Effects of Climate Change on Peanut's Yield in the State of Georgia, USA

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Abstract

The temperature and precipitation have precious role in agricultural production which are varied during year and overtime. Using the historical data of yield, temperature, and precipitation in three adjacent agricultural districts of Georgia, this study attempts to assess the impacts of temperature and precipitation on mean yield of peanut production. Study finds that for all levels of temperature would have positive impact on peanut yield. The precipitation would produce the positive impact on yield up to certain limit but excessive precipitation would have negative effect on peanut yield.

Introduction

Climatic factors like temperature, precipitation, snowfall, wind, windstorm, flooding etc. have crucial role in agricultural production since the beginning of civilization. For all industries including agriculture, manufacturing, and services; the role of change in temperature alone contribute more than 90% amongst all climatic factors followed by rainfall as a second dominant factor (Brockett et al. 2005). In agriculture, both temperature and precipitation are dominant climatic factors to affect crop yield which vary widely throughout the year and overtimes (Alexandrov and Hoogenboom, 2001). According to IPCC (2007) prediction, in the State of Georgia, the average increase in temperature observed was 2.5 to 3 degree Celsius, and average increase in precipitation observed was 5% in the last century (IPCC 2007). Reported extreme weather events such as floods, droughts, tornadoes, and thunderstorms are increasing overtime and we can observe the increase in climatic variability as well. These climatic variability are responsible for more severe periods of drought coupled with water periods which could be inevitable consequences of climate change (Christensen et al 2007).

The climatic factors are more vulnerable to agriculture in developing nations where they do not have irrigation facility, and also lack the more precise prediction facilities (Downing 1996; Watson 1996). Together with the advancement of agricultural technologies, developed nations are being able to minimize losses suffered from change in temperature and precipitation (Almaraz et al. 2008; Schelenker and Roberts 2009). Green house cultivation, resistance variety development and cultivation are some practices to lessen the weather effect in agricultural production. More studies to identify the impacts of such climatic factors on crop yields are essential for the sustainability of agricultural productions.

Using simulation models, several studies have been conducted to access the impact of climate change in crop yield variation such as Eitzinger et al. 2001; Terjung et al. 1984. Same way, some have used the regression technique for this purpose suchas Mendelsohn et al. 1996, Santer 1984. As the simulation based crop yield modeling requires extensive information of weather, and management practices which makes it more complex, and sometimes very difficult to gather all information indicating its less practical application (Walker 1989),so the researcher s are more inclined to using regression techniques based crop yield model to estimate the potential effects of climatic factors on crop yield because of its simplicity.

U.S Congress has recognized peanuts as one of the America's basic crops. Congress has passed the policy to protect domestic industry by keeping prices artificially high for this the USDA provides aids to peanuts farmers through commodity programs. In 2008 Farm Bill, the marketing quota for peanuts was eliminated and the price support program was switched to Direct-Counter-Cyclical Payment Program which provides benefits to peanuts producers who qualify for this criteria whenever the actual price of peanuts falls below the targeted price. Currently, US is the third largest producer of peanuts in the world produces 2.34% of total and largest exporter of peanuts. Georgia is the leading peanut producing State in the U.S. after Texas, and Alabama (USDA, 2012).

Mendelsohn et al. 1996, Santer 1984 have analyzed the effects of climate variation on mean crop yield. However there are very limited studies showing the impacts of climate change on crop yield variation (Mearns et al. 1997). Thus far, little empirical evidences are available on crop yield variation in response to the alterations in climatic conditions. Further, none of previous studies have conducted to access the effects of major climatic factors (

temperature and precipitation) on mean and variance of crop yield in the State of Georgia where peanuts is one of the dominant field crop in Georgian agriculture, it covers 10% acreage alone (USDA, 2012).

