3. Nutrient Management

In this chapter, we briefly describe the role of fertilizer use in U.S. agriculture and why residual nutrients reaching ground- and surface-water sources are a concern. The Area Studies survey data are described with respect to the amount of fertilizer applied, use of nutrient management practices, and sources of information used for making fertilizer application decisions. The results of the simple adoption models for selected nutrient management practices are reported for the combined-areas and single-area models using the modeling framework and core variables described in chapter 2. The human capital, production, agricultural policy, natural resource, and climate factors affecting adoption are described.

The United States saw a virtual explosion in crop yields during the 20th century. Each U.S. farmer, on average, produces enough food for himself and at least 60 other people. Average corn yield quadrupled, and average yields of wheat, soybeans, cotton, and other important crops more than doubled in the last 50 years. This level of production was reached primarily for two reasons: The use of commercial fertilizers that provide low-cost nutrients, and the development of high-yielding crop varieties and hybrids.

The yield potential of a crop is determined by the most limiting of the various factors essential for plant growth. These factors, in addition to plant nutrients, include moisture, temperature, light, and plant density. Plant nutrients are divided into three categories: (1) primary nutrients, (2) secondary nutrients, and (3) micronutrients.[1]

Soil fertility has been of vital concern to farmers since the beginning of agriculture. Historically, farmers settled in areas where soils were rich in nutrients. Producers either included the land in a fallow rotation or farmed until the fertility was exhausted and then moved on. Eventually, the cost of land increased so that there were fewer economic opportunities to fallow or abandon land. As the demand for agricultural commodities increased, generated by an expanding population and economic development, farmers began to replace nutrients that were taken from the soil by extensive farming. Farmers applied manure and other farm refuse to the soil to replenish nutrients before the advent of commercial fertilizers (The Fertilizer Institute, 1976).

Chemical fertilizers contributed significantly to the increase in U.S. agricultural productivity, but use of these chemicals has been associated with environmental, human health, and economic concerns (Kellogg et al., 1992). Most commercial fertilizers contain nitrogen (N), phosphate (P_2O_5), and potash (K_2O). Nitrogen is the key element of increased yields and is usually used in the largest quantity. Crops are estimated to absorb nitrogen from commercial fertilizers at a rate from 30 to 70 percent. The portion of nitrogen that is not absorbed by the plants is free to escape into the environment (Legg and Meisinger, 1982). Residual N by itself does not necessarily result in environmental problems (Ribaudo, 1997). Potential damages will depend on soils, climate, and the nutrient management practices that are used. The runoff and leaching of nitrogen into rivers, lakes, and estuaries is a major contributor to water quality problems (Puckett, 1994). The U.S. EPA (1998) identified nutrient loadings as stressing 15 percent of surveyed river miles and up to 20 percent of lake acreage. Agriculture was the leading contributor of those nutrients. High nitrate concentrations in drinking water may pose human health risks. The adoption of certain nutrient management technologies by farmers has been promoted as a way of obtaining more efficient use of nitrogen fertilizer and of reducing the quantity of residual nutrients available for transport to the environment. Huang (1997) presents a comprehensive summary of nutrient management issues.

Summary of Nutrient Management Practices and Data

In this section, we describe the data on nutrient management obtained from the Area Studies survey. Fertilizer use and the practices and information sources that are used to manage fertilizer applications are presented.

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[1] There are three primary nutrients, nitrogen (N), phosphorus (P), and potassium (K), which are needed in large amounts. The three secondary nutrients, calcium (Ca), magnesium (Mg), and sulfur (S), are applied to correct soil pH. These are as important as primary nutrients but are applied in smaller amounts. Micronutrients are essential to plant nutrition but are needed in even smaller amounts. The seven micronutrients are boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn).

Fertilizer Use

The rate of commercial fertilizer application depends on a variety of factors including soil type, climate, crop mix, crop rotation, irrigation, feasible technology, government programs, and commodity and fertilizer prices (Taylor and Huang, 1994). Of the factors affecting fertilizer use, crop mix may be the most important. In the Area Studies survey sample, nitrogen was applied to 99 percent of the potato and 96 percent of the corn planted acreage, while only 21 percent of the soybean acreage received nitrogen fertilizer applications. Potatoes and corn are crops that utilize large amounts of soil nitrogen in the production of their yields, whereas soybean, a legume[2] with the ability to extract nitrogen from the air to use for the production of its yields, needs very little added soil nitrogen. Crops also differ in the amount of phosphate and potash that are required. Table 3.1 shows the extent of chemical fertilizer usage by major nutrient elements (N-P-K) in the Area Studies data by major crop group.

The pounds of chemical fertilizer used per acre and the expenditures on chemical fertilizer per acre vary greatly by crop mix. Corn growers use, on average, 136 pounds of nitrogen per treated acre, whereas potato growers apply 232 pounds of nitrogen per treated acre. Figure 3.1 shows the distribution of pounds of commercial fertilizer applied on a per acre basis by fertilizer element (N-P-K) and crop. Fertilizer nitrogen application rates vary by region for the same crop due to different soil types and climatic conditions which affect farmers' production practices (irrigation, tillage type, plant variety). For example, average nitrogen applied to potatoes in the Snake River Basin is 234 pounds per treated acre versus 318 pounds per treated acre in the mid-Columbia River Basin. There is less

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[2] Legumes are plants that bear nodules on their roots that contain nitrogen-fixing bacteria of the genus *Rhizobium* and therefore have the unique ability to fix nitrogen to the soil.

