Nutrient Cycles in the Southern Piedmont

A Workbook for Managing Nutrients at the Watershed Scale

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Foreword

In recent years, awareness of water quality problems has grown in Georgia, throughout the U.S., and the world. As major point sources of pollution were decreased, such as from factories, municipalities, or mines, we became more aware of pollutants that were moving diffusely from the land into water bodies. Agriculture occupies a great deal of land in many major watersheds and depending on management practices, can contribute sediments, nutrients (such as nitrate, phosphorus, or other elements), or chemicals to water bodies. Such pollution, termed "nonpoint source" (NPS) pollution in the 1972 Water Quality Act, is by definition difficult to measure or to attribute to specific sources or activities. Better knowledge is needed about amounts of pollutants associated with agricultural systems as well as effectiveness of recommended practices in controlling contamination. Without such knowledge, sustainable management systems can not be developed and solutions to problems will be difficult to find.

In 1996, a coalition of agricultural producers, researchers, extension specialists, and natural resource support personnel joined together to find ways to characterize two typical watersheds in the Southern Piedmont region of Georgia, the Rose Creek and the Greenbriar Creek, tributaries to the Oconee River above Lake Oconee. Farmers and high school educators have committed to making water quality measurements within these watersheds, under the guidance and coordination of USDA Agricultural Research Service and University of Georgia researchers. The team objectives are to 1) assess system-wide distribution of nitrogen and phosphorus in the watersheds, as related to land management practices; 2) compare volunteer water quality data collected to technician data collection and test kit measurement of nitrogen and phosphorus to laboratory analysis of the same samples; 3) evaluate incentives needed to encourage producer adoption of environmentally and economically sustainable management practices; and 4) increase awareness among agricultural producers, youth, and the community of nutrient movement through the watershed.

This workbook was developed to familiarize farmers and high school student volunteers who will collect water quality data in these watersheds with the ecological processes that link land management practices to water quality. In addition, training on specific

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INTRODUCTION

Land resource managers must consider many factors to sustain an economically and environmentally sound business. One of these important factors is the management of animal manures. Application of animal manures to pastures and croplands provide a viable source of nutrients to plants, as well as an efficient way to distribute a potential point-source contaminant. Nowadays, however, agricultural producers are experiencing increased pressure from surrounding citizens to ensure that manures are not managed in a way that may contaminate waters.

Water is essential to every living thing and the quality of the water to meet the needs of humans and other creatures is important. The water quality that exists at any given time is the cumulative result of activities of many people over time interacting with the ecosystems where the activities take place.

Because of limited information available on the effect of manure management practices on N and P concentrations in runoff and surrounding surface waters, self-monitoring would provide land resource managers with data to assist them in appraisal of their management practices. In addition, the 1996 Farm Bill stipulates cost-sharing monies must be spent in areas where a need has been expressed. This need may be identified where elevated levels of N and P have been documented.

It is our hope to discover which management practices are doing the job and to share that information with other farmers, researchers, and educators. In the process we are also looking for ways to prevent potential problems and to provide solutions if there is evidence of problems. It is our belief that if one is going to manipulate or manage the landscape to be most productive and energy efficient (sustaining), then one must have a good understanding of the general patterns and possible pathways that exist for the hydrologic and nutrient cycles. This workbook will discuss the carbon, nitrogen, phosphorus and hydrologic cycles and their importance for the Southern Piedmont regions. Clear knowledge of the consequences that may result from given management systems are vital to the selection of the most sustainable systems. It atmosphere, etc.). Plants, animals and microorganisms play major roles in the transformation and translocation that occurs during the cycling of biogeochemicals . The abundance (or lack) of plants, animals, and microorganisms is often measured as biomass (the amount or mass of a given plant or animal within an area). Biomass is often measured as a way to estimate the degree to which a certain chemical or physical transformation has occurred and/or the efficiency (productivity) of a management system.

All biogeochemical cycles are driven by the radiant energy of the sun. Sunlight (energy) is absorbed, converted, and eventually dissipated within ecosystems. Energy flows almost unidirectionally, through ecosystems. That means it flows in one direction or it comes in one direction and leaves by another. This is what scientists refer to as an open system. The transfer of energy stored in organic compounds from one organism to another (like wheat, soybeans, or cows) establishes food chains, with the transfer occurring in steps or trophic levels. With each step or trophic level up the food chain there is a loss of energy. In fact only about 10% of the energy and biomass from each trophic level is passed on to the succeeding trophic level, the remainder is consumed by respiration or enters the decay portion of the food web. A good visualization of the food chain is given by the biomass pyramid which can be used to evaluate the balance of an ecosystem. Humans and hawks are examples of secondary carnivores and are located at the top of the food chain. Mice and other carnivores that eat primarily

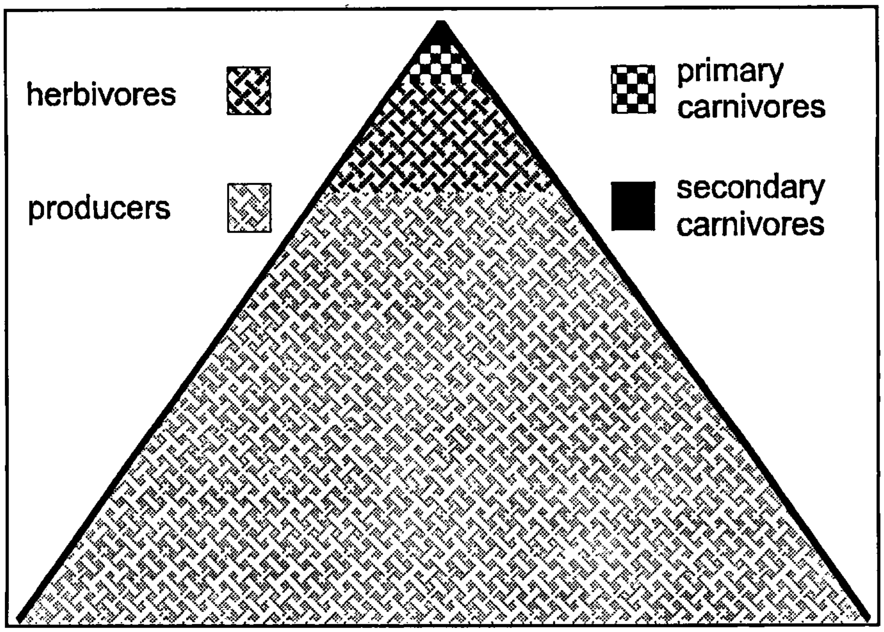


Fig. 1.1. Biomass pyramid illustrates energy requirements of different trophic levels relative to one another. Man is a secondary consumer with high energy requirements.

sediment for extended periods of time. There is still much to be learned on the global cycles of phosphorus. However, in many pristine systems phosphorus is considered to be the major limiting factor to ecosystem productivity. A limiting factor is an element, molecule, or process that holds up the works or production at the expense of others. For example, how fast you can go in a car is dependent on how much gas you deliver with the gas pedal for any particular car. In this case, gas is the limiting factor. This is true up to a certain speed, beyond that speed another factor may limit how fast the car can go.

One of the most dominant influences in all nutrient cycles, and in some cases the limiting factor, is the availability and abundance of water. Water detaches, dissolves, and transports nutrients. The Cooperative Extension Service identified the top ten facts to remember about nutrients and the water cycle (Fact sheets, vol 3, issue 1, summer 1996).

or quality of life. Land managers use indicators like productivity and quality of life. We all know there is a problem when the fish, wildlife, and livestock are ill or we are sick. But there is no doubt that we each want to do our part, to prevent problems from occurring. Most potential problems are off-site in another ecosystem further downhill and/or downstream but the prevention is at the site or field level. Whether a problem exists or not is determined from careful evaluation of observations (data) as to the quality of water. A problem can not be identified with a single reading or even with a single set of annual readings. Trends however, can be identified and solutions or options for change can be discussed. If there is a problem, we are sure that as good stewards of the land, the land manager will try to alleviate the problem.

How do we determine the most feasible solutions? The key is to work together without attack to find feasible solutions. It is the land manager that ultimately decides which solution is most feasible and implements the solution. Specific guidelines can be found in the Guidelines and Troubleshooting Section.

STATE OF AGRICULTURE IN THE SOUTHERN PIEDMONT

Introduction

The Southern Piedmont Land Resource Area extends from northern Virginia southwestward through the Carolinas, Georgia, and into Alabama (Fig. 2. 1). It is a rolling upland plateau lying between the Blue Ridge Mountains and the Coastal Plains covering about 42 million acres. Elevation of the Southern Piedmont region ranges from about 1500 feet above sea level near the mountains to about 400 feet at the southeastern edge. The climate of the region is relatively mild and humid, and agriculturally, is favorable for field crops, forests, grasses, and livestock enterprises. It is also very favorable for habitation by humans. The soil erosion hazard is severe, which necessitates the use of conservation farming practices in order to not only prevent soil loss, but to insure sustained future agricultural production.

The objective of this chapter is to present a general description of the Southern Piedmont Land Resource area with factual summary of current agricultural production.

General Description of the Southern Piedmont

The upland soils are of residual origin, i.e., from weathering of parent rocks that lie beneath them at depths of 25 to 50 feet. Parent rocks are granite, gneiss, and schists. Soils are predominantly Cecil and associated soils. Where there has been little or no erosion, the soils are a brownish-gray and have a loamy sand to sandy loam texture at the surface with a sandy clay to clay subsoil. The distinctive red color, characteristic of many surface soils, is a result of incorporation of subsoils high in iron oxides with surface soils by erosion and tillage. Surface soils of eroded slopes are usually finer textured, shallower, more subject to crusting, and have a lower infiltration capacity than the less eroded slopes or drainageways. Within the Southern Piedmont, there is an area of about 3 million acres along the southeastern edge, primarily in the Carolinas, known as the slate belt. Soils of this area are characterized by their silty texture and smooth flour-like feel. Less-eroded soils in the slate belt will have a grayish-yellow or light-red surface soil and light-red, smooth silty clay subsoils.

The climate is relatively mild and humid. Even during the coldest months of December, January, and February, conditions are such that cool season annual and perennial plants can make growth. This provides an excellent opportunity for production of cool-season forage grasses and legumes; often enabling grazing to occur year around. Annual rainfall ranges from 45 to 55 inches per year with the driest time of the year during the September-November period. Sporadic, short-term droughts typify spring and summer with more prolonged dry periods in autumn. The frost-free period usually extends from late March or early April to late October or early November. Temperatures are comparatively moderate with summer day temperatures usually in the 80s and 90s with an occasional 100 degree day. Winter day temperatures often reach the 40s and 50s with an occasional low below 15 degrees Fahrenheit.

Trends in Southern Piedmont Agriculture

While the primary objective of this chapter is to present the current status of agriculture in the Southern Piedmont, certain trends should be noted, e.g., the reduction in the percent of land in farms. The current percentage of land in farms is about 25, and has been achieved by a steady decline since 1950 when it was over 50 percent. Likewise, total farm acreage has declined steadily since 1950. When discussing trends, it is also important to address a specific interval of time. For example, cotton acreage has been declining from a long-term perspective; however, in recent years there has been a reversal of that trend.

Proportion of Land in Farms, Number of Farms and Size of Farms

Approximately 25 percent of the 42 million acres in the Southern Piedmont is in farms. This ranges from a low of 20.1 percent in Alabama to 30.0 percent in the North Carolina Piedmont (Table 2. 1). There are approximately 64,300 farms which occupy 10,690,481 acres for an average of about 166 acres per farm. About 70 percent of the farms range from 10 to 180 acres in size with only 6.4

Table 2. 3. Farm operator characteristics[a]

Item	AL	GA	NC	SC	VA	Total
No. owner operated farms	2,038	11,583	14,223	6,179	7,893	41,918
No. owner operated acres	317,211	1,264,775	1,352,065	786,121	1,243,051	4,963,226
Principle occupation is on farm, no. farms	1,092	6,232	12,113	3,421	6,218	29,077
Principle occupation is off farm, no. farms	1,774	9,081	12,083	5,564	6,748	35,249
Days worked off farm, none	912	5,367	9,524	3,147	5,026	23,977
Days worked off farm, some	1,756	8,868	12,706	5,278	7,068	35,676
Black & other minorities, no. farms	54	216	749	280	832	2,131
Black & other minorities, no. acres	6,485	22,086	68,058	22,071	88,693	207,394
No. years on present farm, avg.	18.8	18.2	21.1	19.9	19.7	19.5

[a] Based on the 1992 Census of Agriculture.

Table 2. 6. Sorghum, Soybean, and wheat acreages for 1996[a]

State	No. counties	Sorghum acres harvested	Total soybean acres	Total wheat acres	Wheat acres harvested
AL	13	[b]	4,075	2,157	1,748
GA	63	3,635	48,335	31,830	37,500
NC	47	1,358	269,080	152,355	140,220
SC	22	1,600	27,732	28,120	24,180
VA	40	[b]	63,340	62,495	50,600
Total		6,593	412,562	276,957	254,248

[a] Summarized from respective state Agricultural Statistical Services.

[b] Not reported by county or insufficient numbers to report.

Table 2. 7. Tobacco acreages for 1996[a]

State	No. counties	Flue-cured tobacco acres	Sun-cured tobacco acres	Burley tobacco acres	Fire-cured tobacco acres
Al	13	0	0	0	0
GA	63	0	0	0	0
NC	47	105,620	0	0	0
SC	22	107	0	0	0
VA	40	35,843	53	187	1,066
Total	185	141,570	53	187	1,066

[a] Summarized from respective state Agricultural Statistical Services.

Fruits, Nuts, and Vegetables

With the exception of apples and peaches, little county data is available for fruit, nut and vegetable production. Apple and peach acreages, trees, and production estimates are presented in Table 2. 8.

Hogs, Beef Cows, Other Beef Cattle, and Dairy Cattle

Numbers of hogs sold, beef cows, other beef cattle, and dairy cows are presented in Table 2. 10. As of January 1, 1997, there were almost 1.1 million beef cows and 150 thousand dairy cows in the Southern Piedmont.

Table 2. 10. Number of hogs sold and inventory of beef cows, other beef cattle, and dairy cows[a]

State	No. counties	No. hogs sold[b]	No. beef cows	No. of other cattle	No. dairy cows
AL	13	16,026	61,285	54,045	640
GA	63	111,520	295,690	292,767	42,641
NC	47	985,513	309,895	369,115	56,570
SC	22	49,680	159,795	156,795	15,685
VA	40	96,141	242,425	279,280	34,780
Total		1,258,880	1,069,090	1,152,004	150,316

[a] Inventories of beef cows, other cattle, and dairy cows were summarized from the respective state Agricultural Statistical Services for January 1, 1997.

[b] Based on the 1992 Census of Agriculture.

Horses and Mules

Estimates of numbers of horse farms and horse numbers are presented in Table 2. 11. In conversations with horse extension specialists in each of the states of the Southern Piedmont, all suggest that number estimates are far lower than actual numbers. In fact all suggested that the horse and mule populations are growing far faster than number estimates would indicate. Most state Agricultural Statistical Services do not routinely survey numbers of horses and mules even though they occupy considerable land area, consume large quantities of feedstuffs, and produce waste.

Table 2. 12. Estimated manure production by animal category in Southern Piedmont, tons dry matter[a]

State	No. Counties	Beef Cattle	Other Cattle	Dairy Cattle	Hogs Sold	Hens and pullets over 3 months old	Broilers sold
AL	13	81,736	18,789	1,706	1,162	10,310	38,049
GA	63	394,365	101,785	113,656	8,087	128,659	457,388
NC	47	413,310	128,327	150,782	71,464	87,993	257,501
SC	22	213,120	54,512	41,807	3,603	22,418	34,603
VA	40	323,325	97,095	92,703	6,972	4,968	36,468
Total		1,425,856	400,508	400,654	91,287	254,349	824,009

[a] Livestock manure production estimates were taken from the Livestock Waste Facilities Handbook, Midwest Plan Service, Iowa State University, Ames, 1985.

Table 2.13. Annual NPK from manure in Southern Piedmont[a]

	Number in Piedmont	Total Manure Dry Matter (ton)	N (%)	P (%)	K (%)	N (ton)	P (ton)	K (ton)
Beef cows[b]	1,069,090	1,425,856	4.89	3.45	7.47	69,654	49,217	106,443
Calves, steers, other cattle[b]	1,152,004	400,509	3.94	1.51	3.15	15,780	6,048	12,616
Dairy cows and heifers[b]	150,316	400,654	3.90	0.70	2.60	15,637	2,800	10,428
Hogs sold[c]	1,258,881	91,287	7.53	2.49	4.97	6,873	2,271	4,540
Broilers sold[c]	834,151,968	824,009	6.80	1.53	2.12	56,055	12,640	17,447
Laying hens[c]	26,335,877	254,349	5.48	2.08	2.20	13,938	5,287	5,585
Total		3,142,315				177,937	78,263	157,060

[a] Manure estimates from Livestock Waste Facility Handbook, Midwest Plan Service, 1985

[b] From 1996 respective State Agricultural Statistics publications.

[c] From 1992 Census of Agriculture

Therefore, if plant N is provided from manure, then P will be applied in excess and accumulate in the soil. If manure is applied to meet plant P requirements, then much less manure can be applied to a given area of land in a year and an additional source of N is required. Some manures may contain heavy metals, e.g., copper or zinc in poultry manure, that may accumulate to excessive levels

Appendix 2. 1. Counties in the Southern Piedmont Region

Alabama

	County	Fraction in S. Piedmont		County	Fraction in S. Piedmont
1	Autauga	0.03	8	Elmore	0.40
2	Calhoun	0.05	9	Lee	0.55
3	Chanbers	1.00	10	Randolph	1.00
4	Chilton	0.30	11	Shelby	0.10
5	Clay	1.00	12	Talladega	0.35
6	Cleburne	0.90	13	Tallapoosa	0.85
7	Coosa	1.00			

North Carolina

	County	Fraction in S. Piedmont		County	Fraction in S. Piedmont
1	Alexander	0.95	25	McDowell	0.05
2	Alamance	1.00	26	Moore	0.40
3	Anson	0.65	27	Montgomery	0.80
4	Burke	0.50	28	Nash	0.60
5	Caldwell	0.55	29	Northhampton	0.20
6	Caswell	1.00	30	Orange	1.00
7	Catawba	1.00	31	Person	1.00
8	Chatham	1.00	32	Polk	0.90
9	Cleveland	0.85	33	Randolph	1.00
10	Davidson	1.00	34	Richmond	0.15
11	Davie	1.00	35	Rockingham	1.00
12	Durham	1.00	36	Rowan	1.00
13	Forsyth	1.00	37	Rutherford	0.90
14	Franklin	1.00	38	Stanly	1.00
15	Gaston	1.00	39	Stokes	1.00
16	Granville	1.00	40	Surry	0.75
17	Guilford	1.00	41	Union	1.00
18	Halifax	0.45	42	Vance	1.00
19	Harnett	0.15	43	Wake	0.95
20	Iredell	1.00	44	Warren	1.00
21	Johnston	0.50	45	Wilkes	0.55
22	Lee	0.55	46	Wilson	0.15
23	Lincoln	1.00	47	Yadkin	1.00
24	Mecklenburg	1.00			

South Carolina

	County	Fraction in S. Piedmont		County	Fraction in S. Piedmont
1	Abbeville	1.00	12	Laurens	1.00
2	Anderson	1.00	13	Lexington	0.45
3	Cherokee	1.00	14	McCormick	1.00
4	Chester	1.00	15	Newberry	1.00
5	Chesterfield	0.25	16	Oconee	0.50
6	Edgefield	0.75	17	Pickens	0.55
7	Fairfield	1.00	18	Richland	0.40
8	Greenville	0.75	19	Saluda	0.90
9	Greenwood	1.00	20	Spartenburg	1.00
10	Kershaw	0.25	21	Union	1.00
11	Lancaster	0.85	22	York	1.00

WATER CYCLE

The water cycle is the system by which the earth's fixed amount of water is collected, purified, and distributed within the environment. The water cycle is also called the hydrologic cycle and its components are made up of fresh and salt water, water above and below ground, and water in any of its three forms or states (solid, liquid, gas). The hydrologic cycle is a modification of the water cycle and is the process by which water evaporates from the lands and the oceans, falls to earth, and returns to the ocean (Fig. 3.1). On a global scale water covers almost 98% of the earth's surface! So, how can there be shortages? There are shortages because only 0.02% of the earth's water is available for plant and animal use and sometimes consumption (Table 3.1 & Fig. 3.2).

