Managing livestock manure for profitability and water quality protection

Stewart W. Melvin
Iowa State University

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Managing livestock manure for profitability and water quality protection

Abstract
The Manure Management interdisciplinary research issue team formed in 1990 to study several issues related to Iowa's rapidly accelerating increase in animal production, both in the number and size of animal units, particularly swine units. Swine facilities being built in Iowa today include a number of 3,500-head farrowing units and 15,000-head (and larger) finishing units. The poultry industry has also grown rapidly. Economic pressures have caused animal production systems to become larger and more concentrated, requiring significant capital investment. This concentration has occurred at the family farm level as well as in production systems controlled by large agribusiness firms. One disturbing trend is the increase in family farm units that do not own the animals they are producing.

Keywords
Agricultural and Biosystems Engineering, Manure nutrient and compost management

Disciplines
Agriculture | Bioresource and Agricultural Engineering | Environmental Health and Protection | Water Resource Management

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Managing livestock manure for profitability and water quality protection

Background

The Manure Management interdisciplinary research issue team formed in 1990 to study several issues related to Iowa's rapidly accelerating increase in animal production, both in the number and size of animal units, particularly swine units. Swine facilities being built in Iowa today include a number of 3,500-head farrowing units and 15,000-head (and larger) finishing units. The poultry industry has also grown rapidly. Economic pressures have caused animal production systems to become larger and more concentrated, requiring significant capital investment. This concentration has occurred at the family farm level as well as in production systems controlled by large agribusiness firms. One disturbing trend is the increase in family farm units that do not own the animals they are producing.

This team believes that integrated crop and livestock family farms can compete. To do so, they must exploit modern technology and all available resources—including the animal manure produced, which can be utilized as a nutrient source for growing crops. The farm that integrates crops with livestock production can offset some commercial fertilizer use with manure, thus saving money and resolving the issue of disposal at the same time. When properly utilized, manure need not pose a threat to the environment.

The objectives of the Manure Management team are to:
1. encourage sustainable animal production in Iowa,
2. improve profitability of integrated crop and livestock production systems,
3. minimize external resource use, and
4. protect the environment.

To achieve these objectives, the team has focused on four major research thrusts:

1. A sustainable system study. Approximately 1.3 million gallons of liquid swine manure are applied to crop land yearly. Team leader Melvin is directing the investigation by Jeff Lorimor into environmental impacts on surface and groundwater.

Leader:
Stewart W. Melvin, Agricultural and Biosystems Engineering, Iowa State University, Ames

TEAM MEMBERS
Scientists:
Howard Hill, Veterinary Medicine
Palmer Holden, Animal Science
Kenneth H. Holscher, Entomology
Mark S. Honeyman, Outlying Research System
Robert Jolly, Economics
Randy Kilborn, Agronomy
James Kliebenstein, Agricultural Economics

Team Leader:
Melvin

Scientists:
Jeff Lorimor, Agricultural and Biosystems Engineering
Daniel D. Loy, Animal Science
Tom Loyanchak, Agronomy
Charlie Martinson, Plant Pathology
James McKean, Veterinary Medicine
Vern Meyer, Agricultural and Biosystems Engineering
William Owings, Animal Science
Vern Ryan, Sociology

Leadership:
Stewart W. Melvin, Agricultural and Biosystems Engineering, Iowa State University, Ames

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Stewart W. Melvin, Agricultural and Biosystems Engineering, Iowa State University, Ames
2. A large-plot study of manure. Melvin and Lorimor are monitoring soil and groundwater effects of manure applied to large plots prior to corn.

3. A study of manure application to soybeans. ISU agronomist Killorn is testing yield and environmental effects of manure applied prior to soybeans rather than before corn.

4. An economic study. ISU agricultural economist Michael Duffy is studying the economics of livestock agriculture and its effect on the sustainability of family farms.

1. The sustainable system study

This study is investigating the sustainability and environmental friendliness of utilizing approximately 1.3 million gallons of liquid swine waste from the 200-sow farrow-to-finish Swine Nutrition Management and Research Center west of Ames on 525 acres of land. The manure is injected each fall by a commercial applicator at rates of 9,000 to 10,000 gallons per acre. This high rate of liquid is used because the nutrient value of the manure has been quite low to date. Manure analyses from the newly established storage unit show the following nutrient ratios (N = nitrogen, P$_2$O$_5$ = phosphorus, and K$_2$O = potassium):

<table>
<thead>
<tr>
<th>Date</th>
<th>N</th>
<th>P$_2$O$_5$</th>
<th>K$_2$O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall 1991</td>
<td>9</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Spring 1993</td>
<td>15</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Fall 1992</td>
<td>15</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>Fall 1993</td>
<td>17</td>
<td>3</td>
<td>11</td>
</tr>
</tbody>
</table>

Thus, 9,000 gallons per acre application yields a nutrient application of approximately 150+30+110. The manure is applied every other year to approximately 150 acres prior to the next year’s corn crop.

