The Impact of Climate Change on Corn Production in the Southeastern U.S. and the Adaptation Strategy

Juhyun Oh
Food and Resource Economics Department, University of Florida
zooty1213@ufl.edu

Zhengfei Guan
Food and Resource Economics Department, University of Florida
guanz@ufl.edu

Kenneth J. Boote
Agronomy Department, University of Florida
kjboote@ufl.edu

Selected Poster prepared for presentation at the 2015 Agricultural & Applied Economics Association and Western Agricultural Economics Association Joint Annual Meeting, San Francisco, CA, July 26-28..

The Impact of Climate Change on Corn Production in the Southeastern U.S. and the Adaptation Strategy

Juhyun Oh[1], Zhengfei Guan[2], Kenneth J. Boote[3]

[1,2] Food and Resource Economics Department, University of Florida; [3] Agronomy Department, University of Florida

Introduction

- Corn is a very important crop in the United States because it is widely used for food, feed, and fuel production. As the largest producer of corn in the world, the United States produced about 13.8 billion bushels in 2013, accounting for about 32% of world corn production (USDA, 2013).
- Over the last 1-2 decades, corn production has expanded to the southeastern United States due to favorable corn prices. However, this region may face uncertainty of corn yields originated from climate variability. It is expected that the variation of both temperature and precipitation will increase across most of southeastern areas along with more greenhouse gas emissions (Ingram et al., 2013).
- The objectives of this paper are twofold. First, we simulate corn yields in the southeastern U.S. under future climate scenarios using the Decision Support System for Agrotechnology Transfer (DSSAT). Second, based on the simulated yields, we identify the optimal yield and input levels, suggesting the most efficient adaptation strategy to climate change.

Data and Methodology

- Historically observed weather data are obtained from the National Climatic Data Center for the period 1979-2000.
- For the downscaling of the Global Climate Model (GMC), 20th Century Climate Experiment (20C3M) data are used for a baseline, and the Hadley Centre Coupled Model version 3 (HadCM3) is used for the climate projections under two CO2 emission scenarios (SRES-A2 (High) and SRES-B1 (Low)) for different time periods of 2010-2039 (2020s), 2040-2069 (2050s), and 2070-2099 (2080s).
- For DSSAT simulation, a medium season cultivar was used, and annual amount of applied nitrogen was varied from 0 to 240 kg/ha. Also, we consider non-irrigated and a fully irrigated regimes with Silty-Clay and Sandy soils.

