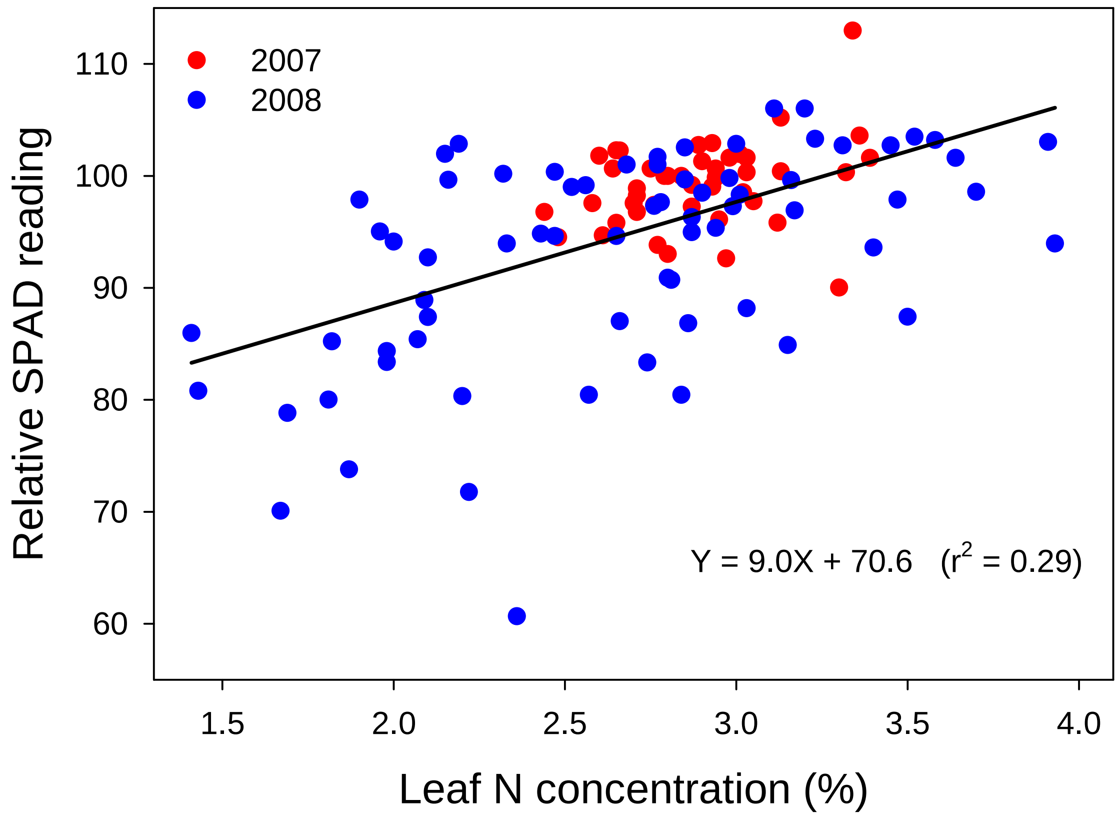

Figure 4-6. Relative SPAD reading as a response to leaf N concentration in 2007 and 2008 irrigated corn.

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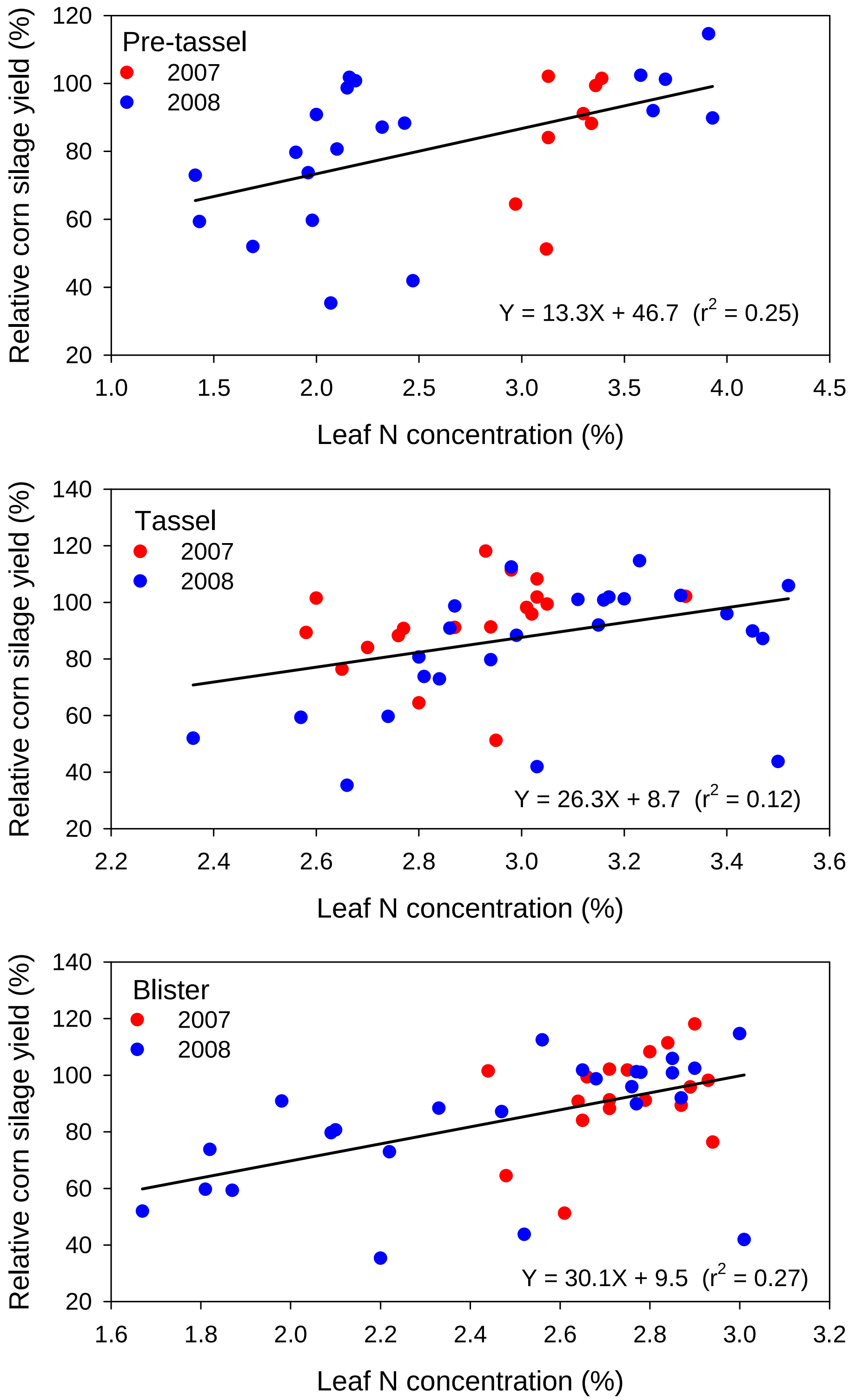

Figure 4-7. Relative SPAD reading at Pre-Tassel, Tassel, and Blister as a response to leaf N concentration in 2007 and 2008 irrigated corn.

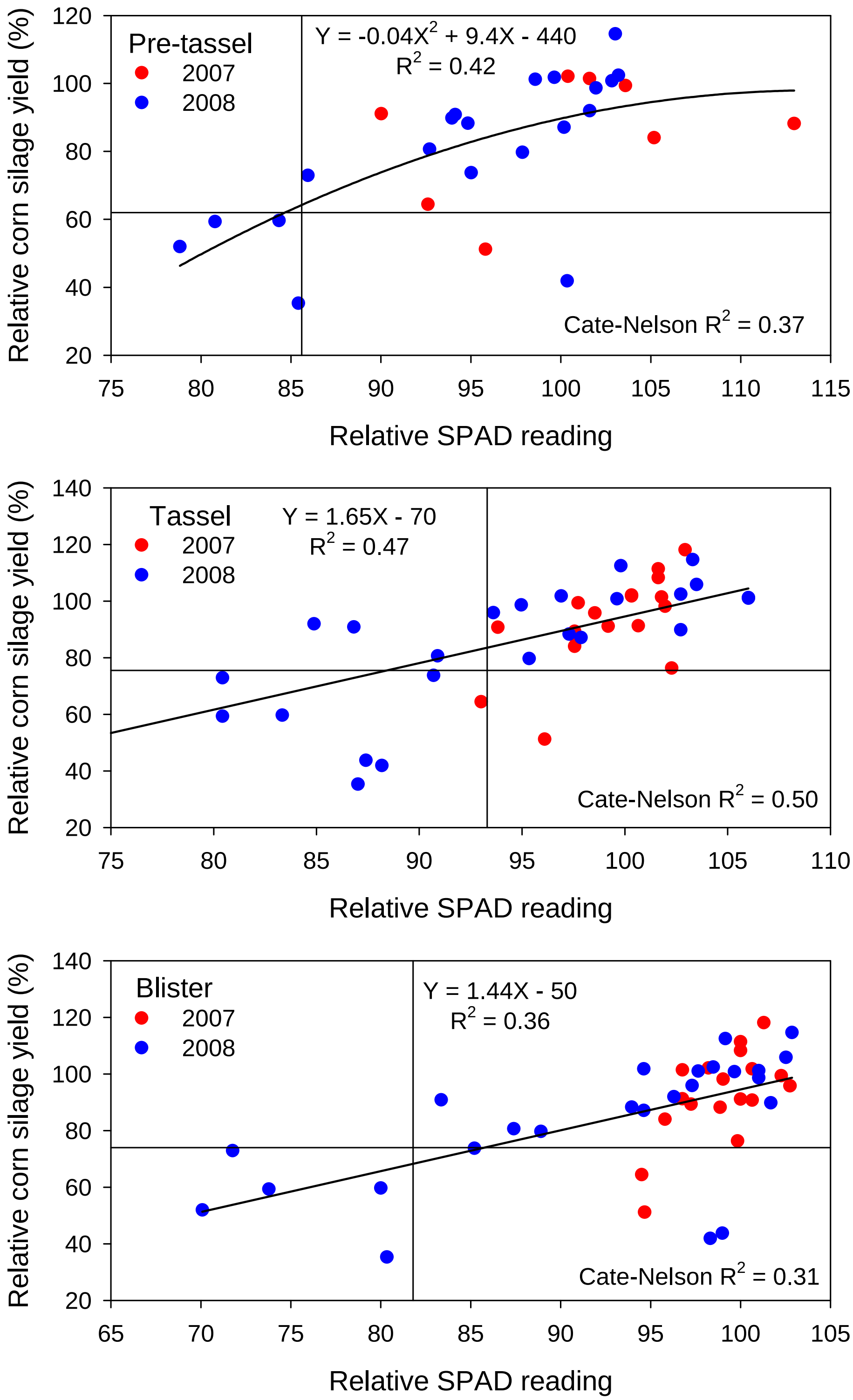

Figure 4-8. Relative corn silage yield as a function of relative SPAD reading in 2007 and 2008 irrigated corn at Pre-Tassel, Tassel, and Blister. Cate-Nelson analysis of critical numbers in 2007 and 2008 irrigated corn at Pre-Tassel (critical value = 86), Tassel (critical value = 94), and Blister (critical value = 82).

