A Conceptual Framework for Evaluating Agricultural Economic and Environmental Tradeoffs in the Central Nebraska Basins Using Field-Level Area Study Data

P.G. Lakshminarayan, Bruce A. Babcock, and Paul Mitchell

Working Paper 96-WP 162
July 1996

A Conceptual Framework for Evaluating Agricultural Economic and Environmental Tradeoffs in the Central Nebraska Basins Using Field-Level Area Study Data

P.G. Lakshminarayan, Bruce A. Babcock, and Paul Mitchell

Working Paper 96-WP 162
July 1996

Center for Agricultural and Rural Development
Iowa State University
Ames, Iowa 50011-1070

For content questions, please contact Bruce Babcock (babcock@iastate.edu) or P.G. Lakshminarayan (plakshm@iastate.edu).

P.G. Lakshminarayan is an associate scientist and manager of CEEPES, CARD; Bruce A. Babcock is an associate professor of economics and head of the Resource and Environmental Policy Division, CARD; and Paul Mitchell is a graduate research assistant.

This research was partially supported by the U.S. Environmental Protection Agency, Region VII, under Cooperative Agreement X007822-01-1.

A Conceptual Framework for Evaluating Agricultural Economic and Environmental Tradeoffs in the Central Nebraska Basins Using Field-Level Area Study Data

Introduction

The high plains aquifer system, which underlies nearly 85 percent of the state of Nebraska, supplies about 95 percent of all groundwater used in Nebraska. Agricultural activities in the state use most of the groundwater (94 percent), while domestic and commercial users also depend heavily on this groundwater source. About 84 percent of the state's public drinking water supplies are from groundwater (Comfort, Shea, and Roeth 1994; Exner and Spalding 1990). With such high dependence on groundwater, preserving groundwater quality is of crucial importance.

Intensive agriculture characterizes this region, especially in the Central Nebraska Basin (CNB), in part because of the good irrigation supplies provided by the Middle Platte alluvial aquifer system. Nearly one-third of the cropland in the CNB is irrigated and 50 percent of all cropland is planted to corn. About 729,000 tons of nitrogen, 184,000 tons of phosphorus, and 33 million pounds of pesticides (45 percent of which is atrazine) are applied annually on Nebraska's cropland. The intensive application of nutrients and chemicals every year creates the potential for nonpoint source contamination, which is a major concern for communities. Exner and Spalding (1990) analyzed 5,826 groundwater samples from the Nebraska basins for nitrates and 2,260 samples for pesticides, and found that about 20 percent of the samples had nitrate-nitrogen concentrations exceeding the drinking water Maximum Contaminant Level (MCL) of 10 parts per million (ppm) and 13.4 percent of the samples had detectable levels of atrazine.

The U.S. Environmental Protection Agency, Region VII, is working with the Nebraska Department of Environmental Quality, Nebraska's Natural Resource Districts (NRDs), and other partners to develop a comprehensive ecosystem approach to manage the Platte River Basin, which is one of the five national case study sites for multiplestressor-based ecological risk assessments. One of the objectives of the Platte River Basin program is to evaluate agricultural economic and environmental tradeoffs resulting from commonly adopted crop production systems and their contributions to nonpoint source nutrient and chemical pollution.

The research team at the Center for Agricultural and Rural Development (CARD), Iowa State University, initiated an effort to develop a comprehensive economic and environmental modeling system to study the effects of alternative crop production systems on edge-of-field nonpoint source loadings of agricultural nutrients and chemicals using the field-level survey data collected under the CNB Area Study project.[1] The CNB is also one of the U.S. Geological Survey's National Water Quality Assessment Program (NAWQA) sites. NAWQA is designed to assess historical, current, and future water quality conditions in representative river basins and aquifers nationwide.

This report describes the integrated modeling system that addresses the economic and environmental tradeoffs associated with agricultural nonpoint source pollution management in the CNB study area and provides a brief description and summary of the field-level Area Study survey data that will operationalize this system. A brief description of policy, economic, and environmental models that make up the integrated system is also provided. Use of an integrated modeling system for evaluating the environmental effects of alternative agricultural production systems, for a given set of resource and other site-specific environmental conditions, is a widely used procedure. Studies by Wossink et al. (1992) and Teague, Bernardo, and Mapp (1995) at the farm level; by Gardner and Young (1988), Setia and Piper (1992), and Lakshminarayan, Johnson, and Bouzaher (1995) at the watershed level; and by Bouzaher et al. (1995), Lakshminarayan, Bouzaher, and Shogren (1996), and Lakshminarayan and Babcock (1995) at the regional level have used integrated modeling systems to assess such tradeoffs resulting from agricultural practices.

[1] The Area Study project is a comprehensive agricultural production and resource use data collection and modeling effort to assess national policy impacts. This is a multi-agency effort involving the U.S. Department of Agriculture's Economic Research Service, Natural Resource Conservation Service, and National Agricultural Statistics Service, and the U.S. Geological Survey.