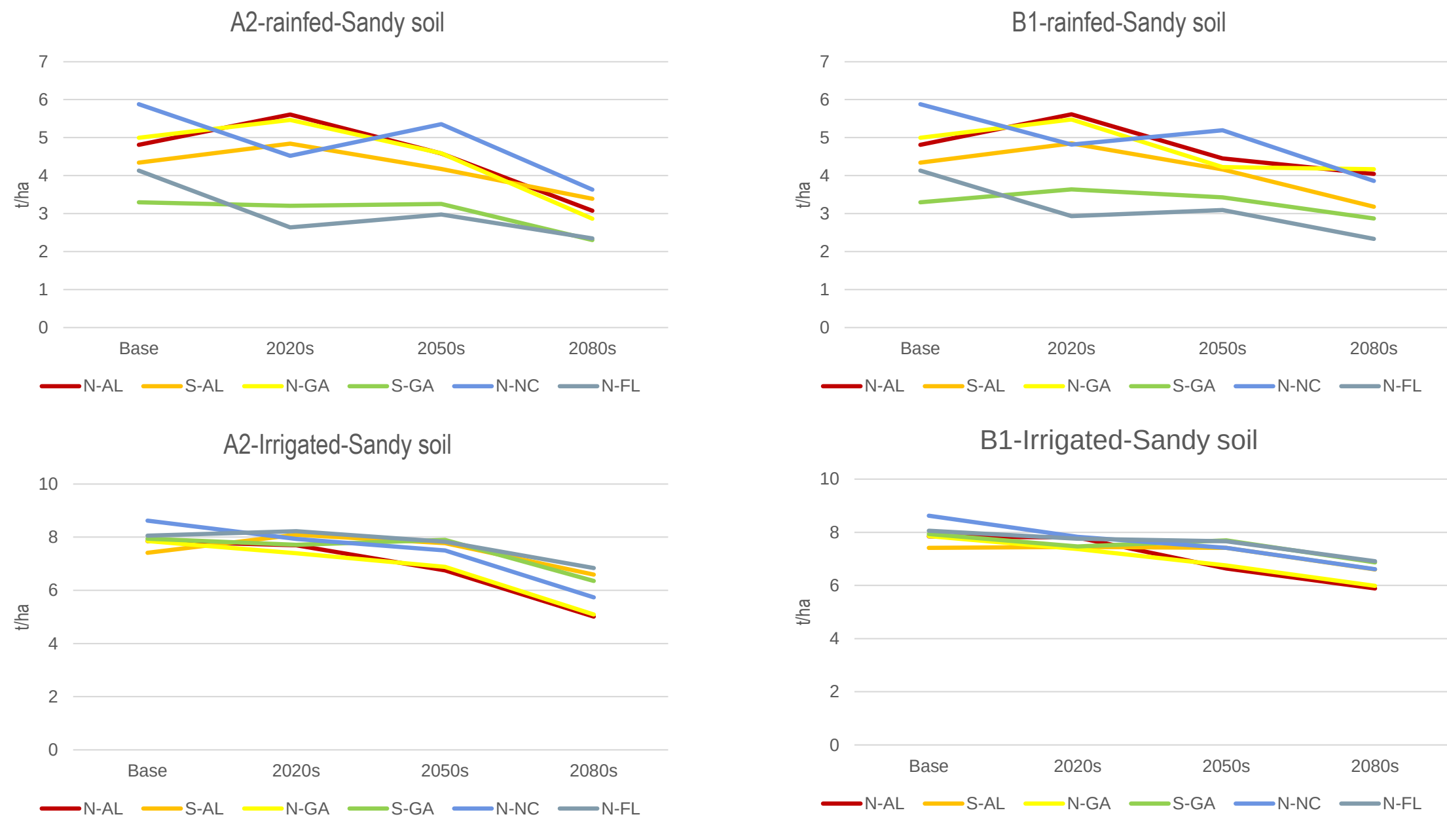
Anomalies of temperature and precipitation for A2 and B1

Temperature (°C)	A2 2020s	2050s	2080s	B1 2020s	2050s	2080s
N-AL	0.83	1.98	3.68	0.83	1.76	2.74
S-AL	0.59	1.59	3.09	0.72	1.45	2.37
N-GA	0.83	1.91	3.60	0.81	1.78	2.70
S-GA	0.56	1.43	2.75	0.66	1.48	2.31
N-NC	0.84	1.93	3.65	0.83	1.76	2.73
N-FL	0.62	1.62	3.13	0.75	1.54	2.43

Precipitation (ratio)	A2 2020s	2050s	2080s	B1 2020s	2050s	2080s
N-AL	0.99	1.01	0.98	0.99	1.01	1.03
S-AL	0.95	0.89	0.90	0.98	0.97	0.98
N-GA	0.94	0.99	0.94	1.03	1.03	1.10
S-GA	0.94	0.94	0.86	1.05	1.02	1.02
N-NC	0.98	1.00	0.98	1.02	1.05	1.08
N-FL	0.94	0.93	0.89	1.00	0.97	1.01

* N-AL, S-AL (North, South Alabama), N-GA, S-GA (North, South Georgia), N-NC (North Carolina), N-FL (North Florida)

DSSAT simulation results- Sandy soils



*The annual amount of nitrogen is 180 kg/ha

DSSAT simulation results- Clay soils

*The annual amount of nitrogen is 180 kg/ha

Production Risk

- Based on the data obtained from DSSAT, we estimate stochastic production function (Just and Pope,1978),

$$Y = f(X,\alpha) + h(Z,\beta)\varepsilon$$

where $f(X,\alpha)$, $\mathrm{h}(Z,\beta)$ are mean production function, variance function, respectively. Z is some or all of the elements in x. α and β are parameters. $(E(\varepsilon) = 0 \text{ and } var(\varepsilon) = 1)$

- Mean production function

$$\mathrm{Y} = \alpha_0 + \alpha_1 N + \alpha_2 WI + 0.5 \cdot [A_{11}N^2 + A_{12}NWI + A_{22}IW^2]$$

where Y is simulated yield, N is nitrogen amount applied (0-240kg/ha), W is irrigation amount applied (mm/ha). I is indicator function if I=0, rainfed, if I=1, Irrigated.