Table 3.1. Distribution of fresh and saline, liquid and frozen water in the world.

Reserve	Volume (mi^3)	Percent of total
Oceans	316,777,000	96
Polar ice caps and all glaciers	6,996,000	2
Exchangeable ground water	5,751,000	1.7
Freshwater lakes	30,000	0.009
Saline lakes and inland seas	24,900	0.008
Soil and subsoil water	15,600	0.005
Atmospheric vapor	3,400	0.001
Rivers and Streams	300	0.00009

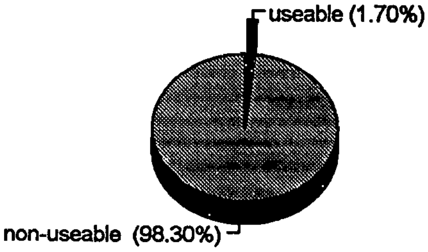


Fig. 3.2. Pie chart of the Earth's water supplies. Illustrates that less than 2 percent of the Earth's water is currently useable.

dipolar in nature (one end is negative and the other is positive) which allows it to join with other water molecules and other charged surfaces. The affinity of other charged molecules to join with the water molecule and separate from itself is strong in very soluble materials, thereby dissolving or separating the material. Because water is a solvent it has a tendency to carry ions with it as it moves around in the liquid part of its cyclic journey.

Global Water Processes

Defining the hydrologic cycle as the process by which water evaporates from the oceans (maritime) and the land mass (continental), falls back as precipitation to the oceans (maritime) or to the Earth's land masses (continental), and returns to the ocean as surface or groundwater helps us see the process on a global and regional scale. Water evaporates from the oceans using radiant energy from the sun. In fact, 89% of the precipitation falling on land originates from the oceans (maritime) while only 15% of the precipitation falling into the ocean originates from land (continental). In addition, most maritime evaporation forms clouds above the oceans and returns to the ocean as precipitation. These percentages are rough estimates, but most scientists agree with the magnitudes (the decimals are in the right place) of these estimates.

When precipitation falls to the earth some **evaporates** on its way down. After reaching earth, some is held on the surface and evaporates directly back to the atmosphere. The rest **infiltrates** into the earth's surface (usually the soil), or **runs off** the land into stream and/or lakes or other large bodies of water. Lakes and streams are fed by both surface runoff and groundwater. Streams and groundwater move downhill in most cases until they reach the ocean (Fig. 3.1). Before a stream enters a larger body of water or the ocean, the flow often slows down or the path spreads out and the water moves slowly through some sort of wetland or marsh. The cycle then continues over and over and on a global scale precipitation and evaporation from water, soils, and/or plants is continuous. This is a very simplified version of the hydrologic cycle. In reality there are all sorts of loops and diversions of water within the water cycle.

In figure 3.1 it is obvious how many uses humans have for water. What are some of the obvious uses of water either depicted in this simplified landscape from the mountains to the sea or from your experience?

Local Hydrologic Cycle

In a typical Southern Piedmont watershed, rainfall amounts and intensities vary over the course of a year. Comparing amounts of rainfall on a monthly basis for Watkinsville, Georgia, it is obvious that some months have more rain than others (Fig. 3.4). Another factor that must be considered is the amount of rainfall relative to evaporation. If Oconee county receives 5 inches of rainfall in a month and evaporation is greater than 8 inches (typical of the summer months, Fig. 3.4), no rainfall can be accounted for in storage. If Oconee county receives 5 inches of rainfall and evaporation is about 2 inches (January) we have gained 3 inches of rainfall assuming all of the rain infiltrated into the soil. This assumption is not usually valid for the winter months in the Southern Piedmont. By January the soils are often close to saturation and much of the rainfall does not infiltrate, becoming overland flow. Rainfall intensities also vary with season (Fig. 3.5). In the winter, rains are usually of lower intensity but may continue for several days. In the summer we may receive an inch of rain within an hour or two. Surface soils in the Southern Piedmont are commonly sandy loam textured and in highly eroded areas sandy clay loam and sandy clay. Sandy loam soils generally allow water to infiltrate at rates of 0.4 to 1.4 inches per hour when they are wet (Table 3.2).

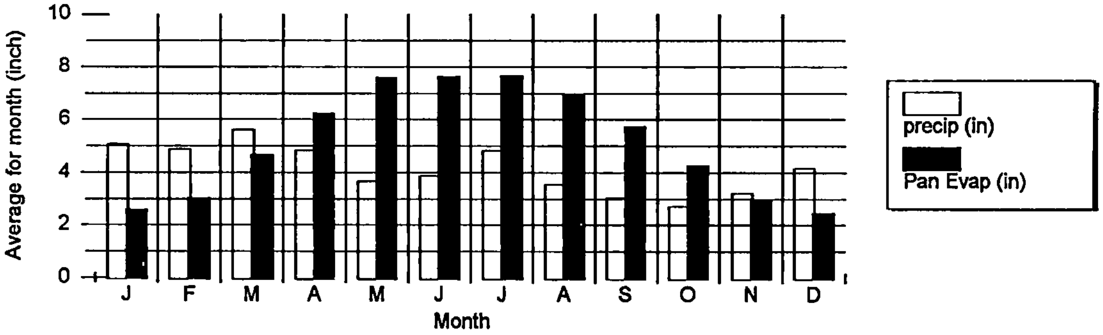


Fig. 3.4. Average rainfall and evapotranspiration in inches for each month, Watkinsville, Georgia (*data provided by Dr. Gerrit Hoogenboom, Georgia Automated Environmental Monitoring Network, UGA*).

In the Coastal Plain the surface soil texture is generally sandier and infiltration rates can be twice as high. This would suggest that a rainfall with an intensity above 1.4 inches per hour would likely result in the occurrence of runoff in the Piedmont but not months because rainfall intensities exceed soil infiltration rate and in the winter because soils may become saturated (rainfall exceeds soil water holding capacity).

Bedrock formations underlying the Piedmont consist primarily of granite, gneiss, schist and quartzite and make up the crystalline rock aquifers. Groundwater storage in these rock formations is limited to joints and fractures because these rock formations are fairly impermeable.

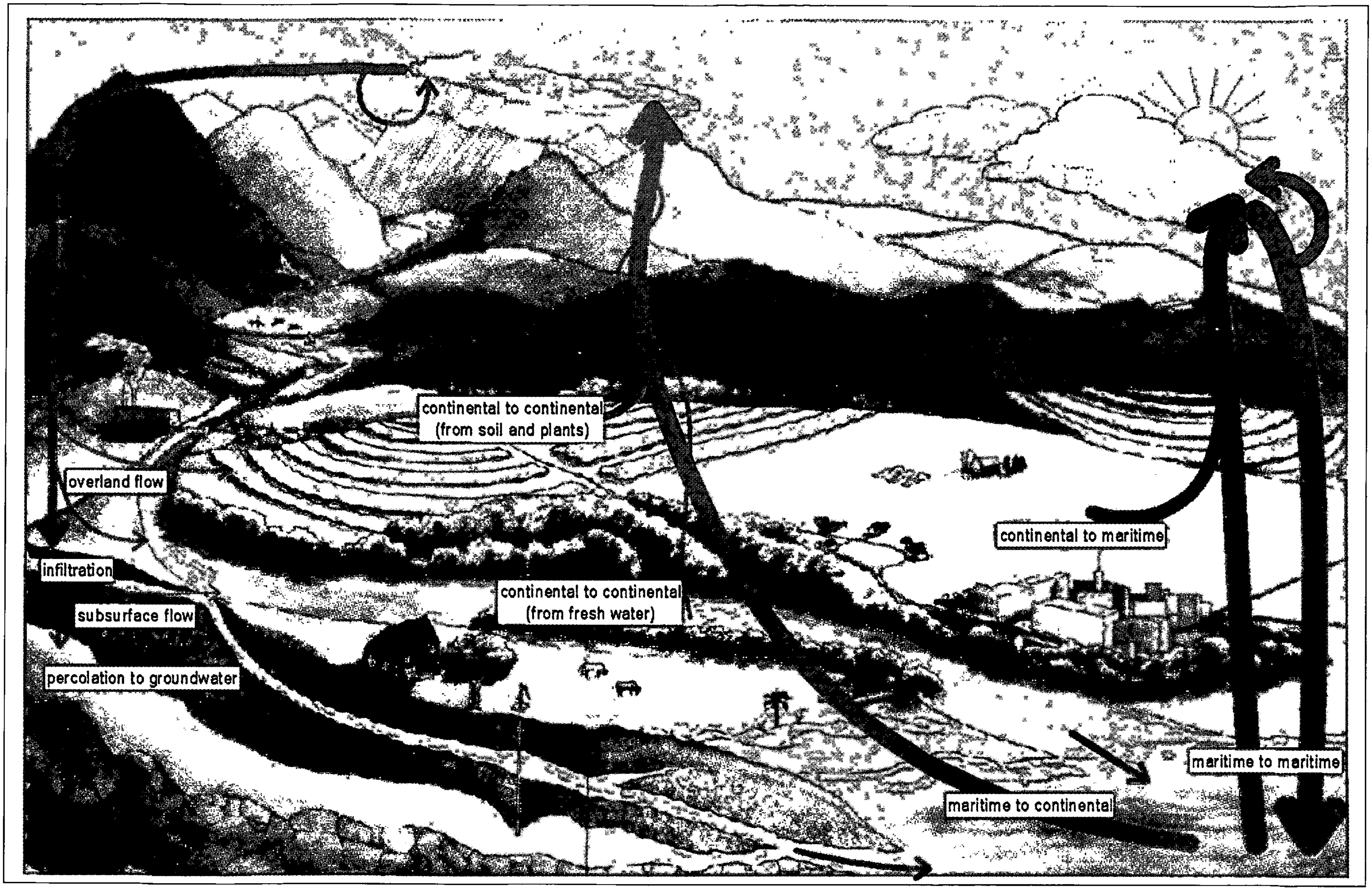


Fig. 3.1. Global scale hydrologic cycle. Arrows indicating movement upward represent evaporation and arrows indicating movement down represent some form of precipitation. Arrows indicating lateral movement represent lateral movement of water in the liquid state. Note that arrow widths suggest the relative amounts of evaporation and precipitation occurring within the global hydrologic cycle.

CARBON CYCLE

What Is Carbon?

Carbon is an element (atomic weight of 12.01) found in a wider array of compounds than all other elements combined, making it unique in nature. There are more than a million known carbon compounds, of which organic compounds are much more numerous than inorganic carbon compounds. Organic, meaning compounds of carbon held together by strong covalent or electron pair bonds, pertains primarily to things living or once living. Inorganic carbon compounds, found in air, water, and rocks, are held together by weaker ionic or electrovalent bonds, and tend to be associated with non-living things.

Why Is Carbon Important?

Carbon is the most important single element in the biological realm and the substance that serves as the building block for living cells. All living things on earth are composed of carbon, primarily in the form of carbohydrates of the general form, $C_x(H_2O)_y$. Carbohydrates include substances such as sugars, starches, cellulose, and other related compounds that can be further transformed into more complex structures to meet the diversity of life in the world. Carbohydrates also provide the energy necessary for living things to do the things that they do.

Table 4. 1. Major carbon reservoirs.

Source	Petagrams[a]
Total atmosphere	733
Carbon dioxide	729
Methane	3.4
Carbon monoxide	0.2
Total ocean	38 433
Dissolved inorganic C	37 400
Dissolved organic C	1 000
Particulate organic C	30
Biota	3
Total terrestrial	2 280
Biota	560
Litter	60
Soils	1 500
Peat	160
Total lithosphere	65 600 000
Sediments	56 000 000
Rock	9 600 000

[a] 1 petagram = 10^{15} grams.

Not only is carbon found in living things, but also in the vast array of compounds that were derived from living things. Think of the oil and gasoline used in cars and natural gas and coal used for heating. These organic compounds are called fossil fuels because they are the transformed remains of buried plant

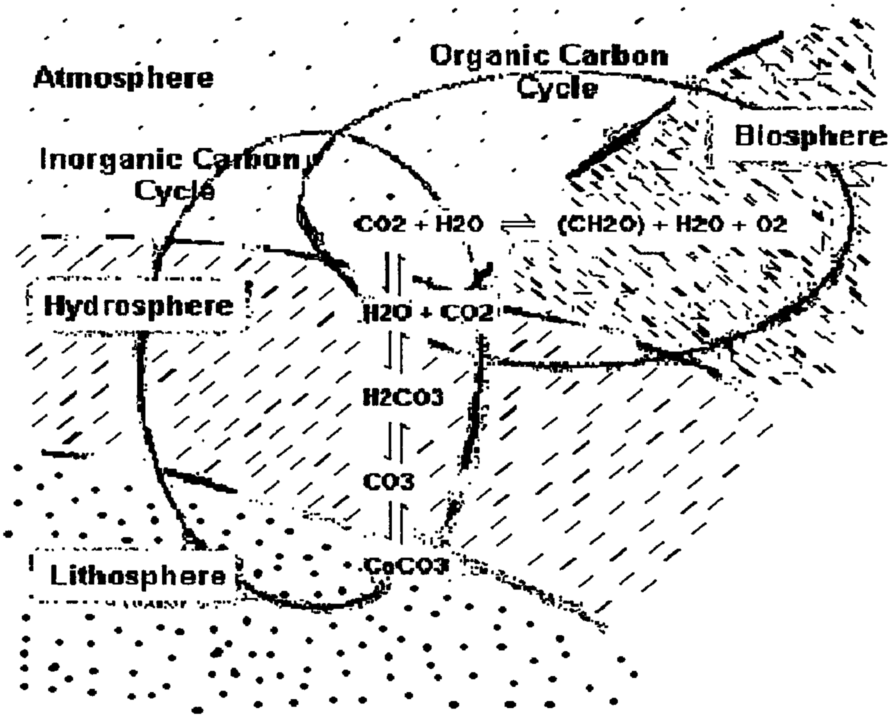


Fig. 4. 1. Interaction between the organic and inorganic carbon cycles.

The relatively small, but active reservoirs of carbon in biota and the atmosphere points to their susceptibility to perturbation. Since 1860 when intensive monitoring of CO_2 concentration in the atmosphere was started, atmospheric CO_2 concentration has risen from 280 parts per million by volume (ppmv) to nearly 360 ppmv at present. The rise, as calculated from CO_2 input from clearing of forest and burning of fossil fuels, should have been higher, but part of the input was apparently absorbed by the ocean as HCO_3^- and/or fixed by marine biomass (Fig. 4. 1). A continued increase in atmospheric CO_2 concentration may create a greenhouse effect. Carbon dioxide is transparent to visible radiation, but absorbs strongly in the infrared range. Sun radiation striking the earth is irradiated back as longer wavelength infrared radiation. An insulating CO_2 blanket would retain most of this radiation and thus would bring about a warming trend in the climate. Prior to industrialization in the 20th century, increasing atmospheric CO_2 concentration could be attributed primarily to forest clearing and plowing of land for agriculture (Fig. 4. 2). Currently, burning of fossil fuels dominates the additional flux of CO_2 to the atmosphere. On a regional basis, North Americans consume more fossil fuel per capita than inhabitants of any other region in the world (Table 4. 3).

How Does Carbon Move Around?

Biologically, there are two important groups of organisms that move carbon around, earth's surface provides the necessary impetus for the regeneration of the carbon cycle through the process of photosynthesis, whereby CO_2 from the atmosphere is fixed into organic compounds by plants and algae. The flow of energy continues along a trophic gradient with the consumption and restructuring of organic carbon by animals. Decomposition of animal and plant tissue provides microorganisms with energy leading to the subsequent mineralization of organically-bound carbon into CO_2 and methane (CH_4).

Table 4. 3. Carbon emissions per person (1980).

Region	Tons C · person^{-1} · yr^{-1}
World	1.2
North America	5.6
Former Soviet Union and East Europe	3.4
Western Europe	2.3
Japan, Australia, etc.	2.2
Asia, centrally planned economies	0.4
Mideast	0.7
Latin America	0.6
Africa	0.3
South and Southeast Asia	0.2

What Regulates Carbon Fluxes?

Temperature. Temperature controls both plant and microbial activity. The actual temperature for maximum activity varies among types of organisms, but all have a suitable range in which temperatures that are too low or too high limit activity (Fig. 4. 3). The diversity of soil microbes allows for decomposition to occur in a wider range of temperatures than is suitable for the growth of the primary producers, the plants.

Table 4. 4. Major carbon fluxes.

Flux	Petagrams · yr^{-1} [a]
Atmosphere to land (net flux)	55
Land to atmosphere	
Soil respiration	55
Fossil fuel combustion (1979-82)	5.1-5.4
Deforestation (net)	0.9-2.5
Land to ocean	
River transport (inorganic)	0.7
River transport (organic)	0.5
Atmosphere to ocean	92.5
Ocean to atmosphere	90
Within ocean fluxes	
Biotic turnover	40
Detritus fallout of surface water	4
Circulation of surface into deeper water	38
Circulation of deeper into surface water	40
Ocean to lithosphere	
Sedimentation (inorganic)	0.15
Sedimentation (organic)	0.04

[a] 1 petagram = 10^{15} grams.

Moisture. All forms of life need water, some needing more than others. Water limits activity when there is not enough available, but also may limit activity when there is too much due to a lack of O_2. Oxygen is much less mobile in water than it is in air. Therefore, both primary production and decomposition are herbaceous nature. Typically, soils formed under grass have higher soil organic carbon content than soils formed under forest (Fig. 4. 5).

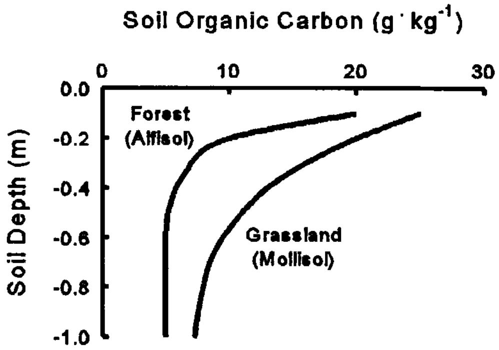


Fig. 4. 5. Depth distribution of soil organic carbon in a typical forest and grassland soil.

Animals grazing on pastures can alter the distribution of carbon by accelerating the input of carbon from plants into the soil system. On grazed land, approximately 10-15% of the energy stored in forage may be directly utilized by the animal, with the remainder excreted as manure. The transformation of plant material into manure facilitates decomposition by soil fauna (earthworms, beetles, spiders, mites) and microorganisms leading to a more diverse and active cycling of carbon.

Soil and aquatic fauna contribute to the cycling of carbon by (i) chewing plant and animal debris into smaller pieces so that more surface area is exposed to microorganisms, (ii) mixing debris and microorganisms throughout the soil and water, and (iii) creating pores in the soil to increase aeration.

Does Carbon Interact With Other Nutrient Cycles?

