Assessing Economic and Environmental Impacts of Ethanol Production on Fertilizer Use in Corn Production

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Abstract: The share of corn used in ethanol production has been growing rapidly. USDA predicts that more than 30 percent of the corn crop will be used for ethanol production in 2009/2010. Expanded corn acreage contributes to the application of more fertilizer and is likely to introduce a larger volume of nutrients into the environment. This study found that an increase in ethanol production is consistent with a significant increase in quality-adjusted fertilizer use in selected corn states.

Key Words: *quality-adjusted fertilizer, corn production, ethanol, excess nutrients*

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Introduction

The share of corn used in ethanol production has been growing rapidly. USDA predicts that more than 30 percent of the corn crop will be used for ethanol production in 2009/2010[1]. Expanded corn acreage contributes to the application of more fertilizer and is likely to introduce a larger volume of nutrients into the environment. These additional nutrients create the potential for an increase in the volume of nutrients in excess of crop requirements during the growing season (excess nutrients).

Fertilizer inputs are important not only for their positive effect on agricultural productivity, as evidenced by the $13.3 billion spent on fertilizers in 2006, but also for their potential to contribute contaminants to the environment. The corn states analyzed in this study averaged 88 (33) pounds of excess nitrogen (phosphorous) per harvested acre of corn production per farm in 2005/2006 compared to 39 (21) pounds in 1996/1997[2]. More than one hundred different fertilizer products are used in corn production; each product has a different percentage of nitrogen (N), phosphorous (P), and potassium (K); and each product is applied at a different rate. Nitrogen and phosphorous in particular are potential contaminants of ground and surface water.

Given this heterogeneity, it does not seem appropriate to compute total

1 www.ers.usda.gov/briefing/Baseline/crops.htm.
2 Excess nutrient calculations are based on the algorithm presented in "Profits, Costs, and the Changing Structure of Dairy Farming." MacDonald, et al., ERS, USDA, ERR-47, September 2007. These calculations of corn production

fertilizer use by adding the quantities of all fertilizers applied, even if expressed in the same units, e.g. tons of product. For example, one ton of urea has a considerably lower percentage of nitrogen per ton than anhydrous ammonia and costs significantly more per actual pound of nitrogen. Further, such products, because of various economic and technical factors, are used in vastly different proportions across regions. Clearly, the total weight of fertilizers used is not an adequate measure from the point of view of economic analysis. This study will therefore follow the quality-adjusted model first formulated for fertilizers by Griliches (Journal of Farm Economics, 1958). Hence, an hedonic price function by state and for the U.S. will be used that expresses the price of the fertilizer as a function of the quantities of the characteristics it embodies –percent nitrogen, percent phosphorous, and percent potassium.

Objectives

This project: 1) uses hedonic methods to calculate for 1989-2006 state-level quality-adjusted price changes, implicit prices of the quality characteristics, and the resulting implicit quantity of fertilizer consumed, 2) assesses trends in fertilizer quantity use by regressing the state level implicit quantity indexes on ethanol production and crop rotations during this time period, and 3) assesses the impact of greater fertilizer application on nutrient balances.

Background

associated excess nutrients ignore nutrients derived from manure applications to the corn crop.

Between 1989 and 2006 U.S. fertilizer expenditures in agriculture increased by about 60 percent to $13.3 billion. While the quality-adjusted model addresses fertilizer use on all crops, the analysis will focus on fertilizer use in major corn producing states[3]. These states include the Corn Belt and traditional wheat producing states that have expanded corn production in recent years, but where the bulk of fertilizer is applied on corn. For the entire United States nitrogen (N), phosphate (P), and potash (K) nutrients used on corn dominates fertilizer consumption (Table 1).

Several state examples illustrate the amount of fertilizer data that must be quantified to update fertilizer files for state-level productivity work, thus allowing a comparison of fertilizer use across states. The 2006 fertilizer file for Iowa contains 14 observations by type of commercial fertilizer. Starting from a relatively large base, fertilizer expenditures in the major corn and soybean states such as Iowa grew at a slower pace than the national average. Fertilizer expenditures in the major cotton states showed quite divergent trends, ranging from only a 32 percent increase in fertilizer expenditures in Texas to a robust 86 percent growth in California. The Fertilizer Institute (TFI) commercial file for California contains close to 50 different commercial fertilizer products. In contrast the TFI commercial file for Arizona contains only about 30 different commercial fertilizer products.

Fertilizer use by state has changed significantly in recent years. Over time

3 Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, North Dakota, Nebraska, South Dakota, Ohio, Texas and Wisconsin.

the average primary nutrient content (N, P, and K) of fertilizers appears quite stable for the U.S. and in Iowa and Minnesota, but has varied more in states like Nebraska and Kansas (Table 2). However, Table 3 shows dramatic shifts in the use of major products for almost all states. For example, while nutrient shares are stable in Iowa and Minnesota, there have been major shifts out of anhydrous ammonia (a gaseous form of nitrogen fertilizer with 82 percent nutrient content)[4] toward nitrogen solutions (a liquid form of nitrogen fertilizer with generally a 30 percent nutrient content) and/or Urea (a granular form of nitrogen fertilizer with 45.5 percent nutrient content). In Illinois there was only a nominal increase in the most cost effective nitrogen source, anhydrous ammonia, but use of nitrogen solutions rose sharply. Note that over time as the western corn states have expanded their corn production their shares by fertilizer product more closely resemble those of the traditional central and eastern corn states.

On August 8, 2005, President Bush signed the Energy Policy Act of 2005 (H.R. 6) into law. This comprehensive energy legislation includes a nationwide renewable fuels standard (RFS) that will double the use of ethanol and biodiesel by 2012. The data set reported in Breneman and Nulph indicates that ethanol production capacity is centered in North Central Iowa and Western Illinois (see Figure 1). Close to 1 billion bushels of corn were processed into ethanol in the Corn Belt in 2005. Table 4 shows estimates of ethanol production capacity and

4 The shift away from fall application of anhydrous ammonia toward greater use of nitrogen solutions and urea likely is driven by a variety of factors including nitrogen losses to the environment through leaching and/or volatilization, seasonal price differentials, etc. Investigation of this phenomenon is beyond the scope of this study, but anecdotal evidence exists that in portions of Iowa and Minnesota with large hog growing facilities hog manure is being used as a replacement for anhydrous ammonia.

relative excess nutrient levels (based on 2006 ARMS data as will be described below) in key corn states —Western Illinois, Northern Iowa and Southern Minnesota, the rest of the Eastern Corn Belt, and the rest of the Western Corn Belt.

Methodology

Regional and temporal differences in fertilizer characteristics or quality prevent the direct comparison of observed prices of fertilizer among states. To account for these differences, indexes of relative prices of fertilizer are constructed using hedonic methods where fertilizer is viewed as a bundle of characteristics which contribute to the output derived from its use. According to the hedonic approach the price of fertilizer represents the valuation of the characteristics "that are bundled in it," and each characteristic is valued by its implicit price (Rosen, 1974). Implicit prices for the characteristics exhibit many of the properties of ordinary prices. But these prices are seldom observed directly and must be estimated from the hedonic price function. Griliches (1964) notes that if we can observe different "quality combinations" selling at different prices, it is possible to estimate, at the margin, the prices of these characteristics.

The hedonic method was pioneered by Waugh (1928) to study the influences of quality factors on vegetable prices at a given point of time, and by Court (1939) to examine if price increases for automobiles were due to quality changes or to monopoly power. Chow (1967) and Griliches (1961), among others, used hedonic methods to obtain quality-adjusted price indexes for automobiles and computers. Hedonic methods have also been used to study markets for agricultural inputs. Griliches (1958) and Rayner and Lingard (1971) studied fertilizer prices. And Palmquist (1989) developed a hedonic model of fertilizer values.