Conceptual Framework

Three major modules— environmental, economic, and policy— constitute the overall integrated framework conceptualized for this study (Figure 1). The framework developed here draws from the Comprehensive Economic and Environmental Policy Evaluation System (CEEPES)[2] developed by CARD, Iowa State University. The CEEPES framework is widely accepted as a meaningful framework for such assessments and is the core of the Resource and Agricultural Policy System (RAPS) used by CARD to assess the economic, resource, and environmental effects of the new farm legislation passed in 1996 (RAPS 1996).

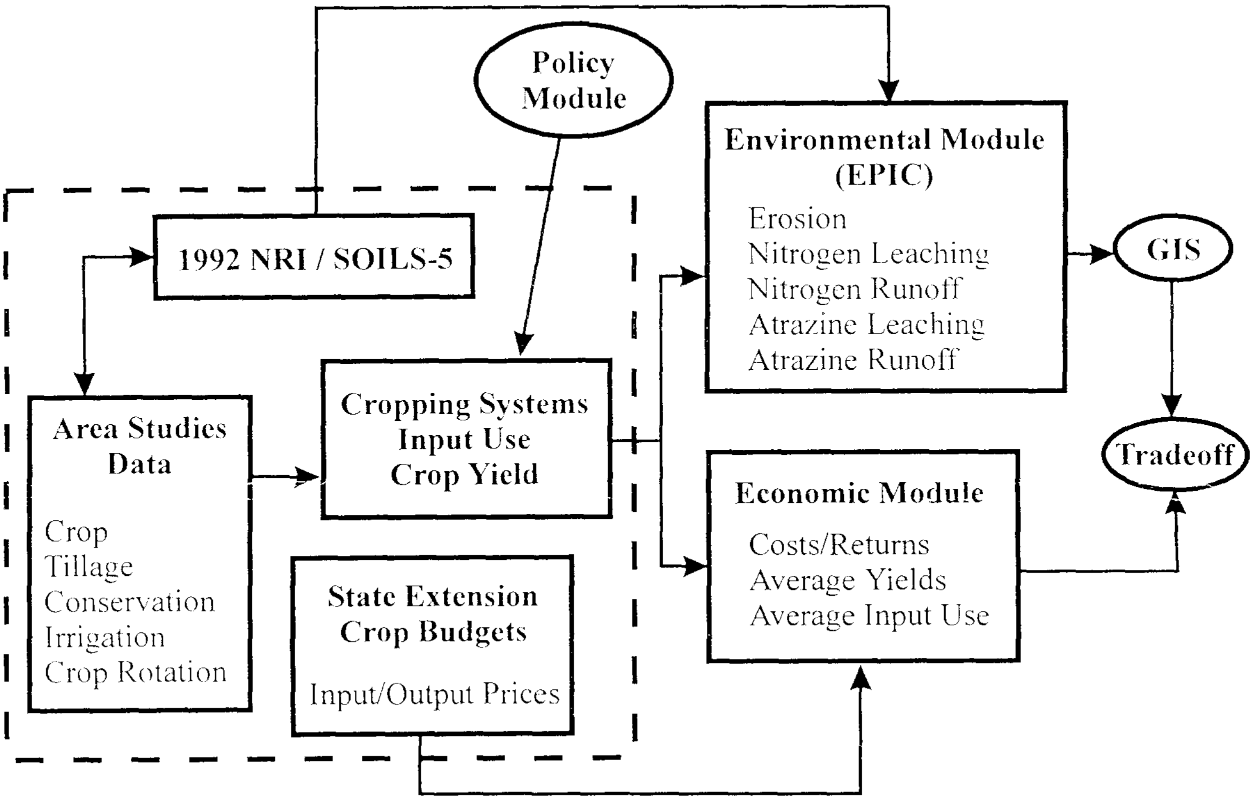


Figure 1. Integrated Modeling Framework

The policy module dictates alternative policies and best management practices (BMPs) for evaluation. The framework developed here allows evaluation of both uniform

[2] CEEPES integrates a watershed-level linear programming model of agricultural decision making with site-specific biogeophysical process (environmental) models, allocates resources, selects alternative production systems, and predicts site-specific environmental effects of choosing those systems.

and targeted policies. A uniform policy is one that is applied to all the producers in the region/watershed whether or not they are potential polluters. A targeted policy, on the other hand, will apply only to those producers who are potential polluters. Environmental benchmarks such as drinking water MCLs for nitrate-nitrogen and atrazine, soil loss tolerance, and aquatic benchmarks are used to determine the sites for targeting. A Geographical Information System (GIS) framework is developed to locate those sites. The economic module evaluates the costs and returns of current cropping systems (reported in the Area Study survey) as well as for alternative best management practices (BMPs) suited for the region.