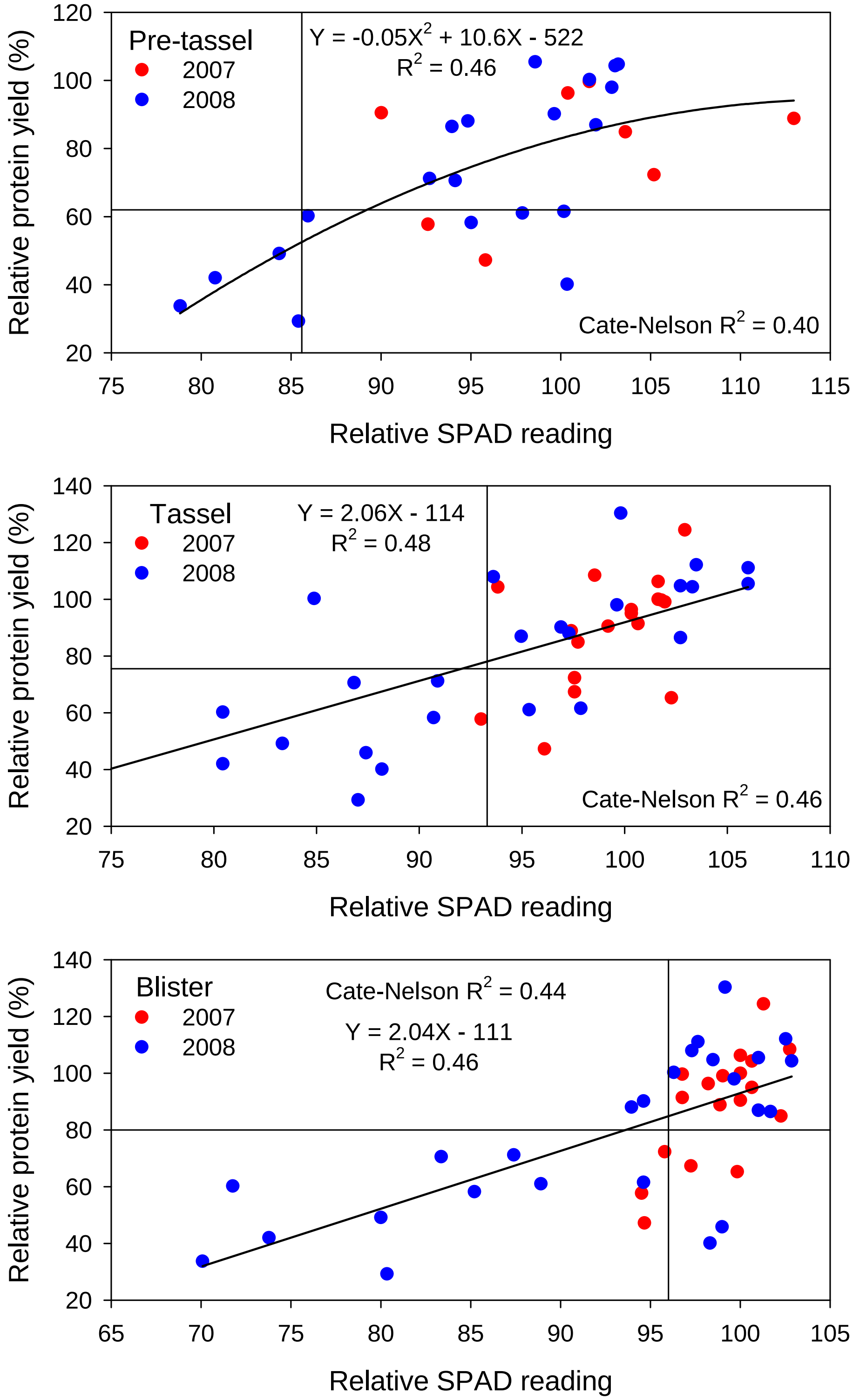

Figure 4-9. Relative protein yield as a function of relative SPAD reading in 2007 and 2008 irrigated corn at Pre-Tassel, Tassel, and Blister. Cate-Nelson analysis of critical numbers in 2007 and 2008 irrigated corn at Pre-Tassel (critical value = 85), Tassel (critical value = 94), and Blister (critical value = 96).

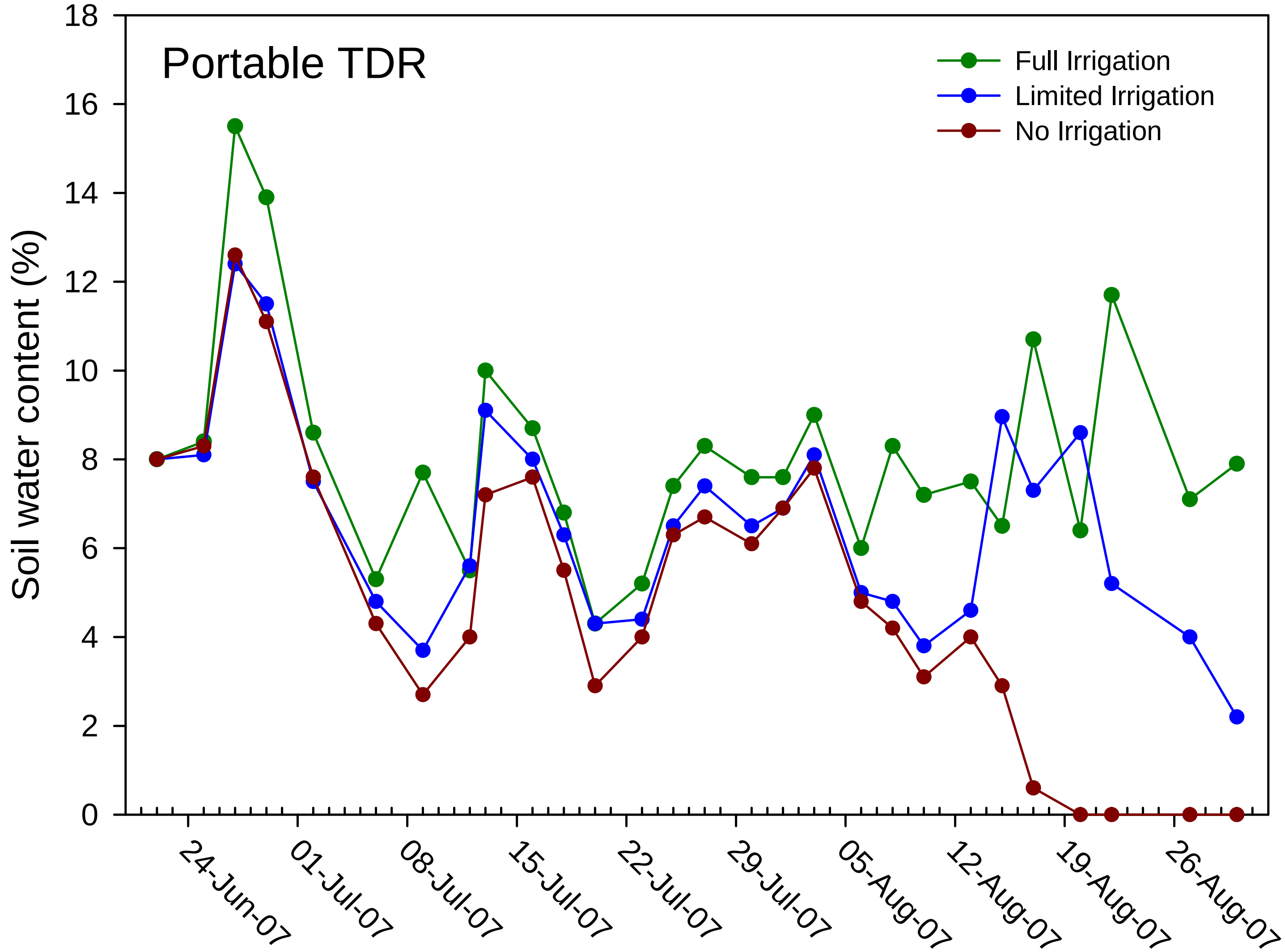

Figure 4-10. Portable TDR readings of soil water content in the full irrigation treatment, limited irrigation treatment, and non-irrigated treatment throughout the 2007 growing season.

