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Agricultural best management practices for water pollution control: current issues

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Abstract

From the first awareness of agricultural sources of water pollution in the US in the 1960s, we finally see in the 1990s a commitment at the national level for agricultural non-point source (NPS) pollution control. This has been occasioned by a growing awareness that, with point sources of some pollutants largely controlled by waste-water treatment, greater attention must be paid to NPS pollution control, a large percentage of which is agricultural. The 1985 Farm Security Act mandated several national erosion control programs that will have some impact on water quality, and there is opportunity to supplement these programs with best management practices (BMPs) specifically designed to address agricultural water pollutants, primarily nitrate, phosphorus and modern pesticides. This paper discusses fundamental processes affecting transport of agricultural pollutants in surface and ground water and suggests how knowledge of these processes can be used to evaluate existing agricultural NPS BMPs and to develop supplemental practices.

Introduction

National awareness of agriculture as a significant source of environmental contamination dates back at least to 1962 with the publication of Rachel Carson's 'Silent Spring', if not earlier. The role of agriculture in water pollution emerges in the same period with the finding that non-point source (NPS) phosphorus from agricultural run-off may be as significant a contributor to eutrophication of lakes and streams as point sources of untreated domestic waste water. National studies of lake eutrophication, and more regional studies of important water bodies such as Lake Tahoe, California and the lower Great Lakes in the early 1970s, implicate NPS phosphorus from soil run-off and erosion, and from livestock waste run-off. In the same period, run-off and leaching from fertilizers and livestock waste are shown to contribute to high nitrate levels in some rivers and water wells in agricultural areas. Concern for pesticide contamination of water in this period focused on sediment contamination by persistent chlorinated insecticides such as DDT, aldrin, dieldrin, heptachlor, endrin, chlordane, and toxaphene. By the late 1970s, extensive regional studies had clearly identified the causes and extent of agricultural NPS surface water pollution by sediment and nutrients. Planners at the State and national level had, by this time, developed remedial plans (e.g. Pollution from Land Use Activities Reference Group, 1978; Lake Erie Wastewater Management Study, 1982 for the lower Great Lakes) to deal with agricultural NPS phosphorus loads, based on voluntary adoption by farmers of conservation tillage and livestock waste management practices, but these were largely unfunded. Modest efforts in States such as Wisconsin achieved some on-farm treatment, but it was for the most part business as usual. Demonstration projects such as the Rural Clean Water Projects, Model Implementation Projects and others (e.g. the Army Corps of Engineers Honey Creek Project in Ohio) fine-tuned field methodologies for quantifying loadings, assessing land use changes and achieving voluntary participation in remedial programs. These efforts were not strongly institutionalized in the US Department of Agriculture (USDA) or State management agencies and had minimal impact.

By the early 1980s several forces combined to change national priorities for agricultural NPS water pollution control. First, the public was environmentally sensitized by incidents such as Love Canal in New York and Times Beach in Missouri to the probable contamination of ground water by chemicals. The US Environmental Protection Agency (USEPA) issued several reports on groundwater contamination including its 'Ground-water protection strategy' (USEPA, 1984). For reasons not clearly understood, the public was much more concerned by the prospect of groundwater contamination in the 1980s than they were with surface water contamination in the 1960s and 1970s. Drinking water wells were surveyed for nitrate and pesticide contamination, and wells in agricultural areas in 23 States were found to have detectable levels of at least 17 pesticides (Cohen et al., 1986). Public and congressional pressures resulted in strong policy statements for groundwater protection by USDA agencies. Section 319 of the Clean Water Act finally provided limited funding to States for implementation of agricultural best management practices (BMPs) for water pollution control. In addition, the 1985 Farm Security Act mandated sweeping changes in the control of farmland erosion that will have impact on agricultural NPS pollution (see below).

