Crop Modeling of Field Trial Data to Estimate Crop Coefficient (Kc) for Weather Station Network-based Irrigation Scheduling System in Aral Sea Basin Site

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SUMMARY

The report provides details on DSSAT modelling results, financed by International Centre for Agricultural Research in the Dry Areas (ICARDA, Activity #912101) and conducted by NGO KRASS within CRP DS activity: Improving water-use efficiency through innovative technologies in irrigation and farming in cereals, potato, vegetable, horticultural and fodder crops.

In CRP-DS contract an agreement was signed between KRASS and ICARDA that pinpointed collaboration between both institutions in the field of crop modeling winter wheat and cotton with DSSAT v4.6 model to develop of crop coefficients for winter wheat and cotton using agronomic data collected in the previous field experiments conducted by KRASS.

The agreement included as well the annual reporting of the activities. This report covers the period 1 October 2013- 31 December 2015, and documents the cotton and winter wheat modeling results to complete the this task implemented: (1) compilation of agronomic and irrigation management data from the past experiments for crop modeling with DSSAT decision support tool, (2) calibration of DSSAT tool to winter wheat and cotton crops, and (3) development of crop coefficients for winter wheat and cotton using crop growth simulation with long-term weather data.

OUTLINE

INTRODUCTION

Cotton (*Gossypium hirsutum* L.) plantation is predominant in the irrigated cropping systems of Uzbekistan. After Uzbekistan's independence in 1991, winter wheat cultivation (*Triticum aestivum* L.) has gradually gained importance but has become, next to cotton, the second strategic crop with the aim of satisfying domestic food needs (Guadagni et al. 2005). Whereas, during the Soviet Union period, the area under wheat in Uzbekistan amounted to around 0.62 million ha (Mha) (in 1992) only and mainly limited to the rainfed areas, following independence the total area rapidly expanded to 1.4 Mha in 1997 and has remained virtually the same since (FAOSTAT 2014).

By promoting winter wheat, Uzbekistan aimed at self-sufficiency in grain production and a decrease in the prior, long-lasting dependency on foreign wheat imports (Eshmirzaev and Yusupov, 1994). At present, winter wheat is cropped annually on almost 31% of the irrigated regions of Uzbekistan (FAO 2014) and cotton-wheat based systems have become the major crop rotation systems in the country (Conrad et al. 2010).

On the other hand, agricultural production in Uzbekistan, including winter wheat, is virtually possible under irrigation only. Yet, as a consequence, producers have to cope with gradually decreasing irrigation water supplies, as well as with secondary soil salinization, low organic matter contents and declining soil fertility, which in turn constrains crop production (Riskieva, 1989).

Decision making and planning in agriculture increasingly makes use of model-based decision support tools, particularly in relation to changing climate issues. Many researchers applied crop growth simulation models, mostly mechanistic, i.e. they attempt to explain not only the relationship between parameters and simulated variables, but also the mechanism of the described processes (Challinor et al., 2009, Nix, 1985, Porter and Semenov, 2005). Hence, much progress can be expected from the use of quantitative, system-dynamic modeling tools, such as crop-soil simulation models, on increasing the understanding of environmental parameters on production and productivity. Hence, with the support of modeling tools, research efforts can be effectively complemented, in particular when integrating key variables or assessing the impact of various variables on production and productivity. In turn, research may, thus, advance with relatively modest means.

Crop simulation models are nowadays widely applied in agriculture to estimate agronomic, environmental and economic interactions of crop management, soil and atmosphere. From an array of models, the model framework DSSAT (Jones et al., 2003) was firstly used in Uzbekistan for assessing cotton and winter wheat production. Like many crop models, the existing DSSAT crop modules are prepared in a way that further use is feasible by a parametrization and calibration of crops, in the case of this study, cotton and winter wheat, before a more systematic use can be envisaged.

