Validation and Application of GOSSYM. A Cotton Growth Simulation Model under the Soil, Climatic and Cultural Conditions of Spain

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ABSTRACT

A field experiment was conducted at Alcalá del Rio (Seville, Spain) on a sandy loam soil in 1994. Three cotton cultivars (Maria del Mar, Deltapine 90 and Deltapine 20) were studied. The statistical model had four splits in the following order: irrigation, density, fertilization and genotypes. Plant height evolution, main stem node number and fruit distribution were quantified on several dates during the season. The model predicted plant height, and number of main stem nodes in the first stages of development, mainly when the file mapping option was used. However, the model did not accurately predict seed cotton yield, flowering and open boll dates at the end of the season. Corrections are needed in GOSSYM to simulate cotton cultivation in Spain with reference to plastic mulch, cultivars, climate and soil type.

Introduction

In Spain the social and economic importance of cotton is considerable. It is cultivated in an area of approximately 100,000 ha in the Guadalquivir Valley (SW Spain). Production and harvesting are all mechanized. Cotton cultivation in Spain is highly intensive with an important application of inputs at all stages of production. In this area, even though high yields are obtained, surpassing 5000 kg ha-1 of seed cotton, many growers say that the costs of production are the highest in the world (Barahona, 1988).

The rationale for developing crop simulation models is that models are useful tools for the interpretation and evaluation of field experiments and for agronomic research and crop management (Whisler *et al.*, 1986). GOSSYM, a cotton simulation model, was developed to integrate all of the growth, development, physiological, and agronomic aspects of cotton production to calculate lint yields and to aid producers in making midseason management decisions (Baker *et al.*, 1983). Coupled with COMAX, an expert system (Lemmon, 1986), GOSSYM can provide management recommendations for irrigation, fertilizer, mepiquat chloride, and harvest aid applications. A survey of GOSSYM-COMAX users in 1991 cited that determining the date of water stress was the most important estimate made by GOSSYM (Ladewig and Thomas, 1992).

The model was developed and validated in the climatic conditions of the Mississippi River Delta in the USA by Mississippi State University, based on the main cotton cultivars in this area. The application of GOSSYM to other areas of the USA - New Mexico (Asare *et al.*, 1992), Texas High Plains (Staggenborg *et al.*, 1996) – required changes in calibration and validation. There has been no validation in Spain to adapt GOSSYM to local conditions. The use of GOSSYM in Spain could lead to improvements in production and greater knowledge of the growth of the crop, resulting in lower input costs and higher profitability. The objective of this study was to validate GOSSYM for the Guadalquivir Valley of western Andalusia where 90% of national cotton crop is produced.

Material and Methods

The field trial was a randomized complete block, multiple split plot design with four replications in two row plots, 10 metres long with 0.95 meters between rows on sandy loam soil at Las Torres Agricultural Research and Development Centre (Seville, Spain), planted on May 4, 1994, under plastic mulch. The statistical model had four splits in the following order: irrigation treatment, plant density, fertilization, and genotypes. Irrigation treatments were 487 l m^{-2} (IRR1) and 308 l m^{-2} (IRR2). Plant densities were 11 plants m^{-2} (PD1) and 18 plants m^{-2} (PD2). The fertilization treatments were 92 (FER1) and 66 Kg of nitrogen (FER2). The genotypes were three upland cotton cultivars, Maria del Mar (G1) from Spain, and Deltapine 90 (G2), and Deltapine 20 (G3), both from the USA. The "Jan 1993" version of GOSSYM-COMAX was used

The GOSSYM model requires site-specific information such as soil physical properties, initial soil water and N content, crop cultivar, irrigation and N inputs, and daily weather data. The soil physical properties used were supplied as part of the GOSSYM software system as soil hydrology files. The soil hydrology file used for this simulation was "CHINO 2" (Whisler, personal communication). Table 1 gives a description of soil properties such as bulk densities, field capacity, and permanent wilting point, for the four defined layers of the "CHINO 2" file. Fertilization dates and irrigation and rainfall dates and amounts are given in Table 2. Crop-specific cultivar parameters that control various growth and development processes were supplied as part of the GOSSYM software. The model does not have a file for Maria del Mar so the DP 90 cultivar file was used because of similarities between the two. Table 3 shows initial soil fertility levels, organic matter and soil water content at various depth increments.

