Conservation of Fertilizers and Livestock Manure: Pollution Prevention

By David Pimentel, Ph.D., Professor of Insect Ecology & Agricultural Sciences, Dept. of Entomology & Section of Ecology & Systematics, Cornell University.

Introduction

When properly used, fertilizers, livestock manure, and cover crops are important assets in productive agricultural systems. However, the heavy use of commercial fertilizers and and overabundance of livestock manure are responsible for plant nutrients — nitrogen, phosphorus, and potassium — being carried beyond the agroecosystem and into environments where they become serious pollutants. As pollutants, they damage animals and plants in aquatic ecosystems and, if at high enough levels in drinking water, cause serious human health problems (ACE, 1982; Baird et al., 1994; Hodgkin and Hamilton, 1993; Huang and Uri, 1994).

In this paper, the extent of fertilizer use and manure production are examined, and then various approaches that can be employed to conserve fertilizers and livestock manures are explained. The goal in conservation of these resources is to make more effective use of them, while at the same time to reduce pollution from the chemicals in fertilizers and livestock manure.

Fertilizer Use

Fossil energy-based, commercial fertilizers are used extensively in U.S. agriculture to increase crop yields and / or compensate for lost nutrients in eroding soils.

The amounts of fertilizer nutrients applied to agricultural land in the United States each year are: 11 million metric tons of nitrogen, 4 million tons of potassium, and 1.5 million tons of phosphorus (Troeh and Thompson, 1993). Nitrogen is the major nutrient needed by crops. In the U.S., some cropland receives no nitrogen while some receives as much as 300 kg per hectare annually; the average amount applied each year is 70 kg / ha. Nearly 80% of the planted acreage receives some nitrogen each year; 60% with phosphate and 40% with potassium (USDA, 1993). For some crops, like corn, the amount of nitrogen fertilizer applied per hectare has increased 20-fold over the last 50 years (Troeh and Thompson, 1993).

Some of the nutrients in fertilizer applications are retained in the crop harvested, but much is lost in various ways (Correll, 1983) (**see Figure 1**). Corn production illustrates this. Although an average of 150 kg of nitrogen is applied annually to each hectare of cornfield, 15–25% of that is lost by volatilization from the soil, and another 10–50% is carried away by soil erosion and leaching (Schroder, 1985). The harvested grain removes 25–50%, with about 20% of the applied nitrogen remaining in the corn residue. Thus, for the subsequent crop year, large applications of nitrogen are needed.

Fertilizers are one of the major costs for U.S. crop production. Approximately $8 billion is spent annually for nitrogen fertilizer and about $4 billion for the remaining fertilizer nutrients (USDA, 1993), making a total of about $12 billion invested in fertilizer nutrients each year in U.S. agriculture.

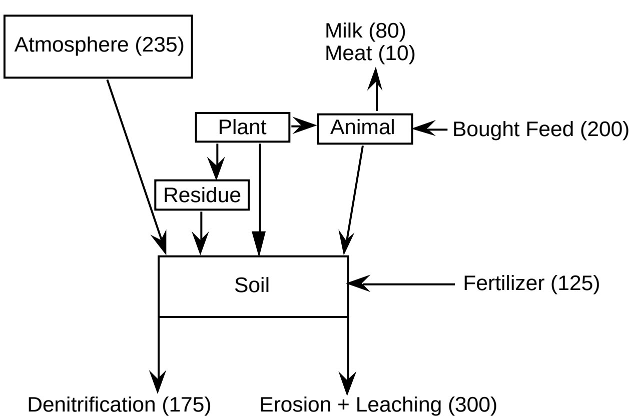
Livestock Manure

Livestock in the United States number about seven billion, with about six billion of these being chickens (USDA, 1993). The total livestock outweigh the U.S. human population by more than four times. The total quantity of manure produced by these animals is about a billion tons wet per year (Taylor, 1994). This manure contains about five million tons of nitrogen, three million tons of potassium, and 1.5 million tons of phosphorus (Troeh and Thompson, 1993; Taylor, 1994); see **Table 1** for percentages.

When the manure supply is located close to crops, it is easily available to be spread on the cropland and its nutrients recycled for use in food production. But specialized U.S. agricultural production, in which livestock production is separated from crops, is making this recycling impossible. Only in the northeast region, where cattle and crops are integrated and 30% of the cattle manure is utilized, are the manure resources being used relatively effectively (Jokela, 1992).