I. Development crop coefficients for winter wheat

1.1. Methodology

The parametrization of the existing DSSAT winter wheat module was based on a complete data set from 2005/06 season. The data was collected from a researcher-managed, on-farm trial conducted on a 1-ha sized field at the Amir Temur Farmers' Association (41°60′N, 60°51′E, 101 m ASL) in the Urgench District of the Khorezm Province (Djumaniyazova et al., 2010). For validation, from Hushnudbek Farmers' Association (41°34855′N, 60°538017′E) in the Yangyarik District of Khorezm.

The climate in the study area is continental and arid, with an annual rainfall of about 100 mm. Following the cold winter, spring is notoriously short and immediately followed by hot, dry and long summers (Glazirin et al., 1999). The annual mean air temperature is about 13°C, but maxima of +42°C (June) and minima of -24°C (January) were recorded during the study period. Each year, about 280 frostfree days occur.

Air temperature, relative air humidity, solar radiation, rainfall and wind speed were recorded with an automatic weather station (WatchDog 900ET) every 30 minutes at the experimental sites.

Experimental design and data collection

To understand the effects of irrigation water amounts in combination with nitrogen (N) fertilizer-use efficiency on winter wheat production (only the local cv Kupava R2 was subject of the research), a two factorial, split plot experiment was implemented, with soil moisture level as the main factor and N level as the split factor. The three irrigation treatments were completely randomized, as were the four N fertilizer levels. The blocks were replicated four times. Plots were 12 m × 10 m in size each.

Second irrigation date: Leaching and irrigation on December 26, 2014: To determine the amount of soil water the wheat crop was allowed to take up before the next irrigation event, the Management Allowable Depletion (MAD), expressed as a percentage of the plant-available water (USDA-NRCS, 1997), was calculated. Hence, for the trial, three MADs were imposed: 65% (Low), 75% (Medium) and

80% (High) of field capacity (FC), representing, respectively, a moisture deficiency (hereafter called WL1), the proxy of an optimal soil moisture (WL2) and a surplus moisture level (WL3). For irrigation scheduling, soil moisture content was estimated by soil sampling. Gravimetric water content determination was carried out every two days throughout the season. Irrigation time was determined according to the imposed soil moisture level for each treatment. The amount of the irrigation water applied was measured with a Cipoletti weir (Table 1).

Table 1: Applied amounts of irrigation water and number of irrigation events during the study seasons

Irrigation-level	2005/06		2006/07	
	Amount, mm	Frequency	Amount, mm	Frequency
Low	521	6	472	6
Medium	469	7	447	7
High	-	-	430	8

In addition to imposing soil moisture content, four levels of N-fertilizer application were compared: 0, 120, 180 and 240 kg N ha^{-1}. Prior to the application of the N-fertilizer, a basal dressing of single superphosphate at a rate of 100 kg P_2O_5 ha^{-1} and potassium chloride at a rate of 70 kg K_2O ha^{-1} was applied manually before seeding to satisfy the crop demand for P and K. N was applied as ammonium-nitrate manually in three splits: 20% of the total N level before seeding, 40% at tillering and the same amount at booting corresponding to F0, F3 and F6/7, respectively, according to the Feekes scale (Zadoks et al., 1974). Winter wheat was seeded at a rate of 250 kg ha^{-1}. Tribenuronmethyl herbicide was applied at a rate of 15 g ha^{-1} for broad-leaf weed control.

Plant sampling and analyses

Plants samples were taken within a 0.5 m^2 sub-sampling area at F3, F6/7, F8/9, F10 and F10-3 stages. For each sampling period, plant samples were separated into stems, leaves and florescence. Fresh weights were measured with an electronic scale whilst the dry matter (DM) was determined after drying sub-samples with a known fresh weight at 70°C for 72 hours till constant weight. Leaf area (LA) was measured with a LI-COR 3100 leaf area scanner, whereas the Leaf Area Index (LAI) was consequently calculated as total leaf area over total ground area. Corresponding leaf DM was determined after ovendrying, and subsequently the Specific Leaf Area (SLA, m^2 kg^{-1}) calculated. At harvest, plants were sampled from 1 m^2 sub-plots, and yield and harvest index (HI).

