Climate Change Adaptation and Shifts in Land Use for Major Crops in the U.S.

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Abstract

This study examines how the U.S. crop mix pattern has responded to climate and in turn the potential effects of projected climate change. We find that there are significant effects of temperature and precipitation on the crop choice decisions.

Introduction

Climate change is influencing agricultural productivity and land use (Davis and Kilian 2011; Feng, Krueger and Oppenheimer 2010; Hertel 2011; McCarl, Villavicencio and Wu 2008; Seo and Mendelsohn 2008a). Farmers facing alterations in productivity often adapt by changing crop and land use mix. Lands can go from crops to livestock as has been found in Mu, McCarl and Wein (2013) and Seo (2010) while crop mixes may change and agricultural land may move to or from forest (Choi and Sohngen 2009; Langpap and Wu 2010; Reilly, et al. 2003; Seo and Mendelsohn 2008b; Souza-Rodrigues 2014). Understanding the nature of such effects provides important insight into how climate change is affecting agriculture and ways that agriculture can adapt. Here empirical data are used to examine the relationships between climate attributes, crop mix, and land use. To do this an econometric approach will be used to see how land use shares vary with climate.

Agricultural crop mix and land use change is often discussed as a response to changing climate (Adams, et al. 1990; Attavanich, et al. 2013; Reilly, et al. 2003). This study examines crop mix shifts based on historical data at the county level in the U.S. We will estimate land shares by applying fractional regression as opposed to using the more common multinomial logistic regression; plus will consider most of the major crops in the U.S. and their price effects.

Background on Estimation Approach

Land uses for each crop can be shown as proportions of the total crop land area. Accordingly, the proportion is falling into the unit interval given the total land normalized to one. Estimating such models by using linear models such as ordinary least squares or logarithm transformation arise several problems and will be discussed below.

Some crops are not grown in some regions and thus we must deal with zero values for the dependent variables. However, zeroes in the dependent variable can cause practical problems since their logs are either negative infinity or undefined. Miller and Plantinga (1999) did a study on land use choices at the aggregate level using a functional form employing the logarithm of the relative expected shares. In the model, each share must be greater than zero to prevent the logarithm from being undefined.

Although Miller and Plantinga (1999) assume that the land use aggregate data did not usually suffer from the zero expected share, we have multiple zero planted acre cases since some crops are not planted at all due to the natural conditions such as climate, soil quality and weather conditions in this analysis. Thus, we estimate the model with the data with zero production by using the fractional regression without modifying the zeroes unlike the previous studies using the log ratios or using the regression with limited dependent variables such as Tobit model.

Another issue is that the study involves multiple crops and land uses. Although Papke and Wooldridge (1996, 2008) employ quasi-maximum likelihood estimator (QMLE) to deal with the fractional dependent variable, their studies are limited to a single dependent variable. Consequently, we are interested in estimating the equations with multinomial choice outcomes.

Some studies have attempted this by using approaches such as multivariate binomial, beta, and Dirichlet regressions (Mullahy 2011; Mullahy and Robert 2010; Murteira and Ramalho

2013; Ramalho, Ramalho and Murteira 2011). In the multinomial setting, full information maximum likelihood (FIML) estimation can be used with extreme value distribution such as Dirichlet regression (Woodland 1979). Nevertheless, the QMLE for the fractional response variables is more robust to distributional misspecification than the regression based on Dirichlet distribution. Furthermore, the Dirichlet distribution allows the predicted values to fall outside the unit interval so it is not the case for our study. (Murteira and Ramalho 2013).

With the ability to deal with the zero fractional dependent variable and the robustness, we use the maximum quasi-likelihood estimation for multinomial fractional regression following Murteira and Ramalho (2013). Following Koch (2010), the specification of multinomial logit for conditional mean function enforces the predicted share falls into the unit interval [0,1]. In turn the conditional mean for land use share with J alternatives by using fractional multinomial logit can be expressed as:

$$(1) \qquad E(s_{ij} \mid \mathbf{x}_i) = G_j(\mathbf{x}_i;\boldsymbol{\beta}) = \frac{\exp(\mathbf{x}_i\boldsymbol{\beta}_j)}{\sum_{k=1}^{J}\exp(\mathbf{x}_i\boldsymbol{\beta}_k)}, \qquad j = 1,\dots,J$$

where s_{ij} is the observed land share for crop j at county i. By setting $\boldsymbol{\beta}_J = 0$ to apply normalization required for identification, we can obtain:

$$(2) \qquad E(s_{ij} \mid \mathbf{x}_i) = G_j(\mathbf{x}_i;\boldsymbol{\beta}) = \frac{\exp(\mathbf{x}_i\boldsymbol{\beta}_j)}{1+\sum_{k=1}^{J-1}\exp(\mathbf{x}_i\boldsymbol{\beta}_k)}, \qquad j = 1,\dots,J-1$$

and

$$(3) \qquad E(s_{iJ} \mid \mathbf{x}_i) = G_J(\mathbf{x}_i;\boldsymbol{\beta}) = \frac{\exp(\mathbf{x}_i\boldsymbol{\beta}_J)}{1+\sum_{k=1}^{J-1}\exp(\mathbf{x}_i\boldsymbol{\beta}_k)}.$$

The estimation by the above equations enforces the conditional expected land shares adding up to one ($\sum_j s_j = 1$) and falling into the unit interval ($s_j \in (0,1)$) given that $P(s_j = 0 | \mathbf{x}) \geq 0$ and $P(s_j = 1 | \mathbf{x}) \geq 0$ for $j = 1, 2, ..., J$.

A quasi-maximum likelihood function can be described as

(4) $$L = \prod_{i=1}^{N} \prod_{j=1}^{J} G(\mathbf{x}_i; \boldsymbol{\beta}_j)^{s_{ij}}$$

and the log-likelihood function of the predicted dependent variable s is

(5) $$l_i(\boldsymbol{\beta}) = s_{i1} \log[G(\mathbf{x}_i; \boldsymbol{\beta}_1)] + s_{i2} \log[G(\mathbf{x}_i; \boldsymbol{\beta}_2)] + ... + s_{iJ} \log[G(\mathbf{x}_i; \boldsymbol{\beta}_J)] .$$

In turn the following first order condition can be solved to obtain estimates for the parameters.

(6) $$\frac{\partial l_i(\boldsymbol{\beta})}{\partial \beta_j} = \sum_{i=1}^{N} \mathbf{x}_i' \left[s_j - G(\mathbf{x}_i; \hat{\boldsymbol{\beta}}) \right] = 0$$

Assuming that the model is correctly specified, the quasi-maximum likelihood estimator is consistent since the log-likelihood function is a member of the linear exponential family (LEF) (Gourieroux, Monfort and Trognon 1984; Nelder and Wedderburn 1972).

Unlike the standard multinomial logit, the multivariate fractional regression does not generally suffer the problem of independence of irrelevant alternatives since it identifies the ratio of the conditional means between alternatives, $G_j / G_k = \exp(\mathbf{x}_i \boldsymbol{\beta}_j) / \exp(\mathbf{x}_i \boldsymbol{\beta}_k)$ $(j \neq k)$, which is functionally independent from the ratio of the other pairs (Murteira and Ramalho 2013).

