Nitrogen and phosphorus movement from agricultural watersheds

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ABSTRACT—We conducted a five-year study on Missouri Valley deep loess watersheds near Treynor, Iowa, to characterize the movement of nitrogen (N) and phosphorus (P) as influenced by applied fertilizer and conservation practice. Our report presents watershed budget-accounting information for measured N and P movement that included (a) corn crop use, (b) surface runoff losses, (c) deep percolation, and (d) subsurface discharge. Erosion control and the application of N and P fertilizer at rates recommended for annual crop use minimized losses of these nutrients from the watersheds.

NITROGEN (N) and phosphorus (P), the major nutrients applied to agricultural land for corn production, exist in various forms in the soil. Generally the supply of these elements was high when cultivation began in this country. Intensified cropping practices have since depleted the natural supply of these nutrients, however; and it is now necessary to apply commercial N and P fertilizers early in the cropping season to meet crop needs.

Both N and P can move from cropland by crop uptake, surface runoff, erosion, and subsurface drainage resulting from deep percolation. This movement of nutrients from agricultural land may enrich surface water, causing aquatic plant growth. Because of potential environmental dangers and economic losses, it is important to understand the pathways by which these nutrients move from cropland.

Research has attempted to determine the effects of various management practices on N and P losses in surface runoff. Barrows and Kilmer (*1*) concluded that significant losses of organic matter were accompanied by removal of N and P through water erosion. More recent research in Georgia (*10*) and in west central Minnesota (*11*) showed that cropping systems that reduce soil erosion also reduce N and P losses.

A 10-year summary of the west central Minnesota study (*4*) showed that N and P transported annually by sediment and surface runoff water from continuous corn were equivalent to 70 and 64 percent, respectively, of applied annual N and P fertilizer. Most annual losses of sediment and associated nutrients occurred in the two months following corn planting, when the clean-tilled soil surface was most susceptible to erosion. The Minnesota study also showed that annual losses of soluble nutrients for five soil cover treatments were greatest during snowmelt runoff, when annual water losses were greatest.

Timmons, Burwell, and Holt (*12*) reported that incorporation of fertilizer into the soil effectively minimized N and P losses in surface runoff.

Considerable data is available on the effects of crop, fertilizer, and land management practices on overland movement of N and P with surface runoff and sediment. Information is limited with regard to the effects of these practices on deep percolation and subsequent losses of soluble N and P by subsurface water movement. Little research has related nutrient losses to fertilizer application practices and their interaction with crop use. Here, we present watershed budget-accounting information for N and P movement that considers (a) crop uptake, (b) surface runoff loss, (c) deep percolation, and (d) subsurface discharge measured over five years (April 1969 through March 1974) on deep loess soil.

Nutrient Research at Treynor

Most nutrient research has been done on small plots. We initiated studies at the Treynor, Iowa, research watersheds because they offered an excellent opportunity to determine nutrient losses from farm-size fields. Part of this study on Missouri Valley loess in southwestern Iowa (*6*) showed that level terraces greatly reduced P losses by reducing runoff and erosion. Also, level terraces and a grass watershed effectively reduced losses of water, sediment, and N by surface runoff, compared with contoured-corn watersheds (*7*). This 3-year watershed study showed that N losses associated with sediment in surface runoff accounted for 92 percent of annual N losses in surface runoff from the contoured-corn watersheds.

During a 2-year study, only small amounts of soluble N and P were discharged in surface runoff and subsurface flow from a contoured-corn watershed and a diversified terraced watershed (*2*). This study also showed that nitrate-nitrogen (NO_3−N) concentrations in stream flow did not exceed 10 parts per million (ppm) during the 2 years. However, concentrations of ammonium-nitrogen (NH_4 −N) and inorganic P in surface runoff and subsurface flow frequently exceeded acceptable limits set by the Federal Water Pollution Control Administration (*13*).

In another study the NO_3−N discharged in subsurface flow greatly exceeded the losses measured in surface runoff (*3*).

The Treynor watersheds are located on highly productive soils typical of the deep loess hills adjacent to the Missouri River Valley. The area is intensively row-cropped. Loess depths on the research watersheds range from 80 feet on the ridges to less than 16 feet in the valleys. Most main upland valleys have moderately to deeply incised channels. A saturated zone above the glacial till-loess interface causes seepage (subsurface stream flow) into the channels throughout the year.

Soil types in the watersheds are typic hapludalls, typic haplorthents, and cumulic hapludalls. These soils

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are fine, silty, mixed mesics with moderate to moderately rapid permeability. Watershed slopes range from 2 to 18 percent.

