

A Watershed-Level Bioeconomic Analysis of the Value of 6-8 Months Climate Forecasts

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Introduction

The purpose of this poster is to demonstrate how accurate, 6-8 month forecasts can help farmers better plan for the upcoming growing season, and to estimate the potential value of climate forecasts. The climate forecasts considered are predictions of monthly precipitation and maximum and minimum temperature for the upcoming season in relation to the current season. We develop a number of climate scenarios, and define the value of forecasts as the difference in net benefits from crop practices adjusted to those climate scenarios, and compare them to those from crop practices if a forecast were unavailable.

Methods

This paper combines the output from a biophysical model with an economic profit maximization model in order to determine the optimal crop practices and land uses for the watershed under a variety of climate scenarios.

The Biophysical Model

The Soil and Water Assessment Tool (SWAT) is used first to create subwatersheds for the Kelly Creek watershed, a 03140201040-HUC level watershed in southeastern Alabama. The Agricultural Policy Environmental Extender (APEX) is then used to estimate crop yields under our weather scenarios. In order to run simulations with APEX, the watershed is divided into subwatersheds that are homogenous in terms of land use and soil type.

The Economic Model

A simple economic model is designed to obtain the optimal crop practices by maximizing the watershed net returns under the constraint of land availability. The net returns optimization model is given by

$$\max (PY - C) \times X_s \quad \text{subject to } X \leq L^0$$

where P is a vector of crop prices, Y is a vector of crop yields, C is a vector of production costs, X is a vector defining land area allocated to each crop, and subscript s represents the watershed; the subwatersheds devoted to total crop production are constrained by total land suitable for crop production in the watershed, L^0 .

Study Area

The study area was the Kelly Creek watershed located in Dale County, Alabama. Digital Elevation Model and 2001 National Land Cover data were obtained from the US Geological Survey. A total of 77 sub-areas were created using ArcView SWAT based on elevation and stream routing. Around 59% of the watershed were used for crop cultivation. Forest and shrubs comprised 19% and 7% of the watershed respectively. Out of the 77 sub-areas, 34 were under crop cultivation with 7 soil types based on land cover map.

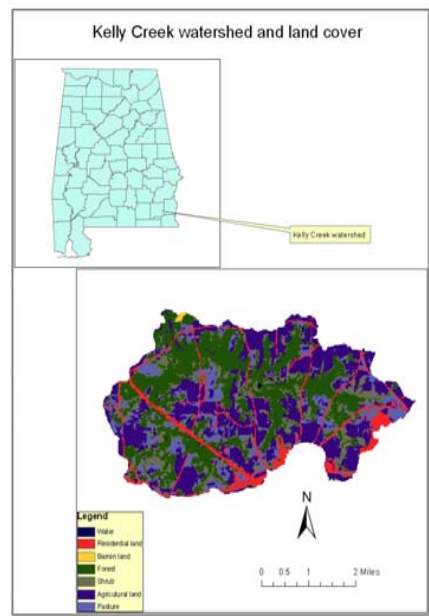


Figure 1: Map of Kelly Creek watershed and land cover

Model Inputs

Inputs required for the APEX model include soil type, weather, crop practices, tillage practices and fertilizer and chemical use. The weather data used in APEX include 13 years of historical temperatures, precipitation, humidity, wind speed, solar radiation for 13 years from 1994 to 2006 from the Headland Station. We examine four major crops grown in the area including corn, cotton, peanuts and soybeans. Within each subwatershed, we simulated growth of these crops as if they were the sole crop in a subwatershed area.

Table 1: Details of 34 subwatershed used for crops

Subarea ID	Area (acres)	% of watershed	Soil type
4	187.89	1.81	Ruston
5	78.72	0.78	Rebay
14	148.42	1.43	Eutis
17	85.21	0.82	Ruston
18	185.72	1.79	Ruston
23	191.13	1.84	Ruston
24	240.85	2.41	Rebay
26	40.88	0.78	Rebay
28	190.59	1.84	Eutis
30	289.30	2.79	Eutis
34	212.02	2.05	Rebay
35	89.53	0.86	Ruston
39	281.02	2.71	Ruston
41	205.36	1.98	Rebay
42	174.38	1.68	Ruston
48	325.15	3.14	Norfolk
50	91.33	0.88	Eutis
51	182.75	1.86	Eutis
52	91.15	0.88	Ruston
53	109.16	1.05	Ruston
54	101.24	0.98	Lakeland
55	170.59	1.65	Ruston
57	389.10	3.75	Caragima
58	99.08	0.96	Norfolk
59	64.13	0.62	Norfolk
60	130.96	1.26	Rebay
64	139.25	1.34	Ruston
66	297.14	2.77	Ruston
67	126.25	1.23	Norfolk
70	486.20	4.69	Ruston
72	240.85	2.32	Eutis
73	110.79	1.07	Ruston
74	111.15	1.07	Ruston
77	180.86	1.74	Ruston
Total	6,109.43	58.93	

