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# Evaluating Livestock System Environmental Performance with Whole-Farm Nutrient Balance

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## ABSTRACT

**As a part of the USEPA's concentrated animal feeding operation (CAFO) final rule, all CAFOs are required to develop and implement a nutrient management plan (NMP). The USEPA's emphasis on better management of nutrients appropriately targets a critical environmental issue associated with animal production. The concentration of animals in livestock feeding operations, often separate from feed grain production, requires importing of substantial quantities of feed nutrients. Due to the inefficiencies of nutrient utilization in livestock production, quantities of nitrogen (N) and phosphorus (P) in manure greater than can be utilized in local crop production often result. With the focus of the USEPA's NMP rules on internal farm manure management planning, nutrient concentrations resulting from animal concentration may not be adequately addressed by compliance with the USEPA rules alone. A review of two mandatory and two voluntary nutrient management strategies is made by comparing whole-farm nutrient balance for a case-study beef cattle feedlot. The results suggest that voluntary BMPs, such as modification to animal feeding program and exporting of manure, can have greater environmental benefits (30–60% reduction in P accumulation for case-study farm) than mandatory NMPs and buffers (5–7% reduction in P accumulation for case-study farm) for a typical beef cattle feedlot. Whole-farm nutrient balance procedures can also be valuable for reviewing the nutrient performance of livestock systems.**

Current regulatory approaches to minimizing nutrient risks associated with livestock operations focus on (i) improving on-farm manure nutrient management practices, (ii) reducing erosion and runoff of land application sites, and (iii) measuring performance by the degree of implementation of required best management practices (BMPs). All CAFOs, regardless of size, are required to develop and implement an NMP in accordance with the nine elements summarized in Table 1. The permitting authority evaluates compliance by reviews of annual reports and on-site inspections checking an individual operation's current management practices against those specified in the NMP (USEPA, 2004).

For large CAFOs, the USEPA (2003) has established effluent limitation guidelines specific to the NMP that require:

- Development and implementation of a site-specific nutrient management plan.
- Determination of application rates.
- Collection and analysis of nutrient content of manure, litter, and process wastewaters.
- Collection and analysis of representative soil samples for P content at least once every 5 yr.
- Maintenance of a no manure application setback of 30 m of cropland or 11 m of vegetated buffer from any down-gradient surface waters and potential connections to surface waters.
- Periodic leak inspections of equipment used for land application.
- Maintenance of on-site records for 5 yr.

The level of adoption of BMPs is commonly associated with improved water quality. However, the value of BMPs is site- and situation-specific. An understanding of the level of BMP implementation provides an indication of potential environmental benefits achieved. However, it provides an imprecise measure of the degree of effectiveness of individual strategies. For example, how can the benefit of a site-specific nutrient plan focused on cropping systems be compared with a nutrient plan targeting a modified feeding program that reduces nutrient excretion? Quantitative measures of performance of individual practices are needed for prioritizing the wide range of potential BMPs and for identifying when a desired environmental goal has been achieved.

Previous authors have used nutrient balance approaches to provide a measurement of environmental performance (Frink, 1969; Aarts et al., 1992; Lanyon and Beegle, 1993; Klausner, 1995; Watts et al., 1994). An integrated whole-farm approach allows comparison of both animal and crop nutrient management options (Dou et al., 1998) as well as a means of evaluating environmental performance resulting from alternative nutrient management strategies (Koelsch and Lesoing, 1999). The imbalance between total N inputs and managed outputs was observed to be 84% for a Pennsylvania dairy (Lanyon and Beegle, 1989), between 59 and 79% for 17 New York dairies (Klausner, 1995), and 86% on a typical Dutch dairy farm (Aarts et al., 1992). (Percentage is an indication of the portion of nutrients in the inputs that is not accounted for in the managed outputs.) A mass N balance by Smolen et al. (1994) for Texas (large beef population) and Adair (large poultry population) counties in Oklahoma suggested an annual N imbalance within these counties of 51% (12 400 Mg) and 53% (2400 Mg) of all imported N, respectively. Watts et al. (1994) observed an imbalance ranging from 36 and 66% of all imported P within two Australian beef feedlots and supporting cropland representing 39 and 161 Mg (43 and 177 U.S. tons), respectively, of P added to the farms annually.

Several factors contribute to the large nutrient imbalance characteristics of many modern livestock opera-

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**Abbreviations:** BMP, best management practice; CAFO, concentrated animal feeding operation; NMP, nutrient management plan.