Each watershed is entirely cropped, but erosion is a serious problem if conservation practices are not used. Table 1 shows watershed size, crops, conservation practices, and fertilizer applied from 1969 through 1973.

Crop Use of N and P

Watershed 1 consistently produced greater yields of corn grain and stalks than watershed 2 (Table 2). Watershed 1 received average annual fertilizer applications of 400 pounds N per acre. Watershed 2 received 155 pounds N per acre, the recommended rate. N content per bushel of grain was similar for the two watersheds. As expected, N content per ton of corn stalks was greater on the more heavily fertilized watershed.

Crop use of P for the two fertility treatments showed trends similar to those for N.

Average annual N content of the corn crop (grain and stalks) on watershed 2 amounted to 104 percent of the average annual N applied per acre (Table 2, summarized in Table 5). This suggests that N mineralized from soil organic matter provided some of the crops' annual N needs. We did not consider N fixation from the atmosphere and N in rainfall as sources for crop use. In comparison with watershed 2, average annual N content of the corn crop for watershed 1 amounted to 48 percent of the average annual N applied per acre (Table 2, summarized in Table 5). The potential loss of N to the environment thus was low when fertilizer was applied at the recommended rate, but considerably greater when excessive amounts were applied.

Average annual P content in mature corn grain and stalks for watershed 2 was 64 percent of the average annual 36 pounds per acre applied (Table 2, summarized in Table 6). In comparison, the average annual P content of the corn crop for watershed 1 was 49 percent of the average annual 59 pounds per acre P applied. These data suggest that the potential loss of P to the environment would be greater when P was applied at 59 pounds per acre per year than when P was applied at the recommended rate.

These facts raise questions about the fate of excessive amounts of N and P in the soil during cropping and noncropping seasons. N fertilizer is usually applied as ammonia (NH_3), ammonium (NH_4), and nitrate (NO_3), which can be used by plants. These N forms can also be immobilized in organic forms, which are not available for plant use until bacteria and fungi release them through mineralization. Most organic N forms are not readily soluble in water and, thus, do not move with water. They primarily move with soil and organic material

Table 1. A description of study watersheds, crops, conservation practices, and fertilizer treatments, Treynor, Iowa, 1969-1973.

Watershed No.	*Year*	*Area (a)*	*Crop*	*Conservation Practice*	*Fertilizer Applied (lb/a)* N	P
1	1969	74	Corn	Contour, conventional tillage	428	100
	1970	74	Corn	Contour, conventional tillage	381	90
	1971	74	Corn	Contour, conventional tillage	395	36
	1972	74	Corn	Contour, conventional tillage	374	36
	1973	74	Corn	Contour, conventional tillage	426	35
	Average annual				400	59
2	1969	83	Corn	Contour, conventional tillage	165	39
	1970	83	Corn	Contour, conventional tillage	134	35
	1971	83	Corn	Contour, conventional tillage	160	35
	1972	83	Corn	Contour, conventional tillage	160	35
	1973	83	Corn	Contour, conventional tillage	156	35
	Average annual				155	36
3	1969	106	Bromegrass	Pasture	165	38
	1970	106	Bromegrass	Pasture	151	35
	1971	106	Bromegrass	Pasture	156	35
	1972	106	Corn	Contour, mulch tillage	176	38
	1973	106	Corn	Contour, mulch tillage	143	39
	Average annual				158	37
4	1969	150	Corn	Level terraced, conventional tillage	419	93
	1970	150	Corn	Level terraced, conventional tillage	383	91
	1971	150	Corn	Level terraced, conventional tillage	398	35
	1972	150	Corn	Subsurface pipe outlet terraces, mulch tillage	152	38
	1973	150	Corn	Subsurface pipe outlet terraces, mulch tillage	177	45
	Average annual				306	60

Table 2. Annual corn yields and crop use of N and P, Treynor, Iowa, 1969-1973.