Table 3.1—Percent of acres for major crops receiving fertilizer applications—combined areas

Crop	Nitrogen (N)	Phosphate (P_2O_5)	Potash (K_2O)
	Percent		
Corn	96	78	70
Cotton	90	62	60
Potatoes	99	98	75
Soybeans	21	24	25
Wheat	77	42	15

variation in the average amount of nitrogen applied to corn. Figure 3.2 shows some of the regional differences in pounds of nitrogen fertilizer applied per treated acre to the same crop mix.
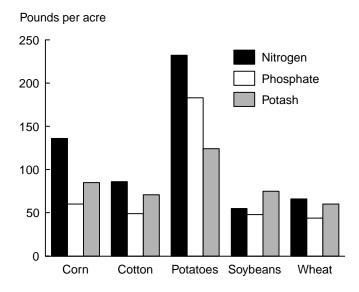
Nutrient Management Practices

Selected nutrient management practices have been designed to help farmers manage fertilizer use more efficiently, while obtaining desired crop yields. Some of these practices are intended for a particular type of farm operation. For example, the use of animal waste for fertilizer may be most profitable only if there is an onfarm or nearby source of manure. The specific practice, or combination of practices, that a farmer will choose depends on the type of crop grown (legume or non-legume) and the type of farm (livestock operation or not). The box on the following page provides definitions of the nutrient management practices analyzed using the Area Studies survey data.

We divided the nutrient management technologies analyzed in this study into two categories: *modern* nutrient management practices and *traditional* nutrient management practices. As the name suggests, modern nutrient management practices are newer technologies that are more information intensive or require a higher level of technical expertise than older practices. For this analysis, we included soil or tissue N-testing, split nitrogen applications, and an aggregate category that included one or more of three practices (N-testing, split nitrogen applications, micronutrient use) as "modern practices" for convenience. *Traditional* nutrient management

Figure 3.1
Average pounds of fertilizer applied per treated area
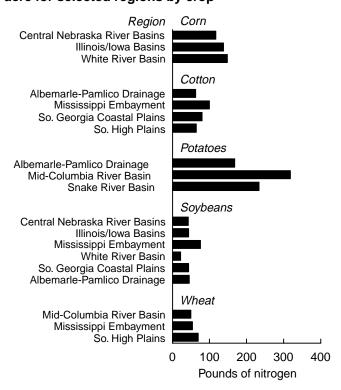
Pounds per acre

practices are technologies that have been used effectively for at least several decades. *Traditional* practices include the planting of legumes in rotation with other crops and the use of manure to provide organic fertilizer for crops. The adoption of both modern and traditional practices would be expected to reduce the application of chemical fertilizers. The modern technologies increase the application efficiency, and the traditional ones substitute organic sources of nutrients for chemical fertilizers.

The adoption rates for the various nutrient management practices in the Area Studies survey are shown in table 3.2. The most common practice category was the combination of three practices (modern practices), with a 44 percent level of adoption. Soil N-testing, split nitrogen applications, and micronutrients each had an adoption level of approximately 20 percent, and producers could use more than one of these methods. There was more variation among traditional technologies. In the sample, 37 percent of the acreage was cultivated using legumes in rotation and more than 9 percent using manure.

Adoption rates for nutrient management technologies also varied greatly depending on the crop grown (fig.

Figure 3.2

Average pounds of nitrogen applied per treated acre for selected regions by crop

Glossary of Nutrient Management Practices

Modern practices (three practices together) includes the use of a single or any combination of the nutrient management practices that are technologically advanced or more modern. These include N-testing, split nitrogen applications, and the use of micronutrients (see below for definitions).

N-Testing refers to soil and plant tissue N tests used by farmers to estimate the residual nitrogen available for plant use in determining fertilizer needs. Soil testing before planting includes estimation of nitrogen in the root zone of the crop being planted. For corn grown in certain areas, the root zone can be 3 feet or more.

Split Nitrogen Applications refers to applying half or less of the required amount of nitrogen for crop production at or before planting, with the remainder applied after emergence. Multiple applications supply nutrients more evenly and at times when the crop can most efficiently use them.

Micronutrients refers to applying micronutrients to the field either alone or mixed in bulk blended fertilizer. Micronutrients are essential to plant nutrition but are needed in relatively small amounts. Judicious use is also important because some of the micronutrients (boron, copper, and molybdenum) can be toxic if applied in excess or to the wrong crop.

Legumes in Rotation refers to practice of growing leguminous crops (soybeans or alfalfa) in rotation with other crops (non-leguminous). This type of cropping pattern is used to improve soil fertility. For the purpose of this study a farmer is said to use legumes in rotation, if a non-leguminous crop is planted in the field one year, where a legume was planted the previous year, or a leguminous crop is planted in the field where a non-legume was planted the previous year. For this study, leguminous crops are defined as alfalfa or soybeans, and non-leguminous crops are any crop excluding hay and pasture.

Manure refers to applying animal manure to the field as a source of nutrient replacement. Use of animal waste as fertilizer is economically feasible only if onfarm or nearby sources exist.

3.3). The technology of N-testing was adopted by 79 percent of the potato farmers, but only 23 percent of the corn and wheat farmers used N-testing. Another example is the adoption of legumes in rotation, a technology used by 48 percent of corn growers compared with 14 percent of small grain farmers. On the other hand, the adoption of split nitrogen application was the most consistent across all crops, ranging from a low of 14 percent for corn to a high of 25 percent for cotton. Crop dummies were used in the analysis (ROW, SMGRAIN, CORN, COTTON, RICE, SOYBEANS, POTATOES, WHEAT, PEANUTS) to capture the crop-specific factors affecting the adoption of nutrient management practices.

There are also regional differences in the rates of adoption of nutrient management technologies. However, these differences may be based on crop mix. For example, legumes in rotation are used on 71 percent of the cropland in the Illinois/Iowa River Basins region, predominantly a corn and soybean area, whereas only 3 percent of the cropland in the mid-Columbia River Basin employ this technology, a region dominated by wheat. The use of manure as a nutrient management practice shows regional differences which may be due to the livestock source constraint. Manure is used on less than 20 percent of the cropland for all the regions except Susquehanna, where it is used on 61 percent of the cropland. This difference may reflect the high livestock concentrations, especially dairy cattle, in the Susquehanna. Figures 3.4-3.8 display the distribution of adoption rates of nutrient management practices by area. For the adoption analysis, a variable (ANIMAL) was created to indicate whether the farm had livestock or not.