Note that, as indicated in Papke and Wooldridge (2008), we need to ensure the standard errors are robust to arbitrary standard errors in using QMLE. To make the standard errors robust to misspecification of conditional variance and arbitrary serial dependence, we used fully robust standard errors with county clustered.

Estimates from discrete response estimation methods pose inherent difficulties in interpreting coefficients since the parameter estimates give relative change to the reference group. The scale of coefficients is different among each model and thus the parameter estimates cannot be compared in magnitude but just in terms of signs. To compare the magnitude of different models or equations, we can use the concept of the average marginal effect (AME). There are various versions of the average marginal effect (Bartus 2005; Long and Freese 2006). For this study, we use the most popular and robust AME $(\partial s / \partial x_m = \sum G'(\mathbf{x}'\boldsymbol{\beta})\boldsymbol{\beta}_m / N)$, which is expressed in our model as

(7) $$\frac{\partial E[s_{ij} \mid \mathbf{x}_i]}{\partial x_{im}} = \beta_{jm} G_j - G_j \sum_{k=1}^{J-1} G_k \beta_{km}$$

where s_{ij} is a share of crop j at county i and x_{im} is one of the continuous explanatory variables at county i. For discrete explanatory variables, the average marginal effect is

(8) $$\frac{\Delta E[s_{ij} \mid \mathbf{x}_i]}{\Delta x_{im}} = G_j[\mathbf{x}_{i\sim m}\boldsymbol{\beta}_{j\sim m} + \beta_{jm}] - G_j[\mathbf{x}_{i\sim m}\boldsymbol{\beta}_{j\sim m}]$$

where $\mathbf{x}_{i\sim m}$ indicates discrete explanatory variables other than x_{im} at county i. We can calculate average marginal effects and corresponding standard errors by using delta method after estimations.

Empirical model specification

In the estimations, the dependent variable is a vector of proportions, $\mathbf{s} = (s_1, s_2, ..., s_J)'$, which gives the land use shares across the J crops that are mutually exclusive. The base crop except for the other major crops is indexed by J and is used for the base reference in the fractional multinomial logit. The explanatory variables consist of the expected net return per unit of commodity, climate variables (5-year average of the annual mean of the temperature and of the total annual precipitation), squared climate variables, county total planted acres, and population density. The exogenous factors are assumed to affect the price per unit and the cost per unit through the yield per area. Following Schlenker and Roberts (2009), we assume that the crop yield is a function of trends, weather, and other factors. To capture technological advance, we include a time trend variable. As shown in the previous section, we include time-averaged explanatory variables to control for heterogeneity and serial correlation.

Planted acres, harvested acres, and crop yield data were drawn from USDA NASS QuickStats[1] on a county basis for barley, corn, cotton, upland cotton, sorghum, soybeans, winter wheat, durum wheat, and spring wheat[2]. Price received by farmers ($ per unit of commodity), Yield (unit of commodity per acre) were also drawn from QuickStats but on the state level. Missing values for price are filled with the price from the adjacent location. Production cost data were drawn from USDA ERS Commodity Costs and Returns[3] report. Because the cost and returns data are differently classified before and after a specific year for each commodity in ERS, the variable costs were re-calculated with the elements consisting of the variable costs to make them compatible.[4] All the costs and prices are normalized by the Producer Prices Received

[1] For the detailed information, see the website (http://quickstats.nass.usda.gov/).

[2] Although hay is considered a major crop in the US, it is a perennial and would not a readily respond to current conditions and was thus omitted.

[3] See the website (http://www.ers.usda.gov/data-products/commodity-costs-and-returns.aspx).

[4] For example, 'hired labor' is considered cash expenses before the 2003 data for barley but it is considered allocated overhead after 2003. After some changing point of the survey year for each crop, we subtract 'interest on operating inputs' that does not exist before the year and add hired labor to operating or variable cost.

Index[5] make them the 1977 constant dollar values. Counties with observations of omitted or zero total harvested acres were excluded from the estimation.

Monthly county level climate data were obtained from the United States Historical Climatology Network (USHCN) on annual average temperature and annual land monthly average precipitation.

The annual data include 2886 counties in the contiguous 40 United States[6] and years from 1975 to 2010. The total number of observations in the pooled estimation is 94,698. Missing values are filled with linear interpolation when the region has some missing observations in analyzed periods. When a county had zero total planted acres or harvested acres across all crops in any year, the county was excluded.

The older farm production regions (FPRs) and the newer farm resource regions (FRRs) by ERS were used for regional categories. Before 1995, ERS used ten FPRs to classify the region and after 1995, they use nine FRRs. Since our study focuses on the locational shifts of the crop variations, we use the older FPRs as the geographic categories. The regional classification is shown in Figure 1.

The means and standard deviations of the dependent and independent variables by region are shown in Table 1 and Table 2. The crop that has mean proportion less than 1% is considered one of the non-major crops and omitted for the regional analyses.

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[5] The Producer Prices Received Index (base: 1977) was drawn from [Quick spreadsheet of the most common indexes and discount rates] at the site (http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/econ/costs/).

[6] Excluded states or territories are Alaska, American Samoa, District of Columbia, Guam, Hawaii, Puerto Rico, and Virgin Islands. From the 48 contiguous U.S., Connecticut, Delaware, Maine, Massachusetts, New Hampshire, Nevada, Rhode Island, and Vermont are excluded because the croplands are too small or lack of data.

Estimation results

The estimation results for average land share allocation are presented in Table 3. Since the estimation was done by QMLE with robust clustered variance-covariance matrix, the conventional Hausman test could not be used. Instead, we used the Akaike information criterion (AIC) and Bayesian information criterion (BIC) to compare models. In terms of AIC and BIC, we do not see significant improvement in including year dummies for time fixed effects. Thus, the year dummies, which result in different intercept across years, are not included in this study.

We tested several specifications regarding the temperature and precipitation terms finding the model including climate squared terms is more desirable than the model without the squared terms. We also find that the inclusion of the net return variables improve the model.

Estimation results indicate the change in the probability of the choice relative to the base choice. It is difficult to interpret the coefficients directly from the estimation results. Instead, the mean of marginal effects capture the marginal impacts of change of one of the explanatory variables on the choice decisions on crop planted acres.

Average marginal effects (AME) are given in Table 4. The relationships between 5-year average annual temperature and predicted proportions for each cropland choice shown in Figure 3. In Figure 4, the predicted proportions for each crop are shown at each level of the 5-year total annual precipitation.

From the results, we can see:

- In Table 4, all of the major crops are statistically significantly affected by changes in temperature and precipitation. Upland cotton, rice, sorghum, soybeans, and winter wheat are more likely chosen when the 5-year average temperature increases. On the other hand, barley, corn, spring wheat, and durum wheat are less likely chosen when the temperature goes down.