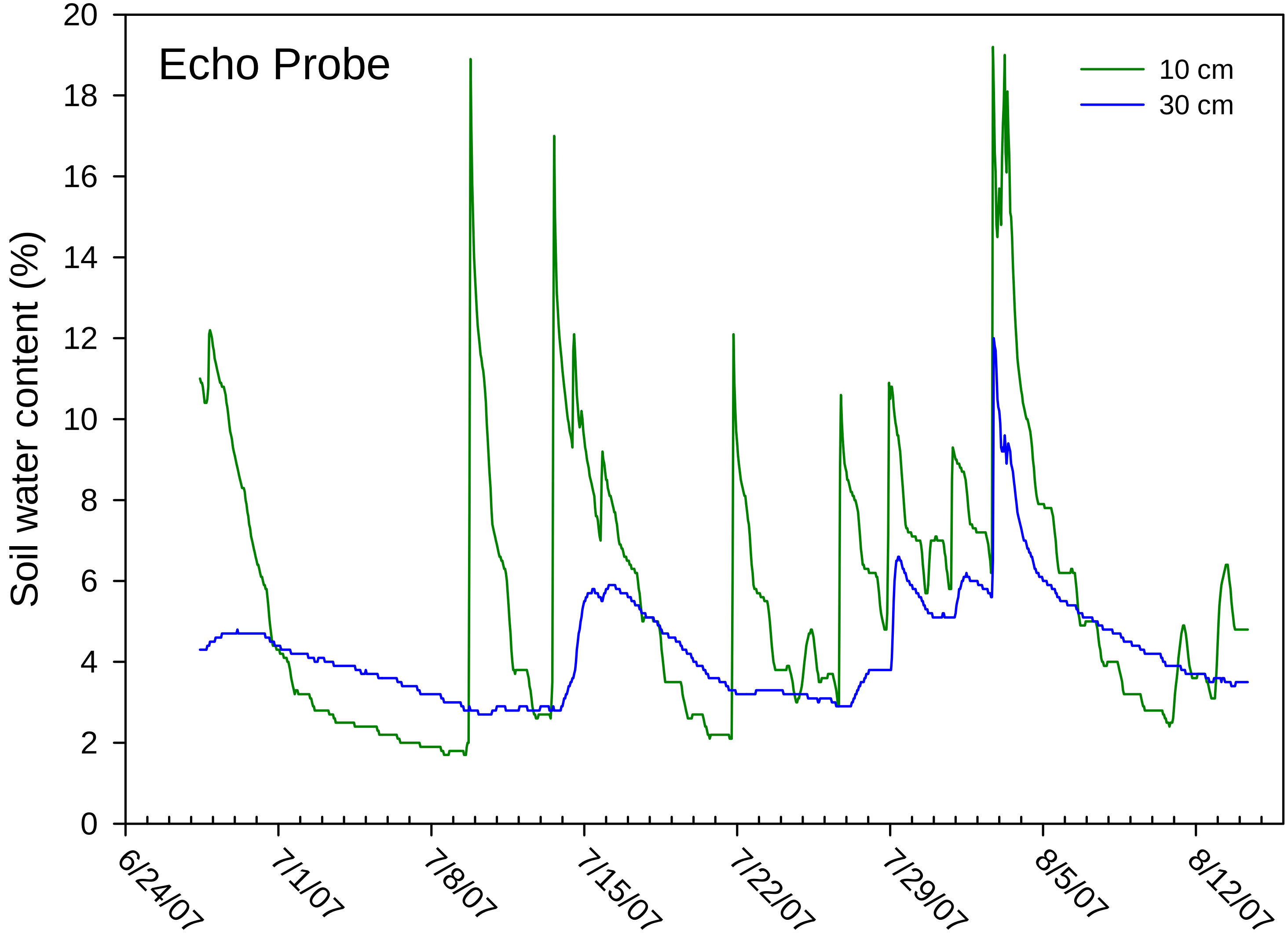

Figure 4-11. ECHO Probe readings of soil water content at depths of 10 cm and 30 cm in the full irrigation treatment throughout the 2007 growing season.

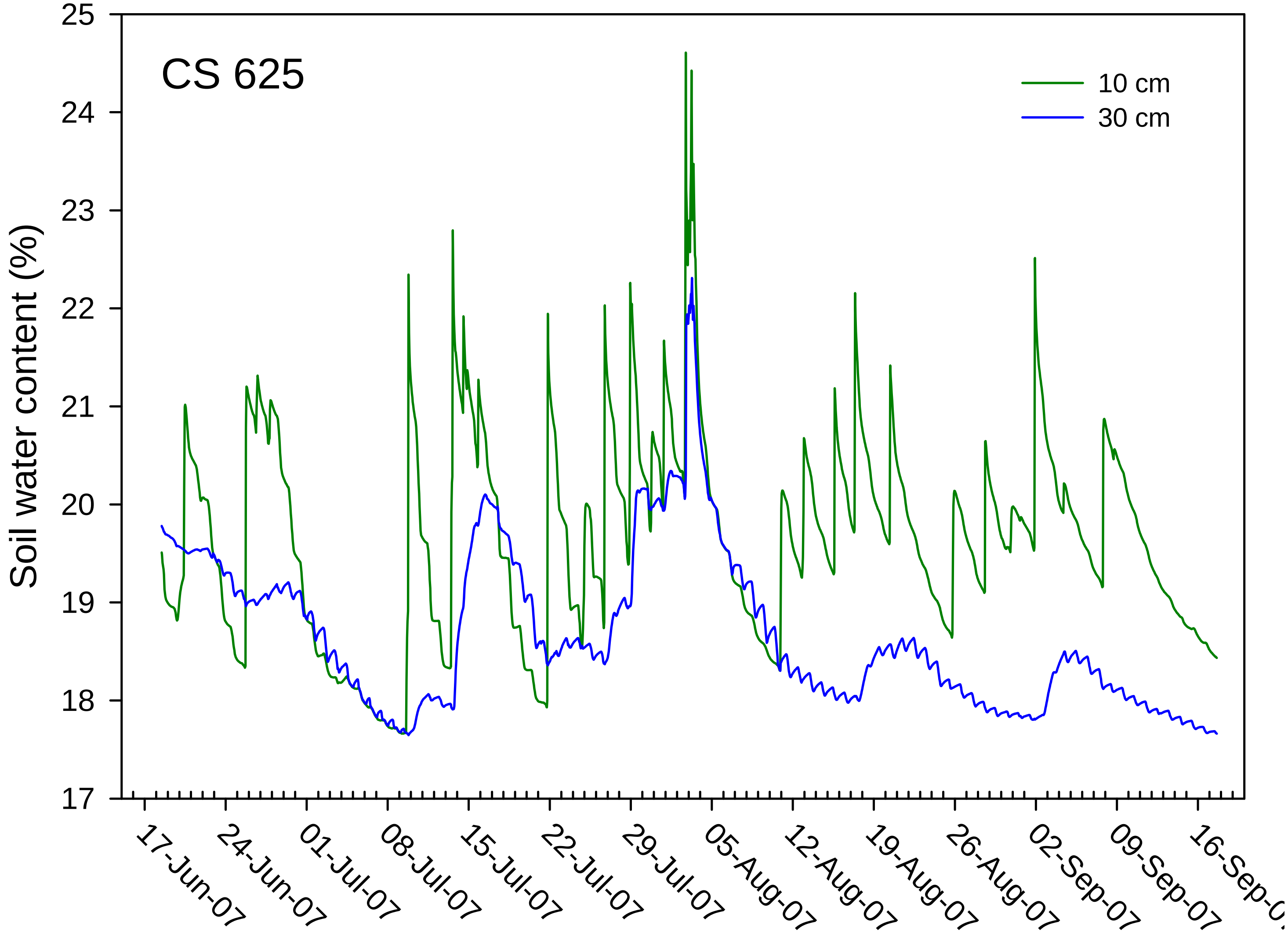

Figure 4-12. CS625 readings of soil water content at depths of 10 cm and 30 cm in the full irrigation treatment throughout the 2007 growing season.

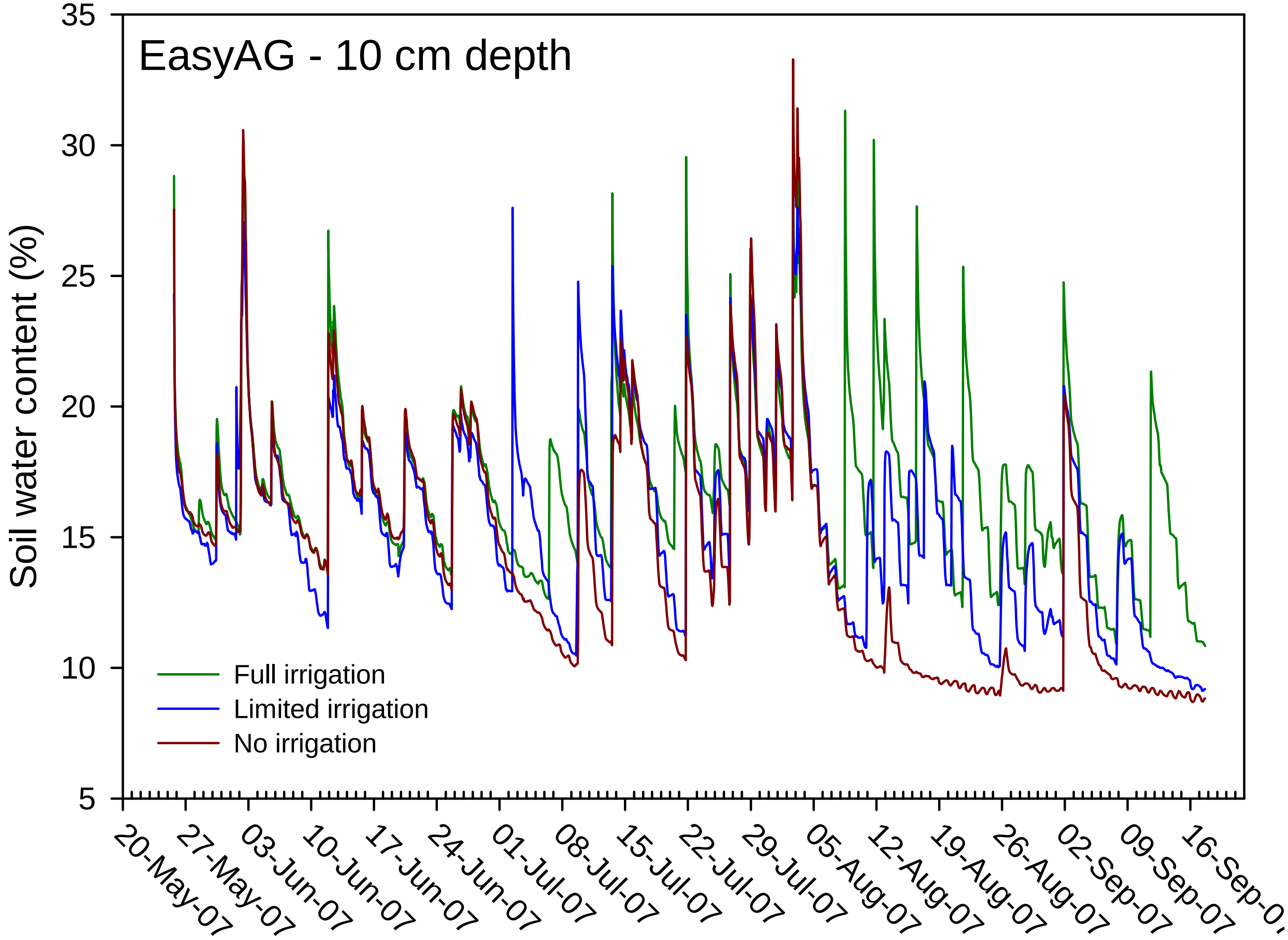

Figure 4-13. EasyAG® readings of soil water content at a depth of 10 cm in the full irrigation treatment, limited irrigation treatment, and non-irrigated treatment throughout the 2007 growing season.

