An economic evaluation of alternative pix application strategies for cotton production using GOSSYM/COMAX

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Abstract

The plant growth regulator pix (mepiquat chloride) is used extensively throughout the USA cotton belt to control excessive plant growth and to enhance early crop maturity in cotton production. Economic returns from pix use can vary greatly across different production environments. This study evaluates the economic returns to dryland cotton obtained from 12 different pix application strategies under two different soil types (Bosket sandy loam and Dundee silty clay loam) and three different weather conditions (normal, cold-wet, and hot-dry) in the Mississippi delta using simulated output from the GOSSYM/COMAX cotton management system. The most profitable pix application strategies varied by soil type. Also, economic returns were larger when using different pix application strategies for different weather conditions as opposed to using one pix application strategy for all weather conditions. Published by Elsevier Science B.V.

Keywords: Expected lint yields; Expected returns; Mepiquat chloride; Soil type; Weather

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1. Introduction

High insect pressure and high incidence of boll weathering, often accompanied by a late maturing cotton crop, are major problems of cotton producers in the Mississippi delta (AR, LA, and MS). Such unfavorable outcomes usually result in increased insecticide usage, increased defoliant applications, decreased lint quality, or decreased lint yield, which in turn reduce profitability and increase the possibility of environmental contamination. An early cotton crop decreases the likelihood of these outcomes. Cotton bolls set by early August are less attractive to the tobacco budworm, a major insect pest of cotton in the Mississippi delta (Coburn, 1994; Leonard et al., 1994). An early cotton crop tends to be less rank and leafy than a late crop, thus allowing for greater ease of defoliation (Cathey, 1986). Finally, an early cotton crop often leads to a timely harvest that escapes severe boll weathering damage from late-season rainfall events (Williford, 1992).

The plant growth regulator pix (mepiquat chloride) is used extensively throughout the USA cotton belt to control excessive plant growth and to enhance early crop maturity (Supak, 1991; Weir, 1993). pix suppresses excessive plant growth by decreasing plant height, number of main stem and branch nodes, branch length, and leaf area (Reddy et al., 1992; York, 1983a,b). It is thought that this plant growth regulator inhibits the synthesis of gibberellins which have a role in cell division and cell expansion (O'Neal, 1988). The early, uniform crop maturity that often accompanies pix use is thought to result from greater boll (fruit) retention on the lower fruiting branches of the cotton plant (York, 1983a).

Many studies have been conducted to determine the best timings and rates for pix application in cotton. The most effective pix strategies tend to vary by location, management practice, field situation, and weather (Guthrie, 1989; McCarty et al., 1990; Metzer and Wilde, 1990; Weir and Kerby, 1990; Ebelhar et al., 1996). However, most studies are concerned with the physiological effects of pix strategies on cotton (e.g. higher yields, reduced plant height, or increased earliness) and do not compare the economic returns obtained from different strategies. The objective of this study is to identify profitable pix application strategies for dryland cotton production in the Mississippi delta under different field and weather conditions. This objective is accomplished using generated output from the GOSSYM/COMAX cotton management system. Simulated lint yields and economic returns from 12 different pix strategies are evaluated by soil type and weather condition.

2. The GOSSYM/COMAX cotton management system

Actual field experimentation of a biological system (e.g. cotton production under various pix application strategies) is often too costly and too time-consuming. Formal experimentation is frequently difficult because of a lack of control of precipitation and other variables. A reliable simulation model of the biological system can be very useful in such situations.

The GOSSYM/COMAX cotton management system applies computer simulation and artificial intelligence techniques to cotton production (Albers et al., 1991). It has been tested extensively on research and commercial farms throughout the Cotton Belt (Reddy et al., 1985; Landivar et al., 1989) and has been proven to be an effective aid to cotton growers, crop consultants and researchers in the management of irrigation water, nitrogen, plant growth regulators, and crop termination chemicals (Landivar et al., 1989; McKinion et al., 1993). The system is composed of two parts: (1) GOSSYM, which simulates the growth and development of a representative cotton plant from emergence to physiological maturity (Baker et al., 1983); and (2) COMAX, which is a companion expert system that hypothesizes cultural practices to optimize growth and yield (Lemmon, 1986). This study uses the GOSSYM component to simulate dryland cotton production under different pix application strategies, soil types and weather conditions in the Mississippi delta.