The date of flowering and open boll was obtained by taking the day in which one flower m^{-2} or open boll m^{-2} appeared using a five m^{-2} plot. During plant development, five plants per plot were collected every 15 days approximately, starting at the beginning of June and ending at the end of September for mapping and to obtain data on plant height, number of main stem nodes and number of fruit, bolls and flowers. Cotton was hand picked on a 12-14.25 m^{-2} plot on two dates. Data collected as input to simulate plant growth by GOSSYM were weather, plant height, node number, fruit maps, and final yield. Weather data were collected from a SAINCO station (Teletransmisión Teletransa-80) 100 m from the plot.

A multiple split plot analysis of variance (ANOVA) was performed on real yield. Significance of differences among treatments were determined using Duncan's multiple range tests.

Results and Discussion

Phenology

The difference between the real values and those estimated by the model in date of first flower and first open boll show that the model undervalues the measured data by 5-12 days for first flower and 4 to 9 days for first open boll, depending on the cultivars (Table 4).

Plant height and total number of nodes

The difference between real values and those estimated by the model with respect to plant height on differents dates in the growing season show that the adjustment for plant height is generally good when we use the file mapping option but when this is not used, the model gives a very poor adjustment, principally in the Maria del Mar and DP 90 cultivars (Figure 1). The model undervalues plant height in the first 45 days after sowing (DAS), and then overestimates the height by amounts that can exceed 50% of the real value in the higher irrigation treatments until approximately 85 DAS, equivalent to a plant height of 90 cm. After this the model ajusted well to the real values (+/- 10%), although the Deltapine 90 cultivar in treatments with greater irrigation gave values that were overestimated by between 17-27%. This coorresponds with results obtained by Colomer (1997), and Colomer *et al.* (1998), who found that in cotton sown under plastic mulch, growth in the early stages of development is superior to that in the absence of plastic mulch. The opposite occurs in the middle and end of the growing season in when cotton sown under plastic mulch is significantly shorter than that sown without plastic mulch.

Difference in real values and those estimated by the model with respect to total number of nodes on different dates in the growing season show that in the first 45 DAS, the model gives a good estimates of the total number of main stem nodes but then it underestimates them by between 15-25% (1-4 nodes) in the Maria del Mar and Deltapine 90 cultivars. Deltapine 20 displayed good adjustment (+/- 10%) in the majority of dates and treatments (Figure 2).

Seed cotton yield

Comparison between observed and simulated estimate for seedcotton yields for cotton cultivars shows that a better estimate of seedcotton yield is obtained by the model when the plant mapping option is used (Figure 3). The model displayed differencial behaviour with respect to cultivars. María del Mar gave good estimates (+/- 10%) in the high irrigation treatments (IRR1) but underestimating values (40%) in the low irrigation treatments (IRR2). The model may have underestimated the real value in low irrigation treatments because this cultivar is considered drought tolerant (Gutiérrez, 1997). The model over estimated the Deltapine 90 real figure in all irrigation treatments but it was higher in the high irrigation treatments (IRR1) (45-60%) than in low irrigation treatments (IRR2) (12-18%). The model´s estimate was good for Deltapine 20 (+/- 10%) in most treatments, although in plant density treatment 1 (11 plants m^{-2}), fertilizer 1 (92 units of nitrogen), and irrigation 2 (308 l m^{-2}), value were underestimated by 18%.

The model did not detect differences between the fertilizer treatments (Figure 4), probably because of large quantities of residual nitrogen in the soil (Table 3).

The analysis of variance (ANOVA) on the real seed cotton yield (Table 5) showed significant differences for plant density, fertilization and genotypes. Irrigation was not significant but the interaction plant density and irrigation was. Yields were similar in high irrigation treatments but declined significantly in treatments with high plant density and low irrigation treatments. María del Mar gave high yields in low irrigation treatments with high plant density supporting the suggestion of drought resistance of this cultivar (Figure 5). The Duncan Multiple Range test of significance showed that treatments with low plant density, high fertilizer rates and María del Mar gave the highest yields (Table 6).

