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Crop and Soil Science Department
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-Internship report-

Crop-coefficient model for scheduling irrigation on cotton in Georgia

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Table of Contents

List of Figures

List of tables

List of abbreviations

A	Acres
e.g.	for example
ET	Evapotranspiration
F	Fahrenheit
FAO	Food and Agriculture Organization of the United Nations
GAEMN	Georgia Automated Environmental Monitoring Network
GDU	Growing Degree Units
in	inch
K_c	crop coefficient
kPa	kilopascal
lb	pound
Max	Maximum
Min	Minimum
NRCS	Natural Resources Conservation Survey
SIRP	Stripling irrigation research park
UGA	University of Georgia
US	United States
USDA	United States Department of Agriculture
WHC	Water Holding Capacity

1 Abstract

At the University of Georgia, Tifton Campus a crop-coefficient model for scheduling irrigation on cotton in Georgia was developed and tested during the 2012 growing season. The model uses a check-book approach to estimate when available soil moisture has been depleted by adding precipitation and irrigation to available soil moisture and subtracting FAO-56 evapotranspiration (ET) adjusted by the crop coefficient from it. It was used to schedule irrigation in four experimental blocks at the University of Georgia's Stripling Irrigation Research Park (SIRP). Soil water tension in the experimental blocks was recorded continuously with a Watermark-based soil moisture sensing system. The model will be developed into a smartphone App and beta-tested during the 2013 growing season.

2 Introduction

The following two paragraphs give a brief overview about cotton growth, and cotton irrigation in Georgia. The given environmental conditions and the management based on explicit knowledge in combination with irrigation practice lead to an economically feasible yield of lint and seed.

2.1 Physical cotton growth

Domestic cotton has its origin in a unique, tropical and perennial species. Development, breeding and cultivation of the cotton plant mainly took place in Africa, Australia, Arabia and Mesoamerica. Today different varieties of upland cotton (Gossypium hirsutum L.) are the typical species grown in the US. Despite huge breeding efforts, including genetically modification, cotton management und cultivation is still unique and difficult. Despite its natural physical precondition cotton is managed as an annual plant. That’s the way how farmers try to produce as much lint and seed as possible. The vegetation period of cotton in Georgia counts about 180-200 days. Seeding takes place at May and harvesting is expected at the end of October. The cotton plant as a dicotyledon develops its first square at 35-40 days after planting, its first flowers 60-65 days after planting and starts filling its bolls approximately 70 days after planting. Flowering is a remarkable and important process. Only pollinated flowers form cotton bolls. The bloom process takes several days. The first day, the flower has a white color, the second day it turns to a pink-like color and the third day it turns to a red flower. After 5-7 days a flower appears, it dries and falls from the plant exposing the boll. Boll development can be characterized by three stages: enlargement, filling and maturation. Optimal conditions lead a boll to “open” in about 50 days. At the beginning of maturation, the capsule walls dry, following that the cells begin to shrink and the suture between the carpel open. During the vegetation period different treatments concerning weed and insect control must be carried out like in common crops. In addition there are chemical means needed to regulate the growth and terminate it. Defoliants are used to remove leafs from the plant chemically in order to harvest the crop mechanically. (RITCHIE et al, 2004)

2.2 Cotton irrigation in Georgia

The following figures concerning implemented irrigation systems and water use give a brief overview about the actual situation in Georgia. It is not appropriate to name an amount of water which is used for agricultural irrigation because it highly depends on the weather conditions. But there are several meaningful statements concerning irrigated Acres. The total irrigation acreage during the year 2008 show a number of 1.446.754 acres (out of agricultural land). Irrigated cotton covered an area of 451.204 acres during the year 2008. Further the number 18.066 count the amount of installed irrigation systems. The most common irrigation technology (81%) is the center pivot system (HARRISON, 2009). Figure 1 shows the geographical distribution of center pivots throughout Georgia. Every red spot shows a single center pivot location.