**Table 1. The nutrient management plan (NMP) must address the following nine elements to comply with the National Pollutant Discharge Elimination System (NPDES) permit requirements of the concentrated animal feeding operation (CAFO) regulations (USEPA, 2003).**

| Category | Required NMP elements |
|---|---|
| Facility design and management | Ensure adequate storage of manure, litter, and process wastewater, including adequate operation and maintenance capability. |
| | Ensure proper management of animal mortalities by avoiding disposal in manure storage or treatment systems. |
| | Ensure that clean water is diverted from the production area. |
| | Prevent direct contact of confined animals with waters of the United States. |
| | Ensure that chemicals handled on-site are not disposed of in any manure storage and treatment system. |
| Land application | Identify appropriate site-specific conservation practices to be implemented to control runoff of pollutants to waters of the United States. |
| | Identify protocols for appropriate testing of manure, litter, process wastewater, and soil. |
| | Establish protocols to land-apply manure in accordance with site-specific nutrient management practices. |
| Record-keeping | Identify specific records that will be maintained to document the implementation and management of the minimum elements described above. |

tions. Yearling cattle retain only 11 and 16% of the N and P fed, respectively (Erickson et al., 1998), whereas swine retain only 40 to 55% of N and 20 to 50% of P (Korenegay and Harper, 1997), leaving most fed nutrients in the manure. Kohn et al. (1997) observed that the differences between a low and improved dairy herd efficiency resulting from feeding program changes produced greater overall reductions in N losses than efforts to reduce N losses from manure storage and land application. Dou et al. (1998) observed that fertilizer inputs accounted for only a small portion of the total N inputs to dairies, limiting the potential environmental benefits associated with improved manure nutrient management, which substitutes manure nutrients for purchased commercial fertilizer. The authors concluded that systems analysis, including analysis of feeding program and animal performance, identified potential management points for improvement in N efficiency not commonly addressed by conventional agronomic studies (Dou et al., 1998).

As livestock operations become more concentrated, more feeds are purchased from off-farm sources. Purchased feed has become the primary nutrient input to many modern livestock farms (Klausner, 1995; Lanyon and Beegle, 1989; Smolen et al., 1994). An upper limit to imported feeds is likely to exist for recycling manure nutrients within the available land base accessible to the livestock operation. Kohn et al. (1997) estimated this limit to be 70% of feed N from purchased feeds or legumes produced on-farm for dairy farms. Klausner (1995) further observed that as the land base decreases relative to animal numbers, the nutrient imbalance appears to be a larger fraction of the total N and P inputs to those farms. A review of nutrient balance for 33 Nebraska livestock operations noted that farm size and ratio of animals to land base provided little explanation of variation in N and P balances observed (Koelsch and Lesoing, 1999). Feed program and manure export practices were more significant indicators of nutrient balance variation.

## METHODS AND ASSUMPTIONS

The following discussion reviews the effects of key aspects of the CAFO nutrient planning regulations on a case-study farm's ability to reduce the farm's whole-farm nutrient imbalance (Fig. 1) following procedures established by Klausner (1995) and Koelsch (2001) and using a whole-farm nutrient balance analysis tool (University of Nebraska, 2004). By conducting a mass balance of nutrients entering and leaving (as managed products) a livestock operation, one can estimate a whole-farm nutrient imbalance. The imbalance represents the quantity of direct