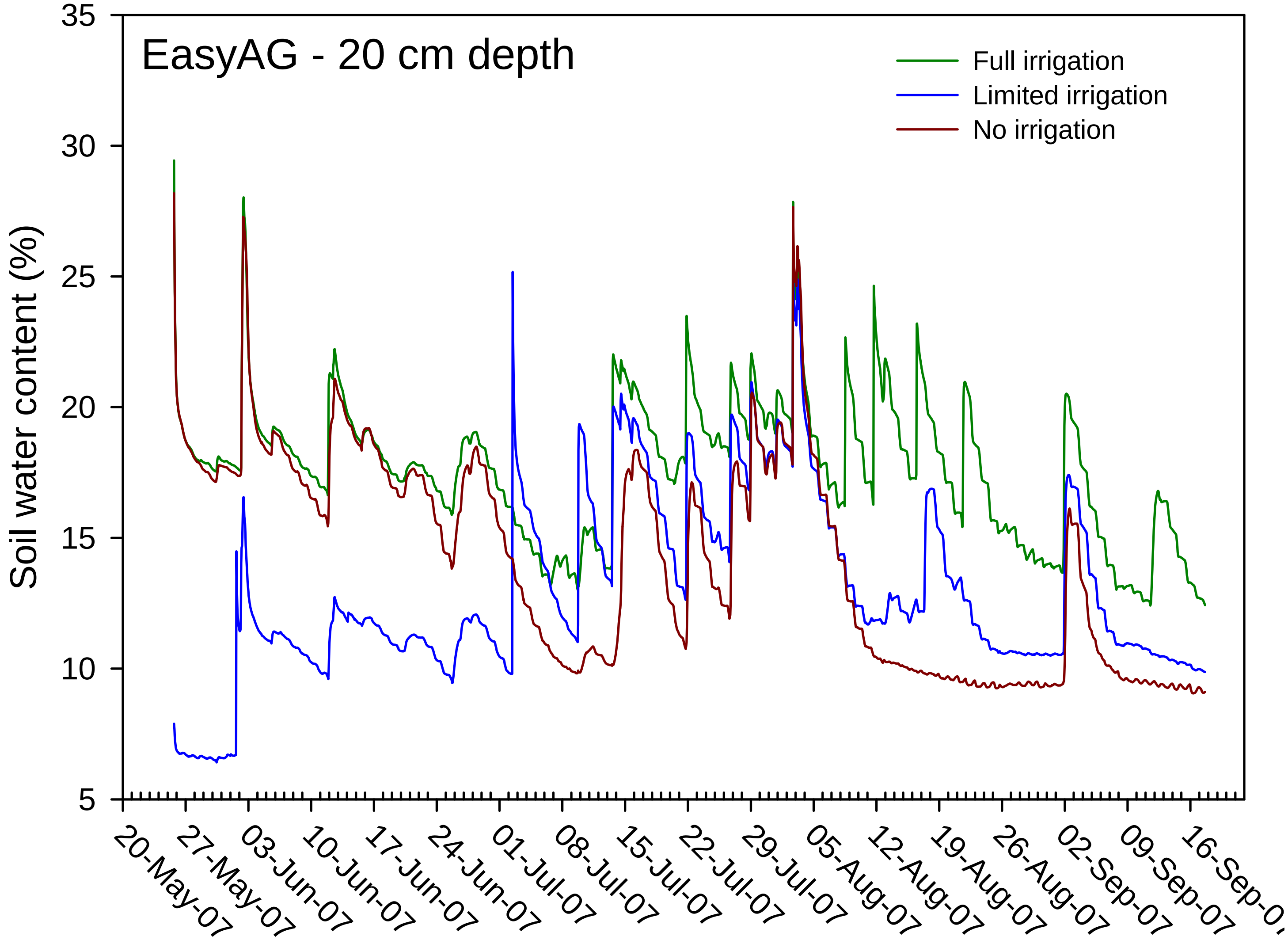

Figure 4-14. EasyAG® readings of soil water content at a depth of 20 cm in the full irrigation treatment, limited irrigation treatment, and non-irrigated treatment throughout the 2007 growing season.

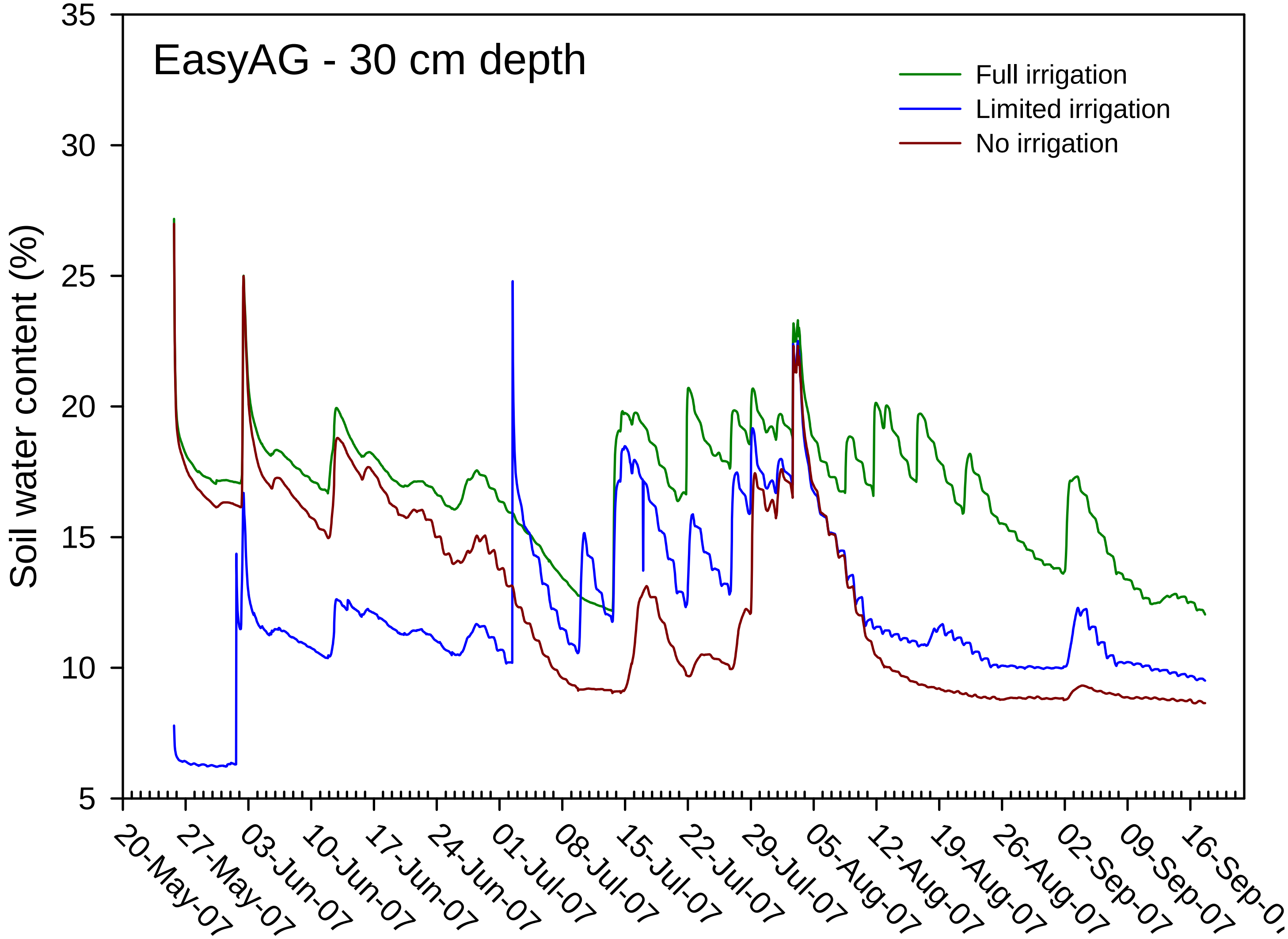

Figure 4-15. EasyAG® readings of soil water content at a depth of 30 cm in the full irrigation treatment, limited irrigation treatment, and non-irrigated treatment throughout the 2007 growing season.