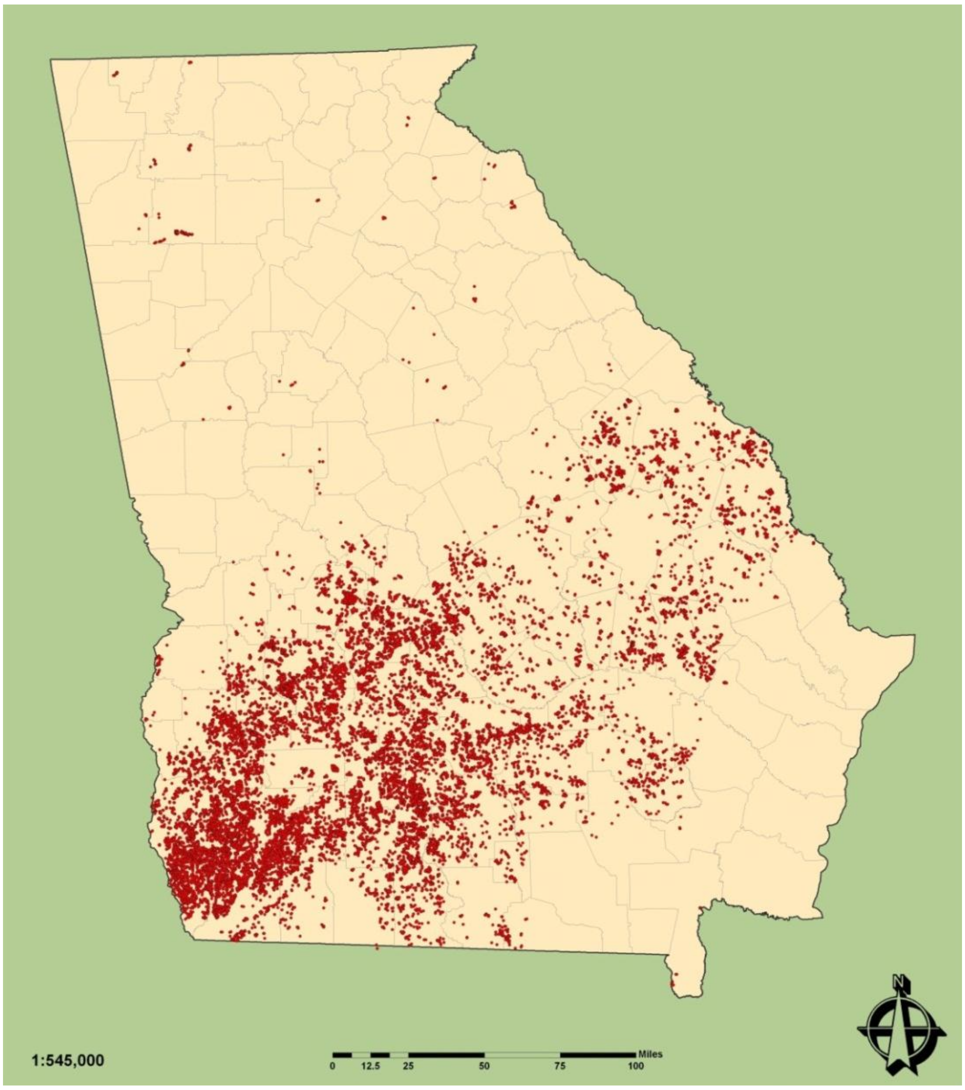

Figure 1: Georgia center pivot Locations (Source: Perry, 2012, UGA)

Cotton in general is considered as a drought-tolerant plant. Nevertheless most of the cultivated cotton plants in Georgia are irrigated. Especially areas which have frequently droughts and sandy soils require irrigation to reach a certain yield. Irrigation may improve yield from 0 to 800 lb/A. An Improvement of 200-400lb/A is common. Not only yield is influenced by water availability also fiber quality. Most critical time periods concerning water availability are during the bloom and the boll maturation. Cotton has at these stages high water requirements up to 0.3 inches per day and individual plant. (RITCHIE et al, 2004)

From an agricultural point of view irrigation of different crops has a considerable impact on plant physiology, environmental issues, and economic perspectives. The optimum of cotton irrigation is still a kind of miracle. In recent years with severe dry weather conditions many irrigated cotton fields have fallen well below expectations in terms of yield and quality. There exists a demand to research organizations to provide answers about the plant water use, irrigation timing and irrigation efficiency. Usually a farmer started irrigating when the plant started to wilt at mid-day. New research results show, once a cotton plant begins to wilt it has already been under physiological stress for some time. To optimize the yield potential under hot and dry conditions a specific amount of water prior to the signs of stress is required (FARAHINI et al, 2012).

An optimal yield requires an optimal supply of water. The goal of different research projects in Georgia is to establish practical models to find out how is it possible to supply as less water as possible but as much water as needed at a certain point of time.

3 Objectives

Precise and smart irrigation systems seem to be a solution to improve the supplementary supply of water significantly. Several approaches are already used for irrigation scheduling. Especially cotton in Georgia is a heavily irrigated crop. To get the maximum yield it is important to irrigate at a certain point at time. A proper farm irrigation management is based on any scheduling approach to determine the rate at which water stress accumulates in cotton. However, every approach shows advantages and disadvantages. The success of irrigation scheduling is usually based on the different default assumptions. To understand how climate and soil water availability affect crop the water status is primarily the key to good water practices. Water use depends on plant physiology, soil physiology and meteorological data. The named parameters vary between different regions. This variability shows a challenge for every irrigation scheduling approach. The Crop and Soil Sciences Department at the University of Georgia is working on a water balance model for cotton irrigation scheduling in Georgia. This model is supposed to be released as a Smartphone App for Georgia's cotton farmers. This approach based on regional metrological data is supposed to support the farmers to find a quick and proper irrigation decision.