Sources of Nitrogen Fertilizer Application Information

Farmers often seek information about when to apply nitrogen fertilizer and how much to apply. The timing of application and the quantity of nitrogen fertilizer

Table 3.2—Adoption of nutrient management practices—combined areas

Nutrient management practice	Percent of acres
Modern practices (any of the three practices)	44.1
N-testing	21.2
Split nitrogen applications	18.6
Micronutrients	19.7
Legumes in rotation	37.0
Manure	9.3

applied can greatly affect crop yields and the amount of nutrients that can be transported to groundwater or rivers and lakes. A non-optimal use of nitrogen fertilizer is an economic loss to the farmer and could adversely affect the environment. The Area Studies survey asked farmers to indicate the most important source of information they used in making their nitrogen fertilizer management decisions. The possible responses were:

(a) no nitrogen applied,
(b) fertilizer company recommendation,
(c) consultant recommendation,
(d) judgment based on crop appearance,
(e) judgment based on soil or tissue test,
(f) Extension Service recommendation,
(g) standard amount for the crop when in this rotation, and
(h) other.

Figure 3.9 shows the responses across all the survey sample, and figure 3.10 shows a distribution of the percentage of farms using each of these sources of information, by area.

For the nutrient management adoption models, a variable (ADVICE) was created to indicate whether farmers had used some outside source of information. Included in the (ADVICE) variable were: fertilizer company recommendation, consultant recommendation, and Extension Service advice. In general, we expect that farmers who receive information or advice

Figure 3.3
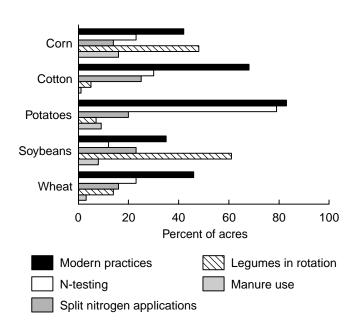**Adoption of nutrient practices by crop**
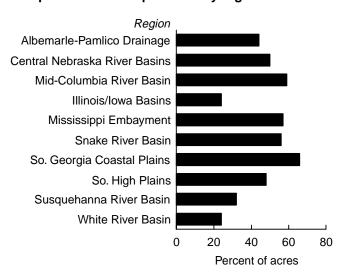
Figure 3.4
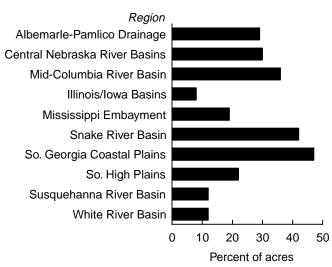**Adoption of modern practices by region**

Region

Region	Percent of acres
Albemarle-Pamlico Drainage	
Central Nebraska River Basins	
Mid-Columbia River Basin	
Illinois/Iowa Basins	
Mississippi Embayment	
Snake River Basin	
So. Georgia Coastal Plains	
So. High Plains	
Susquehanna River Basin	
White River Basin	

Percent of acres
0   20   40   60   80

Figure 3.7
Adoption of legumes in rotation by region

Region

Albemarle-Pamlico Drainage
Central Nebraska River Basins
Mid-Columbia River Basin
Illinois/Iowa Basins
Mississippi Embayment
Snake River Basin
So. Georgia Coastal Plains
So. High Plains
Susquehanna River Basin
White River Basin

Percent of acres
0   20   40   60   80

Figure 3.5
Adoption of N-testing by region

Region

Albemarle-Pamlico Drainage
Central Nebraska River Basins
Mid-Columbia River Basin
Illinois/Iowa Basins
Mississippi Embayment
Snake River Basin
So. Georgia Coastal Plains
So. High Plains
Susquehanna River Basin
White River Basin

Percent of acres
0   10   20   30   40   50

Figure 3.8
Adoption of manure use for nutrient management by region

Region

Albemarle-Pamlico Drainage
Central Nebraska River Basins
Mid-Columbia River Basin
Illinois/Iowa Basins
Mississippi Embayment
Snake River Basin
So. Georgia Coastal Plains
So. High Plains
Susquehanna River Basin
White River Basin

Percent of acres
0   20   40   60   80

Figure 3.6
Adoption of split nitrogen applications by region

Region

Albemarle-Pamlico Drainage
Central Nebraska River Basins
Mid-Columbia River Basin
Illinois/Iowa Basins
Mississippi Embayment
Snake River Basin
So. Georgia Coastal Plains
So. High Plains
Susquehanna River Basin
White River Basin

Percent of acres
0   10   20   30   40

Figure 3.9
Principal sources of information for nitrogen fertilizer application decisions, all areas

No nitrogen applied
Fertilizer co. recommendation
Consultant recommendation
Crop appearance
Soil/tissue test
Extension Service
Standard amount
Other

Percent of acres
0   10   20   30

from one of these three sources to be more aware of modern nutrient management technologies. The (ADVICE) variable does not include: judgment based on soil or tissue test, a more technical source of information, in which fertilizer recommendations are based on a chemical analysis of soil samples. The use of soil or tissue test (see N-testing in "Glossary," p. 29) is one of the nutrient management adoption models analyzed.

Adoption of Nutrient Management Practices

To investigate which factors affect the adoption of nutrient management practices, we selected five models of nutrient management technologies. Under the category of *modern* nutrient management practices are: (1) an aggregate practice category that includes N-testing, split nitrogen application, or micronutrient use; (2) N-testing; and (3) split nitrogen applications.[3] Under the category of *traditional* nutrient management practices are the use of: (1) legumes in rotation and (2) manure. These particular practices were chosen because they have relatively high adoption rates and they provide the best insight into the human capital, production characteristics, agricultural policy, natural resource, and climate factors affecting adoption.

For each selected nutrient management practice, adoption analysis results are reported for the combined areas (all 10 of the Area Studies regions combined) and from selected single areas. The selection criteria for choosing the regions for the single-area analyses were based on whether there were a sufficient number of observations in an adoption category. Also, the discussion refers to tables displaying the sample means, changes in percent predicted adoption, and the significance levels from the models. We present the sample means for the combined-areas and single-area models in table 3.3. Details of the modeling framework and core set of variables are presented in chapter 2.