An hedonic price function expresses the price of a good or service as a function of the quantities of the characteristics it embodies. Thus, a fertilizer hedonic function may be expressed as $w = W(X, D)$, where *w* represents the price of fertilizer, *X* is a vector of characteristics or quality variables and *D* is a vector of other variables. In the hedonic framework, the different fertilizer products are regarded as alternative bundles of a smaller number of characteristics. These characteristics reflect measures of fertilizer quality.

Whether other variables (denoted by *D*) are also included in the hedonic equation, their selection depends not only on the underlying theory, but also on the objectives of the study. If the main objective of the study is to obtain price indexes adjusted for quality, as in our case, the only variables that should be included in *D* are year dummy variables, which will capture all price effects other than quality. After allowing for differences in the levels of the characteristics, the part of the price difference not accounted for by the included characteristics will be reflected in the year dummy coefficients.

Most empirical studies adopt the semilog or double-log form of the hedonic price function. However, the functional form of the hedonic function is entirely an empirical matter. In this study, a generalized linear form is presented where the dependent variable and each of the continuous independent variables is represented by the Box-Cox transformation. This is a mathematical expression that assumes a different functional form depending on the transformation parameter, and which can assume both linear and logarithmic forms, as well as intermediate non-linear functional forms.

Thus the general functional form of our model is given by:

$$(1) \qquad w(\lambda_0) = \sum_{n=1}^{N} \alpha_n X_n(\lambda_n) + \sum_{m=1}^{M} \gamma_m D_m + \varepsilon,$$

where $w(\lambda_0)$ is the Box-Cox transformation of the dependent price variable

$$w(\lambda_0) = \begin{cases} \dfrac{w^{\lambda_0} - 1}{\lambda_0}, \lambda_0 \neq 0, \\ \ln w, \lambda_0 = 0. \end{cases}$$

Similarly, $X_n(\lambda_n)$ is the Box-Cox transformation of the continuous quality variable X_n where $X_n(\lambda_n) = (X_n^{\lambda_n} - 1)/\lambda_n$ if $\lambda_n \neq 0$ and $X_n(\lambda_n) = \ln X_n$ if $\lambda_n = 0$. Variables represented by *D* are year dummy variables, not subject to transformation; λ, α, and γ are unknown parameter vectors, and ε is a stochastic disturbance.

Several methods have been used to calculate price indexes adjusted for quality using hedonic functions, including characteristics prices and dummy variable techniques. The latter is used in this study because it is simpler, and Triplett (1989) has provided extensive empirical evidence of the robustness of the hedonic price indexes to the method of calculation. Using the dummy variable technique, quality-adjusted prices indexes are calculated directly from the coefficients on the year dummy variables *D* in the hedonic regression.

Data and Methods

The analysis employs: TFI's state-level commercial fertilizer use data by type and USDA's Agricultural Price data. The analysis identifies and uses close to 20 important commercial fertilizer products used by these crops. See appendix A for an example of the prices, quantities, and characteristics data used in the quality-adjustment estimates for Illinois for 2006. Each row in the table identifies a product and its percent of N, P, and K, and its Price and Quantities. Other data from ARMS and other sources are used in the driver analysis. Ethanol production capacity data are from Breneman and Nulph "Ethanol Plant Mapping and Analysis." PowerPoint presentation, ERS, October, 2007 (see Figure 1). GMO data are obtained from ERS analysis (Fernandez and Caswell). Crop price data are from Agricultural Statistics. Conservation tillage data are assembled from various ERS publications. The estimates of excess nutrients are based on the algorithm employed in MacDonald, et al. Finally, proxies for continuous corn data are constructed from ARMS data, by using the proportion of corn acres relative to total corn acres by state for 1996 through 2006. To complete the series for the period 1989-1995, data averages for 1996/97 were backcasted to 1989.

Specification of quality-adjusted fertilizer estimation:

The basic theoretical model in (1) is estimated using The Fertilizer Institute and Agricultural Prices data (see Data Appendix A) and sets λ_o =1, and λ_n =1. That is, a linear model is specified. Specific characteristics included in the vector X_n are defined as percent of N, P, and K by product.

Specification of the model identifying key drivers of the quality-adjusted fertilizer use:

In a second stage, the determinants of quality-adjusted fertilizer use are assessed. Like a demand function, input consumption will be regressed over its own price (unadjusted) and the price of the output. In addition, we hypothesize that several exogenous factors also have an impact on input use. The driver elasticity analysis using 1989 to 2006 cross-section data could then be specified as:

(2) $\ln Y_{FERT,i} = \beta_0 + \beta_P \ln (X_{P,,t}) + \beta_{CNSBP} \ln (X_{CNSBP,,t}) + \beta_G \ln (X_{E,,i})$

$+ \beta_{CGMO} \ln (X_{CGMO,,i}) + \beta_{CSGMO} \ln (X_{SGMO,,i}) + \beta_{CCorn} \ln (X_{CC,,i}) +$

$\beta_{CTill} \ln (X_{CTill,,i}) + \beta_{SBTill} (D_{SBTill,,i}) + \beta_{Trend} (D_{Trend,,it}) + v_{it},$

where subscript i refers to the i-th state. Y_{FERT} is the quality-adjusted tons of fertilizer deflated by an index of corn acres by state. X_P is the real lagged price of fertilizer per ton (deflated by the lagged price of corn per ton), X_{PCNSB} is the real lagged price of corn per ton relative to the soybean price per ton, X_E is the tons of ethanol produced, X_{CGMO} is the proportion of GMO corn acres (X_{CGMO}), X_{SGMO} the proportion of GMO soybean acres, X_{CC} is the percentage of continuous corn, X_{CCtill} is the share of conservation tillage on corn, $X_{SBCtill}$ conservation tillage on soybeans, and Y_{Trend} is a time trend. Separate estimates were constructed for all study states, including Texas; for the eastern and central corn states (II, IN, IA, MO, MI, MN, OH, and WI); and for all western corn and ethanol producing states (KS, NE, ND, and SD) as shown in table 6. The expectation is that $X_{P,}$ X_{CCtill}, and $X_{SBCtill}$ will have a negative impact on the adjusted-quantities of fertilizer used; while X_{PCNSB}, X_E, and X_{CC} will have a positive influence. The percentage of GMO crops is introduced into the analysis to capture an eventual impact due to the introduction of these new classes of seed technologies. It is expected that these new seeds will have a negative impact on pesticide consumption; therefore it would be interesting to see if a similar effect could be captured on fertilizer consumption. A time trend is introduced to reflect the general innovation process. Finally two regional models were estimated because of the concentrated locations of ethanol plants.

Results

The hedonic regression results validate the use of the hedonic framework. Table 6 shows the estimated coefficients of the quality variables of three different hedonic regressions corresponding to the price of fertilizers used in the United States, and two selected states--Iowa and South Dakota. Structural breaks were necessary--as confirmed by the Chow-tests--due to significant structural changes over time in the coefficients of Nitrogen, Phosphorous, and Potassium. The R-squared values are all above 0.98 and most coefficients are positive and significant at the 5 percent level for the United States and Iowa. In South Dakota, Potassium is significant at the 10 percent level in the 1990 to 1995 period but it is not in the first period. However, it always has a positive sign. Time dummies were not shown in the table but were all significant at the 1 percent level.

Over time, the results suggest a continuous increase in the influence on fertilizer prices of Potassium and especially Nitrogen content, the major nutrient applied as suggested in Tables 1 and 2. A resulting positive quality-adjustment shift in the quantities will then indicate an increase in the productive effectiveness of nitrogen content among fertilizer products. Higher coefficients for Iowa with respect to South Dakota confirm our prior that farms in Iowa have been earlier adopters of improved fertilizer technologies.