The amount of carbon fixed by plants depends largely on the availability of nutrients if given adequate sunlight, temperature, and moisture. An adequate supply of nitrogen is necessary for the production of chlorophyll and amino acids. Phosphorus can also limit carbon fixation by plants because phosphorus is needed to make high-energy

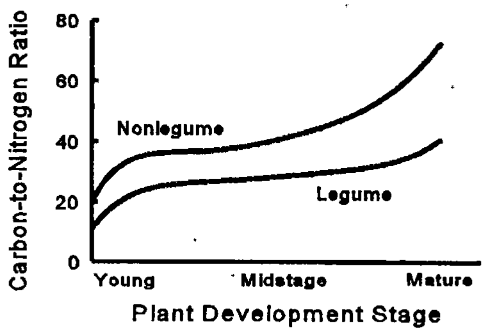


Fig. 4. 6. Carbon-to-nitrogen ratios of plant materials at various stages of growth.

living organisms, primarily bacteria, fungi, actinomycetes, nematodes, and protozoans. Few clear boundaries can be drawn between these fractions, but rather there is a gradation from resistant to active fractions. Soil organic matter is in a continuous state of change with opposing processes of formation and decomposition.

Soil organic matter is amazing in that it contributes to many physical, chemical, and biological properties of the soil. The resistant fractions of organic matter are most important in controlling physical and chemical properties, while the active fractions are most important in controlling biological and chemical properties. Physically, soil organic matter improves soil structure by (i) helping cement soil particles into aggregates, (ii) improving aeration and decreasing bulk density, and (iii) increasing water-holding capacity because of its sponge-like behavior. These improvements in soil structure lead to increased water infiltration, greater rooting capacity of plants, and overall improved water-use efficiency. Because of this increase in water-use by plants, less water runs off the surface of soil and subsequently into stream and surface waters. Less water runoff from agricultural soils especially, reduces the transport of soil particles and chemical pollutants and subsequent damage to surface waters.

Chemically, soil organic matter (i) buffers against pH changes, which can be harmful to plant and microbial communities, (ii) increases the cation and anion exchange capacities of soil, which are essential for the retention of nutrients near the soil surface where plants can use them, (iii) and serves as a giant reservoir of slow-release nutrients, including all the macro- (N, P, K, Ca, Mg, S) and micro-nutrients (Fe, Mn, Zn, Cu, Bo, Mo, Co, Cl).

Biologically, soil organic matter is the energy source for growth and maintenance of soil microorganisms and soil fauna, which are the primary agents that manipulate soil organic matter for improvements in physical and chemical attributes.

Maintenance and increase in soil organic matter can be achieved by maximizing CO_2 fixation by plants, returning as much plant-fixed carbon as possible to the soil, allowing plants rather than microorganisms to utilize soil water, reducing soil temperature by the shading of soil with plants and residues, and keeping soil undisturbed.

land area when animals are not allowed to physically disturb the soil.

Fully vegetated, forested riparian areas along water channels are an excellent way to fix more CO_2 from the atmosphere and convert it into lumber, soil organic matter, and aesthetic beauty. On a landscape scale, riparian areas serve to filter organically-based nutrients and pollutants that would otherwise enter streams and potentially deteriorate surface water quality (Fig. 4. 10). Vegetated riparian areas sequester valuable organic matter compared with an unvegetated and unprotected stream channel, which is susceptible to loss of soil and nutrients.

When land is cultivated for producing higher quality food or fiber resources for animal consumption or human utilization, ecologically-based land management can help achieve economic success and environmental protection. Cropping systems that maintain vegetative cover year-round are well adapted to the Piedmont region, helping to produce large quantities of grain or fiber, improve water-use efficiency of yearly rainfall, reduce soil erosion, and increase soil organic matter (Fig. 4. 11). An increase in soil organic carbon near the soil surface with double-cropping and conservation tillage strategies buffers the soil from periods of extended drought, increases infiltration of water during intense thunderstorms for later crop usage, improves the physical rooting environment by creating more permanent macropores when soil animals consume organic residues, improves the chemical rooting environment by buffering against acidity, increases macro- and micro-nutrient retention near the soil surface for crop uptake, and provides a food source for soil microorganisms to help in balancing conservation and release of nutrients.

The soil surface along with sunlight and rainfall are valuable resources that can give land managers abundant production, but the land resource has limits that need to be respected in order to maintain sustainability. A landscape with abundant pastures can bring steady economic return to land managers and help maintain good quality air, soil, and water resources when environmental limits are respected. However, when a land manager asks too much from the land such as increasing the stocking rate beyond the carrying capacity of the environment, then soils become threatened, erosion increases, water becomes polluted, and economic return from the land diminishes with time (Fig. 4. 12). Long-term stewards of the land realize the importance of maintaining a balance

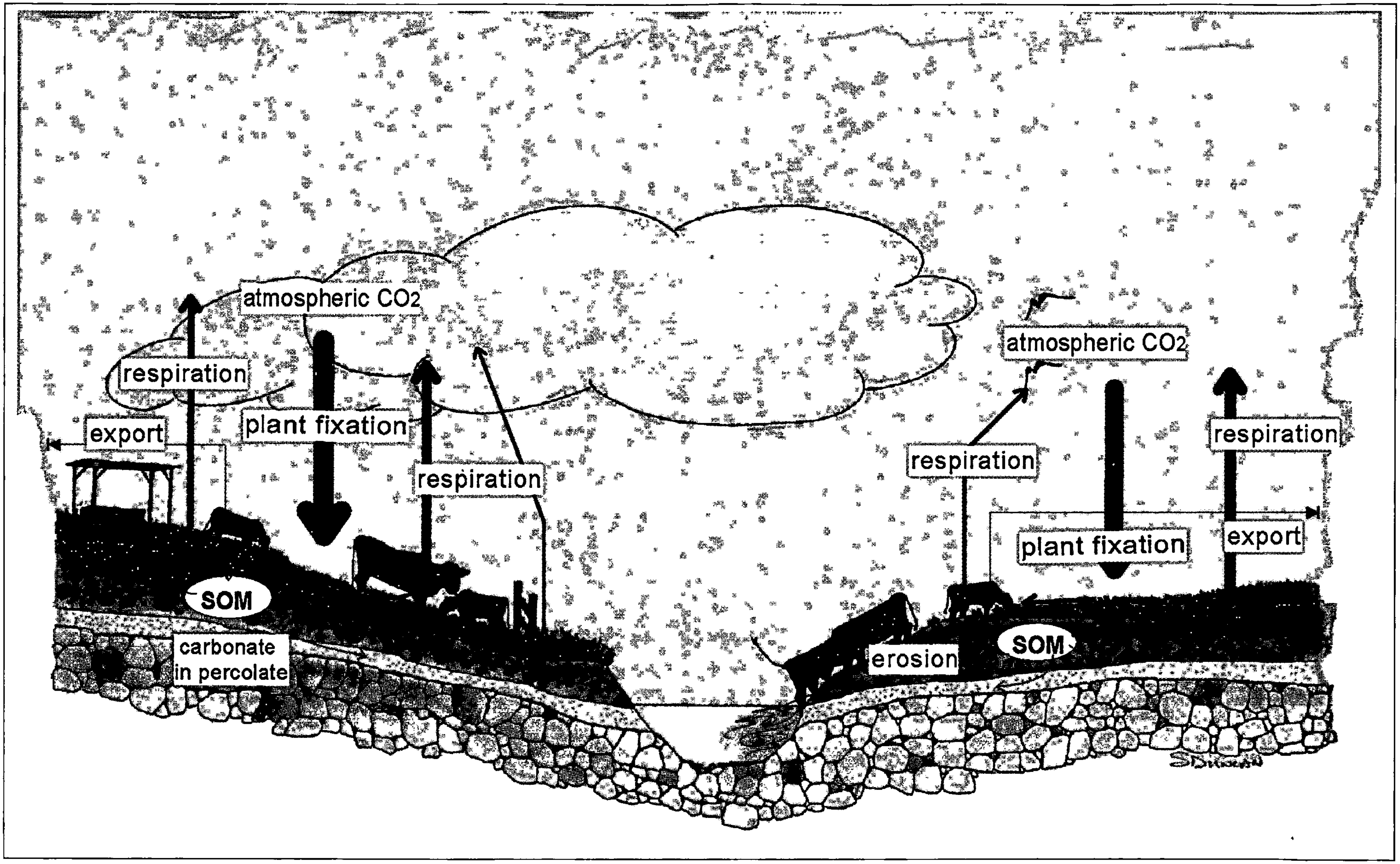


Fig. 4.9. Fenced riparian filter strips (left) reduce the potential of manure and associated bacterial constituents from polluting water. Riparian vegetation filters nutrients and sediments. Erosion of stream banks (right) can lead to loss of soil organic matter (SOM) and reduce potential productivity of the land.

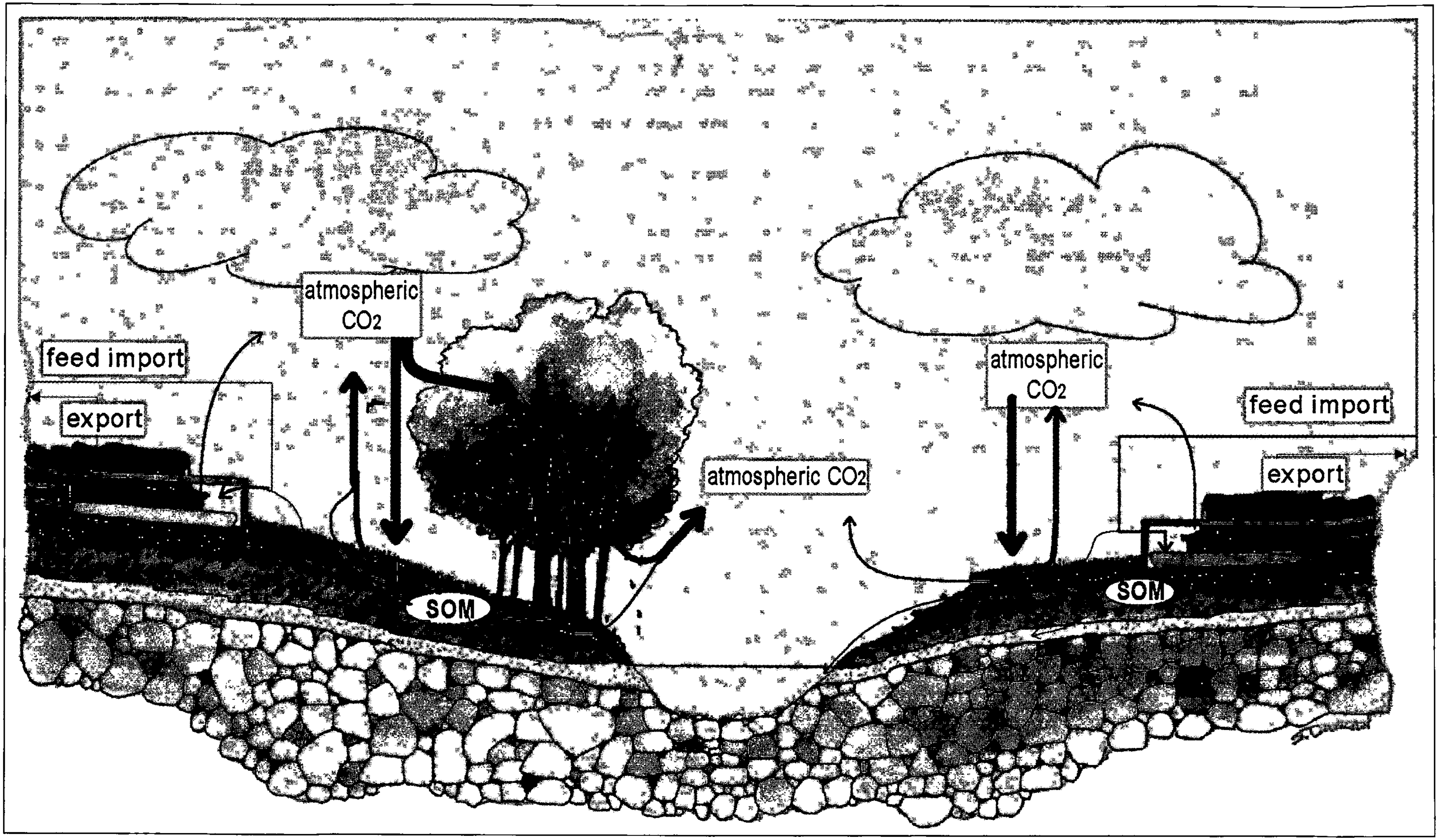


Fig. 4.10. Riparian buffers (left) reduce the potential of manure and associated bacterial constituents from polluting water. Riparian vegetation filters nutrients and sediments and allows for build-up of soil organic matter (SOM). Erosion of stream banks and side slopes (right) leads to loss of organic matter and potentially productive land.

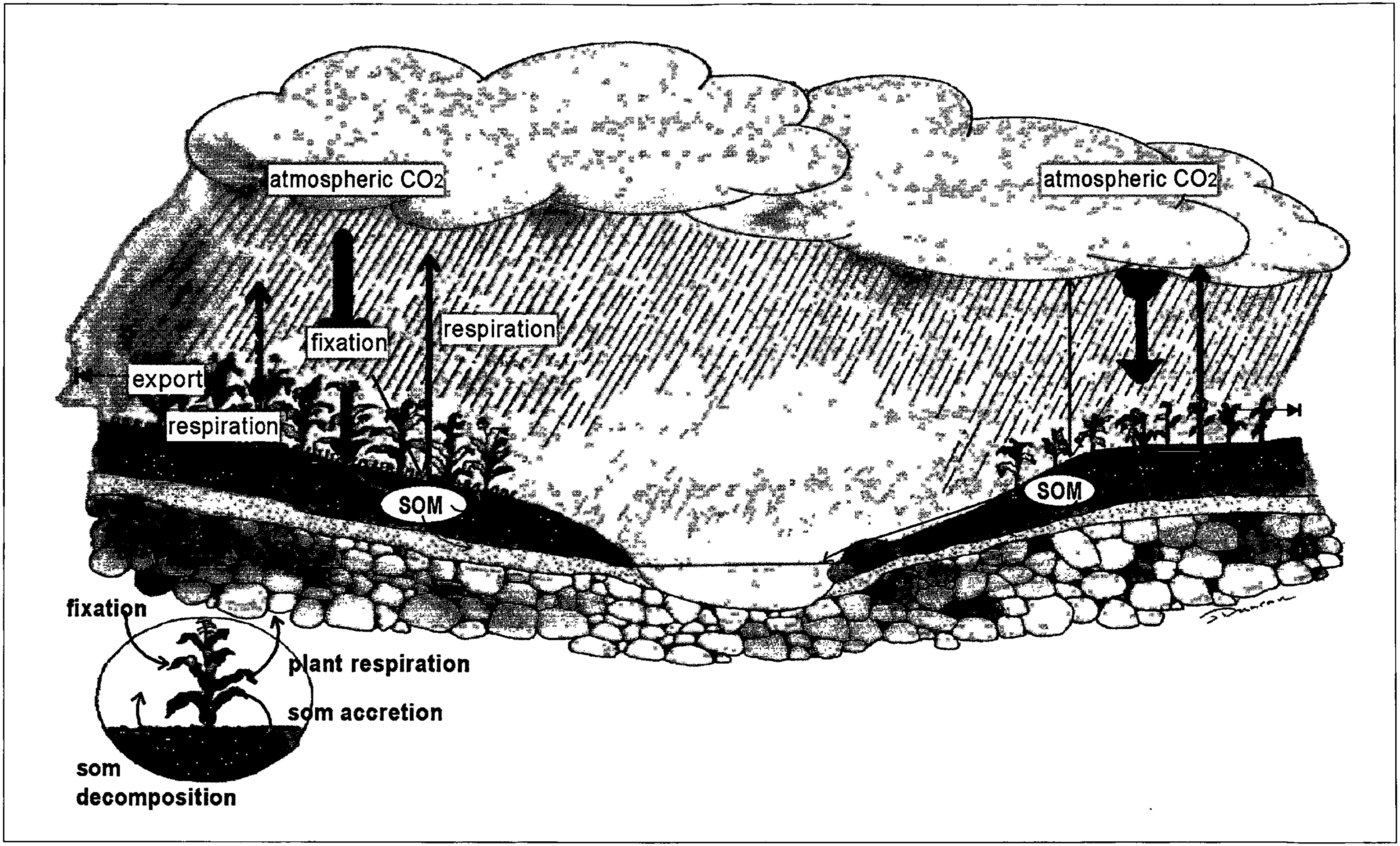


Fig. 4.11. Conservation cropping systems that maintain vegetation and residue covers on the soil year-round (left) produce larger quantities of grain or fiber, improve water-use efficiency of yearly rainfall, reduce soil erosion, and increase soil organic matter (SOM). An increase in soil organic matter buffers crops from extended drought, improves rooting, and increases soil fertility. Width of arrow is related to flux.

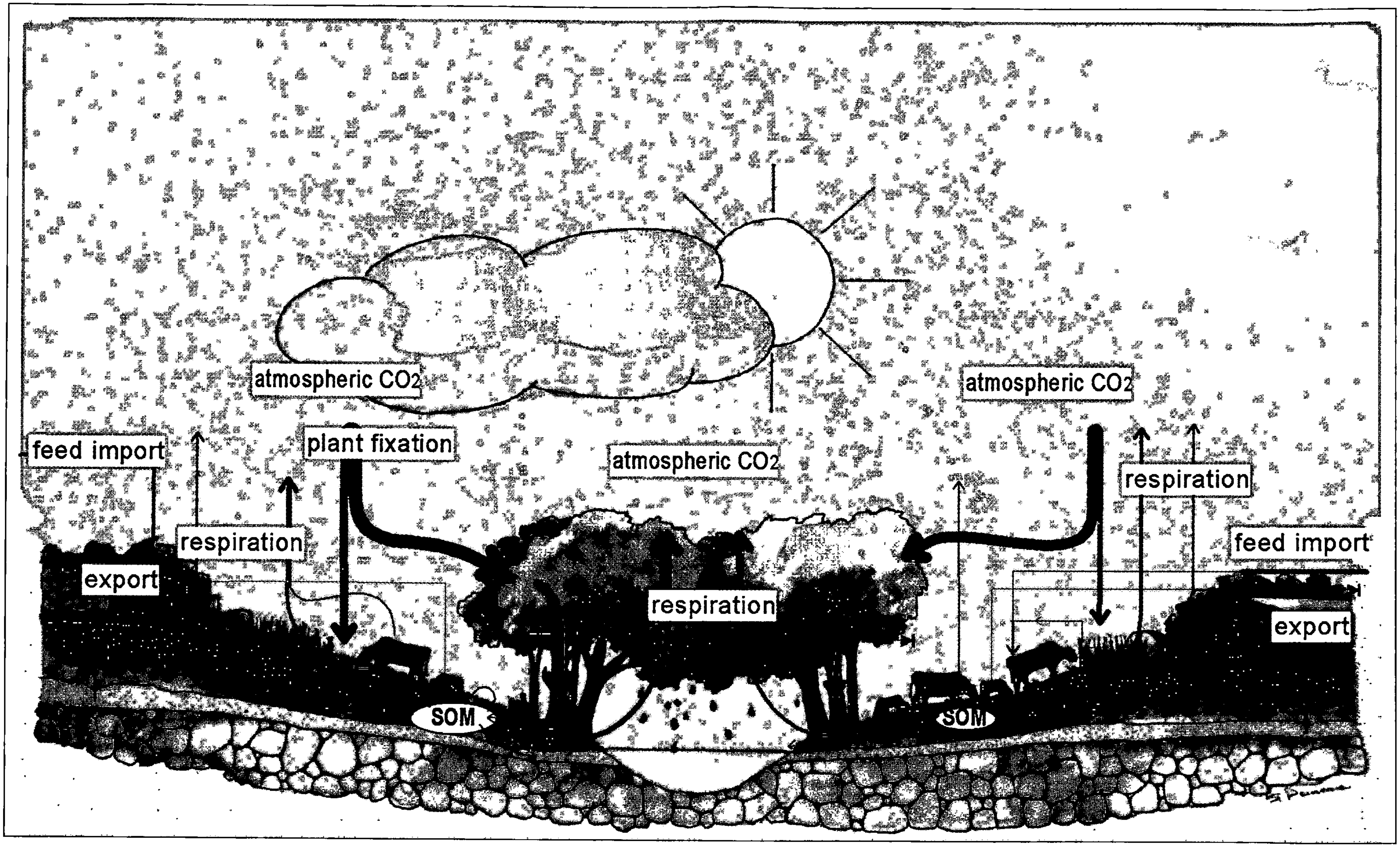


Fig. 4.12. The land and climate have limits. Asking too much from the land increases its susceptibility to erosion and water pollution (right) which results in a reduction of productivity for the land resource manager and the ecosphere. The implementation of best managemnt practices (left) can improve productivity while ensuring preservation of environmental resources. Width of arrow is related to flux.