4 Material and Method

The following sections show the sources and meaning of different parameters which are used to develop a water balance calculation method (check-book method) under local conditions in Georgia. Furthermore the method how to calculate important parameters for irrigation scheduling will be explained.

4.1 Field experiment

A model to schedule cotton irrigation in a humid climate in Georgia was developed and tested in the year 2012. The model was applied to four experimental blocks in Stripling Irrigation Research Park (SIRP, 31°16'43.28"N, 84°17'47.81"W, elevation 160 ft) in Camilla, Georgia. Cotton was planted in the Newton Lateral South plots in May 18. The planted variety is DP 1252 B2RF. Half of the plots is conventional tillage with sub-soiling. The other half is long-term conservation tillage (strip-tillage with sub-soiling). Wheat cover crop was burned down in early April. A total of 78 lbs of nitrogen have been applied. PGR (Stance 3 oz/ac) has been applied twice. Standard herbicide and insecticides have also been applied. Cotton was defoliated at October 23. Harvest took place 174 days after planting at November 9. The cotton crop received 2602 heat units during the growing period. Irrigations treatments were carried out according Vellidis K_c-method after July 25. Prior to that point of time irrigation was scheduled according to “IrrigatorPro”. “IrrigatorPro” is another irrigation scheduling tool provided by United States Department of Agriculture, Agricultural Research Service (USDA) which was used while Vellidis-K_c-method was under development.

4.2 Checkbook approach

The model uses the check-book approach. This method was developed by Lundstrom and Stegman in 1988. The water balance is calculated like a checkbook, inputs like precipitation and irrigation are credited to the total soil water and withdrawals like evapotranspiration are debited from the soil water. Regional variations make these parameters unsuitable for use across multiple regions. Soil water balance calculations depend on local and plant physiological conditions (LUNDSTROM et al, 1988). Several applications of the check-book method for different regions and different crops are already available. The following abstracts describe the development of a K_c-calculation-method especially for cotton cultivation in the humid climate in Georgia.

4.3 Parameters

Different parameters are used to estimate reliable values for the irrigation scheduling method. Involved parameters are parameters concerning plant physiology like K_c-factor and rooting depth. Metrological data are represented by evapotranspiration and rainfall. Regarding soil physiology properties water holding capacity will be taken into account.

4.3.1 Plant physiological stages

Several classifications are available to determine the plant physiological stages. To develop a crop specific irrigation scheduling tool a specific crop coefficient which adjusts the evapotranspiration values is required to estimate the daily water use. The K_c-values which are used in the Vellidis K_c-method are provided by Ed Barnes. A study on K_c-values on cotton in humid climate was conducted in Northeast Louisiana and Stoneville, Mississippi in 2011 (FISHER et al, 2012). According to the results of this study the plant phenological stages and the matching K_c-values have been determinated. To assign a proper crop coefficient to a certain time period the continuously changing crop coefficient-function was translated into five different observable phonological stages. Two slightly different scenarios how to assign the K_c-value to a certain time period during the growing season have been tested during the development of the Vellidis K_c-method. The first scenario assigns the K_c-value to different growth stages according to the phonological change during a growing season (Table 1). To apply the method for commercial use the determinate plant phonological stages need to be categorized and applied to the calculation method through observation.

Table 1: K_c-factor assigned to the obervable phenologicalstages (Source: own figure)

phenological stage	Assumed length of stage (days)	Recorded length of stage (days)	Avg Kc
Emergence/Initial	25	25	0.48
First square	35	35	1.02
First flower	70	59	1.41
80%at least 1 open boll	no recommendation	21	0.75
50% open bolls	no recommendation	34	0.55

The second scenario allows calculating the plant phenological stage through the growing degree day (GDD) method. Growing degree Units in Fahrenheit are calculated like in equation (1).

$$growing\ degree\ units = \frac{Temperature(F)_{max} + Temperature(F)_{min}}{2} - 60 \qquad (1)$$

The K_c-factors are assigned to the phenological stages which are determinate through specific threshold levels of Growing Degree Units (Table 2).

Table 2: K_c-factor assigned to the Growing Degree Units (Source: own figure)

phenological stage	GDU Fahrenheit	Recorded length of stage (days)	Avg Kc
Emergence/Initial	50	30	0.48
First Square	550	25	1.02
First Flower	950	65	1.41
80% at least 1 open Boll	2150	22	0.75
50% open bolls	2450	21	0.55

Maximum and minimum temperature allow to calculate the Growing Degree Units and following that the different growth stages can be assigned automatically without observation.

4.3.2 Precipitation and irrigation

Irrigation is supposed to guarantee the water supply for plants in addition to precipitation. To know which amount of water is needed to replenish the missing amount, daily precipitation records are required. In Georgia the GAEMN a meteorological network established by the University of Georgia allows to get automated precipitation data from weather stations in a maximum distance from about 50 miles. The objective of Automated Environmental Monitoring Network is to collect reliable weather data for agricultural and environmental purposes and applications. 77 sites provide daily several meteorological data.

