FACTORS AFFECTING LEACHING IN AGRICULTURAL AREAS AND AN ASSESSMENT OF AGRICULTURAL CHEMICALS IN THE GROUND WATER OF KANSAS

By Charles A. Perry, F. Victor Robbins, and Philip L. Barnes

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CONVERSION FACTORS

Information in the following table may be used to convert the inch-pound units of measurement used in this report to metric (International System) units:

Multiply inch-pound unit	*By*	*To obtain metric unit*
inch	25.4	millimeter
foot	0.3048	meter
mile	1.609	kilometer
acre	4,047	square meter
quart	0.9464	liter
pound	453.6	gram
ounce	28,349	milligram
ton (short)	0.9072	megagram
pound per acre (lb/acre)	0.112	gram per square meter
inch per foot	83.333	millimeter per meter
gallon per minute	0.06308	liter per second
pound per square inch	6.895	kilopascal
degree Fahrenheit (°F)	°C = 5/9 (°F -32)	degree Celsius (°C)

Sea level: In this report, sea level refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level."

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By Charles A. Perry[1], Victor Robbins[2], and Philip L. Barnes[3]

ABSTRACT

Hydrologic factors and agricultural practices that affect the leaching of agricultural chemicals were assessed to evaluate the extent and severity of chemical contamination of ground water in Kansas. Climate, surficial geology, soil type, and principal aquifers determine the types of crops suitable to be planted, types of tillage, conservation and irrigation practices, and affect the quantity and method of application of agricultural chemicals.

In general, the more sand in the soil the more susceptible it will be to leaching of agricultural chemicals. Soils in Kansas are grouped into four classes of leachability--from class 1, with the largest permeability, to class 4, with the smallest.

As a result of years of nitrogen application to the soil, the 10-milligram-per-liter drinking-water standard for nitrate-nitrogen was exceeded occasionally in 13 of 14 geohydrologic regions in the State.

During 1978, about 23.8 million pounds of herbicides and 4.3 million pounds of insecticides were used in the State. Atrazine was the most extensively used herbicide, with 5.7 million pounds applied. However, in areal extent, 2,4-D was the most extensively used, being applied to more than 4 million acres.

One or more herbicides were detected in water samples from 11 of 56 wells during 1985-86. These wells were located in areas susceptible to agricultural leaching. Atrazine was the most common herbicide detected; it was detected in water at 9 of 11 wells. Cyanazine was detected in water at three wells; metolachlor at two wells; and metribuzin, alachlor, simazine, and propazine were detected at one well each.

Because the largest concentrations of atrazine (46 micrograms per liter), cyanazine (3.7 micrograms per liter), metolachlor (55 micrograms per liter), and the only detectable concentrations of metribuzin (14 micrograms per liter) and alachlor (1.9 micrograms per liter) were from water at only one site, it is uncertain how widespread the problem of large concentrations of these herbicides is throughout the State. The herbicides 2,4-D, 2,4,5-T, picloram, and alachlor and the insecticides chlordane and heptachlor epoxide have been detected by other researchers in ground water from domestic-supply wells in the State.

A plan for a proposed study of the leaching and fate of pesticides in the saturated and unsaturated zones in Kansas includes a comprehensive investigation of pesticides in soil and ground water, data collection, process interpretation, and numerical modeling.

INTRODUCTION

Contamination of ground-water resources by potentially toxic agricultural chemicals is increasing. The use of fertilizers and pesticides in Kansas has increased significantly during the past three decades. Most cropland is fertilized (Freeze and Cherry, 1979), and a part of this fertilizer reaches the water table. Pesticides encompass a variety of organic chemicals with greatly differing properties that affect their behavioral patterns and ultimate environmental fate. During 1978, an estimated 28.1 million pounds of herbicides and insecticides were applied to Kansas soils and crops (Nilson and Johnson, 1980). As a result of this extensive use, introduction of pesticides

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into the subsurface environment becomes possible, as indicated by residues of pesticides being detected in shallow aquifers in farming areas free from other manmade chemical inputs. For example, the herbicides atrazine, 2,4-D, 2,4,5-T, picloram, and alachlor and the insecticides chlordane and heptachlor epoxide (degradation product of heptachlor) have been detected in domestic-supply wells in Kansas (Steichen and others, 1986). Ground water in areas where the water table is near the land surface and in areas where the soil and vadose zones consist of permeable sand may be the most susceptible to contamination by agricultural chemicals.

Little is known about the leaching and fate of agricultural chemicals in the subsurface environment. To understand the dynamics and fate of these chemicals in hydrologic settings, it is necessary to understand the factors that affect the environmental fate of agricultural chemicals.