Many studies have been conducted to assess the overall changes in weather and climatic factors and its impacts in crop yield, but there are few studies done to specify how mean, and variances of crop yield fluctuates as per the changes in temperatures. The coefficient of variation of peanuts yield impacted due to temperature and precipitation would analyze the relative uncertainty of mean yield. Amongst, specific study to estimate the effect of specific climatic factors temperatures and precipitation on the individual crop yield which deserve very high economic values are need to be conducted. This study has tried to bridge that gap to some extent.

Data

The peanut's yield data from the selected agricultural districts (district 4, 5, and 6) of Georgia were obtained from the National Agricultural Statistics Service (NASS) of the United States Department of Agriculture (NASS/USDA, 2012). This data ranges from 1981 to 2011 for the west central (WC), central, and east central (EC) agricultural districts of Georgia. For the similar zones and time period, the average temperature and average precipitation data for the growing season of peanuts were obtained from the National Climatic Data Center (NCDS) of the National Oceanic and Atmospheric Administration (NCDC, NOAA 2012).

Model

The yield is a random variable function of temperature and precipitation, the mean yield is estimated using the equation;

$$E(y) = \sum_{i=1}^{N} y_i \qquad (1)$$

where y denotes yield and i. stands for 1, 2. …..N.

The variance of yield is estimated by the equation;

$$Var(y_i) = \sigma_i^2 = (y_i - E(y_i))^2 \,. \quad (2)$$

The relative variability of yield is estimated by the coefficient of variation (CV) equation as;

$$CV(y_i) = \sigma_i / E(y_i).$$

The stochastic production function which was first used by Just and Pop in 1978 is the major econometric model for this study is;

$$y_{it} = f(x_{it};\beta) + \omega_{it}\, h(x_{it};\delta)^{1/2} \qquad (3)$$

Where; y_{it} is the stochastic county yield for county i, in year t,

ω_{it} is the stochastic term with mean zero and variance σ_ω^2 , and β and δ are the production function parameters to be estimated.

In this model, the expected crop yield, E(y_{it}) is $f(x_{it};\beta)$, and estimation of $f(x_{it};\beta)$ gives the effects of independent variables on the mean crop yield (Isik and Devadoss 2006). The variance of crop yield, V(y_{it}) is given by σ_ω^2 h($x_{it}; \delta$) and therefore estimation of h(x_{it};δ) gives the effects of the independent variables on the variance of crop yield (Just and Pope

1978). The explanatory variable,(x_{it}) used for the estimations includes a constant, precipitation, temperature, and trend (Isik and Devadoss 2006).

The asymptotic efficiency for β, and δ can be obtained under the normality assumption using maximum likelihood (ML) function for the above equation. The Log likelihood function for the above equation is;

$$\text{LLF}== -[N * Ln(2\pi) + \sum_{i=1}^{N} \frac{y_{it} - f(x_{it}; \beta)^2}{\exp(x_{it\ ;}\ \delta)} + \sum_{i=1}^{n} \delta x_{it}] \qquad (4)$$

The inverse of the information matrix or, asymptotic covariance matrix of the ML estimator $(\tilde{\beta}\tilde{\delta})'$ of $(\beta'\delta')'$ is$\{E[\begin{matrix} \frac{\partial^2 \ln L}{\partial\beta\partial\beta\prime} & \frac{\partial^2 \ln L}{\partial\beta\partial\delta\prime} \\ \frac{\partial^2 \ln L}{\partial\delta\partial\beta\prime} & \frac{\partial^2 \ln L}{\partial\delta\partial\delta\prime} \end{matrix}]\}^{-1}$

The matrix then is ;

$$= \begin{pmatrix} (\sum_{t=1}^{T} \exp[2x_{it}(\beta - \delta)]\, x_{it}x_{it}') & 0 \\ 0 & \frac{1}{2}(\sum_{t=1}^{T} x_{it}x_{it}')^{-1} \end{pmatrix}$$

The regression equation uses yield as a dependent variable where, trend, temperature, precipitation, their squares and interaction were used as independent variable to estimate the effect on mean yield is;

$$y_{it}=\beta_1 + \beta_2\, Trend + \beta_3 \text{T} + \beta_4 \text{P} + \beta_5 T^2 + \beta_6 P^2 + \beta_7 \text{T*P} + \varepsilon_{it} \qquad (5)$$

Where y is yield, T stands for temperature, and P stands for precipitation.