In conclusion, the model does not predict plant phenology and height and is eratic in predicting yield, depending on the cultivars and treatments. In high irrigation treatments, the model performs well for María del Mar and Deltapine 20 but overvalues Deltapine 90. In low irrigation treatments, the model is satisfactory for Deltapine 20, underestimates María del Mar and overestimates Deltapine 90. These results indicate that corrections are needed to adjust GOSSYM to Spanish cotton cultivation. The use of plastic mulch, different cultivars and the climatic and soil conditions that differ from the Mississipi Delta might help explain these conclusions. The better functioning of the model with Deltapine 20 could indicate that since this cultivar originates from the Mississipi Delta, necessary corrections in other cultivars would make the model useful tool for decision-making on cotton in Spain. The yields reached were generally high, opening the way to optimize cultivation in the Guadalquivir Valley, since high inputs have generally not used in this study.

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Table 1. Field capacity, permanent wilting point, and bulk density for four layers of the GOSSYM soil hydrology file CHINO2.HYD, used as input in the GOSSYM simulations.

Layer nº.	Depth (m)	Field capacity	Permanent wilting pt.	Bulk density (g cc^{-1})
1	0.20	0.282	0.124	1.423
2	0.46	0.292	0.156	1.293
3	0.77	0.282	0.164	1.359
4	2.01	0.272	0.169	1.389

Table 2. Rainfall, irrigation and fertilization during the experiment periodod in Seville (Spain), 1994.

DDS	Date	Rainfall mm	Irrigation (mm)		Fertilization (kg/ha)	
			Treatment 1	Treatment 2	Treatment 1	Treatment 2
0	01/25/94	0			40	40
9	05/13/94	16				
10	05/14/94	2.8				
11	05/15/94	16.8				
14	05/17/94	4.6				
19	05/23/94	6.3				
20	05/24/94	7.9				
49	06/22/94		80	60		
65	07/08/94		76	57	52	26
79	07/22/94		54	40		
86	07/29/94		55	41		
90	08/02/94		24	18		
99	08/11/94		66	49		
112	08/24/94		75	0		
121	09/02/94		57	43		
148	09/29/94	1.5				
Total		55.9	487	308	92	66

Table 3. Initial NO_3-N and NH_3- N, organic matter, and water content values by depth, used as input in the GOSSYM simulations.

Depth increment (m)	Nitrate (kg/ha)	Ammonia (kg/ha)	Organic matter (%)	Water content (%)
0.00-0.15	76	6	0.57	0.85
0.15-0.30	76	6	0.57	0.71
0.30-0.45	76	7	0.28	0.71
0.45-0.60	76	8	0.28	0.71
0.60-0.75	50	7	0.27	0.90
0.75-0.90	17	2	0.27	0.90
0.90-1.20	3	2	0	100

Table 4. Date of first flower and first open boll. Reals values (observed) and estimated by model, and difference (reals values - observed).

G	PD	FER	IRR	First Flower (DAS)			First Open Boll (DAS)		
				Observed	Simulated	Difference	Observed	Simulated	Difference
1	1	1	1	71	64	7	114	108	6
1	1	1	2	72	64	8	113	108	5
1	1	2	1	71	64	7	114	108	6
1	1	2	2	72	64	8	113	108	5
1	2	1	1	71	64	7	114	108	6
1	2	1	2	71	64	7	113	108	5
1	2	2	1	71	64	7	113	108	5
1	2	2	2	72	64	8	113	108	5
2	1	1	1	75	64	11	116	108	8
2	1	1	2	76	64	12	117	108	9
2	1	2	1	74	64	10	115	108	7
2	1	2	2	75	64	11	116	108	8
2	2	1	1	75	64	11	116	108	8
2	2	1	2	76	64	12	117	108	9
2	2	2	1	74	64	10	115	108	7
2	2	2	2	74	64	10	115	108	7
3	1	1	1	72	65	7	114	109	5
3	1	1	2	72	65	7	114	109	5
3	1	2	1	70	65	5	113	109	4
3	1	2	2	72	65	7	115	109	6
3	2	1	1	71	65	6	114	109	5
3	2	1	2	71	65	6	114	109	5
3	2	2	1	72	65	7	115	109	6
3	2	2	2	70	65	5	113	109	4