Irrigation needs to be recorded by the people who apply the irrigation scheduling method e.g. farmers or consultants. For the experimental blocks the nominal amount of applied water was recorded by employees of Stripling irrigation Research Park and collected in a daily updated excel spreadsheet.

4.3.3 Evapotranspiration

The evapotranspiration process refers to two separate processes. On the one hand evapotranspiration refers to the water which is lost by the soil surface and on the other hand there is loss form the crop surface by transpiration. Both ways of water loss are lumped together as “evapotranspiration” or ET (Figure 2) (SASSENRATH et al, 2012). Different approaches are available to estimate evapotranspiration. The results from different methods are slightly different. The ET which is used in the following irrigation scheduling approach is based on the Pennman-Monteith-Method which is published in the FAO-paper 56. This calculation approach is known an international adopted approach.

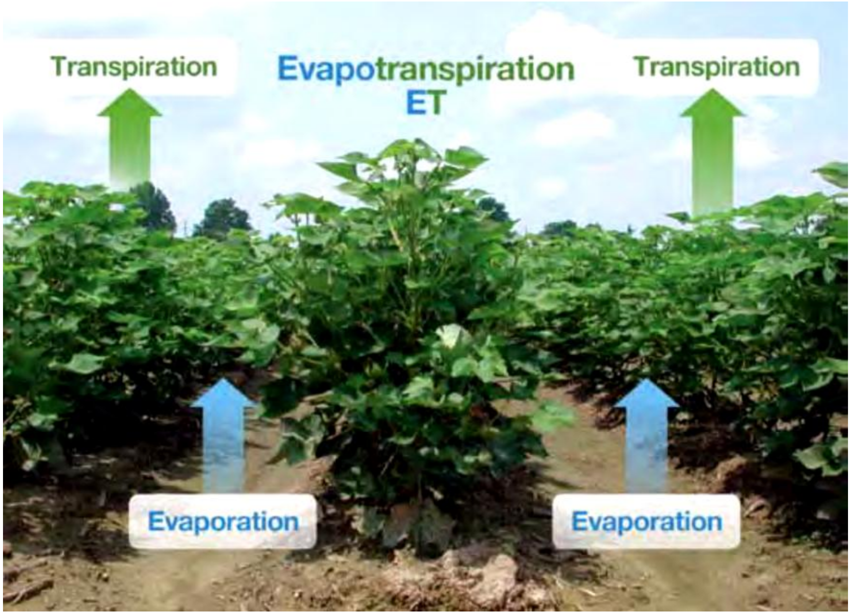

Figure 2: “Evapotranspiration” and commonly abbreviated “ET.” (Source: SASSENRATH et al, 2012)

4.3.4 Soil properties

Physical soil properties show a further important factor which influences the irrigation scheduling method. The availability of water storage depends on the soil type. A representative factor which needs to be included in the irrigation scheduling method is the Water Holding Capacity. Each soil type and also the different Soil layers show a different Water Holding Capacity according to its physical soil properties. The Natural Resource Conservation Service, an extension service that belongs to USDA provides an online web soil survey over all states in the United States. These data are accessible for free. To create a solid baseline for the water holding capacity data in the model data provided by NRCS are included.

According to NRCS Web soil survey the soil type of the experimental block in Stripling Irrigation research Park is Lucy loamy sand, 0 to 5 percent slopes (LmB). The Water Holding Capacity of this soil type shows a value of 0.11 inch per inch. The soil profile depth in total is recorded with 72 inches.

4.3.5 Rooting depth

Rooting depth belongs to the plant physiological data. It is one of the most critical parameters. Different factors for example: soil conditions, climate, variety, etc. have an influence on this parameter which causes a high heterogeneity within a short local distance. Even from plant to plant a difference can be identified. A conversation with a local expert leaded to assume root growth until Midseason and a final average of 36.60 inch. There is no useful information available about the temporal distribution of root growth during the growing season. This results in the rough assumption of a linear connection between days after planting and rooting depth until Midseason. Especially in the Vellidis-K_c-method an additional root growth of 0.6 inch per growing day until Midseason is assumed. After Midseason a fixed value of 36.60 inch is assumed.

Another option how to estimate the rooting depth is to assign a specific value to a growing degree unit (GDU). The second scenario of the Vellidis Kc-method assigns a value of 0.06 to each GDU until the final rooting depth of 36.60 inches is reached.

4.4 Calculation method

The described parameters provide the basis for the estimations of daily soil water availability and daily soil water depletion.