Because this research focuses in part on determining whether the manure applications affect the quality of surface water or tile flow leaving the farm, instrumentation has been installed in the northeast corner of the farm to measure and sample both (see photo).

Tile flow monitoring began in early March of 1994. The tile line flows continuously. A baseflow of under 0.1 cubic feet per second (0.1 acre-inch per hour), and a high flow of 2.78 cfs were observed. The high flow occurred on June 23 following a 1.78-inch rain. The tile line reacts very quickly to precipitation events from the influence of some surface intakes. Nitrate levels, which have been sampled since 1991, have averaged 16.1 parts per million as nitrate-nitrogen. They show no signs of increasing with increased usage of manure nutrients. The 1994 average (as of mid-October) was 11.7 ppm. The phosphorus average since 1991 is 0.065 ppm as P. The 1994 average (as of mid-October) was 0.044 ppm. Monitoring continues.

Surface flow monitoring also began in spring 1994. The only sizable surface runoff event occurred on June 23 with the 1.78-inch rain mentioned above. Other, smaller events have been recorded, but data analysis is not complete for any of the surface events. The nutrient content of surface runoff is different from the tile flow, as expected. Runoff from the June stormcarried 2.65-1.55-27.5 ppm, respectively, of N-P$_2$O$_5$-K$_2$O. Now that instrumentation is completely installed, data collection continues on a monthly basis, and analysis is underway.

2. Large-plot study of manure

In fall 1992, a set of 12 large plots (120 feet X 180 feet) was established on the research center farm. The plots are large enough that edge effects from surrounding plots should not af-
feet groundwater samples taken at the center of each plot. Treatments for the study were (1) manure applied at a standard rate (approximately 5000 gallons per acre), (2) manure applied at two times that rate, (3) commercial fertilizer according to the early spring nitrate test, and (4) no fertilizer. The following year was so wet that commercial fertilizer could not be applied and sample well installation could not take place until late in the summer. Only one groundwater sample was obtained in 1993. During harvest, some wells were broken off by field machinery, so all were removed.

In fall 1993, 12 more plots were established on another part of the farm, and one and two times the standard manure treatments were again applied. In spring 1994, shallow groundwater wells (down to six feet) were installed in all 24 plots on the two locations. Groundwater samples are being collected monthly from each of the two wells. The groundwater samples obtained in 1993 and 1994 showed no significant differences due to manure treatment.

Soil nitrate profiles were run on the soil cores obtained during well installation. The wells were installed in the spring or early summer following fall manure application. Differences were significant by depth, as would be expected, but manure treatment differences were not significant.

**Future directions:** Both this study and the sustainable system study were not fully established until late spring 1994; thus, data collection continues. Higher rates of nutrient applications will be used to see if differences can be detected. Now that flow measuring equipment is installed and working, total nutrient losses can be measured for use in determining mass balances for the farm. After harvest and manure removal, solids accumulation in the storage tank will be measured to try to account for the low nutrient test levels in the liquid portion of the manure. Manure will be sampled monthly ahead of the storage tank as well as in the fall during land spreading. Surface and groundwater sampling will continue.

**Education and outreach:** Information from the study is already being disseminated via meetings, presentations, and tours. The Swine Nutrition and Management Research Center was toured as part of the annual Leopold Center’s annual conference.

### 3. Manure applications to soybeans

The Iowa Department of Agriculture and Land Stewardship estimated the 1987 farm animal populations at 4.6 million cattle and calves and 13.8 million hogs (26% of the nation’s total). These animals produced approximately 142,000 tons of plant-available nitrogen (N), assuming that 50% of the excreted N is available the first year of application. This amounts to 22 pounds N for every corn acre in Iowa. Unfortunately, animal manure is often treated not as an on-farm resource but as a disposal problem. Large quantities of manure are applied to small areas of land to reduce the amount of time spent disposing of it. It is likely that nitrate-nitrogen is leaching from these overapplied areas into ground- and surface water.

Current research is focused on finding optimal times, methods, and manure application rates for continuous corn production. However, approximately eight million acres are planted to soybeans annually in Iowa. Application of animal manure to these fields would be advantageous because (1) soybeans are efficient at scavenging N from soil; (2) animal manure could be broadcast and incorporated in the fall without increasing the potential for erosion, since the preceding crop is usually corn; and (3) applying the animal manure to soybeans nearly doubles the number of acres available for land application.

But research is necessary to determine the effects of manure application on soybean yield and the environment.