G 1 = Maria del Mar genotype; **G 2** = Deltapine 90 genotype; **G 3** = Deltapine 20 genotype; **PD 1** = Plant density 11 plants m^{-2}; **PD 2** = Plant density 18 plants m^{-2}; **FER 1** = Fertilization treatment 92 kg nitrogen; **FER 2** = Fertilizer treatment 66 kg nitrogen; **IRR 1** = Irrigation treatment 487 l m^{-2}; **IRR 2** = Irrigation treatment 308 l m^{-2}.

Table 5. Analysis of variance for real seedcotton yield.

Source	df	Mean square value
Irrigation (A)	1	1303700**ns**
A*R (error a)	6	739460
Plant Density (B)	1	1936100*****
A*B	1	788950****
A*B*R (error b)	6	70164
Fertilization (C)	1	1659700***
C*A	1	36731**ns**
C*B	1	60421**ns**
A*B*C*R (error c)	13	246430
Genotype (D)	2	19586000*****
D*A	2	189740**ns**
D*B	2	233690**ns**
D*C	2	40292**ns**
A*B*C*D*R (error d)	56	211090
Total	95	

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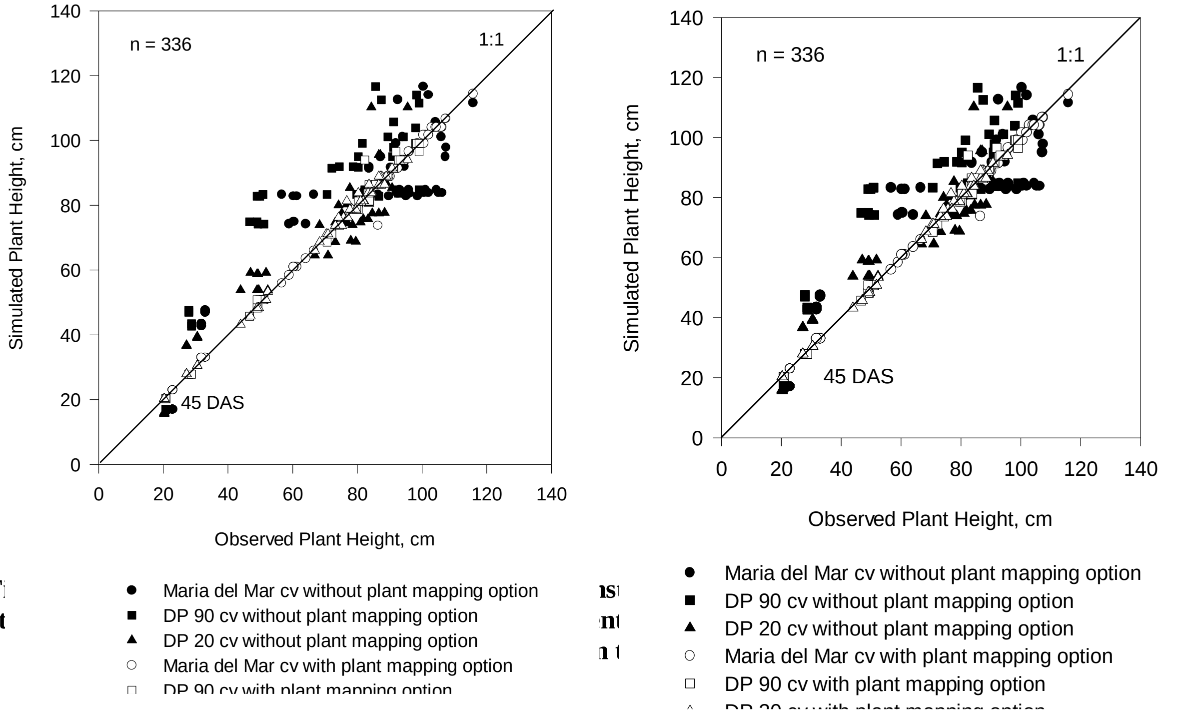
*****, ******,******* Significant at the 0.05, 0.01 and 0.001 probability levels,. **ns**, not significant at the 0.05 level

Table 6. Duncan test for real yield, plant density, fertilizers and cultivar.