- When the annual precipitation increases, the proportions of planted acres for corn, rice, and soybeans increase with the proportions for barley, upland cotton, sorghum, and all types of wheat declining.
- In Table 4, own net return coefficients are statistically significant at the 1% level with positive signs except for rice, sorghum, and durum wheat. Since this model includes almost all the counties in the U.S. and the county-specific characteristics vary substantially, some location-specific crops such as rice and some major crops may have insignificant effects of own net return.
- As population density in the county increases, the marginal effects are mixed. Specifically, barley and soybeans are grown in more populated areas. On the other hand, upland cotton, sorghum, and winter wheat are more likely chosen in less populated areas.
- The predicted proportions of crop planted acres over the 5-year average of the mean temperature are shown in Figure 3. Around the 1975-2010 mean (12.4 degrees Celsius), warming causes increasing proportions of winter wheat, upland cotton, sorghum, and rice as the temperature warms. On the other hand, the predicted proportions of spring wheat, barley, corn, durum wheat, spring wheat, and soybeans decreases as the annual mean temperature increases. The figure follows the results of the average marginal effects. However, winter wheat and soybeans start decreasing as the temperature goes beyond 14 degrees Celsius.
- In Figure 4, we can see the results of the predicted proportions of crop choice under changes in precipitation. Around the 1975-2010 mean of the annual precipitation (95.1

cm), more precipitation causes increasing proportions of corn, soybeans, and rice. On the other hand, from the mean precipitation, more precipitation makes the predicted proportions of winter wheat, spring wheat, durum wheat, sorghum, and barley smaller. The figure also follows the results of the average marginal effects. We see the change in land share proportions is nonlinear to a unit change of temperature and precipitation. The further the deviation from the mean temperature and precipitation goes the more severe the crop mix change.

Estimation results by region

Farmers in various locations produce different crops depending on economic, agronomic, social, and other location specific characteristics. We estimate the same model with subsampled counties for the old ERS farm production regions. The average marginal effects of temperature and precipitation on the proportions of planted acres by region are shown in Table 5. With the locational figures, the results are also summarized in Figure 5 for the marginal effects of temperature and Figure 6 for the marginal effects of precipitation on the choice of planting crops. Based on the results in Figure 5, we see when the annual temperature increases:

- The proportion of planted acres for corn increases in the Southern Plains, Southeast, and Mountain regions but decreases in the Northern Plains, Lake States, Corn Belt, Appalachian, and Northeast regions. Thus increasing temperature has mixed effects on different regions.
- The proportion of soybeans and winter wheat planted acres in the southern regions decreases but the proportions in the northern regions increases with an exception of

soybeans decrease in the Northern Plains. This indicates that the overall temperature increase may cause the soybean and winter wheat production regions to move north.

- Both of the major regions for rice production (Pacific and Delta) show increases in the proportion of the planted acres for rice when it gets hotter.
- The proportion of sorghum increases in the Mountain, Northern Plains, and Southern Plains regions but decreases in the Delta and Southeast regions. This indicates that the sorghum production may move northwest when the overall temperature goes up.
- The proportion of spring wheat in all of the planted regions (Pacific, Mountain, Northern Plains, and Lake States) decreases when temperature increases. The decreased spring wheat might cause Canada to increase planted acres for spring wheat. However, this study does not see the effects since the analysis is bounded in the US.

Based on the results in Figure 6, we see when the annual precipitation increases:

- The proportion of winter wheat increases in the Mountain but decreases in the eastern and central regions. This implies that the planted acres for winter wheat might move west when precipitation increases.
- The proportion of planted acres for rice increases in the Southern Plains and Pacific regions but decreases in the Delta. It indicates that the rice production may move west when the overall increased precipitation in the regions.
- The proportion of corn has spatially mixed results to increases in precipitation. In the Appalachian and Mountain regions, the proportion decreases but in the Lake States, Corn Belt, Southern Plains, Delta, and Southeast regions, the proportion increases.

- The proportion of planted acres for soybeans also has mixed results. The proportion increases in the Northern Plains, Appalachian, and Southern Plains regions but it decreases in the Lake States.

Concluding remarks

The primary goal of this study was to examine how climate influences land use choice among major crops in the US. In doing this, this study applies fractional regression. Lastly, this study examines crop mix shifts considering the price effects.

We found that when the annual temperature goes up that the overall proportions of cotton, rice, sorghum, soybeans, and winter wheat are likely to increase with barley, corn, spring wheat, and durum wheat declining. We also found that increased precipitation reduces barley, cotton, sorghum, and all types of wheat but increases corn, rice, and soybeans.

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Tables

Table 1 Means and standard deviations of variables by region

Variable	Appalachian	Corn Belt	Delta States	Lake States	Mountain	Northeast
% Barley planted acres	0.02 (0.04)	0.00 (0.00)	0.00 (0.00)	0.05 (0.14)	0.27 (0.29)	0.02 (0.03)
% Corn planted acres	0.52 (0.29)	0.47 (0.18)	0.13 (0.20)	0.62 (0.25)	0.15 (0.24)	0.76 (0.24)
% Cotton planted acres	0.03 (0.10)	0.00 (0.02)	0.13 (0.18)	0.00 (0.00)	0.03 (0.14)	0.00 (0.00)
% Rice planted acres	0.00 (0.00)	0.00 (0.02)	0.08 (0.14)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
% Sorghum planted acres	0.01 (0.03)	0.02 (0.05)	0.04 (0.08)	0.00 (0.00)	0.03 (0.10)	0.00 (0.00)
% Soybean planted acres	0.28 (0.21)	0.42 (0.14)	0.49 (0.24)	0.22 (0.18)	0.00 (0.00)	0.14 (0.18)
% Wheat (winter) planted acres	0.15 (0.13)	0.09 (0.11)	0.13 (0.16)	0.06 (0.10)	0.36 (0.30)	0.08 (0.09)
% Wheat (spring) planted acres	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.06 (0.16)	0.15 (0.20)	0.00 (0.00)
% Wheat (durum) planted acres	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.01 (0.06)	0.00 (0.00)
Annual mean emperature (C)	13.67 (1.78)	10.86 (1.79)	17.43 (1.63)	6.70 (1.60)	8.73 (3.64)	9.76 (2.14)
Annual total precipitation (cm)	122.70 (16.78)	100.82 (14.20)	142.97 (17.39)	79.09 (11.74)	36.77 (12.77)	108.61 (12.79)
Barley net return ($/bu)	0.81 (0.15)	0.85 (0.13)	0.89 (0.12)	0.87 (0.25)	1.08 (0.18)	0.81 (0.17)
Corn net return ($/bu)	1.08 (0.21)	1.01 (0.22)	1.09 (0.22)	0.97 (0.21)	1.13 (0.22)	1.14 (0.23)
Cotton net return ($/cwt)	23.66 (5.55)	23.15 (5.14)	23.78 (5.12)	23.18 (5.12)	23.73 (5.15)	23.18 (5.13)
Rice net return ($/cwt)	3.39 (0.91)	3.36 (0.90)	3.37 (0.88)	3.38 (0.90)	3.38 (0.91)	3.36 (0.90)
Sorghum net return ($/bu)	0.92 (0.18)	0.92 (0.19)	0.94 (0.16)	0.94 (0.17)	0.95 (0.19)	0.97 (0.18)
Soybean net return ($/bu)	2.52 (0.53)	2.55 (0.52)	2.57 (0.46)	2.49 (0.51)	2.49 (0.47)	2.48 (0.53)
Wheat (winter) net return ($/bu)	1.29 (0.23)	1.29 (0.24)	1.34 (0.21)	1.30 (0.28)	1.39 (0.26)	1.33 (0.27)
Wheat (spring) net return ($/bu)	1.44 (0.28)	1.45 (0.28)	1.44 (0.27)	1.40 (0.29)	1.44 (0.32)	1.44 (0.28)
Wheat (durum) net return ($/bu)	1.64 (0.41)	1.63 (0.42)	1.65 (0.40)	1.61 (0.43)	1.64 (0.39)	1.65 (0.41)
Log (Population density)	4.72 (0.89)	4.57 (1.07)	4.17 (0.80)	4.40 (1.24)	2.31 (1.53)	5.57 (1.13)
Log (Planted acres)	9.29 (1.57)	11.45 (1.32)	10.28 (1.77)	10.78 (1.72)	9.91 (1.94)	9.82 (1.25)
Number of counties	459	495	218	236	248	158