Two groups of states can be identified in terms of their quality-adjusted evolution over the last 18 years. For example, the quality-adjusted quantity index increases sharply for Illinois and Iowa due to declining adjusted prices. In sharp contrast, somewhat declining real prices and dramatic shifts to corn out of other crops lead to sharper increases in quality-adjusted fertilizer use in western corn states. At the aggregate level of the corn states, the adjusted U.S. price index of fertilizer used in corn states is relatively flat and, hence, the quality-adjusted quantity index increases only modestly in recent years in the U.S.

The results of the second stage identify statistically significant differences in the impact of ethanol production and crop rotations over time and across states. Table 5 shows that a 10 percent increase in ethanol production is consistent with a 0.5 percent increase in quality-adjusted fertilizer use for the entire sample. A much larger impact was found in the central and eastern corn states—1.7 percent, nearly double the impact in the West. This is interpreted to mean that fertilizer application rates are much higher in the central and eastern corn states. For the entire sample, the results show that quality-adjusted fertilizer use is positively related to soybean GMO use, continuous corn, and soybean conservation tillage, and negatively related to the real lagged price of fertilizer and corn GMO use. The time trend is positive but not significant.

Summary and Conclusions

The share of corn used in ethanol production has been growing rapidly. USDA predicts that more than 30 percent of the corn crop will be used for ethanol production in 2009/2010. Expanded corn acreage contributes to the application of more fertilizer and is likely to introduce a larger volume of nutrients into the environment.

Inherent differences in fertilizer characteristics or quality prevent the direct comparison of observed prices of fertilizer over time and across regions. Hence, an hedonic price function is estimated to express the price of a good or service as a function of the quantities of the characteristics it embodies—percent nitrogen, percent phosphorous, and percent potassium. Separate hedonic functions are estimated for fertilizer by state and for the U.S. The use of quality-adjusted fertilizer indices helps provide an unbiased estimate of fertilizer use in agricultural production. Given the increasing importance of fertilizer in the production of corn based ethanol, development of readily modifiable state level data files and hedonic models is desirable.

This study found that an increase in ethanol production is consistent with a significant increase in quality-adjusted fertilizer use in selected corn states. These additional nutrients create the potential for an increase in the volume of nutrients in excess of crop requirements during the growing season (excess nutrients). The implications of excess nutrients generated from expanded corn production including the impact on the environment are the focus of additional research.

Table 1. Estimated U.S. plant nutrient use by selected crops 1/

Year ending June 30	Nitrogen					Phosphate					Potash				
	Corn	Cotton	Soybeans	Wheat	Other	Corn	Cotton	Soybeans	Wheat	Other	Corn	Cotton	Soybeans	Wheat	Other
	1,000 nutrient tons														
1989	4,601	347	93	1,924	3,628	1,798	120	392	751	1,056	2,196	68	720	317	1,537
1990	4,748	419	118	1,800	3,990	1,891	133	326	723	1,271	2,399	90	679	323	1,712
1991	4,715	477	118	1,734	4,243	1,868	151	312	679	1,189	2,245	98	568	301	1,789
1992	4,887	466	98	1,889	4,106	1,854	153	320	688	1,204	2,256	140	584	254	1,808
1993	4,369	508	84	1,986	4,445	1,681	171	304	736	1,543	2,054	140	641	215	2,091
1994	4,603	649	100	2,050	5,240	1,740	159	290	726	1,605	2,119	140	624	227	2,158
1995	4,158	700	154	1,955	4,752	1,496	204	372	719	1,635	1,800	173	665	236	2,254
1996	4,829	563	116	2,208	4,588	1,795	193	393	755	1,391	2,136	230	737	263	1,892
1997	4,792	525	175	2,043	4,816	1,783	219	490	719	1,402	2,172	286	1,016	257	1,694
1998	4,846	472	141	2,017	4,837	1,666	212	415	735	1,586	2,012	259	788	279	1,963
1999	4,650	544	139	1,907	5,212	1,580	215	441	669	1,349	1,936	309	805	246	1,657
2000	4,909	567	160	1,891	4,808	1,763	225	428	636	1,262	1,920	304	762	228	1,757
2001	4,249	569	148	1,764	4,805	1,552	236	448	617	1,404	1,888	314	793	221	1,710
2002	4,720	508	155	1,751	4,875	1,701	204	470	632	1,623	2,074	281	952	227	1,447
2003	4,710	508	154	1,804	4,815	1,682	210	448	651	1,281	1,963	280	827	234	1,707
2004	4,792	502	156	1,957	5,691	1,729	206	464	697	1,717	2,076	277	873	216	2,055
2005	4,959	521	151	1,625	5,080	1,758	215	448	581	1,636	1,823	290	860	198	2,002
2006	4,690	571	109	1,430	5,244	1,696	232	400	538	1,613	1,901	310	755	138	1,619

1/ Source: USDA/NASS and AAPFCO/TFI. Estimates of plant nutrient use for other crops are determined by subtracting the plant use of the four selected crops from total use of each plant nutrient. Shaded values are constructed by planted acres, and estimated application rates and percents of acres applied using three-year-moving average. Plant nutrient use only for corn grains, excluding for corn silage.

Table 2. Average Primary Nutrient Content (in percent) by State 1989 to 2006

Item	N (Nitrogen)	P_2O_5 (Phosphate)	K_2O_5 (Potash)	Total
	Primary Nutrient Content (percent)			
United States 1989	24.68	9.68	11.59	45.95
United States 1996	24.91	9.17	10.62	44.70
United States 2006	24.30	9.03	9.53	42.86
Illinois 1989	25.52	10.89	18.08	54.48
Illinois 1996	23.31	10.15	16.09	49.55
Illinois 2006	27.49	8.78	13.56	49.83
Indiana 1989	22.02	9.51	16.20	47.72
Indiana 1996	20.76	9.65	18.31	48.71
Indiana 2006	23.24	8.82	16.33	48.39
Iowa 1989	29.83	10.34	18.08	54.48
Iowa 1996	30.16	9.57	16.09	49.55
Iowa 2006	29.44	9.59	13.58	52.61
Kansas 1989	39.29	11.10	2.99	53.88
Kansas 1996	40.69	10.62	2.70	54.02
Kansas 2006	34.91	9.99	2.37	47.27
Minnesota 1989	29.00	11.69	18.22	58.91
Minnesota 1996	30.98	12.15	13.39	56.52
Minnesota 2006	30.35	13.04	10.57	53.96
Nebraska 1989	39.32	8.43	2.14	49.89
Nebraska 1996	38.64	8.67	1.59	48.90
Nebraska 2006	30.36	10.50	1.77	42.64
North Dakota 1989	38.31	20.34	3.70	62.35
North Dakota 1996	46.92	14.48	2.33	63.73
North Dakota 2006	39.14	15.59	2.32	57.05
South Dakota 1989	31.99	15.86	4.21	52.06
South Dakota 1996	28.62	17.56	3.01	49.19
South Dakota 2006	30.09	14.01	3.83	47.92
Texas 1989	29.15	8.36	4.10	41.60
Texas 1996	28.59	7.36	4.47	40.42
Texas 2006	24.31	6.99	5.15	36.44

Table 3 Summary Statistics: Fertilizer application quantities, 13 states, 1989 and 2006 (thousands of short tons)

