MISSISSIPPI SOYBEAN PROMOTION BOARD
PROJECT NO. 62-2015 (YEAR 2)
2015 Annual Report

TITLE: Determine irrigation rate and timing, and water availability for optimum yield, water use efficiency, and profitability of soybean in the Mississippi Blackland Prairie region

PI: Gary Feng, USDA-ARS, Starkville, MS

Report of Progress/Activity

Progress for Objective 1.

Experimental design

The project utilizes a 3-acre, furrow-irrigated field located at the Mississippi State University Black Belt Branch Station in Noxubee County. The field contains Brooksville silty clay soil, which was divided into four blocks from the west to east. Three treatments are replicated four times and completely randomized in the four blocks (Fig.1). Treatments are (i) 'Rainfed', not irrigated, (ii) 'SM', irrigation when root zone soil moisture measured by sensors is 50% of plant available water, and (iii) 'ET', irrigation when estimated soil moisture reaches 50% of plant available water, soil moisture estimated in terms of initial soil water at given date and soil water consumed by daily crop evapotranspiration (ET) calculated using weather data. A group IV cultivar, Asgrow 4632, was planted at 120,000 seeds per acre on May 19, 2015. Row spacing was 38 inch.

Sensor installation, soil and plant measurements

In each plot (6 rows × 365 ft) we have installed soil matric potential sensors (Watermark, Irrometer) used widely by local producers at 3, 9, 15, 19, 21 and 31 inch depths. In order to determine the soil-water release curve on site, the irrigation trigger point to schedule an irrigation, and 'calibrate' the Watermark sensors, each plot has TDR soil moisture sensor (Acclima Inc.) coupled to a datalogger (Campbell Scientific Inc.) at depths of 0-6, 6-12, 12-18, 18-24 and 28-36 inches (Fig. 1 and 2).

Water balance components, percolation below root zone, and runoff were measured using a pen lysimeter (Soil Moisture Corp.) in the six plots and microflume runoff collectors located at the tail end (north side) of the plots. The effective rainfall and canopy interception are estimated using a rain gauge above the canopy and a complementary gauge below the canopy of different plots (Fig. 1). Soil pits were dug to 36 inch depth in each block in order to collect three undisturbed soil cores (rings) of 1 and 6 cm thickness from the surface in both the bed and furrow, and at 6, 12, 24, and 36 inch depths. Undisturbed soil cores were transported to laboratory for measurements of saturated hydraulic conductivity, soil porosity, soil moisture retention curve, soil water content at field capacity (1/3 bar), and wilting point (15 bar). These soil properties provide knowledge of plant available water content and management allowable depletion point for irrigation scheduling. Soil samples were taken 12 times for measurement of soil moisture, and extractable nutrients at bed and furrow locations at 0-6, 6-12, 12-18, and 18-24 inch depths. Soybean developmental growth stage, height, canopy cover, rooting depth, leaf area index, dry biomass, and nutrient status were determined 10 times for every treatment. Plots were mechanically harvested on Oct. 15, 2015.

Irrigation management tool

A STELLA (Structural Thinking, Experiential Learning Laboratory with Animation) irrigation management model was developed to determine when and how much irrigation should be applied to soybean. The daily dynamic model can calculate various soil water balance components including surface water runoff, percolation, soil evaporation, evapotranspiration (ETc), and root zone moisture content. The STELLA model is capable of determining timing and amount of irrigation under different weather conditions. The tool was used to schedule irrigation for SM and ET treatments. Estimates of available soil water in the effective rooting zone and daily ET are made through monitoring soil sensor data on daily basis and/or on site at least weekly, and data are downloaded from a local ARS weather station located on Good Farm, Noxubee county, east central Mississippi.

Irrigation amount and timing

The STELLA irrigation tool determined that soybean did not need irrigation for only 12 out of 120 years. Average amount of required irrigation was 7.1 inch yr^{-1} over 120 years and 6.4 inch yr^{-1} over 60 normal years. Soybean required irrigation between June 29 and September 7, five and more times of irrigation were needed from R3 to R7 critical water sensitive stages. Rain water deficit calculated as the difference between ETc (18 inch) and rainfall (15.3 inch) was 2.6 inch in 2015. The SM treatment received 4.5 inch of irrigation and the ET treatment received 3 inch of irrigation.