Water depletion is estimated according to FAO 56 as a product of an 5-day moving average of evapotranspiration (ET avg) and the specific crop coefficient (K_c).

$$daily\ water\ use = ET_{avg} \times K_c \tag{2}$$

Maximum water availability is calculated as a function of Water Holding Capacity (WHC) and rooting depth.

$$maximum\ available\ water = WHC \times rooting\ depth \tag{3}$$

To calculate the specific amount of water which is available at a specific point of time during the growing season daily water use is subtracted and rain and irrigation amounts are added to the available amount of water from the previous day.

$$available\ water\ today = amount\ of\ water\ from\ previous\ day - daily\ water\ use + rain + amount\ of\ irrigation \tag{4}$$

The required parameter were daily added to an excel spreadsheet. Based on the daily results the point of time and the needed amount of irrigation water has been determined.

4.5 Daily Evaluation of the Vellidis K_c-method and determination of the irrigation amount

To evaluate the results of the Vellidis K_c-method reference values are required. These values are provided through UGA watermark units. The applied soil moisture monitoring system has been developed at the Crop and Soil Sciences department at the University of Georgia, Tifton campus. One watermark sensor unit consists of sensors and electronics which collect hourly soil moisture data in three different depths. The depths are 8 inch, 16 inch and 24 inches. In each of the experimental blocks one watermark sensor unit has been installed to record soil water tension values.

To be able to evaluate the results of the Vellidis K_c-method the soil moisture data has been extracted and compressed. The calculated value was generated once per day in the morning therefore the soil moisture data which were daily recorded at 8.00 AM have been selected to evaluate the results of the Vellidis K_c-method. An average of two watermark units (one in each experimental block) for the conventional tillage and an average of two watermark units (one in each experimental block) for the strip tillage provided the reference values to evaluate the Vellidis K_c-method during its development. Despite the evaluation of the two different tillage systems no difference in the applied amount of irrigation water has been made. The Vellidis K_c-method itself doesn't allow distinguishing between strip and conventional tillage. The goal of the daily comparison was to observe the performance of the calculation and adjust different parameters if necessary to be able to keep the soil moisture values in the depth of 16 and 24 inches between 60 and 80 kPa.

The following graphs show the performance of the Vellidis-K_c-method in comparison to the soil moisture values.

5 Results

Figure 4 and Figure 3 show the different results and calculated values over the complete growing season of the conventional cultivated research plots. Figure 4 shows the first scenario where the K_c-factor is assigned to the observation of the five different defined growth stages by the method user. The Graph shows a direct comparison of the values generated by UGA watermark units and the calculated values by the Vellidis K_c-method. The green, blue and purple lines on the top part of the chart show the soil moisture values of every single day in 6, 8 and 24 inches soil depth at 8.00 AM. The lower part of the chart shows a blue line which gives an overview over the precipitation amount. The red line shows the calculated available amount of water and the orange line shows the recommended amount of irrigation water according to the calculated available amount of water.