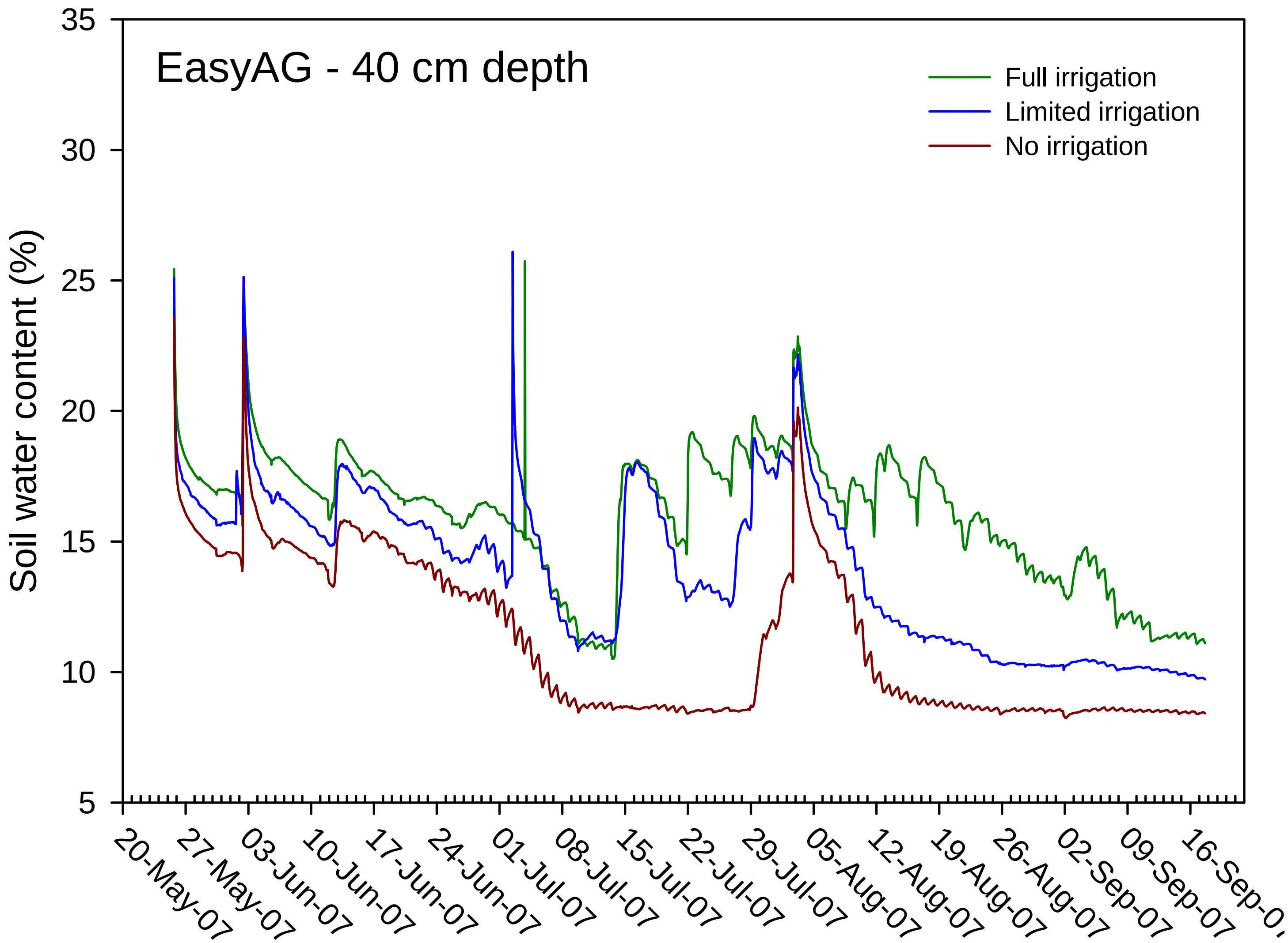

Figure 4-16. EasyAG® readings of soil water content at a depth of 40 cm in the full irrigation treatment, limited irrigation treatment, and non-irrigated treatment throughout the 2007 growing season.

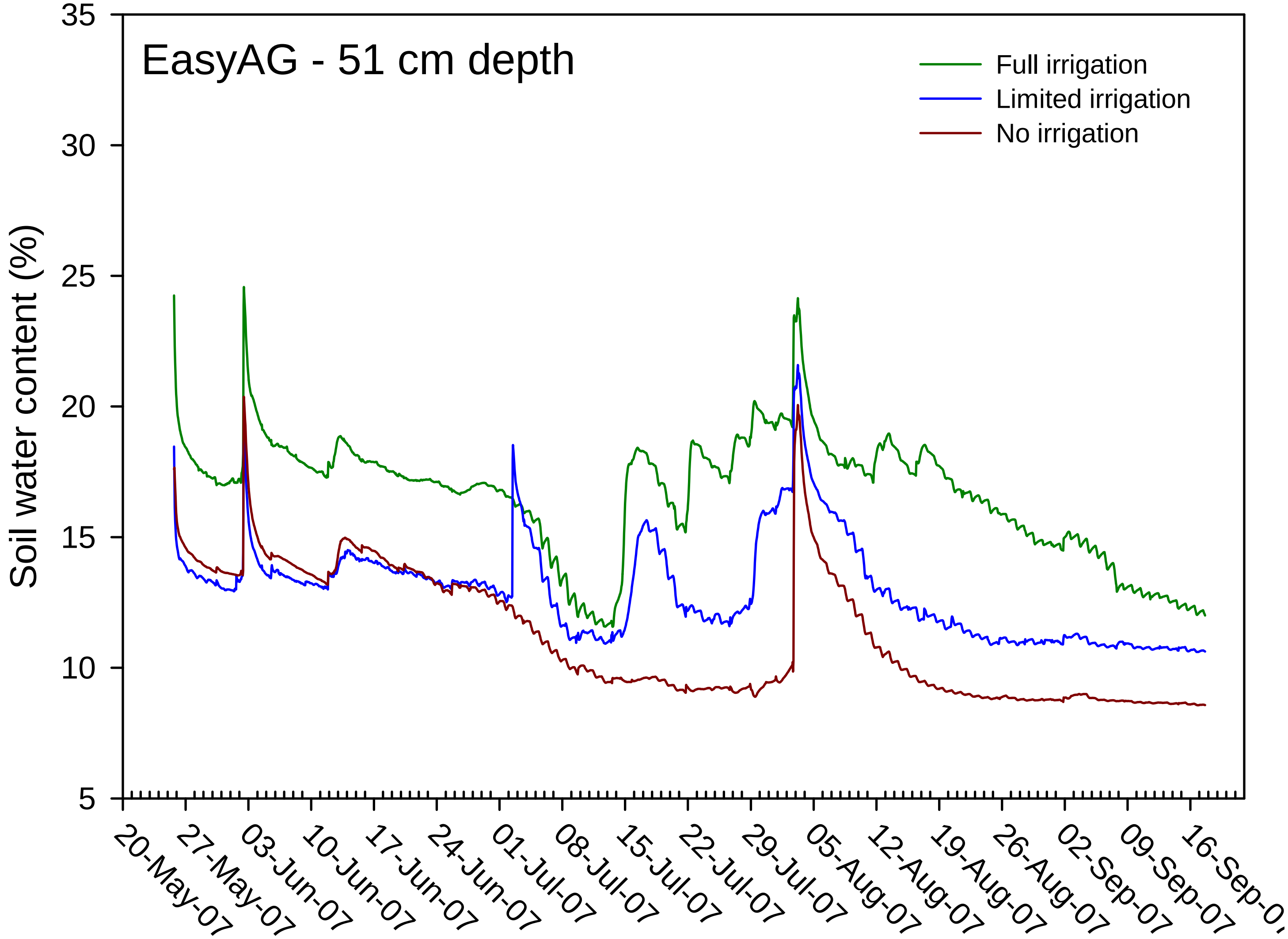

Figure 4-17. EasyAG® readings of soil water content at a depth of 51 cm in the full irrigation treatment, limited irrigation treatment, and non-irrigated treatment throughout the 2007 growing season.

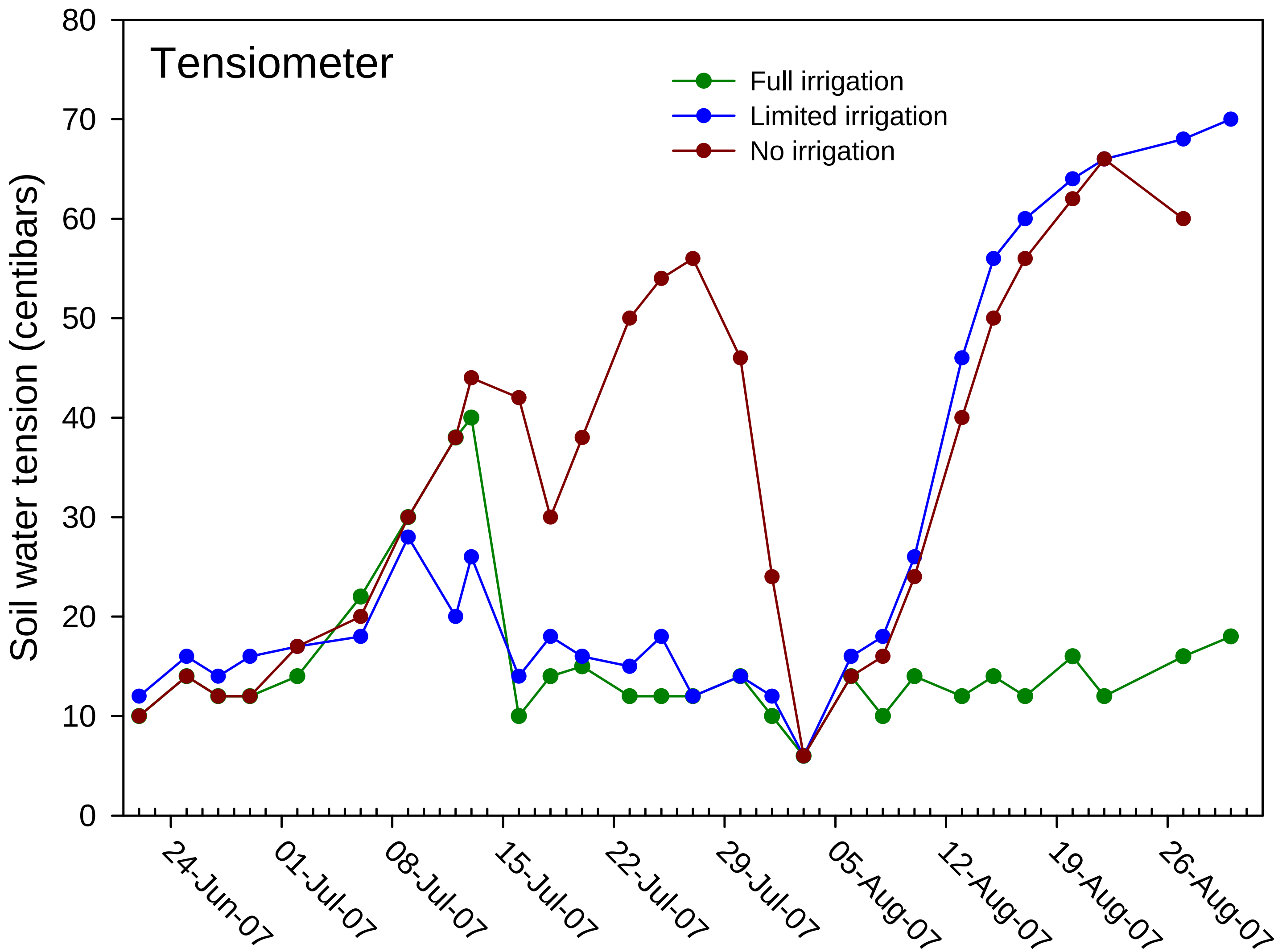

Figure 4-18. Tensiometer readings of soil water tension at a depth of 30 cm in the full irrigation treatment, limited irrigation treatment, and non-irrigated treatment throughout the 2007 growing season.