The environmental inputs necessary to run GOSSYM/COMAX include daily solar radiation, maximum and minimum air temperature, rainfall, irrigation water applied, and wind speed (Reddy and Baker, 1990). Additional necessary inputs are emergence date, plant population, row spacing, latitude, nitrogen fertility and the physical and hydraulic properties of the soil (Reddy and Baker, 1990).

3. Cotton management practices and data used in the analysis

Mississippi delta cotton producers place emphasis on earliness and try to produce a cotton crop in 130 days. Many producers use early maturing cotton varieties, although some producers in Louisiana and southern Mississippi use mid-season varieties. Cotton is planted as early as possible, depending on the weather. Planting dates can vary from as early as April 15 to as late as June 5, but most cotton is typically planted between April 25 and May 25. In general, harvest starts in the last week of September and continues until the last week of November. An early harvest usually begins around mid-September and is usually completed around November 1 (D.W. Albers and M.R. Williams, 1995. personal communication). Both planting and harvest dates are highly dependent on the weather. This analysis assumed that the cotton producer uses an early maturing variety and plants cotton around May 2, with emergence occurring on May 9. Row spacing was set at 96.5 cm, the conventional row width for cotton in the Mississippi delta. The plant population was set to $\approx 99\,000$ plants ha^{-1}, and latitude was set to 35°.

Cotton is produced on a wide variety of soil types in the Mississippi delta. The most productive soils are the Bosket sandy loam and the Beulah loamy fine sand soils due to their high hydraulic conductivity. However, the most prevalent soil types used for cotton production in the Mississippi delta are the Dundee soils and the Forestdale soils (M.W. Ebelhar, 1995, personal communication). The Dundee soils range in a wide variety of textures (e.g. sandy loam, loamy sand, silty loam or silty clay loam) while the Forestdale soils range from silty clay soils to silt loam soils. Bosket sandy loam soil and Dundee silty clay loam soil were chosen for this analysis, primarily to demonstrate how different soils with varying productivity's

and characteristics affect the profitability and usefulness of alternative pix application strategies in Mississippi delta dryland cotton production.

Nitrogen management varies throughout the Mississippi delta. Some producers apply a portion of their nitrogen at preplant and the remainder as sidedress, while others apply all nitrogen in one preplant application. Some producers supplement soil-applied nitrogen with foliar applications of urea after flowering begins (D.W. Albers and M.R. Williams, 1995, personal communication). Total nitrogen applications in Mississippi can range from 101–134 kg ha^{-1} depending on soil type and yield potential (Guthrie et al., 1994). All nitrogen in this study is applied at preplant in the form of nitrate, with 123 kg ha^{-1} applied on Bosket sandy loam soil and 134 kg ha^{-1} applied on Dundee silty clay loam soil.

The GOSSYM/COMAX cotton management system can be used as a management aid for crop termination as well as pix application. Crop termination was modeled in this study based on data from Snipes et al., (1992). It was assumed that the producer would apply a mixture of ethephon, thidiazuron, and tribufos in application rates of 1120, 67, and 627 g active ingredient (g a.i.) ha^{-1}, respectively, whenever the cotton crop reached the '60% open boll' date.

Weather has a strong effect on cotton production. Cold, wet weather can result in a delayed harvest and can also reduce lint yield and lint quality due to boll weathering (Hake et al., 1989). Hot, dry weather can reduce cotton yields. High temperatures combined with water stress result in boll shed, small boll size, and leaf damage (Hake and Silvertooth, 1990). Stoneville, Mississippi weather files for a normal year, a cold-wet year, and a hot-dry year were used to represent the range of weather conditions facing cotton producers in the Mississippi delta. These weather files were supplied by the distributors of GOSSYM/COMAX, and contain the necessary environmental inputs required to run the system (e.g. daily solar radiation, maximum and minimum air temperature, rainfall, and wind speed).