One ton of wet manure contains approximately the same nutrients that are in a 45-kg (100-lb.) bag of 5-10-5 fertilizer (N-P-K), and costs about $3.50. To move and apply one ton of manure cannot cost more than about $1 to be profitable for farmers. Not only does the location of the manure relative to the crops affect its use, but the fact that it is 85% water makes it difficult and expensive to use. When available, applying manure and its nutrients to cropland represents a saving to the farmer. In addition, manure improves soil bulk density, soil organic matter, cation exchange capacity, and soil structure (Sweeten and Mathers, 1985).

FIGURE 1. NITROGEN INPUTS AND LOSSES ON A DAIRY FARM IN CONNECTICUT. Inputs and outputs are presented as "kg per cow per year" (after Frink, 1969; Parrish, 1993).



% Nitrogen		% Phosphorus		% Potassium	
Solid	Wet	Solid	Wet	Solid	Wet
0.5	0.25	0.11	0.06	0.4	0.2

TABLE 1. PERCENTAGE OF NITROGEN, PHOSPHORUS, AND POTASSIUM IN LIVESTOCK MANURE (Troeh and Thompson, 1993; Taylor, 1994).

Compost

The amount of crop residues left in the field after corn harvest is about 7,000 kg / ha. Because this quantity contains about 70 kg of nitrogen, it is important that these residues be recycled. When corn residues are removed, not only are its nutrients lost, but soil erosion is intensified on the unprotected soil. For example, removing corn residues reduced yields about 25% more than leaving the residues in the field (Royer et al., 1949).

Without corn residues, soil erosion was increased five-fold and water runoff increased by 22 times (Ketcheson and Onderdonk, 1973). Approximately 20 tons / ha of soil is lost by erosion each year in U.S. corn production (Pimentel et al., 1995). Each ton of soil may contain about four kg of nitrogen — a significant loss of soil nutrients. Thus, it is important that crop residues are not removed for composting or other purposes.

Sometimes crop residues, leaves, manure, or other organic matter are collected, composted, and exposed to the air. Under these aerobic conditions, up to 75% of the nitrogen is lost by volatilization (Pimentel et al., 1989), as the aerobic microbes decompose the organic matter in the compost and release the nitrogen to the atmosphere. The only way to prevent this loss of nitrogen is to store the organic matter under anaerobic conditions. This can be done by storing it in liquid form in a pond and / or placing it in a sealed plastic or similar closed unit to prevent oxygen from reaching it. Under these anaerobic conditions, the carbon is lost as methane but nitrogen, phosphorus, and potassium nutrients are conserved.

Similar to handling manure, compost must to be buried or covered with soil immediately upon its application to the field, or the volatile nitrogen in the manure or compost is lost. For this same reason, manure or other organic matter should immediately be moved to anaerobic storage as soon as possible. Leaving it in the barn for several hours or piling it as organic matter allows it to decompose aerobically.

Green Manures

Green manures are legume crops, like vetch and clover, that are able to add nitrogen by fixation to the soil and thereby reduce the need for commercial nitrogen. The use of green manures was essential to U.S. agriculture until 1950, when commercial fertilizers became available to farmers. In general, one hectare was planted to a green manure crop and the following year the green manure was plowed under. At that time, it had added from 50 to 150 kg of nitrogen to the soil for use by next crop that was planted. Thus, to raise corn then, two hectares was needed for one hectare of corn, because one was devoted to the green-manure legume crop.

Now, to make more efficient use of land, some farmers plant a legume crop like vetch as a cover crop. For example, winter vetch may be interplanted in the corn field during mid-August just before the corn grain is harvested, allowing the vetch to make a good start. The vetch is driven over during the corn harvest but is not damaged or killed. The vetch grows during the fall and again during the early spring before the corn is planted. With this system, the vetch can add as much as 150 kg of nitrogen per hectare. In addition, the vetch takes up excess nitrogen in the soil during the fall and spring month, keeping it from being lost by leaching, erosion, or volatilization. The dense-growing vetch also helps reduce weed problems and controls soil erosion. The disadvantage of using vetch is that the land has to be tilled in early spring, putting extra pressure on the busy farmer in the spring months.