The environmental component of the proposed integrated system is a biogeophysical process model, which is a mathematical model simulating the interaction of complex crop growth, soil erosion, and nutrient and chemical runoff and leaching processes at the field-level. Because it is prohibitive in terms of cost and time to conduct field experiments covering a large area, models simulating the crop growth process and its impact on physical processes such as soil degradation and chemical fate and transport are frequently used to assess multimedia (soil, groundwater, surface water, and atmosphere) environmental impacts (Wagenet and Hutson 1991).

Agricultural nonpoint source pollution is a significant cause of soil and water quality problems. Alternative best management practices are being developed to combat the nonpoint source pollution threat. Proper management of any system requires estimates of the impacts of alternatives being considered. To adequately address soil and water quality, several resource quality constituents have to be measured simultaneously. Therefore, the data requirements for comprehensive resource quality assessments are extensive. An effective plan can be developed only from good data. However, the environmental data representing a larger geographic scale are not readily available. These data gaps are filled by outputs from mathematical simulation models, where the simulation experiment is performed according to a well-designed statistical sampling plan similar to agronomic field experiments. The plan starts at the homogenous spatial unit, soil. At present, mathematical simulation models are the only hope for a timely evaluation of alternative policies, ex ante. These models consider site-specific attributes including land use patterns and management practices.

In EPIC-WQ, the proposed framework uses the calibrated, field-based physical process model called the Erosion Productivity Impact Calculator and Water Quality (EPIC-WQ) developed by the Blackland Research Center, U.S. Department of Agriculture (Williams, Jones, and Dyke 1988; Kiniry et al. 1995). The design objectives of EPIC are consistent with the objectives of current research, and it is clearly the most comprehensive tool to assess simultaneously the impacts of physical, hydrological, and management factors on crop production and soil and water resources. EPIC is a time-tested model that is useful, economical, and realistic in several applications, including evaluating impacts on water quality and soil erosion, both in the United States and around the world. The current version of EPIC includes a water quality component, called GLEAMS (Groundwater Leaching Effects on Agricultural Management Systems), which allows simulation of pesticide degradation and movement in the soil. EPIC-WQ can simulate the movement of pesticides and nutrients toward ground and surface waters, both in solute, and as applicable, sediment phases.

EPIC-WQ will be used to simulate the impacts of crop rotation, irrigation, tillage, conservation, N-management, and corn and sorghum weed management on crop yield, nitrate-N and atrazine leaching, nitrate-N and atrazine runoff, sheet and rill erosion, and wind erosion. EPIC simulations will be performed with "site-specific" physical, crop, crop rotation, irrigation, and conservation management data from the Area Study survey to generate input-output relationships characterizing various biogeophysical processes of crop production.

Each observation in the Area Study data represents a physical site, which is a geographically-based random sample drawn from the National Resources Inventory (NRI). In other words, each observation in the Area Study database is a sampling point of the 1992 NRI (USDA 1995). A layered soil record from the SOILS-5 database is associated with each Area Study observation, which provides information on site-specific soil texture, slope and slope length, and other soil physical properties. A combination of historical climate data from the neighboring weather and wind station and an EPICgenerated daily weather array, over a 30-year period (length of the simulation), will be used to simulate site-specific weather effects for each of the sites.

GIS is used to map resource and environmental indicators. GIS coverage defined by the intersection of an 8-digit hydrologic unit code (HUC), Major Land Resource Area (MLRA), and the county is the basic geographical unit for mapping. A unique characteristic of this coverage is that the HUCs provide watershed homogeneity, MLRAs provide land resource homogeneity, and the county provides production and economic homogeneity. Both the long-term average (30-year average) and average annual edge-of-field loads and concentrations of nitrate-N and atrazine and average annual soil loss from wind and water erosion will be recorded for each simulation run. An index constructed from these environmental indicators and the economic returns associated with the simulated cropping system provide the necessary information for constructing the risk-benefit tradeoff curves.

Central Nebraska Basin Area Study Survey

The Area Study project is a comprehensive agricultural production and resource use data collection and modeling effort to assess national policy impacts. The sites chosen for the Area Study were primarily selected from those included in the USGS's NAWQA program. The primary focus of Area Study is to gather multiyear, farm-level data that link production activities to resource and environmental characteristics. The survey collected information on crop production technologies, cropping systems, irrigation practices, soil, nutrient, and chemical management practices, and livestock manure management practices at both the field and whole farm levels. A unique feature of this survey is that its sample points were chosen to correspond with National Resource Inventory sample points, thus establishing a link between site-specific production practices and resource characteristics.