- Variance function

$$Var(u) = \exp(\beta_0 + \beta_1 N \cdot + \beta_2 WI)$$

Economic Model

- The Certainty Equivalent (CE) is maximized subject to the production function (Finger et al., 2011),

$$\underset{N,W}{Max} \quad CE = E\big(\pi(N,W)\big) - Risk\ Premium\ (RP) \qquad s.t \quad Y = f(N,W)$$

where $\mathrm{R}P = {}^{0.5\gamma p^2 \sigma_y^2}/_{E(\pi(N,W))}$. γ is the coefficient of risk aversion by assuming Constant coefficient of relative risk aversion (CCRA), equal to 2.

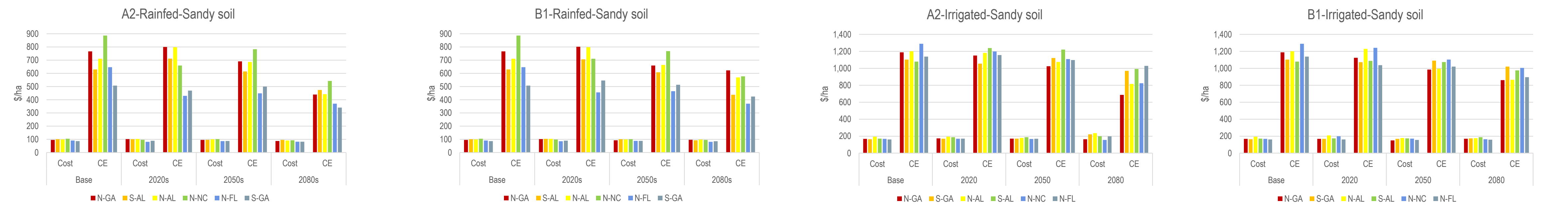
- From the first order conditions, optimal inputs (N*,W*), yield (Y*), and CE* are obtained.

Optimal inputs, CE, and yield –Sandy soil

Rainfed	Base					A2 Scenario															B1 Scenario														
						2020s					2050s					2080s					2020s					2050s					2080s				
	N*	W*	CE*	Y*	R	N*	W*	CE*	Y*	R	N*	W*	CE*	Y*	R	N*	W*	CE*	Y*	R	N*	W*	CE*	Y*	R	N*	W*	CE*	Y*	R	N*	W*	CE*	Y*	R
N-GA	159.2	0	766.6	5388.5	1.1	169.7	0	800.2	5638.1	1.0	160.1	0	691.5	4922.7	1.1	145.5	0	439.5	3292.6	1.1	170.4	0	802.0	5651.4	1.0	155.3	0	659.8	4706.2	1.1	160.5	0	622.7	4493.5	1.1
S-GA	145.3	0	507.1	3714.1	1.1	148.6	0	469.5	3491.5	1.1	145.6	0	500.0	3671.1	1.1	137.5	0	340.7	2644.9	1.1	149.9	0	546.0	3974.9	1.1	147.5	0	514.0	3765.3	1.1	142.6	0	424.2	3185.7	1.1
N-AL	165.4	0	710.8	5062.5	1.1	171.3	0	798.7	5634.1	1.0	167.2	0	686.3	4916.4	1.1	151.5	0	442.8	3335.7	1.1	172.9	0	798.5	5639.0	1.0	164.9	0	664.0	4768.3	1.1	163.5	0	569.2	4170.6	1.0
S-AL	168.2	0	630.1	4568.9	1.1	169.2	0	711.9	5083.6	1.1	161.9	0	615.0	4450.8	1.1	160.0	0	474.0	3562.3	1.1	173.7	0	706.1	5064.3	1.0	168.5	0	608.6	4436.0	1.1	154.7	0	438.1	3318.2	1.0
N-NC	175.2	0	886.5	6197.4	1.1	161.4	0	659.3	4725.9	1.0	170.8	0	782.8	5533.3	1.0	155.3	0	542.5	3973.2	1.1	164.4	0	711.0	5060.0	1.1	168.0	0	768.6	5433.7	1.0	159.5	0	577.3	4206.5	1.1
N-FL	151.9	0	647.2	4615.1	1.1	136.0	0	430.4	3199.9	1.2	145.0	0	448.5	3347.0	1.1	136.6	0	370.5	2827.9	1.2	143.6	0	456.0	3388.2	1.2	147.3	0	464.8	3457.4	1.1	136.3	0	370.6	2827.5	1.2