Note: Standard deviations are in parentheses. All of the crop net returns are in 1977 constant US dollars.

Table 2 Means and standard deviations of variables by region (continued)

Variable	Northern Plains	Pacific	Southeast	Southern Plains	Total
% Barley planted acres	0.03 (0.07)	0.24 (0.29)	0.00 (0.01)	0.00 (0.02)	0.04 (0.14)
% Corn planted acres	0.29 (0.26)	0.17 (0.29)	0.32 (0.28)	0.10 (0.16)	0.37 (0.31)
% Cotton planted acres	0.00 (0.00)	0.03 (0.13)	0.18 (0.25)	0.16 (0.24)	0.05 (0.15)
% Rice planted acres	0.00 (0.00)	0.05 (0.18)	0.00 (0.00)	0.02 (0.10)	0.01 (0.07)
% Sorghum planted acres	0.09 (0.11)	0.00 (0.03)	0.03 (0.06)	0.16 (0.18)	0.04 (0.10)
% Soybean planted acres	0.16 (0.18)	0.00 (0.00)	0.29 (0.23)	0.06 (0.14)	0.23 (0.23)
% Wheat (winter) planted acres	0.27 (0.29)	0.41 (0.31)	0.18 (0.22)	0.51 (0.34)	0.21 (0.26)
% Wheat (spring) planted acres	0.13 (0.23)	0.08 (0.15)	0.00 (0.00)	0.00 (0.00)	0.04 (0.12)
% Wheat (durum) planted acres	0.03 (0.11)	0.01 (0.07)	0.00 (0.00)	0.00 (0.00)	0.00 (0.04)
Annual mean emperature (C)	9.47 (3.00)	12.12 (3.45)	17.56 (1.65)	17.43 (2.35)	12.40 (4.29)
Annual total precipitation (cm)	62.33 (19.41)	62.43 (42.69)	131.08 (17.62)	82.55 (28.76)	95.11 (35.75)
Barley net return ($/bu)	0.84 (0.18)	1.02 (0.20)	0.89 (0.11)	0.93 (0.14)	0.88 (0.18)
Corn net return ($/bu)	0.98 (0.21)	1.23 (0.22)	1.12 (0.21)	1.11 (0.19)	1.07 (0.22)
Cotton net return ($/cwt)	22.71 (5.35)	24.90 (5.16)	24.25 (5.39)	21.84 (4.94)	23.30 (5.28)
Rice net return ($/cwt)	3.38 (0.90)	3.35 (1.04)	3.39 (0.91)	3.45 (0.92)	3.39 (0.91)
Sorghum net return ($/bu)	0.89 (0.21)	1.00 (0.20)	0.96 (0.19)	0.96 (0.18)	0.94 (0.19)
Soybean net return ($/bu)	2.45 (0.51)	2.48 (0.47)	2.55 (0.51)	2.39 (0.49)	2.50 (0.51)
Wheat (winter) net return ($/bu)	1.34 (0.26)	1.48 (0.26)	1.28 (0.23)	1.36 (0.27)	1.32 (0.25)
Wheat (spring) net return ($/bu)	1.46 (0.29)	1.49 (0.29)	1.43 (0.27)	1.43 (0.28)	1.44 (0.29)
Wheat (durum) net return ($/bu)	1.62 (0.44)	1.70 (0.44)	1.65 (0.40)	1.64 (0.40)	1.64 (0.41)
Log (Population density)	2.63 (1.26)	4.12 (1.83)	4.47 (0.94)	3.47 (1.49)	4.04 (1.50)
Log (Planted acres)	11.88 (0.92)	9.63 (2.18)	9.32 (1.53)	10.51 (1.60)	10.43 (1.79)
Number of counties	317	122	311	322	2886

Note: Standard deviations are in parentheses. All of the crop net returns are in 1977 constant US dollars.