DSSAT simulation

The DSSAT/ Cropping System Model (CSM) simulates growth, development and yield of a crop growing on a uniform area of land under prescribed or simulated management as well as by taking account of changes in soil water, carbon, and nitrogen that take place under the cropping system over time. The DSSAT/CSM is structured using the modular approach as described by Jones et al. (2001 and 2003) and Porter et al. (2000).

Data of the 2005/06 and 2006/07 seasons were used for model parameterization, whereas the data of the third year (2014/2015) were used for validation. We used the DSSAT CSM version 4.6 that simulates growth and development of a crop over time, as well as the soil water, carbon and nitrogen processes and management practices (Jones et al., 2010).

For simulating soil water dynamics, the finite difference method of DSSAT was applied that builds on the Richards equation and the Campbell (1985) model to describe soil water retention and hydraulic conductivity.

Estimation of crop coefficient for crop using DSSAT simulation

Crop coefficients (Kc) are calculated by dividing actual evapotranspiration for non-stress conditions by ET_0 (for grass) according to:

1) **ET_0** calculated using Bushland Reference ET calculator (http://www.cprl.ars.usda.gov/swmru-software-bretc.php) or using the formulas summarized in FAO 56.

2) **Actual transpiration.** After crop parametrization and validation, the selected non-stress conditions were simulated which resulted in actual evapotranspiration. Following the simulation of the non-stress scenarios, ET_a can be estimated.

3) The Kc values for each day of growing season were calculated by dividing ET_a by ET_0 . Extract/average **Kc** values for each growing stage were presented.

1.2. Results

Observed and simulated phenological growth stages of wheat matched well in 2005/06 season (Table 3). Therefore, the result of simulation used to calculate the crop coefficient dynamics during the growth of crops.

Table 3. Observed and simulated crop growth stage for winter wheat considering day after planting (DAP).

Growth stage	**Observed**	**Simulated**
Sowing	0	0
Germinate	4	2
Emergence	12	7
Term Spikelet	216	205
End Vegetation	220	223
End Ear Gr	238	234
Beg Grain Filling	243	243
End Grain Filling	259	265
Harvest	275	265

The DSSAT simulated nitrogen fertilizer rates did not affect the yield and AGB, but on water levels did make a difference. Considering all simulations for the season 2005/06, the difference between simulated and observed AGB amounted to 3% (Table 4). The corresponding RMSE and RRMSE were 431 kg ha^{-1} and 3%, respectively. This is academically a very acceptable value for accuracy and hence the findings can be taken as sufficiently robust. The same is true for the grain yield impacts by soil water level. Given the RMSE and RRMSE between simulated and observed grain yield of 134 kg ha^{-1} and 2%, respectively, the findings can be considered sufficiently robust.

Table. 4. Differences in above ground biomass and grain of winter wheat of the empirical and with DSSAT-modeled findings under three soil moisture regimes. RMSE =431 for AGB, 134 for GY; RRMSE =3% for AGB, 2% for GY.

	Irrigation, mm	AGB kg ha^{-1}		GY kg ha^{-1}	
		Measured	Simulated	Measured	Simulated
WL1N240 65-65-65%	521 mm (6)+	14164	14568	5370	5507
WL2N240 75-75-65%	469 mm (7)	15189	15645	5820	5690
RMSE	-	431		134	
RRMSE	-	3%		2%	

+ between brackets the number of irrigation events

The determination of Crop coefficients (Kc) dynamic data during the winter wheat growth started in early spring (figure 1). The resulting crop coefficients have been compared with the data available from SANIIRI. The comparison shows that the estimated Kc matches with the data from SANIIRI so we concluded that simulation results are acceptable and can be used for Khorezm conditions.