This experiment was established west of Ames in spring 1992. The treatments were arranged in a split-plot, randomized, complete block design with four replications. Animal manure was applied to main plots either via spring broadcast, spring injected, or broadcast urea-ammonium nitrate (UAN) fertilizer (28% N). Liquid swine manure was applied at rates of 0, 1500, 3000, and 4500 gallons per acre to 15 ft
X 40 ft subplots. The manure used in 1993 contained 33 pounds N/1000 gal., 20 lb P\textsubscript{2}O\textsubscript{5}/1000 gal., 22 lb K\textsubscript{2}O/1000 gal., and 2.7% solids. Liquid UAN was applied at rates of 0, 75, 150, and 225 pounds N/acre. The treatments were applied to the soybean half of the corn-soybean rotation in May. Soybeans were planted with no prior tillage the following day. Investigators measured plant residue on the soil surface before treatments were applied and after planting. Nitrogen fertilizer was applied to the corn plots about two months later at four rates, depending on results of soil tests taken one month after planting. Rainfall and soil and air temperatures were recorded.

The effects of the treatments were determined by measuring the yield and N, P, and K uptake by the soybeans. Environmental effects are being estimated by soil sampling to monitor nitrogen transformations and movement of N in the top four feet of the soil.

**Soil sampling:** To establish baseline data on the concentration and variability of phosphorus and potassium in the 0-6-inch layer of soil, the experimental area was sampled intensively before the initial treatments were applied. The field was also sampled in one-foot increments to a depth of four feet to determine the nitrate-nitrogen (NO\textsubscript{3}-N) and ammonium nitrogen concentrations. Amounts of NO\textsubscript{3}-N in soil water at four feet were measured periodically with porous, ceramic-cup samplers in selected plots.

**Plant sampling:** About half of the soybean plots were harvested by combine; the remainder were selectively hand harvested following a mechanical malfunction. Total N, P, and K content were determined on a subsample of the grain. Uptake of the nutrients was calculated from these data.

**Results:** Residue coverage for the field planted to soybeans in 1993 was 88% before planting. After planting, residue counts decreased to 83% on broadcast manure and UAN fertilizer plots. Residue on injected manure plots decreased to 59%. Soil was sampled on four dates in 1993; soil NO\textsubscript{3}-N and NH\textsubscript{4}-N (ammonium-nitrogen) concentrations to four feet were determined for the first three sampling dates. Nitrate-nitrogen concentrations after fertilizer application were highest in the surface foot and decreased with depth. Plots that received manure had similar concentrations across all rates for all depths for the second and third sampling dates. Plots that received the high rate of UAN fertilizer had higher nitrate-nitrogen concentrations in the soil at all depths than the control plots did.

Concentrations of NH\textsubscript{4}-N after fertilizer application were higher in the surface foot for all treatments; they too decreased with depth. Later sampling dates showed little variation between depths and treatments. Soil P and K, 0 to 1 foot, appeared to be similar for all treatments and rates.

Plant populations for the individual treatments and rates were taken and the means recorded. Generally, populations decreased as application rates increased. UAN fertilizer plots had higher plant populations than plots treated with manure at all rates. Manure plots may have been adversely affected by compaction caused by heavy machinery. Injected manure plots showed the lowest population counts. Due to the injection bands, some seeds were planted deeper on these plots. This may have resulted in poor germination. Yields ranged from approximately 30 to 50 bushels per acre; no significant variation existed between treatments. Heavy rainfall throughout the growing season may have negatively affected yields.

Soil water samples were collected weekly at a depth of four feet and following significant rainfall throughout the summer months (see Fig. 1). The high rate of broadcast manure and of the UAN fertilizer showed a similar pattern for the concentration of NO\textsubscript{3}-N. Both started at approximately 6 ppm and steadily increased through the summer months. At the end of September, the rates were steady at approximately 11 ppm. Nitrate-nitrogen in the soil solution of plots injected with manure contained about 12 ppm nitrate-nitrogen in late May. The concentration declined throughout the summer, ending at approximately 4 ppm, though it had been measured at a low of 1.5 ppm.
The samples taken in control plots started at 13 ppm, peaked in July with 26 ppm, and then declined to about 12 ppm by the end of September. Control plots had a higher concentration of nitrogen than the treated plots; the investigators have not discovered an explanation for this anomaly.

This study was repeated in 1994. Results are being analyzed and summarized.

ISU plant pathologist Charlie Martinson also conducted research into the effects of hog and chicken manures on soil-borne pathogens. This work has informed the team’s research into applications of manures on land slated for soybean production (see p. 92 of this volume).

4. An economic study

This study investigated the impact of swine production on farm income and labor. Results indicate that an operator can have a significantly higher income on a 400-acre farm with a 120-sow farrow-to-finish herd than an operator on a 1,000-acre cash grain farm. Thus, an increase in swine production can have a significant impact not only on farm income and labor, but on farm structure and rural communities as well. The results are encouraging not only because they show how smaller farms can increase their income, but because they offer potential for protecting the natural resource base by recycling the livestock manure back onto the crop land, decreasing the need for purchased fertilizer.