Table 3 Fractional multinomial logit estimation results

	% Planted acres							
	Barley	**Cotton**	**Rice**	**Sorghum**	**Soybeans**	**Winter Wheat**	**Spring Wheat**	**Durum Wheat**
Temperature	-0.4592***	3.7628***	1.2821*	0.3462***	0.1255***	0.4615***	-0.3874***	-1.3075***
	(0.0854)	(0.3305)	(0.7509)	(0.0918)	(0.0384)	(0.0719)	(0.1045)	(0.1156)
Temperature squared	0.0128***	-0.0953***	-0.0285	-0.0010	-0.0008	-0.0117***	-0.0014	0.0547***
	(0.0032)	(0.0094)	(0.0213)	(0.0031)	(0.0015)	(0.0025)	(0.0059)	(0.0043)
Precipitation	-0.0222**	-0.0689***	-0.0091	-0.0048	0.0305***	-0.0123**	-0.0532***	-0.0463
	(0.0095)	(0.0067)	(0.0135)	(0.0062)	(0.0043)	(0.0060)	(0.0118)	(0.0483)
Precipitation squared	-0.0000	0.0003***	0.0001*	-0.0000	-0.0001***	-0.0000	0.0001	-0.0009
	(0.0001)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0001)	(0.0006)
Trend	-0.0052	0.0397***	0.0681***	-0.0522***	0.0062***	-0.0066***	0.0178***	0.0127*
	(0.0038)	(0.0036)	(0.0117)	(0.0023)	(0.0011)	(0.0015)	(0.0028)	(0.0065)
Barley net return	1.1618***	0.8995***	3.5028***	0.4020**	-0.2146***	1.1678***	0.4046*	0.4611
	(0.2438)	(0.1670)	(0.4005)	(0.1728)	(0.0744)	(0.1307)	(0.2376)	(0.3173)
Corn net return	1.0070***	-0.1389	-1.4646***	-1.8547***	-1.0533***	0.7584***	-0.6755**	-1.9046***
	(0.2849)	(0.1882)	(0.5329)	(0.1730)	(0.1053)	(0.1498)	(0.2730)	(0.6494)
Cotton net return	0.0176***	0.0131***	0.0157	-0.0142***	-0.0104***	-0.0161***	0.0025	-0.0337
	(0.0052)	(0.0040)	(0.0137)	(0.0036)	(0.0015)	(0.0023)	(0.0041)	(0.0206)
Rice net return	-0.2480***	-0.0955***	-0.0315	-0.0132	0.0482***	-0.1472***	-0.1018***	0.0708**
	(0.0202)	(0.0193)	(0.0383)	(0.0123)	(0.0058)	(0.0091)	(0.0149)	(0.0342)
Sorghum net return	0.8588***	1.0810***	2.1971***	0.2407*	-0.0127	-0.1233	0.9386***	4.8378***
	(0.3241)	(0.1210)	(0.5023)	(0.1313)	(0.0610)	(0.1019)	(0.3130)	(1.2105)
Soybean net return	-0.4336***	-0.1761***	-0.8006***	-0.0905***	0.2813***	-0.1652***	-0.2678***	-0.6467***
	(0.0515)	(0.0378)	(0.1774)	(0.0346)	(0.0213)	(0.0292)	(0.0455)	(0.1037)
Wheat (winter) net return	0.1080	-0.7767***	0.9079***	0.7067***	0.2377***	0.2607***	0.4763***	-0.5859*
	(0.1090)	(0.1010)	(0.2481)	(0.0683)	(0.0352)	(0.0642)	(0.1266)	(0.3019)
Wheat (spring) net return	-0.4404**	-0.5071***	-0.8759**	0.1595*	0.3051***	-0.3245***	0.3318**	-0.2911
	(0.1778)	(0.1016)	(0.3491)	(0.0919)	(0.0574)	(0.0755)	(0.1333)	(0.3492)
Wheat (durum) net return	-0.1499**	0.1087***	-0.2827***	0.0075	-0.1980***	-0.1441***	-0.2889***	-0.0697
	(0.0612)	(0.0402)	(0.1018)	(0.0435)	(0.0207)	(0.0334)	(0.0503)	(0.0933)
log (Population density)	0.0464	-0.2247***	0.0655	-0.1362***	0.0401**	-0.0854***	-0.0258	0.0351
	(0.0440)	(0.0414)	(0.1247)	(0.0336)	(0.0196)	(0.0250)	(0.0514)	(0.1001)
log (Total planted acre)	-0.1222***	0.5720***	0.8033***	0.2280***	0.3812***	0.0910***	0.0928*	0.4614***
	(0.0366)	(0.0382)	(0.0855)	(0.0314)	(0.0170)	(0.0215)	(0.0478)	(0.1165)
Number of counties	2886							

Note: Base reference is proportion of planted acres for corn. County-clustered robust standard errors are shown in parentheses and *, **, and *** indicate statistically significance at 10%, 5%, and 1% levels, respectively. The pooled model does not include group means and so it is estimated as the model with cross-sectional data. Farm resource region dummies are included but suppressed from the table. The full set of coefficients including the dummy variables is available upon request.

Table 4 Average marginal effects on proportions of planted acres

	Barley	Corn	Cotton	Rice	Sorghum	Soybeans	Winter Wheat	Spring Wheat	Durum Wheat
Temperature	-0.0068***	-0.0206***	0.0132***	0.0013**	0.0076***	0.0042***	0.0105***	-0.0083***	-0.0013***
	(0.0007)	(0.0019)	(0.0008)	(0.0006)	(0.0006)	(0.0013)	(0.0017)	(0.0007)	(0.0003)
Precipitation	-0.0003***	0.0005**	-0.0004***	0.0001**	-0.0002***	0.0023***	-0.0011***	-0.0006***	-0.0003***
	(0.0001)	(0.0002)	(0.0001)	(0.0001)	(0.0000)	(0.0001)	(0.0002)	(0.0001)	(0.0000)
Trend	-0.0003***	-0.0002	0.0015***	0.0005***	-0.0019***	0.0011***	-0.0011***	0.0004***	-0.0000
	(0.0001)	(0.0002)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0002)	(0.0001)	(0.0000)
Barley net return	0.0208***	-0.0804***	0.0154**	0.0279***	-0.0093*	-0.0911***	0.1226***	-0.0060	-0.0000
	(0.0069)	(0.0155)	(0.0060)	(0.0051)	(0.0053)	(0.0087)	(0.0150)	(0.0048)	(0.0010)
Corn net return	0.0304***	0.0642***	0.0040	-0.0114***	-0.0648***	-0.1516***	0.1585***	-0.0215***	-0.0077***
	(0.0076)	(0.0191)	(0.0062)	(0.0031)	(0.0054)	(0.0125)	(0.0163)	(0.0056)	(0.0025)
Cotton net return	0.0007***	0.0017***	0.0009***	0.0002	-0.0003**	-0.0010***	-0.0021***	0.0001	-0.0001
	(0.0002)	(0.0003)	(0.0002)	(0.0001)	(0.0001)	(0.0002)	(0.0003)	(0.0001)	(0.0001)
Rice net return	-0.0053***	0.0086***	-0.0018**	0.0001	0.0018***	0.0121***	-0.0165***	0.0002	0.0008***
	(0.0006)	(0.0011)	(0.0007)	(0.0003)	(0.0004)	(0.0007)	(0.0011)	(0.0003)	(0.0001)
Sorghum net return	0.0117	-0.0201	0.0319***	0.0143***	0.0055	-0.0082	-0.0532***	0.0030	0.0150***
	(0.0081)	(0.0130)	(0.0044)	(0.0042)	(0.0040)	(0.0072)	(0.0112)	(0.0059)	(0.0045)
Soybean net return	-0.0098***	-0.0056	-0.0057***	-0.0066***	-0.0008	0.0513***	-0.0194***	-0.0017*	-0.0018***
	(0.0015)	(0.0040)	(0.0012)	(0.0017)	(0.0009)	(0.0023)	(0.0029)	(0.0009)	(0.0004)
Wheat (winter) net return	-0.0022	-0.0434***	-0.0414***	0.0070***	0.0211***	0.0274***	0.0236***	0.0109***	-0.0029**
	(0.0029)	(0.0075)	(0.0037)	(0.0022)	(0.0020)	(0.0046)	(0.0072)	(0.0027)	(0.0011)
Wheat (spring) net return	-0.0102*	0.0007	-0.0164***	-0.0063**	0.0107***	0.0567***	-0.0471***	0.0128***	-0.0009
	(0.0053)	(0.0098)	(0.0032)	(0.0027)	(0.0026)	(0.0064)	(0.0079)	(0.0029)	(0.0012)
Wheat (durum) net return	-0.0017	0.0278***	0.0079***	-0.0017*	0.0036***	-0.0209***	-0.0103***	-0.0049***	0.0002
	(0.0018)	(0.0038)	(0.0013)	(0.0009)	(0.0014)	(0.0026)	(0.0038)	(0.0010)	(0.0003)
log (Population density)	0.0026**	0.0037	-0.0079***	0.0010	-0.0029***	0.0119***	-0.0082***	-0.0005	0.0003
	(0.0012)	(0.0034)	(0.0015)	(0.0010)	(0.0010)	(0.0025)	(0.0027)	(0.0011)	(0.0004)
log (Total planted acre)	-0.0069***	-0.0472***	0.0147***	0.0043***	0.0018**	0.0426***	-0.0115***	0.0008	0.0015***
	(0.0010)	(0.0029)	(0.0014)	(0.0008)	(0.0009)	(0.0020)	(0.0024)	(0.0010)	(0.0005)

Note: Delta method standard errors are shown in parentheses and *, **, and *** indicate statistically significance at 10%, 5%, and 1% levels, respectively. Farm resource region dummies are included but suppressed from the table.