Where do we stand in 1992? With respect to phosphorus-induced eutrophication, advanced waste-water treatment in the last 15 years has resulted in dramatic reductions in point source P loadings to lakes and streams with corresponding improvements in water quality. Yet, eutrophication persists in many water bodies and further reductions will have to be made in agricultural NPS loads. Most plans call for this to be achieved by a combination of conservation tillage and other soil erosion control practices, livestock waste management, and P fertility management. Survey data on conservation tillage use in the US (McCain, 1990) suggest that adoption of these practices has slowed in recent years with about 73 million acres under some form of conservation tillage practice. The impact that the 1985 Farm Security Act provisions will have on this figure is discussed later. Most efforts in livestock waste management have focused on cost sharing for waste storage facilities. However, there is a persistent problem in many livestock areas with inadequate land base for agronomic utilization of livestock waste nutrients. With respect to P fertility, management, significant acreages of agricultural soils in the US have available P levels in the excessive range. It is heartening to note that P fertilizer use in the US has decreased in recent years (Wallingford, 1991), and Baker (1993) has shown from trend analysis of long-term tributary loading data for northern Ohio that both dissolved and total P loads attributable to non-point sources may have declined in the last few years; greatest reductions were seen for dissolved P. This suggests that watershed loadings of the most bioavailable P form, dissolved inorganic P, may decline more rapidly than previously thought.

Unlike P loads, Baker has found that nitrate levels have increased in tributaries in agricultural watersheds in northern Ohio, and the recent USEPA national water well survey (USEPA, 1990a) shows that 2.4% of rural private and 1.2% of community wells have nitrate N levels above the maximum contaminant level (MCL) of 10 mg l^{-1}. Other indications nationwide suggest that high nitrate in surface water is a persistent seasonal problem (from late winter to early summer), far more so than groundwater contamination which is more localized, being found primarily in areas of high rainfall or irrigation use, intensive agriculture and on highly permeable soils and bedrock geology. Unlike P, there is no indication at the national level that N use rates on major crops has declined (Wallingford, 1991), and there is some evidence to suggest that farmers will be utilizing more of the agricultural and domestic wastes produced in the nation as communities move towards complete recycling of wastes rather than disposal.

Pesticides found in water today are not the persistent chlorinated insecticides found in sediments in the 1960s and 1970s. They are the high-volume use herbicides, such as atrazine, alachlor, metolachlor, metribuzin, and cyanazine, and widely used fungicides and nematicides such as aldicarb. These compounds are sufficiently persistent, water soluble and low in soil attenuation that they can move readily in surface run-off and leach to tile drains (or to deeper groundwater aquifers if they are sufficiently conducting). Baker (1993) has shown that tributaries draining agricultural watersheds in northern Ohio can have seasonal concentrations above the MCL for atrazine and alachlor. He also found that less than 1% of private wells in Ohio had atrazine concentrations above the MCL; atrazine was the most commonly detected pesticide. The national water well survey found that the most commonly detected pesticide residues were the acid metabolites of DCPA, a turfgrass herbicide (common name is Dacthal) (USEPA, 1990a). Atrazine was the next most commonly detected compound. Several of the compounds found in earlier well screening (Cohen et al., 1986) have been banned or removed from the market by the manufacturer, including aldicarb which was found in ground water throughout the US wherever it was used to any significant degree. Developing factors which will determine which of the leachable compounds will retain their registration in the future are: (1) the overall process of retesting and registration under Federal Insecticide, Fungicide and Rodenticide Act (FIFRA); (2) development by EPA of MCLs for a wider range of pesticides than presently exists; (3) implementation of USDA–Soil Conservation Service (SCS) technical criteria which specify that farmers with approved conservation plans under the Conservation Compliance (CC) provisions of the 1985 Farm Security Act may have to select alternative pesticides if the compounds they are presently using are shown to have potential to move to ground water in their local environment (Hornsby et al., 1993).