	1989						2006					
State	Short Tons Fertilizers (thousands)	Anhydrous Ammonia (thousands)	Nitrogen Solutions (thousands)	Urea (thousands)	Diam Phosphate (thousands)	Potash (thousands)	Short Tons of Fertilizers (thousands)	Anhydrous Ammonia (thousands)	Nitrogen Solutions (thousands)	Urea (thousands)	Diam Phosphate (thousands)	Potash (thousands)
Illinois	3,517	645(18.3)	658(18.7)	179(5.1)	572(16.3)	941(26.8)	3,449	662(19.2)	1,007(29.2)	101(2.9)	508(14.7)	723 (21.0)
Indiana	2,672	203(7.6)	434(16.2)	95 (3.6)	95 (3.6)	318 (11.9)	2,223	253(11.4)	596(26.8)	90(4.1)	137(6.2)	422(19.0)
Iowa	3,187	704 (22.1)	566(17.8)	165(5.2)	389(12.2)	674(21.2)	3,704	625(16.9)	919(24.8)	232(6.3)	386(10.4)	753 (20.0)
Kansas	1,485	410(27.6)	281(18.9)	131(8.8)	148(10.0)	69(4.7)	2,055	316((15.40	674(32.8)	303(14.7)	132(6.4)	76(3.7)
Michigan	1,279	81(6.3)	137(10.7)	100(7.8)	52(4.1)	241(14.3)	1,313	34(2.6)	279(21.3)	108(8.2)	40(3.1)	212(16.2)
Minnesota	2,296	374(16.3)	102(4.4)	283(12.3)	342(14.9)	466(20.3)	2,083	266(12.8)	205(9.8)	503(24.2)	349(16.8)	353(17.0)
Missouri	1,684	97(5.8)	215(12.8)	271(16.1)	241(14.3)	374(22.2)	1,964	144(7.3)	230(11.7)	219(11.2)	240(12.2)	326(16.6)
Nebraska	1,889	598(31.7)	441(23.6)	59(3.1)	85(4.5)	38(2.1)	2,656	278(10.5)	1,163(43.8)	142(5.4)	26(1.0)	72(2.7)
N Dakota	729	133(18.2)	31(4.3)	83(11.4)	171(23.5)	31(4.3)	1,567	331(21.1)	86(5.5)	509(32.5)	96(6.1)	59(3.8)
Ohio	1,856	104(5.6)	393(21.2)	100(5.4)	139(7.5)	353(19.0)	1,947	90(4.6)	602(30.9)	94(4.8)	87(4.5)	339(17.4)
S Dakota	528	47(8.9)	76(14.4)	209(39.6)	130(24.6)	29(5.5)	1,767	36(2.0)	253(14.3)	721(40.8)	166(9.4)	107(6.1)
Texas	2,854	345(12.1)	469(16.4)	123(4.3)	61(2.1)	17(0.6)	3,130	88(2.8)	682(21.8)	147(4.7)	30(1.0)	22(0.7)
Wisconsin	1,332	81(6.1)	143(10.7)	127(9.5)	155(11.6)	451(33.9)	1,319	41(3.1)	290(22.0)	184(14.0)	86(6.5)	320(24.26)
West CB	10114	2266(2.4)	1497(14.8)	930(9.2)	1265(12.5)	1307(12.9)	13832	1852(13.4)	3300(23.9)	2410(17.4)	1155(8.4)	1406(10.2)
East CB	10484	1107(10.6)	1587(15.1)	772(7.4)	1115(10.6)	2325(22.2)	10268	1134(11.0)	2402(23.4)	702(6.8)	1011(9.9)	2012(19.6)
California*	3,823	136(3.6)**	721(18.9)	66(1.73)	11(0.29)	31(0.81)	5,235	241(4.6)	548(10.5)	122(2.3)	8(0.2)	249(4.8)
Total: U.S.	47,619	6624(9.7)	7057(14.8)	3382(7.1)	3340(7.0)	4875(10.2)	53888	3822(7.1)	3822(7.1)	5369(10.0)	3000(5.6)	4889(9.1)

*California tons in 2006 break down as 28 percent organics and micronutrients, 43 percent single nutrients (led by nitrogen solutions), and 29 percent multiple nutrients (led by 11-52-0)

** Values in parentheses are the product share of the total quantity of fertilizers applied.

Table 4. USDA 2006 Agricultural Resource Management Survey estimates, by group

Item	Northern and Central IL	Southern MN & Northern IA	Other Eastern Corn Belt	Other Western Corn Belt
Million gallons of ethanol capacity	745	1,691	663	1,339
Millions of gallons of ethanol capacity per county	56.5	62.6	1.83	5.56
Number of observations	501	930	2,114	2,516
Number of farms	$35{,}484^{BCD}$	$67{,}495^{ACD}$	$177{,}486^{ABD}$	$204{,}629^{ABC}$
Percent of farms	7.3	13.9	36.6	42.2
Percent of value of production	10.2	24.1	28.4	37.2
Government payments per acre operated ($/acre)	15^{D}	14^{D}	10^{D}	3^{ABC}
Conservation payments per acre operated ($/acre)	2^{D}	2^{D}	4	6^{AB}
Corn revenue per acre operated	172.782^{BCD}	142.217^{ACD}	77.060^{ABD}	40.503^{ABC}
Total off-farm income relative to total income (percent)	33.30^{CD}	29.99^{D}	51.40^{AB}	55.50^{AB}
Net return on assets (percent)	0.055^{CD}	0.063^{CD}	0.034^{AB}	0.032^{AB}
Net return on household assets (percent)	0.051^{CD}	0.053^{CD}	0.028^{AB}	0.027^{AB}
Water holding capacity	8.3^{B}	11.7^{ACD}	7.9^{B}	8.6^{B}
Soil texture	7.1^{BCD}	6.4^{ACD}	5.5^{ABD}	6.1^{ABC}
Population accessibility score	144.1^{BD}	71.7^{AC}	161.2^{BD}	68.4^{AC}
Variable costs per acre ($)	160.8^{BCD}	211.5^{AD}	206.0^{AD}	103.9^{ABC}
Labor costs per acre ($)	67.1^{CD}	80.5^{CD}	104.8^{ABD}	49.8^{ABC}
Fuel costs per acre ($)	19.4^{D}	21.2^{D}	19.6^{D}	12.1^{ABC}
Fertilizer costs per acre ($)	74^{BCD}	65^{AD}	64^{AD}	51^{ABC}
Miscellaneous costs per acre ($)	28.7^{BCD}	43.2^{AD}	37.4^{AD}	18.4^{ABC}
Machinery costs per acre ($)	45.1^{BCD}	58.2^{AD}	58.1^{AD}	29.2^{ABC}
Corn yield in bushels per acre	169.19^{CD}	171.46^{CD}	147.42^{ABD}	143.25^{ABC}
Soybean yield in bushels per acre	50.83^{CD}	51.20^{CD}	46.22^{ABD}	42.05^{ABC}
Corrected average price of land per acre ($/acre)	$4{,}363^{BCD}$	$3{,}584^{ACD}$	$3{,}084^{ABD}$	$1{,}632^{ABC}$
manurenp per harvested acre ($/acre)	1^{BCD}	7^{AD}	8^{AD}	4^{ABC}
manurepp per harvested acre ($/acre)	1^{BCD}	5^{ACD}	4^{ABD}	3^{ABC}
Government payments per acre with landlord($/acre)	30^{BCD}	34^{ACD}	25^{ABD}	15^{ABC}
Excess nitrogen per acre (lbs.)	106	94	92	72
Excess phosphorous per acre (lbs.)	50	39	35	26

Source: USDA 2006 Agricultural Resource Management Survey.

Notes: The t-statistics are based on 6,061 observations using weighting techniques described in Dubman, page 24, and correspond to the test of the null hypotheses of equal means.

A = Northern and Central IL, B = Southern MN and Northern IA, C = other Eastern Corn Belt States, and D = other Western Corn Belt States.