The Central Nebraska Basin Area Study surveyed 1,433 sites over an area of about 19 million acres of total farmland, of which cropland is 42 percent and pasture and range land is 58 percent (Table 1). Nearly 46 percent of the cropland is corn land and 21 percent is soybean land. The study area is approximately 30,000 square miles, and serves as a major drainage basin for the Platte River and its tributaries. Figure 2 shows the study

Table 1. Crop Acreage and AverageYield,1991

Crop	Acreage	Crop acreage as percent of Total Land	Crop/Past. Land	Yield/acre	Units
Cropland					
ALFALFA	633,400	3.39	8.07	3.5	tons
CORN SILAGE	127,800	0.68	1.63	10.9	tons
FIELD CORN	3,623,900	19.41	46.16	127.9	bu.
FORAGE	77,700	0.42	0.99	3.3	tons
HAY	618,100	3.31	7.87	2.0	tons
OATS	58,300	0.31	0.74	30.7	bu.
SORGHUM-SLG	19,900	0.11	0.25	15.7	tons
SORGHUM	317,400	1.70	4.04	90.3	bu.
SOYBEANS	1,659,100	8.89	21.13	33.3	bu.
WHEAT	154,400	0.83	1.97	30.3	bu.
SOD	20,200	0.11	0.26		
FALLOW LAND	12,600	0.07	0.16		
CRP	327,500	1.75	4.17		
SET ASIDE	158,000	0.85	2.01		
IDLE CROPLAND	42,300	0.23	0.54		
Total	7,850,600		100.00		
Range/Pasture					
PASTURE	10,149,000	54.37	93.82		
WOODLAND	6,800	0.04	0.06		
RANGELAND	661,300	3.54	6.11		
Total	10,817,100		100.00		
Total Land	18,667,700	100.00			

area and the distribution of cropland, pasture and rangeland, irrigated cropland, and cropland with conservation tillage. Nearly 35 percent of the cropland is irrigated, of which 78 percent is in corn (Table 2). And 60 percent of total corn acreage in this area is irrigated, producing an average of 146 bushels per acre (about 69 bushels more than nonirrigated corn yield). Appendix A summarizes total cropland acres by crop rotations for irrigated and nonirrigated cropping systems.

Table 3 reports total acres of cropland with conservation tillage. Nearly 55 percent of the total cropland is under conservation tillage and 81 percent of soybean and 61 percent of corn acres are under conservation tillage. Appendix B shows tillage-specific crop acreage and yield. Frequently used tillage practices in this region are conventional tillage with moldboard plowing, other conventional tillage, mulch and ridge till (reduced tillage), and no-till. About 5 percent of corn and 9 percent of soybeans are grown under no-till. Table 4 reports total fertilizer treated acres, average acre-treatments, and average rates of nitrogen (N) and phosphorus (P) applied per acre. Nearly 90 percent of corn and 18 percent of soybean acres are treated with fertilizers with an average acre-treatment of 1.7 for corn and 0.85 for soybeans. On average, 114 pounds of N are applied per acre of corn and 42 pounds of N is applied per acre of soybeans. Appendix C summarizes total N, P, and K (potassium) use and methods of fertilizer application.

Concluding Remarks

To determine how alternative management practices affect water quality requires estimating the sensitivity of sediment, nutrient, and chemical loadings to these alternative practices. How these alternative management practices affect the economic performance of agriculture will be determined from the farm-level Area Study data applying the commodity and input price information from the state agricultural extension service. The research provides information to farmers, policymakers, and water and soil resource planners for better management of these resources.