A newer approach with vetch or clover is to use them as “living mulches”: they are planted and maintained as a permanent cover crop. After the vetch is partially killed by an herbicide, the commercial crop is planted directly into the cover crop. Because the vetch or clover is partially killed and its growth retarded, it does not compete with the establishment of the corn crop. Using this system, the farmer is literally employing a type of living no-till system. The advantages of this system are that soil erosion is prevented, there is excellent weed control, and about 150 kg of nitrogen / ha are added to the soil when completely decomposed.

The use of a cover crop also adds organic matter to the soil. A hectare of good soil may have more than 100 tons of organic matter, which may contain as much as 3,300 kg of nitrogen. Each year, 1–5% of the nitrogen in this organic matter may be released for use by the crop (Troeh and Thompson, 1993).

Conserving Nitrogen, Phosphorus, and Potassium

Many strategies can be used to protect the environment, reduce production costs, and make agriculture more sustainable. First, the farmer should have the soil in his / her different fields analyzed for its content of nitrogen, phosphorus and potassium. This will help prevent over-fertilization and save money.

When fertilizers are applied to croplands, it is desirable to apply fertilizer nutrients several times so that only as much fertilizer as the crop can take up from the soil is available. Young, small plants need and can use only small amounts of nutrients. If large amounts of fertilizers are applied, the excess nitrogen is lost by leaching, volatilization, and by soil erosion.

As the crop becomes establishes itself and requires more fertilizer, more nutrients should be applied. Although this procedure conserves fertilizers, the additional applications require more labor and machinery than a single application in early spring. These trade-offs have to be examined to determine how many fertilizer applications are economically and environmentally feasible.

Adding paraformaldehyde to ureaform nitrogen fertilizer was found to reduce the loss of nitrogen through volatilization by 37% (Christianson et al., 1988). Of course, this slightly increases the cost of the fertilizer.

With manure, only a single application should be made — just before the crop is planted, not during the winter or at other times. When fresh manure is applied to the surface of the land, 15–35% of its nitrogen is lost by volatilization within about 24 hours (MPS, 1985).

The fresh manure that has been stored under anaerobic conditions should be buried immediately after application (MPS, 1985). Another method of application is to inject the manure into the soil. Both ways will help prevent the loss of nitrogen by volatilization, in particular the loss of ammonium nitrogen.

As mentioned, cover crops can be killed by an herbicide and then the crops planted directly into the land as a no-till system. No-till protects the soil from erosion and helps it maintain a relatively high moisture level. Disadvantages include the heavy use of herbicides and other pesticides and planting into a cold wet soil. This may result in the rotting of the seeds, which will require the replanting of the crop.

Ridge-planting gives the farmer the advantages of no-till type planting with fewer disadvantages. In ridge-planting, permanent ridges, about 15 cm high, are constructed along the contour of the land. The upper 3 cm of the ridge is cut off and dropped into the trench. The seeds of the crop are then planted in the top of the ridge in a relatively dry, warm soil; the rotting of seeds is avoided. The vegetation left on the surface of the land and trenches collects moisture for use by the crop. Erosion is minimized because of the biomass cover and the use of contours, which slow water runoff.

Ridge-planting combined with a no-till system eliminates the use of herbicides. After the upper 3 cm of the ridge is cut off and the crop becomes well-established, the soil and vegetation in the trench is then tilled and moved up the sides of the trench to mulch the growing crop. The tilling and moving of soil and vegetation kills the cover crop and any weeds growing in the trench.

Culturing corn in a ridge-planting system produced higher yields compared to other agricultural systems (Dobbs et al., 1988). Low-input, no-till systems also have advantages in reducing soil erosion, conserving nutrients, and conserving biodiversity (House and Brust, 1989).

Pests and Fertilizer Nutrients

The view that a healthy plant is more resistant to pests (insects and plant pathogens) is true for a few pests, but increasing the nutrient levels and the health of a crop plant often increases pest attack (Stachow et al., 1991). Nitrogen levels are especially important for insect and plant pathogens. For example, increasing nitrogen levels in a crop increases the abundance of many insect and plant pathogen pests (McNeil and Southwood, 1978); Mattson, 1980; Denno, 1985; Stachow et al., 1991). Aphid numbers were reported to be more abundant on alfalfa that had high levels of water-soluble nitrogen (Auclair, 1963). To maintain crop yields, insecticides and fungicides may have to be applied to the crops.