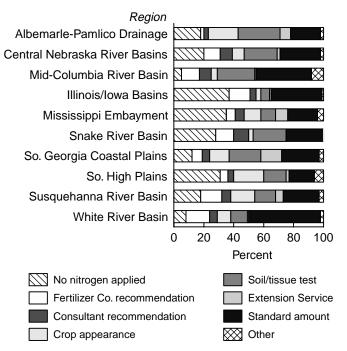### *"Modern" Practices (N-testing, Split Nitrogen Applications, or Micronutrient Use)*

The model results, along with the significance level, from the adoption study of the three modern practices analyzed jointly are displayed in table 3.4. For the combined-areas models, table 3.5 presents the percent

predicted adoption for varying values of selected variables. The results for the adoption of N-testing and split nitrogen applications are reported in tables 3.6 and 3.7 respectively. Five regions were chosen to compare adoption results for the group of modern practices, four areas for N-testing, and only one area for split nitrogen applications based on the levels of adoption in each area.

In the combined-areas model, about 44 percent of producers used one or more of the modern practices, 21 percent used N-testing, and 19 percent used split nitrogen applications. Table 3.4 shows that the predicted adoption of the modern practices as a group was 43 percent calculated at the sample means. The percent of correct predictions for that model was 70 percent and the pseudo R^2 was 0.31. For the model of the adoption of N-testing, the predicted probability was 16 percent (table 3.6). The percent correct predictions was 79 percent and the pseudo R^2 was 0.30. The adoption model for split nitrogen application has a predicted probability of adoption of 16 percent. The percent correct predictions was 84 percent and the pseudo R^2 was 0.18 (table 3.7).

In the combined-areas models, the human capital variables, COLLEGE, EXPERIENCE, and WORKOFF, were all significant for the three practices studied as a group and indicate that more highly educated, less experienced (younger) farmers, and those who worked

Figure 3.10
Principal sources of information for nitrogen fertilizer application decisions by region

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[3] The use of micronutrients is included in the "modern practice" category, but not analyzed separately.

Table 3.3—Sample means from nutrient management adoption models

Variables	Combined areas	Central Nebraska	Mid-Columbia River Basin	Illinois/Iowa Basins	Mississippi Embayment	Snake River Basin	Southern Georgia	Southern High Plains	Susquehanna River Basin	White River Basin
MODERN PRACTICES	.44	.50	.59	.24	.57	.57	.66	.48	.33	.24
NITROGEN TESTING	.21	.30	.36	.08	.19	.44	.47	.22	.12	.12
SPLIT NITROGEN APPLICATION	.19	.14	.11	.12	.36	.21	.08	.16	.10	.08
LEGUMES IN ROTATION	.38	.35	.02	.72	.30	.05	.18	.03	.20	.63
MANURE USE	.09	.10	.02	.19	.01	.10	.03	.05	.62	.10
COLLEGE	.44	.39	.70	.38	.47	.60	.39	.55	.14	.42
EXPERIENCE	24	24	22	25	23	21	25	23	22	25
WORKOFF	32	30	14	41	21	35	42	24	47	64
TENURE	.38	.43	.43	.37	.30	.63	.47	.36	.61	.40
ACRES	1702	1645	3030	912	2335	2591	1506	1974	467	933
ROW	.48	.55	.02	.58	.40	.14	.44	.75	.34	.51
SMGRAIN	.13	.03	.78	.03	.08	.49	.13	.21	.13	.06
CORN	.30	.50	.02	.57	.07	.01	.26	.07	.33	.51
COTTON	.15	00	00	00	.30	00	.15	.60	00	00
POTATOES	.01	00	.01	00	00	.13	00	00	.01	00
WHEAT	.10	.02	.67	.01	.08	.31	.09	.19	.06	.06
PEANUTS	.02	00	00	00	00	00	.23	.03	00	00
SOYBEANS	.31	.23	00	.43	.49	00	.19	00	.09	.43
DBL-CROP	.06	.01	.19	.02	.08	00	.11	.06	.04	.02
IRRIGATION	.26	.41	.25	.02	.39	.80	.26	.45	.02	00
ANIMAL	.17	.46	.01	.21	.03	.15	.15	.08	.75	.20
PROGRAM	.80	.74	.78	.85	.87	.47	.80	.92	.15	.68
ADVICE	.19	.21	.19	.19	.20	.21	.26	.12	.25	.21
INSURE	.40	.42	.57	.63	.14	.27	.32	.71	.04	.18
SLP	118	125	143	91	116	150	148	151	100	112
PISOIL	.80	.85	.87	.94	.80	.82	.37	.69	.68	.90
EROTON	33	46	59	26	19	38	16	71	50	27
RAIN	3.1	2.1	1.1	3.0	4.3	1.2	4.1	1.6	3.4	3.4
TEMP	55	49	49	50	61	44	65	58	51	52
Number of observations	6429	694	235	1269	818	509	507	505	400	743

* Refer to table 2.2 for variable definitions and units.

fewer days off-farm were more likely to adopt modern practices. The effect of education on the adoption of modern practices also was positive and significant for the Central Nebraska River Basins and Southern Georgia Coastal Plain. As shown in table 3.5, some college education increased predicted adoption to about 48 percent whereas predicted adoption was around 40 percent for farmers without any college education for the modern practice category. COLLEGE also had a positive and significant effect on the adoption of split nitrogen applications. The increased probability of adoption for modern practices by educated farmers and those who worked fewer days off-farm was expected due to the time-intensive and technical nature of these practices. The result that more experienced farmers are less likely to adopt modern practices and N-testing could indicate that long-time farmers may feel they already have sufficient knowledge to determine appropriate fertilizer needs, or perhaps they are more reluctant to switch from technologies they have used for years. Land ownership, TENURE, did not have a significant influence on the adoption of modern practices either as a group or singly. This is not unexpected since there is no longrun productivity advantage of using these methods, and either tenants or owners would gain the same benefits from adoption. Results were the same for the single-areas models.