The second part of the equation (4) which is could measure the effect of temperature and precipitation on the variance of yield hasn't been estimated here.

Results and Discussion

Data Characteristics

The mean, standard deviation, maximum and minimum values of sample data set have been presented below.

Table 1: Summary statistics of the sampled data. N=31

Variable,District	Mean	Std.Dev	Minimum	Median	Maximum
Yield, 4	2538.0	565.0	1185.0	2450.0	3605
Yield, 5	2489.2	445.5	1360.0	2553.0	3125
Yield, 6	2724.6	448.2	1375.0	2712.0	3471
Temperature, 4	73.426	1.229	70.820	73.420	76.25
Temperature, 5	73.908	1.383	70.280	74.060	77.08
Temperature, 6	74.852	1.274	71.980	74.960	77.64
Precipitation, 4	3.985	1.235	2.414	3.596	7.116
Precipitation, 5	3.778	1.030	2.232	3.558	6.034
Precipitation,6	4.022	1.112	2.314	3.616	6.980

*District 4= WestCentral; District 5=Central; District 6= East Central.

Using the collected time series for three different districts, the panel data was constructed. The summary statistics of panel data has been presented in table 2 below.

Table 2: Summary statistics of the panel data. N=93

Variable	Mean	StDev	Minimum	Median	Maximum
Yield	2584.0	494.8	1185.0	2569.0	3606.0
Temperature	74.062	1.414	70.280	74.080	77.64
Precipitation	3.929	1.122	2.232	3.614	7.116

The histogram of dependent variable yield is approximately normal, and the well scattered scatter plot shows the randomness and independent sampling distribution. The scatter plot has been presented in figure 4 at the end of the paper. The sampling agricultural districts have been highlighted and presented at the end of paper in figure 3.

The test for equal variance was conducted using Leven's test which was found insignificant (p-value is greater than 0.05 i.e. 0.64), which would help to claim that agricultural districts wouldn't have created significant variability in the peanut yield. This is expected becau ss the adjacent districts spreaded along the very narrower geographical locations have been selected for this study. This has been presented in figure 1. Same way, the popularly known technique, rule of thumb which is the ratio of largest standard deviation to smallest standard deviation is fairly lower than 2 also satisfy our claim of equal variance. The standard deviation of yield for each districts have been presented in table 3 below.

Table 3.standard Deviation

Ag. District	N	Mean	StDev
4	31	2538.3	565.4
5	31	2489.2	445.5
6	31	2724.6	448.2

The rule of Thumb= Largest stdev/ smallest stdev= 556.4/445.5=1.24 <2. Satisfied.

The Maximum Likelihood Estimates

As suggested by Just and Pop, here is used maximum likelihood technique using the same equation 6, the result produces meaningful outome where temperaturature , precipitation and their squares are found significant. The result has been presented in table 4 below.

Table 4.Maximum Likelihood Results for the effect of Mean Yield

Log likelihood at convergence: -683.2174

Convergence criterion achieved: 0.01000

Parameter	Estimate	td.Err~R	Std.Err~H	Z~R
Constant	-35839.5462	5.3142	644.7500	-6744.1514
Trend	-164.9257	215.4158	247.7332	-0.7656
Temperature	1066.1183	44.8344	66.4606	23.7790*
Precipitation	173.6678	39.3241	37.2600	4.4163*
$(\text{Temperature})^2$	3.7330	0.5992	0.6139	6.2305*
$(\text{Precipitation})^2$	-7.4171	0.6026	0.8753	-12.3087*
Interaction	0.7279	2.9909	3.4184	0.2434
Sigma Square	140776.7886	2118.8609	0.0000	66.4398

The Effects of Temperature and Precipitation on Mean Yield

Based on the maximum likelihood results presented in table 6, temperature and precipitation both produce significant effects on the mean yield of peanuts in Georgia. Temperature and temperature square both have positively significant impact on mean yield of peanuts. It could be claimed that temperature would enhance the yield of peanuts for this geographical location as mu as it could be. So, we prefer higher and higher temperature in the State of Georgia in producing peanuts.