Weeds often reduce crop yields by 10% or more (Pimentel et al., 1991) by removing nutrients and water from the soil and competing for sunlight. Weeds are most often controlled by mechanical tilling of the soil and the use of chemical (herbicide) methods (Pimentel et al., 1991). If only tractor fuel is measured, then herbicide weed-control is more efficient in terms of energy expenditures. However, when the energy inputs for the herbicides production are included, tillage turns out to be less energy-intensive. For example, in corn production, energy inputs for chemical weed control were two to three times greater than using tillage (Clements et al., 1995).

Environmental Pollution by Fertilizers

Some fertilizer / manure nutrients are washed into ground and surface waters when application rates are high. Much is transported as a part of eroding soil particles. Each year in the U.S. more than four billion tons of agricultural soil make their way into streams and lakes (USDA, 1989).

Approximately 60% of the eroded soil ends up in aquatic ecosystems (USDA, 1989) where it adds to the eutrophication problem and the heavy growth of macro- and microscopic weeds (Couillard and Li, 1993; DeBusk et al., 1994). When this occurs, the polluted water becomes unsuitable for swimming, boating, and other recreational use. In addition, the heavy growth of vegetation results in fish kills because when the weeds die and decompose, there is a shortage of oxygen in the aquatic ecosystem.

In addition to eutrophication, high nitrogen levels in drinking water are known to cause dangerous public health problems. For example, when infants ingest drinking water with nitrate-nitrogen levels above 10 ppm, they can develop cyanotic methemoglobinemia, known as the “blue baby” syndrome (NAS, 1972; EPA, 1986; OECD, 1986; NIPHEP, 1992; Nash, 1993). Livestock are also adversely affected by high nitrate-nitrogen levels: concentrations of 5 ppm in drinking water may cause methemoglobinemia in young animals (Pimentel et al., 1989).

Although not as serious a pollution problem as eutrophication and cyanotic methemoglobinemia, strong odors coming from large amounts of livestock manure are unpleasant if one is downwind from large manure storage or handling systems (Wassenhove, 1992; Hartung and Phillips, 1994; Geyer and Findley, 1994). Recently, lawsuits against livestock farmers have become common because the livestock production systems are located close to residential areas (Geyer and Findley, 1994). In some cases, new residential areas are constructed near existing livestock units.

Conclusion

Serious pollution of groundwater and surface waters in the United States is occurring because of poor management of commercial fertilizers and livestock manures. With commercial nitrogen fertilizer use, 10–50% of nitrogen is lost due to leaching and erosion. A similar, and perhaps greater, loss of the nutrients in livestock manure is taking place. In fact, a relatively small percentage of livestock manure is being utilized effectively in agriculture because of previous government actions that encouraged the separation of livestock production from grain and other crop production systems. Many large livestock farms have experienced difficulty in disposing of their wastes.

Although compost is not widely used at present, the practice of composting is growing rapidly, particularly in urban and suburban regions. Although normal aerobic composting has certain advantages, it does result in the loss of about 75% of the nitrogen in the organic resource. Conserving the nitrogen requires that composting be carried out under anaerobic conditions. In addition, when the anaerobic compost is applied, it must be buried immediately to prevent most of its nitrogen from being lost.

Planting green manures is an effective means of adding nitrogen to the land. The biological nitrogen fixation it utilizes plays an important role in pasture production, but special management procedures are required to use this technology in crop production.

Conservation of commercial fertilizers and livestock manures is possible, and it can provide important economic and environmental benefits to farmers. For example, agriculture loses an estimated $20 billion in nutrients each year. Clearly, keeping these nutrients on the farm has major advantages. The prime cause of the loss of nutrients from agriculture is soil erosion; however, a great many technologies exist for conserving soil and preventing rapid water runoff.

References

ACE, *Prulean Farms, Inc., Dare Couty, North Carolina* (Wilmington, N.C.: United States Army Corps of Engineers, 1982).

J. L. Auclair, "Aphid Feeding and Nutrition," *Annual Review of Entomology* 8 (1963): 439–490.

J. V. Baird, J. P. Zublena, and S. C. Hodges, "Nitrogen Management and Water Quality," *North Carolina Agricultural Extension Service* (1994): 439–442.

C. B. Christianson, M. F. Carter, and L. S. Holt, "Mineralization and Nitrification of Ureaform Fertilizers," *Fertilizer Research* 17 (1988): 85–95.

