Soil Use and Water Quality—A Look into the Future

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Increasing use of commercial fertilizers is being blamed for substantial eutrophication of surface water and nitrate accumulation in ground water. Most of the available evidence is circumstantial rather than direct. The importance of nitrogen and phosphorus in eutrophication is not known. Agronomists, soil scientists, economists, and chemists have not been sufficiently aware of pollution problems to collect facts so badly needed now. Bans on or regulations of fertilizer use are not justified on the basis of existing information, but regulation on a local option basis along with other nutrient control measures may be needed when the facts become sufficient.

Will we find it necessary to limit the rate of fertilizer a farmer applies by some system of permits under the framework of regulations authorized by state laws to meet the federal requirements on water quality? It is a good question because some scientists (Commoner, 1968a), often not too familiar with or ignoring the needs of agriculture, have called for total bans on the use of fertilizers, particularly nitrogen. Bills have been introduced into state legislatures in California, Massachusetts, and South Dakota calling for limitations on the amount of fertilizer a farmer can apply.

The rate of fertilizer application is now controlled voluntarily, although very imperfectly, by the cost of materials and an extensive system of soil testing laboratories and recommendations, both public and private, that are unsurpassed anywhere in the world. An American farmer can get more advice on fertilizer and rates of application than he can get on almost any of his other farm operations. Farmers themselves are finding that too much fertilizer is unprofitable and that excessive amounts can reduce yields and quality. Too much protein in the white wheats of the Pacific Northwest, lodging of small grains, and low sugar content of sugar beets and cane are examples of the deleterious effects of too much nitrogen. Fertilizers and lime cost farmers about $2.16 billion in 1967, or 6.2% of their total production expense of $34.8 billion (USDA, 1968).

In spite of these voluntary controls and the specific information—field by field and crop by crop—that is available, we do find that some fertilizer companies are overpromoting high and excessive rates of application. Fortunately, this is not the predominant attitude.

That every benefit or improvement has its cost is an old axiom. The benefit-cost ratio is applied by sensible people for many kinds of endeavors when money and expenditures are involved. However, application of benefit-cost ratios to problems of environmental quality are different because some of the benefits and some of the costs are so difficult to measure and to apportion. Some avid environmentalists feel that environmental preservation is so important we can forget the costs, either direct or indirect ones. The author feels that in the long run the American public will consider costs and will make compromises between environmental quality and the need for the environment to produce the necessities of life. For example, what if we should find that the need for nitrogen to produce our food supply will eventually result in too much nitrate in well water in some locations for babies and ruminant livestock. Why then can we not consider dual supplies, such as bottled water or even two water systems, if that is a better alternative than severe limitation or banning of nitrogen use?

Another example of the conflict in interests is the high level of nutrients needed in surface waters for fish production and a good sport fishery on the one hand, and the lower levels desirable for recreational and municipal purposes on the other. The desirable goal is simply not to impose the same nutrient levels on all waters.

One of the problems facing us is to determine how much of this nitrate and eutrophy is directly due to runoff and deep percolation of fertilizers as indicated by direct evidence and not by circumstantial evidence. The anti-fertilizer interests point to the phenomenal increase in the use of phosphate and nitrogen fertilizers in the last three decades and infer that these must be major sources of our eutrophication and nitrate problems (Commoner, 1968b). Although it cannot be denied that there are instances where improper fertilizer use can be blamed, wholesale indictment of fertilizers cannot be justified.

The causes of eutrophication are poorly understood. Excess nitrogen, and particularly phosphate, have been blamed in the last 3 yr, but now several authorities (Weiss, 1969; Legge and Dingeldein, 1970) in a review of "The Lange-Kuentzel-Kerr Thesis," point out that organic pollution is essential to have the CO_2 needed by algae.

The usual approach to the study of eutrophication of water has been to assign certain inputs to identifiable industries, municipal sewage plants, washoff from storm sewers and rainfall, and to charge the rest by difference to agricultural runoff. In the latter is animal waste flushed off of feedlots, fields and pastures, eroding soil, washout of nutrients from dead vegetation and, of course, fertilizer either in solution or adsorbed on eroding sediment. Too often forgotten are the changes in atmospheric inputs, such as nitrate in rainfall and ammonia absorbed directly from the air in the vicinity of large cattle feedlots (Hutchinson and Viets, 1969). Changes in the bottom environment of the lake that may make deposits of nitrogen- and phosphate-containing materials more soluble are overlooked.