NITROGEN CYCLE

Why is Nitrogen Important?

Compared with carbon, hydrogen, and oxygen, nitrogen is only a minor constituent of living matter, but it is an essential element for life on Earth. Nitrogen is part of DNA and RNA molecules whose main function is to transmit genetic information in plants and animals. In addition, nitrogen is a constituent of proteins that play important roles as structural components and catalysts in plant and animal cells. Nitrogen is also a component of chlorophyll, the pigment that allows plants to trap solar energy for the synthesis of organic compounds.

Where is Nitrogen Stored?

Nitrogen on Earth exists in igneous rocks, in the atmosphere, in waters, and in soils. The amount of N held in igneous rocks is much larger than that present in the atmosphere, and the amount present in the atmosphere is much larger than the amounts present in waters and in soils. For the most part, the N present in igneous rocks is not available to plants and animals and therefore does not play an important role in the N cycle. Thus, most of the N cycling occurs in the atmosphere, waters, and soils.

The atmosphere contains about 78% N by volume, which amounts to about 3 tons of N over each square foot of the Earth's surface. Atmospheric N is in the form of N gas (N_2), which cannot be used directly by plants or animals but must be converted (or "fixed") to ammonia (NH_3) or ammonium (NH_4) before it can be utilized. This N fixation is carried out industrially by N fertilizer factories, or biologically by either free-living microorganisms or by microorganisms that live in association with plants (Fig. 5.1).

The N fixed industrially or biologically is subsequently transformed by living organisms into organic compounds such as RNA, DNA, and proteins. When these organisms die, their N-containing residues are decomposed and N is converted back to inorganic forms (ammonium and nitrate) that can be utilized by plants and other living organisms. The inorganic forms of N can also be converted to gaseous forms such as ammonia,

Nitrogen Mineralization/Immobilization Nitrogen mineralization is a biological process through which microorganisms convert organic N (like proteins) into ammonium (NH_4^+), an inorganic form available to plants and microbes. This process occurs during the decomposition of soil organic matter, plant residues, animal manures, and other organic wastes. Nitrogen mineralization is a very important process because it recycles N within the soil: the N that plants and microorganisms had absorbed and converted into organic forms (RNA, DNA, proteins) is converted back to an inorganic form (NH_4^+) that can be utilized again by plants and microorganisms.

Organic Nitrogen (crop residues, manures) ---> Ammonium (NH_4^+)

As a biological process, N mineralization is affected by environmental factors such as temperature, soil pH, and soil water content. Although the process can occur from temperatures just above freezing to about 160°F, the optimum temperature is around 95°F. Similarly, N mineralization can proceed from a soil pH slightly below 5 to values as high as 9, but the optimum soil pH is around 7 (neutral - not acid and not alkaline). Nitrogen mineralization stops or proceeds very slowly under dry soil conditions, and increases as the soil water content increases. Typically, the optimum soil water content is when the soil contains 50% of the maximum amount of water that it can hold. At that water content, 50% of the soil pore space is filled with water and 50% is filled with air, providing adequate water and air for microbial growth. Nitrogen mineralization can proceed under a wide range of environmental conditions because of the diversity of the microorganisms involved.

Ammonium, the product generated by the mineralization process, is positively charged and is consequently held tightly by the soil negative charges. This mechanism conserves N because it prevents its leaching by rain water percolating through the soil profile.

Immobilization is the process through which inorganic N is immobilized into organic forms by microorganisms. Typically significant immobilization can occur during the

Denitrification Denitrification is a biological process through which nitrate is converted into gaseous forms (nitrous oxide and molecular N) that can escape to the atmosphere. The process requires lack of oxygen because it occurs when microorganisms use nitrate instead of oxygen for respiration. Therefore, denitrification can occur in water-saturated soils in which water has displaced air from the soil, as well as in soils in which the oxygen concentration of the soil atmosphere has been depleted due to high biological activity. The latter case typically occurs after the addition of animal manures to soil. In addition to nitrate and lack of oxygen, denitrifiers also require easily decomposable organic compounds as a source of carbon. Denitrification has an optimum temperature around 75°F, but it can occur, albeit slowly, at temperatures close to freezing.

Nitrate (NO_3^-) ---> Nitrous oxide (N_2O) ---> Nitrogen Gas (N_2)

Denitrification is of agronomic importance because the nitrogen lost through this process is no longer available for plant uptake. In addition, denitrification is a key process in the global N cycle because it is the only process that returns N in large amounts to the atmosphere, counterbalancing the N removed from the atmosphere by the N fixation process. Denitrification also has environmental importance because nitrous oxide (N_2O), one of the gases generated by denitrification, is a gas involved in the "greenhouse effect", a process that keeps the Earth warm and is apparently responsible for the current overall warming of the planet.

What are the Main Mechanisms of Nitrogen Transport?

Besides processes that transform N, there are processes responsible for the transport of N out of the soil. Some of the most important N transport processes are ammonia volatilization, nitrate leaching, and surface runoff.

Ammonia Volatilization Ammonia volatilization is a physico-chemical process through which ammonia gas (NH_3) is lost to the atmosphere. Ammonia is formed from ammonium (NH_4^+) at a relatively fast rate when the soil pH is larger than 7.5 to 8.

Nitrogen Cycling in a Typical Southern Piedmont Landscape

In a typical Southern Piedmont agricultural landscape, most of the land is occupied by forests, and the area in pasture is usually larger than that in crops. The percentage of the area in forests that is fertilized with nitrogen is currently low, although it is increasing at a steady rate. Pastures and crops are commonly fertilized with nitrogen in the form of inorganic fertilizers or animal manures. Some of the common inorganic N fertilizers used for pasture and crop fertilization are urea and ammonium nitrate.

Urea is an organic N compound that once applied can mineralize quickly to produce ammonium, an inorganic N form directly available for plant uptake. When urea is surface applied, its mineralization temporarily increases soil pH to a point that favors ammonia volatilization, a gaseous loss of N from the system (Fig. 5.2, 5.3). In contrast, when urea is incorporated into the soil ammonia volatilization is minimal because the ammonium formed (which is positively charged) is retained by negatively charged clays in the soil. Ammonium nitrate, another common fertilizer, has half of its nitrogen in the form of ammonium and half in the form of nitrate. Since all the nitrogen is in inorganic form, there is no mineralization process that could raise the soil pH, and consequently there is no loss of N through ammonia volatilization even if ammonium nitrate is surface applied. On average, about 50 to 60% of the N applied with inorganic fertilizers is taken up by pastures and crops; the rest of the N is partly lost from the system and partly immobilized by microorganisms.

Manures typically used to fertilize pastures and crops in the Southern Piedmont are those generated by the poultry industry. These are layer manure and broiler litter, a mixture of broiler excreta and wood-based bedding material. In general, these manures have 5 to 20% of their total N in inorganic form (mainly ammonium) with the remaining N in organic form. When layer manure and broiler litter are applied to soil, the inorganic N is immediately available for plant uptake, but the organic N must be mineralized and converted to ammonium before it can be utilized by plants. In general, about 60% of the organic N in these manures mineralizes within a growing season, with the remaining N staying in the soil and only a small portion mineralizing in subsequent growing seasons. Consequently, application of manures usually leads to a buildup of organic N in soil.

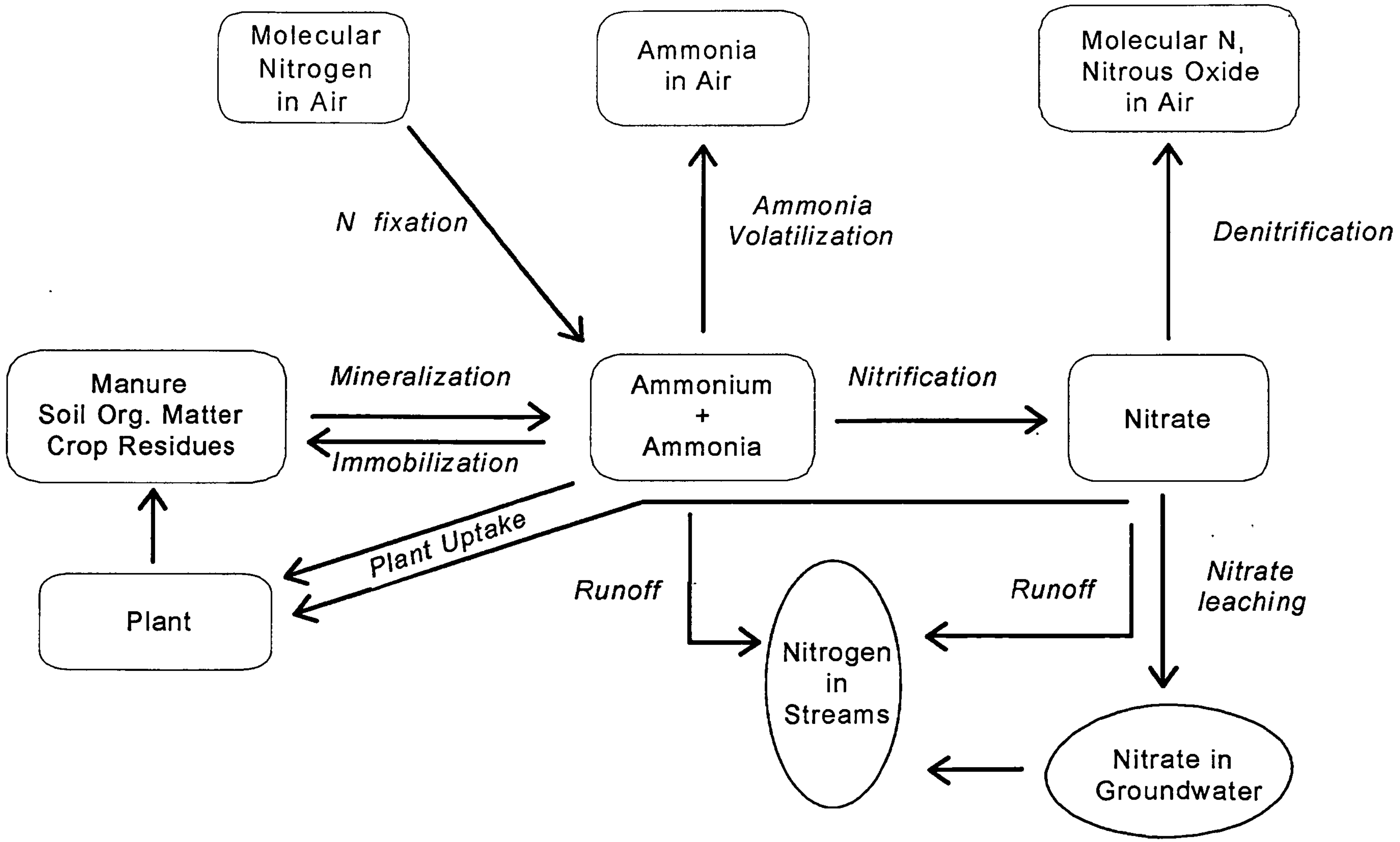


Fig. 5.1. Diagram of the nitrogen cycle

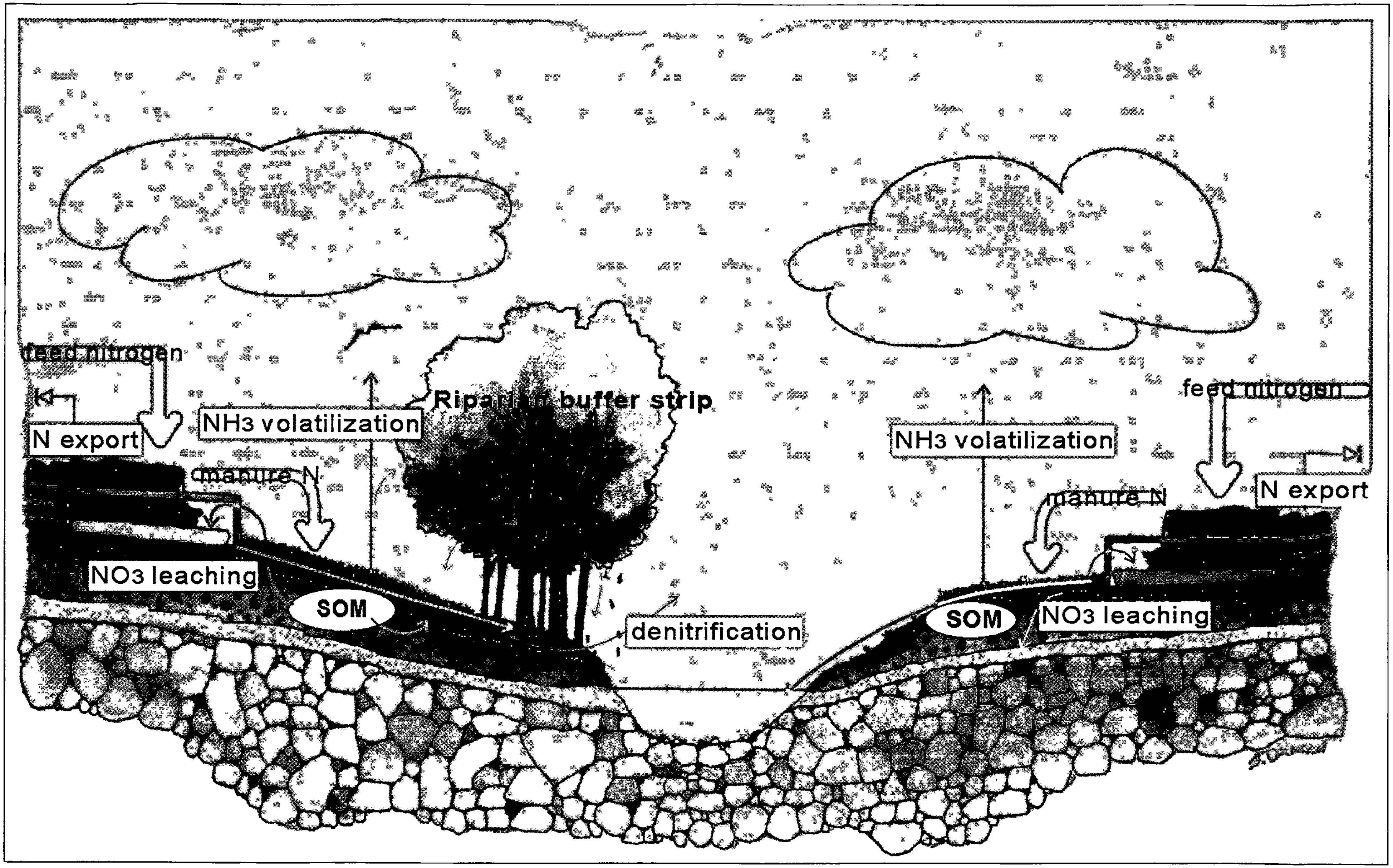
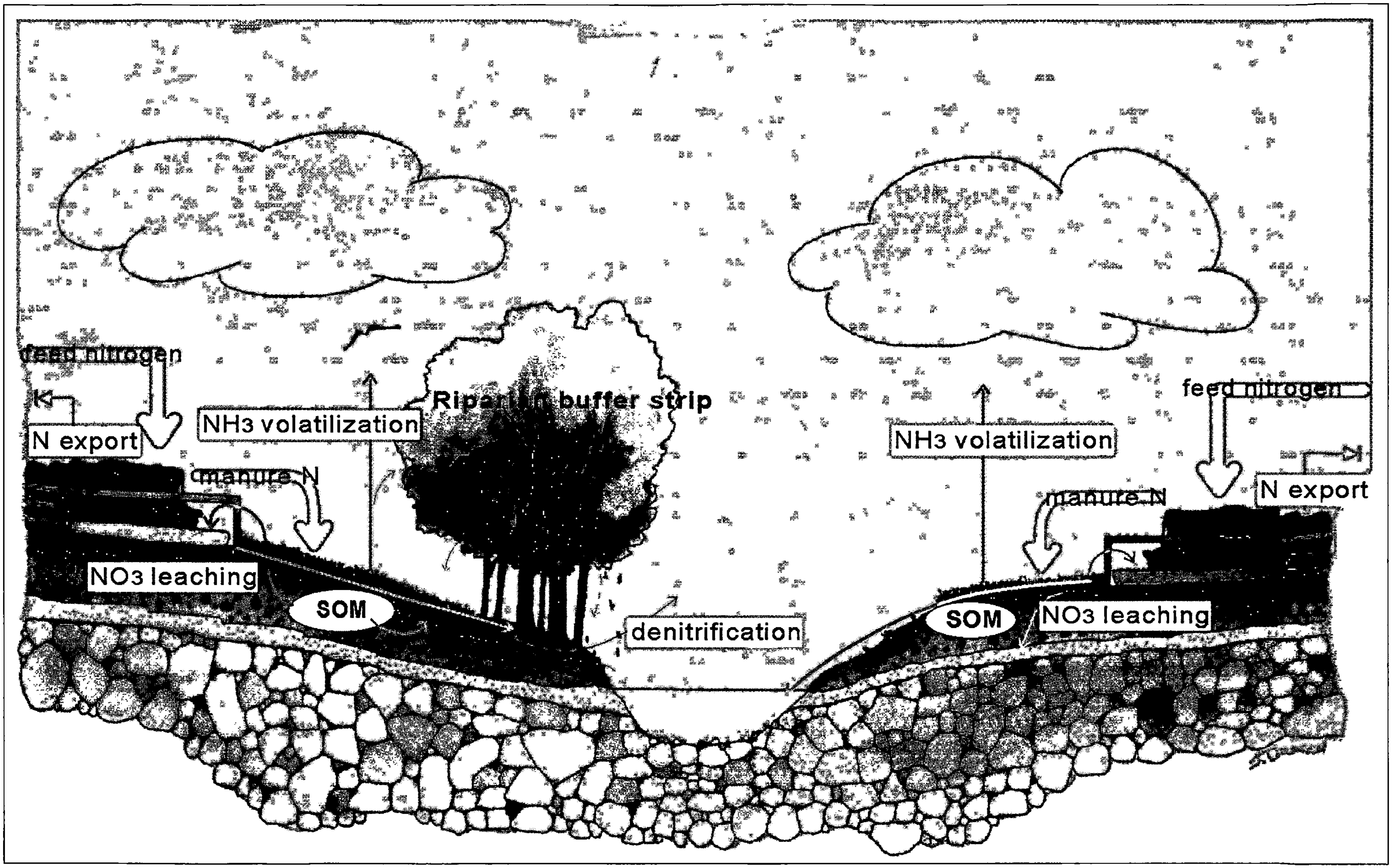


Fig. 5.3. Riparian buffer strips (containing grasses, shrubs, and trees) located near confined animal operations (left) can reduce loss of nitrogen to streams by slowing surface flow, thereby filtering particulate N and allowing plant uptake of soluble N. Riparian buffers also create the conditions necessary to denitrify any nitrate reaching them. Degraded stream banks near confined animal operations (right) lack the mechanisms to slow down runoff, increase infiltration, and reduce nitrogen levels, thereby resulting in higher amounts of nitrogen reaching the stream.