D. R. Clements, S. F. Weise, R. Brown, D. P. Stonehouse, D. J. Hume, and C. J. Swanton, "Energy Analysis of Tillage and Herbicide Inputs in Alternative Weed Management Systems," *Agriculture, Ecosystems, and Environment* 52 (1995): 119–128.

D. L. Correll, "N and P in soils and runoff of three coastal plain land users," in *Nutrient Cycling in Agricultural Ecosystems*, ed. R. R. Lowrance et al. (Athens: University of Georgia Exp. Station, 1983), 207–244.

D. Couillard and J. F. Li, "Assessment of Manure-Application Effects Upon the Runoff Water Quality by Algal Assays and Chemical Analyses," *Environmental Pollution* 80 (1993): 273–279.

W. F. DeBusk, K. R. Reddy, M. S. Koch, and Y. Wang, "Spatial Distribution of Soil Nutrients in a Northern Everglades Marsh: Water Conservation Area 2A," *Soil Science Society of America Journal* 58 (1994): 543–552.

R. F. Denno, "The Role of Host Plant Condition and Nutrition in the Migration of Phytophagous Insects," in *The Movement and Dispersal of Agriculturally Important Biotic Agents,* ed. D. R. MacKenzie et al. (Baton Rouge: Claitor's Publishing, 1985), 151–172.

T. L. Dobbs, M. G. Leddy, and J. D. Smolik, "Factors Influencing the Economic Potential for Alternative Farming Systems: Case Analyses in South Dakota," *American Journal of Alternative Agriculture* 3 (1988): 26–34.

EPA, *Quality Criteria for Water 1986* (Washington: U. S. Environmental Protection Agency, Office of Water Regulations and Standards; 1986).

C. R. Frink, *Frontiers of Plant Science* (New Haven: Connecticut Agricultural Experiment Station, 1969).

L. L. Geyer and M. Findley, "Legal Guidelines for Swine Manure Management." Extension Bulletin E-1160 (East Lansing: Michigan State University Cooperative Extension Service, April 1994): 4 pp.

J. Hartung and V. R. Phillips, "Control of Gaseous Emissions from Livestock Buildings and Manure Stores," *Journal of Agricultural Engineering Research* 57 (1994): 173–189.

E. P. Hodgkin and B. H. Hamilton, "Fertilizers and Eutrophication in Southwestern Australia: Setting the Scene," *Dordrecht* 36 (1993): 95–103.

G. J. House and G. E. Brust, "Ecology of Low-input, No-tillage Agroecosystems," *Agriculture, Ecosystems, and Environment* 27 (1989): 331–346.

W. Huang and N. D. Uri, "The Effect of Farming Practices on Reducing Excess Nitrogen Fertilizer Use," *Water, Air and Soil Pollution* 77 (1994): 79–95.

W. E. Jokela, "Nitrogen Fertilizer and Dairy Manure Effects on Corn Yield and Soil Nitrate," *Soil Science Society of America Journal* 56 (1992): 148–154.

J. W. Ketcheson and J. J. Onderdonk, "Effect of Corn Stover on Phosphorus in Runoff from Nontilled Soil," *Agronomy Journal* 65 (1973): 69–71.

W. J. Mattson, "Herbivory in Relation to Plant Nitrogen Content," *Annual Review of Ecology and Systematics* 11 (1980): 119–161.

S. McNeil and T. R. E. Southwood, "The Role of Nitrogen in the Development of Insect / Plant Relationships," in *Biochemical Aspects of Plant and Animal Coevolution,* ed. J. B. Harborne (London: Academic Press, 1978), 77–98.

MPS Livestock Wastes Subcommittee, Iowa State University, *Livestock Waste Facilities Handbook* (Ames, Iowa: Midwest Plan Service, Iowa State University, 1985).

NAS, *Water Quality Criteria 1972*. (Washington: National Academy of Sciences, 1972).

L. Nash, "Water Quality and Health," in *Water in Crisis: A Guide to the World's Fresh Water Resources,* ed. P. Gleick (New York: Oxford University Press, 1993).

NIPHEP, in cooperation with Rijkswaterstaat, *National Environmental Outlook 2 — 1990–2010,* ed. N. J. P. Hoogervorst (Bilthoven, Netherlands: Rijksinstituut voor Volksgezondheid en Miieuhygiene (National Inst. of Public Health and Environmental Protection), 1992).