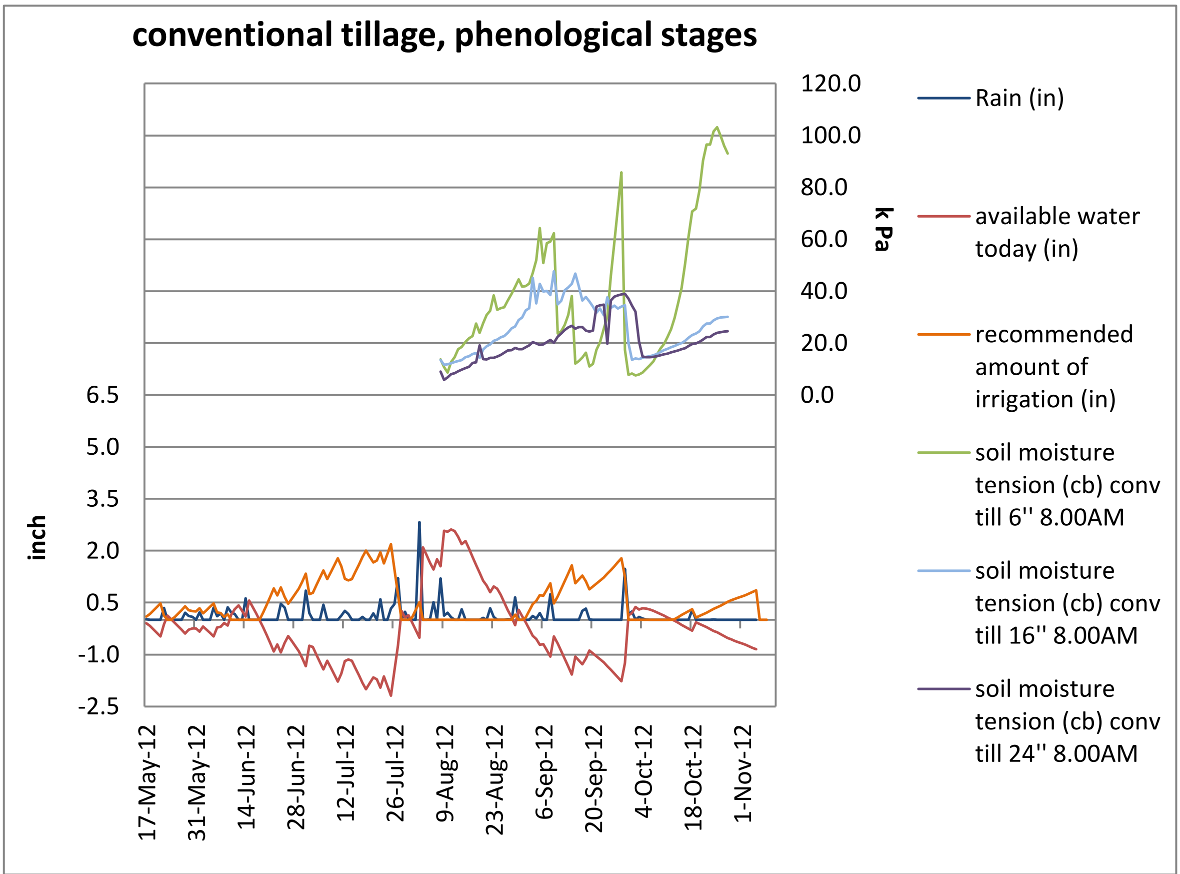

Figure 3: Comparison of the UGA soil moisture unit values in an experimental field cultivated with conventional tillage and the associated Vellidis-K_c-Method values, calculations based on observed phenological stages (first scenario). (Source: own figure, 2012)

Figure 3 show the same parameters as in Figure 4. The values in the lower part of the graph present the second scenario where the K_c-factor is assigned to the Growing Degree Units.

The UGA watermark units are used as reference. The model is supposed to call for irrigation when soil water tension exceeded 60 kPa at 16 or 24 inches. During the first part of the growing season the model performs well. From the stage of “80% at least 1 open boll” the first scenario calls for irrigation when the soil water tension is much lower than 60 kPa. It means that the model would overwater the soil. In comparison to the first scenario the second scenario shows a better performance. The soil water tension values and the calculated “available amount of water” show a better accordance in the second scenario than the values of the first scenario.