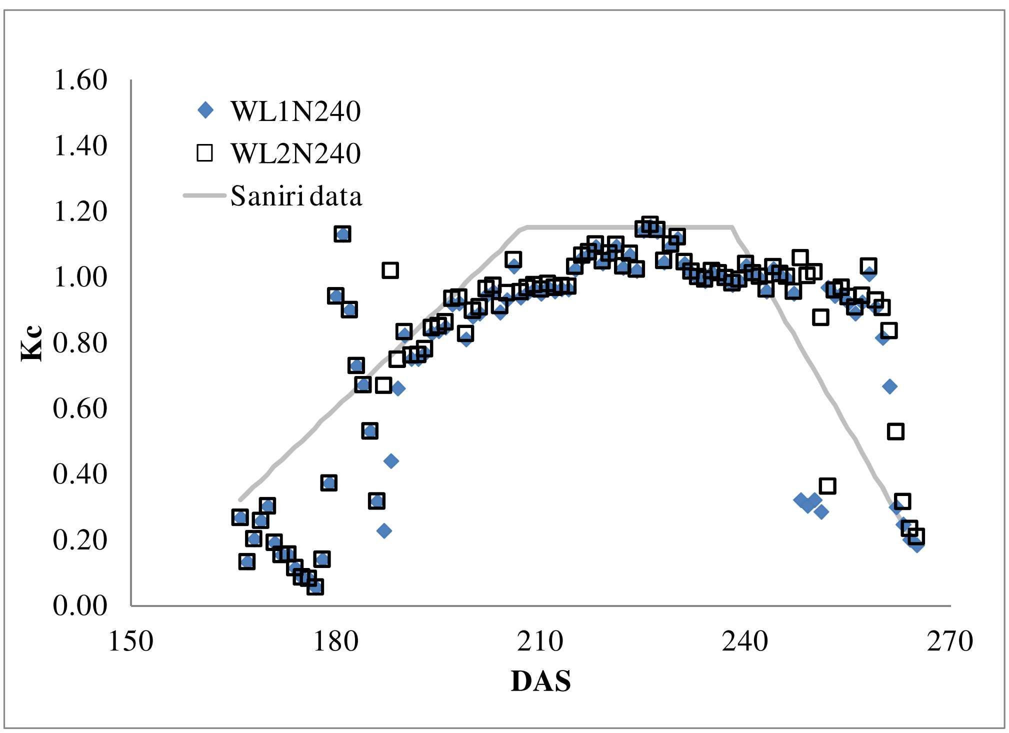

Figure 1. Crop coefficient dynamics during the growth of winter wheat for two different moisture and N application regimes (WL1N240, WL2N240) and SANIIRI data.

The maximum crop coefficient is 1.16, which matches well with the 1.2 previously estimated for similar regions in Uzbekistan SANIIRI data (figure 2). Maximum crop coefficient were determined for the onset of April mid May, about 10 days longer than the SANIIRI Kc, means longer vegetation period of the crop.