Crop insurance reduces the risk to farmers from losses in crop yields due to events such as adverse weather or

Table 3.4—Change in percent predicted adoption of modern practices (N-testing, split N application, micronutrients)

Variables	Combined areas	Central Nebraska	Mid-Columbia River Basin	Mississippi Embayment	Snake River Basin	Southern Georgia
CONSTANT	-1.1028**	26.982**	-0.7394	-3.4064**	-1.1235**	-2.6634**
COLLEGE	0.0809**	0.2275**	0.0319	0.0471	0.0286	0.1048**
EXPERIENCE	-0.0523**	-0.0436	0.0365	-0.0401	-0.0097	-0.0623
WORKOFF	-0.0132**	-0.0085	-0.0085	-0.0166**	-0.0070	-0.0027
TENURE	0.0126	-0.0720	-0.0498	0.0092	0.0172	0.0349
ACRES	0.0109**	0.0296	-0.0332	0.0399*	0.0693**	0.08467**
ROW	0.1999**	0.3446**	—	0.1003[1]	—	0.1116**[1]
SMGRAIN	-0.0371	-0.0974	0.5755**	0.0158	0.0635	-0.1481*
COTTON	—	—	—	0.2734**	—	0.3253**
CROP	—	—	—	—	0.9071**[2]	0.2009**[3]
SOYBEANS	0.0476**	0.2213**	—	—	—	—
DBL-CROP	0.0282	—	0.2248**	—	—	0.1217
IRRIGATION	0.2574**	0.4730**	0.7539**	0.0632	0.4756**	0.1328**
ANIMAL	-0.0466**	0.0013	—	-0.0871	-0.2347**	-0.0319
PROGRAM	0.1281**	0.0701	-0.0527	0.3069**	0.1776**	0.0750
ADVICE	0.1457**	0.2873**	0.0380	0.2754**	0.2541**	-0.0949*
INSURE	0.0653**	0.0116	-0.0609	0.0602	0.0055	-0.0324
SLP	0.1079**	0.0953	-0.0205	0.1561*	0.2942	0.0183
PISOIL	-0.0178	0.1004	-0.0170	-0.0297	0.2340*	0.1043
EROTON	0.0106*	-0.0050	0.1539**	-0.0059	0.0231	-0.0016
RAIN	0.5774**	0.6751*	0.3643*	1.8758**	-0.4297**	1.9947**
TEMP	-0.1582	-7.2675**	—	—	—	—
Number of observations	6429	694	235	818	509	507
% predicted adoption	43.1	51.8	63.8	58.0	64.9	72.0
% correct predictions	70	77	75	71	75	76
Pseudo R^2 [4]	.31	.52	.35	.33	.46	.38

— Variable not included in the adoption model.
** Significant at the 5-percent level.
 * Significant at the 10-percent level.
[1] ROW1 = row crops (corn, sorghum, potatoes, tobacco) except cotton.
[2] CROP1 = potatoes.
[3] CROP2 = peanuts.
[4] Veall and Zimmerman's pseudo R^2.

Note: For the table, the coefficients estimated from the limited dependent model have been converted into change in percent predicted adoption. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, RAIN AND TEMP), the reported value is the change in the percent predicted adoption given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in the percent predicted adoption between the values of 0 and 1. See Appendixes 2-A and 2-B for further details.

pest infestations. In the combined-areas model, farmers who had crop insurance were more likely to adopt one or more of the three modern practices, and more likely to adopt N-testing alone. Participation in the insurance program did not influence the adoption of split nitrogen application.

Farm size had a positive and significant effect on the adoption of the three modern practices and of N-testing for the combined areas, the Snake River Basin and Southern Georgia Coastal Plain models. Table 3.5 shows that producers who operated 5000 acres of land were more likely to adopt modern practices, about 45 percent, compared with 42 percent for farmers who operated 500 acres. The difference in predicted probability is even greater for N-testing — 22 percent compared with 14 percent for smaller operations. The effect of farm size on the adoption of split nitrogen applications was not significant. The results of these models support the argument that large farms are often associated with lower management and information costs per unit of output.

A farmer's adoption of modern practices for nutrient management may also be influenced by crop choice. We expected that farmers who cultivate legumes would have less need for adopting modern practices since they may apply small amounts of nitrogen fertilizer. The benefits of nutrient application efficiency are larger as the amounts of fertilizer increase. However, there could be a positive association with the adoption of modern practices since farmers may be growing legumes as part of a nutrient management plan, used in rotation with other crops (see following analysis of the adoption of legumes in rotation as a nutrient management practice). For this analysis, soybeans (SOYBEANS) were the only legume crops included, and the crop was produced by 31 percent of the farmers. Another group of crops, small grains (SMGRAIN), are modest users of nitrogen fertilizer. We expected small grain farmers to have less need to adopt modern practices, since these crops require relatively fewer nutrient inputs. The small grains were produced by about 13 percent of farmers and were defined as either wheat, oats, barley, or rye. Row crops (ROW) are considered the most nitrogen-intensive crop group and one would expect these farmers to adopt modern practices. Row crops were grown by 48 percent of the farmers in the Area Studies sample and were defined as either corn, cotton, potatoes, sorghum, or tobacco. Dummy variables for row crop, small grains, and soybeans (legume) were included in the combined-areas model. The model results indicate that the probability of a