The tool was used to determine when root zone water depletion (SWD) reaches irrigation trigger points of 50% total available water (TAW) in 2015. Both SM and ET irrigation treatments were triggered at the same time on July 15, 2015 (R3), and July 28, 2015 (R5). Using the TAW curve, it was determined that 1.5 inch of irrigation was needed, so 1.5 in irrigation was applied to the two treatments on July 15 and 28, 2015. On August 4, the irrigation tool indicated the SM treatment needed irrigation; whereas, ET-based treatment was not forecasted to receive irrigation until August 11. On August 5 (R6), approximately 1.5 inch of irrigation was applied to SM based treatment only. From August 6-9, 2015, 2 inch of rainfall was recorded, pushing back all of the ET based irrigation treatment needs. Over the next week August 13-19 in 2015, 2.5 inch of rainfall was recorded, causing all treatments to have ample water until R7 growth stage. No irrigation was needed after this time.

Historical effective rainfall deficit

Effective rainfall (or net rainfall) is defined as difference between total amount of rainfall and runoff as well as drainage in a given period of time. The developed STELLA irrigation management model was applied to calculate daily runoff, drainage, and ETc using long-term weather data from 1895 to 2014 in the Blackland Prairie region, east central Mississippi. As a result, effective rainfall deficit during soybean season was determined over the last ten decades. The average annual rainfall of century long record was 51.2 in. The probability of occurrence of annual rainfall ≥ 44.3 inch is 75%. Annual rainfall of wet, normal and dry category years was in the range of 57.7 to 76.0 in, 44.5 to 57.6 in and 31.6 to 44.3 in, respectively. Rainfall over 50% frequency ranged from 8.9 to 16.2 inch during soybean season, accounted for 30% of annual rainfall in the normal and dry years. In 2015, annual rainfall was 51 inch which is a normal category year.

Total effective rain water deficit of 7.9 in was found during entire growing season for soybean over 120 years. During dry years, as much as 13.4 inch yr^{-1}effective rain water deficit was estimated. Weekly effective rainfall deficit ranged from 0.3-1.0 inch during soybean developmental stages that correspond with peak water demand.

Reference evapotranspiration (ETr) and actual crop evapotranspiration (ETc)

Fig. 3 displays daily reference evapotranspiration (ETr) that was calculated during soybean growing season (5/19-10/10) using weather data observed at three nearby weather stations within a 20 mile radius of the study site: MSU Brooksville station, MS; ARS Macon station, MS; and NRC S Dee River station in Aliceville, AL. Difference in ETr and ETc between Dee River and Macon station was only 1 inch from 7/17 (R3) to Oct. 4 (mature), and between Dee River and Brooksville station was 0.8 inch from 5/19 (sowing) to 8/15 (R4). Relatively low ETr and ETc was calculated using Dee River station. Difference in ETr and ETc between Macon and Brooksville station was 0.6 inch from July 10 (R2) to August 13 (R5). It appears weather data at any of the three stations can be used to calculate ETc, and one station may substitute for another if data are missing.

The three-station average during the 2015 growing season was 25 inch for ETr and 18 inch for ETc. These are less than the average long-term ETr and ETc of 28.4 inch and 21.3 inch during soybean growing season from 1895 to 2014. During the entire soybean season, average rainfall of last 10 decades was 17 inches, rainfall of wet, normal and dry category years was 23.5 in., 16.6 in. and 11.0 in. The rainfall during soybean season in 2015 is 15.3 in., which is within the range observed for previous 60 normal category years of 13.4 to 20 inches.

Water balance

No runoff was measured in any collectors. Rainfall intercepted by canopy was only 0.4 inch during the entire growing season. Leachate waters ranging from 50 to 950 ml in “SM” plots, 13 to 1000 ml in “ET” plots, and 100 to 1000 ml in “RF” plots at 36 inch depth was observed from July 1 to Aug. 27 during R1-R7 stage of soybean. Variation in leaching was observed due to different soil physical and chemical characteristics of varying depth of soil above shallow chalk layer.

Soil moisture sensors installed in the field indicated that the soybean plants still consumed water down to 90 cm soil profile in the humid region (Fig. 4). Watermark sensor readings suggest that irrigation trigger point was 90 kPa on the Brooksville silty clay soil.