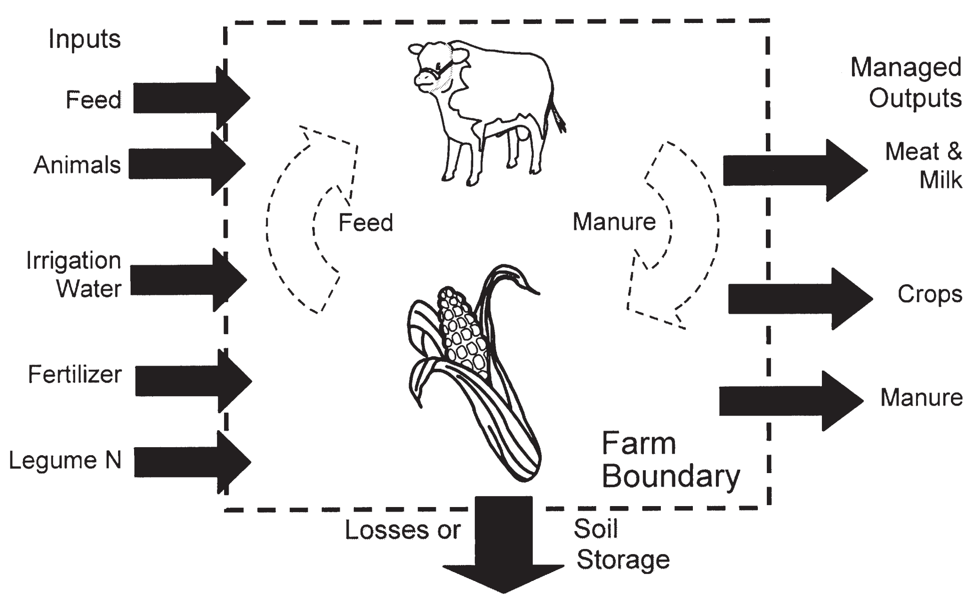


**Fig. 1. A whole-farm nutrient balance provides a measure of nutrient use efficiency for evaluating the value of alternative nutrient strategies.**

nutrient losses (e.g., ammonia volatilization) or increased nutrient inventories (e.g., increased soil P level) within a livestock operation. For N, most imbalances will be direct losses to the environment as ammonia into the air or nitrates into the ground water. While the soil has significant potential for storing N, most manure-related N will be available within a few years and either is utilized by the crop or lost to the environment. An imbalance in P is more commonly seen as increased inventories of P in the soil, increasing site-related runoff risk to local surface waters.

For the purpose of this paper, we apply four BMPs (two based on USEPA CAFO regulations and two voluntary changes) to a case-study farm and evaluate effects on the whole-farm nutrient balance. For brevity, we focus primarily on P balance. This case-study farm is a 2500-head beef finisher feedlot located in Nebraska. The farm participated in a survey of 33 farms from which data were collected for the purpose of estimating a whole-farm nutrient balance for each farm (see Table 2). To protect the identity of the farm, the case-study farm used in this discussion is shown on a site (Fig. 2) different from the farm's actual site but with a comparable land base and production potential. Specific information about the farm and its land application sites are summarized in Table 2 and Fig. 2. This case-study farm is used in producer training in Nebraska on nutrient management planning.

## RESULTS AND DISCUSSION

### Initial Farm Nutrient Balance

The P balance for the beef case-study farm, as currently operated, suggests that for every three units of P entering the farm (59 500 kg P $yr^{-1}$ of inputs in Table 3, Balance 1), only one unit leaves (19 200 kg P $yr^{-1}$ of

**Table 2. Summary of characteristics for the beef cattle feedlot used in case-study problem.†**

| Characteristic | Value |
|---|---|
| **Feedlot performance indicators** | |
| Location | Pierce, NE |
| Head | 2500 |
| Average turns per year | 2 |
| Average daily gain, kg $d^{-1}$ | 1.8 |
| Feed/gain, kg feed $kg^{-1}$ gain | 6.5 |
| Weight gain of cattle, kg | 295–590 |

**Ration information**

| | Feed | | Feeding program‡ | | | Feeding program, Option 1‡ | | |
|---|---|---|---|---|---|---|---|---|
| | CP | P | Fed | Purchased | | Fed | Purchased | |
| | – % of dry matter – | | kg $animal^{-1}$ $d^{-1}$ | —— Mg $yr^{-1}$ —— | | kg $animal^{-1}$ $d^{-1}$ | —— Mg $yr^{-1}$ —— | |
| Feed intake | | | 11.8 | | | 11.8 | | |
| CP, % of dry matter | | | | 13.6% | | | 13.0% | |
| P, % of dry matter | | | | 0.51% | | | 0.27% | |
| Corn | 9.8 | 0.31 | 6.6 | 5430 | 4630 | 9.0 | 7410 | 6600 |
| Molasses | 8.5 | 0.03 | | | | 0.6 | 220 | 220 |
| Alfalfa | 19.0 | 0.24 | 0.8 | 660 | 130 | 1.6 | 1320 | 780 |
| Supplement | 50.0 | 0 | | | | 0.6 | 470 | 470 |
| Supplement, no urea | 0 | 0 | 0.6 | 470 | 470 | | | |
| Corn gluten feed | 21 | 1.00 | 3.8 | 3150 | 3150 | | | |