Table 3.5—Percent predicted adoption—combined areas

Variables	Modern practices	Nitrogen testing	Split nitrogen application	Legumes in rotation	Manure use
College	**		**		
Yes	47.7	16.9	19.0	30.7	3.7
No	39.6	15.5	14.1	29.7	4.1
Land tenure				**	**
Yes	43.9	15.9	16.8	27.4	5.6
No	42.6	16.3	16.8	31.9	3.2
Land operated	**	**		*	**
500 acres	42.3	14.3	15.7	30.8	4.8
5,000 acres	45.2	21.6	17.3	28.4	2.4
Use irrigation	**	**	**	**	**
Yes	62.2	29.8	19.6	33.7	6.9
No	36.5	12.7	15.0	28.9	3.2
Received information	**	**	**		
Yes	55.0	25.4	15.5	30.1	3.8
No	40.3	14.5	18.9	30.2	4.0
Program	**	**	**	**	
Yes	45.7	16.7	9.9	31.4	3.9
No	33.3	14.0	18.1	25.3	4.2
Percent adoption at means	43.1	16.1	16.1	30.1	3.9

** Significant at the 5-percent level.
 * Significant at the 10-percent level.

farmer's adopting one or more of the three modern practices significantly increased for farmers growing row crops or soybeans (the result for soybeans is driven by a single area). The production of soybeans also had a positive effect on the adoption of split nitrogen applications. Growing small grains did not have any significant influence on the adoption of modern practices as a group, but had a significant negative effect on the adoption of N-testing. In the single-area models, the specific crop types were significant, showing the importance of site-specific knowledge for predicting adoption.

Double-cropping is a measure of cropping intensity, and had no significant impact on the adoption of any of the modern nutrient management categories (except in the mid-Columbia River Basin model for the modern practice group), whereas the use of irrigation had

an overall positive and significant effect on the adoption of all modern practices. The result was consistent with the belief that irrigated crops have the potential to reduce nutrient availability through leaching, and farmers may be less certain of the nutrient content that remains available to the crop. In addition, use of irrigation may raise a producer's average yield, which will, in turn, increase the use of inputs such as nitrogen. Therefore, we expected that a farmer who irrigated would be more likely to adopt modern nutrient management practices.

A livestock component (ANIMAL) of farm production was expected to influence the adoption of nutrient management technologies (see the following analysis of the adoption of manure-use nutrient management practice). The effect of a livestock operation on the adoption of the three modern practices and N-testing

Table 3.6—Change in percent predicted adoption of N-testing

Variables	Combined areas	Central Nebraska	Mid-Columbia River Basin	Snake River Basin	Southern Georgia
CONSTANT	-0.7604**	-0.9253**	-1.7724**	-20.574**	-1.4109**
COLLEGE	0.0135	0.0915**	0.0805	-0.0576	0.0660
EXPERIENCE	-0.0264**	-0.0468	0.0208	-0.0621	-0.0760
WORKOFF	0.0004	0.0075	-0.0038	-0.0020	-0.0088
TENURE	-0.0042	-0.0570	0.0430	0.0822	0.0394
ACRES	0.0295**	0.0022	-0.0510	0.0860**	0.0696**
ROW	0.0861**	—	—	0.9582**[1]	0.1538**
SMGRAIN	-0.0565**	—	0.3221**	0.0241[2]	-0.0222
CORN	—	0.1250**	—	—	—
WHEAT	—	—	—	0.2473**	—
SOYBEANS	-0.0011	0.1916**	—	—	—
DBL-CROP	-0.0024	—	0.1081	—	-0.0788
IRRIGATION	0.1452**	0.3397**	0.5389**	0.6716**	0.1475**
ANIMAL	-0.0467**	-0.0367	—	-0.1694*	-0.0659
PROGRAM	0.0283**	0.0429	-0.0029	0.1137*	0.0921
ADVICE	0.0863**	0.1391**	0.0564	0.4339**	-0.1641**
INSURE	0.0601**	0.1754**	0.0726	0.1704**	0.1190**
SLP	0.1174**	0.1951*	0.7994**	0.4734**	-0.2413
PISOIL	0.0643**	0.0081	-0.0536	0.1276	0.0991
EROTON	0.0057	-0.02810	0.0647*	0.0071	-0.0081
RAIN	0.0201	0.0638	0.3170	0.6523**	0.9441**
TEMP	0.0162	—	—	4.8540**	—
Number of observations	6429	694	235	509	507
% predicted adoption	16.1	21.9	34.1	42.2	45.8
% correct predictions	79	78	70	78	65
Pseudo R^2 [3]	.30	.50	.32	.58	.24

— Variable not included in the adoption model.
** Significant at the 5-percent level.
 * Significant at the 10-percent level.
[1] Potatoes and sugar beets.
[2] Small grain crops (oats, barley, rye) except wheat.
[3] Veall and Zimmerman's pseudo R^2.

Note: For the table, the coefficients estimated from the limited dependent model have been converted into change in percent predicted adoption. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, RAIN AND TEMP), the reported value is the change in the percent predicted adoption given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in the percent predicted adoption between the values of 0 and 1. See Appendixes 2-A and 2-B for further details.

was negative and significant, indicating that farms with livestock operations may be less likely to adopt modern practices. This result may reflect more a grower's need to dispose of livestock waste than the use of manure for its nutrient content.

Farmers who received government farm program benefits (PROGRAM) were significantly more likely to adopt each of the modern practice categories than those who did not. The results are mixed for the single-area models. The data on participation is limited, so we cannot test whether farmers receiving program benefits are more likely to be enrolled in other USDA incentive programs that involve nutrient management. Receiving some form of outside information (ADVICE) on nitrogen fertilizer application was posi-

tively and significantly related to the adoption of each modern practice. Table 3.5 shows that agricultural producers who received nitrogen fertilizer application information had a 55 percent predicted adoption for the three modern practices, whereas producers who did not had only a 40 percent predicted adoption level. The single-area models generally had the same results. These results strongly support the hypothesis that the provision of advice may be an important determinant of adoption for technologies that require a relatively high level of information or expertise for efficient use.