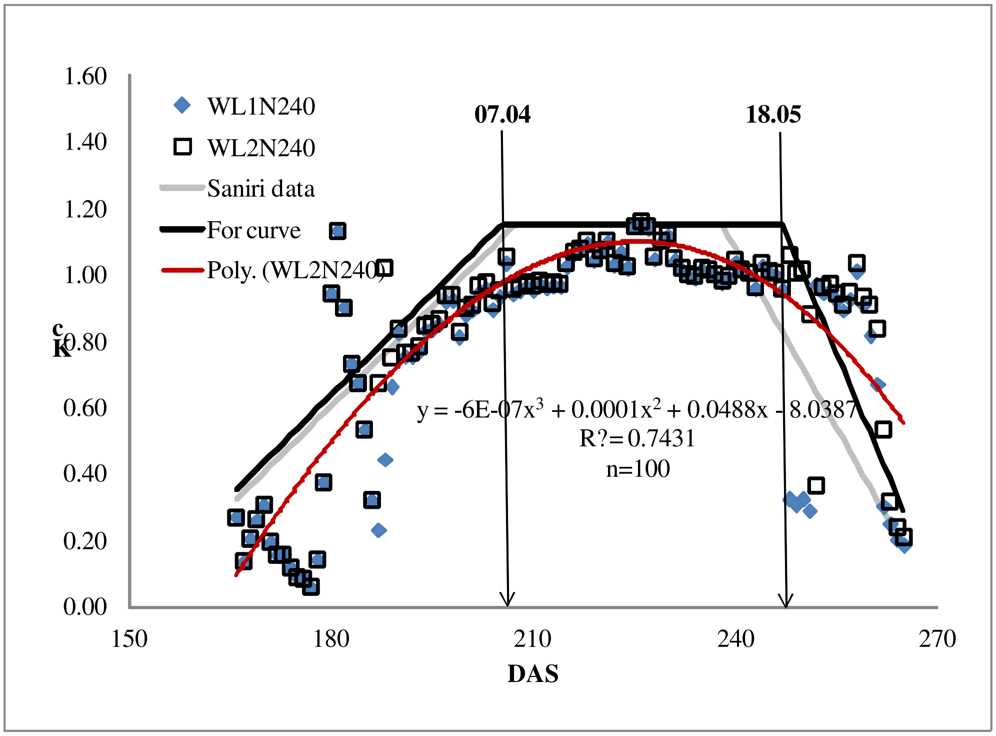

Figure 2. Crop coefficient dynamics during the growth of winter wheat two different moisture and N application regimes and SANIRI data.

The simulation data used to develop of crop coefficients for winter wheat with long-term weather data is presented in figure 3.