Climate Forecasts and Climate Scenarios

Twelve different climate scenarios were created to represent 'typical' wet, dry, hot and cold weather based on quantiles of historical weather outcomes data. Wet weather was defined as the condition under which monthly precipitation is greater than the median, and dry weather as the condition in which monthly precipitation is less than the median. Similarly, hot weather was defined as the condition under which monthly maximum and minimum temperatures were greater than the median, and cold weather as the condition under which monthly maximum and minimum temperatures were less than the median.

Table 2: Descriptions for the twelve climate scenarios

Climate scenarios	Description
Very wet	95th quantile precipitation
Wet	75th quantile precipitation
Dry	25th quantile precipitation
Very dry	05th quantile precipitation
Very hot	95th quantile temperature
Hot	75th quantile temperature
Cold	25th quantile temperature
Very cold	05th quantile temperature
Very wet and very cold	95th quantile precipitation and 05th temperature
Wet and cold	75th quantile precipitation and 25th temperature
Dry and hot	25th quantile precipitation and 75th temperature
Very dry and very hot	05th quantile precipitation and 95th temperature

Figure 2: Mean precipitation by climate scenario

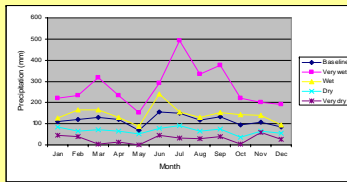
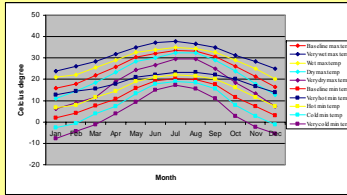


Figure 3: Mean maximum and minimum temperatures by climate scenario



Value of climate forecasts

We define the value of climate forecasts similarly to Jones et al. (2000):

$$V = (\pi^f - \pi^N) / a$$

where π^f and π^N are returns for the watershed with climate forecast and without climate forecast respectively, and a is the number of acres of the watershed under crop cultivation. We assume that in the absence of a climate forecast, farmers would repeat the same crop practices from the previous year in the upcoming season. The inputs for the APEX model are the same for the model with climate forecasts and without climate forecasts.

Results

In the biophysical model, APEX simulations were run to obtain annual yields on four crops for each subwatershed. Compared to the baseline, average yields are higher under wet and very wet conditions for all crops except cotton; average yields are lower under dry and very dry conditions for all crops except for cotton. Hot and very hot conditions reduce crop yields. Cold weather increases yields for all crops except for peanuts, and very cold weather reduces yields for all four crops. Under very wet and very cold conditions, yields are reduced dramatically while under wet and cold condition, yields are much higher for corn, peanut and soybean.

Scenario	Corn		Cotton		Peanut		Soybean	
	Yield (pounds/acre)	% Δ from baseline	Yield (bushels/acre)	% Δ from baseline	Yield (bushels/acre)	% Δ from baseline	Yield (bushels/acre)	% Δ from baseline
Baseline	95		766		2944		30	
Very wet	113	20	599	-27	4004	36	49	63
Wet	112	19	667	-13	3372	15	41	36
Dry	62	-34	955	25	1963	-33	20	-33
Very dry	9	-90	373	-51	525	-82	6	-79
Very hot	74	-22	659	-14	1721	-42	20	-34
Hot	89	-6	711	-7	2275	-3	27	-11
Cold	100	6	879	15	2480	-3	32	7
Very cold	66	-30	464	-39	1071	-64	26	-14
Very wet and very cold	62	-35	307	-60	1249	-58	29	-2
Wet and cold	118	22	798	-1	3298	22	44	47
Dry and hot	61	-35	832	9	1556	-47	18	-41
Very dry and very hot	22	-77	685	-11	706	-76	9	-68

Table 3: Weighted average crop yields by climate scenario

Hot and dry are the most favorable conditions for cotton. Cold and wet conditions are relatively more favorable to peanuts. Very wet and very cold conditions favor the planting of soybeans. By relating the crop yields different climate scenarios, we can identify the most favorable crops to be grown for different ENSO phases. For example, an El Niño year is more favorable for growing cotton in the watershed, while peanuts and soybeans fare better during La Niña years.