Irrigate	Base					A2 Scenario															B1 Scenarios														
						2020s					2050s					2080s					2020s					2050s					2080s				
	N*	W*	CE*	Y*	R	N*	W*	CE*	Y*	R	N*	W*	CE*	Y*	R	N*	W*	CE*	Y*	R	N*	W*	CE*	Y*	R	N*	W*	CE*	Y*	R	N*	W*	CE*	Y*	R
N-GA	221.5	224.3	1189.2	8487.4	1.1	224.2	246.3	1150.3	8276.6	1.1	218.8	252.9	1025.4	7482.2	1.1	207.3	255.3	686.6	5324.0	1.0	220.5	226.2	1124.4	8080.5	1.1	199.9	189.2	985.9	7100.9	1.1	211.5	270.6	861.1	6445.6	1.1
S-GA	217.9	213.0	1103.1	7924.7	1.0	224.5	221.3	1055.3	7658.9	1.0	224.5	231.4	1121.1	8079.9	1.0	268.8	378.5	970.1	7449.6	1.2	216.7	238.1	1071.9	7749.7	1.0	221.4	223.5	1090.3	7868.0	1.0	226.4	237.9	1020.5	7464.9	1.1
N-AL	245.8	294.8	1201.2	8724.2	1.1	244.0	298.3	1181.7	8599.0	1.1	222.3	293.6	1075.3	7847.8	1.2	258.3	508.1	815.8	6575.7	1.3	258.1	344.4	1228.9	8992.7	1.2	223.3	277.7	997.2	7347.5	1.1	221.5	276.3	865.1	6514.2	1.1
S-AL	230.9	203.4	1078.9	7812.8	1.1	245.7	258.1	1238.6	8920.8	1.1	242.6	268.9	1221.5	8813.4	1.1	250.6	309.4	992.2	7450.5	1.1	230.3	227.8	1087.5	7888.5	1.1	230.9	221.9	1073.7	7798.4	1.1	246.5	251.5	975.6	7273.0	1.1
N-NC	226.2	208.4	1290.1	9119.5	1.1	228.9	203.6	1198.3	8551.4	1.1	219.8	219.7	1109.4	7977.9	1.1	201.6	218.8	824.6	6128.6	1.1	252.4	298.6	1242.5	9010.6	1.2	222.4	237.7	1102.9	7964.6	1.1	216.6	217.7	1005.2	7312.4	1.1
N-FL	210.3	221.4	1138.8	8127.4	1.0	224.5	228.4	1156.9	8300.8	1.0	220.9	238.2	1097.7	7926.8	1.0	241.5	333.3	1028.8	7668.8	1.1	214.1	210.2	1037.6	7498.3	1.0	205.7	204.2	1020.4	7364.1	1.0	203.1	231.5	895.9	6592.8	1.0

* N*,W*, and Y* is the optimal nitrogen (kg/ha), irrigation amount (mm/ha) and yield (kg/ha), respectively. CE* is the certainty equivalent ($/ha). R is the ratio of optimal yield and simulated yield from DSSAT.