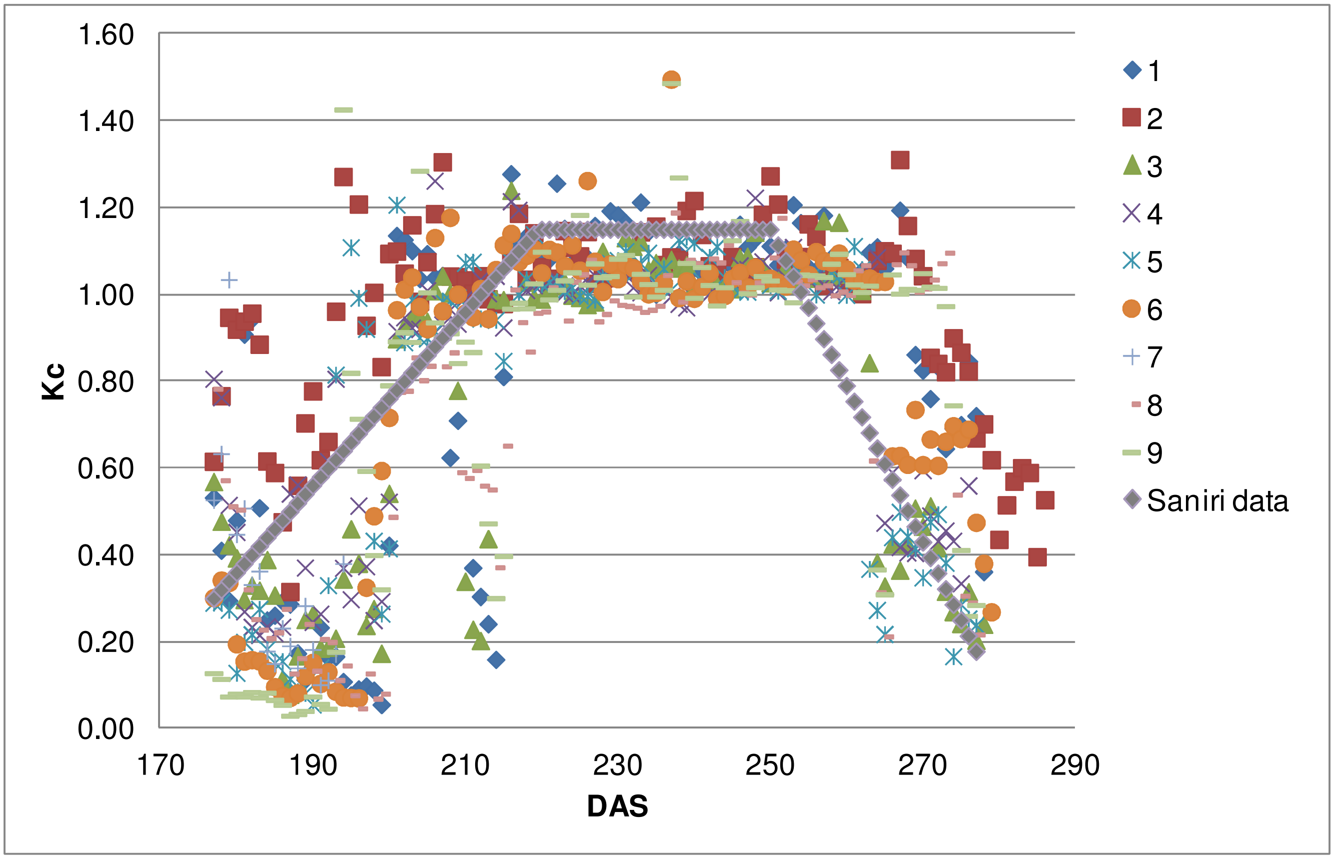

Figure 3. Crop coefficient dynamics during the growth of winter wheat for 9 seasons compared to SANIRI data.

II. Development of crop coefficients for cotton.

2.1 Methodology

The parametrization of the existing DSSAT cotton module was based on a complete data set from 2009 and 2012 seasons. Field experiments for collecting the necessary data were conducted at the research site of the ZEF/UNESCO project in Urgench District (60°40´44``N and 41°32`12``E) of Khorezm Province (Devkota, 2011; Egamberdiev, 2012). For validation, data from Hushnudbek Farmers' Association (41°34855′N, 60°538017′E) in the Yangyarik District of the Khorezm was used.

The soil in the experimental area is an irrigated alluvial meadow, with a sandy loam to loamy soil structure, low in organic matter (0.3-0.6%) and moderate to high saline (salinity ranging from 2-16 dS m^{-1}).

Based on the officially recommended N application rates for cotton of 160-180 kg ha^{-1} (MAWR 2000), N was top dressed as a band application in two equal split during budding (38 days after sowing; DAS) and flowering (52 DAS). Phosphorus (P) and potash (K) at 140 and 100 kg ha^{-1}, respectively, were applied as basal applications during sowing in all treatments. The subplot (12 m x 6 m size) treatments were completely randomized.

Irrigation water applied was measured using a standard trapezoidal Cipolletti weir combined with a DL/N 70 diver, which measured the water flow through the weir based on pressure in one-minute intervals. Cotton was furrow irrigated four times totaling 395 mm ha^{-1}.

The general inefficient and excessive use of irrigation water on the agricultural lands in the region over several decades has resulted a widespread soil salinity (Ibragimov 2007). In particular the rising ground water levels during the growing season is the culprit whereas this fluctuation of the groundwater table is driven by irrigation and leaching activities (Ibrakhimov et al. 2004). During the growing period, i.e., March to August, the average groundwater table rises up to 1.2 m and drops to about 1.8 m in October. The average salinity of the groundwater ranges between 1.68 g l^{-1} in October and 1.81 g l^{-1} in April (Ibrakhimov et al. 2004). The higher groundwater levels enhance soil salinization by annually adding 3.5-14 t ha^{-1} of salts, depending on the salinity level of the groundwater (Ibrakhimov et al. 2007). According to official government data (1999-2001), the entire irrigated area in the Khorezm Province suffers more or less from groundwater-driven soil salinization, and about 81% of the area has waterlogging problems (Abdullaev 2003). Thus, prior to crop planting, i.e., in early spring, 20-25% of the total water applied during irrigation events in in addition applied to leach the salts from fields (Conrad et al. 2011). Although perhaps effective in terms of lowering soil salinity, the leaching with such huge amounts of water raises the groundwater tables further and hence increases the risk of increasing soil salinization (Akramkhanov et al. 2010). In the absence of an efficient drainage system, this is common in most areas under saline and shallow groundwater table conditions, agriculture practices such as conservation agriculture which reduces irrigation water use and minimizes soil salinity, may help to sustain the agriculture systems.