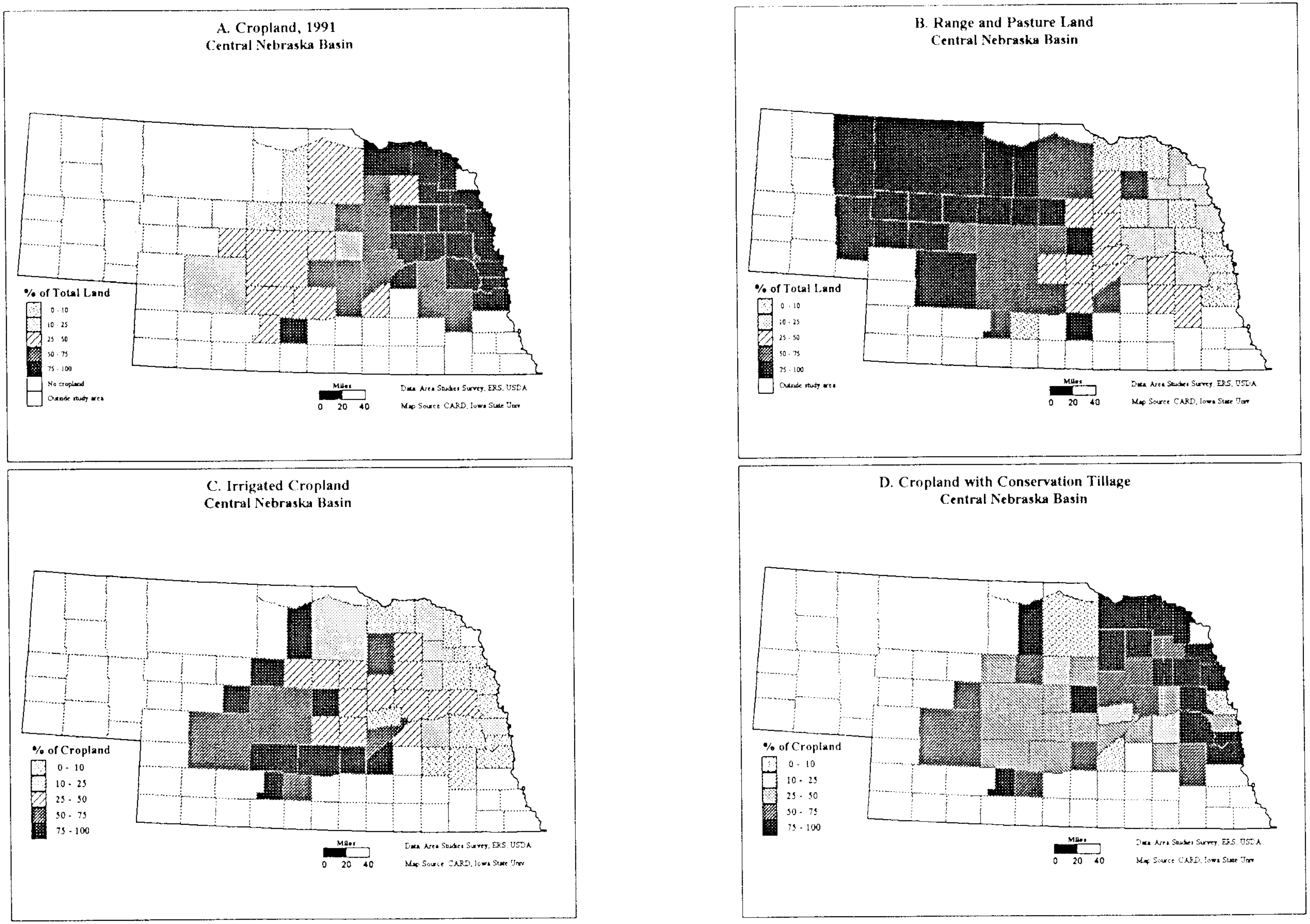


Figure 2. Distribution of cropland, range land, and cropland with irrigation and conservation tillage in the CNB Area Study region

Table 2. Irrigated Cropland and Yield per Acre

Crop	Total acreage	Irrigated acreage	Percent irrigated	Percent share	Crop Yield Irrig.	Crop Yield Nonirrig.
ALFALFA	633,400	175,535	27.7	6.3	na	4.3
HAY-NOT ALF	618,100	60,500	9.8	2.2	5.2	2.1
CORN SILAGE	127,800	77,807	60.9	2.8	10.5	11.6
FIELD CORN	3,623,900	2,174,324	60.0	78.1	146.0	76.8
OATS	58,300	0	0.0	0.0	na	30.7
SORGHUM-SLG	19,900	3,673	18.5	0.1	22.0	15.7
SORGHUM	317,400	10,460	3.3	0.4	95.0	89.8
SOYBEANS	1,659,100	253,790	15.3	9.1	44.4	29.7
WHEAT	154,400	0	0.0	0.0	na	30.3
OTHERS	657,800	29,500	4.5	1.1	na	na
Total	7,870,100	2,785,589	35.4	100.0		

Table 3. Cropland with Conservation Tillage and Yield per Acre

Crop	Total acreage	Conservation tillage (CST) ac.	Percent CST	Percent share	Crop Yield With CST	Crop Yield Without CST
CORN SILAGE	127,800	80,800	63.2	1.9	11.6	9.3
FIELD CORN	3,623,900	2,291,700	63.2	52.9	125.0	133.0
OATS	58,300	44,900	77.0	1.0	28.3	30.7
SORGHUM-SLG	19,900	19,900	100.0	0.5	15.7	na
SORGHUM	317,400	187,100	58.9	4.3	92.2	87.0
SOYBEANS	1,659,100	1,348,000	81.2	31.1	33.5	33.0
WHEAT	154,400	101,500	65.7	2.3	29.9	31.3
OTHERS	657,800	261,800	13.7	6.0	na	na
Total	7,870,100	4,335,700	55.1	100.0		

Table 4. Fertilizer Use: Acres Treated and Average Rate per Acre

Crop	Total acreage	Fertilizer treated acres	Percent treated	Average acre-treatment	Average rate, lb/acre N	Average rate, lb/acre P
ALFALFA	633,400	133,944	21.1	0.65	33	
HAY	618,100	142,294	23.0	0.31	32	
CORN SILAGE	127,800	124,824	97.7	2.18	100	56
FIELD CORN	3,623,900	3,263,269	90.0	1.70	114	56
OATS	58,300	20,572	35.3	1.25	78	
SORGHUM-SLG	19,900	0	0.0	0.00	na	na
SORGHUM	317,400	274,154	86.4	1.38	95	28
SOYBEANS	1,659,100	303,630	18.3	0.85	42	36
WHEAT	154,400	95,805	62.0	0.83	40	
Total	7,212,300	4,358,492	60.4			