Table 5 Average marginal effects of temperature and precipitation on proportions of planted acres by region

Region		Barley	Corn	Cotton	Rice	Sorghum	Soybeans	Winter Wheat	Spring Wheat	Durum Wheat
Appalachian	Temperature	-0.0041***	-0.0500***	0.0160***			0.0318***	0.0063**		
		(0.0006)	(0.0054)	(0.0028)			(0.0045)	(0.0028)		
	Precipitation	-0.0003***	-0.0017***	0.0002			0.0023***	-0.0004		
		(0.0001)	(0.0004)	(0.0001)			(0.0003)	(0.0003)		
Corn Belt	Temperature		-0.0615***				0.0226***	0.0388***		
			(0.0035)				(0.0030)	(0.0022)		
	Precipitation		0.0003				0.0002	-0.0005***		
			(0.0003)				(0.0003)	(0.0002)		
Delta	Temperature		-0.0100**	-0.0057	0.0282***	-0.0062***	-0.0016	-0.0046		
			(0.0049)	(0.0046)	(0.0081)	(0.0015)	(0.0073)	(0.0045)		
	Precipitation		0.0016***	0.0002	-0.0007***	0.0001	0.0007	-0.0019***		
			(0.0004)	(0.0004)	(0.0002)	(0.0001)	(0.0005)	(0.0004)		
Lake States	Temperature	-0.0191***	-0.0221***				0.0407***	0.0225***	-0.0220***	
		(0.0027)	(0.0080)				(0.0046)	(0.0042)	(0.0058)	
	Precipitation	-0.0000	0.0055***				-0.0029***	0.0000	-0.0026***	
		(0.0004)	(0.0007)				(0.0005)	(0.0003)	(0.0004)	
Mountain	Temperature	-0.0383***	0.0194***	0.0083***		0.0053***		0.0218***	-0.0165***	
		(0.0064)	(0.0059)	(0.0024)		(0.0011)		(0.0058)	(0.0036)	
	Precipitation	-0.0027***	-0.0044***	-0.0005		0.0002		0.0082***	-0.0007	
		(0.0010)	(0.0010)	(0.0004)		(0.0003)		(0.0011)	(0.0006)	
Northeast	Temperature	0.0086***	-0.0598***				0.0383***	0.0128***		
		(0.0010)	(0.0073)				(0.0049)	(0.0031)		
	Precipitation	0.0000	0.0012				0.0002	-0.0014***		
		(0.0001)	(0.0008)				(0.0005)	(0.0004)		
Northern Plains	Temperature	-0.0101***	-0.0328***			0.0159***	-0.0218***	0.0848***	-0.0211***	-0.0149***
		(0.0008)	(0.0061)			(0.0028)	(0.0027)	(0.0063)	(0.0029)	(0.0021)
	Precipitation	-0.0003*	0.0021***			0.0004*	0.0067***	-0.0043***	-0.0024***	-0.0022***
		(0.0001)	(0.0008)			(0.0003)	(0.0003)	(0.0007)	(0.0004)	(0.0004)
Pacific	Temperature	-0.0110	0.0058	0.0148***	0.0172**			-0.0143*	-0.0125***	
		(0.0073)	(0.0064)	(0.0029)	(0.0069)			(0.0086)	(0.0033)	
	Precipitation	-0.0010	0.0010*	-0.0013***	0.0022***			0.0002	-0.0011**	
		(0.0008)	(0.0005)	(0.0003)	(0.0006)			(0.0009)	(0.0004)	
Southeast	Temperature		0.0254***	0.0350***		-0.0027**	-0.0396***	-0.0180***		
			(0.0070)	(0.0046)		(0.0012)	(0.0056)	(0.0048)		
	Precipitation		0.0025***	0.0009**		-0.0003***	-0.0005	-0.0027***		
			(0.0005)	(0.0004)		(0.0001)	(0.0004)	(0.0004)		
Southern Plains	Temperature		0.0298***	0.0295***	-0.0016	0.0289***	-0.0071**	-0.0796***		
			(0.0054)	(0.0048)	(0.0033)	(0.0041)	(0.0028)	(0.0074)		
	Precipitation		0.0013***	-0.0052***	0.0005***	0.0002	0.0018***	0.0014**		
			(0.0004)	(0.0005)	(0.0002)	(0.0002)	(0.0002)	(0.0006)		

Note: Delta method standard errors are shown in parentheses and *, **, and *** indicate statistically significance at 10%, 5%, and 1% levels, respectively. Farm resource region dummies and other explanatory variables such as net return and socioeconomic factors are included but suppressed from the table.

Figures

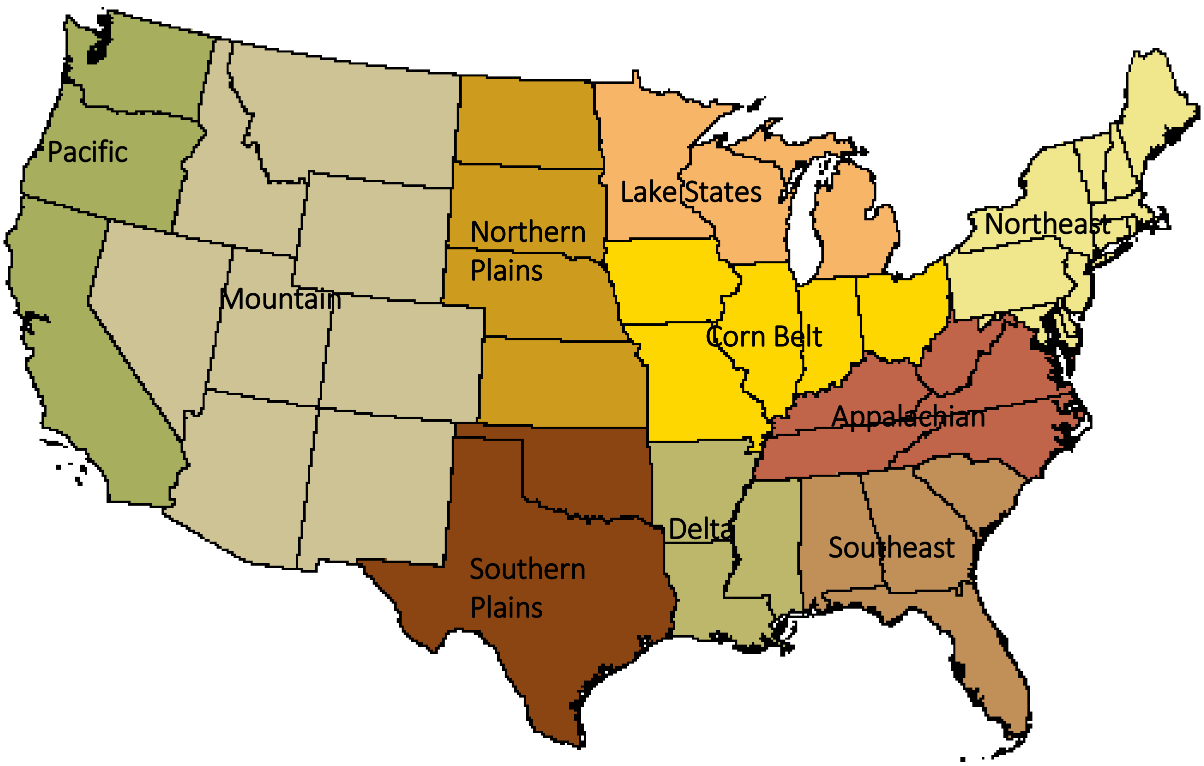

Figure 1 Farm Production Regions[7] (Source: Economic Research Service, USDA)

[7] The map is available at http://webarchives.cdlib.org/wayback.public/UERS_ag_1/20110913212914/http://www.ers.usda.gov/Briefing/ARMS/resourceregions/older.gif.