Livestock waste disposal has evolved in the last 20 years from being primarily a problem of lack of or improper storage of manure to one of inadequate land base for efficient reutilization of manure nutrients. This is evidenced in areas of large beef, dairy and poultry operations where the livestock enterprise controls only a fraction of the land base required. Even where there are State-level controls on manure utilization at agronomic rates, rates are usually based on crop N needs. The result is that available P levels can increase rapidly to excessive levels. A few States, including Ohio, are attempting to impose a P limit based on an upper bound soil test (300 kg ha^{-1} Bray P1 in Ohio) but in many areas soil P levels already exceed these values. Another emerging factor is the national movement towards beneficial re-use of a wide range of domestic organic wastes including municipal sewage sludge, sludge compost, yard waste compost, municipal solid waste (MSW) compost, and food processing waste. This trend has occurred for a number of reasons: (1) the quality of municipal sewage sludge with respect to pathogen levels and to the content of trace elements and trace organics (USEPA, 1990b) has improved in recent years, thereby increasing the percentage of sludge that can safely be recycled; (2) new technologies such as sludge composting, alkaline stabilization and pelleting can transform sludge into products that are acceptable to communities and potentially marketable; (3) new national sludge regulations to be released in 1992 will greatly increase the beneficial re-use of sludge (USEPA, 1989); (4) ocean dumping of sludge has been banned as of 1992, and there is great community pressure to exclude sludges, yard waste and MSW from declining landfill space; (5) community acceptance of sludge and MSW incineration has declined. Farmers with access to these materials are using them now and will continue to do so as long as they are economically attractive. Lack of data and understanding on nutrient supply from these materials can result in overfertilization if farmers do not adjust fertilizer rates to compensate for organic waste nutrients.

Evaluation of agricultural best management practices for water quality

Agricultural BMPs for NPS pollution control have focussed primarily on soil erosion control. Logan (1990) reviewed the SCS technical guide practices and classified them as structural, cultural or management. Structural practices include such things as terraces and grassed waterways and their impact is primarily to reduce run-off through increased infiltration and to reduce soil erosion. Cultural practices include conservation tillage, contour cropping and cover cropping. They protect the soil surface and reduce erosion; however, they may or may not increase infiltration and decrease run-off, depending on the hydraulic conductivity of the soil (Logan, 1990). Management practices for fertilizer, pesticide and livestock waste application, and, more generally, integrated pest management and integrated fertility management primarily affect the source of a potential contaminant by increasing use efficiency.

These practices can be evaluated as to their potential to decrease (or even increase) contaminant losses by run-off, erosion (contaminant attached to sediment) or leaching. Two factors must be considered: (1) Is there a reduction in the amount of the potential contaminant in the soil as a result of the practice (e.g. rotation of corn with a small grain can reduce average N use versus continuous corn)? (2) How will the practice affect mass distribution of the contaminant between eroded sediment, run-off water and percolating water? The latter information can be obtained by combining simple (universal soil loss equation and SCS run-off curve number) or more complex erosion/hydrology models (AGNPS, GLEAMS) with knowledge of the fate of the contaminant, particularly the partitioning of the contaminant between soil/sediment and water. Figure 1 illustrates how partitioning can be used to evaluate mass transfer to run-off, sediment or leachate. Use of this approach suggests that structural practices that reduce run-off by increasing infiltration can reduce sediment P losses and pesticide run-off losses, but could increase

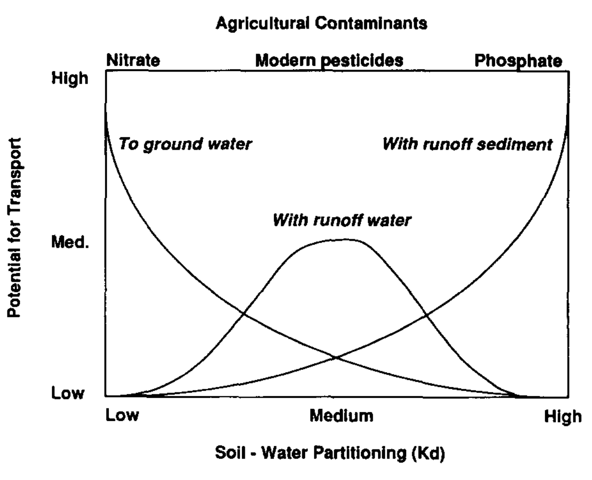

Fig. 1. Potential of agricultural contaminants to be transported in run-off and leaching as a function of their soil/water partitioning.