Soil characteristics are important in explaining where nutrient management practices occur. Soil leaching potential (SLP) is an index that measures the potential of chemicals to leach through soil into groundwater, but can be used as a proxy for soil texture, etc. (see description in chapter 2). Typically, the higher the SLP index, the sandier the soil and the more likely that

Table 3.7—Change in percent predicted adoption of split nitrogen applications

Variables	Combined areas	Mississippi Embayment
CONSTANT	-0.9800**	-2.6886**
COLLEGE	0.0481**	0.1118**
EXPERIENCE	-0.0116	-0.0091
WORKOFF	-0.0065**	-0.0265**
TENURE	0.0010	-0.0309
ACRES	0.0070	-0.0224
ROW	0.0253*	0.0962
SMGRAIN	—	—
RICE	0.0682**	0.2173**
SOYBEANS	0.0469**	0.2036**
DBL-CROP	-0.0020	—
IRRIGATION	0.0438**	0.0132
ANIMAL	0.0159	0.0234
PROGRAM	0.0949**	0.3603**
ADVICE	0.0324**	0.1435**
INSURE	0.0073	0.0020
SLP	0.0189	0.0786
PISOIL	-0.0783**	-0.1963*
EROTON	-0.0055	-0.0371
RAIN	0.1767**	2.1879**
TEMP	0.3869**	—
Number of observations	6429	818
% predicted adoption	16.1	32.1
% correct predictions	84	71
Pseudo R^2 [1]	.18	.26

** Significant at the 5-percent level.
* Significant at the 10-percent level.
[1] Veall and Zimmerman's pseudo R^2.

Note: For the table, the coefficients estimated from the limited dependent model have been converted into change in percent predicted adoption. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, RAIN AND TEMP), the reported value is the change in the percent predicted adoption given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in the percent predicted adoption between the values of 0 and 1. See Appendixes 2-A and 2-B for further details.

Table 3.8—Change in percent predicted adoption of legumes in rotation

Variables	Combined areas	Illinois/Iowa River Basins	White River Basin
CONSTANT	0.2556**	0.0646	1.8514**
COLLEGE	0.0100	-0.0014	-0.0154
EXPERIENCE	-0.0053	0.0012	-0.0581
WORKOFF	-0.0016	0.0031	-0.0085
TENURE	-0.0454**	-0.0895**	-0.0949**
ACRES	-0.0090*	0.0149	0.0564**
DBL-CROP	0.0463	-0.2725**	-0.3702**
IRRIGATION	0.0467**	-0.2943**	—
ANIMAL	-0.0924**	-0.1085**	-0.0571
PROGRAM	0.0634**	0.0991**	0.0038
ADVICE	-0.0008	-0.0715**	-0.0091
INSURE	-0.0316**	0.0174	-0.0243
SLP	-0.2133**	-0.1496**	0.0734
PISOIL	0.2011**	0.0218	-0.2452
EROTON	-0.0040	-0.0140	-0.0100
RAIN	-0.1300	0.1464	-1.4508**
TEMP	—	—	—
Number of observations	6429	1269	743
% predicted adoption	30.1	73.3	64.9
% correct predictions	75	75	69
Pseudo R^2 [1]	.43	.14	.15

** Significant at the 5-percent level.
* Significant at the 10-percent level.
[1] Veall and Zimmerman's pseudo R^2.

Note: For the table, the coefficients estimated from the limited dependent model have been converted into change in percent predicted adoption. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, RAIN AND TEMP), the reported value is the change in the percent predicted adoption given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in the percent predicted adoption between the values of 0 and 1. See Appendixes 2-A and 2-B for further details.

nitrogen will leach below the root zone. SLP had a positive and significant impact on the adoption of the combined modern practices and N-testing. This result, however, was realized only for N-testing in the single-area models.

A soil productivity index (PISOIL) was calculated to measure soil quality for crop growth. The index values range from 0 to 1, with higher values indicating more productive soils. Higher productivity soils have higher yields than those of lower quality, so the value of information (N-testing) is higher. The risk associated with not being able to apply nitrogen during the growing season is more costly for highly productive soils. For the combined-areas model, the productive capacity of soil (PISOIL) had a positive effect on N-testing adoption, but a negative influence on split nitrogen application use. Inherent erosion levels

(EROTON) had no impact on the adoption of any of the modern practices.

Climate can play a major role in the need for nutrient management practices. Higher monthly average rainfall increases the potential for leaching and runoff of soil nutrients. We expected that in areas with elevated rainfall levels, agricultural producers would be more likely to adopt modern practices. Monthly temperatures were not expected to impact the adoption of modern practices. In the combined-areas model, average rainfall had a positive and significant influence on the adoption of the three modern practices and split nitrogen applications, whereas temperature had a positive effect only for split nitrogen application. That climate variables were significant for several single-area models supports the use of individual resource characteristics rather than just area dummies.

Table 3.9—Change in percent predicted adoption of manure use

Variables	Combined areas	Susquehanna River Basin
CONSTANT	0.7201**	-1.2068
COLLEGE	-0.0045	-0.1502*
EXPERIENCE	0.0009	0.0133
WORKOFF	-0.0026**	-0.0250*
TENURE	0.0224**	0.3006**
ACRES	-0.0115**	-0.1272**
ROW	0.0116**	0.1792**
SMGRAIN	-0.0013	0.1858**
DBL-CROP	-0.0072	—
IRRIGATION	0.0306**	—
ANIMAL	0.0537**	0.4781**
PROGRAM	-0.0031	0.0405
ADVICE	-0.0020	0.3237**
INSURE	0.0024	—
SLP	-0.0052	0.0673
PISOIL	0.0373**	0.1509
EROTON	0.0024*	-0.0284
RAIN	—	0.9591
TEMP	-0.2015**	—
Number of observations	6429	400
% predicted adoption	3.9	66.0
% correct predictions	91	77
Pseudo R^2 [1]	.36	.45

** Significant at the 5-percent level.
 * Significant at the 10-percent level.
[1]Veall and Zimmerman's pseudo R^2.

Note: For the table, the coefficients estimated from the limited dependent model have been converted into change in percent predicted adoption. For continuous variables (EXPERIENCE, WORKOFF, ACRES, SLP, PISOIL, EROTON, RAIN AND TEMP), the reported value is the change in the percent predicted adoption given a 1-percent change in the variable mean. For binomial variables that have a value of either 0 (no) or 1 (yes), the reported value indicates the change in the percent predicted adoption between the values of 0 and 1. See Appendixes 2-A and 2-B for further details.