Purpose and Scope

The purposes of this report are to: (1) Describe the physical, geological, and climatological factors that affect the leaching and fate of agricultural chemicals in the saturated and unsaturated zones in Kansas; (2) describe the agricultural practices, such as minimum tillage or double-cropping, and their possible relation to the type and quantity of applied chemicals; (3) tabulate fertilizer and pesticide applications (weight and acreage) throughout the State; (4) present a description of the complexities of pesticide-soil interactions; (5) tabulate the most commonly used pesticides in Kansas with their chemical properties, toxicities, and application rates; (6) examine ground-water analyses for pesticides at selected sites; and (7) outline a plan of study for a much needed comprehensive investigation of the leaching and fate of agricultural pesticides in the saturated and unsaturated zones in Kansas.

Acknowledgments

The study described in this report was conducted in 1985-86 by the U.S. Geological Survey in cooperation with the Kansas Department of Health and Environment. The authors gratefully acknowledge the assistance of the Kansas State University Agronomy Farms, especially personnel from the Kansas River Valley Agronomy Experimental Field, Topeka, Kans. Their assistance included compilation of agricultural factors.

HYDROLOGIC FACTORS AFFECTING LEACHING

The hydrologic factors that affect the response of the environment to chemical applications are numerous and varied. The geology of an area is generally responsible for the type of soil found at the surface, the structure of the underlying vadose zone, and the material that comprises the saturated zone (aquifer). The climate of a particular area determines the availability of water, at the surface and in the ground, for the growth of plants. This in turn determines the types of crops to be planted or whether the land is to be used for pasture. Agricultural practices, including types of tillage, conservation practices, and irrigation, can have an important effect on the hydrology of certain areas.

Surficial Geology

Kansas is part of the Great Plains physiographic province that extends from Canada to Mexico east of the Rocky Mountains (Fenneman, 1946). The land surface generally slopes eastward from a maximum altitude of 4,135 feet above sea level along the western border with Colorado to a low of about 700 feet above sea level where the Verdigris River crosses into Oklahoma. The oldest rocks are exposed in the extreme southeast part of the State where outcrops of Mississippian age occur in the Ozark Plateaus (fig. 1). The rocks are progressively younger and increase in altitude to the west.

The eastern one-third of the State has outcrops of Pennsylvanian- and Permian-age rocks. This part of Kansas is called the Osage Plains (Fenneman, 1946). In this area, east-facing limestone escarpments lie between gently rolling plains that were formed from softer rocks, such as shale. Soil along the escarpments is generally rocky and is not farmed. Soil formed from the softer rocks in the eastern one-third of the State is relatively impermeable except along the flood plains of rivers and streams