Table 5. Hedonic Regression Results for Fertilizer Used in the United States, Iowa, and South Dakota 1987 to 1989, 1990 to 1995, and 1996 to 2006

	87/89		90/95		96/06	
	Parameter	t-statistic[a]	Parameter	t-statistic[a]	Parameter	t-statistic[a]
United States						
Nitrogen percent	**1.456**	(13.45)	**1.663**	(15.09)	**2.881**	(18.63)
Phosphorous percent	**3.317**	(28.96)	**2.932**	(25.10)	**2.906**	(17.26)
Potassium percent	**1.448**	(12.22)	**1.484**	(12.22)	**1.665**	(10.30)
Observations	96		161		179	
R-Squared	0.989		0.983		0.981	
Iowa						
Nitrogen percent	**1.243**	(11.57)	**1.536**	(15.09)	**3.245**	(19.26)
Phosphorous percent	**2.565**	(17.72)	**2.066**	(25.10)	**2.904**	(13.93)
Potassium percent	**0.065**	(4.95)	**0.065**	(12.22)	**1.552**	(8.38)
Observations	38		64		114	
R-Squared	0.996		0.989		0.985	
South Dakota						
Nitrogen percent	**0.965**	(4.01)	**1.624**	(6.81)	**2.525**	(10.56)
Phosphorous percent	**2.100**	(9.17)	**1.729**	(7.49)	**2.111**	(10.71)
Potassium percent	0.288	(0.81)	**0.580**	(1.83)	**0.855**	(3.17)
Observations	30		60		115	
R-Squared	0.993		0.986		0.988	

Note: Significance at the 1% level (t=2.576), at the 5% level (t=1.96), and at the 10% level (t=1.645). Time period breaks based on Chow tests for the United States were conducted (F-test for the stability of the coefficients for N, P, and K for the period 1987 to 1995 and 1990 to 2006 reject the null hypothesis. Scores were F=4.49 and F=21.72 respectively for the two studied periods, above the p-value of 2.62 at 0.05%.
Source: Authors' analysis of The Fertilizer Institute data.

Table 6. Factors Influencing Quality-Adjusted Fertilizer Use

	Whole Sample		Eastern and Central Corn States		Western Corn States	
	Parameter	t-statistic[a]	Parameter	t-statistic[a]	Parameter	t-statistic[a]
β_0	-27.494	(-0.75)	79.054	(1.47)	**-101.700**	(-1.76)
β_{XFertp}	**- 0.143**	(-2.10)	- 0.211	(-1.57)	**- 0.453**	(-2.19)
β_{XCNSBP}	**0.548**	(2.19)	0.172	(0.64)	0.127	(0.33)
$\beta_{XEthanol}$	**0.053**	(3.02)	**0.167**	(7.87)	**0.093**	(2.06)
β_{XCGMO}	**-1.258**	(-3.30)	-0.381	(-0.62)	**-1.471**	(-2.79)
β_{XSBGMO}	**0.417**	(1.75)	**0.485**	(1.76)	-0.032	(-0.09)
$\beta_{XContCorn}$	**0.248**	(3.67)	**0.646**	(3.08)	-0.079	(-0.84)
$\beta_{XCornCtillage}$	**-1.280**	(-4.94)	-0.528	(-1.19)	0.293	(0.43)
$\beta_{XSBCTillage}$	**0.696**	(2.56)	**0.871**	(2.11)	0.208	(0.36)
β_{XTrend}	0.015	(0.80)	-0.039	(-1.63)	**0.051**	(1.92)
Observations	244		144		72	
RSquared	0.430		0.615		0.387	

Note: Significance at the 1% level (t=2.576), at the 5% level (t=1.96), and at the 10% level (t=1.645).
Source: Authors' analysis of The Fertilizer Institute data.

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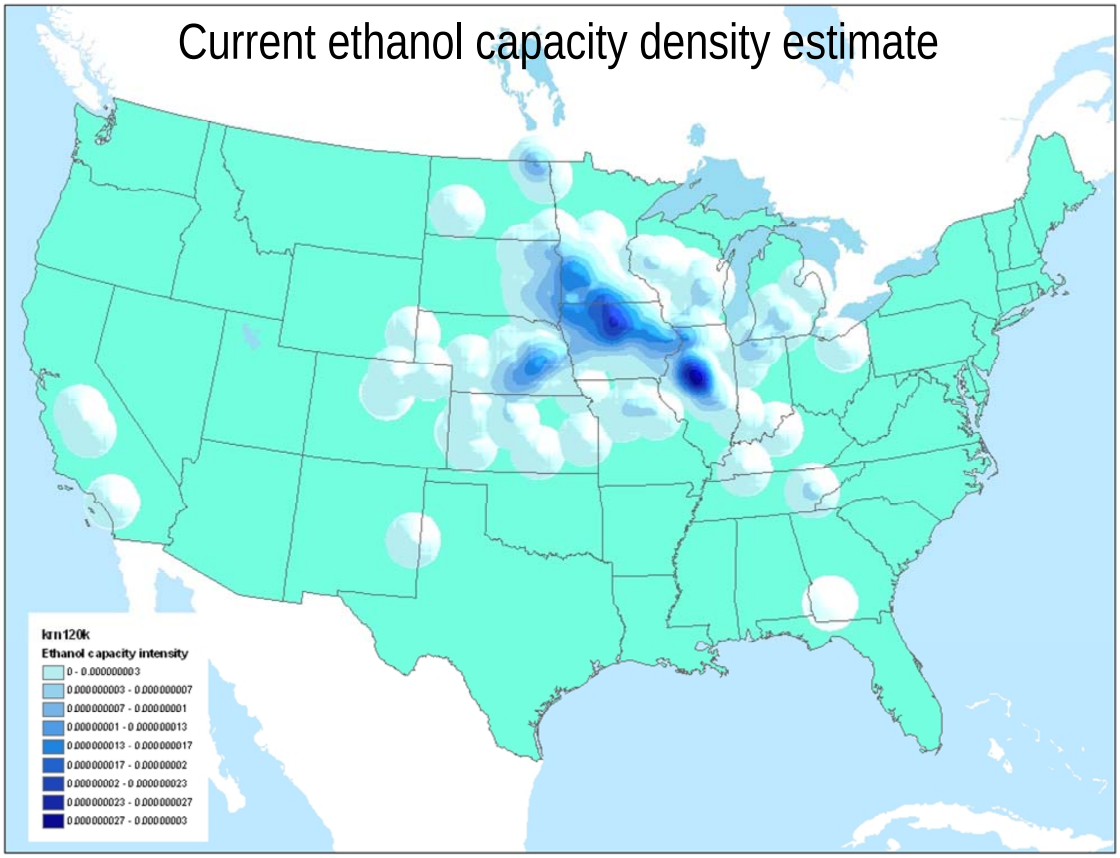
10(1928):185-96.