**Soil test results and fertilizer use**

| | Field 1: Pivot | Field 2: Feedlot quarter | Field 3: Dry quarter |
|---|---|---|---|
| Crop grown and land area | pivot: 49 ha continuous corn; corners: 12 ha alfalfa | 37 ha of alfalfa | 52 ha in corn–soybean rotation |
| Five-year yield average, kg $ha^{-1}$ | 10 700 and 6 700 | 11 200 | 6300 (corn), 2800 (soybean) |
| University of Nebraska N recommendations | pivot: 170 kg N $ha^{-1}$§; corners: – | – | 45 kg $ha^{-1}$ for corn |
| University of Nebraska $P_2O_5$ recommendations | pivot: 45 kg $ha^{-1}$ broadcast or 22 kg $ha^{-1}$ as starter; corners: 34 kg $ha^{-1}$ broadcast | 0 kg $ha^{-1}$ broadcast | – |
| Fertilizer application history | pivot: 170 kg of anhydrous ammonia and 90 kg of MAP¶ $ha^{-1}$; corners: 67 kg of MAP $ha^{-1}$ | none | 67 kg of anhydrous ammonia $ha^{-1}$ |

**Manure**

| | |
|---|---|
| Harvest | Manure is harvested typically after each turn of cattle and stockpiled until land-applied. |
| Application of manure solids | It is typically surface-applied on alfalfa (feedlot quarter) in summer after second cutting and on row crops in February and not incorporated. |
| Application of open lot runoff | Open lot runoff water is collected for a 12-ha drainage area and land-applied through a big traveling gun, typically just before spring green up on alfalfa and after the third cutting in August. |

† The farm participated in a survey of 33 farms from which data was collected for the purpose of estimating a whole-farm nutrient balance for each farm (Koelsch and Lesoing, 1999). To protect the identity of the farm, the case-study farm used in this discussion is shown on a site (Fig. 2) different from the farm's actual site but with a comparable land base and production potential.

‡ Feeding program represents actual farm feeding program at the time of the survey and Option 1 represents a standard feeding program option without the corn gluten feed designed to provide similar energy and protein levels. Purchased feeds are for year in which corn is grown on dry quarter. Values are on a dry-matter basis.

§ Irrigation nitrate credit is not included.

¶ Monoammonium phosphate (11–52–0).