Production

Soybean irrigated three times a R3 (7/15/15), R5 (7/28/15) and R6 (8/5/15) stage had mean grain yield (n=4) of 2881 lb ac^{-1} (48 bu per acre, based on combine harvest) and a harvest index of 61%. While soybean irrigated twice at R3 and R5 had mean grain yield (n=4) of 2667 lb ac^{-1} (45 bu per acre) and a harvest index of 66% (Table 1). Irrigation three times and two times increased grain yield by 18% and 9%, aboveground biomass by 23% and 44%, thousand grain weight and harvest index by 34% and 40%, respectively. Pod filling was not significantly affected, and thousand grain weight averaged 142 and 127 g for irrigated and rainfed treatments, respectively. Table 2 indicates that the two irrigation treatments had similar water consumption (21 in) and grain water use efficiency (134 lb ac^{-1} in^{-1}). It appears that both sensor-based method and ET-based method can be used for scheduling soybean irrigation in this region. 70% of water was consumed during reproductive (R) stages.

Table 1. Yield, yield components, harvest index (HI), and plant dry biomass in three treatments.

Treatment	Grain Yield, lb/ac	Thousand grain weight, g	Total above dry biomass, ib/ac	Stems dry biomass, ib/ac	Leaves dry biomass, ib/ac	HI	Seeds per plant	Pods per plant
SM	2881a	153.60	37672	8529	10778	0.61	113	41
ET	2667ab	130.20	51570	14113	12039	0.66	118	45
RF	2441b	127.01	29003	7231	8491	0.40	58	21

Table 2. Soybean consumed water and water use efficiency.

Treat-ment	Total water consumed in	Water consumed in V stage mm	Water consumed in R stage mm	Water consumed in V stage %	Water consumed in R stage %	WUE grain ib/ac/in
SM	20.2a	6.3a	13.8a	31	69	134.6a
ET	21.2a	6.2a	15.1a	29	71	133.9a
RF	16.4b	4.5a	11.9a	28	72	153.7a

Progress for Objective 2.

A STELLA model has been developed to estimate farm pond hydrological dynamics and water budget, based on the following hydrological processes and farm practices: surface runoff, evaporation, irrigation usage, precipitation, spillage, seepage, deep drainage, and upper and lower pond water level operational limits. The STELLA irrigation management model and the farm pond hydrological water budget model are being incorporated and employed to determine the ratio of pond size to crop land for sustainable soybean irrigation.

A 20-acre irrigation pond is being monitored with flow gauges on the pond inlet (runoff water) and outlet (service line to center pivot). The pond is used to drive a center-pivot system that irrigates about 375 acres of soybeans on a producer's farm adjoining the soybean irrigation plots on the experiment station. The observed data will be used to calibrate and validate the incorporated STELLA models.

Staffs from USDA-NRCS in Mississippi have roughly approximated that the pond size to crop irrigation area is about 1:13 (personal communication). However, an accurate ratio based on the pond and its surrounding hydrological processes, local climate conditions, and crop irrigation demands has yet to be determined. Knowledge of this ratio is crucial to pond size construction, pond water management, and stream and groundwater conservation in Mississippi.

Project scientists applied the pond water budget model to estimate the ratio of pond size to irrigated soybean land area based on the soybean irrigation demands. Preliminary results show that the ratio is 1:18; i.e., a 1-ac pond with an average depth of 6.6 feet could irrigate 18 acres of soybeans if the crop received 1 in irrigation and the low limit of the pond water level was above 15 in. Under this ratio, model results further revealed 1-ac in soybeans could save about 399,682 acre feet groundwater each year if pond water was used. If the average loss of groundwater is 13 billion gallon/yr in some parts of

Mississippi due to irrigation, a 24,710-ac soybean land irrigated with pond water could save groundwater resources by 11% each year. Results suggest that an on-farm storage pond seems to be one of the promising alternatives to conserve groundwater resources. A manuscript entitled, “Estimating the ratio of pond size to irrigated soybeans land in Mississippi: A case study” was prepared and one of the peer reviewers remarked that the modeling tool will be very helpful to irrigation system designers.