The nutrients contained in agricultural runoff are difficult to measure because they are difficult to collect. The usual practice of calculating nutrient inputs from agricultural land by difference makes tidy tables, but at best can be only a crude measure of agricultural input. Unfortunately, agriculturists have not collected enough of the correct type of data or have not been sufficiently aware of the problem to defend agriculture or fertilizer use against attacks.

Severe restrictions on or banning of fertilizer use would have serious effects on our supply and cost of food. Fertilizers are conservatively estimated to be responsible for one-third to

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one-half of our food and fiber production. Even in 1954, when fertilizer use was much lower than now, one-fifth of the yields of all crops and pasture was attributed to fertilizer (Ibach and Lindberg, 1958). Indeed, there are many areas with naturally poor or impoverished soils where food production would be impossible without fertilizers. To stop all fertilizer use would mean that, on the average, our food supply would be much more expensive.

The author is not aware of studies on the effects of substantial reductions in food supply on price in the elastic demand-price economy that would result. However, we can make some estimates. Economic studies have shown that under our present conditions of plentiful food supply and inelastic demand, a 1% increase in production of all food would require a drop of 4.5% in the market price before the extra supply would be used. For specific commodities, the percentage drop in price required to have an additional 1% increase in production consumed is 2.5% for wheat, 2.4% for milk, 5% for potatoes and 2.5% for feed grains (Heady, 1967). If you can go up a curve, you can go down it over its valid range. Hence, a 1% drop in wheat production would result in an increase of 2.5% in price; a 33% reduction in production would result in 82.5% increase in price (33 × 2.5). However, such a drop in production would have elastic consumption–price relationships rather than the inelastic ones we have become accustomed to in our present situation. The increase in price would be much greater than the 83% calculated, barring an increase in imports. In spite of our present abundance of food, we are told that we have several million people who are sub- or malnourished. Who wants to pay such a price for pure water when there is serious doubt that a prohibition on fertilizer use would accomplish any improvement in water quality? Obviously, a ban on fertilizer use is not a possible solution. In spite of all of the interest in pollution control, Harris and Gallup polls concluded in 1969 that the average citizen is not willing to pay much out of his own pocket for control.

Let us look now at some of the past and present mistakes that people of different viewpoints have made or are making on the fertilizer use–eutrophication–pollution complex. These are mistakes or errors in assumptions that originate from failure to see the future problem, or to see the ramifications of one practice on other processes in the total environment.

The first set of erroneous assumptions is made by the naturalists and ecologists who are genuinely concerned about eutrophy of our waterways and nitrates in our ground water supplies. Although many lakes have become eutrophic, we are misled into believing this is a general and recent situation. Wadleigh and Britt (1969) pointed out the great number of reservoirs in the Great Plains area that were made by man and protected against sedimentation by him which now hold water of excellent quality where once there were only buffalo wallows unsuitable for drinking or even washing. Many western creeks, named in the early mining days, did not get their impolite names from use of Chilean nitrate on farmland.

The ecologists know that the use of nitrogen and phosphate fertilizers on farms has grown at a phenomenal rate, according to a report of the Agricultural Nitrogen Institute (1969). About a third of a million tons of fertilizer nitrogen were used in 1940. In 1969, almost 7 million tons were used, or actually 18.5 times more. Agricultural consumption in 1969 is about 65% of the total nitrogen synthetically fixed. By 1971 ammonia-fixing capacity is estimated to be 20,848,000 tons, including 2,032,000 tons capacity now shut down because the ammonia price is too low. The naturalists are quite right in their contention that we have never had experience with fixed nitrogen input into our environment of such magnitude. To this input we could add the estimated 2.5 million tons of nitrogen as the oxides added to the air annually by the process of combustion, largely from internal combustion motors and power plants (National Academy of Sciences–National Research Council, 1966). These oxides of nitrogen along with ammonia and volatile amines become oxidized to nitrate and fall in precipitation (Cadle and Allen, 1970).