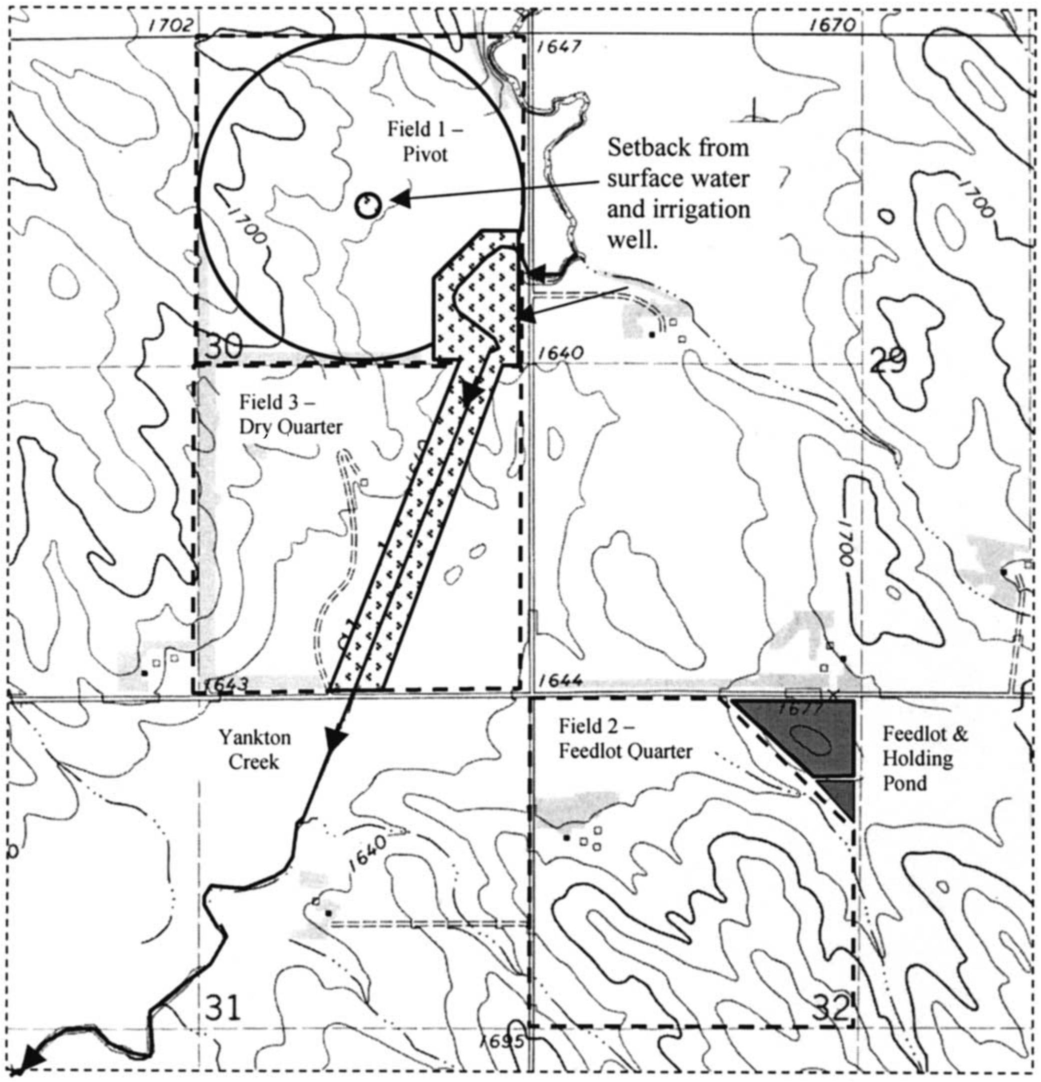


**Fig. 2. Site maps for case-study feedlot and crop production sites.**

managed output in Table 3, Balance 1). The remaining two units are either lost to the environment or stored on the farm (40 400 kg P $yr^{-1}$ imbalance in Table 3, Balance 1). If this imbalance remains constant, this farm will add 40 000 kg of elemental P to the soil reservoir or the feedlot surface each year. Note that the primary source of P arriving on this farm is feed (46 300 kg) and that fertilizer is the smallest P input (2400 kg). Best management practices that address this primary P input will potentially produce the more significant environmental benefits.

The observed P imbalance can represent an increased inventory of soil P after all crop removal of P has been discounted. If we assume that 4 kg of elemental P beyond crop removal will raise soil P levels by 1 ppm, the imbalance will increase soil test values by about 25 ppm per year. In spite of the potential errors inherent to this assumption, the observed P imbalance still suggests the potential for continuing increases in soil P levels for this farm if all manures are applied to the existing land base. In reality, some excess manure will likely not be harvested from the feedlot.

Achieving a ratio closer to 1 unit of P input to 1 unit of P as managed outputs is our goal if stable soil P levels are to be attained. Thus, the farm needs to identify BMPs that either reduce P inputs or increase P outputs by roughly the amount of the imbalance.

## Effect of Agronomic Manure Application Rates

The most common strategy for addressing nutrient issues is to implement an on-farm plan based on agronomic application of manure and associated adjustments in commercial fertilizer applications (Balance 2 of Table 3). Currently, application of manure based on N is required in all situations and will be assumed for this situation. Application of manure nutrients at agronomic rates based on N should eliminate the need for all fertilizer purchases, with the possible exception of a starter N fertilizer for corn. For our case-study farm, elimination of all purchased fertilizer would eliminate only 2400 kg of a 40 400 kg P imbalance. For this specific farm, a significant P imbalance would be anticipated to remain after implementation of the nutrient management plan based on

**Table 3. Effect of alternative best management practices (BMPs) on whole-farm phosphorus balance for beef case-study farm.**

| Characteristic | Balance 1: initial farm balance, no BMPs† | Balance 2: nutrient management plan (NMP) implemented on land managed by feedlot‡ | Balance 3: NMP + setbacks from water implemented‡ | Balance 4: 50% of manure transferred to off-farm users + previous BMPs§ | Balance 5: feeding program Option 1 + NMP and setbacks (no corn gluten feed used)¶ |
|---|---|---|---|---|---|
| | | Inputs | | | |
| Animals, kg P yr$^{-1}$ | 10 800 | 10 800 | 10 800 | 10 800 | 10 800 |
| Feed, kg P yr$^{-1}$ | 46 300 | 46 300 | 46 300 | 46 300 | 24 500 |
| Fertilizer, kg P yr$^{-1}$ | 2400 | 0 | 400 | 400 | 400 |
| | | Managed outputs | | | |
| Animals, kg P yr$^{-1}$ | 19 200 | 19 200 | 19 200 | 19 200 | 19 200 |
| Crops, kg P yr$^{-1}$ | 0 | 0 | 0 | 0 | 0 |
| Manure, kg P yr$^{-1}$ | 0 | 0 | 0 | 18 100 | 0 |
| | | Imbalance (or surplus) | | | |
| P, kg P yr$^{-1}$ | 40 400 | 37 900 | 38 300 | 20 200 | 16 500 |
| P, kg P ha$^{-1}$ yr$^{-1}$ | 270 | 250 | 260 | 130 | 110 |
| Ratio of inputs to outputs | 3.1:1 | 3.0:1 | 3.0:1 | 1.5:1 | 1.9:1 |