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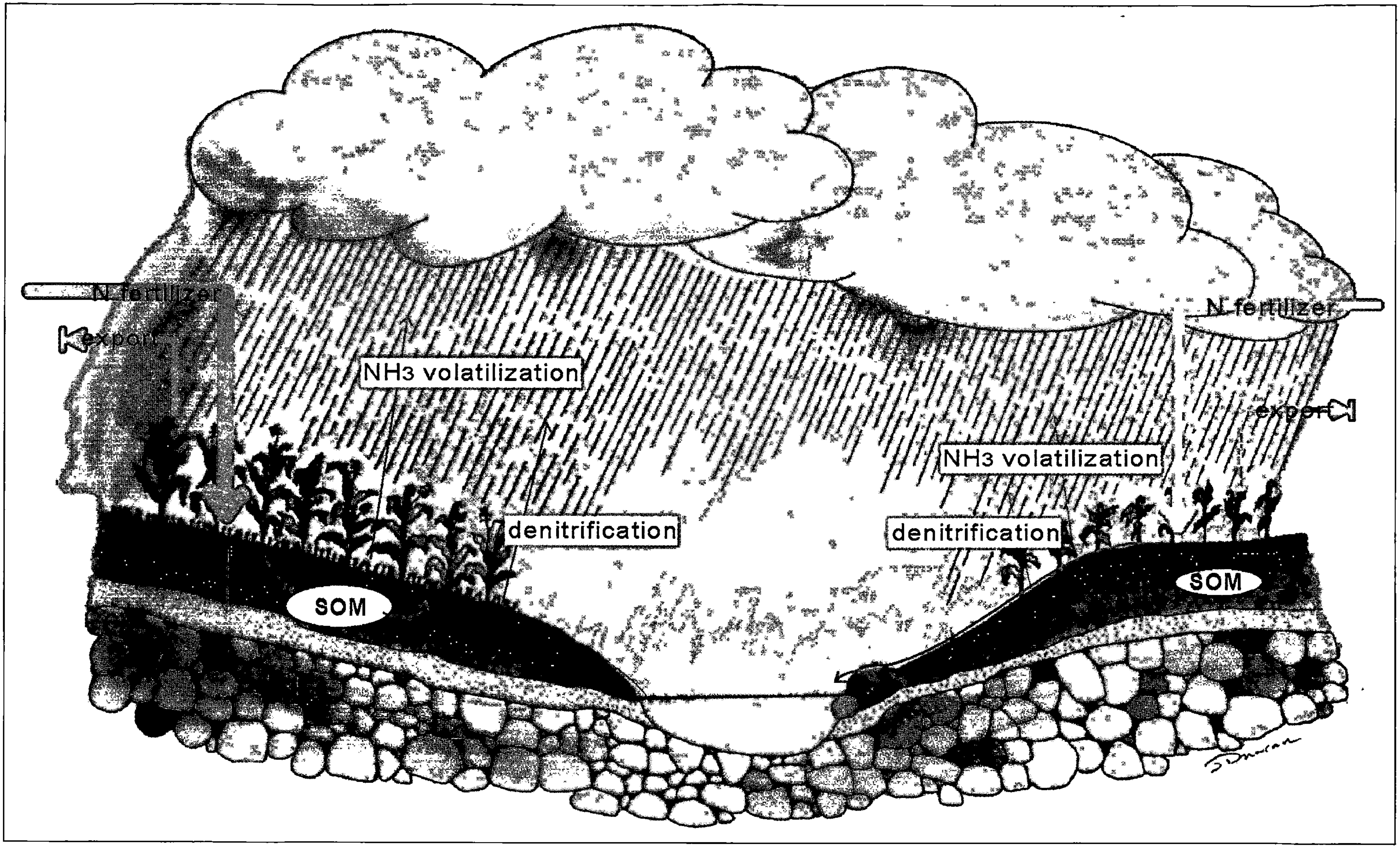

Fig. 5.4. Conservation tillage in crop production can reduce the potential for nitrogen loss due to erosion and surface runoff. Crop residues on the soil surface (left) prevent soil crusting and increase water infiltration, thereby reducing surface runoff and erosion. Increased water infiltration in conservation tillage usually leads to higher yields and better N fertilizer efficiency in dry years, and may lead to higher nitrate leaching in wet years. Crusting of bare soil in conventional tillage (right) reduces water infiltration and increases surface runoff, which can lead to increased soil erosion, losses of particulate and soluble N to streams, and reductions in crop yield.

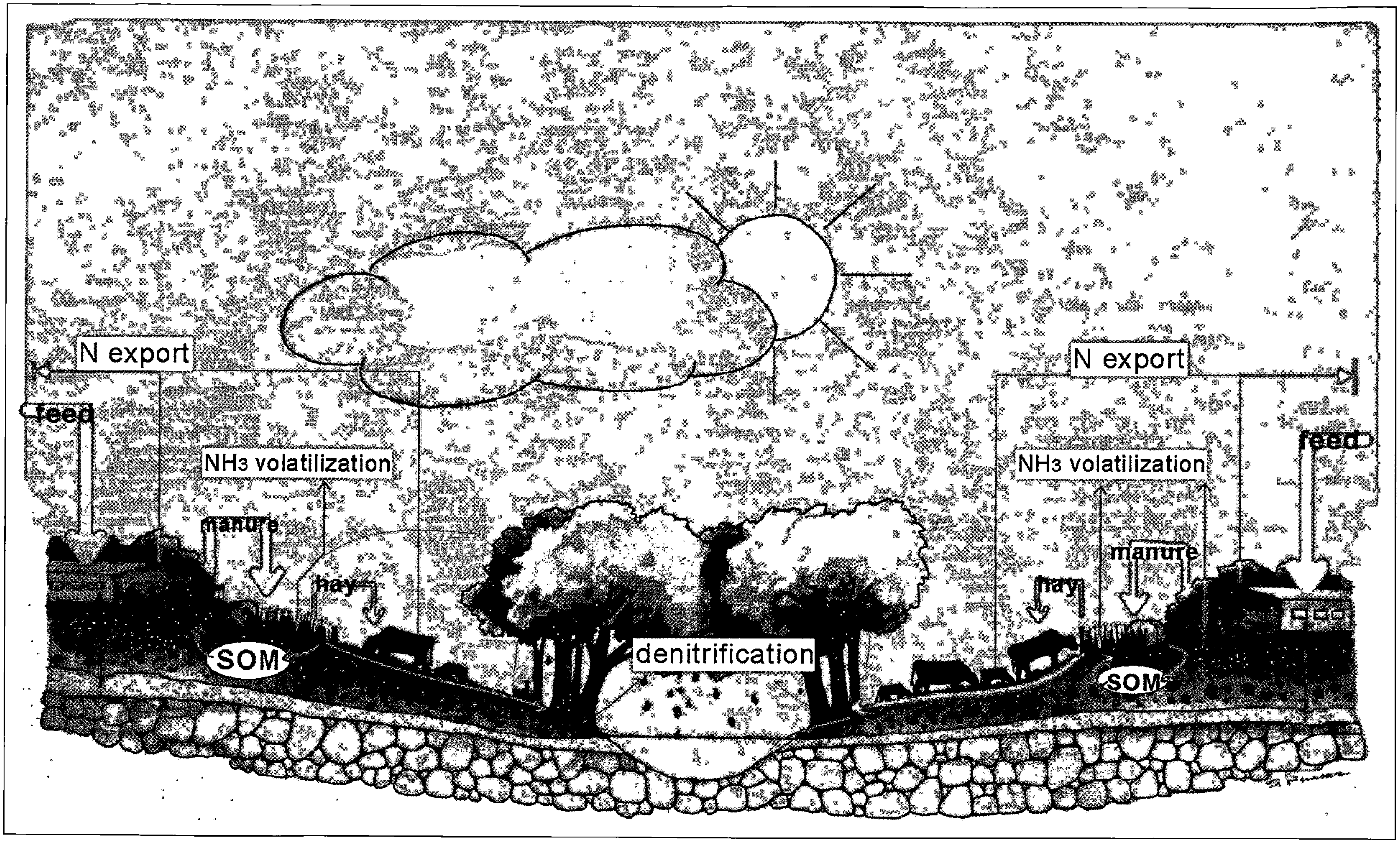

Fig. 5.5. Storing manure from poultry operations in a stack house prevents runoff water from being contaminated with manure nitrogen (left). Fenced riparian buffer strips next to adequately stocked pastures (left) minimize contamination of surface and groundwater with nitrogen. Leaving manure exposed to the weather (right) leads to contamination of surface runoff with nitrogen and to increased losses through ammonia volatilization. Overgrazing of pastures near riparian buffers (right) leads to increased surface runoff and increased transport of manure N from the pasture to the stream.

PHOSPHORUS CYCLE

Introduction

Why are we concerned about Phosphorus? We are concerned because phosphorus (P) is an essential element for the reproduction, growth and maintenance of all living organisms. You and me, the birds and the bees, the cows and the grasses, the trees and the seeds that present the world with new life all require approximately 0.3 to 0.6 percent of our dry body weight in phosphorus. As in all things, there can be either too much or too little. A balance must be maintained to ensure a highly productive, sustainable ecosystem.

What does phosphorus do in the ecosystem? Phosphorus plays an essential role in plant and animal growth and has an irreplaceable role as a structural link in genetic materials DNA and RNA. Its functions are primarily concerned with energy transfers in both respiration and with photosynthesis and internal translocation of nutrients and energy within plants. Its effects include enhanced cell division, fat formation, flowering, fruiting, seed formation, and development of lateral and fibrous roots of plants. Phosphorus also improves disease resistance and forage quality in most plants. In fact, it is often the most common growth-limiting factor both in the soil and in freshwater, and may be a major factor in obtaining a balanced system. (see workbook introduction on limiting factors).

Why is phosphorus a limitation? There are several reasons why phosphorus can be a limiting factor. First, in the watershed, rock breakdown releases little usable phosphorus. This is especially true in the Southeastern United States where most rocks or geology are naturally low in phosphorus. Second, unlike nitrogen, phosphorus

Fig. 6.1. Diagram of phosphorus availability to plants in the environment. Note that there is less readily available phosphorus than there is very slowly available phosphorus.

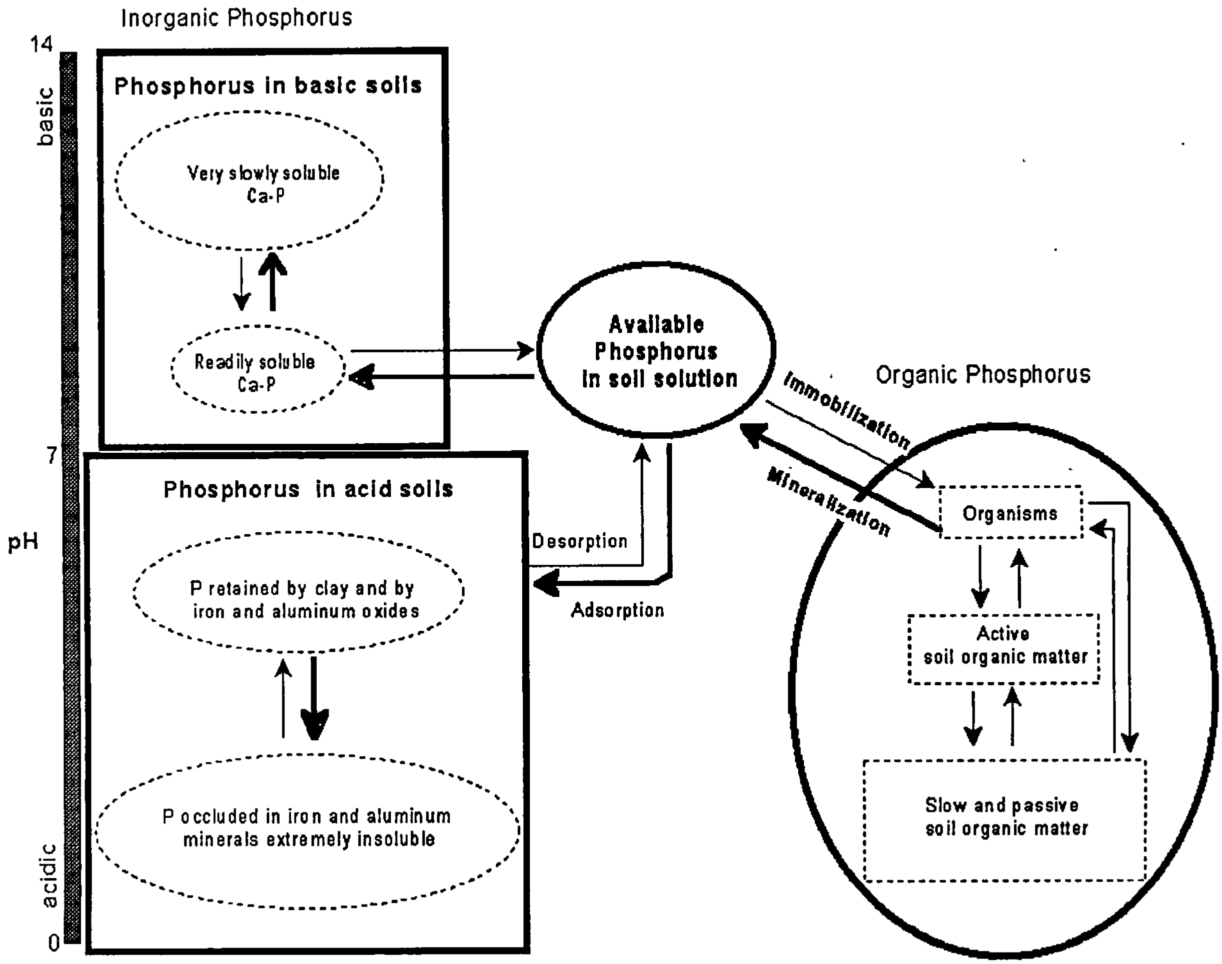

Fig. 6.2. The phosphorus cycle in soils. The boxes represent pool sizes of the various forms of phosphorus in the cycle, while the arrows represent translocations and transformations among these pools (the larger the arrow the greater movement). The pools with solid lines indicate the principal groups and the pools identified with dashed lines indicate major pools within each of the principal groups. Note that on the left side of the illustration the inorganic forms of phosphorus are represented and are related to pH. Organic forms of phosphorus represented on the right side of the illustration. Within each of these groups, the less soluble, less available forms tend to dominate.

absorption capacities. In the Southeastern United States many of the soils are acidic and are high in aluminum and iron oxide clays which can absorb large amount of phosphorus. This is the primary reason soil test phosphorus levels do not rapidly increase with repeated phosphorus fertilizer and/or manure applications. There are, however, maximum levels of phosphorus that soils can absorb (maximum absorption capacity). Once a soil has reached its maximum phosphorus absorption capacity,

Phosphorus and Plant Uptake

Crop response as a function of soil test phosphorus may be described as levels of nutrition; deficient, critical, adequate, and excessive levels. The requirement for fertilizer P is that amount of P required to assure non-limiting status for plant growth (adequate level). Since P is immobile in the soil, primary processes by which P is supplied are diffusion to the root surfaces and root interception. Critical phosphorus concentrations in shoot tissue are in the range of 0.14 to 0.4 % for most cultivated plants. Once P is absorbed by the roots, it becomes mobile within the plant and is readily translocated between tissues. This is a form of recycling within the plant. Phosphorus absorbed by the plant may be eaten by herbivores with portions retained within the body growth of the animals, with the balance excreted primarily in fecal material, may be recycled within the plant, or may be returned to the soil as uneaten, and dead plant material. Soil organisms play extremely important roles in the decomposition (turnover) of fecal and plant litter material. Plant roots absorb phosphorus from soil solution primarily as the $H_2PO_4^-$ ion.

Phosphorus in the Water

In water (streams and groundwater), phosphorus can be found in several forms but bioavailable phosphorus (PO_4 or orthophosphate, which is what the test kit measures) is the form that is readily utilized by biota. In fact P is one of those solutes or nutrients that regulates biological processes in streams relative to concentrations of P or relative to supply and demand. So the more P there is, (up to a certain

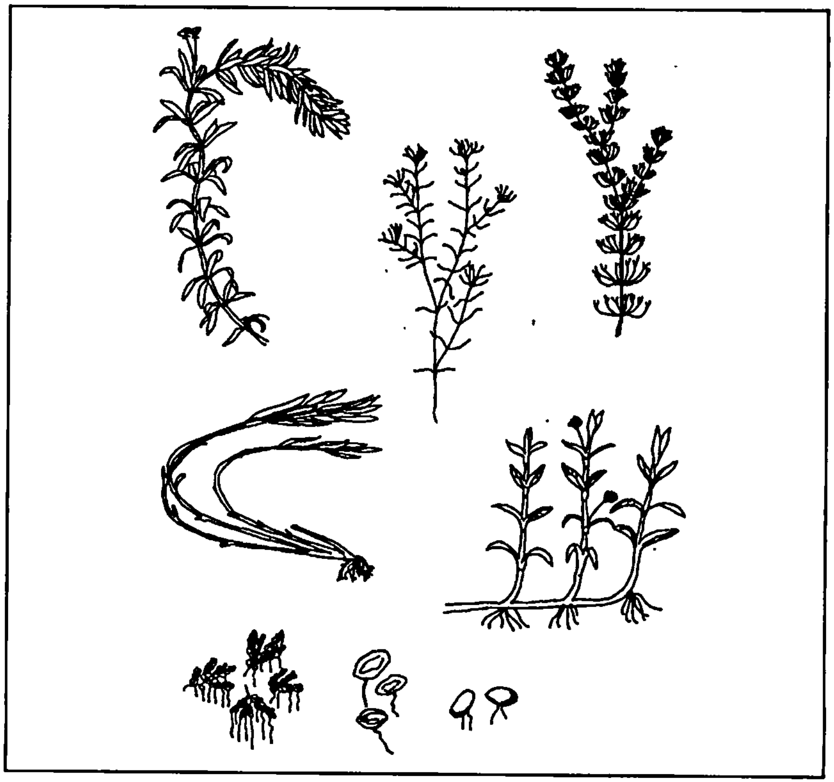

Fig. 6.4. A few examples of periphyton commonly found in temperate freshwater streams.

Unlike phosphorus in soil solution, phosphorus in the stream network is considered mobile and is transported primarily in the particulate form.

Phosphorus uptake by plants (phytoplankton and algae are tiny plants) both in the water and in the soil solution depends on the amount and concentration of "bioavailable phosphorus" (in the soil solution or in the stream), genus and species of plants, stage of growth at harvest and environmental factors such as temperature, amount of sunlight and rainfall. The amount of rainfall may influence the concentration of phosphorus in varying degrees and directions. Generally, if rainfall increases and runoff occurs, erosion may also increase and with the increased erosion phosphorus in particulate form enters the streams. In figure 6.5 one can see that the general trend is, as the stream rises phosphorus concentrations in the stream usually increase. But, also notice how variable this can be, several other factors are influential. For example, if large amounts of rain fall on pastures with good ground coverage, little erosion may occur. Resulting in large amounts of runoff low in particulates flowing into the stream, which will dilute inherent phosphorus concentrations in the stream. Another effect is drought, if there is little rain, less water moves into the streams and streams lose water through evaporation. The phosphorus does not evaporate with the water. Because there is the same amount of phosphorus in less water this results in higher concentrations of phosphorus in the stream.

In some areas of the southeastern USA, phosphorus concentrations have been going up. In 1972 the average total phosphorus concentration in the Ogeechee river near Eden, Georgia was 0.03 ppm, but in 1990 it was above 0.09 ppm. What does this indicate? Are we throwing moneys down the drain? Are fertilizers being applied at the optimal time? How will we know if we don't look more closely at phosphorus concentrations in streams and in runoff relative to management practices.