The assumption that large inputs of fertilizer nitrogen to land must be accompanied by large inputs of fixed nitrogen to ground and surface waters is by no means proven for the broad scale assumed. Commoner (1968a) pointed out in his AAAS address that the nitrate in the Missouri River had increased in the last 20 yr, and that this paralleled the increased use of fertilizer nitrogen in the Nebraska and South Dakota section of the drainage. He gave similar data for three rivers in Illinois. Dawes *et al.* (1969) of the Illinois State Water Survey show that the nitrate in the rivers of Illinois has about doubled since 1945 and fertilizer nitrogen use has increased about 125-fold in the State. Neither paper presented direct evidence that the nitrate came from fertilizer use. A comparison of 125 with 2 suggests that cause–effect relations are, at best, weak. It is well known that nitrate accumulates in water as the soluble form of nitrogen when there is insufficient phytoplankton or algae to use it or bacterial denitrifiers to denitrify it. One of the characteristics of a highly polluted stream is the high biological oxygen demand (BOD) of the polluting organic matter. Aerobic organisms use dissolved oxygen first and then reduce nitrate to get oxygen. Hence, high nitrate and high BOD cannot coexist very long in a system with life at favorable temperatures. It is entirely possible that the nitrate increases observed in these rivers are the first symptoms of stream recovery from organic pollution by raw sewage. Because of the Water Quality Act of 1965 and the Clean Waters Restoration Act of 1966, all cities and towns have had to construct (but may not have completed) secondary sewage treatment plants in the period when the nitrate measurements were made on these rivers. Secondary treatment reduces BOD about 80 to 90% and may produce nitrate, depending on how the plant is operated. These effluents are dumped directly into streams. One cannot look at nitrate alone in assessing pollution, but must look at a number of stream parameters simultaneously, including soluble organic nitrogen, phosphorus, ammonium, and BOD.

Insufficient information on certain aspects of the nitrogen cycle under field conditions exists to permit us to jump to the conclusion that increased fertilizer use perils our underground water supplies and our surface waters. Insufficient data exists on rate of denitrification to enable us to judge how much of the 7 million tons of input from fertilizers is offset by accelerated denitrification. We appear to have only started to measure the input of free-living forms, such as the blue-green algae on the nitrogen balance of surface waters.

The difficulty of getting direct evidence of underground pollution with nitrate from fertilizer or other sources can be seen from the data in Table I. One hundred and twenty-nine locations with different kinds of land use in the South Platte valley of Colorado were core-drilled to the water table. The cores and the samples of water that percolated into the core holes when the water table was reached were analyzed. The virgin grassland and the dryland fields had never received nitrogen fertilizers. The irrigated cropland not in alfalfa probably received on the average about 100 lb of nitrogen per acre per yr, at least in the last 5 yr. The cattle feedlots got as much as 10 tons of organic and urea nitrogen annually. Although the average amount of nitrate in 20 ft of profile was greatly different under the different kinds of land use, there was little difference in the nitrate content of the water. Is denitrification more active than presently believed, or is more time required to get nitrate pollution? Except for the rotation of alfalfa with other crops on irrigated land, and some younger feedlots, these lands had been in this kind of use for over 40 yr.

The high nitrate (11.5 ppm NO_3-N) in the water table under the grassland illustrates the problem of attributing high nitrate in water to fertilizer under western conditions. Nitrate frequently occurs in soils and geologic strata of western environments to considerable depth (Mansfield and Boardman, 1932; Headden, 1910). Its source is often unknown. We do know that most soils taken out of grass and put under cultivation have lost about a third of their total nitrogen in 30 to 40 yr (Haas *et al.*, 1957). How much of this nitrogen went to the ground water as nitrate is not known, but this source greatly complicates attempts to equate nitrate in underground water with current fertilizer practice.

The next group who may be accused of failing to grasp the whole environmental picture are the economists and the agronomists who assisted them in interpreting yield data on crop response to fertilizer application in dollars and cents. The crop response to progressive increments of fertilizer application is fit with one of several types of mathematical functions that call for a smaller increase in yield for each new increment of fertilizer. Thus, the first 50 lb of nitrogen costing $4 might produce 25 more bushels of corn for a net profit increase of $21. The next 50-lb increment might produce 12 more bushels for a net profit gain of $8. So it is profitable to use at least 100 lb of nitrogen. The next 50 lb might produce 5 more bushels for a profit gain of $1. It is assumed nitrogen was worth 8 cents per lb applied and corn was worth $1 a bushel in this simplified example. The economist has reasoned that the grower took little risk in applying the extra 50 lb of nitrogen. He might get a dollar profit out of it (Paschal and French, 1956). In other words, the reasoning has been that since response curves derived from experiments are relatively flat near the optimum economic rate, and that rate cannot be predicted with certainty for a wide range of field conditions, the grower had little to gain or lose if he overshot the optimum nitrogen rate by 50 or even 100 lb. The economist failed to consider what this extra 50 or 100 lb of nitrogen might mean to enrichment of runoff and ground water. Unfortunately, the soil scientist and the agronomist have not taken much interest in the water pollution problem either.