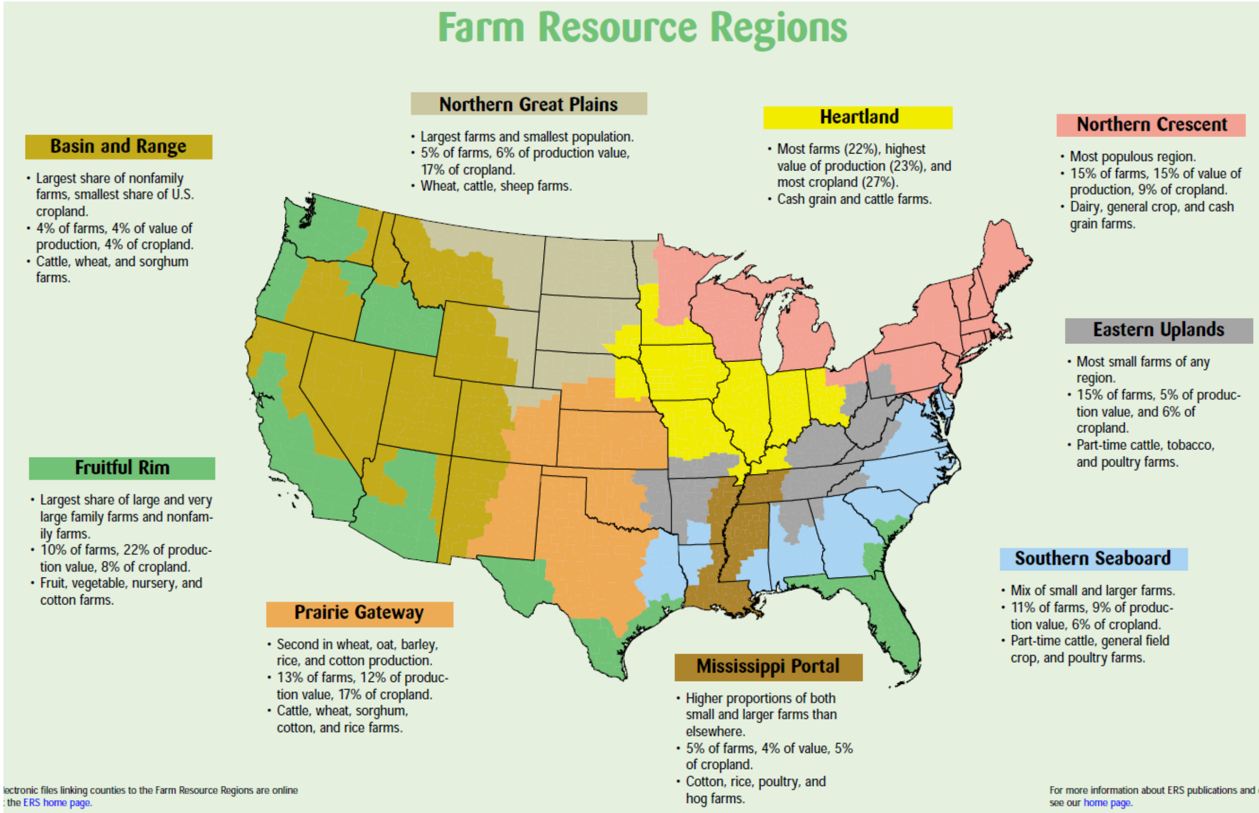

Figure 2 Farm Resource Regions[8] (Source: Economic Research Service, USDA)

[8] The map is available at http://webarchives.cdlib.org/wayback.public/UERS_ag_1/20110913212904/http://www.ers.usda.gov/Briefing/ARMS/resourceregions/new-regions.gif.

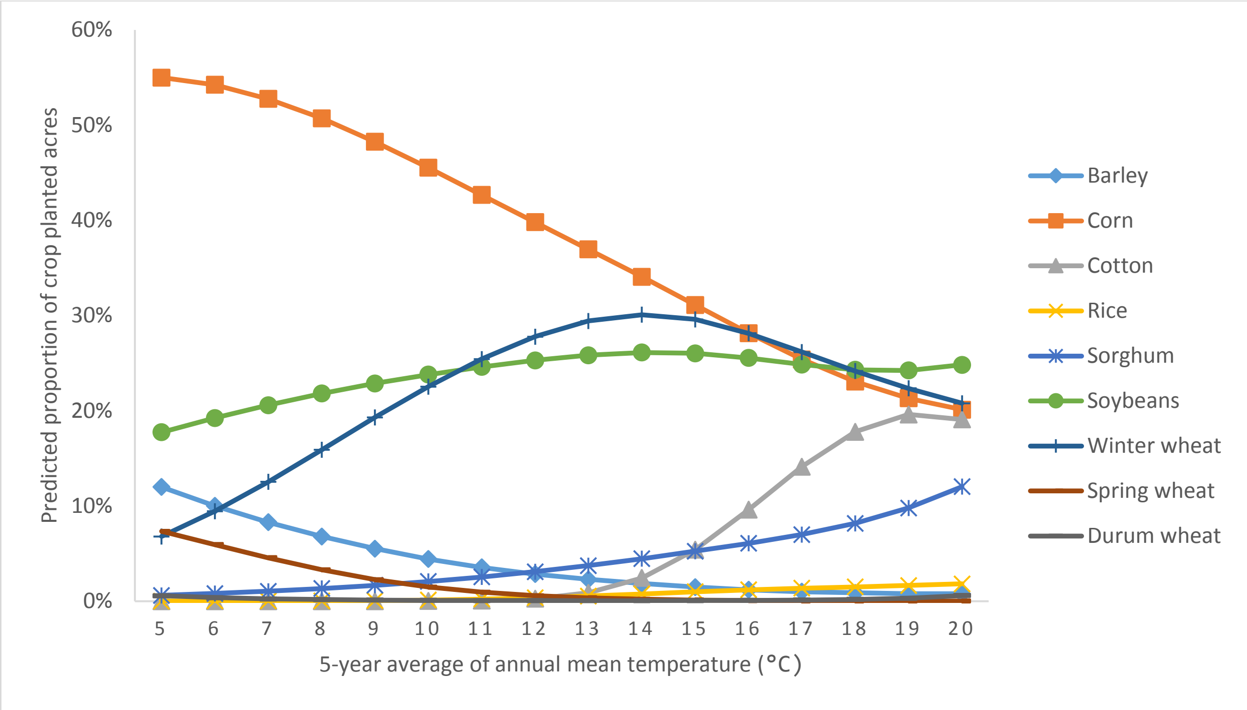

Figure 3 Predicted proportions of crop planted acres over temperature

Note: Annual mean temperature over 1975-2010 has mean (12.4 degrees Celsius) and standard deviation (4.29).