† Original farm balance is based on the farm characteristics described in Table 2 and Fig. 2.
‡ These options assume the base feeding program (see Table 2) and modifications to crop nutrient management program to apply manure on an N basis (Balance 2) and addition of 30.5 m manure application setback (Balance 3), minimum requirements of the USEPA CAFO regulations.
§ This option assumes the same situation as Balance 3 (base feeding program, N-based NMP, and setback) plus the export of 50% of manure production to off-farm uses.
¶ This option assumes the same situation as Balance 3 (base feeding program, N-based NMP, and setback) plus the implementation of feeding program Option 1 (see Table 2).

agronomic manure applications. Some implications to consider include:

- The mandatory nutrient management plan focused on manure management has not solved the accumulation of nutrients on this farm. A producer's good-faith effort to meet the regulatory standards does not ensure correction of the underlying environmental problems associated with nutrient concentration observed by many animal feeding operations. Will the regulatory community be forced to set higher standards at a future time if a lack of environmental progress is observed?
- If manure is applied at agronomic rates on this farm according to a USEPA-required nutrient management plan, no use is available for significant portions of the manure. Manure application planning at an N-based rate leaves a 25% manure excess for our case-study farm. If manure is applied at a P-based rate, approximately 90% of the harvested manure will not be utilized on-farm. Implementation of a nutrient management plan without an associated program to export manure commonly results in a growing accumulation of manure within the feedlot. Decomposition of the dry manure solids within the feedlot minimizes any visible accumulation of manure and results in greater C and N release to the atmosphere and P accumulation in the lot. Many feedlots have found that it is possible to operate open lots without harvesting all manure, probably with additional odor and dust emissions and accumulation of additional P within the feedlot. Thus, for many open-lot production systems, a strategy based on on-farm agronomic application of manure may have only minimal effect on overall farm P imbalance and encourages less harvesting of manure solids.

## Effect of Setback Requirements

The 30.5-m (100-foot) mandatory setback from waters of the United States and agricultural well heads will reduce the available land base for manure application by about 12 ha on the case-study farm (Balance 3 results shown in Table 3). This assumes that "waters of the United States" will not include intermittent streams and that "conduits to surface waters" do not include road ditches and grassed waterways. Inclusion of some or all of these additional sites from which setbacks would be needed could substantially increase the acreage lost for manure application. Regulatory interpretation of situations to which the setback must be applied will have substantial effect on losses of land for manure application. As an alternative, a vegetated buffer could be established, removing about 2 ha of land from production, requiring an increase in purchases of feed from off-farm sources.

Several implications, some often not intended, result from setbacks on which manure cannot be applied but commercial fertilizer can be applied:

- If the setback is maintained in crop production, commercial fertilizer will be required. For our case-study farm, an additional 400 kg of P will be brought onto this farm as commercial fertilizer, increasing slightly the overall farm P imbalance (Table 3). Setback from surface water will add to the nutrient imbalance, but only slightly for the case-study farm.
- Setbacks can create considerable inconvenience in meeting the nutrient requirements of a crop. If those inconveniences become significant, some producers will chose to use commercial fertilizer on entire fields or significant areas beyond the setback area (see Fig. 2). Equipment spread patterns that do not match setbacks, challenges in tracking where manure leaves off and commercial fertilizer begins, and the inconvenience of operating two sets of

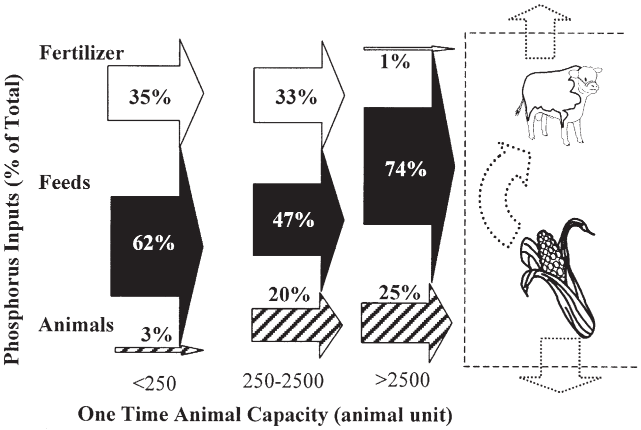


**Fig. 3. Source of P inputs to 33 Nebraska confined swine and beef cattle operations.**

equipment in smaller fields may significantly reduce land available for manure application. In turn, this will encourage a greater reliance on imported commercial fertilizer resources on agricultural operations with an existing excess of nutrients.