Table 1
Classification of conservation practices and agricultural BMPs by environmental objective, pollutant type, and medium impacted (Logan, 1990)

BMP	Primary environmental objective[1]	Pollutant type[2]	Medium impacted[3]			
			Surface water	Ground water	Air	Soil
Structural						
Terraces, hillside ditches	E	E, P	P	N/A	N	P
Grass waterways	E	E, P	P	N	N	P
Subsurface (tile) drains, water table management	S	E, P, N, S	P/A	P	N	P
Irrigation systems	S, E	S, N	P	P	P	P
Chemigation backsiphon devices	Q	C, N	N	P	N	N
Sediment and water retention basins	L, Q	E, P, N	P	A	A	N
Surface drains	N, Q	N	A	P	N	P
Manure storage, run-off control, filter strips	W, L, Q	N, P, B, O, M	P	P	P	P
Irrigation tailwater recovery systems	E	E, C, S	P	N	N	P
Cultural						
Conservation tillage	E, L, Q	E, P	P	N/A	N/A	P
Contour cropping	E, L	E	P	N/A	N	P
Stripcropping	E, L	E	P	N/A	N	P
Contour stripcropping	E, L	E	P	N/A	N	P
Cover cropping	E, L, Q	E	P	P	N	P
Crop rotation	E	E	P	N/P	N	P
Subsoiling	S	S, E	P	N/A	N	P
Land grading	S, E	S, E	A	N/P	N/P	P
Critical area planting	E, L, Q	E, P, N	P	P	P	P
Stream bank protection	E	E	P	N/P	N/P	P
Low input farming	E, L, Q	E,C	P	N/P	P	P
Management						
Integrated pest management	Q	C, M	P	P	P	P
Animal waste management	L, W, Q	N, P, M	P	P	P	P
Fertilizer management	L, Q	N, P	P	P	P	P
Pesticide management	Q	C, M	P	P	P	P
Irrigation management	S, L, Q	S. N. P	P	P	P	P

[1]E, erosion control; L, eutrophication; W, animal waste management; Q, water quality; S, salinity; N, none, for example, surface drains primarily eliminate wetness problems.
[2]E, sediment; P, phosphorus; N, nitrogen; C, pesticide; B, biological oxygen demand; S, salt; M, heavy metals; O, pathogenic organisms.
[3]P, positive impact; A, adverse impact; N, no impact.

nitrate leaching losses. Conservation tillage on a permeable soil would reduce sediment P losses, reduce run-off pesticide losses (provided pesticide application rates did not increase substantially), and increase nitrate leaching. On

Table 2
Summary of proposed practices to modify or supplement conservation compliance practices for control of agricultural water contamination (Logan, 1991)