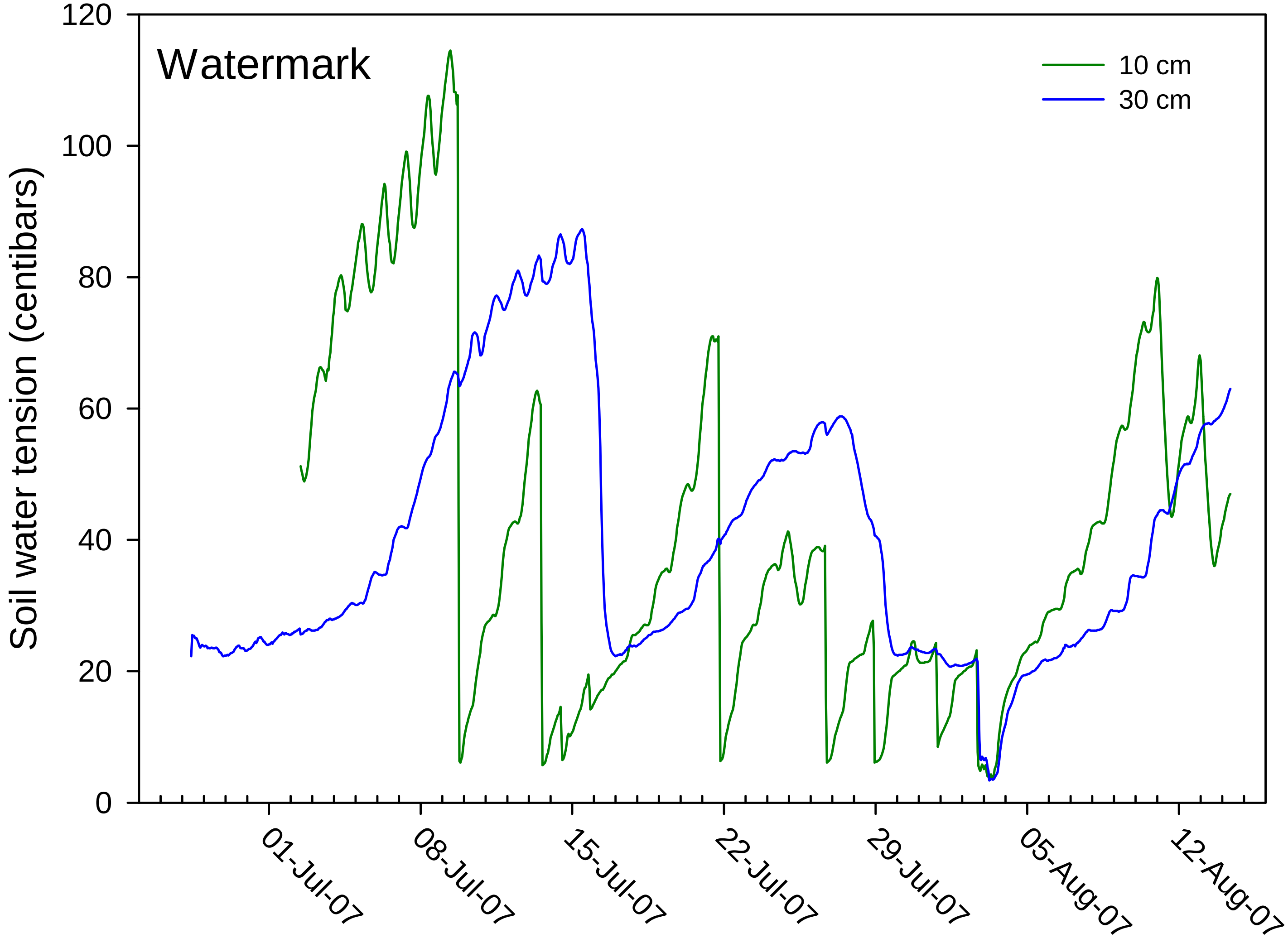

Figure 4-19. Watermark readings of soil water tension at depths of 10 cm 30 cm in the full irrigation treatment throughout the 2007 growing season.

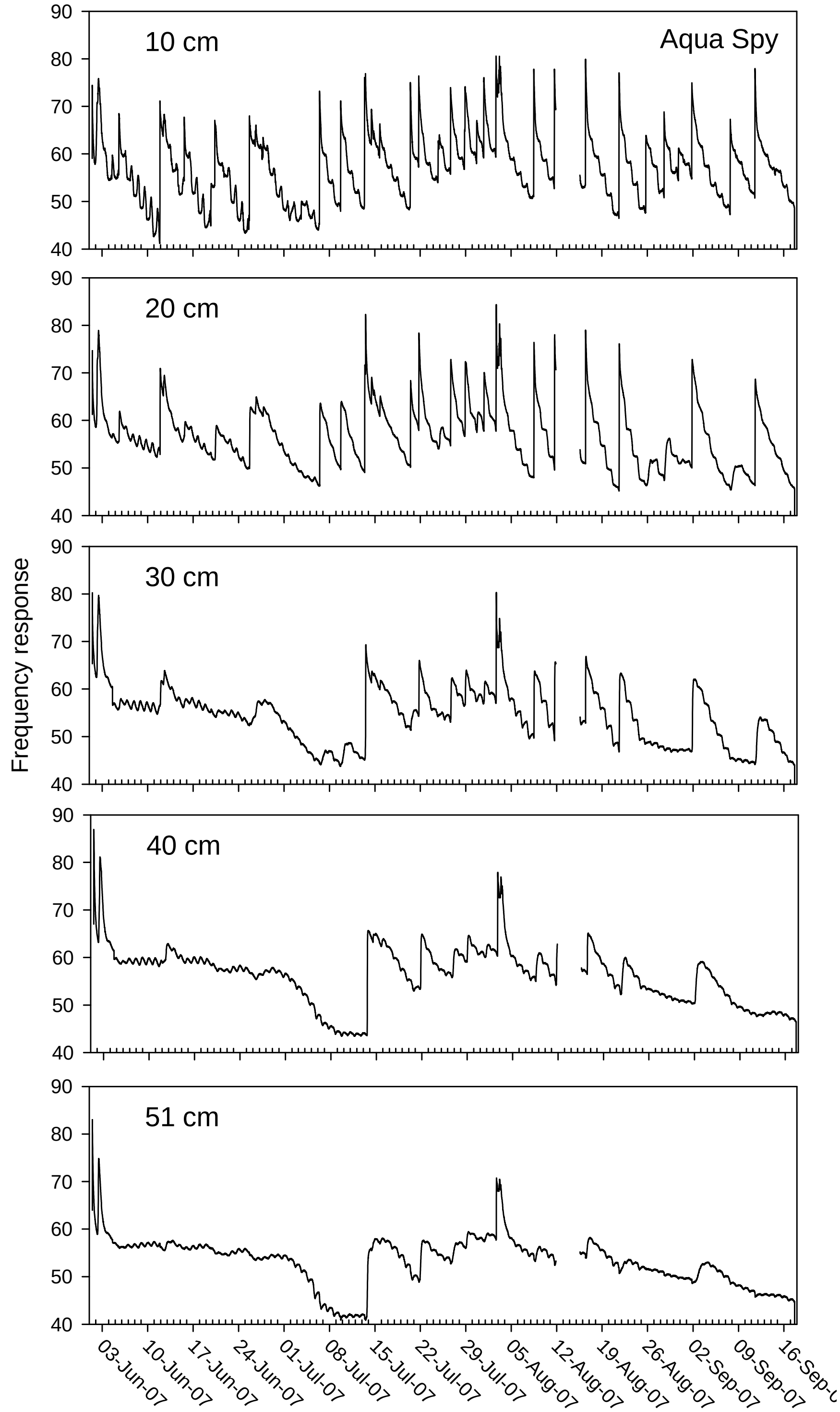

Figure 4-20. AquaSpy™ readings of frequency response at depths of 10 cm, 20 cm, 30 cm, 40 cm, and 51 cm in the full irrigation treatment throughout the 2007 growing season.

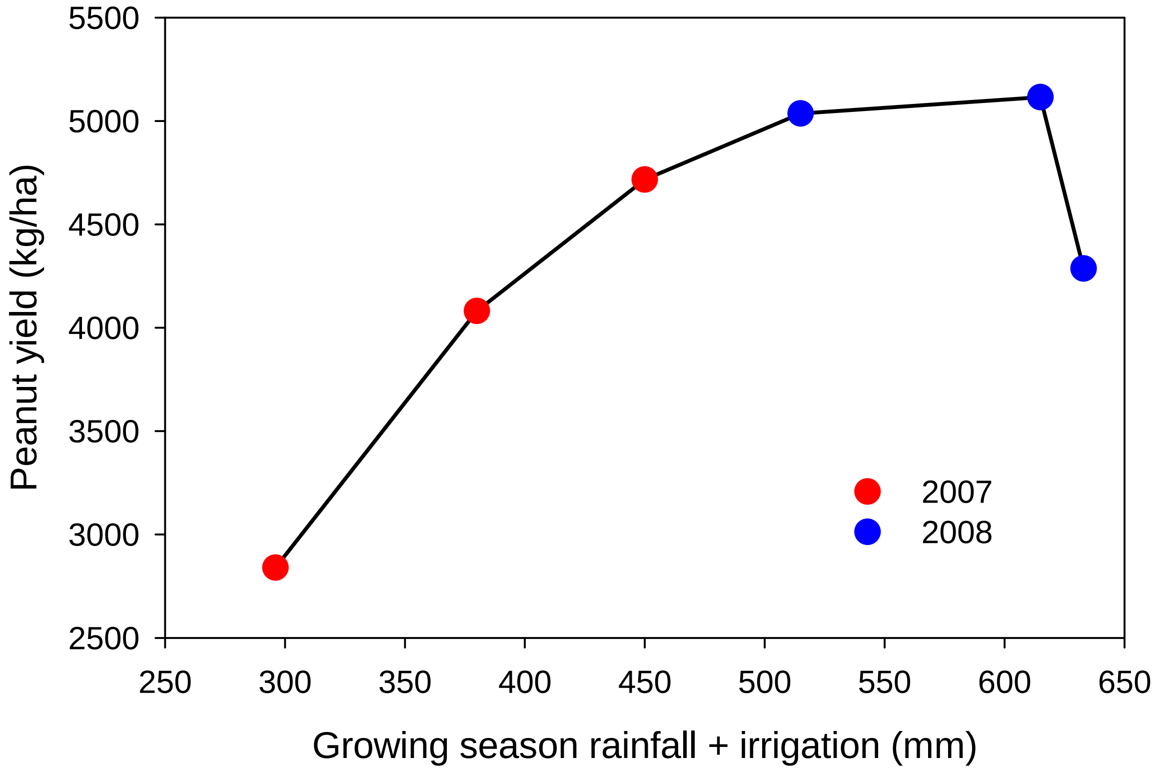

Figure 4-21. Peanut yield as a function of water applied (rainfall and irrigation) for 2007 and 2008.