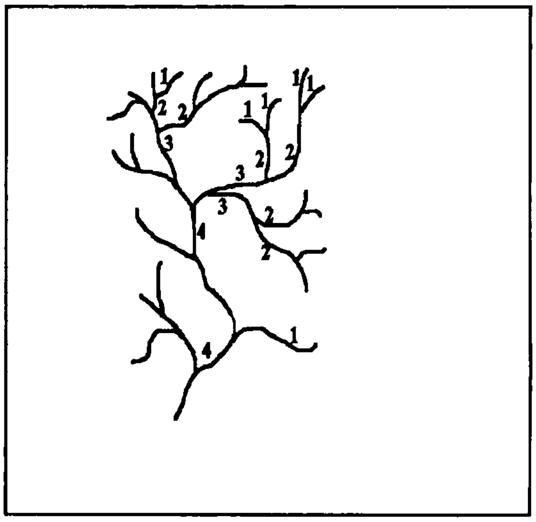

Fig. 6.6. Network of streams or drainage network illustrating stream order classification. This method of stream order classification requires two streams of the same order must come together to increase stream order. This is a fourth-order stream.

is strongly regulated by the gradient and type of organic matter. The relative importance of the major functional invertebrate groups (how and what they eat), shredders, grazers, collectors, and predators gradually changes downstream with food supply (Fig. 6.7 and Appendix I). So, specific ratios of the different types of aquatic insects are present depending on whether the habitat is in a fast moving headwater stream (steep gradient) or a slow, lazy meandering river (flat gradient), or whether the stream has more coarse particulate organic matter (leaves falling into the stream) than fine particulate organic matter. Upstream concentrations of P are normally lower than downstream concentrations of P which has often been attributed to various kinds of land use and the percentages of those land uses within a watershed. The amount of nutrients present in the stream is directly related to the amount and type of algae growing in the stream (Fig. 6.8 & 6.9) which in effect influences the type of functional group (aquatic insects) present. Grazers feed on periphyton and can out compete shredders and collectors when algae is prominent. Algae is most commonly found in

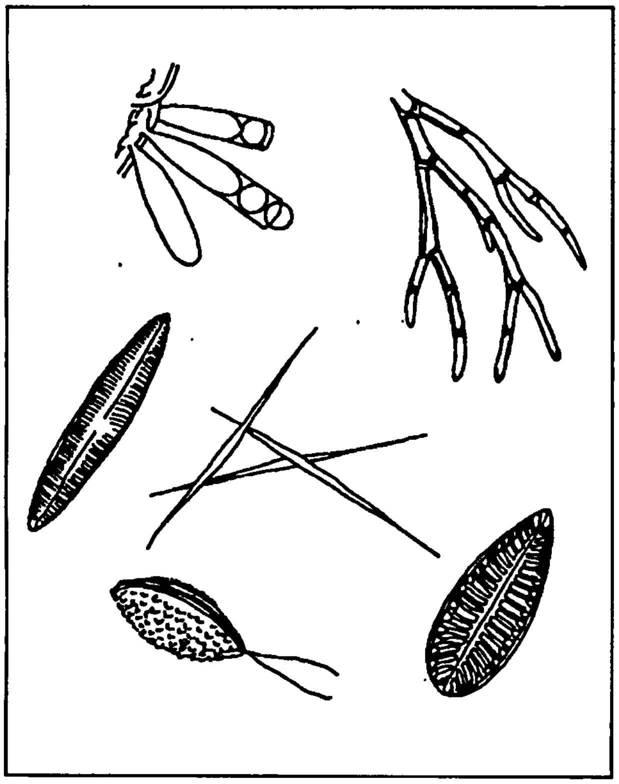

Fig. 6.8. Examples of algae commonly present in clean water with relatively low concentrations of N and P.

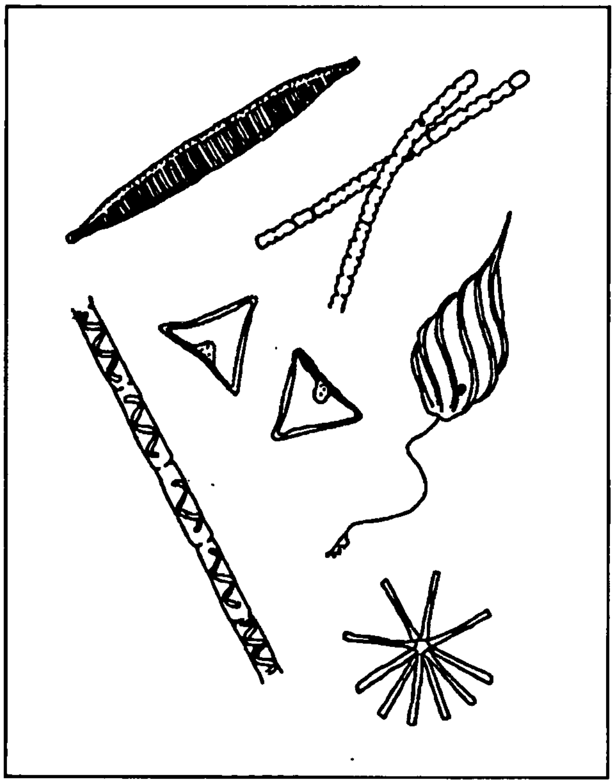

Fig. 6.9. Examples of algae that influence the taste and smell of water which are commonly found in polluted surface waters.

Table 6.1. Increase in transport of nitrogen and phosphorus with increase in the slope of arable land in Wisconsin drainage basins. Modified form Mackenthun et al., 1964

Slope	**N, kg ha $^{-1}$**	**% increase**	**P kg ha^{-1}**	**% increase**
8°	16	–	0.45	–
20°	34	210	1.6	360

This however may be modified in the case of the Southern Piedmont where manures are applied to the surface of pastures as fertilizers. While some of the P is dissolved and makes its way to the soil some of the P remains attached to the particulate organic matter. At first this organic particulate P is lost in storm runoff. Over time as manure is applied and reapplied to the same area, to supply the N required by the pasture, P begins to build up. The P builds up because there is more P in the manure than the plant can use. This build up is in the upper layers of soil as well as in erosional deposition areas which are usually closer to the streams and groundwater (further downhill in depressions or riparian areas). The soils may then begin to reach their absorption capacities for P and dissolved P begins to move through the soil profile and into groundwater. Resulting in P being mobile in and on the landscape.

The phosphorus cycle in a pasture, crop field, turf, or forest is polycyclic, that is, cycles between soil and residues, soluble P and plant uptake, plants and animals that consume them, and internal cycling between roots, leaves and stems of plants occur simultaneously. Generally, most P cycling occurs through the action of plants and animals in the hydrosphere and movement of P is seaward with water drainage. When P is deficient for plants growth (primary producers), P may be said to be in "tight" circulation (the spiral would be like a very tightly wound spring) and the amount available for transport to pathways of loss by drainage water is greatly reduced. If P supply is excessive, then the amounts available for transport losses by drainage water may be relatively large (loose, or open circulation).

It's important to realize that certain principles of ecology apply. These can be stated as follows: 1) everything is connected to everything else, 2) everything must go

Management Scenarios in the Southern Piedmont

Grazing In the last twenty years many acres in the Southern Piedmont have been converted to pasture and either grazed or hayed. Because this region is highly dissected by small streams, streams are a fairly reliable source of water for the grazing animal. When cattle are permitted to access streams at will, side slopes often end up denuded of vegetation (Fig. 6.11, right). The absence of vegetation leaves the slope vulnerable to erosion and provides less forage for the grazing animal. On the other hand if animals are given limited access to streams or are provided shades with ample drinking water, side slopes are not trampled and denuded of vegetation and act as a buffer strip Figure 6.11, left). Phosphorus attached to soil particle or particulate organic matter are not lost with erosion but are retained in the lush vegetation of the buffer strip.

The technical side - When broiler manure is applied at rates to supply the nitrogen requirements of the plant which removes N & P in an approximate ratio of 7-8 parts of N to 1 part P. Research has indicated that broiler manure has N equivalent value of about 65% compared to NH_4NO_3 (65% as effective as NH_4NO_3 on a unit basis). Consequently to obtain the same level of response to N, one would apply 1.5 times as much broiler manure N. However the N:P ratio in broiler litter is about 2.5 N to 1.0 P. Because of the volatilization of N loss ratio narrows to less than 2.0 N to 1.0 P. Furthermore, the non-volatile immobile nature of P permits longer residence time in the soil. Consequently one can readily document accumulation of P in soils which have been amended with manure for long periods. For hay fields and grazed pastures, this accumulation is at or near the soil surface making it easily accessible for transport by overland flow of water.

Feedlots and holding areas Confined animal enterprises can be managed to maximize production and minimize nutrient losses. Phosphorus imported to feed the animals is quickly converted into animal weight gain and manure. The manure (phosphorus) can then be applied to hay fields which are between the confined animal areas and the stream. The hay is then harvested and the P is once again fed to the animals. There is more P in the manure than the hay will use. This excess may be captured as runoff in the riparian buffer strips. Much of this P will be recycled within the riparian vegetation but some of the P will fall into the stream as leaf litter (Fig. 6.12, internally within the plant. Other losses which may occur from the ecosystem include deep percolation on sandier soils, surface runoff and erosion in both particulate and dissolved form, and transfer to non-productive areas such as shades or to some pasture areas. Applying P fertilizer to soils containing very high available P levels, or livestock management systems which result in large transfers of excreta to high risk land areas represent economic and environmental loss of efficiency , and contribute to decreased sustainability. When phosphorus is applied to areas where it is a non-limiting factor for growth or when transfers of phosphorus represent a loss of efficiency in use of recycled P the management system is not successful.

Successful nutrient management plans keep P as non- limiting in the crop root zone, and limiting for algae growth in drainage water (runoff and groundwater). This may be easier to manage with commercial fertilizers where rates of P input can be precisely controlled. However, manure is often available at lower costs per unit of available nutrients in areas of concentrated animal production such as the Southern Piedmont. With nutrient analysis of manures, application rates can become more precise and therefore controlled.

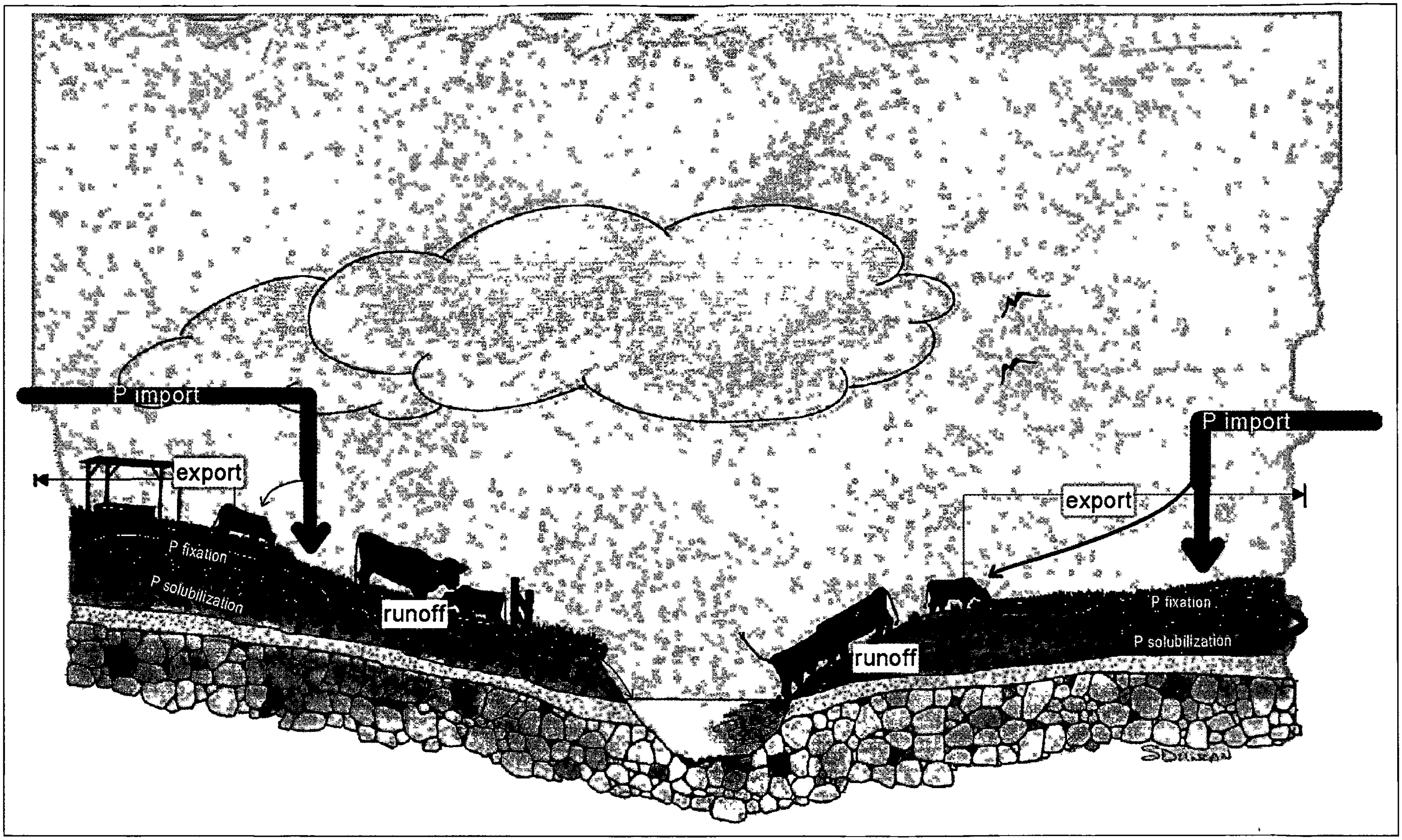

Fig. 6.11. Providing shade and water to animals and limiting animal access to streams (left) can minimize erosion and other potential water quality problems associated with runoff losses of phosphorus. Reduced production of forage in eroded fields and critical areas (right) requires added cost of feed to maintain animal productivity. Higher levels of phosphorus enter streams when stream banks are denuded by animals (right). Phosphorus inputs to streams come directly from animals wastes deposited in streams and indirectly from phosphorus adsorbed onto eroded soil particles, which are transported to streams in runoff. Note: the wider the arrow the greater the flow of phosphorus.

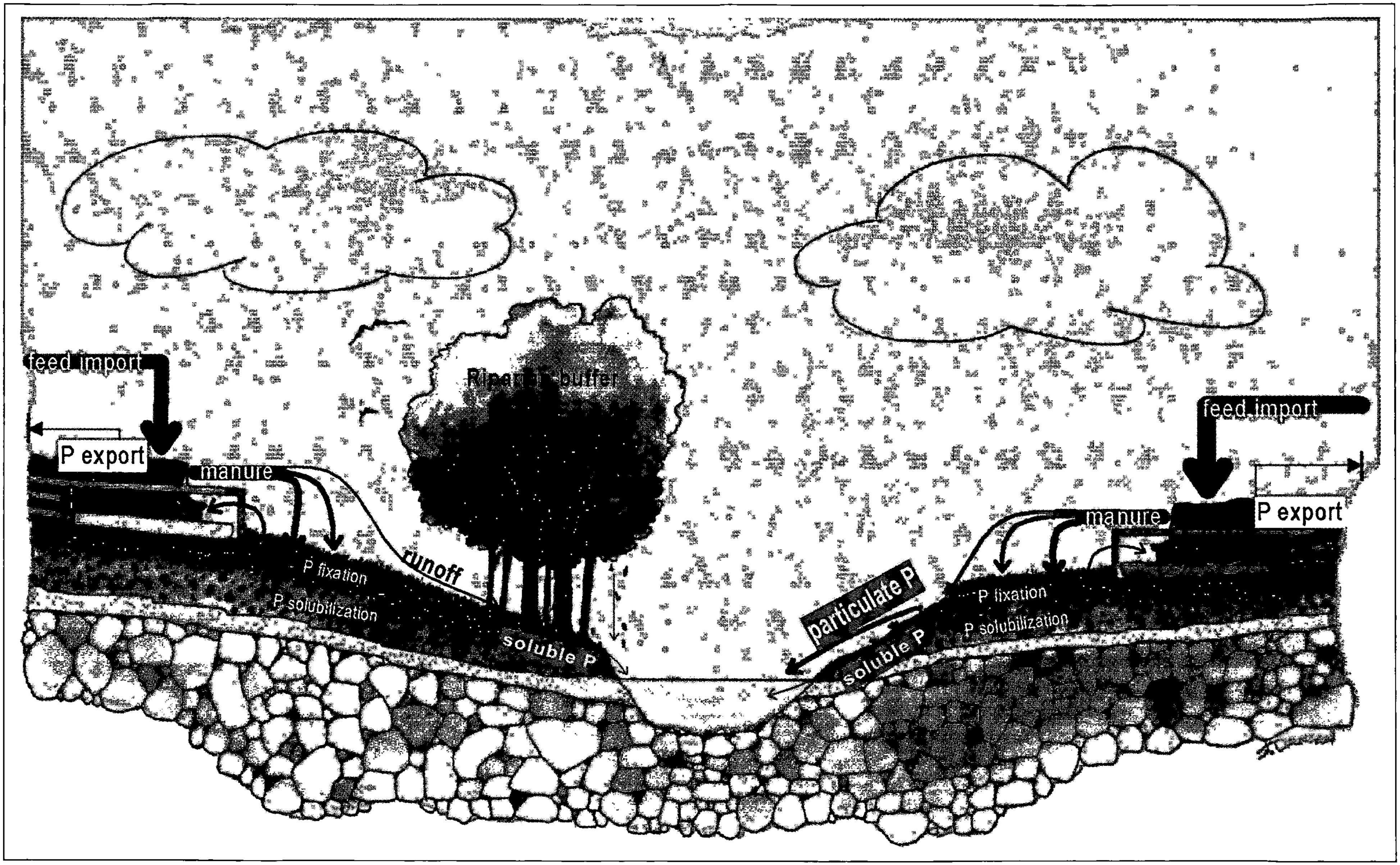

Fig. 6.12. Riparian buffers (left) can minimize losses of nutrients such as phosphorus from feedlots and holding areas to streams. Most phosphorus is in the soil-plant cycle for both management scenarios. Unprotected side slopes are easily eroded (right) and particulate as well as soluble phosphorus are transported with runoff. Note that the wider the arrow the higher the concentration of phosphorus. Most of the phosphorus in runoff is particulate when the soil is bare as on the right. Soluble forms of phosphorus entering the streams are approximately equal on both sides of the stream.