Progress for Objective 3:

The Agricultural Policy/Environmental eXtender (APEX) model was employed to simulate soybean yields on nine major soil types in the Blackland Prairie under both rainfed and non-water stress/irrigation conditions for 13 years. Results indicated the average net return of irrigated soybean can be increased by approximately $38 per acre among nine soil types from 2002 to 2014 compared to rainfed conditions.

Irrigation can increase net return regardless of dry, normal or wet years. The average net return of each hectare increased by $79, $24 and $28 for dry, normal and wet years, respectively. Vaiden clay, Catlapa silty clay, and Leeper silty clay had the relatively lower increase in average net return, ranging from $5 to $16 per acre. In comparison, Griffith silty clay, Sumter silty clay and Demopolis clay loam had relatively higher increase in average net return, ranging from $70 to $87 per acre. A manuscript entitled, “Simulated yield potential without water stress by irrigation and yield gap of rainfed soybean using APEX model in a humid region” was submitted to the journal of Field Crop Research.

End Products.

Presentations:

Feng, G. 2015. Analysis and prediction of water deficit for soybean, corn and cotton in the state of Mississippi. The Annual Mississippi Water Resources Conference, Jackson, MS. April 7-8, 2015.

Feng, G. 2015. Irrigation of soybean in Prairie soils. Mississippi Chapter-American Society of Agronomy, Summer Agronomy Tour in Noxubee County, On-site presentation in the field day. June 24, 2015.

Feng, G., Y. Ouyang, J. Read, A. Adeli, D. Reginelli, and J. Jenkins. 2015. A Farm Pond Water Irrigation Management System in Mid-South United States. American Society of Agricultural and Biological Engineers (ASABE) Annual International Meeting, New Orleans, Louisiana. July 26-29, 2015.

Feng, G., J. Read, Y. Ouyang, A. Adeli, D. Reginelli, and J. Jenkins. 2015. Soil water sensor-based and evapotranspiration-based irrigation scheduling for soybean production on a Blackland Prairie soil in humid climate. American Society of Agronomy Annual Meeting, Minneapolis, MN. Nov. 15-18, 2015.

Feng, G., R. Sui, Y. Ouyang, J. Read, A. Adeli, D. Reginelli, and J. Jenkins. 2015. Irrigation scheduling as affected by field capacity and wilting point water content from different data sources. Soil Science Society of America Annual Meeting, Minneapolis, MN. Nov. 15-18, 2015.

Zhang, B., **G. Feng,** X. Kong, Y. Ouyang, J. Read, A. Adeli, D. Reginelli, and J. Jenkins. 2015. Soybean productivity under various rainfed conditions and irrigation levels determined by WinAPEX Model in Blackland Prairie of East Central Mississippi State. Soil Science Society of America Annual Meeting, Minneapolis, MN. Nov. 15-18, 2015.

Feng, G., Y. Ouyang, D. Reginelli, and J. Jenkins. Prediction of future agricultural water needs in Mississippi Delta and Blackland Prairie under pond/ditch surface water supply and groundwater pumping scenarios. The Annual Mississippi Water Resources Conference, Jackson, MS. April 5-6, 2016.

Ouyang, Y., J.O. Paz, **G. Feng**, J. Read, A. Adeli, and J. Jenkins. 2016. A model to estimate hydrological processes and water budget from on-farm ponds in Mississippi. Institute of Biological Engineering Annual Conference, Greenville, SC, April 7-9, 2016.

Feng, G. (invited speaker). Crop model application to soybean irrigation management in a humid region. Invited presentation at the American Society of Agricultural and Biological Engineers (ASABE) Annual International Meeting, Orlando, FL. July 17-20, 2016.

Ouyang, Y., **G. Feng**, J. Read, T. Leininger, and J. Jenkins. 2016. Estimating the ratio of pond size to irrigated soybeans land in Mississippi: A case study. ASABE Annual International Meeting. Orlando, FL. July 17-20, 2016.

Feng, G., Y. Ouyang, D. Reginelli, and J. Jenkins. Irrigation using on-farm impounded surface water to reduce overdraft of Mississippi Alluvial Aquifer. 2016 UCOWR (Universities Council on Water Resources)/NIWR (National Institute of Water Resources) Conference Pensacola, FL, June 21-23, 2016.

Ouyang, Y., **G. Feng**, T. Leininger, and J. Jenkins. 2016. A STELLA model to estimate water quantity and quality from on-farm water storage system. 2016 UCOWR/NIWR Conference, Pensacola Beach, FL, June 21-23, 2016.