Addition of a 120-sow swine operation dramatically increased the labor demand—for a 400-acre corn/soybean rotation, by almost 3.5 times. Coupled with this increased labor was a tremendous increase in the return per hour of operator labor. The added value to the operator's labor varied greatly depending on the yield potential of the land.

When amounts of labor in the 400-acre operation were compared with and without the livestock element, the value of an operator's hour was still considerably higher with livestock. The labor for 1,000 acres was 3,000 hours. Stopping the farrow-to-finish at 3,000 hours (and paying the extra labor needed at $6.50/hour) showed a tremendous variation in the value of an operator's hour. For low-yielding ground, the livestock operation returned over 10 times as much, and even the high-yielding ground still showed a 75% higher return per operator hour.

Returns to management also varied greatly with or without the swine herd. With low-yielding soils (see Table 1), the livestock turned a loss into almost a $32,000 gain. Even with the high-yielding soils, adding a swine herd added over $35,000 to the returns. These increased returns are attributable not only to more labor use and diversification, but to improved efficiency.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Low yield</th>
<th>Medium yield</th>
<th>High yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 acres—corn/soybeans</td>
<td>($1,616)</td>
<td>$6,711</td>
<td>$11,844</td>
</tr>
<tr>
<td>1,000 acres—corn/soybeans</td>
<td>(1,410)</td>
<td>16,777</td>
<td>29,609</td>
</tr>
<tr>
<td>400 acres—continuous corn</td>
<td>24,035</td>
<td>31,532</td>
<td>35,885</td>
</tr>
<tr>
<td>w/120 sows</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>400 acres—corn/soybeans</td>
<td>29,283</td>
<td>39,320</td>
<td>44,668</td>
</tr>
<tr>
<td>w/120 sows</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

By converting manure from a waste product to fertilizer, on low-yielding soils the farmer can save $0.15 per bushel for corn and $0.37 per bushel for soybeans. The savings increase to $0.20 per bushel for corn on the high-yielding soils while still showing a $0.07 per bushel savings for soybeans.
In short, the addition of a swine enterprise increases the labor but generates enough additional income to increase the hourly return. This advantage decreases as the quality of the ground increases, but it is present even with high-quality soil. Moreover, adding swine also improves the efficiency of the cropping enterprise. Again, although the advantage decreases as land quality increases, it still results in more than $0.20 per bushel lower production costs for corn.

Owner-operators of family-sized Iowa farms must realize that the advantages of large farrowing units can be offset by taking advantage of these efficiencies—the $0.20 per bushel cost advantage on corn production means a more than $1 per hundredweight advantage in pork production.

Energy and environment: Concerns about the environmental impacts of agriculture are increasing. Energy costs pose another major concern. Traditional crop production depends heavily on fossil fuel energy, especially for manufacture of fertilizer. Although comparing energy use and production can be difficult due to the different forms of energy, most of the energy used in crop production comes from petroleum or natural gas. In typical corn production systems, fertilizer accounts for between one-half and two-thirds of all energy used.

While feeding livestock will always require energy, producers need to remember that much of the energy needed is returned in the form of manure. In the swine enterprise analyzed in this study, the 22,820 bushels of corn represent over 1.22 billion BTUs of energy if converted to ethanol. As animal feed, the corn would represent over 649 million BTUs. These would be equivalent to 8,855 and 4,708 gallons of diesel fuel equivalents, respectively. (One gallon of diesel fuel has approximately 138,000 BTUs.) The pork produced represents slightly more than 91 million BTUs of energy. However, the manure replaces over 626 million BTUs for nitrogen, 233 million BTUs for phosphorus, and over 60 million BTUs for potassium. Altogether, the manure from the 120-sow operation could replace approximately 6,708 gallons of diesel fuel equivalents used for fertilizer.

On a per head basis, it takes an estimated 0.7 BTUs to produce a hog in a farrow-to-finish operation. The manure energy value is 0.5 BTUs per head. It is clear that proper use of animal manure as a fertilizer source can help alleviate environmental and energy concerns.

This economic study has recently been expanded to investigate beef enterprises as well—specifically, a cow/calf operation with corn, soybeans, oats, and alfalfa, where oats are grown as a cover crop for the alfalfa, some grain is used as feed, and the straw is baled. Calves are fed out, and some feeder animals are purchased. Cow/calf manure is naturally applied to pasture and alfalfa crops. Manure from the feedlot is scraped and applied to cropland. In addition to examining production costs and returns, this model will compare returns for effective utilization of manure versus simple disposal.