Figure 1. Ethanol Production Capacity in Corn States

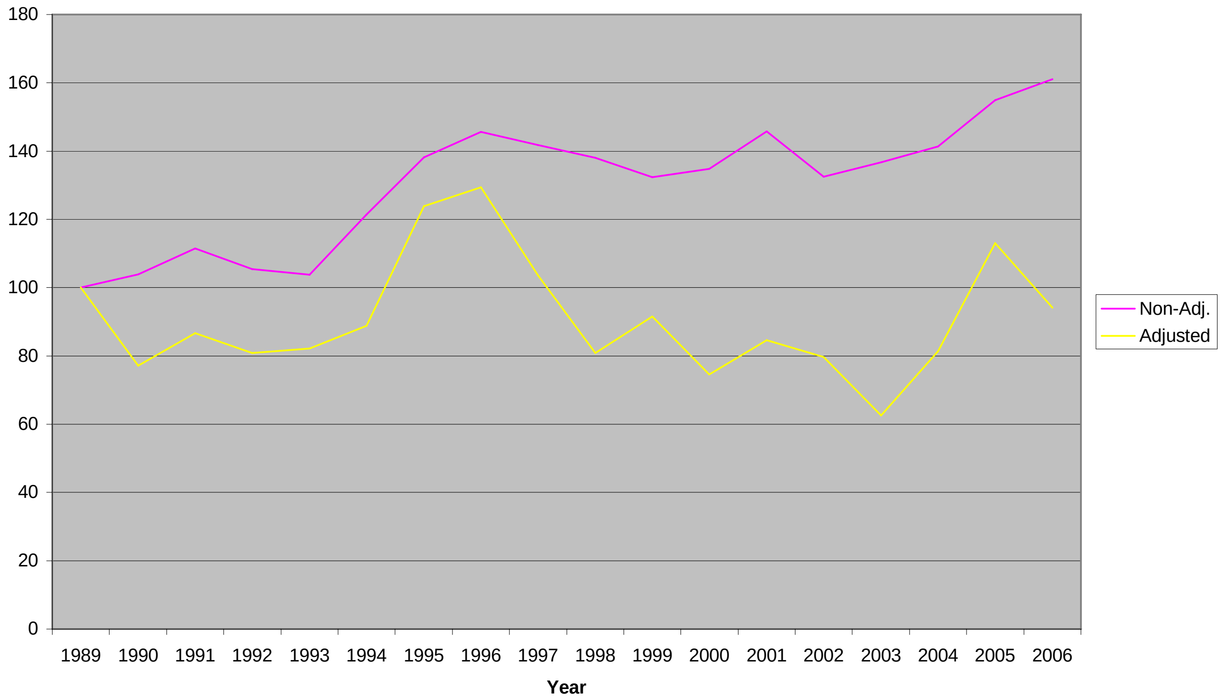


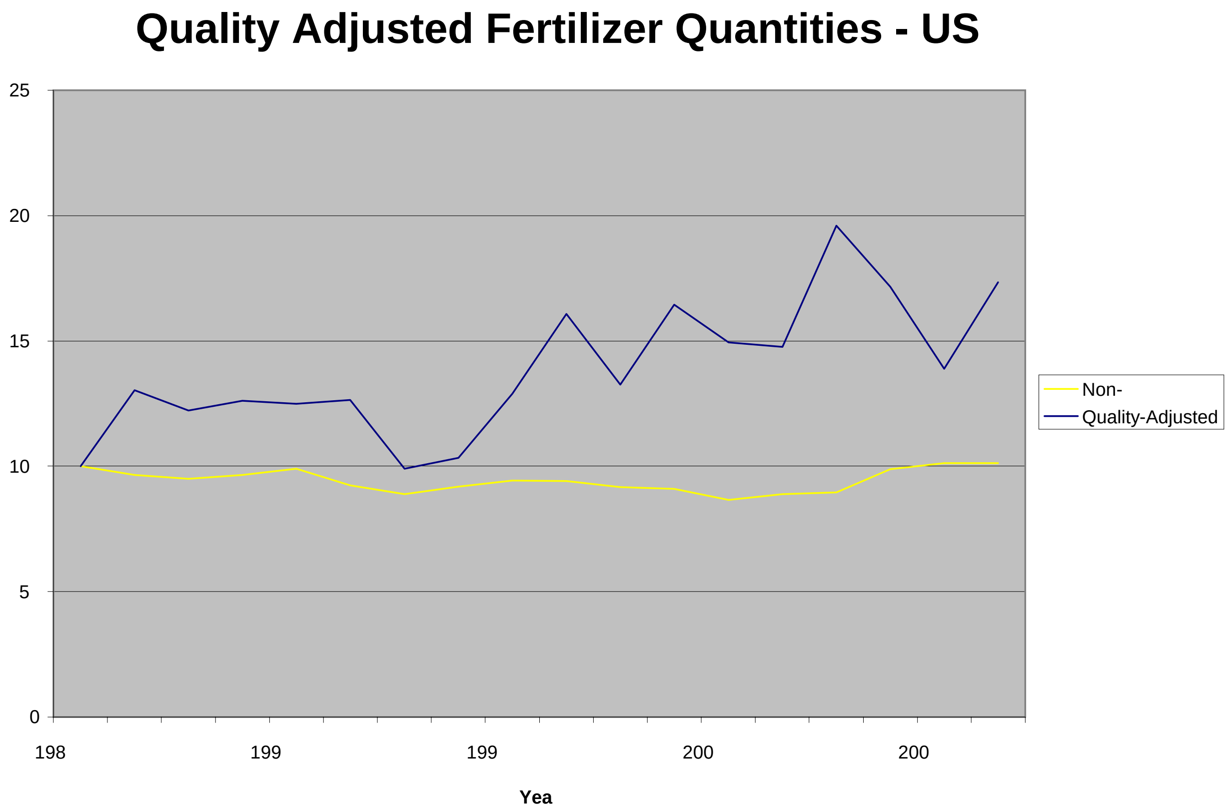
Source: Breneman V. and D. Nulph. "Ethanol Plant Mapping and Analysis." PowerPoint presentation, ERS, USDA, October, 2007.

Appendix Table A. Examples of Price and Quantity data for Fertilizer used in Illinois, 2006

Year		Nitrogen (percent)	Phosphorus (percent)	Potassium (percent)	Price ($/ton)	Tons
2006	Anhydrous Ammonia	82	0	0	523	662498
2006	Urea	45.5	0	0	368	100536
2006	Ammonium Nitrate	33.5	0	0	427	7395
2006	Nitrogen Solutions	30	0	0	241	1007754
2006	Ammonium Sulfate	20.75	0	0	263	8183
2006	Diammonium Phosphate	18	46	0	337	508235
2006	Triple Super Phosphate	0	45	0	315	17565
2006	Potash	0	0	61	271	722874
2006	Multiple Nutrient	16	20	0	323	0
2006	Multiple Nutrient	11	52	0	339	53928
2006	Multiple Nutrient	10	34	0	331	23676
2006	Multiple Nutrient	10	10	10	259	0
2006	Multiple Nutrient	9	23	30	313	0
2006	Multiple Nutrient	0	18	36	277	0