2.2. Results

Cotton simulation results of 2009 with the aim of comparing growth stages from empirical and simulated showed good match. Only at the onset the values were slightly underestimated (Table 6).

Table 6. Observed and simulated crop growth stage for cotton considering day after planting (DAP).

Growth stage	Observed	Simulated
Planting	0	0
Budding	38	20
Flowering	52	49
Boll formation	120	129
First harvest	142	150

Cotton simulation for crop growth phenology, above ground biomass accumulation and yield results showed no difference between nitrogen rates. The crop coefficient for 2009 and 2012 year simulation used treatment with highest nitrogen fertilizer N250 kg ha^{-1} rate (figure 4). From the two year experiment, 2009 year highest crop coefficient value determined and results matched well with SANIRI data.

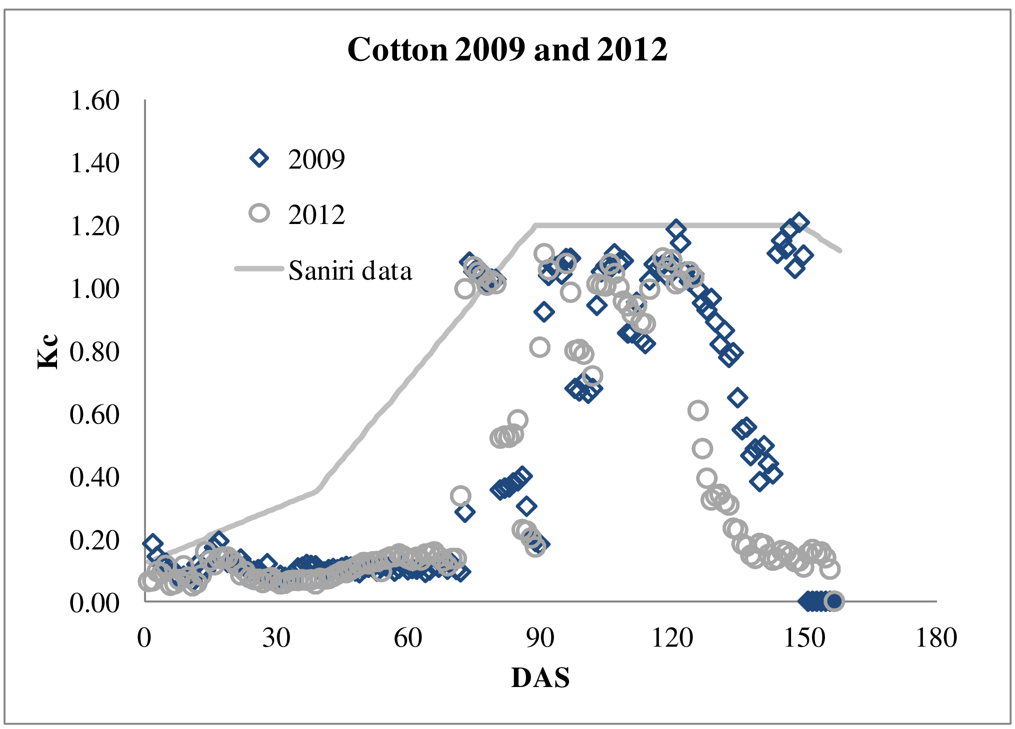

Figure 4. Crop coefficient dynamics during the growth of Cotton for two years and SANIRII data

Crop coefficient dynamics for cotton changed during the growth and maximum value reached to 1.2 acceptable result. This simulation data was used to develop of crop coefficients for cotton with long-term weather data (Figure 5).