Watershed No.	*Year*	*Yield* Grain[a] (bu/a)	Stalks[b] (t/a)	*Crop Use (lb/a)* Nitrogen Grain	Stalks	Total	Phosphorus Grain	Stalks	Total
1	1969	150.1	4.2	136	78	214	17	8	25
	1970	122.0	3.8	112	66	178	23	16	39
	1971	136.0	4.9	120	99	219	19	9	28
	1972	134.1	3.3	97	64	161	22	6	28
	1973	135.5	4.1	111	68	179	20	8	28
	Average annual	135.5	4.1	115	75	190	20	9	29
2	1969	136.0	3.9	114	74	188	13	8	21
	1970	114.1	3.5	100	54	154	19	6	25
	1971	128.1	4.9	109	75	184	19	7	26
	1972	135.1	2.9	96	43	139	20	4	24
	1973	121.1	3.4	98	44	142	16	7	23
	Average annual	126.9	3.7	103	58	161	17	6	23
3	1969	—	—	—	—	—	—	—	—
	1970	—	—	—	—	—	—	—	—
	1971	—	—	—	—	—	—	—	—
	1972	148.1	3.6	131	70	201	26	10	36
	1973	134.1	3.9	113	67	180	21	8	29
	Average annual	141.1	3.7	122	69	190	24	9	33
4	1969	132.1	4.0	122	75	197	14	9	23
	1970	112.7	4.0	122	71	193	23	8	31
	1971	115.0	4.4	112	87	199	20	9	29
	1972	125.6	2.8	103	55	158	22	7	29
	1973	112.7	3.7	99	54	153	19	7	26
	Average annual	119.6	3.8	112	68	181	20	8	28

[a]Based on 15.5 percent moisture.
[b]Based on oven-dried weight.

associated with erosion.

Although organic N forms are not available for plant use, they represent a potential N source for plant nutrition. NO_3-N is available for plant use. It also can be lost to the atmosphere by denitrification or removed by leaching and surface runoff.

Water-soluble P added as commercial fertilizer readily associates with clay or complexes with calcium, iron, and aluminum. This does not allow P to be moved easily by water. Therefore, P is lost primarily by soil erosion.

Surface Runoff Losses

Sediment losses from sheet and rill erosion on the contoured-corn watersheds 1 and 2 during the 1969-1974 water quality sampling period were less than the average annual losses measured during the decade from 1964 to 1974 (Table 3).

Sediment N concentrations were similar for the two contoured-corn watersheds regardless of annual fertilization rate. The 5-year average annual weighted concentrations were 1,450 parts per million (ppm) and 1,465 ppm, respectively, for watersheds 1 and 2. Sediment N concentrations were higher for watersheds 3 and 4. However, the amounts of sediment N discharged from watersheds 3 and 4 were considerably less than from watersheds 1 and 2 because of lower sediment losses (Table 3). The greater sediment N concentrations from watersheds 3 and 4 were probably caused by a higher percentage of organic material in extremely low runoff-sediment loads, compared with a higher percentage of mineral soil material in the higher runoff-sediment loads (watersheds 1 and 2).

Ninety-four percent of the N and 82 percent of the average annual P discharges in surface runoff from the two contoured-corn watersheds were transported with sediment (Table 4). Obviously, then, the most practical first step to prevent surface water pollution with these fertilizers is to reduce soil erosion on cropland, which also conserves N and P for future crop production.

The amount of water-soluble N discharged in surface runoff was low for all watersheds, compared with N applied and used annually by the corn crop (Table 5). Generally, the N discharged in surface runoff for given years and watershed conservation management treatments depended on runoff amount. However, concentrations of NO_3-N and NH_4-N were consistently greater on the highly fertilized contoured-corn watershed (No. 1) than on the watershed fertilized at the recommended rate (No. 2). Average annual weighted discharge concentrations of NO_3-N were 2.01 and 1.03 ppm, respectively, for watersheds 1 and 2. For NH_4-N the concentrations were 1.02 and 0.79 ppm, respectively.

Concentrations of water-soluble N in surface runoff usually were highest at the beginning of the cropping season and declined progressively during the remainder of the year (7). This seasonal effect was attributed to progressive N removal by crop use, leaching losses, and N in the equilibration process with organic matter. We must consider this seasonal effect in developing fertilizer application and runoff control management practices to reduce N losses during critical runoff and erosion periods.

A 2-year study on the watersheds showed that annual soluble N in surface runoff amounted to 20 percent of that in the annual precipitation (8). Soluble N contributed by rainfall during surface runoff events was equivalent to 69 percent of the soluble N discharged from the contoured-corn watershed fertilized at the recommended N rate. Therefore, N in rainfall was a major source of the soluble N measured in surface runoff.

The corn crop used no more than two-thirds of the annual P applied for any treatment. The average annual stream discharge of P in surface runoff was less than 0.9 pound per acre for each of the four watersheds (Table 4), which is less than 2 percent of the average annual P applications (Table 6). Much of the remaining P fertilizer applied was adsorbed by soil particles and only removed from the field by

Table 3. Annual precipitation and discharges of water and sediment, Treynor, Iowa, 1969-1974.