Plant Density	Seed Cotton Yield kg ha^{-1}
11 plants m^{-2}	4419 a
18 plants m^{-2}	4134 b
Fertilization	**Seed Cotton Yield kg ha^{-1}**
92 kg N	4408 a
66 kg N	4145 b
Cultivars	**Seed Cotton Yield kg ha^{-1}**
Maria del Mar	5175 a
DP 20	3910 b
DP 90	3743 b

Means with the same letter are not signicantly different at the 0.05 level.

Figure 1. Comparison of observed and simulated plant height for three cotton cultivars. The data collected from plants grown on various management practices were used for model validation. They are from multiple observations in time.



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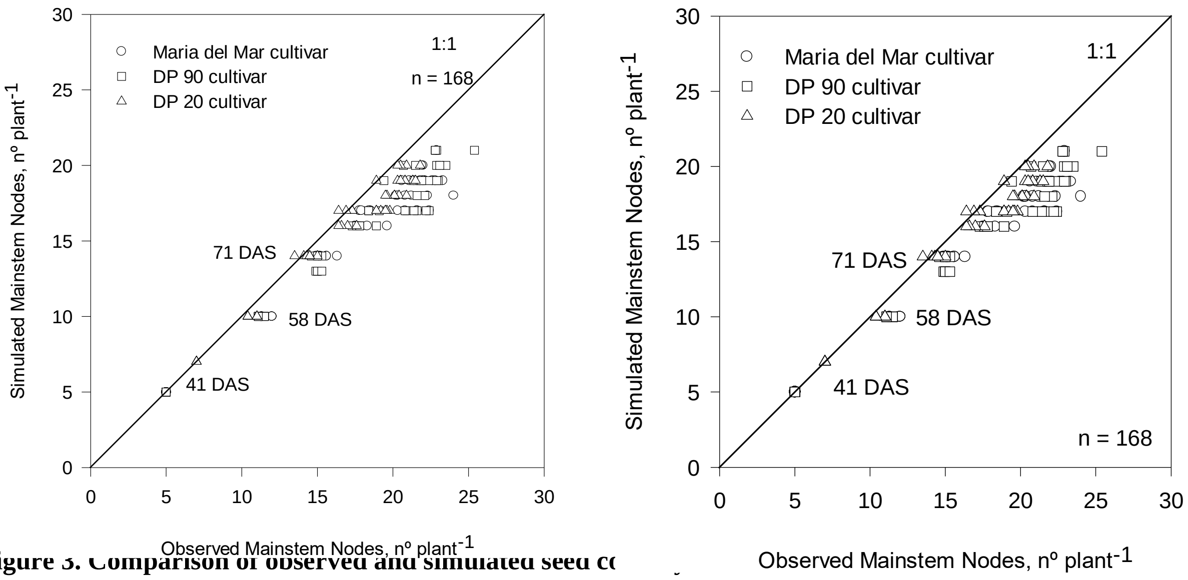

Figure 3. Comparison of observed and simulated seed co... data collected from plants grown on various management practices were used for model validation.