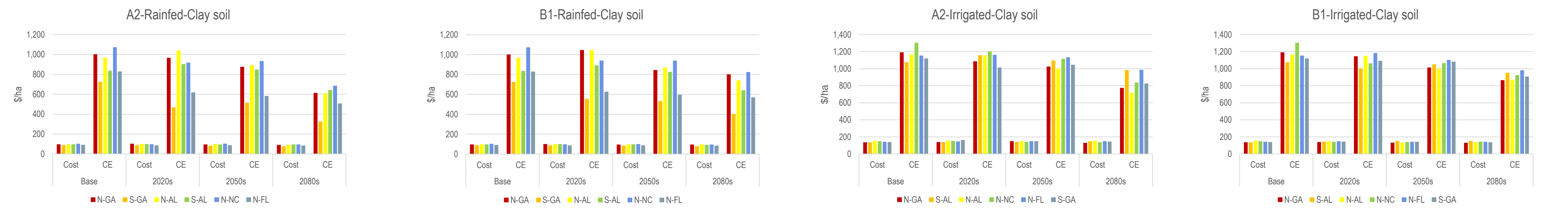


Optimal inputs, CE, and yield –Clay soil

Rainfed	Base					A2 Scenario															B1 Scenario														
						2020s					2050s					2080s					2020s					2050s					2080s				
	N*	W*	CE*	Y*	R	N*	W*	CE*	Y*	R	N*	W*	CE*	Y*	R	N*	W*	CE*	Y*	R	N*	W*	CE*	Y*	R	N*	W*	CE*	Y*	R	N*	W*	CE*	Y*	R
N-GA	162.2	0	1002.1	6871.2	1.1	171.3	0	967.0	6686.0	1.0	160.6	0	876.2	6078.9	1.1	151.9	0	613.1	4401.4	1.1	168.2	0	1046.3	7170.0	1.0	159.4	0	845.2	5880.4	1.1	160.9	0	801.7	5614.2	1.1
S-GA	147.7	0	724.8	5083.7	1.1	148.6	0	469.5	3491.5	1.1	138.4	0	516.4	3746.2	1.2	130.5	0	326.1	2527.7	1.2	146.5	0	554.3	4013.7	1.1	141.7	0	534.8	3874.3	1.1	133.6	0	404.1	3027.0	1.2
N-AL	164.5	0	968.1	6667.6	1.1	167.4	0	1041.4	7136.7	1.0	165.1	0	894.9	6212.1	1.1	152.4	0	610.1	4385.1	1.1	168.2	0	1046.3	7170.0	1.0	164.9	0	872.1	6069.3	1.1	161.8	0	741.5	5241.3	1.0
S-AL	161.5	0	836.7	5835.2	1.1	164.8	0	904.4	6270.4	1.0	158.1	0	848.6	5897.0	1.1	159.9	0	643.6	4622.1	1.1	168.4	0	892.5	6209.8	1.1	163.7	0	826.3	5778.0	1.0	155.0	0	642.6	4597.3	1.0
N-NC	172.7	0	1073.9	7359.4	1.0	164.4	0	918.0	6354.2	1.1	173.0	0	934.6	6489.9	1.0	159.2	0	686.3	4886.6	1.1	163.8	0	940.5	6492.5	1.1	168.2	0	939.9	6505.0	1.0	159.2	0	824.8	5752.0	1.1
N-FL	153.6	0	829.8	5762.6	1.1	144.3	0	619.9	4415.4	1.2	146.9	0	583.7	4198.9	1.1	142.1	0	507.7	3706.3	1.2	146.9	0	626.6	4466.9	1.1	148.4	0	597.4	4290.3	1.1	141.5	0	570.7	4097.5	1.1