Quality Adjusted Prices - US




Quality Adjusted Fertilizer Quantities - US
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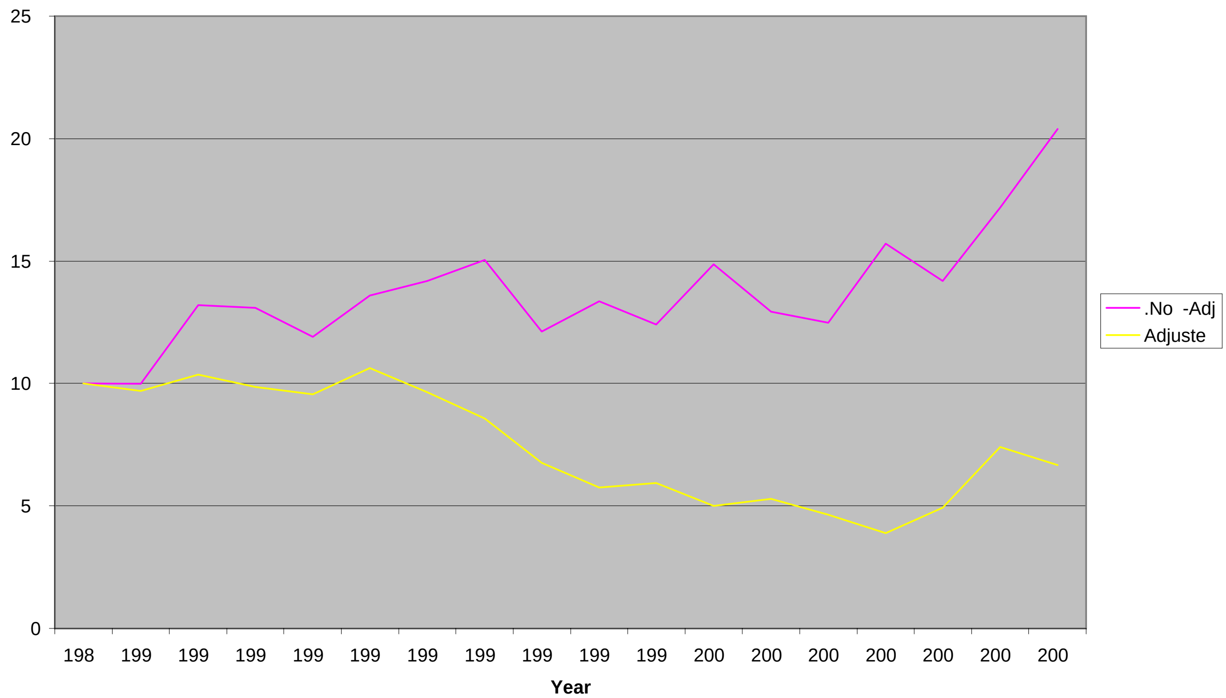
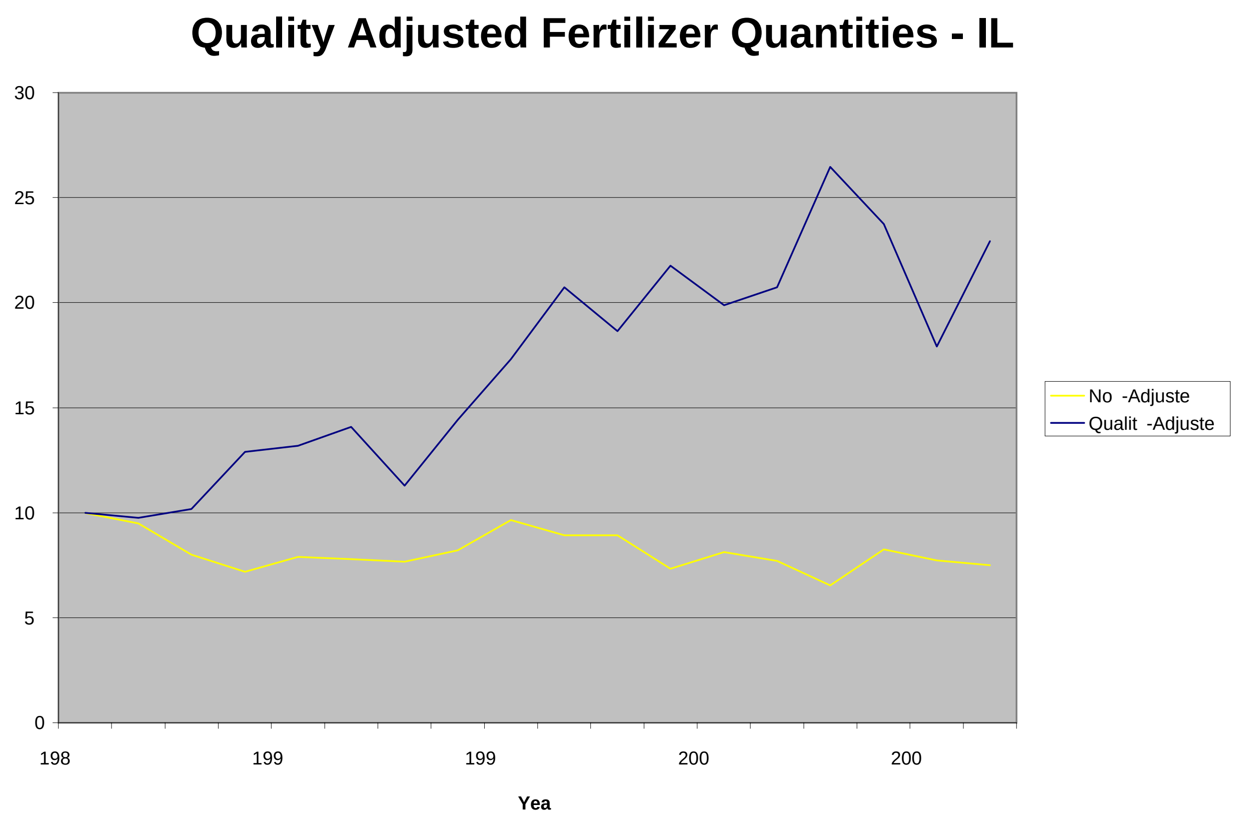
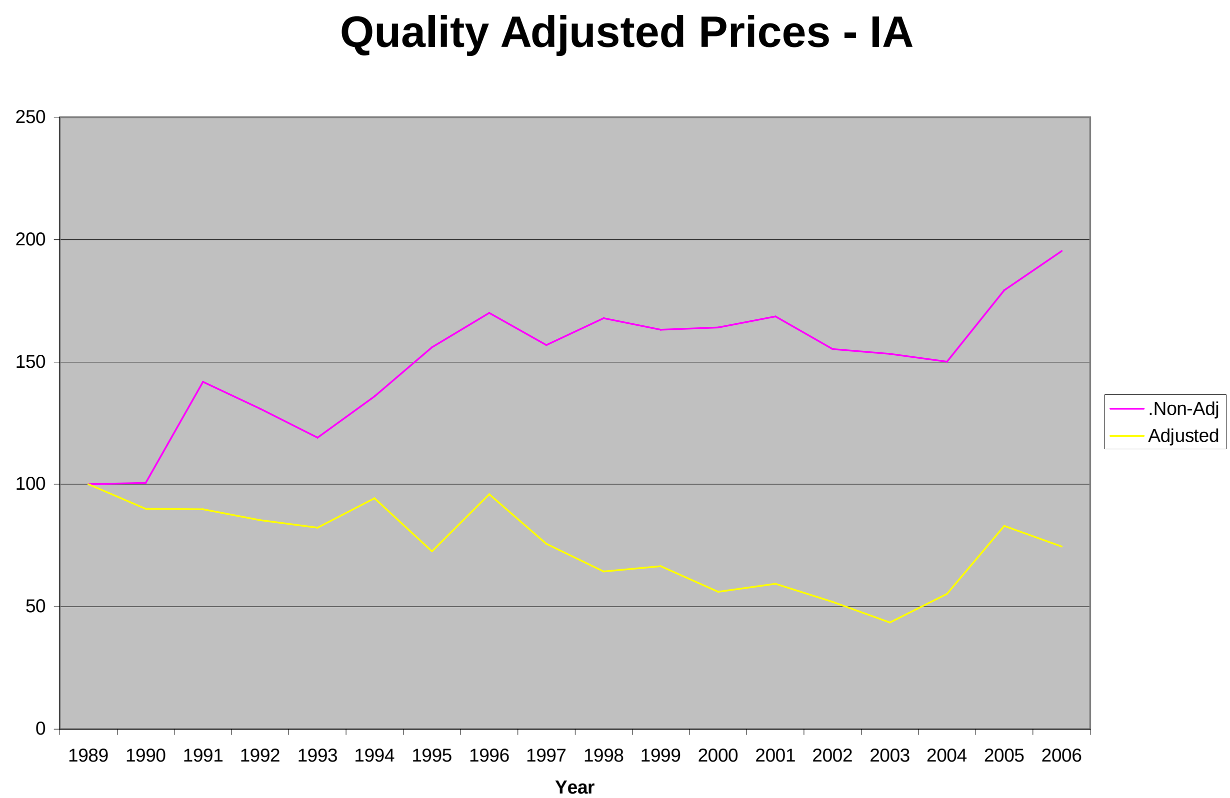
15
10
5
0
198
199
199
200
200
Yea
Non-
Quality-Adjusted