"Traditional" Practices
(Legumes in Rotation or Manure Use)

Long before commercial fertilizers became available, farmers were using legumes in rotation with other crops to provide nitrogen to soils. Even today, legumes are still the main source of fixed nitrogen for the majority of the world's soils. Adoption of legumes in rotation with grain crops has been a popular cropping practice because it allows farmers to reduce commercial nitrogen application on the succeeding crop. A rotation with legumes is a *traditional* nutrient management practice that offers economic and environmental benefits to producers and the public.

Farmers also have applied manure and other farm refuse to soils to replenish the soil nutrients removed by cultivated crops. Animal wastes are a source of organic nutrients and can be substituted for commercial fertilizers in crop production. Animal wastes can be an economical supply of nitrogen, phosphorus, potassium and other nutrients needed for crop production so long as there is a nearby source so that manure transportation costs are not high. Manure is not standard, however, but varies in its N-P-K content. The use of land application as a manure disposal option can also result in residual nutrients' being available for transport to the environment. The use of livestock manure does not indicate a more efficient use of nutrients necessarily, but does represent an organic rather than chemical source of nutrients.

The sample means for the combined-areas and single-area models are presented in table 3.3. The Illinois/Iowa and White River Basins areas were

selected for the single-area models of legume adoption, and the Susquehanna River Basin for manure use because these areas had a significant number of adopters. The model results, along with the significance levels, from the adoption studies are displayed in table 3.8 for legumes in rotation and in table 3.9 for the use of manure.

For the combined Area Studies sample, about 38 percent of producers used legumes in rotation. Tables 3.8 and 3.9 show that the predicted adoption of legumes in rotation for all areas combined was 30 percent, and predicted adoption for manure use was only 4 percent for the combined areas, but 66 percent for the Susquehanna River Basin (calculated at the sample means). The percent of correct predictions was 75 percent for the combined-areas legume model and 91 percent for manure use. The pseudo R^2 calculations were 0.43 and 0.36 respectively.

The human capital variables, EXPERIENCE, COLLEGE and WORKOFF, did not have much influence on the adoption of legumes in rotation as a nutrient management practice. The same result was obtained for the manure use model except for a negative effect for WORKOFF. Manure use is usually associated with livestock production which is very labor intensive and less likely to be chosen by producers who work off the farm. Farm ownership (TENURE) had a significant effect on adoption for both traditional practices for all models. Ownership had a positive influence on the use of manure and a negative effect on the use of legumes in rotation. Crop insurance (INSURE) had a negative and significant influence on adoption of legumes, but had no effect on manure use. Crop rotation may be the risk management strategy chosen by farmers to use instead of crop insurance.

Soil characteristics are important in explaining where legumes in rotation occur. Soil leaching potential (SLP) had a significant and negative effect on the adoption of legumes in rotation. The nutrient benefits of legume planting would dissipate in highly leachable soils. Manure use is not affected by SLP. For operations on which manure availability is not a limiting factor (i.e., manure disposal has a higher value to the producer than nutrient management), the reduction of nutrient leaching would not be considered as important to the individual decision maker. For the combined-areas models of legume adoption and manure use, the greater the productive capacity of the soil (PISOIL) the more likely the producers were using legumes in rotation. These results, however, do not hold for the single-areas models.

The amount of rainfall had no impact on adoption of legumes in the combined-areas model, but had a negative impact in the White River Basin. TEMP was significant and negative for manure use in the combined-areas model.

Summary

Although the results from the adoption models vary depending on the region and nutrient management practice examined, there were some general findings. As we expected, human capital had significant effects on the adoption of the more modern nutrient management technologies, which require a higher level of skill and management commitment than the more traditional technologies to use effectively. Working more days off-farm negatively affected the adoption of the modern practices and split nitrogen applications. An interesting result was that experience also negatively affected the adoption of modern practices and N-testing. Landownership had a negative and positive effect on the adoption of legumes in rotation and the use of manure, respectively. In addition, working more days off-farm reduced the probability of manure use. Crop insurance positively affected the adoption of modern practices and n-testing, although it had a negative impact on the adoption of legumes in rotation.

Farm size and cropping patterns also influenced the adoption of nutrient management technologies. Larger farm sizes increased the probability that a farmer would adopt modern practices or N-testing, indicating there may be economies of scale associated with larger farms. Smaller size farms were significantly more likely to adopt legumes in rotation and to use manure. Crop choice and irrigation were positive and significant determinants of all nutrient management practices in this study.

Resource characteristics helped explain the pattern of adoption for nutrient management practices. Producers with less sandy soils (measured by SLP) were more likely to adopt legumes in rotation, whereas those with more leachable sandy soils were more likely to adopt modern practices and N-testing. An interesting result was that those with highly productive soils as measured by the PISOIL index were more likely to adopt N-testing and the traditional nutrient management technologies of legumes in rotation and manure use only in the combined-areas models; these effects were not significant in the individual area models. Farmers with less productive soils were more likely to adopt split nitrogen applications. The use of a general productivity index may mask the importance of certain

individual soil characteristics such as organic composition. In a region-specific model, it may be best to identify resource characteristics known to be important in the area.

Climate had varying effects on the adoption of nutrient management practices. In some places, higher average monthly rainfall and temperature were associated with the adoption of some of the *modern* nutrient management technologies. In contrast, lower average monthly temperature was associated with the adoption of manure use, a *traditional* nutrient management technology.

A significant factor in the adoption of all of the *modern* nutrient management technology models was receiving some outside information on nitrogen fertilizer applications. This result was strong and positive in all cases, indicating that the outside information encourages farmers to adopt *modern* nutrient management technologies. Advice was less important for the adoption of traditional practices, with the exception of manure use in the Susquehanna River Basin.

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