4. Pix application strategies and economic return assumptions

The pix application strategies analyzed in this study can be grouped into two categories: (1) single applications applied at first bloom; and (2) low rate multiple (LRM) applications starting at first square. First bloom refers to the time when the first bloom appears on the cotton plant, while first square refers to the time when the first flower bud (square) appears on the cotton plant. The application rates used for the single rate pix strategies were 24.6, 37.0, and 49.3 g a.i. ha^{-1}, respectively, while the application rates used for the LRM strategies were 6.2, 9.2, and 12.3 g a.i. ha^{-1}, respectively, applied four times in 7, 10, and 14 day intervals. Thus a total of 12 pix strategies were analyzed:

1. LFB-24.6 g a.i. ha^{-1} applied once at first bloom;
2. MFB-37.0 g a.i. ha^{-1} applied once at first bloom;
3. HFB-49.3 g a.i. ha^{-1} applied once at first bloom;
4. LFS7-6.2 g a.i. ha^{-1} applied four times in 7 day intervals beginning at first square;

5. LFS10-6.2 g a.i. ha^{-1} applied four times in 10 day intervals beginning at first square;
6. LFS14-6.2 g a.i. ha^{-1} applied four times in 14 day intervals beginning at first square;
7. MFS7-9.2 g a.i. ha^{-1} applied four times in 7-day intervals beginning at first square;
8. MFS10-9.2 g a.i. ha^{-1} applied four times in 10-day intervals beginning at first square;
9. MFS14-9.2 g a.i. ha^{-1} applied four times in 14-day intervals beginning at first square;
10. HFS7-12.3 g a.i. ha^{-1} applied four times in 7-day intervals beginning at first square;
11. HFS10-12.3 g a.i. ha^{-1} applied four times in 10-day intervals beginning at first square; and
12. HFS14-12.3 g a.i. ha^{-1} applied four times in 14-day intervals beginning at first square.

Where 'L', 'M' and 'H' refer to low, medium, and high pix application rates, 'FB' is first bloom, 'FS' is first square, and '7', '10', and '14' represent time intervals in days between pix applications. The application rates and timings are based on pix strategies evaluated in the literature (Guthrie, 1989; McCarty et al., 1990; Metzer and Wilde, 1990; Weir and Kerby, 1990; Ebelhar et al., 1996).

Returns above variable and fixed costs were calculated for each pix application strategy as:

$$R_{ijk} = (LP*LY_{ijk} + SP*SY_{ijk}) - VC_{ijk} - FC_k \tag{1}$$

where $i = 1$–12 pix application strategies; $j = 1$–3 weather conditions; $k = 1$–2 soils; R_{ijk} is the monetary return for pix application strategy i given weather condition j, and soil type k; LP and SP represent the lint price and the seed price ($ kg^{-1}); LY_{ijk} and SY_{ijk} are the lint yield and seed yield for pix application strategy i given weather condition j and soil type k (kg ha^{-1}); VC_{ijk} is the variable cost ($ ha^{-1}) for pix application strategy i given weather condition j and soil type k; and FC_k is the fixed cost ($ ha^{-1}) of dryland cotton production on soil type k.

The cost data were obtained from Mississippi Cooperative Extension Service cotton budgets (Mississippi Agricultural and Forestry Experiment Station, 1994). Variable costs included machinery operating costs (fuel, lubrication, repairs), costs of materials used in production (fertilizer, insecticide, pix, etc.), custom costs (chemical applications by air, insect scouting, cotton haul and gin costs etc.), operator labor costs, and interest charges on short term capital. Fixed costs consisted of annual machinery cost estimates and were calculated as a function of machinery replacement costs and interest on machinery investment. A sandy soil budget was used for cotton produced on Bosket sandy loam soil and a clay soil budget was used for cotton produced on Dundee silty clay loam soil. Cost data in both budgets were in 1994 $ and depicted costs of producing solid cotton in the Mississippi delta using eight-row equipment.