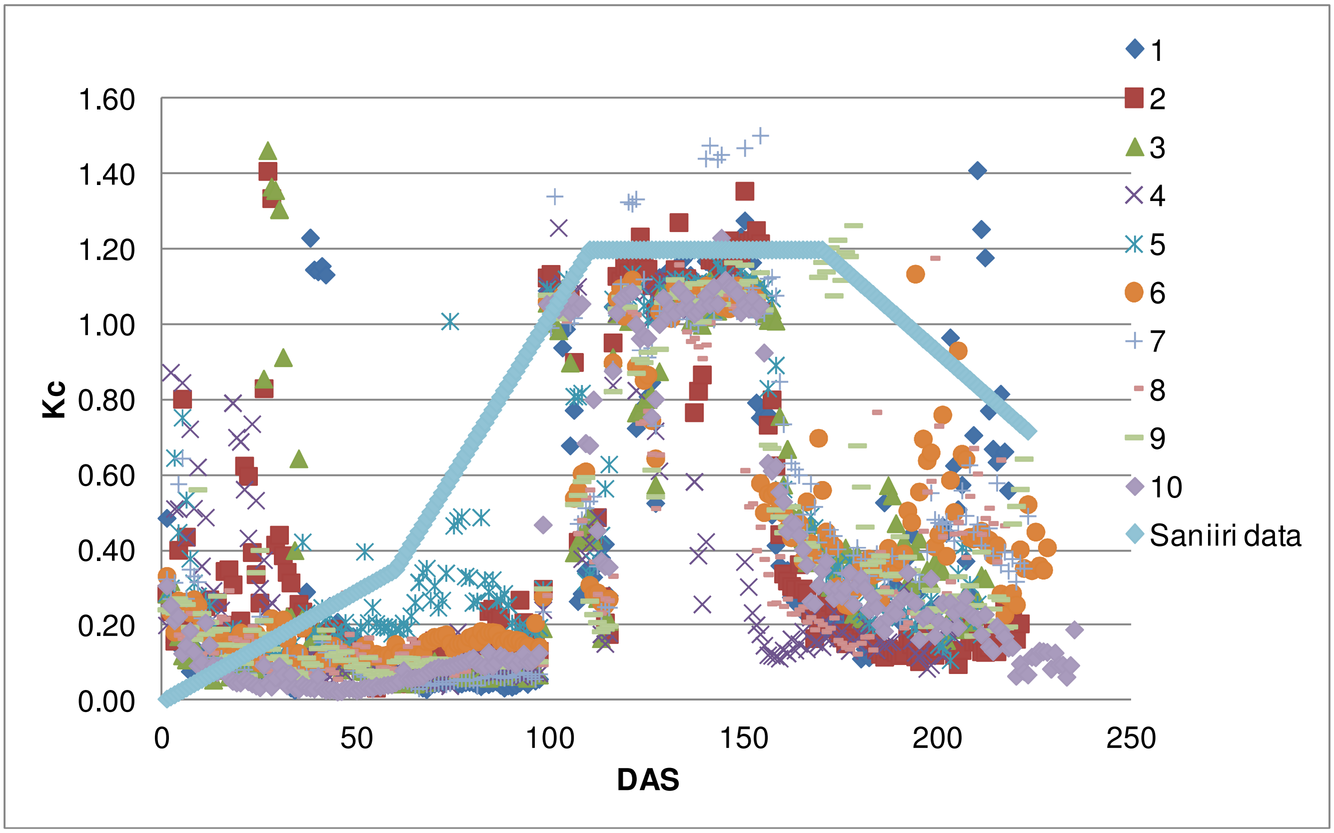

Figure 5. Crop coefficient dynamics during the growth of cotton for 10 years as to compared to SANIRI data.

DSSAT model result crop coefficient can be used for winter wheat varieties in the region and could be shared in conditions like this.

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