Manuscripts:

Feng, G., S. Cobb, Z. Abdo, D.K. Fisher, Y. Ouyang, A. Adeli, and J. Jenkins. 2015. Trend analysis and forecast of precipitation, reference evapotranspiration and rainfall deficit in the Blackland Prairie of Eastern Mississippi. *J. of Applied Meteorology and Climatology*. (under revision).

Ouyang, Y., J.O. Paz, **G. Feng**, J. Read, A. Adeli, and J. Jenkins. 2015. A model to estimate hydrological processes and water budget from an irrigation farm pond in Mississippi. *Water Resources Management* (submitted).

Feng, G., Y. Ouyang, A. Adeli, J. Read and J. Jenkins. 2015. Rainfall deficit and irrigation demand for major row crops in the Blackland Prairie of Mississippi. *Soil Science Society of American Journal* (submitted).

Zhang, B., **G. Feng**, J. Read, X. Kong, Y. Ouyang, A. Adeli and J. Jenkins. 2016. Simulating soybean productivity under rainfed conditions for major soil types using APEX model in East Central Mississippi. *Agricultural Water Management*. (submitted).

Ouyang, Y., **G. Feng**, J. Read, T. Leininger, and J. Jenkins. 2016. Estimating the ratio of pond size to irrigated soybeans land in Mississippi: A case study. *Water Resources Management* (submitted).

Zhang, B., **G. Feng**, X. Kong, L. Rattan, Y. Ouyang, A. Adeli and J. Jenkins. 2016. Simulated yield potential without water stress by irrigation and yield gap of rainfed soybean using APEX model in a humid region. *Field Crop Research*. (submitted).

Fig. 1. Layout for three irrigation scheduling treatments of Rainfed, SM (Soil moisture deficit based on sensor readings) and ET (EvapoTranspiration based on ET demand). Squares indicate the geo-referenced locations where four soil profiles were dug. Circles display where watermark and TDR sensors, pen lysimeters and rain gauges were installed. Triangles show where microflume runoff collectors were installed.