Gross returns for each pix application strategy were calculated based on the maximum lint yields simulated by the GOSSYM/COMAX system. Simulated lint yields from GOSSYM/COMAX do not account for yield losses from weathered bolls, boll rot, insects, or lint cleaning. Thus, simulated lint yields were adjusted downward using average yield loss coefficients from the literature (National Cotton Council, Mangialardi, 1993). Cotton seed yields were calculated by multiplying adjusted lint yields by 1.55, the proportion of seed yield to lint yield used in the cotton budgets. The cotton lint price was held constant at $1.27 kg^{-1} ($0.58 lb^{-1}), the average lint price reported in the cotton budgets. A cotton seed price of $0.0882 kg^{-1} ($0.04 lb^{-1}) was used to calculate gross returns to cotton seed yield.

Expected lint yields and expected returns were calculated to identify the pix application strategy with the largest lint yield and the largest return to the farmer on average. Expected yields and expected returns were calculated as:

$$\mathrm{ELY}_{ik} = \sum_{j=1}^{3} (P_j * \mathrm{LY}_{ijk}) \tag{2}$$

and

$$\mathrm{ER}_{ik} = \sum_{j=1}^{3} (P_j * R_{ijk}) \tag{3}$$

where ELY_{ik} and ER_{ik} are the expected lint yield and expected return across weather conditions for pix application strategy i on soil type k; P_j is the probability of weather condition j; and LY_{ijk} and R_{ijk} are as defined above.

Weather condition probabilities were calculated using weather data from Stoneville, Mississippi for the period 1964–1993. Each year was classified as 'normal', 'cold-wet', or 'hot-dry' based on total rainfall amounts and average maximum and minimum temperatures for the months of June through September. Sixteen out of 30 years were classified as normal, 6 out of 30 years were classified as cold-wet, and 8 out of 30 years were classified as hot-dry. Thus the probabilities for a normal, cold-wet, and hot-dry year were 0.53, 0.20, and 0.27, respectively, over the 30-year period.

5. Lint yield results

GOSSYM/COMAX simulated dryland cotton lint yields by soil type, weather condition, and pix application strategy are presented in Table 1. Lint yields are larger on Bosket sandy loam soil than on Dundee silty clay loam soil under normal and cold-wet weather conditions. However, the opposite is true when weather is hot and dry. These results indicate that Bosket sandy loam is more productive than Dundee silty clay loam when water is available, due to the former soil's greater hydraulic conductivity. However, the water mobility advantage of Bosket sandy loam may be lost during drought conditions, since course textured soils tend to dry out more easily than fine textured soils during hot weather (Hake et al., 1992). Thus, dryland cotton may experience less water stress on Dundee silty clay loam soil during periods of hot, dry weather.

Table 1
GOSSYM/COMAX simulated Mississippi delta dryland cotton lint yields at maximum yield date by pix application strategy, soil type, and weather condition.

Pix strategy	Lint yield (kg ha^{-1})[a]							
	Bosket sandy loam				Dundee silty clay loam			
	Normal weather	Cold-wet weather	Hot-dry weather	Expected yield	Normal weather	Cold-wet weather	Hot-dry weather	Expected yield
None	1142	1192	791	1058[c]	1029	1125	837	997
LFB	1188	1217	811	1093	1100	1175	874	1055
MFB	1205	1238	828	1111	1121	1188	862	1065
HFB	1205	1238	807	1105	1121	1184	853	1062
LFS7	1171	1209	782	1075	1096	1163	874	1050
LFS10	1171	1209	799	1079	1100	1159	862	1048
LFS14	1171	1196	770	1069	1079	1159	866	1038
MFS7	1192	1234	811	1099	1121	1188	857	1064
MFS10	1200	1226	820	1104	1125	1188	883	1073
MFS14	1200	1238	816	1105	1146	1180	866	1078
HFS7	1205	1251	841	1117	1142	1205	903	1091
HFS10	1205	1251	837	1116	1146	1205	887	1089
HFS14	1213	1255	832	1120	1150	1209	883	1091
Weather probability	0.53[b]	0.20	0.27		0.53	0.20	0.27	
Maximum yield strategy	HFS14	HFS14	HFS7	1122	HFS14	HFS14	HFS7	1096

[a] GOSSYM/COMAX simulated lint yields were adjusted downward to account for yield losses to diseases, insects, and lint cleaning.
[b] Calculated from 30 years of weather data from Stoneville, Mississippi for the period 1964–1993. Normal weather occurred 16 out of 30 years; cold-wet weather occurred 6 out of 30 years; and hot-dry weather occurred 8 out of 30 years.
[c] Calculated by multiplying the lint yield ha^{-1} of each weather condition by its associated probability of occurrence and summing across weather conditions.