The two mandatory BMPs, on-farm nutrient management plans and manure application setbacks, did not create a nutrient balance situation for this farm. The environmental benefits achieved by currently mandated BMPs will vary among farms, depending on the distribution of nutrients arriving on farm as feed or fertilizer. A reliance on BMPs that focus on improved on-farm manure utilization and reduced fertilizer purchases benefits those farms importing more nutrients as fertilizer. Based on results from 33 Nebraska swine and confined beef operations (Fig. 3), the environmental benefits will be the greatest for smaller operations. Smaller and medium-sized livestock operations typically have greater relative land base and greater reliance on purchased fertilizers. Larger livestock operations, which typically import most of their feed, gain the least environmental benefit from the currently mandated BMPs. Because of the limited land base associated with the case-study feedlot, the whole-farm nutrient imbalance remains large and the potential environmental value of the two mandatory BMPs is likely to be small.

## Manure Transfer to Off-Site Users

The new USEPA CAFO regulations do not explicitly encourage or discourage manure transfer to off-farm users. The current rules only require that large CAFOs maintain records that document the amount of manure transferred, date of transfer, and recipient. As livestock systems, including the case-study farm, implement mandatory NMPs, there will likely be an extended learning curve for many livestock operations relative to the need for manure export. Time will lapse as farmers realize that their land base is no longer sufficient and implement measures necessary to transfer manure to off-farm sites. Gaining the trust and willingness of neighboring crop producers to accept manure as a nutrient source can require many years. Implementation of a NMP will likely not spur the immediate manure export programs that should accompany the NMP for many farms.

If the beef case-study farm transfers 50% of the manure to off-site uses, excess P will reduce from approximately 38 000 to 20 200 kg $yr^{-1}$ (Balance 4 of Table 3). This BMP should reduce the farm's nutrient-related risks substantially more than either of the previous two alternatives. Implementation of this practice will require identifying of neighboring crop farms willing to accept 2270 Mg of manure.

## Feeding Program

An additional practice that can affect feedlot nutrient balance is the level of P in feed programs. Many by-product feeds that are growing in popularity produce a feed ration high in P. Corn gluten feeds and ethanol distilling by-products can produce dietary P levels of 4 to 5 g P $kg^{-1}$. Corn-based rations are typically $<3$ g $kg^{-1}$ P, whereas National Research Council recommendations for beef cattle are $<2.5$ g $kg^{-1}$ P (National Research Council, 1996). Any excess P in the diet beyond minimum requirements is likely to be excreted in the manure. Koelsch and Lesoing (1999) observed significantly greater whole-farm nutrient imbalance for beef cattle feedlots feeding by-products of ethanol production and corn processing.

For the beef case-study farm, an alternative feeding program (feed program Option 1 in Table 2) was proposed that involved removal of the 3150 Mg of corn gluten feed from the diet and rebalancing the diet based on corn, alfalfa, and supplements. This approach represents a common feeding program used in regions without access to by-product feeds. This feed program change would reduce the whole-farm P balance from 37 900 kg to 16 500 kg of excess P $yr^{-1}$ (Balance 5 of Table 3). For this farm, the practice would appear to have the single greatest value for addressing P-related environmental risks. However, the environmental benefits of this voluntary practice are commonly not recognized by the producer or regulator as achieving the goals of current regulations. Many producers do not recognize that excess P in the diet produces significantly greater quantities of P in animal manure, and current regulatory focus does not raise this issue as one of importance. Without incentives, adoption rate of this change is likely to be low especially considering the economic benefits of using these by-products.

## CONCLUSIONS

The implementation of the nutrient management planning requirements of the new USEPA CAFO regulations appropriately focuses the livestock industry's attention on nutrient-related issues. However, based on a review of the application of these regulations to a single typical beef feedlot, the following conclusions can be drawn:

- An on-farm nutrient management plan targeting cropping systems as required by the CAFO regulations will reduce the concentration of P on beef cattle feedlots, but the reductions are likely to be small especially for farms with limited land base and significant concentrations of animals.

- The edge of field setback requirements of the CAFO regulations will likely remove some land from manure application resulting in additional purchases of commercial P fertilizer by livestock operations and a small increase in the whole-farm nutrient imbalance. The alternative is to take some land out of production for buffers and purchase additional feed from off-farm sources, further adding to nutrient imbalances.
- Voluntary BMPs may have the greatest environmental benefit for reducing environmental risk on beef cattle feedlots. The export of manure to off-farm users is a valuable BMP alternative for many operations. For some animal feeding operations, dietary options such as removal of by-product feeds high in P will reduce the accumulation of P within feedlots. However, the incentives for introducing these practices are limited at this time.
- Whole-farm nutrient balance provides a valuable tool for measuring nutrient performance and evaluating alternative BMPs. Regulatory and incentive-based programs should consider this as a tool for evaluating the environmental benefit of alternative nutrient strategies.