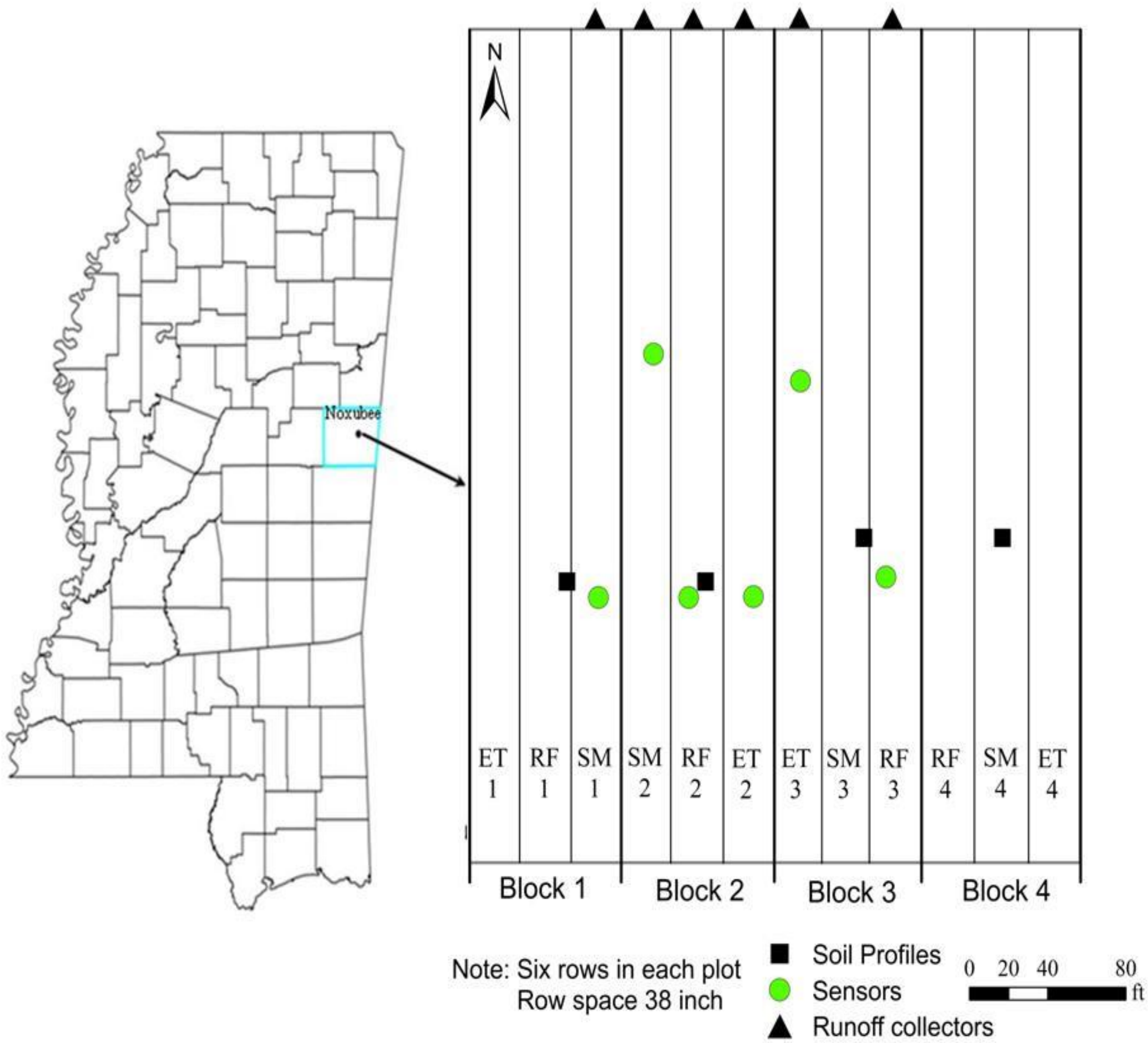

Fig. 2. Soil moisture TDR sensors (left side) and soil matric potential sensors (right side) were installed at depths of 6, 12, 18 and 24 inches in each of two treatment replicates. A data logger along with a radio modem can transfer the measured data to a base cell modem from which field real-time data can be accessed anywhere and anytime.