The probabilities of each weather condition are also presented in Table 1. If no pix is applied to dryland cotton on Bosket sandy loam soil, the farm operator would expect to receive a lint yield of 1142 kg ha^{-1} 53% of the time, a lint yield of 1192 kg ha^{-1} 20% of the time, and a lint yield of 791 kg ha^{-1} 27% of the time. The expected yield for the no pix strategy on Bosket sandy loam across all weather conditions is 1058 kg ha^{-1} (1142*0.53 + 1192*0.20 + 791*0.27). If one pix application strategy is used during all weather conditions, the farm operator would expect to receive the largest lint yield using HFS14 on Bosket sandy loam soil (1120 kg ha^{-1}) and either HFS7 or HFS14 on Dundee silty clay loam soil (1091 kg ha^{-1} each). If pix applications are tailored to weather conditions, the farm operator would expect to receive the largest lint yield on both soils (1122 kg ha^{-1} on Bosket sandy loam and 1096 kg ha^{-1} on Dundee silty clay loam) using HFS14 during normal and cold-wet weather and HFS7 during hot-dry weather. The difference in expected lint yield between the maximum yield strategy and the no pix strategy is larger on Dundee silty clay loam soil (+ 99 kg ha^{-1}) than on Bosket sandy loam soil (+ 64 kg ha^{-1}). Therefore, pix applications appear to have a greater yield effect on Dundee silty clay loam than on Bosket sandy loam.

6. Economic results

Returns above variable and fixed costs to dryland cotton by pix application strategy, soil type, and weather condition are presented in Table 2. During hot-dry weather, every pix application strategy in Table 2 has a negative return on Bosket sandy loam soil at the $1.27 kg^{-1} cotton lint price. The breakeven lint price for this strategy during hot-dry weather (e.g. the lint price necessary to cover all costs of MFB, the lint yield strategy with the smallest negative return during hot-dry weather) is $1.32 kg^{-1} ($ 0.60 lb^{-1}). Thus, dryland cotton production on Bosket sandy loam soil during hot-dry weather would be unprofitable at cotton lint prices below $1.32 kg^{-1} given the assumptions of this study. Irrigation water may be required for profitable cotton production on Bosket sandy loam soil during hot, dry weather.

Weather condition probabilities and expected returns are also reported in Table 2. If no pix is applied to Bosket sandy loam soil, the farm operator would expect to receive $373 ha^{-1} 53% of the time, $434 ha^{-1} 20% of the time, and − $59 ha^{-1} 27% of the time, with an overall expected return of $270 ha^{-1} across all weather conditions. If one pix application strategy is used for all weather conditions, the farm operator would expect to receive the largest return using MFB on Bosket sandy loam ($311 ha^{-1}) and HFS14 on Dundee silty clay loam ($276 ha^{-1}). If pix applications conform to weather conditions, the farm operator would earn the largest return on Bosket sandy loam ($312 ha^{-1}) using MFB during normal and hot-dry weather and HFS14 during cold-wet weather. However, this return is only $1 ha^{-1} greater than using MFB for all weather conditions. Similarly, the farm operator would expect to receive the largest return on Dundee silty clay loam ($281 ha^{-1}) using MFS14 during normal weather, HFS14 during cold-wet weather, and LFB during hot-dry weather.