## REFERENCES

Aarts, H.F.M., E.E. Biewinga, and H. Van Keulen. 1992. Dairy farming systems based on efficient nutrient management. Neth. J. Agric. Sci. 40:285–299.

Dou, Z., L.E. Lanyon, J.D. Ferguson, R.A. Kohn, R.C. Boston, and W. Chalupa. 1998. An integrated approach of managing nitrogen on dairy farms: Evaluating farm performance using the dairy nitrogen planner. Agron. J. 90:573–581.

Erickson, G., T. Klopfenstein, D. Walters, and G. Lesoing. 1998. Nutrient balance of nitrogen, organic matter, phosphorus, and sulfur in the feedlot. p. 86. *In* 1998 Beef cattle report. Publ. MP69-a [Online]. Available at http://ianrpubs.unl.edu/beef/mp69.pdf (verified 1 Sept. 2004). Univ. of Nebraska Inst. of Agric. and Natural Resour., Lincoln.

Frink, C.R. 1969. Water pollution potential estimated from farm nutrient budgets. Agron. J. 61:550–553.

Klausner, S. 1995. Nutrient management planning. p. 383–392. *In* K. Steele (ed.) Animal waste and the land-water interface. Lewis Publ., New York.

Koelsch, R. 2001. Whole farm nutrient planning. Lesson 2 of Livestock and Poultry Environmental Stewardship curriculum. MidWest Plan Service, Ames, IA.

Koelsch, R., and G. Lesoing. 1999. Nutrient balance on Nebraska livestock confinement systems. J. Anim. Sci. 77(Supplement 2/J): 63–71.

Kohn, R.A., Z. Dou, J.D. Ferguson, and R.C. Boston. 1997. A sensitivity analysis of nitrogen losses from dairy farms. J. Environ. Manage. 50:417–428.

Kornegay, E.T., and A.F. Harper. 1997. Environmental nutrition: Nutrient management strategies to reduce nutrient excretion of swine. The Professional Animal Sci. 13:99–111.

Lanyon, L.E., and D.B. Beegle. 1989. The role of on-farm nutrient balance assessments in an integrated approach on nutrient management. J. Soil Water Conserv. 44:164–168.

Lanyon, L.E., and D.B. Beegle. 1993. A nutrient management approach for Pennsylvania: Plant nutrient stocks and flows. Penn State Agronomy Facts 38-B. Pennsylvania State Univ., State College.

National Research Council. 1996. Nutrient requirements of beef cattle. Natl. Academy Press, Washington, DC.

Smolen, M.D., D.E. Storm, D. Peel, and P. Kenkel. 1994. Mass balance analysis of nutrient flow through feed and waste in the livestock industry in the southern plains. p. 168–174. *In* D.E. Storm and K.G. Casey (ed.) Proc. of the Great Plains Animal Waste Conf. on Confined Animal Production and Water Quality: Balancing Animal Production and the Environ., Denver. 19–21 Oct. 1994. Great Plains Publ. 151. Natl. Cattlemen's Assoc., Englewood, CO.

University of Nebraska. 2004. Whole farm nutrient balance analysis tool [Online]. Available at http://cnmp.unl.edu/cnmpsoftware.html (verified 16 July 2004).

USEPA. 2003. National pollutant discharge elimination system permit regulation and standards for concentrated animal feeding operations (CAFOs). Final rule. Fed. Regist. 68(29):7176–7274.

USEPA. 2004. Producers' compliance guide for CAFOs. EPA 821-R-03-010 [Online]. Available at www.epa.gov/npdes/cafo/producersguide (verified 16 July 2004). USEPA, Washington, DC.

Watts, P.J., E.A. Gardnes, R.W. Tucker, and K.D. Casey. 1994. Mass-balance approach to design of nutrient management systems at cattle feedlots. p. 27–33. *In* D.E. Storm and K.G. Casey (ed.) Proc. of the Great Plains Animal Waste Conf. on Confined Animal Production and Water Quality: Balancing Animal Production and the Environ., Denver. 19–21 Oct. 1994. Great Plains Publ. 151. Natl. Cattlemen's Assoc., Englewood, CO.