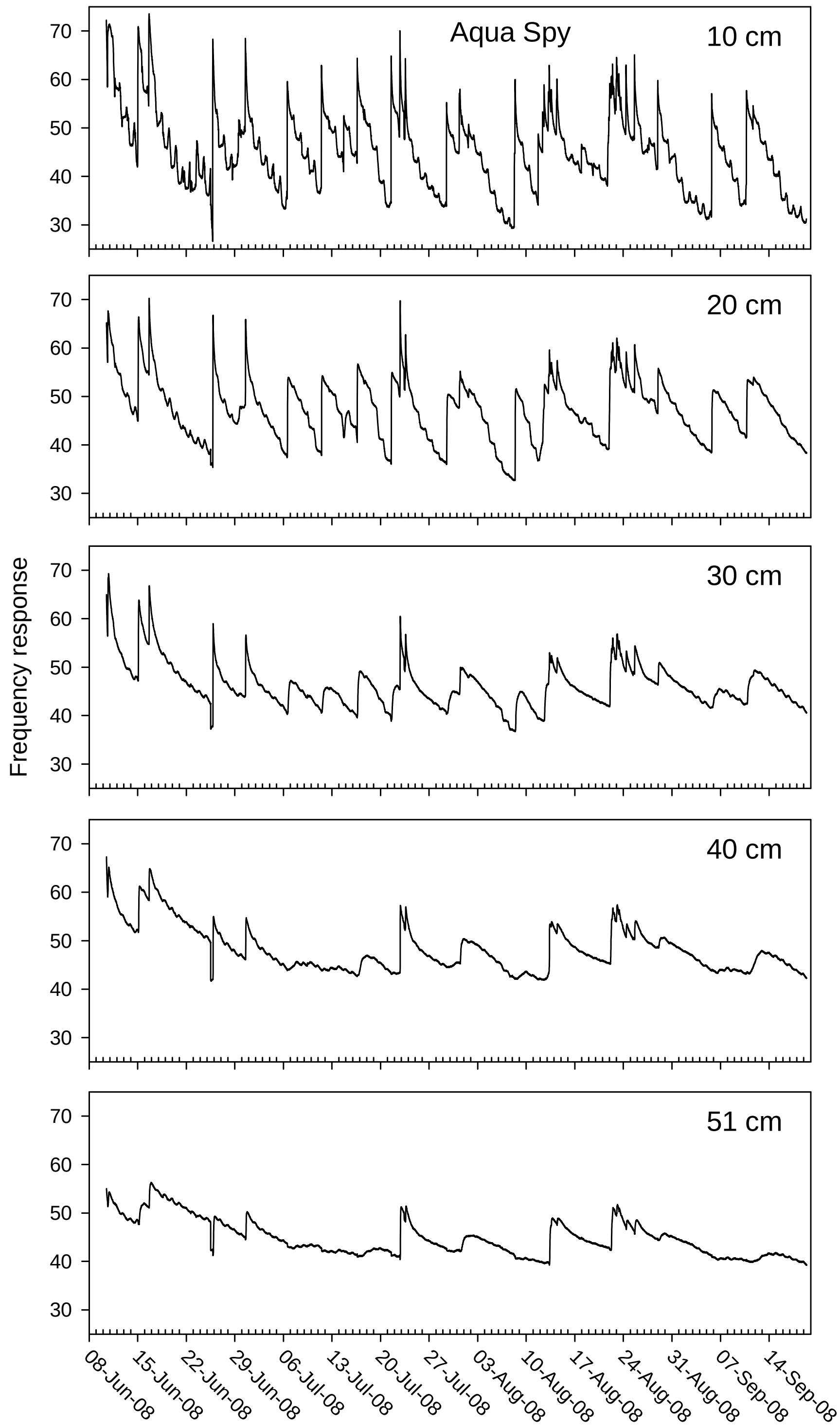

Figure 4-22. AquaSpy™ readings of frequency response at depths of 10 cm, 20 cm, 30 cm, 40 cm, and 51 cm in the full irrigation treatment throughout the 2008 growing season.

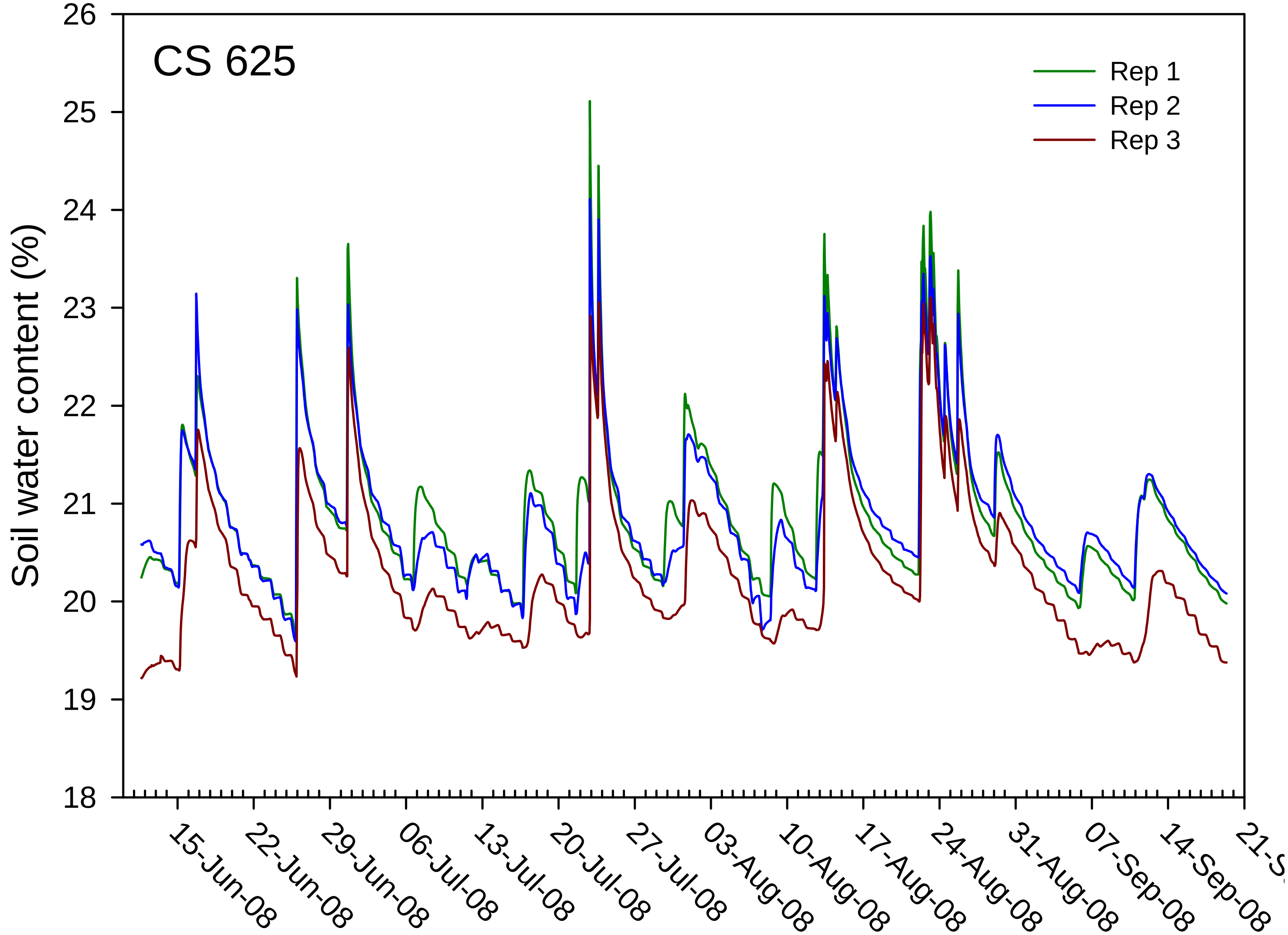

Figure 4-23. CS625 readings of soil water content at a depth of 30 cm in the SM based irrigation treatment throughout the 2008 growing season.