Simulated crop yields, along with production costs and crop prices, are used in the profit model to solve for optimal allocation of subwatersheds to the various crops. For the baseline model, the watershed is most profitable with 389 acres of land devoted to cotton, 3,507 acres to peanut and 2,212 acres to soybean. The most adaptable crop is soybeans since they are grown under all climate scenarios except for dry conditions, and corn would not be grown in any climate scenario. We can also demonstrate which crop should be grown in each subwatershed. The results thus allow farmers to match crops to physical conditions of a watershed to obtain the highest profit.

Scenarios	Corn	Cotton	Peanut	Soybean
Baseline	389.10	3,507.86	2,212.47	
Very wet			5,720.33	389.10
Wet			3,507.86	2,601.58
Dry	6,109.43			
Very dry				
Very hot		325.15		5,794.28
Hot				6,109.43
Cold		1,535.15		4,574.28
Very cold				6,109.43
Very wet and very cold				
Wet and cold			5,619.01	480.34
Dry and hot	4,498.40			1,411.03
Very dry and very hot	6,019.90			89.53

Table 4: Optimal land allocation by crops (acre)

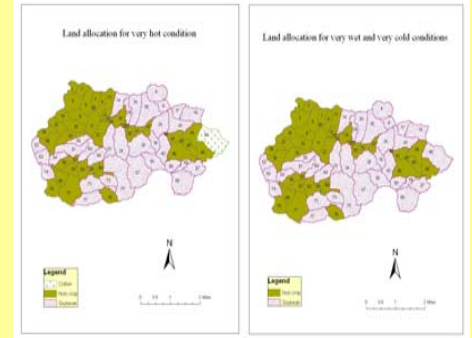
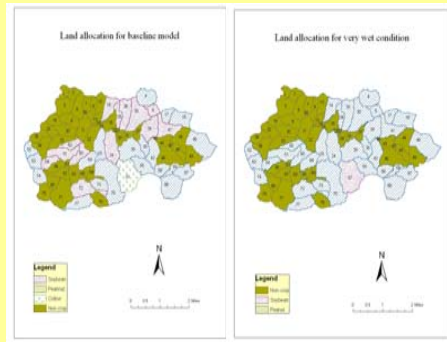


Figure 5: Optimal land allocation for very hot weather and very wet and very hot weather

Scenario	Forecast value for watershed (\$)	Forecast value per acre (k\$acre)
Very wet	156,746	25.66
Wet	56,638	9.27
Dry	887,052	145.19
Very dry	1,008,753	165.11
Very hot	519,281	85.00
Hot	343,823	56.28
Cold	113,646	18.63
Very cold	1,079,696	176.73
Very wet and very cold	1,116,707	182.78
Wet and cold	69,860	11.43
Dry and hot	826,671	135.31
Very dry and very hot	1,066,086	174.50

Table 5: Value of climate forecast by climate scenario

The forecast values represent benefits that farmers would gain if they could adjust their crop practices according to an exact monthly forecast. Forecast values vary considerably with the climate scenarios ranging from \$9.27 per wet condition to \$182.78 per acre for very wet and very cold conditions. Farmers benefit the most from precise forecasts for the following seasons: dry, very dry, dry and hot, very dry and very hot, and very cold. The average value of climate forecasts across the twelve scenarios is \$98.82 per acre.

Conclusion

This study demonstrates the potential for climate forecast to help farmers at the watershed level manage their cropping practices. The model also provides recommendations on what crop should be planted within a given subwatershed.

The intensity of the ENSO phase will result in variations in the intensities of the wet, cool, hot, and dry weather conditions. The degree to which those variations can be predicted will affect individual farm profitability as demonstrated by the wide range of estimated per acre values. It should be noted that these estimated values can also be affected by price supports and other exogenous conditions, which are not considered here.

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