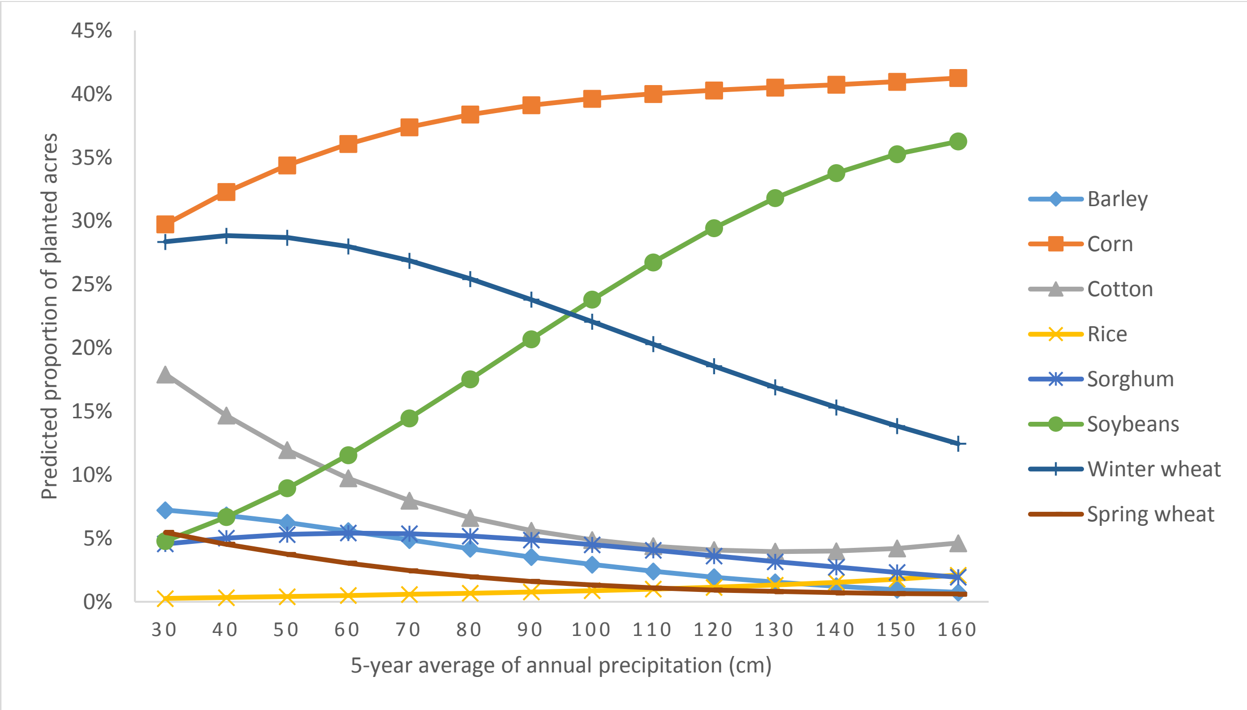

Figure 4 Predicted proportions of crop planted acres over precipitation

Note: Annual total precipitation over 1975-2010 has mean (95.1 cm) and standard deviation (35.75).

<table>
<tr><td rowspan="3"><u>Pacific</u>
Barley –
Corn +
Cotton (+)
Rice (+)
Winter Wheat (–)
Spring Wheat (–)</td><td rowspan="3"><u>Mountain</u>
Barley (–)
Corn (+)
Cotton (+)
Sorghum (+)
Winter Wheat (+)
Spring Wheat (–)</td><td rowspan="2"><u>Northern Plains</u>
Barley (–)
Corn (–)
Sorghum (+)
Soybeans (–)
Winter Wheat (+)
Spring Wheat (–)
Durum Wheat (–)</td><td><u>Lake States</u>
Barley (–)
Corn (–)
Soybeans (+)
Winter Wheat (+)
Spring Wheat (–)</td><td><u>Northeast</u>
Barley (+)
Corn (–)
Soybeans (+)
Winter Wheat (+)</td></tr>
<tr><td><u>Corn Belt</u>
Corn (–)
Soybeans (+)
Winter Wheat (+)</td><td><u>Appalachian</u>
Barley (–)
Corn (–)
Cotton (+)
Soybeans (+)
Winter Wheat +</td></tr>
<tr><td><u>Southern Plains</u>
Corn (+)
Cotton (+)
Rice –
Sorghum (+)
Soybeans (–)
Winter Wheat (–)</td><td><u>Delta</u>
Corn [–]
Cotton –
Rice (+)
Sorghum (–)
Soybeans +
Winter Wheat (–)</td><td><u>Southeast</u>
Corn (+)
Cotton (+)
Sorghum (–)
Soybeans (–)
Winter Wheat (–)</td></tr>
</table>

Figure 5 Average marginal effects of temperature on proportion of planted acres by region

Note: The signs in parentheses and in brackets are statistically significant at level 5% and at level 10%, respectively.

<table>
<tr><td rowspan="3"><u>Pacific</u>
Barley –
Corn +
Cotton (–)
Rice (+)
Winter Wheat +
Spring Wheat (–)</td><td rowspan="3"><u>Mountain</u>
Barley (–)
Corn (–)
Cotton –
Sorghum +
Winter Wheat (+)
Spring Wheat –</td><td rowspan="2"><u>Northern Plains</u>
Barley (–)
Corn (+)
Sorghum +
Soybeans (+)
Winter Wheat (–)
Spring Wheat (–)
Durum Wheat (–)</td><td><u>Lake States</u>
Barley –
Corn (+)
Soybeans (–)
Winter Wheat +
Spring Wheat (–)</td><td><u>Northeast</u>
Barley +
Corn +
Soybeans +
Winter Wheat (–)</td></tr>
<tr><td><u>Corn Belt</u>
Corn +
Soybeans +
Winter Wheat –</td><td><u>Appalachian</u>
Barley (–)
Corn (–)
Cotton +
Soybeans (+)
Winter Wheat –</td></tr>
<tr><td><u>Southern Plains</u>
Corn (+)
Cotton (–)
Rice (+)
Sorghum +
Soybeans (+)
Winter Wheat –</td><td><u>Delta</u>
Corn (+)
Cotton +
Rice (–)
Sorghum +
Soybeans +
Winter Wheat (–)</td><td><u>Southeast</u>
Corn (+)
Cotton (+)
Sorghum (–)
Soybeans –
Winter Wheat (–)</td></tr>
</table>

Figure 6 Average marginal effects of precipitation on proportion of planted acres by region

Note: The signs in parentheses and in brackets are statistically significant at level 5% and level 10%, respectively.