Practice (Pollutant)	Objective	Description
(1) Yield goals (N, P)	Restrict nutrient application to actual crop utilization	Establish long-term potential of climate and soil to produce economic crop yields
(2) Soil and manure tests (N, P)	Restrict nutrient application to actual crop needs	Establish actual nutrient supply capacity of soil, and nutrient content of manure through chemical analysis
(3) Fertilizer management (N, P)	Optimize nutrient utilization by the crop, reduce run-off and leaching losses	Lower application rates to meet realistic yield goals; time fertilizer application to optimize crop utilization; inject or incorporate fertilizer to reduce run-off losses
(4) Residue nutrient credits (N, P)	Prevent excess fertilizer application by better utilizing nutrients in residue, green manure crops	Determine nutrient carry-over from crop residues and green manure crops and adjust fertilizer rates accordingly
(5) Management of green manure crops (N, P)	Optimize nutrient utilization from green manure crops by subsequent crops	Method and timing of incorporation of green manure crops to optimize nutrient utilization by the subsequent crop and to avoid losses
(6) Manure management (N, P)	Optimize manure nutrient utilization by the crop and minimize losses	Rate, timing and method of application of manure to optimize nutrient utilization by the crop, minimize nutrient build-up, and reduce losses
(7) Pesticide management (pesticide)	Reduce the potential for pesticide movement by run-off or leaching	Pesticide selection for mobility and half-life; formulation; and timing and method of application to reduce potential for run-off and leaching losses
(8) IPM (pesticide)	Reduce pesticide use	Field scouting and other IPM practices to reduce pesticide use
(9) Management of permanent vegetation (N, P, pesticide)	Reduce or eliminate fertilizer, manure or pesticide use on permanent plantings	Selection of appropriate species, mowing, and other practices which reduce or eliminate the need for nutrient or pesticide additions to permanent plantings
(10) Irrigation management (N, P, Pesticide)	Manage irrigation to reduce excessive run-off and leaching	Rate and timing of irrigation to reduce excessive run-off or leaching; coordinating irrigation with fertilization and spraying to minimize chemical loss; installation of chemigation back-siphon devices

a slowly permeable soil, run-off volume and pesticide losses in run-off would be little affected as would nitrate leaching. P losses with sediment would still be decreased because of the erosion control provided by residue cover. Logan (1990) used this approach to evaluate a wide range of potential BMPs for contaminant control. Table 1 summarizes those findings. They suggest that, whereas traditional soil erosion control practices will be effective in reducing sediment P losses, pest and fertility management approaches will also be required to achieve significant reductions in pesticide and nitrate contamination of surface and ground water. In a study conducted for the USEPA, Logan (1991) evaluated the potential of CC practices, mandated by the 1985 Farm Security Act to reduce phosphate, nitrate and pesticide contamination of surface and ground water. Specifically, proposed alternative conservation systems (ACSs) were reviewed for 29 states. The ACSs are the sets of minimum practices that farmers can adopt to be in compliance with the CC program. Few of the states included structural measures in the ACSs except for ephemeral gully erosion control. Most states relied on cultural practices, including conservation cropping sequence (close-grown crops in rotation), residue management, contour cropping and cover crops. Permanent plantings were also specified by a few states. The conclusion from evaluation of the ACSs (Logan, 1991) is that they would achieve significant reductions in sediment P at the national level, but would have little impact on pesticide or nitrate levels in surface or ground water.

Logan (1991) also identified practices that could modify or supplement State ACSs to reduce surface and groundwater contamination by agricultural contaminants. These are summarized in Table 2. They primarily involve nutrient and pest management with emphasis on establishing accurate and realistic yield goals and taking nutrient credits for organic wastes, residues and cover crops. It is important that they be integrated with selected ACSs and not used in isolation.

Conclusions

Agricultural NPS pollution of surface and ground water by nutrients and pesticides has been identified as a major problem in the US since the 1960s, but, in spite of major research efforts to quantify the problems and develop solutions in the 1970s, significant programs and federal funds to reduce these contaminants have not been forthcoming until now.

Existing agricultural BMPs are designed primarily to control soil erosion and will have little impact on NPS pollutants except for sediment-bound P which will be significantly reduced. Significant reductions in surface and groundwater contamination by nitrate, phosphate and pesticides will only be achieved by use of fertility and pest management practices integrated with other BMPs. Integration of agricultural BMPs to achieve water pollution control must be made at the level of technical assistance. Too often, agencies present technical information piecemeal, leaving it to the farmer to integrate this data into workable systems.

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