Watershed No.	*Year*	*Precipitation (in)*	*Water Discharge (in)*			*Sediment Yield (t/a)*
			Subsurface Flow	*Surface Runoff*	*Total*	
1	1969[a]	29.03	2.56	.77	3.33	1.65
	1970	31.54	2.21	2.14	4.35	12.06
	1971	29.08	2.06	4.94	7.00	19.98
	1972	33 97	2.67	1.51	4.18	7.51
	1973	41.73	8.19	2.61	10.80	1.03
	1974[b]	1.33	1.76	.08	1.84	0
	60-month total	166.68	19.45	12.05	31.50	42.23
	Average annual	33.34	3.89	2.41	6.30	8.45
	1964-73 average annual	33.97	3.03	4.23	7.26	22.08
2	1969[a]	29.15	2.41	.65	3.06	.91
	1970	30.84	2.35	1.79	4.14	8.00
	1971	29.19	2.62	3.84	6.46	13.16
	1972	34.06	3.00	1.54	4.54	7.85
	1973	41.21	10.08	2.95	13.03	.46
	1974[b]	1.33	2.88	.14	3.02	0
	60-month total	165.78	23.34	10.91	34.25	30.38
	Average annual	33.16	4.67	2.18	6.85	6.08
	1964-73 average annual	33.71	3.29	3.96	7.25	17.88
3	1969[a]	28.39	2.44	.42	2.86	.08
	1970	28.88	2.19	.37	2.56	.04
	1971	29.84	2.84	1.52	4.36	.64
	1972	37.52	6.23	.83	7.06	1.16
	1973	40.66	14.58	1.07	15.65	.14
	1974[b]	1.46	2.29	.01	2.30	0
	60-month total	166.75	30.57	4.22	34.79	2.06
	Average annual	33.35	6.11	.84	6.95	.41
	1964-73 average annual	33.28	4.35	1.46	5.81	.40
4	1969[a]	28.54	4.80[c]	.12	4.92	.05
	1970	28.81	3.99[c]	.13	4.12	.10
	1971	30.10	5.52[c]	.70	6.22	1.62
	1972	37.53	5.75[c]	4.22	9.97	6.51
	1973	40.42	12.02[c]	3.34	15.36	1.04
	1974[b]	1.39	2.52[c]	.03	2.55	0
	60-month total	166.79	34.60[c]	8.54	43.14	9.32
	Average annual	33.36	6.92[c]	1.71	8.63	1.86
	1964-73 average annual	33.60	6.71[c]	1.30	8.01	1.50

[a]Measurements include April through December.
[b]Measurements include January through March.
[c]Includes discharge from subsurface tile flow drainage alluvial plain at base of slopes.

soil erosion.

Deep Percolation of N

Soluble N within the deep loess profile is subject to deep percolation and subsequent subsurface discharge. Most water that moves through the loess profile in northwestern Missouri and western Iowa returns to the land surface via subsurface stream flow.

To better understand the movement of NO_3−N through the loess profile, Schuman and associates (9) conducted a 3-year soil-coring study on the two contoured-corn watersheds. The researchers reported that N fertilization at the recommended rate of 155 pounds per acre per year did not result in appreciable N accumulations within the 20-foot profile, did not increase NO_3−N below the corn root zone, and only increased the NO_3−N concentration at the groundwater surface from 2.0 to 4.5 ppm. However, excessive applications (at the rate of 400 pounds per acre per year) increased N 540 pounds per acre in the 20-foot profile, increased NO_3−N 642 pounds per acre below the corn root zone, and increased the NO_3−N concentration from 3.7 to 12.9 ppm at the groundwater surface during the 3 years.

Obviously, a considerable amount of N applied in excess of crop use leached to the saturated zone above the glacial till and significantly increased the NO_3−N concentration in subsurface flow. Also, the large amount of NO_3−N accumulated in the loess profile below the corn root zone will continue to be leached and eventually appear in subsurface flow.

In contrast, very little NO_3−N was leached to the groundwater and discharged in subsurface flow when N was applied at the recommended rate. Also, we expect subsurface discharges to be low for the 155-pound-per-acre application because little NO_3−N accumulated in the loess profile below the corn root depth.