Results show precipitation up to certain limit produces positive effect on mean yield but the excessive precipitation would start producing negative effect. Historical evidence in peanuts production suggest that there could be great reduction in peanuts yield due to excesive rainfall during its production season. Thus our result is consistent with the farmer's experience.

The approximate equation from the obtained result for effect of temperature on mean yield could be written as,

Yield= 1066 T + 3.7 T^2

The F.O.C is 1006 + 7.4 T=0.

Therefore, T= - 135

This relation can be explained by figure 2 below.

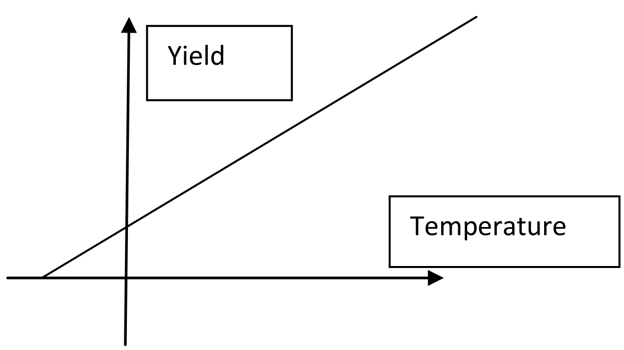

Figure 2: Effets of Temperature on Mean Yield

Similarly, the approximate equation for the effect of precipitation on mean yield be written as;

Yield= 173 P – 7.41 P^2 , Then the F.O.C. is 173 – 14.82 P=0

Thus, P= 11.67

This relation can be shown in figure 3 below.

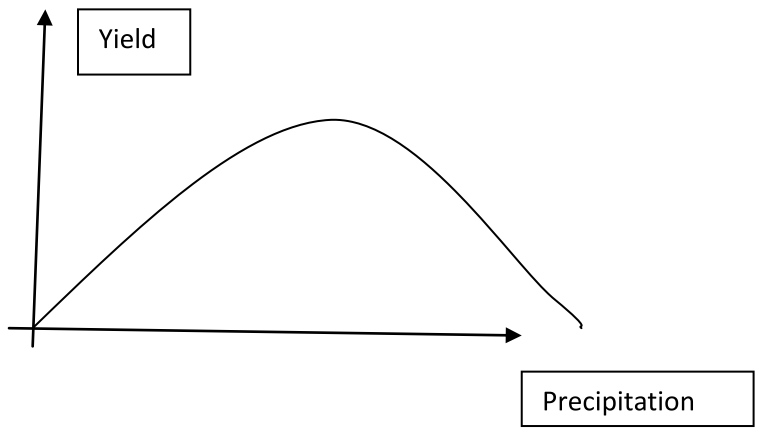

Figure 3. Effect of precipitation on mean yield

Conclusions:

The mean yield of peanuts in the study area can be predicted by the variables temperature and precipitation. In this region, temperature produces positive impact on peanut yield for all levels of temperature. The precipitation produces the positive impact up to certain limit but excessive precipitation would retard the peanut yield. Thus, it can be concluded that climate change is not just a myth; it is producing significant impacts on agricultural production.

This study has assessed the impact of temperature and precipitation on mean yield only, but hasn’t shown cleared about the effects of those factors on variance of yield which could be the immediate further research topic. And It has taken only one crop to study, inclusion of other important field crops in study could make its result more robust.

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