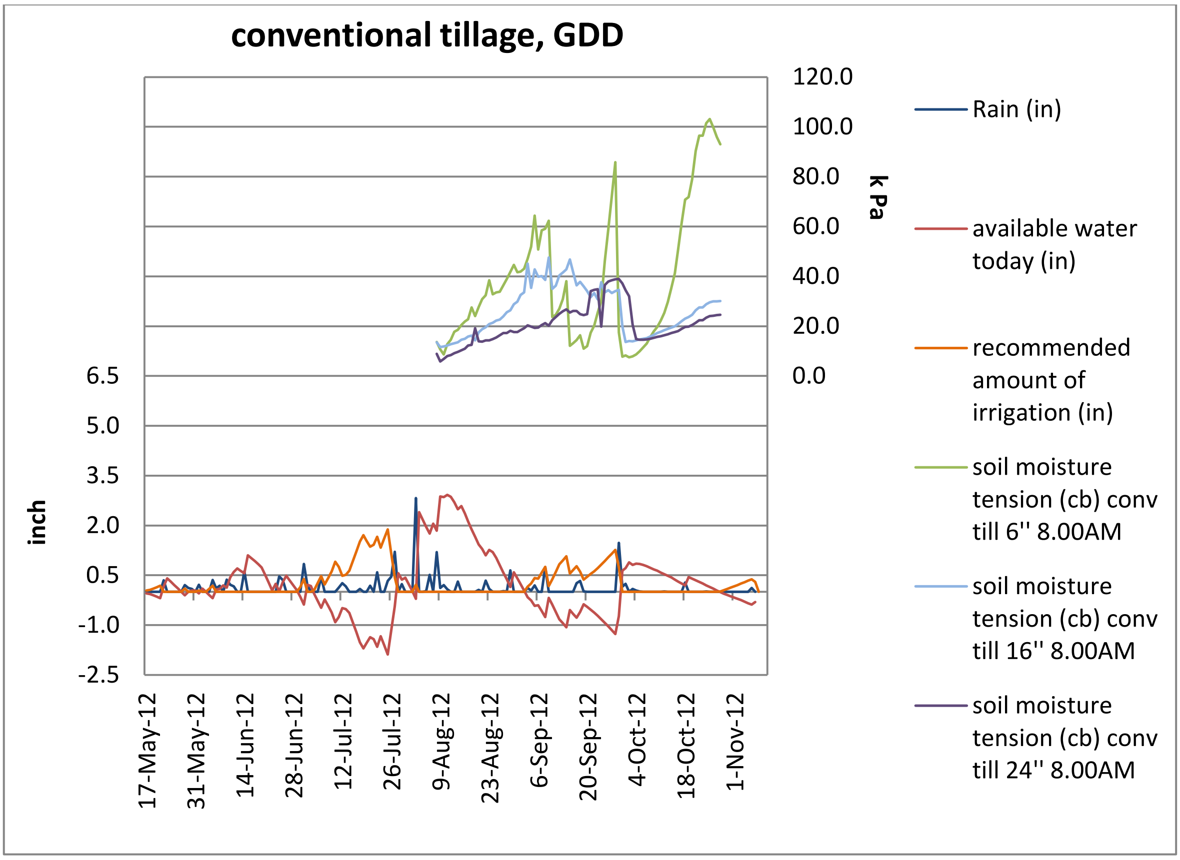

Figure 4: Comparison of the UGA soil moisture unit values in an experimental field cultivated with conventional tillage and the associated Vellidis-K_c-Method values, calculations based on Growing Degree Units (second scenario). (Source: own figure, 2012)

6 Future work

The development of the Vellidis-K_c-Method started during the growing season 2012 and was adjusted as much as possible. But different problems have been faced during the past growing season. To startup the model a completely saturated soil profile is assumed. Less rain during several past winter times and spring times does not guarantee a completely saturated profile at planting. A solution needs to be found to determine the soil moisture value at the start of the model. Moreover the rooting depth is one of these aspects which raise the question how to determine the rooting depth. Another point which needs to be considered is the cultivation method. During the experiment a difference between conventional and strip tillage could be observed (Figure 4, Figure 3, Annex Figure 5, Figure 6). Therefore a study concerning the soil moisture structure in different cultivation systems in Georgia would be needed. If a significant difference concerning the soil moisture structure will be discovered another parameter should be implemented to the model. Further the model needs to be tested in another growing season if the performance of the second scenario is really the better one, maybe it provided just for this specific year better results. In addition yield needs to be considered as an evaluation factor. How is the yield affected by the model? For the year 2012 there are no reliable results available. No significant difference between the final yield of the irrigated and the non-irrigated plots could be identified. Since in 2012 19.48 in were provided by rain and just 5.17 in of water were supplemented trough irrigation.

These questions need to get clarified in a beta test during the 2013 growing season. The next step is to program and release the App to be able to use it on demonstration sites during the 2013 growing season. The data needs to be collected precisely to be able to evaluate the performance of the applied tool and answer the named questions.

7 Literature

FARAHANI, H., MUNK D., 2012 Benefits of irrigation. In: Perry, C., Barnes, E. Cotton irrigation managements in humid regions. Cotton Incorporated

FISHER, K., UDEIGWE, T., 2012. Cotton Water Requirements. In: Perry, C., Barnes, E. Cotton irrigation managements in humid regions. Cotton Incorporated

HARRISON, K., 2009. 2008 Irrigation survey. UGA University of Georgia Collage of Agricultural and Environmental, Cooperative Extension Service, Tifton Georgia 31793

LUNDSTROM, D.R., STEGMAN, E.C., 1988. Irrigation scheduling by the checkbook method. NDSU Extension Service, North Dakota State University, Fargo ND 58105.

RITCHIE, G.L., BEDNARZ, C.W., JOST, PH.H., BROWN,S.M., 2004 Cotton Growth and Development. UGA University of Georgia Collage of Agricultural and Environmental, Cooperative Extension Service, Tifton Georgia 31793

SASSENRATH, G., SCHMIDT, A., LEIB, B., 2012. Irrigation scheduling Tools. In: Perry, C., Barnes, E. Cotton irrigation managements in humid regions. Cotton Incorporated