Subsurface Stream Discharges

Subsurface discharge represents a large portion of the total annual stream flow and is highly influenced by conservation management (5). Water retention by terraces increases percolation and subsequent subsurface discharge compared with contouring.

NO_3−N discharged in subsurface flow accounted for at least 84 percent of the average annual soluble N discharged from the Treynor watersheds (3). Therefore, the influence of conservation and fertilizer management practices on the quantity and quality of water discharged as subsurface flow is of prime concern.

Excessive N fertilization on the terraced watershed for the first 3 years

Table 4. Annual discharges of N and P, Treynor, Iowa, 1969-1974.

		Nitrogen (lb/a)						*Phosphorus (lb/a)*			
			Soluble N								
			NO_3−N		*NH_4−N*				*Soluble P*		
Watershed No.	*Year*	*Sediment N*	*Subsurface*	*Surface*	*Subsurface*	*Surface*	*Total N*	*Sediment P*	*Subsurface*	*Surface*	*Total P*
1	1969[a]	4.67	8.66	0.97	0.29	0.05	14.64	0.27	0	0.17	0.44
	1970	31.02	4.31	1.30	.03	.37	37.03	.85	.08	.08	1.01
	1971	61.66	3.25	1.17	.06	1.88	68.02	1.69	.06	.21	1.96
	1972	20.91	6.96	.58	.07	.25	28.77	.49	.01	.04	.54
	1973	4.18	58.38	1.60	.20	.29	64.65	.08	.05	.15	.28
	1974[b]	0	10.87	0	.07	0	10.94	0	.01	0	.01
	60-month total	122.44	92.43	5.62	.72	2.84	224.05	3.38	.21	.65	4.24
	Average annual	24.49	18.49	1.12	.14	.57	44.81	.68	.04	.13	.85
2	1969[a]	2.29	1.17	.29	.26	.03	4.04	.15	0	.08	.23
	1970	22.46	.90	.47	.23	.31	24.37	.43	.05	.04	.52
	1971	36.88	1.45	.84	.05	1.30	40.52	.98	.02	.17	1.17
	1972	23.82	3.14	.44	.05	.15	27.60	.38	.01	.03	.42
	1973	3.48	18.54	.53	.25	.19	22.99	.08	.07	.20	.35
	1974[b]	0	5.28	.07	.28	.03	5.66	0	.02	.01	.03
	60-month total	88.93	30.48	2.64	1.12	2.01	125.18	2.02	.17	.53	2.72
	Average annual	17.79	6.10	.53	.22	.40	25.04	.40	.03	.11	.54
3	1969[a]	.24	.37	.27	.29	.06	1.23	.05	0	.17	.22
	1970	.19	.40	.15	.13	.08	.95	.02	.02	.06	.10
	1971	2.58	1.57	.86	.06	.38	5.45	.11	.02	.34	.47
	1972[c]	5.36	6.19	.38	.11	.07	12.11	.13	.02	.04	.19
	1973	.67	35.76	.83	.36	.15	37.77	.04	.06	.11	.21
	1974[b]	0	5.37	0	.10	0	5.47	0	.02	0	.02
	60-month total	9.04	49.66	2.49	1.05	.74	62.98	.35	.14	.72	1.21
	Average annual	1.81	9.93	.50	.21	.15	12.60	.07	.03	.14	.24
4	1969[a]	0.23	9.82[d]	0.10	1.12[d]	0.02	11.29	0.01	0.50[d]	0.07	0.58
	1970	.46	5.44[d]	.13	.25[d]	.03	6.31	.01	.15[d]	0	.16
	1971	6.23	23.91[d]	.14	.08[d]	.52	30.88	.20	.12[d]	.05	.37
	1972[e]	23.41	25.62[d]	2.91	.09[d]	.33	52.36	.52	.03[d]	.11	.66
	1973	4.11	76.23[d]	2.31	.15[d]	.31	83.11	.16	.05[d]	.20	.41
	1974[b]	0	15.61[d]	.02	.13[d]	0	15.76	0	.01[d]	0	.01
	60-month total	34.44	156.63[d]	5.61	1.82[d]	1.21	199.71	.90	.86[d]	.43	2.19
	Average annual	6.89	31.33[d]	1.12	.36[d]	.24	39.94	.18	.17[d]	.09	.44

[a]Measurements include April through December.
[b]Measurements include January through March.
[c]Treatment changed from pasture to till-planted corn.
[d]Includes discharge from subsurface tile flow drainage alluvial plain at base of slopes.
[e]Treatment changed from level terraces to pipe-drain terraces. Annual N application changed from 500 lb/a to 164 lb/a. Tillage changed from conventional to till-plant.