Appendix A. Crop Rotation Systems of Central Nebraska Basin

Crop Rotation	Acreage	% Share
Nonirrigated and Irrigated Systems		
CRN-CRN-CRN	2,224,900	29.34
CRN-SOY	1,760,200	23.21
HAY-HAY-HAY	617,800	8.15
ALF-ALF-ALF	460,600	6.07
CRN-CRN-SOY	315,300	4.16
CRN-CRN-ALF	187,600	2.47
SOY-SRG	155,800	2.05
CRN-CRN-FAL	121,500	1.60
SOY-SOY-SOY	99,400	1.31
WHT-SRG	91,900	1.21
CRN-CRN-HAY	90,500	1.19
PST-PST-PST	82,800	1.09
SRG-SRG-SRG	76,000	1.00
SOY-WHT	70,700	0.93
CRN-CRN-CSL	65,500	0.86
CRN-WHT-FAL	62,200	0.82
CRN-SRG	61,900	0.82
CRN-FAL	61,400	0.81
CRN-OTS-SOY	58,500	0.77
FAL-FAL-FAL	57,100	0.75
CRN-SOY-FAL	52,700	0.69
SRG-SRG-SOY	52,600	0.69
SOY-SOY-ALF	51,000	0.67
SOY-SOY-SRG	46,200	0.61
WHT-FAL	44,600	0.59
WHT-SRG-FAL	42,000	0.55
SOY-FAL	37,700	0.50
CRN-SRG-SOY	37,200	0.49
SRG-SRG-CRN	37,200	0.49
CRN-SOY-ALF	37,000	0.49
CRN-HAY	30,800	0.41
SRG-ALF	30,600	0.40
WHT-WHT-WHT	30,000	0.40
SOY-CSL	29.700	0.39
CRN-HAY-CSL	25,800	0.34
CRN-CRN-WHT	25,300	0.33
WHT-WHT-CRN	24,100	0.32
CRN-OTS	22,200	0.29
SOY-OTS-SRG	21,700	0.29
SOY-HAY	21,700	0.29
WHT-ALF	20,400	0.27
SOY-SSL-CSL	15,400	0.20
CRN CRN-OTS	15,400	0.20
OTS-OTS-ALF	14,900	0.20
Others	95,300	1.26
Total	7,583,100	100.00

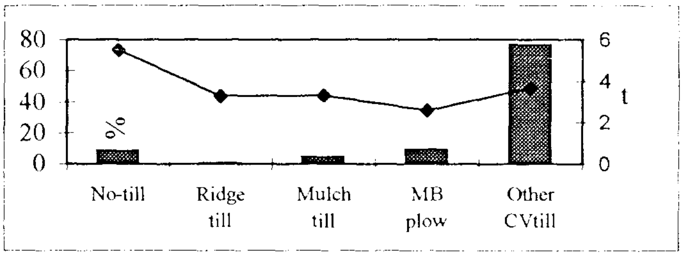
Crop Rotation	Acreage	% Share
Irrigated Systems		
CRN-CRN-CRN	1,839,400	60.46
CRN-SOY	262,200	8.62
CRN-CRN-SOY	242,700	7.98
CRN-CRN-ALF	134,400	4.42
HAY-HAY-HAY	122,200	4.02
ALF-ALF-ALF	100,400	3.30
CRN-CRN-FAL	70,700	2.32
SOY-SOY-SOY	61,600	2.02
CRN-CRN-CSL	58,700	1.93
OTS-OTS-ALF	14,900	0.49
FAL-FAL-FAL	14,500	0.48
SOY-CSL	14,400	0.47
OTS-OTS-FRG	14,400	0.47
SSL-SSL-SSL	13,600	0.45
CRN-OTS	6,900	0.23
CRN-SOY-FAL	6,800	0.22
CRN-HAY-SSL	6,800	0.22
SOY-SOY-ALF	6,800	0.22
CRN-CRN-HAY	6,400	0.21
SOY-OTS-SRG	6,400	0.21
CRN-OTS-SOY	6,400	0.21
CRN-FAL	6,300	0.21
CRN-CRN-SRG	6,300	0.21
SOY-HAY	6,300	0.21
SRG-SRG-CRN	6,300	0.21
SRG-SRG-SOY	6,300	0.21
Total	3,042,100	100.00

Appendix B. Tillage Specific Crop Acreage and Yield, 1991

(Central Nebraska Basin)