OECD, *Water Pollution by Fertilizers and Pesticides* (Paris: Organisation for Economic Co-operation and Development, 1986).

D. H. Parish, *Agricultural Productivity, Sustainability, and Fertilizer Use* (Muscle Shoals, Alabama: International Fertilizer Development Center, 1993).

D. Pimentel, T. Culliney, I. Butler, D. Reinemann, and K. Beckman, "Low-Input Sustainable Agriculture Using Ecological Management Practices," in *Agricultural Ecology and Environment,* ed. M. G. Paoletti, B. R. Stinner and G. G. Lorenzoni (Amsterdam: Elsevier, 1989), 3–24.

D. Pimentel, L. McLaughlin, A. Zepp, B. Lakitan, T. Kraus, P. Kleinman, F. Vancini, W. J. Roach, E. Graap, W. S. Keeton, and G. Selig, *Environmental and Economic Impacts of Reducing U.S. Agricultural Pesticide Use* (Boca Raton, FL: CRC Press, 1991).

D. Pimentel, C. Harvey, P. Resosudarmo, K. Sinclair, D. Kurz, M. McNair, S. Crist, L. Shpritz, L. Fitton, R. Saffouri, and R. Blair, "Environmental and Economic Costs of Soil Erosion and Conservation Benefits," *Science* 267 (1995): 1,117–1,123.

A. E. Royer, B. R. Bertramson, and R. R. Mulvey, "Soil Fertility Levels as Influenced by One-Time Differential Fertilization Practices," *Journal of the American Society of Agronomy* 40, no. 8 (1948): 685–693.

H. Schroder, "Nitrogen Losses from Danish Agriculture — Trends and Consequences," *Agriculture, Ecosystems and Environment* 14 (1985): 279–289.

U. Stachow, G. Cerretelli, and D. Pimentel, "Agricultural Practices, Plant Stress, and Crop Susceptibility to Insect Attack," *Advances in Ecology* 1 (1991): 225–238.

J. M. Sweeten and A. C. Mathers, "Improving Soils With Livestock Manure," *Journal of Soil and Water Conservation* 40 (1985): 207–210.

D. C. Taylor, *Livestock Manure Production and Disposition: South Dakota Feedlots-Farms-Ranches,* Economics Research Report 94-4, November 1994 (Brookings, SD: Economics Department, South Dakota State University, 1994).

F. R. Troeh and L. M. Thompson, *Soils and Soil Fertility,* 5th ed. (New York: Oxford University Press, 1993).

USDA, *The Second RCA Appraisal — Soil, Water, and Related Resources on Nonfederal Land in the United States — Analysis of Conditions and Trends* (Washington: U.S. Department of Agriculture, 1989).

———, *Agricultural Statistics* (Washington: USDA, 1993).

F. van Wassenhove, "Olfactometric Characterization of Odour Generation Potential of Pigery Manure Samples," *Studies in Environmental Science* 51 (1992): 425–430.

Original produced on Hammermill Unity DP,
a 50% post-consumer / 50% pre-consumer recycled paper
made from de-inked old newspapers and magazines.

The National Pollution Prevention Center for Higher Education
University of Michigan, Dana Building
430 East University Ave.
Ann Arbor, MI 48109-1115
• Phone: 313-764-1412
• Fax: 313-647-5841
• E-mail: nppc@umich.edu

The mission of the NPPC is to promote sustainable development by educating students, faculty, and professionals about pollution prevention; create educational materials; provide tools and strategies for addressing relevant environmental problems; and establish a national network of pollution prevention educators. In addition to developing educational materials and conducting research, the NPPC also offers an internship program, professional education and training, and conferences.

Your Input is Welcome!

We are very interested in your feedback on these materials. Please take a moment to offer your comments and communicate them to us. Also contact us if you wish to receive a documents list, order any of our materials, collaborate on or review NPPC resources, or be listed in our *Directory of Pollution Prevention in Higher Education*.

We're Online!

The NPPC provides information on its programs and educational materials through the Internet's Worldwide Web; our URL is:
http://www.umich.edu/~nppcpub/
Please contact us at nppcpub@umich.edu if you have comments about our online resources or suggestions for publicizing our educational materials through the Internet. Thank you!