and continued excessive fertilization of the contoured-corn watershed greatly increased NO_3-N in subsurface flow over 5 years, compared with that in subsurface discharges from the watersheds fertilized annually at rates recommended for crop use (Table 4). Excessive precipitation and percolation in the fall of 1972 and throughout 1973 drastically increased NO_3-N discharged in subsurface flow from all watersheds. NO_3-N discharged in subsurface flow in 1973 accounted for 90, 80, 94, and 91 percent of the total annual N discharges (solution N + sediment N) for watersheds 1, 2, 3, and 4, respectively (Table 4). This discharge source contrasted with previous years when sediment N was the major source of N discharged.

Terraces effectively controlled erosion, but they also increased deep percolation and subsequent subsurface discharge. They have thus caused subsurface discharge to be the major source of NO_3-N discharge. Subsurface discharge of soluble N from the terraced watershed 4 amounted to 10 percent of the N applied during the 5-year period (Table 5). In comparison, sediment N and soluble N discharged in surface runoff from the terraced watershed amounted to 2.2 and 0.4 percent of the N applied. Although more N was applied to the contoured-corn watershed 1 than to the terraced watershed 4 during the 5-year study, the average annual discharges of soluble N (surface + subsurface) were less from watershed 1 than from watershed 4 (Table 5). We attributed this difference of soluble N in subsurface discharge for the two watersheds to the difference in the amounts of water moving through the soil.

Soluble P in subsurface discharge amounted to a very small percentage of the annual P applied and that used by the crop (Table 6). This was of little significance to stream pollution. The P discharge data (Tables 4 and 6) illustrate that the soil mineral and organic material adsorb this element, and it moves from cropland primarily as a result of erosion.

Table 5. Average annual N movement by crop use and stream discharge, corn watersheds, Treynor, Iowa, 1969-1974.

	Management Practice					
	Watershed 2, Contoured 155 lb/a N		*Watershed 1, Contoured 400 lb/a N*		*Watershed 4, Terraced 306 lb/a N*[a]	
Movement Pathway	*(lb/a)*	*(%)*[b]	*(lb/a)*	*(%)*[b]	*(lb/a)*	*(%)*[b]
Crop use:						
Corn grain	103	67	115	29	112	37
Corn stalks	58	37	75	19	69	22
Total corn use	161	104	190	48	181	59
Stream discharge:						
Sediment	17.8	11.4	24.5	6.1	6.9	2.2
Surface runoff	.9	0.6	1.7	0.4	1.4	0.4
Subsurface flow	6.3	4.1	18.6	4.7	31.7	10.3
Total stream discharge	25.0	16.1	44.8	11.2	39.9	13.0
Total crop use and stream discharge	186	120.0	234.8	58.7	220.9	72.2

[a]Applied at an average annual rate of 400 lb/a in 1969, 1970, and 1971. Applied at an average annual rate of 164 lb/a in 1972 and 1973.
[b]Expressed as a percentage of applied nitrogen.

Table 6. Average annual P movement by crop use and stream discharge, corn watersheds, Treynor, Iowa, 1969-1974.

	Management Practice					
	Watershed 2, Contoured 36 lb/a P		*Watershed 1, Contoured 59 lb/a P*[a]		*Watershed 4, Terraced 60 lb/a P*[b]	
Movement Pathway	*(lb/a)*	*(%)*[c]	*(lb/a)*	*(%)*[c]	*(lb/a)*	*(%)*[c]
Crop use:						
Corn grain	17	47	20	34	20	33
Corn stalks	6	17	9	15	8	13
Total corn use	23	64	29	49	28	47
Stream discharge:						
Sediment	0.40	1.1	0.68	1.1	0.18	0.3
Surface runoff	.11	0.3	.13	0.2	.09	0.2
Subsurface flow	.03	0.1	.04	0.1	.17	0.3
Total stream discharge	.54	1.5	.85	1.4	.44	0.7
Total crop use and stream discharge	23.54	65.4	29.85	50.6	28.44	47.4

[a]Applied at an average annual rate of 95 lb/a in 1969 and 1970. Applied at an average annual rate of 36 lb/a in 1971, 1972, and 1973.
[b]Applied at an average annual rate of 92 lb/a in 1969 and 1970. Applied at an average annual rate of 39 lb/a in 1971, 1972, and 1973.
[c]Expressed as a percentage of applied P.

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