Practically no attention has been given to the problems discussed in this paper until the soil scientists and agronomists were forced out of their limited perspective about 3 yr ago. It is difficult to find much information in the literature on the composition of sediments or of runoff and percolating water from farm fields fertilized at the rates now used and essential for the yields needed for the farmer to stay in business.

Table I. Average Nitrate in 20-foot Profiles and Water at Surface of Water Table

Adapted from Stewart *et al.* (1967)

	Profiles			**Water Table NO_3-N**	
	No.	**NO_3-N lb/acre**	**No.**	**Mean ppm**	**Range ppm**
Virgin grassland	17	90	8	11.5	0.1–19
Dryland	21	261	4	7.4	5–9.5
Irrigated land (except alfalfa)	28	506	19	11.1	0–36
Irrigated land (alfalfa)	13	79	11	9.5	1–44
Feedlots	47	1436	33	13.4	0–41

We have possibly erred in underestimating the effect of a small agricultural loss on the quality of water. We have not appreciated the differences in magnitudes. Although there is no agreement on the relative roles of N, P, vitamins, and organic compounds in contributing to eutrophy (Weiss, 1959), let us take phosphorus as an example. Ten parts per billion of inorganic P in water in the spring is commonly regarded as sufficient to produce an obnoxious algal bloom in midsummer (Sawyer, 1947). But, let us assume it is 15 ppb. This amounts to 0.038 lb of P (0.086 lb of P_2O_5) per acre-ft. If a farmer applies 40 lb of P_2O_5 per acre, a very modest amount, and 1% runs off, this is enough to eutrophy 5 acre-ft of water to the noxious level. This amount of water is equivalent to 60 in. of runoff. This loss of P cost the farmer about 5 cents. Agronomists and soil scientists are not accustomed to think in these terms. A recent popular article defending the farm use of fertilizer stated: "...Data show that water issuing from tile lines in the spring contained only 3 parts per million of nitrogen and 1 part per million of phosphorus. These are exceptionally low quantities considering the fact that the soil from the fields from which the water was flowing is fertilized at rates of more than three times that used by the average farmer in the county." Did the writer stop to consider that this concentration of P in one volume of water could eutrophy 66 volumes of pure water? The drainage from one acre of this land could "spoil" the "pure" drainage water from 66 acres of other land in the same rainfall zone.

The situation is much the same for nitrogen—0.3 ppm of inorganic nitrogen is commonly regarded as the level needed for obnoxious algal blooms (Sawyer, 1947). If a farmer applies 160 lb of N per acre and 1% is lost by runoff and deep percolation, he has lost 1.6 lb of nitrogen, costing him 6 to 10 cents. This is enough to eutrophy 2 acre-ft of water equivalent to 24 in. of runoff from an acre.

With these enormous differences in magnitudes, one might ask if eutrophication of all water is not inevitable. The answer may lie either in chemical and biological reactions in soil and in water whose magnitude we do not appreciate or the need for other factors mentioned by Weiss (1969). Certainly, simple dilution chemistry cannot be applied. We are far from an understanding of the relation of phosphate in runoff and sorbed on sediment to the available phosphate in a lake.