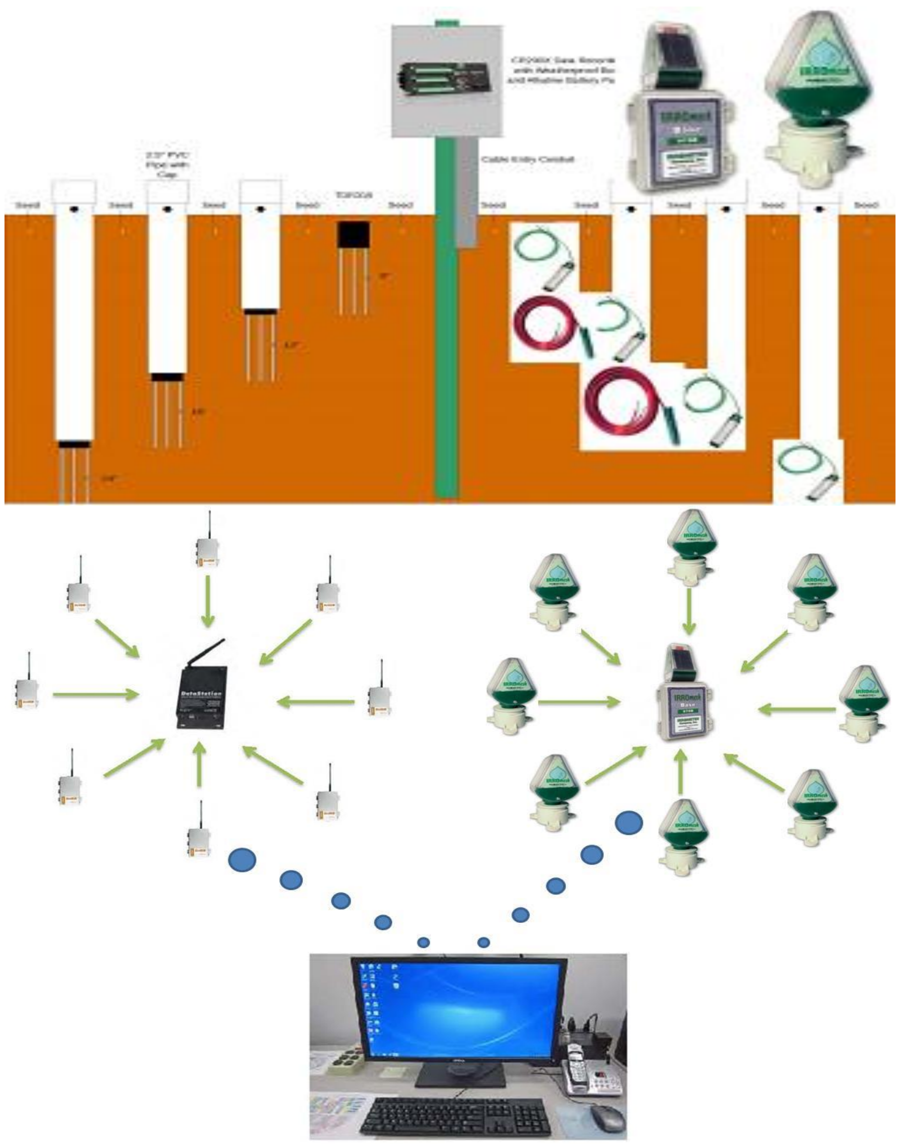

Fig. 3. Reference evapotranspiration (ETr) calculated by Penman-Monteith method using weather data recorded at the nearby three weather stations within a 20-mile radius of the study site: MSU Brooksville station, MS; ARS Good Farm station in Macon, MS; and NRCS Dee River station in Aliceville, AL.

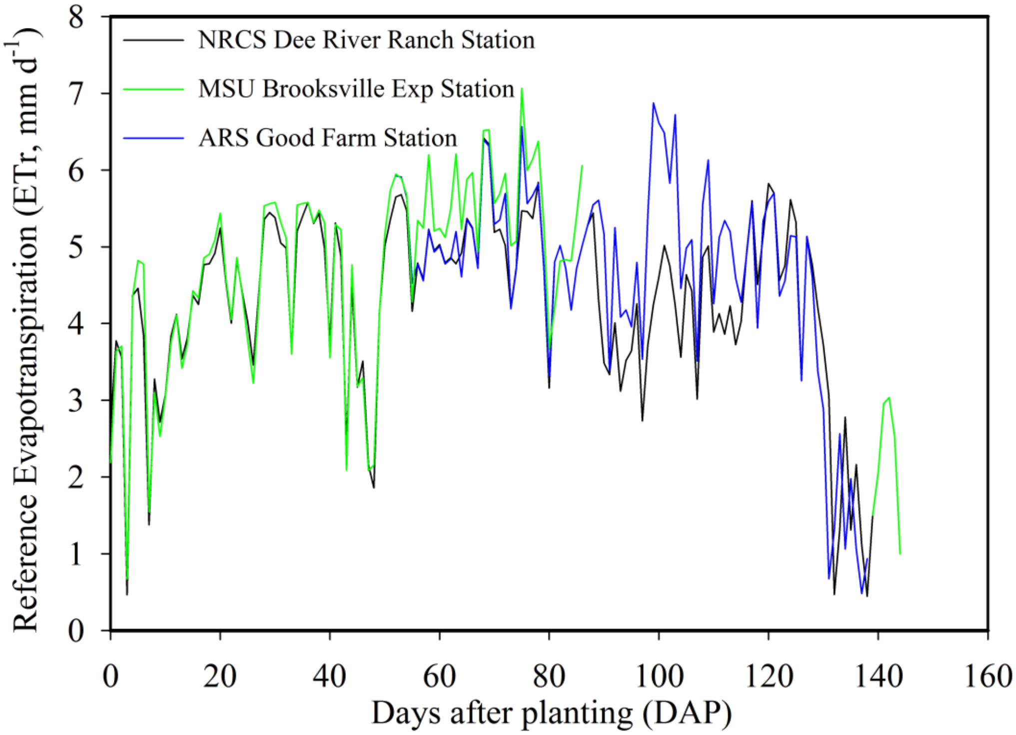

Fig. 4. Dynamic of soil moisture content at 30-36 inch depth measured by TDR sensors in the plots of three treatments—Rainfed, SM, and ET in a soybean field at Brooksville Experiment Station in 2015.