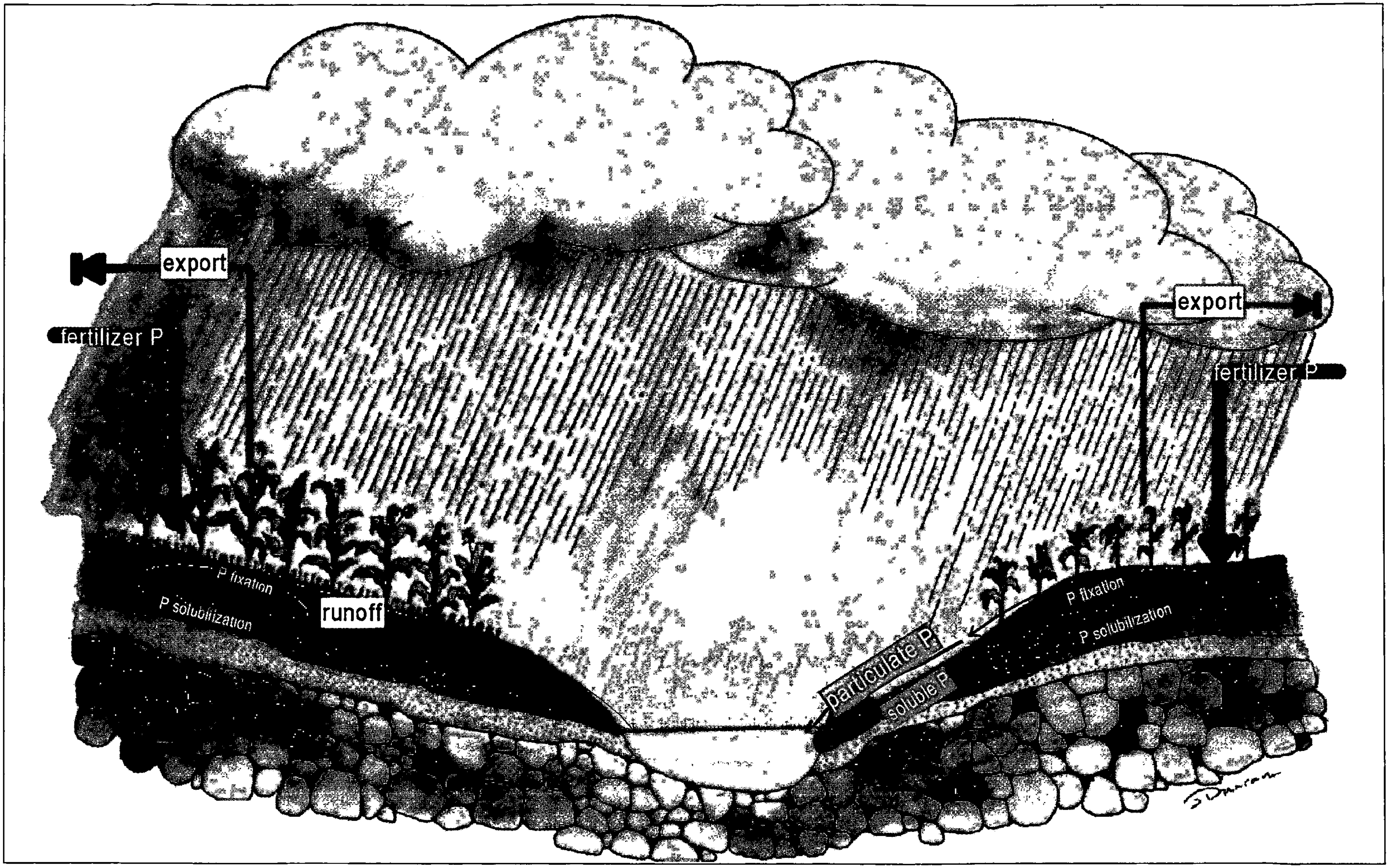

Fig. 6.13. Conservation tillage (left) can reduce the potential for water quality problems associated with sediment and phosphorus losses. Most of the fertilizer phosphorus applied to the surface is retained in the upper portion of the surface horizon. When soil surfaces are not protected (right), erosion is more likely and phosphorus adsorbed onto the organic and inorganic materials in the upper horizons is transported off site primarily as particulate phosphorus. Note that the wider the arrow the greater the flux. For example, more corn is exported from the no-till system (left) than from the conventional tillage system (right).

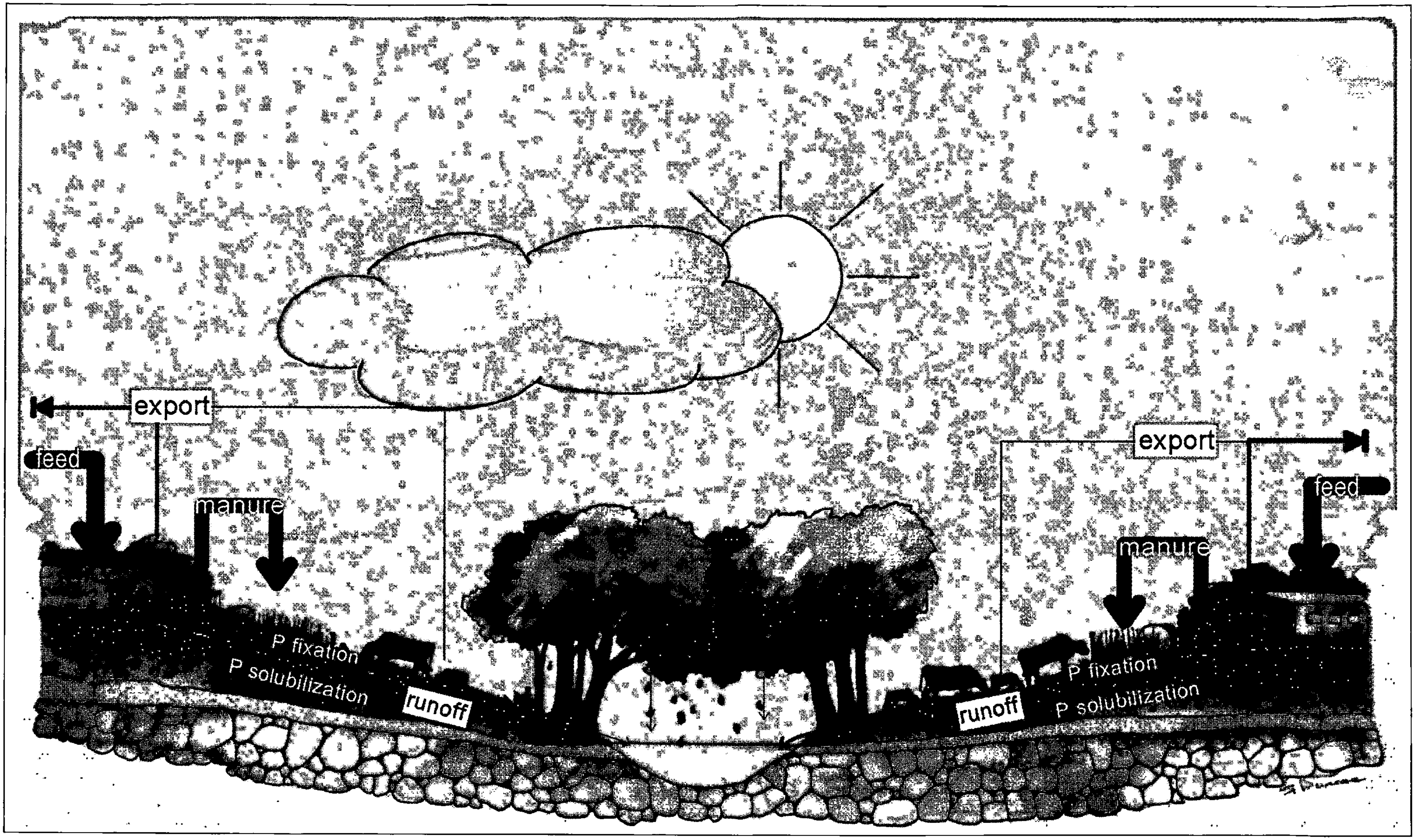

Fig. 6.14. Poultry and cattle systems are common in the Southern Piedmont. The use of stack houses and riparian buffer strips (left) can protect manure from the weather and prevent untimely losses of phosphorus to streams. Overgrazing (right) can greatly reduce ground cover and reduce production of forage, allowing for accelerated erosion and higher losses of nutrients such as phosphorus. Grazing within the riparian buffer strip can be controlled with fencing (left) which limits grazing and trampling of vegetation. Increased vegetative cover can increase the buffer strips ability to slow runoff water down and capture entrained sediments and nutrients.

BEST MANAGEMENT PRACTICES FOR CLEAN, SAFE WATER

Introduction

Water purity and pollution are difficult to define because both terms are relative. Very little water is pure since water is an excellent solvent that dissolves or caries almost everything it touches. Water that is ideal for one use may be unfit for another. For example, sea water may be fine for ocean aquatic life, yet it is contaminated with salt at levels that make it unfit for human consumption. Regardless of what is in water, a plentiful supply of clean, safe water will always be essential for human and animal health. When the natural quality of water is degraded through the activity of people, we call this "pollution." Most pollution occurs when we exceed the natural capacity of water to purify itself. Natural processes can contaminate water, but human activities often lead to more rapid and widespread contamination. While this sounds bad and tends to blame the problems on human activities, the good part of it is that we can change our activities and have a dramatic affect on the quality of our water.

If we are to achieve any improvements in our water quality, we must recognize what the potential water pollutants are, we must know where they come from and how they are transported through the environment, and we must understand how our management practices can effectively prevent pollution. This chapter is designed to give you these tools. Yet, this alone will not be enough. Improving water quality takes a commitment. We must realize that water is a shared resource and that each of us contribute to the pollution threat. Then we must make a conscientious decision to change the way we conduct our daily activities to improve our water quality.

Point Source and Nonpoint Source Differences

Groundwater and surface water are both affected by the surrounding soils and land features but not in the same manner. Surface water is primarily affected by contaminants that readily dissolve in water or pollutants carried on eroded soil particles. It usually contains more suspended solids, but less mineral and iron than groundwater. Because of its accessibility and exposure to air and rainfall, surface water is easy to contaminate but it is also easier to purify than groundwater. In

Sediments Soil material eroded from land surfaces and transported to streams and lakes by runoff water is the largest single pollutant of surface water by weight and volume. Erosion occurring on Georgia's 8.9 million acres of land produces about 7.6 million tons of sediment each year. Since soil erosion is accelerated when land is disturbed, agricultural cropland and gullies, construction sites, and road projects are the principle sources of sediment. The sediment resulting from soil erosion causes considerable off-farm damage and is detrimental to production on the farm.

Sediment has been identified as the leading source of impairment to rivers and lakes. It affects the use of water in many ways. Sediment can accumulate and fill in stream channels and lakes, which contributes significantly to flooding. It can also clog water filters, damage pumping equipment, and shorten the economic life of reservoirs and farm ponds. Soil particles are also the main carrier of other chemical pollutants and nutrients. Therefore, controlling soil erosion can often reduce the amount of other pollutants that enter the water. Suspended soil particles reduce the water's capacity to sustain life. It clouds the water, reducing light penetration, and in turn photosynthesis by plant life. More importantly, it alters bottom conditions, sometimes covering up suitable spawning sites and suffocating fish eggs and aquatic insects. When suspended in the water, sediment may clog the gills of fish, and have other negative effects on organisms that are dependent on clear water.

On the farm, erosion by wind and water causes yield reduction through loss of crop stands, damage and stress to seedlings and young plants, and a deterioration in soil quality. Soil quality is affected by the separation and gradual removal of organic matter, silt, and clay from the soil surface. In fact, cotton yields from eroded soils in Georgia can be as much as 50% less than yields from non-eroded fields. This problem is compounded by the fact that eroded soils will often require increased inputs to sustain comparable yields.

Sediment concentrations in rivers and streams range from 100 to 50,000 parts per million (ppm) with occasional concentrations as high as 500,000 ppm. The amount of sediment carried within the flow of water is often measured as "suspended solids". Since heavier soil particles are prone to settle out of water quicker than light particles, large sand particles are often deposited as soon as they enter a river or stream.

soil particles containing phosphorus is the primary mechanism for phosphorous transport to surface water. The adsorption capacity of the soil can, over time, become depleted if manures are repeatedly applied to the same area. As phosphorus migrates to lower, less weathered soil, it becomes more mobile. While ground water is usually not contaminated by phosphorus, repeated over application of phosphorus could contaminate ground water, especially in shallow aquifers.

While nitrogen is less of a concern from the eutrophication point of view, it is a much greater public health concern in the groundwater. The chief problem with nitrogen is the formation of nitrates and nitrites. Nitrate nitrogen is highly mobile in the soil, especially in wet, warm, acid soil conditions and weathered clays and sands that exist over much of Georgia. Once nitrates migrate below the soil surface horizon there is little chance of plant uptake or biological conversion under normal field situations. This means little if any nitrate is retained by adsorption in the subsoil and most moves through the soil with the water(Fig. 5.2, 5.3, 5.4, & 5.5). Severe nitrogen migration to the subsoil can lead to groundwater contamination. The drinking water standard for nitrate is 10 ppm. At 40 ppm nitrates can be toxic to warm-blooded animals. Infants are particularly susceptible to nitrate in water as it can result in methemoglobinemia (nitrate cyanosis) that can cause blindness or death. Nitrate in drinking water may also affect fetal development and cause reproductive problems in livestock. In Georgia, 3.8% if 3,419 shallow wells (having depths of less than 100 feet) tested between 1989 and 1993 had nitrate concentrations exceeding 10 ppm. Of the deep wells, 0.9% had concentrations exceeding 10 ppm. While these numbers do not suggest a significant problem, it is imperative that wellhead protection measures be used to prevent further contamination. Since rural residents depend on groundwater for their drinking water supply, nitrates can pose a serious threat to health.

Nutrients can be derived from both point and nonpoint sources. All forms of decomposing organic matter including animal waste and domestic sewage contain significant amounts of nutrients. While municipal water treatment plants and industrial sources contribute to the problem, agriculture can have the greatest impact on reducing nutrient loads to our lakes and rivers. Crop fertilization is essential to agricultural production but it is also a readily available source of nutrients that large rainfall events can rapidly transport from the soil to our water. Nutrients are the most common

Toxins Although the focus of this workbook is nutrients, no discussion of water quality is complete without at least mentioning this final class of pollutants. Toxins are chemical substances that can cause cancer or other harmful health effects. Their impact on health may be acute, occurring quickly after exposure, or chronic, occurring over a long period of time. Toxins include certain metals (such as lead, mercury, and cadmium), pesticides, and other organic chemicals. Because our society is so dependent on them pesticides, industrial solvents, chemical wastes, petroleum products, and heavy metals are washed into our waters daily. Often these discharges are accidental-spills, leaks, or improper storage, however anytime a toxic material is used, we must realize that some of it may be escaping to the environment.

We do not know the long term effects of low dosages of many of these substances. We do know however, that high concentrations can be very dangerous. The presence of toxins in the water may render it unusable for fishing and swimming and will make it more difficult and expensive to treat so that it can safely be used for drinking. Another problem with most toxins is that any aquatic organisms will concentrate these chemicals in their bodies. This is called bioaccumulation and it can often lead to concentrations within the fish or other organism this is much greater than the average concentration in the water.

Most agricultural production requires the use of chemicals including pesticides and fuels. Pesticides and other agrochemicals can contaminate both ground and surface water. They can enter groundwater by direct routes such as spills, back siphoning, poor well construction, improperly maintained equipment, and improper disposal or by long term doses of low concentrations. They can be transported to water by runoff, percolation, seepage, or careless application procedures. They may be dissolved in water (highly soluble pesticides) or suspended in the water. The varying chemical properties of pesticides and other chemicals, such as solubility, toxicity, and chemical breakdown rate, help determine the damage that they inflict on the water quality. Very small amounts of these chemicals can create concentrations in water in excess of health standards. Seepage of pesticides into groundwater is a particular concern to farm families since their own well may be affected. Well contamination can make the water unusable for years and the cost of cleaning contaminated wells is extremely high. Nationally, more than 74 different pesticides have been detected in groundwater in 38 less runoff and corresponding erosion, Knowledge of rainfall patterns will also allow farmers to insure that the soil is protected during the periods of the year when they receive the largest amounts of rainfall. The organic matter of a given soil can also be manipulated over time to produce a soil with more organic matter that will produce less erosion.

Slope steepness and slope length depend on topography and have historically been the primary means of erosion control. Since the dawn of agriculture, man has known that longer and steeper slopes produce more soil erosion and has used methods such as the construction of levies and terraces to reduce slope length and steepness. More recently, practices such as strip cropping and vegetated waterway construction have been used to reduce runoff velocities and effective slope length. The main reason that longer and steeper slopes produce more erosion is that the water flowing downhill accumulates energy that dislodges and transports more soil particles. Any methods that can slow the flow velocity or reduce the amount of water flowing over the surface will also reduce soil erosion.

Cropping and management also has a dramatic affect on soil erosion. Crop canopy and surface cover or residue acts as a buffer between the soil surface and the raindrops, absorbing much of the rainfall energy and ultimately reducing soil erosion. Therefore, crops that produce more vegetative cover, have longer growing seasons, or produce a persistent residue will have less erosion. Management is also important as tillage can drastically reduce the amount of surface cover and residue. The arrival of modern no-till and conservation tillage systems was primarily in response to the effectiveness that these systems have on maintaining surface cover and reducing soil erosion (Fig. 4.11, 5.4, & 6.13). Any cropping system with less tillage or greater amounts of biomass production, such as forage production, will result in less sediment leaving the field.

Soil loss can also be reduced using cultural practices such as contouring, strip cropping, and the construction of terraces. As runoff and accompanying sediment leave fields it constantly moves through differing environments where the rate and volume of movement are affected. Any time this movement is slowed down, it causes sediment to be dropped out of suspension along the water course. Heavy vegetation, One also needs to remember that the most effective plan will probably consist of several different BMPs that target different mechanisms. Some BMPs may solve a surface water quality problem but create a ground water quality problem. This should be considered when the selection is being made rather than after a new problem arises. Finally, if a BMP is not economically feasible and well suited for the site, one probably shouldn't use it. Consider all costs including effects on yield, production and machinery costs, labor and maintenance, and field conditions when selecting BMPs. Often a very effective BMP will rapidly become a problem if all the costs are not considered before implementation.

BMP Descriptions and TABLE

There are many BMPs that are applicable to a wide range of pollutants and as more research results become available more BMPs are developed and refined. In this text, our discussion will focus on the BMPs that are applicable to farming systems prevalent in the Southern Piedmont. Table 1 presents a review of BMPs that are particularly applicable and practiced to varying degrees. Some of these BMPs are discussed in more detail in the text following the table. All of them are proven techniques that prevent pollution.

Filter strips and riparian buffers All streams, rivers, lakes, ponds, and other water bodies in the Southern Piedmont are more sensitive to environmental pollutants than the land that surrounds them. By managing the area around these water bodies more intensively, many conditions that may lead to surface or groundwater contamination can be prevented. All potential agricultural pollutants, including pesticides, herbicides, fertilizers, manures, petroleum products, and sediment should be handled with extreme care around any water body. Stream channels and banks should be protected to prevent erosion. Often this can be accomplished using vegetation, however, at times structural measures such as rock rip-rap may need to be used. Generally, livestock should never have unlimited access to any body of water, but when they do it should be in areas with dense vegetation, smooth stable slopes, and firm surfaces.

The area immediately surrounding a stream or lake can also be used to remove sediment or nutrients from runoff or groundwater before it reaches areas where it becomes a pollutant. Filter strips are strips of grass, shrubs, or other close growing many of the nutrients in the ground water. The roots and surface cover also protect the soil surface to prevent surface soil erosion and stabilize the stream bank. While these BMPs require little maintenance once they are established, if the sediment loads entering the filter strip are heavy, you may have to periodically remove them and reestablish the vegetation.

Livestock exclusion/ alternate water facilities Animal access to surface water and adjacent areas also represents a possible source of water contamination. Not only does the manure deposited directly in or adjacent to streams pollute the water, but the livestock also reduce stream-side vegetation by foraging or trampling which disturbs soil on the stream bank and bed, thereby creating additional sediments for transport (Fig. 4.9, 4.12, 5.2, 5.5, 6.11, & 6.14). This increases erosion and decreases the buffering capacity of the stream-side vegetation. Stream and waterways protection can be accomplished by limiting livestock access and stabilizing stream banks. Livestock exclusion is the use of fencing or other barriers to prevent cattle from having access to streams, rivers, and lakes. The primary mechanism of this BMP is the elimination of manure and sediment deposited directly in the stream from animals and less transport through surface flow as a "buffer" zone is established. Vegetation or rip-rap established along the edges of the stream buffer protects the banks from channel erosion as well as the erosion caused by animal traffic. The main drawbacks of livestock exclusion are the costs associated with establishing and maintaining fences and watering sources for the animals.

An alternate solution to building fences for total exclusion of livestock is the development of alternate watering facilities (Fig. 4.9, 5.2, & 6.11). Several research projects have recently documented improvements in water quality through simply suppling a watering tank or trough at selected location away from the stream or water body that needs protection. When given a choice, cattle will usually drink from the closest source of water. Therefore, alternate water sources reduce the total amount of time cattle spend in the water and traveling to and from the stream. One study showed that stream bank erosion was reduced by 77% and concentrations of total suspended solids, total nitrogen, ammonium, total phosphorus, and fecal coliform were reduced by 90%, 54%, 70%, 81%, and 51% respectively, due to the installation of an off steam watering source. In other words, the results clearly indicated that off stream watering sources were an effective BMP.