Table 2
Returns above variable and fixed costs in 1994 US dollars from Mississippi delta dryland cotton by pix application strategy, soil type, and weather condition

Pix strategy	Returns above variable and fixed costs ($ ha^{-1})							
	Bosket sandy loam				Dundee silty clay loam			
	Normal weather	Cold-wet weather	Hot-dry weather	Expected return	Normal weather	Cold-wet weather	Hot-dry weather	Expected return
None	373	434	−59	270[b]	241	359	4	201
LFB	413	449	−49	297	312	405	35	257
MFB	426	467	−37	311	330	413	12	262
HFB	418	459	−70	296	322	400	−7	250
LFS7	365	412	−113	247	280	362	8	224
LFS10	375	421	−83	262	294	366	1	230
LFS14	384	414	−110	258	278	375	15	227
MFS7	383	435	−85	269	303	385	−21	233
MFS10	403	433	−65	284	317	394	19	253
MFS14	412	458	−61	295	352	393	8	268
HFS7	391	447	−57	283	321	398	28	258
HFS10	400	456	−53	290	335	407	16	264
HFS14	419	471	−49	305	349	421	20	276
Weather probability	0.53[a]	0.20	0.27		0.53	0.20	0.27	
Maximum return strategy	MFB	HFS14	MFB	312	MFS14	HFS14	LFB	281

[a] Calculated from 30 years of weather data from Stoneville, Mississippi for the period 1964–1993. Normal weather occurred 16 out of 30 years; cold-wet weather occurred 6 out of 30 years; and hot-dry weather occurred 8 out of 30 years.

[b] Calculated by multiplying the return ha^{-1} of each weather condition by its associated probability of occurrence and summing across weather conditions.

The difference in expected returns between the maximum return strategy and the no pix strategy is larger on Dundee silty clay loam ($+\$80$ ha^{-1}) than on Bosket silty clay loam ($+\$42$ ha^{-1}). Thus, pix applications have a greater positive effect on returns to dryland cotton produced on Dundee silty clay loam than on Bosket sandy loam. However, note that the maximum return strategies in Table 2 are not the same as the maximum yield strategies in Table 1. Thus, maximum yields do not result in maximum profits in this instance.

7. Conclusions

The most profitable pix application strategies were not the same for the two soils analyzed. In addition, tailoring pix application according to weather conditions resulted in the largest expected returns to the farmer. The most profitable pix application strategies for the farmer on Bosket sandy loam and Dundee silty clay loam were as follows:

7.1. Bosket sandy loam

7.1.1. Normal and hot-dry weather
One pix application of 37 g a.i. ha^{-1} at first bloom.

7.1.2. Cold-wet weather
Four pix applications of 12.3 g a.i. ha^{-1} every 2 weeks starting at first square.

7.2. Dundee silty clay loam

7.2.1. Normal weather
Four pix applications of 9.2 g a.i. ha^{-1} every 2 weeks starting at first square.

7.2.2. Cold-wet weather
Four pix applications of 12.3 g a.i. ha^{-1} every 2 weeks starting at first square.

7.2.3. Hot-dry weather
One pix application of 24.6 g a.i. ha^{-1} at first bloom.

These findings parallel those reported in physiological studies to the extent that no one pix application strategy provides the best results for all situations (Guthrie, 1989; McCarty et al., 1990; Metzer and Wilde, 1990; Weir and Kerby, 1990). However, the profit maximizing strategies differed from those producing the largest expected lint yields for the farmer. The results also indicate that tailoring pix application according to weather conditions may be less important for cotton production on sandy soils. One first bloom pix application of 37 g a.i. ha^{-1} during all weather conditions produced nearly the same maximum expected return as the profit maximizing strategy tailored to weather conditions on Bosket sandy loam soil. This was not true of cotton production on Dundee silty clay loam soil.

8. Discussion

This study demonstrates that soil characteristics and weather have a strong influence on the profitability of pix application in dryland cotton production. However, one shortcoming of this study is that no economic value could be assigned to account for reduced lint damage (e.g. gin trash) resulting from shorter cotton plants. Such an undertaking would require an established relationship between the quality of the ginned cotton and plant heights generated by GOSSYM/COMAX. Also, row spacing, planting date, the method of nitrogen application, and the method of crop termination were all held constant across soil types and weather conditions in the study. Variations in any of these management practices or irrigation will likely affect the profitability of pix application strategies. Thus, future research should focus on the profitability of pix application strategies combined with other management practices.

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