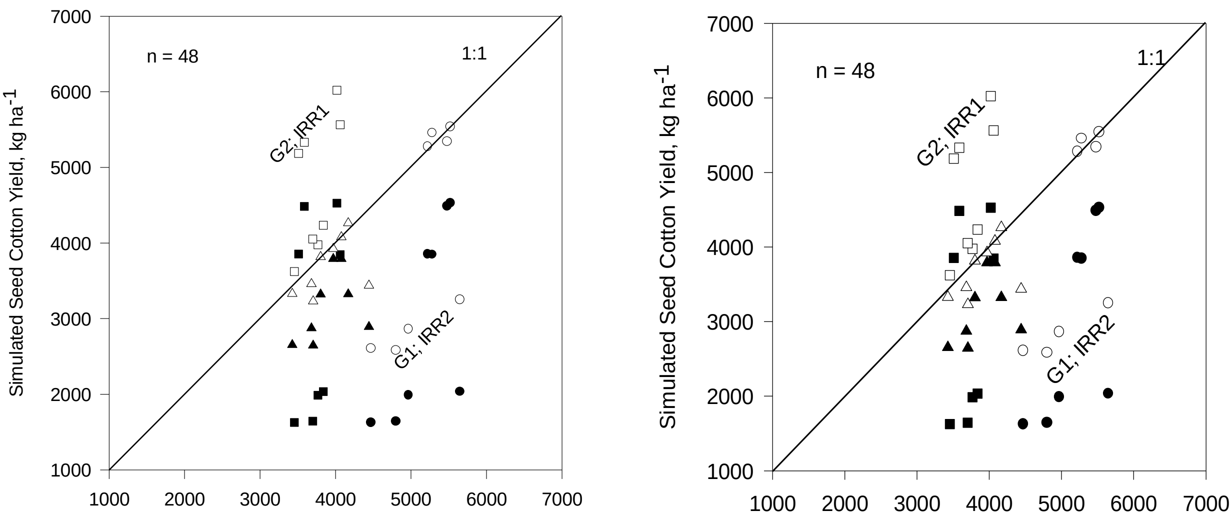

Figure 4. Comparison of simulated seed cotton yield for GOSSYM for two fertilization treatments for three cotton cultivars.

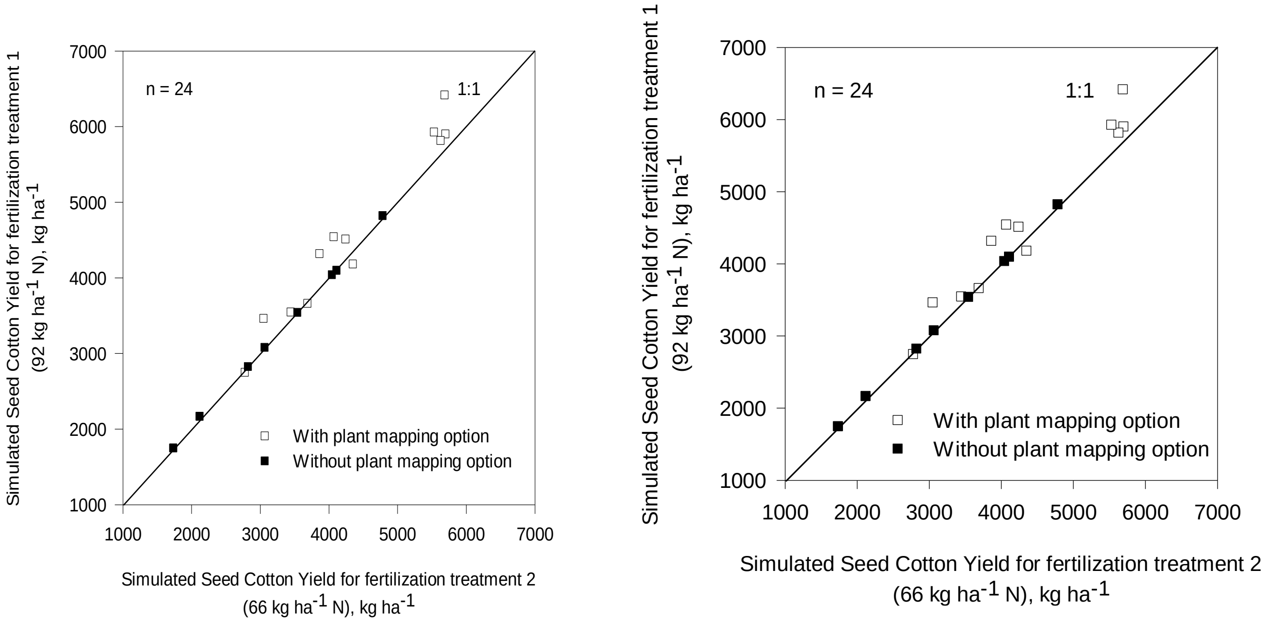

Figure 5. Seed cotton yield for three cotton cultivars on various management practices (plant densities and irrigation).