Annex

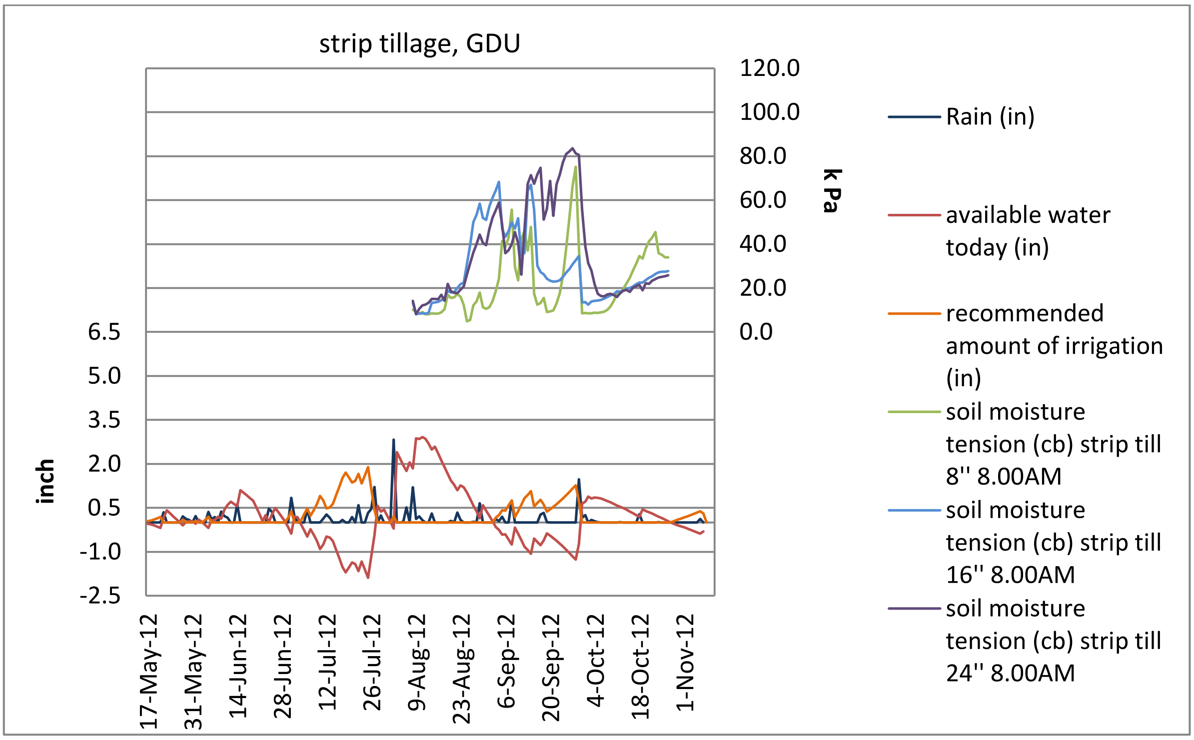

Figure 5: Comparison of the UGA soil moisture unit values in an experimental field cultivated with strip tillage and the associated Vellidis-K_c-Method values, calculations based on Growing Degree Units. (Source: own figure, 2012)

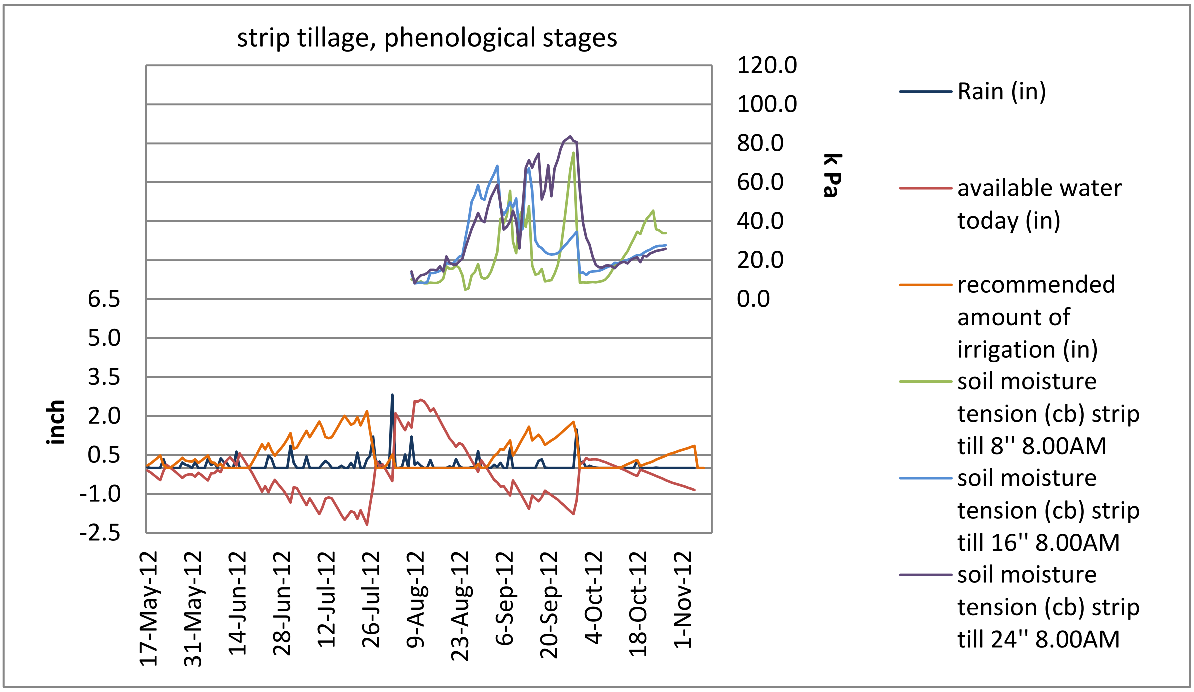

Figure 6: Comparison of the UGA soil moisture unit values in an experimental field cultivated with conventional tillage and the associated Vellidis-K_c-Method values, calculations based on observed phenological stages. (Source: own figure, 2012)

Affirmation

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