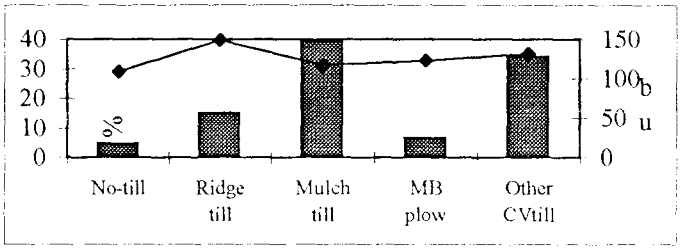
Crop/Tillage	Acreage	% share	Yield
ALFALFA			
No-till	53,700	8.48	5.5
Ridge till	6,300	0.99	3.3
Mulch till	27,100	4.28	3.3
MB plow	59,400	9.38	2.6
Other CVtill	486,900	76.87	3.7
Total	633,400	100.00	

ALFALFA



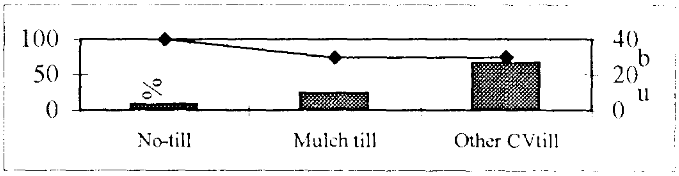
FIELD CORN			
No-till	171,000	4.72	109.4
Ridge till	546,000	15.07	149.5
Mulch till	1,430,900	39.49	117.5
MB plow	240,200	6.63	123.6
Other CVtill	1,235,800	34.10	132.2
Total	3,623,900	100.00	

FIELD CORN



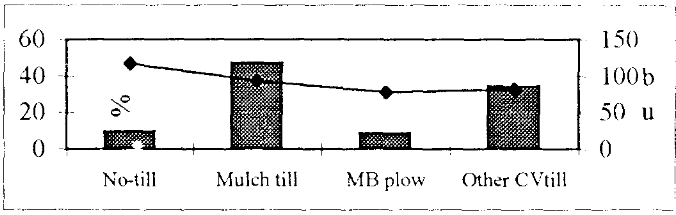
WHEAT			
No-till	13,900	9.00	40.0
Mulch till	37,300	24.16	29.7
Other CVtill	103,200	66.84	30.0
Total	154,400	100.00	

WHEAT



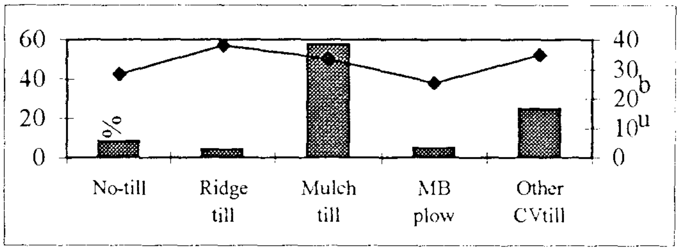
SORGHUM			
No-till	31,000	9.77	117.0
Mulch till	149,900	47.23	93.3
MB plow	28,000	8.82	78.3
Other CVtill	108,500	34.18	82.6
Total	317,400	100.00	

SORGHUM



SOYBEANS			
No-till	141,800	8.55	28.4
Ridge till	67,100	4.04	38.0
Mulch till	959,300	57.82	33.6
MB plow	81,300	4.90	25.3
Other CVtill	409,600	24.69	34.9
Total	1,659,100	100.00	

SOYBEANS



Appendix C. Fertilizer Treatment Methods
(Central Nebraska Basin)

Crop/Method	Total N, lb.	% share	Total P, lb.	% share	Total K, lb.	% share
ALFALFA						
Broadcast-dry	1,125,310	25.1	3,566,303	79.5	321,200	58.2
Broadcast-Liq	427,484	9.5	504,894	11.3	70,194	12.7
Band-Dry	321,106	7.2	412,851	9.2	160,553	29.1
Injected	2,602,549	58.1	0	0.0	0	0.0
CORN SILAGE						
Broadcast-dry	2,436,760	19.5	1,165,800	40.5	77,000	17.5
Broadcast-Liq	1,015,200	8.1	0	0.0	0	0.0
Band-Dry	576,400	4.6	879,200	30.6	302,200	68.6
Band-Liq	752,681	6.0	831,587	28.9	61,569	14.0
Injected	6,887,197	55.0	0	0.0	0	0.0
Fertigation	851,544	6.8	0	0.0	0	0.0
FIELD CORN						
Broadcast-dry	30,361,479	8.2	18,567,016	23.9	7,357,142	40.3
Broadcast-Liq	47,657,049	12.8	9,959,538	12.8	2,468,300	13.5
Band-Dry	7,271,474	2.0	14,988,395	19.3	3,468,372	19.0
Band-Liq	22,459,534	6.0	24,053,714	30.9	3,616,129	19.8
Band-Sol	1,961,777	0.5	1,885,634	2.4	138,588	0.8
Injected	251,748,423	67.6	8,289,930	10.7	1,148,003	6.3
Fertigation	8,401,585	2.3	0	0.0	34,500	0.2
Other	2,302,526	0.6	72,756	0.1	26,928	0.1
HAY						
Broadcast-dry	3,098,273	68.1	1,108,319	23.0	109,515	100.0
Broadcast-Liq	1,449,900	31.9	3,705,300	77.0	0	0.0
OATS						
Broadcast-dry	1,602,790	100.0	808,945	100.0	221,970	100.0
SORGHUM						
Broadcast-dry	1,281,600	4.9	96,000	3.9	57,600	28.1
Broadcast-Liq	951,060	3.7	530,400	21.7	0	0.0
Band-Dry	246,000	0.9	658,960	27.0	112,600	55.0
Band-Liq	341,161	1.3	852,744	34.9	34,650	16.9
Band-Sol	89,650	0.3	304,810	12.5	0	0.0
Injected	23,101,109	88.8	0	0.0	0	0.0
SOYBEANS						
Broadcast-dry	6,080,775	48.1	5,688,863	64.3	1,738,743	97.7
Broadcast-Liq	3,056,921	24.2	50,400	0.6	0	0.0
Band-Liq	650,094	5.1	2,210,318	25.0	0	0.0
Band-Sol	438,115	3.5	796,572	9.0	0	0.0
Injected	1,978,555	15.7	103,918	1.2	41,567	2.3
Foliar	428,400	3.4	0	0.0	0	0.0
WHEAT						
Broadcast-dry	1,723,560	45.4	2,111,320	100.0	0	
Broadcast-Liq	2,073,209	54.6	0	0.0	0	