Quality Adjusted Prices - IL




Quality Adjusted Fertilizer Quantities - IL
30
25
20
15
10
5
0
198
199
199
200
200
Yea
No -Adjuste
Qualit -Adjuste


Quality Adjusted Prices - IA
250
200
150
100
50
0
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
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2001
2002
2003
2004
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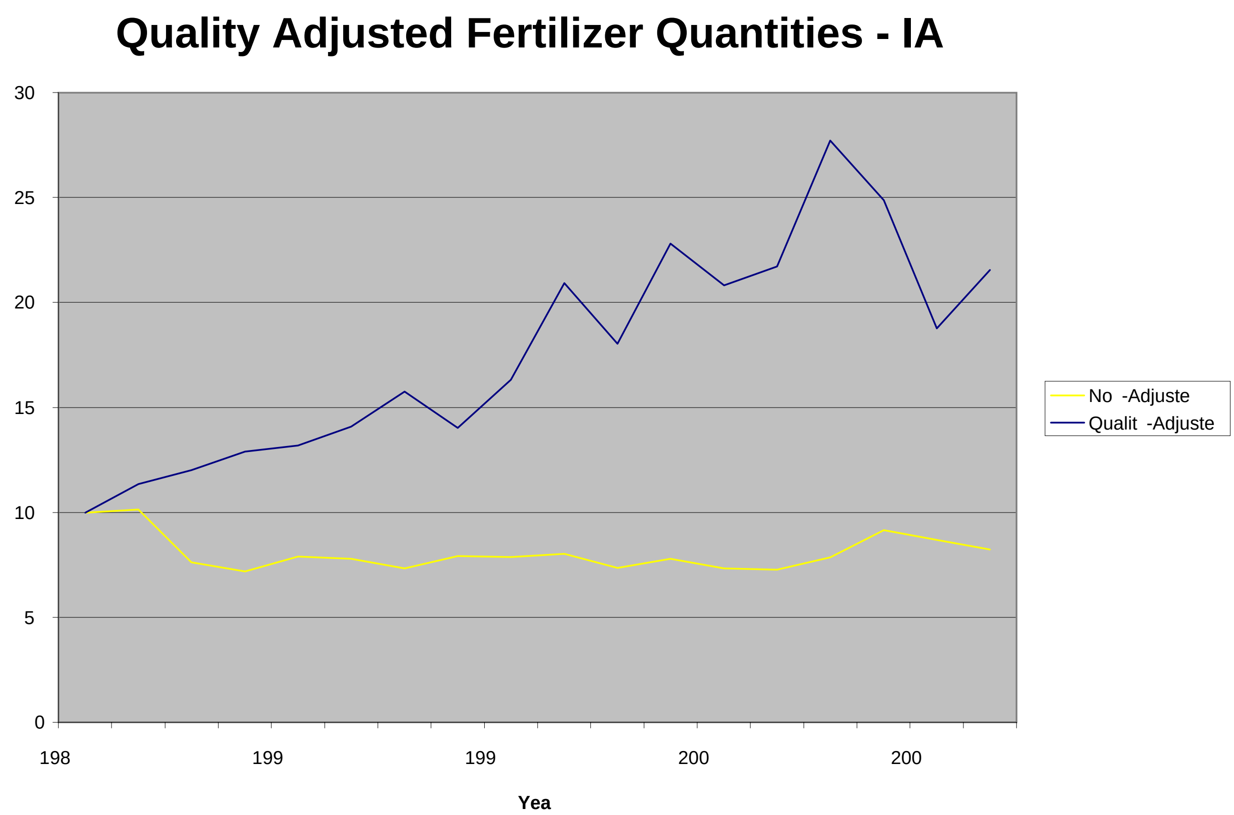
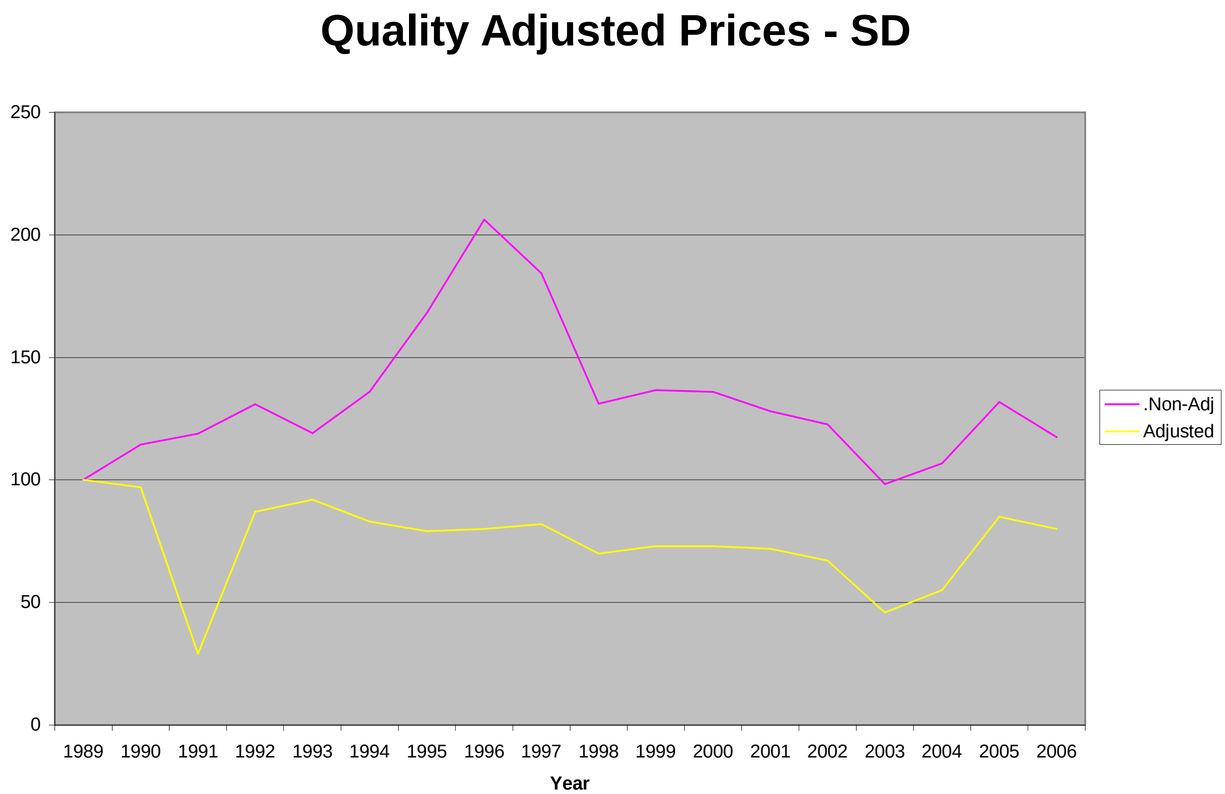
2006
Year
.Non-Adj
Adjusted



Quality Adjusted Fertilizer Quantities - IA
30
25
20
15
10
5
0
198
199
199
200
200
Yea
No -Adjuste
Qualit -Adjuste


Quality Adjusted Prices - SD
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200
150
100
50
0
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
.Non-Adj
Adjusted

Quality Adjusted Fertilizer Quantities - SD