Irrigate	Base					A2 Scenarios															B1 Scenario														
						2020s					2050s					2080s					2020s					2050s					2080s				
	N*	W*	CE*	Y*	R	N*	W*	CE*	Y*	R	N*	W*	CE*	Y*	R	N*	W*	CE*	Y*	R	N*	W*	CE*	Y*	R	N*	W*	CE*	Y*	R	N*	W*	CE*	Y*	R
N-GA	184.0	164.3	1192.4	8307.1	1.1	187.8	172.4	1087.4	7672.8	1.0	186.6	237.8	1025.7	7347.9	1.1	173.6	161.2	774.5	5652.9	1.1	183.3	182.3	1145.9	8031.6	1.0	179.4	153.7	1013.4	7160.2	1.1	175.1	165.9	865.2	6230.4	1.0
S-GA	181.3	190.1	1121.1	7876.8	1.0	218.3	203.1	1014.3	7361.0	1.0	193.0	209.9	1047.0	7477.1	0.9	185.4	211.5	826.9	6074.8	1.0	187.6	201.4	1002.9	7173.2	1.0	195.7	215.1	1049.9	7510.8	1.0	195.3	219.8	951.7	6900.1	1.0
N-AL	193.0	250.6	1167.5	8271.1	1.0	188.8	264.2	1155.3	8193.0	1.1	184.0	252.1	1000.3	7193.8	1.1	179.3	298.4	718.1	5459.1	1.1	197.2	197.2	1151.1	8083.9	1.0	179.9	154.7	998.4	7069.4	1.1	181.2	191.1	871.5	6317.3	1.1
S-AL	184.6	158.7	1075.3	7572.0	1.0	188.7	167.4	1157.8	8110.8	1.0	184.9	189.3	1097.3	7741.1	1.0	195.7	201.3	984.2	7086.7	1.1	187.7	188.3	1062.8	7534.9	1.0	186.4	177.9	1065.7	7537.6	1.0	189.6	201.2	925.9	6698.8	1.0
N-NC	199.1	186.6	1303.8	9082.0	1.0	200.7	209.6	1202.8	8479.4	1.1	191.1	176.7	1116.8	7873.1	1.0	179.5	188.0	836.9	6091.7	1.1	193.7	210.6	1183.1	8331.0	1.1	188.8	184.2	1102.8	7784.9	1.0	180.6	215.0	981.8	7028.8	1.1
N-FL	184.3	198.2	1154.1	8102.6	1.0	191.8	201.5	1162.6	8187.0	1.0	194.7	214.3	1132.9	8025.5	1.0	188.7	226.4	988.0	7109.1	1.0	187.5	197.2	1092.7	7729.5	1.0	188.3	186.3	1082.8	7659.9	1.0	174.2	203.4	907.3	6527.7	1.0

* N*,W*, and Y* is the optimal nitrogen (kg/ha), irrigation amount (mm/ha) and yield (kg/ha), respectively. CE* is the certainty equivalent ($/ha). R is the ratio of optimal yield and simulated yield from DSSAT.



Conclusions

- It is expected that future climate in Southeastern U.S. will have a tendency of higher temperature with less amount of precipitation.
- The DSSAT simulation results imply that climate variability has negative impact on the corn yields associated with greater variation. The corn yields with irrigation are higher than without irrigation for each climate scenarios. For two soil types, corn yields under Silty-Clay soil are higher than under Sandy soil because Sandy soil is capable to hold less water.
- The optimal levels of nitrogen and irrigation obtained from the maximization of CE reflect producers' risk attitudes and market conditions, which provides producers with critical information to adapt to climate change.
- While the optimal yield and CE levels decrease under future climate scenarios, the results indicate that more irrigation water will be required for the optimal corn production. Moreover, It is evident that profitability of corn production will decrease due to the climate change.

References

- Finger, R., Hediger, W., & Schmid, S. 2011. Irrigation as Adaptation Strategy to Climate Change - A Biophysical and Economic Appraisal for Swiss Maize Production. Climatic Change, 105.
- Hoogenboom, G., J.W. Jones, P.W. Wilkens, C.H. Porter, K.J. Boote, L.A. Hunt, U. Singh, J.L. Lizaso, J.W. White, O. Uryasev, F.S. Royce, R. Ogoshi, A.J. Gijsman, G.Y. Tsuji, and J. Koo. 2012. Decision Support System for Agrotechnology Transfer (DSSAT) Version 4.5.
- Ingram, K.T., K. Dow, L. Carter, and J. Anderson. 2013. Climate of the Southeast United States: Variability, Change, Impacts, and Vulnerability. Washington, DC: Island Press.
- Just, R.E., and R.D. Pope. 1978. Stochastic Specification of Production Functions and Economic Implications. Journal of Econometrics 7..
- USDA. 2013. Crop Production. National Agricultural Statistics Services.