References

Bouzaher, A., J. Shogren, P. W. Gassman, D. Holtkamp and A. Manale. 1995. Use of a linked biophysical and economic modeling system to evaluate risk-benefit tradeoffs of corn herbicide use in the Midwest. In. *Agrochemical Environmental Fate: State of the Art.* ed. M. Leng, E.M.K. Leovey, and P. Zubkoff. CRC Press, Boca Raton, Florida. pp. 369-381.

Comfort, S. D., P. J. Shea, and F. W. Roeth. 1994. Understanding pesticides and water quality in Nebraska. Nebraska Cooperative Extension report EC 94-135, Institute of Agricultural and Natural Resources, The University of Nebraska, Lincoln.

Exner, M. E. and R. F. Spalding. 1990. Occurrence of pesticides and nitrate in Nebraska's ground water. Water Center report WC-1, Instituteof Agricultural and Natural Resources, The University of Nebraska, Lincoln.

Gardner, R. L. and R. A. Young. 1988. Assessing strategies for control of irrigation-induced salinity in the upper Colorado River basin. *American Journal of Agricultural Economics* 70:37-49.

Kiniry, J. R., D. J. Major, R. C. Izaurralde, J. R. Williams, P. W. Gassman, M. Morrison, R. Bergentine and R. P. Zentner. 1995. EPIC model parameters for cereal, oilseed and forage crops in the northern Great Plains region. *Canadian Journal of Plant Science* 75:679-688

Lakshminarayan, P. G. and B. Babcock. 1995. An economic and environmental evaluation of farm bill policy option using the CEEPES-FAPRI modeling system. Working Paper 95-WP 137, Center for Agricultural and Rural Development, Iowa State University, Ames.

Lakshminarayan, P. G., S. R. Johnson and A. Bouzaher. 1995. Multi-objective approach to integrating agricultural economic and environmental policies. *Journal of Environmental Management* 45:109-122.

Lakshminarayan, P. G., A. Bouzaher, and J. Shogren. 1996. Atrazine and water quality: An evaluation of alternative policy options. *Journal of Environmental Management* 47:xx-xx.

Resource and Agricultural Policy System (RAPS). 1996. RAPS 1996: An agricultural and economic outlook. Working Paper 96-WP xxx, Center for Agricultural and Rural Development, Iowa State University, Ames.

Setia, P. and S. Piper. 1992. Effects of soil and agricultural chemicals management on farm returns and groundwater quality. *Review of Agricultural Economics* 14:65-80.

Teague, M. L., D. J. Bernardo, and H. P. Mapp. 1995. Farm-level economic analysis incorporating stochastic environmental risk assessment. *American Journal of Agricultural Economics* 77:8-19.

USDA. 1995. Summary Report 1992 National Resources Inventory. Natural Resources Conservation Service, U.S. Department of Agriculture, Washington, D.C.

Wagenet, R. and J. Hutson. 1991. Modeling pesticide transport and transformation in the soil-plant system. In *Pesticide Chemistry* ed. H. Freshe. VCH publisher, New York.

Williams, J. R., C. Jones, and P. Dyke. 1988. EPIC, the erosion productivity impact calculator. *Model Documentation*, vol. 1. U.S. Department of Agriculture, Agricultural Research Service, Temple, Texas.

Wossink, G. A. A., T. J. de Koeijer and J. A. Renkema. 1992. Environmental-Economic policy assessment: A farm economic approach. *Agricultural Systems* 39:421-438.