Nutrient management planning Managing the amount, source, form, placement, and timing of nutrient applications are activities that will accomplish both production and water quality goals. This holds true for all nutrient sources including manure, organic wastes, chemical fertilizers, and crop residues. Nutrient management plans are or compost one should also have these products tested for nutrient content. If unable to have these products tested, there are a variety of sources, including your County Extension Office, which can provide you with estimated nutrient contents. Using the nutrient needs of the plant and the nutrient content of the fertilizer, the recommended application rate can be calculated. These recommendations are usually supplied with the soil test results but can also be made based on Extension Service publications or computer programs. The entire process of formulating a nutrient management plan can be rather complex, but a number of worksheets are available to assist you in making these calculations.

Proper nutrient management encompasses more than simply applying the right amount of nutrients. It is also important to make sure these nutrients are applied at the right time and in the proper locations. Proper maintenance and calibration of the application equipment is critical since a precisely calculated application rate does little if your machinery is not functioning properly. In calibrating manure spreaders, consider the uniformity of application as well as the application rate. Nutrients also need to be applied when the vegetation can use it, during the spring or before periods of rapid growth. Avoid applying any nutrients during periods when the soil is saturated or frozen. It does little good to spend a lot of time and money on nutrients that will be washed off the surface with the first large rainfall so avoid land application immediately preceding large rainfall events. If possible, incorporation with little disturbance to the soil is the best way to insure that the plant nutrients are available to the plants and remain in the soil.

Waste storage structures Effectively using animal wastes as fertilizer is the best way to insure that it does not become a pollutant. Waste storage structures are designed to promote more effective utilization of animal waste and to prevent undesirable storage methods such as stockpiling in areas that are susceptible to runoff and erosion (Fig. 4.12, 5.5, & 6.14). Waste storage structures can include earthen impoundments such as lagoons, concrete basins or tanks, or specially designed buildings such as stack houses. Waste storage structures are considered effective BMPs because they allow for timely application of animal manures, they often preserve the nutrient content of the manure, and they prevent the manure from becoming a pollutant.

Rotational grazing Properly designed rotational grazing systems have both production and water quality benefits. A planned grazing system rotates livestock grazing into different pastures. This improves vegetative cover, forage quality, and evenly distributes manure nutrient resources. In this system, fences are used to partition a pasture into many smaller paddocks. Animals graze in a paddock for a short period and then are moved to a fresh paddock. Forage plants in the first paddock are relieved from grazing pressure so that they have time to regrow. Not only does this result in better quality forage, but it can also increase productivity and stocking rates. Timing and paddock design are the key design variables in rotational grazing systems. For timing, the goal is to keep pasture plants as palatable and nutritious as possible by keeping them in the vegetative state. Since pasture growth changes throughout the year, the timing and total amount of area required for grazing cannot usually be set. Therefore, these systems are often management intensive and require more time.

Since rotational grazing systems usually result in less animal confinement, there is less manure handling labor and fewer environmental risks associated with manure storage and application. This results in better utilization of the manure nutrients and less soil erosion and pesticide use as a result of healthier pasture. These benefits all translate to improved water quality as a result of having healthier vegetative systems with fewer losses to the environment.

Protecting critical areas Livestock producers should also consider leaving critical areas out of production. Critical areas are those that are sensitive to water quality problems or those that cannot usually be stabilized by ordinary conservation treatment and if left unmanaged can cause severe erosion problems. Examples of critical areas susceptible to erosion include dams, dikes, levees, cuts, fills, areas of concentrated water flow, and denuded areas where vegetation is difficult to establish. These areas will become reoccurring problem spots if they are put into pasture or cropland. Instead, vegetation should be established and they should be left out of production.

As discussed earlier, stream, lake and pond banks are also prone to erosion and should be left out of production using riparian buffers or filter strips. If cattle must have access to pastures on both sides of a stream, stream crossings should be constructed. Stream crossings can either function as a bridge using a culvert and fencing to prevent from the fields or pastures without excessive soil erosion. Waterways prevent gully erosion in areas of concentrated flow. The vegetation also acts as a filter to remove suspended sediment and some nutrients. Grassed waterways require careful maintenance and periodic reshaping, especially after large or intense storms. Performing this maintenance regularly is important as the concentrated flow conditions can lead to rapid gully formation if minor washouts are left unchecked.

The use of sediment basins or small farm ponds is one final method of preventing off-farm pollution. A sediment basin is a barrier or dam constructed across a waterway to reduce the velocity of runoff water so that much of the sediment and associated nutrients settle to the basin bottom. Small sediment basins require regular sediment removal while larger basins can almost appear to be a pond and may support fish and wildlife. A well-placed pond can collect all of the runoff from a farm and have a positive impact on water quality. It acts as a detention basin by removing sediment and nutrients from the flow and reducing the volumes of flow occurring at peak conditions. It can also filter many nutrients if aquatic vegetation or fish are used. Finally, the pond can act as a buffer between the farm and the external environment.

Others Many BMPs are designed to reduce the water quality impacts of cultivated cropland and may not be applicable to beef and poultry producers in the Piedmont. Traditional methods used in crop production include conservation tillage, contour farming, and strip cropping, These methods, along with a few others, will be addressed briefly below. Your local county Extension or Natural Resource Conservation Service office can provide more details on any of these BMPs.

Conservation Tillage Conservation or minimum tillage includes a variety of tillage systems where soil disturbance and the number of cultural operations are reduced to a minimum and where mulch residue from the previous crop is left on the soil surface to retard weed growth, conserve moisture, and control erosion . No-till, ridge plant, strip till, wheel track planting and listing are all examples of conservation tillage systems. Soil disturbance or tillage is the primary reason agricultural fields produce more erosion than most other land uses. It exposes the soil surface to rainfall impact that detaches soil particles, increases the amount of soil crusting that occurs causing greater amounts of runoff, and decreases vegetation at the soil surface which holds the soil in

<u>**Site Specific Management**</u> Site specific management or "Precision farming" is a relatively new BMP designed to precisely target inputs such as fertilizers and chemicals according to the localized requirement within the field. It takes into account variations in soil quality, nutrient levels, and pests that occur on most arable fields. Application rates of nutrients, pesticides, and other agronomic inputs are not predetermined and constant, but vary continuously based on specific soil and micro-environmental variations. The purpose is to precisely match the inputs and management to unique crop, land, and climate attributes rather than averaging across a field. The application of precision farming requires accurate field maps based on field attributes which influence production. These attributes can be soils, fertility status, yield, and plant characteristics and are digitally mapped for arable crops. Some forms of the technology are already well established. For example, yield mapping is frequently used on larger farms and many new combines and harvesters are sold with yield mapping capabilities. While the water quality effects of precision agriculture have not been well documented, it will result in more appropriate use of pesticides and fertilizers with an overall reduction in application rates and the potential for excessive availability of nutrients or pesticides.

<u>**Integrated Pest Management**</u> IPM is defined as an interdisciplinary approach to pest control incorporating the judicious application of ecological principles, management techniques, and biological and chemical methods to maintain pest populations at tolerable levels. It is a system that anticipates pest population increases and prevents pests from reaching damaging levels by using natural enemies, pest resistant plants, cultural management, pesticides, and other techniques. IPM systems minimize the use of pesticides through careful planning of guidelines to help growers decide when pesticides are necessary. Pesticides are not applied unless pest levels are high enough to potentially reduce profits. Scouting and surveillance are probably the most import aspects of an IPM system. Crop rotation, cover crops, nutrient management, maintenance of soil biology, supplementation with commercial parasites, and adjusting planting and harvesting times are also essential components of integrated pest management plans.

SAMPLING, MEASURING AND REPORTING

Now comes the fun part, we get to collect samples and measure them for ammonium, nitrate, orthophosphate, pH and total suspended sediments. The general steps in the monitoring sequence are: 1) Prepare to sample; 2) collect sample; 3) re-establish collection system; 4) prepare to analyze; 5) analyze; 6) report; 7) clean-up and prepare for the next round of analysis. The technician should provide you with deionized water and clean, labeled sampling bottles every time samples and reports are picked up. If you have any questions feel free to ask at that time. If you need any other equipment replacements please call and let the technician know to bring them out.

Our goal is to collect scientifically credible data that we can all use with confidence. Scientifically credible data are data that are precise and as accurate as the variable will allow. Consistent technique across participants and by each participant will help increase precision. That is why we have set up a sampling protocol. This protocol can be changed but it should be changed early in the sampling period and by all participants. There is room for discussion to improve ease, efficiency and accuracy of data collection. We will be collecting stream water samples, runoff water samples, and groundwater samples. Sample collection procedures for each of these sources varies slightly. Each procedure follows:

Groundwater:

1. Once a month and/or following each rainfall event sample from outflow point of interest.

2. Before sampling run water for 30 seconds. While water is running label bottle, unscrew and remove cap of sampling bottle and hold under outflow point. Fill bottle, replace cap, and tighten immediately.

3. Once the sample bottle has been sealed place in cooler provided.

9. If there is excess runoff within the exterior in-ground collection cylinder this must be pumped out using the provided pump. Please remember to discard the excess water downslope from the runoff collection system.

10. Once excess runoff has been discarded and cylinders have been cleaned place cylinders back in and level.

11. Cap in-ground collection cylinders and replace the protector. If vegetation is becoming overgrown please make comment so that we may trim the excess growth.

12. Go to raingauge and record amount in space provide on the worksheet. Pour rain water out of the rain gauge and secure in holder.

Streams:

1. Streams samples will be taken twice a month. Something like the first and the 15th or the first and third Thursday. The day will be decided at our first workshop when we can determine which day is most convenient for all participants.

2. Each participant should have a pair of stream waders or rubber boots. Waders should not be above hip level. Go to stream collector, approach from the downstream side and always collect the downstream sample before the upstream sample.

3. Observe and record the height of the stream water on the gauge height stick.

4. Collect the base flow sample first. Pinch the siphon hose closed. Dislocate hose from stopper. Remove bottle from bottle cage. Gently shake bottle (hold your index finger on stopper while shaking). Remove stopper with bottle in upright position. Seal bottle with a screw on cap. Rinse stopper with distilled water and place stopper in clean one liter, labeled nalgene bottle. Place clean properly labeled bottle back in cage, reconnect siphon tube to stopper and undo pinch clamp.

5. If there is water in the next bottle up, collect that sample in the same way as the baseflow sample.

Measuring

Nitrate (Cadmium reduction method, PRGM 55)

Samples should be room temperature before running the test. However, if testing must be delayed more than 12 hours it is important to keep samples refrigerated. Sample pH must be adjusted to 2 or less if the samples will be in the refrigerator longer than 48 hours. This requires sulfuric acid which is a strong acid and can be dangerous. We therefore ask that all samples be read within 12 to 16 hours. The sooner the sample is read the more reliable the reading. We are expecting low numbers for nitrate and have chosen the low range (0.o to 0.5 mg/L NO_3-N) reagents.

Step by step procedures can also be found in the Hach procedures book which will be included in the kit. You will only find a few variations when comparing the following procedures with those in the manual. We have gone through and added or deleted steps for ease and efficiency.

1. Enter the stored program number (55). Press PRGM, 55, ENTER. Make sure the display reads mg/L NO_3-N and the ZERO icon

2. Fill a 25-ml graduated cylinder to the 15-ml mark with sample.

3. Add contents of one NitraVer6 Nitrate Reagent Powder Pillow to the cylinder. Stopper. *It is important to transfer all the powder from the foil pillow into the cylinder. Check corners of pillow.*

4. Press TIMER ENTER. Shake closed cylinder until the timer beeps. The timer is set for three minutes and you should be able to see it count down. Shake vigorously for three minutes.

5. When the timer beeps set the cylinder down. The display should read 2:00 TIMER PRESS ENTER. This is to allow for the reaction to occur.

6. When the timer beeps pour 10 ml of sample into sample cell. Try not to transfer any of the particulates.

Ammonium (Salicylate Method, PRGM 64)

Samples should be analyzed as soon as possible for the greatest reliability. If chlorine is present we will have to treat the sample before we can analyze for ammonium. Chlorine might be present in well water for example if the well has been treated with Clorox. Samples should be at room temperature to analyze.

Step by step procedures can also be found in the Hach procedures book which will be included in the kit. You will only find a few variations when comparing the following procedures with those in the manual. We have gone through and added or deleted steps for ease and efficiency.

1. Enter the stored program number (64). Press PRGM, 64, ENTER. Make sure the display reads mg/L NH_3-N and the ZERO icon

2. Fill the sample cell with 10 ml of deionized water. This will serve as your blank.

3. Fill a second sample cell with 10 ml of the sample.

4. Add the contents of one Ammonia Salicylate Reagent Powder Pillow to each sample cell. Cap both and shake til they are both dissolved.

5. Press TIMER ENTER. The timer is set for three minutes and you should be able to see it count down.

6. After the timer beeps add the contents of one Ammonia Cyanurate Reagent Powder Pillow to each sample cell. Cap and shake to dissolve reagent. A green color indicates the presence of ammonia. Once dissolved set sample cells down.

7. The display should read 15:00 TIMER 2 Press ENTER. You have a 15 minute reaction period.

8. After the timer beeps place the blank (triangle vertex facing notch) into the cell holder. Before placing the sample cell into holder remove fingerprints and escess

Phosphorus (Ascorbic acid method, PRGM 79)

Samples should be analyzed as soon as possible to ensure the most reliable results. Samples should be room temperature before running the test. However, if testing must be delayed more than 12 hours it is important to keep samples refrigerated. Sample pH must be adjusted to 2 or less if the samples will be in the refrigerator longer than 48 hours. This requires sulfuric acid which is a strong acid and can be dangerous. We therefore ask that all samples be read within 12 to 16 hours

Step by step procedures can also be found in the Hach procedures book which will be included in the kit. You will only find a few variations when comparing the following procedures with those in the manual. We have gone through and added or deleted steps for ease and efficiency.

1. Enter the stored program number (79). Press PRGM, 79, ENTER. Make sure the display reads mg/L PO_4 and the ZERO icon.

2. Fill the sample cell with 10ml of sample. Clean glassware is a must in this procedure we recommend that you analyze P first.

3. Add the contents of one PhosVer3 Phosphate Powder Pillow to the sample cell. Cap and shake for 15 seconds.

4. Set sample cell down and Press TIMER ENTER. The timer is set for three minutes and you should be able to see it count down. This is the time needed for the reaction to take place. A blue color indicates the presence of phosphate.

5. While waiting fill another sample cell with 10 ml of sample. This will serve as your blank.

6. After timer beeps, place the blank into the cell holder (triangle apex aligned with notch). Tightly cover the sample cell with the instrument cap.

7. Press ZERO. The display should read 0.00 mg/L PO_4.

Dissolved Oxygen (High range, 0 to 15.0 mg/L O_2, PRGM 7)

Sampling technique and sample handling can dramatically change the results. Dissolved oxygen is a measure of the amount of dissolved oxygen (DO) in solution. The dissolved oxygen content of the water being tested can be expected to change with depth, amount of agitation to water, temperature, organic deposits, light ,microbial action, and time. It is important to test for DO as soon as possible. The main consideration is to prevent the sample from becoming contaminated with atmospheric oxygen. This is accomplished by capping the ampule with an ampule cap whenever possible.

Step by step procedures can also be found in the Hach procedures book which will be included in the kit. You will only find a few variations when comparing the following procedures with those in the manual. We have gone through and added or deleted steps for ease and efficiency.

1. Enter the stored program number for dissolved oxygen (DO, 70). Press PRGM, 70, ENTER. Make sure the display reads mg/L O_2 and the ZERO icon.

2. Fill the sample cell (the blank) with at least 10 ml of sample. Fill a blue ampule cap with sample. Collect at least 40 ml of sample in a 50-ml beaker.

3. Fill DO accuVac Oxygen Ampule from sample in beaker. Break off the top underwater if possible and do not allow atmospheric O2 to enter the ampule. This is critical: Keep the tip immersed while the ampul fills completely.

4. Without inverting the ampule, immediately place the ampule cap that has been filled with sample securely over the tip of the ampule. Shake for about 30 seconds. Note the accuracy is not affected by undissolved powder.

5. Press TIMER ENTER (a 2-minute reaction time countdown should be displayed on the colorimeter. When the timer beeps, shake the ampul for 30 seconds.

GLOSSARY

actynomyctes Bacteria that form branched filaments.

adsorption Adhesion of a substance to a solid or liquid surface; often used to extract pollutants by causing them to be attached to such adsorbents as activated carbon or silica gel. Cations are adsorbed to negatively charged clay surfaces.

algae An informal assemblage of predominantly aquatic organisms that carry out oxygen-evolving photosynthesis, but lack specialized water-conducting and food-conducting tissues.

aquifer Porous layer of underground rock in which water is stored. A geologic formation or structure that transmits water in sufficient quantity to supply a specific need or use.

artificial eutrophication Over nourishment of an aquatic ecosystem by nutrients such as nitrates and phosphates. In artificial eutrophication the pace of eutrophication is accelerated quite rapidly due to human activities such as agriculture or discharges from sewage treatment plants.

bankfull discharge Discharge at which the channel is completely full. Bankfull discharge is said to have a return period of 1.5 years.

baseflow The stream discharge composed of groundwater drainage and delayed surface drainage.

bacteria Extremely small (naked to the human eye), relatively simple microorganisms possessing a prokaryotic type of construction (unicellular, lacking nuclei, and having asexual reproduction).

biota The plant and animal life of a region.

carnivore An animal that feeds on other animals; flesh eater. Compare herbivore and omnivore.

cation Positively charged ion; ion which, during electrolysis, is attracted to the cathode. Common soil cations are calcium, magnesium, sodium, potassium, and hydrogen.

chlorophyll The generic name for the intensely colored green pigments that are the photoreceptor of light energy in photosynthesis.

DNA Deoxyribonucleic acid. Present in a cell's chromosomes, DNA contains the genetic information for all living organisms.

immobilization The conversion of an element from the inorganic to the organic form in microbial tissues or in plant tissues, thus rendering the element not readily available to other organisms or to plants.

inorganic A chemical that does not contain carbon and is not associated with life.

lithosphere The soil and rocks of Earth' s crust.

macropore Voids found in the soil which are greater that 0.02 micron. These spaces are often caused by soil fauna and structural variations within the soil.

mineralization The conversion of an element from an organic form to an inorganic state as a result of microbial decomposition.

nematodes Unsegmented or pseudo segmented bilaterally symmetrical worms with a basically circular cross section.

organic A compound that contains the element carbon and is either naturally occurring (in living things) or synthetic (manufactured by humans).

oxidation The loss of electron by a substance; therefore a gain in positive valence charge, and in some cases, the chemical, combination with oxygen gas.

perturbation Something that irritates; disturbance.

pH A number from 1 to 14 that indicates the degree of acidity or alkalinity of a substance. The negative logarithm of the hydrogen ion activity (concentration).

phosphorus fixation Process of making phosphorus unavailable to plants by adsorption and precipitation of phosphorus compounds caused by interaction with mainly clay size mineral particles in soils and water by mineral. Phosphorus initially soluble that has become attached to the solid phase of the soil in forms relatively unavailable to plants.

photosynthesis The biological process that captures light energy and transforms it into the chemical energy of organic molecules (such as glucose), which are manufactured from carbon dioxide and water. Photosynthesis is performed by plants, algae, and several kinds of bacteria.

protozoa Eukaryotic microorganisms that exhibit either primitive animal or plant characteristics.

reduction The gain of electrons, and therefore the loss of positive valence charge by a substance. In some cases, a loss or a gain of hydrogen is also involved.