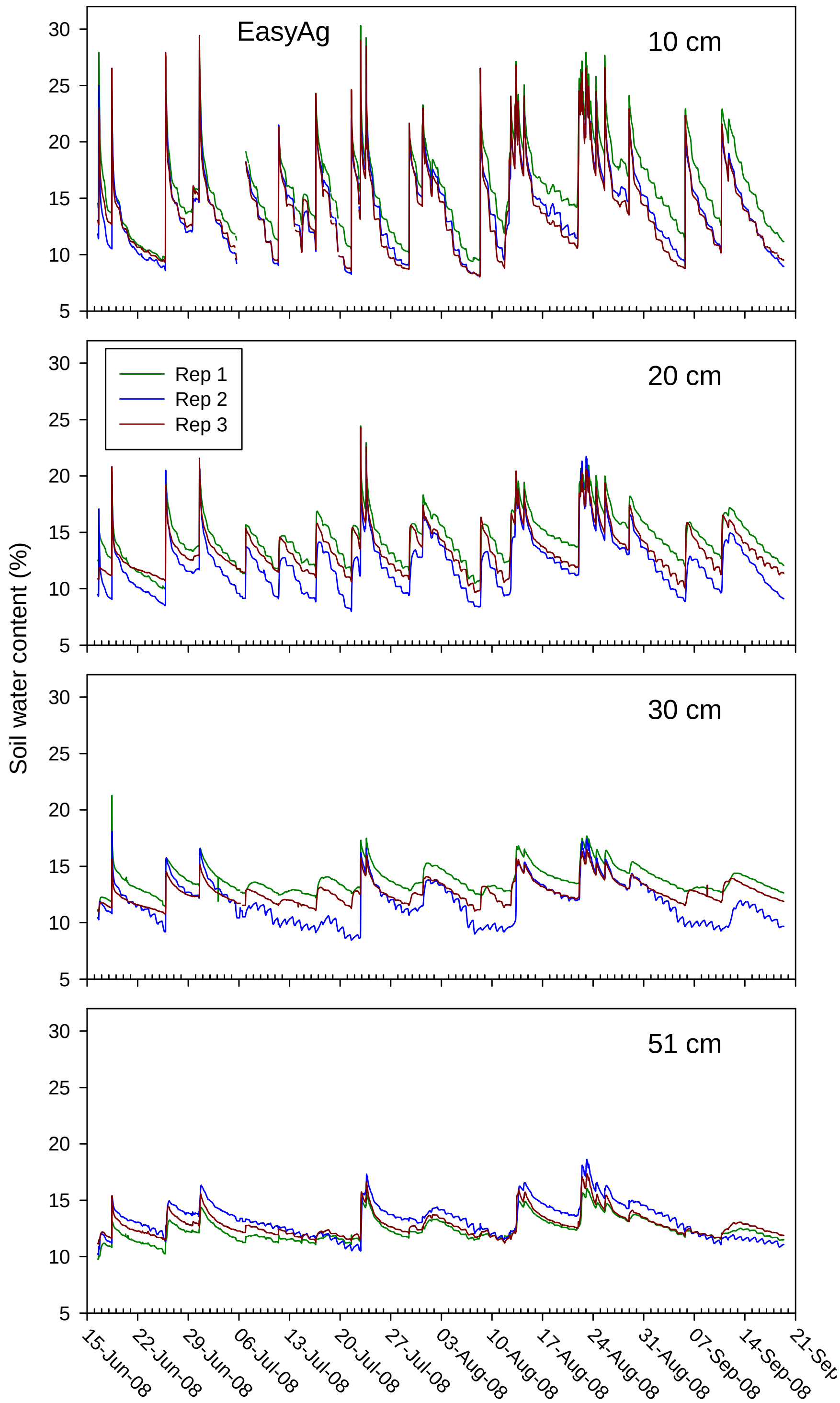

Figure 4-24. EasyAG® readings of soil water content at depths of 10 cm, 20 cm, 30 cm, 40 cm, and 51 cm in the SM based irrigation treatment throughout the 2008 growing season.

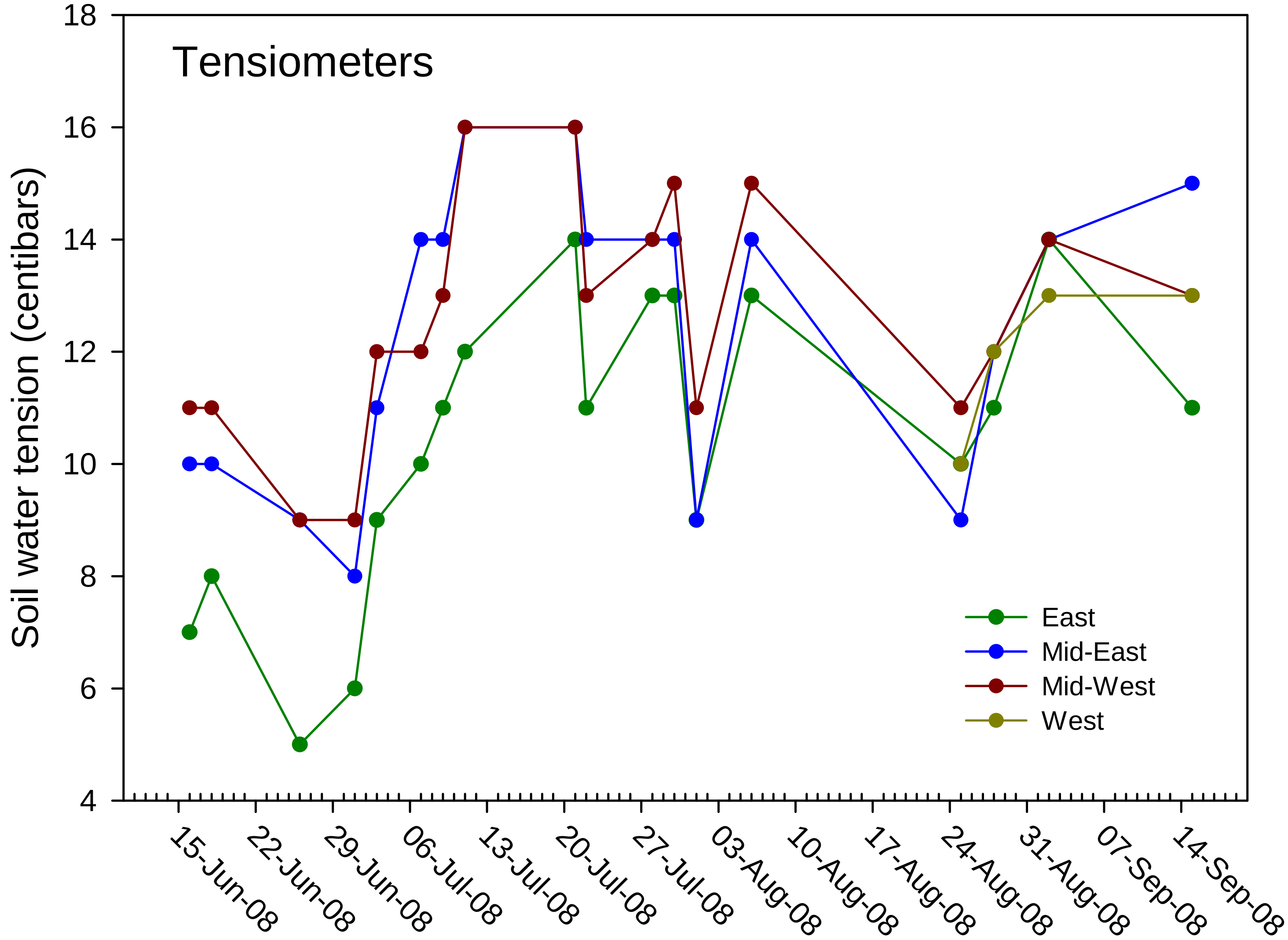

Figure 4-25. Tensiometer readings of soil water tension at a depth of 30 cm in the SM based irrigation treatment throughout the 2008 growing season.

CHAPTER 5
SUMMARY AND CONCLUSIONS

Hypothesis 1: SPAD meter readings will correlate with a) plant tissue nitrogen, b) silage corn yield, and c) protein yield. Results from this study showed that SPAD 502 meter readings could be used to predict both corn silage yield and protein yield. However, the SPAD meter readings did not correlate with leaf N concentration as well as expected. Therefore, the portion of this hypothesis relative to silage and protein yields is not rejected, but the portion relative to plant tissue N is rejected.

Hypothesis 2: SPAD readings will be able to be used in order to determine whether or not supplemental N fertilizer application is needed at tasseling. Based on the results from the 2007 and 2008 growing seasons, this hypothesis is not rejected. For corn silage yield, critical values for relative SPAD reading were 86, 94, and 82% for the pre-tassel, tassel, and blister growth stages, respectively. For protein yield, the critical SPAD numbers were 85, 94, and 96% for the same three growth stages. If relative SPAD readings are above these critical values at the specified growth stage, then supplemental N fertilization is not required. These values compare well with research from the Midwest, indicated that a critical value of 95% relative SPAD reading is recommended as the basis to determine whether or not N fertilization is necessary at tassel.

Hypothesis 3: Certain soil moisture devices will prove to be more effective and easier to install and use than others. This hypothesis is not rejected since certain soil moisture devices, such as the EasyAG® and AquaSpy™, were easier to install and were more effective than other instruments, such as the AquaPro or WaterMark, for example. The EasyAG® and AquaSpy™ were the two most accurate sensors over the course of the two growing seasons, and are recommended for use in the LSRB.

Hypothesis 4: Soil moisture equipment can be used as a tool for effective irrigation scheduling to avoid water stress. With regard to irrigation, the critical values at which water stress occurs and a grower should irrigate are around 45 for the AquaSpy™ and 15% soil moisture for the EasyAG®. These may be high estimates based on data from the 2007 limited irrigation treatment and non-irrigated treatment, as well as the 2008 soil moisture based irrigation treatment, but no further conclusions were drawn and more research is needed. More research is also needed to verify the critical values for the AquaSpy™, since we did not have replicates of this instrument in the testing plots.

If a grower is not ready to make the transition to a computer-based continuous recording device, tensiometers are recommended as an alternative. Even though they do not record continuous measurements, growers can get a general idea as to the soil water available to the plant by checking the tensiometer at the same time every day, or multiple times a day. There are also dataloggers specifically designed for tensiometers in order to record data continuously, which may help growers better manage their irrigation.

Soil moisture equipment can be used as a tool to improve water use efficiency must be rejected as a hypothesis based on the 2008 growing season data. There was no significant difference in irrigation water levels between the soil moisture irrigation treatment and the ET based irrigation treatment. More research is needed to prove the utility and efficacy of these devices with regards to water conservation in the LSRB.

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BIOGRAPHICAL SKETCH

Rotem Shahar was born in 1984 in Tel-Aviv, Israel. Elder of two children, she grew up in Miami, Florida after her family moved there when she was two years old. She graduated from Dr. Michael M. Krop Senior High School in 2002, and went on to study at the University of Florida (UF). Rotem earned her B.S. in soil and water science at UF in 2007, and continued with her education at the university working toward an M.S. in soil and water science. Upon completion of her M.S. program at UF, Rotem will move to Israel to study at Ben Gurion University and earn her Ph.D.