The second indictment of agronomists and soil scientists concerns their failure to make the right kind of measurements on either their short- or their long-term field experiments. Their administrators are also at fault in failing to provide the funds or the incentives to get the information we badly need now. Tens of thousands of field experiments have been run throughout the country in the last 30 yr to assess the need for fertilizers and how much and when to apply them. Almost universally the experiments have failed to determine how much of the fertilizer runs off, is carried off on eroding particles of soil, or percolates below the root zone. Information on the latter could be determined by the simple process of analyzing cores taken with deep coring equipment. In particular we need this information for high rates of application necessary to modern agriculture. In long-term experiments we do not have a balance sheet of inputs and outputs of nutrients applied to a cropping system over a long period of time in any section of the country. By inputs is meant a summation of a nutrient applied either in fertilizers, manure, or precipitation. By outputs is meant removal in crops, runoff, deep percolation, and changes in quantity of the total nutrient in the soil. For six decades ending about 1940, long-term rotation experiments such as the Jordon, Sanborn, and Morrow plots were fashionable, but the needed information for a nutrient balance sheet was not collected. No long-term experiments of the kind I am suggesting are now in existence. We do have the results of lysimeter investigations showing that little phosphate is contained in percolate and only about 80% of the nitrogen added in fertilizers or manure can be accounted for in crop removal, the soil, or leacheate. About 20% of the input of nitrogen appears to be lost by some process of denitrification. We are sure, however, that very little of this 20% was lost as the oxides of nitrogen to return again in rain as nitrate, as had been contended. In short, the question of fertilizer efficiency has not been looked at closely enough to meet the modern demands for clean water.

What about the future? From the inconsistencies in data and statements, the future is not clear. Some scientists believe that nitrogen eutrophication and accumulation of nitrate in water supplies is an inevitable consequence of modern society. There are three possibilities: (1) a complete ban on fertilizer nitrogen or phosphorus, or both; (2) controls imposed by permit under regulations; and (3) voluntary controls, as some might argue, no control at all.

I have already mentioned what a complete ban would mean in terms of decreased food production and exorbitant food costs for the consumer. Except in the semiarid and desert regions where irrigation is practiced or essential, most of our soils have lost a substantial part of their native organic matter containing nitrogen, phosphorus, and other available nutrients. This loss has not been accompanied by a serious deterioration of soil tilth, as some scientists contend. George Stanford (Wadleigh, 1968) has calculated that we have lost 35 billion tons of organic matter containing 1.75 billion tons of organic nitrogen from our cultivated soils in the 48 states in the last 100 yr. An Iowa prairie soil that once could produce 50 bushels of corn without fertilizer could probably produce only 35 bushels now. With fertilizers, it can produce 150 bushels. We cannot return to the "good old days" and still feed ourselves.

Controls imposed nationwide on a permit basis are likewise unpalatable considering the present lack of knowledge on the direct effects of fertilizer on water eutrophication and nitrate pollution. American farmers are not willing to accept more controls over what they do. We should leave open the possibility and feasibility of fertilizer controls under a local option system in closed water basins and small watersheds where investigation definitely shows that fertilizers are making substantial contributions to poor water quality.

Voluntary controls imposed by cost, deleterious effects on crop quality, education, soil tests, and sound recommendations are the best solution to the problem until overuse of fertilizer is more deeply and unequivocally implicated in water quality deterioration.

Pertinent to the question of voluntary control is the question of whether fertilizer use will continue to expand at the rates of the last decade, thus posing greater hazard. The Agricultural Nitrogen Institute (1969) estimates that agricultural use of nitrogen will rise from 6,980,000 tons in 1969 to 10,080,000 tons in 1974. Others project proportional increases for phosphate. Many extension specialists make similar forecasts based on their observations of crops needing more fertilizer. These optimistic projections appear to be unrealistic in view of USDA projections of need for the next 15 to 20 yr of a 1.9% increase per yr in crop production for domestic and export markets, and 1.7% increase per yr in livestock for domestic use.

It should not be forgotten that sediment is still the greatest enemy of surface water quality. In the USDA-Office of Science and Technology Report "Control of Agriculture-Related Pollution" (1969), 3.8 billion dollars of a total of 5 billion dollars for a 5-yr period was suggested for federal action programs on sedimentation, and only 253 million was suggested for control of plant nutrients. Needed fertilizers play a vital and often unappreciated role in producing vegetation and plant residues that keep soils from eroding. Keep the soil in place and you keep practically all of the phosphorus and all of the organic nitrogen from fields, rangeland, and forest out of the water.

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Received for review January 16, 1970. Accepted May 15, 1970. Presented at the Division of Fertilizers and Soil Chemistry, 159th Meeting, ACS, New York, New York, September 1969. Contribution of the Northern Plains Branch, Soil and Water Conservation Research Division, Agricultural Research Service, USDA.

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