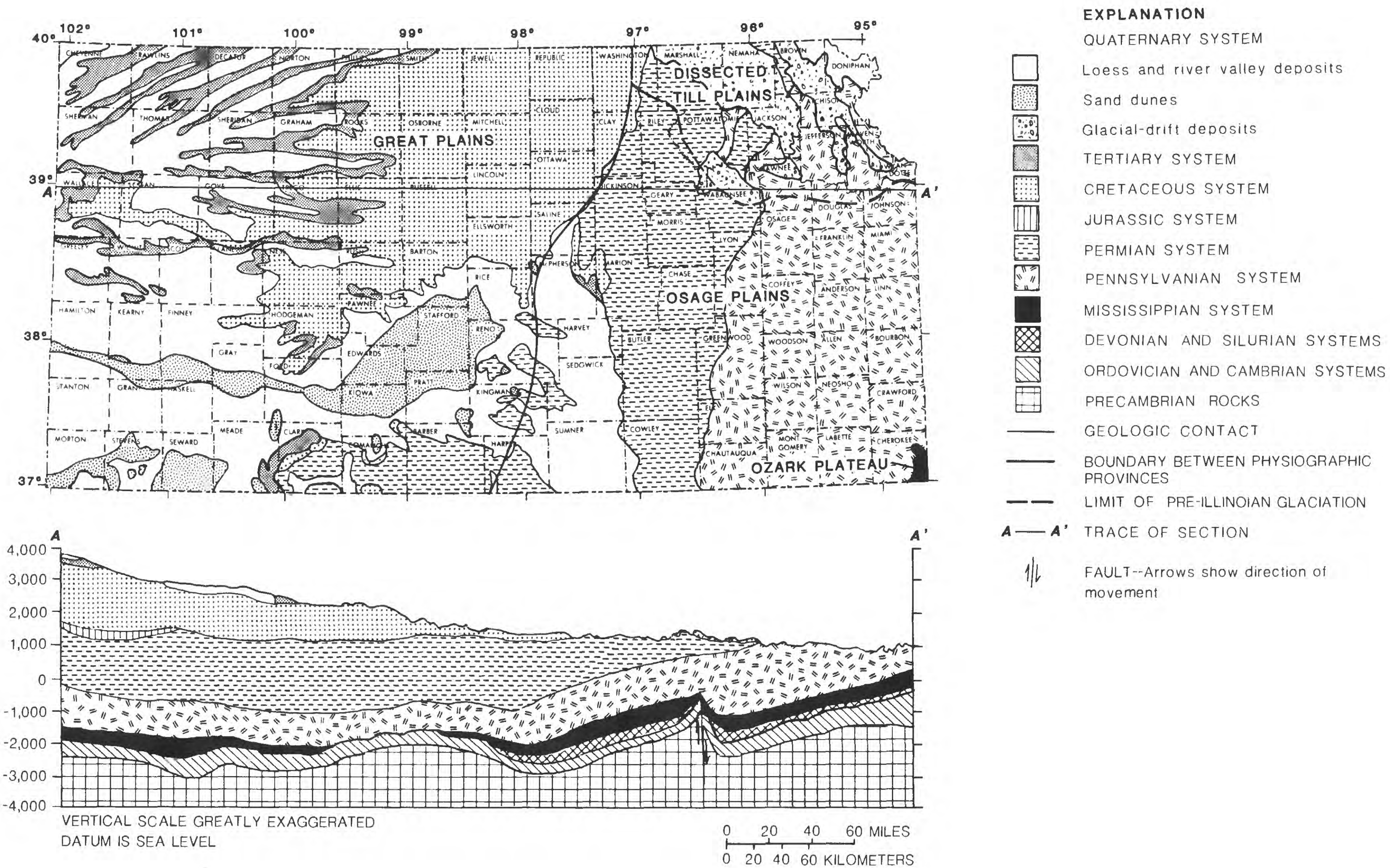

Figure 1. Generalized geology and physiographic provinces (modified from American Geological Institute, 1977).

where silt and sand have improved infiltration characteristics of the soil. The northern one-fourth of the Osage Plains has been modified by glacial drift of the pre-Illinoian glaciation and by windblown deposits of loess.

The western two-thirds of the State is in the Great Plains physiographic province. Cretaceous rocks with layers of hard limestone characterize the north-central part of the State. Westward, the uplands blend into Tertiary and Quaternary deposits of sand and gravel overlain with windblown loess. The loess soil is somewhat more permeable than the eastern soil and therefore is slightly more susceptible to leaching. The Arkansas River enters Kansas from Colorado and has been responsible for the sand and sand-dune deposits that cover much of south-central Kansas. Soil is permeable in this area, and leaching can be a major soil-management problem.

Principal Aquifers

Principal aquifers in Kansas usually are unconfined and consist of either unconsolidated gravel, sand, silt, and clay, or consolidated sandstone, limestone, and dolomite (fig. 2). The largest alluvial aquifers are associated with the major rivers--the Missouri, Kansas, Arkansas, Republican, and Pawnee Rivers. Wells completed in these aquifers typically yield more than 500 gallons per minute, and static water levels usually are less than 50 feet below land surface. Wells adjacent to the tributaries of these larger rivers commonly yield less than 100 gallons per minute but are still very important as domestic- and municipal-water supplies. Recharge to these alluvial aquifers is mainly from direct infiltration of precipitation and from the stream itself, especially during periods of drought when reservoir releases maintain low flows. Therefore, the stream-aquifer boundary can be a pathway by which chemicals in surface runoff enter the ground-water system.

The glacial-drift aquifer is the major source of ground water in the northeast part of the State. This unconfined aquifer consists of sand, gravel, and clay deposited during the pre-Illinoian glaciation. Most wells in this aquifer yield 10 to 100 gallons per minute, with the most productive wells yielding almost 500 gallons per minute.

The eastern part of the High Plains aquifer consists of the buried valleys of the ancestral Smoky Hill River (*Equus* beds aquifer) and the Arkansas and Pawnee Rivers (Great Bend Prairie aquifer) (fig. 2). The High Plains aquifer extends westward to the Colorado border. Cenozoic fluvial and eolian deposits of gravel, sand, silt, and clay in the High Plains aquifer yield 500 to 1,500 gallons per minute. This generally unconfined aquifer lies near or at the land surface and is susceptible to contamination by leaching.

The Great Plains aquifer, which generally is unconfined, is formed by the Dakota and Cheyenne Sandstones of Cretaceous age. The use of this aquifer as a water supply extends from Republic and Washington Counties south-southwestward to Ellsworth County, then westward to eastern Finney County (fig. 2). Wells in the Great Plains aquifer commonly yield 10 to 100 gallons per minute in the northeast part and up to 1,000 gallons per minute in the south and west. Areas where the aquifer crops out are the most susceptible to contamination.

The Chase-Council Grove aquifer in the Chase and Council Grove Groups extends from Riley County to Cowley County and consists of fractured limestone of Permian age. Wells typically yield 10 to 20 gallons per minute. Much of this area is mantled with a thin soil that is best suited for rangeland grazing. However, some chemicals are applied for noxious-weed control on the rangeland and could leach into the aquifer.

The Douglas aquifer in the Douglas Group consists of channel sandstone of Pennsylvanian age that stretches from just west of Kansas City south-southwestward to Chautauqua County (fig. 2). Several cities use this aquifer as a municipal-water supply, especially in the northern outcrop area where it is most susceptible to contamination. Wells yield from 10 to 40 gallons per minute.

The Ozark aquifer is a major source of ground water in the Ozark Plateaus in extreme

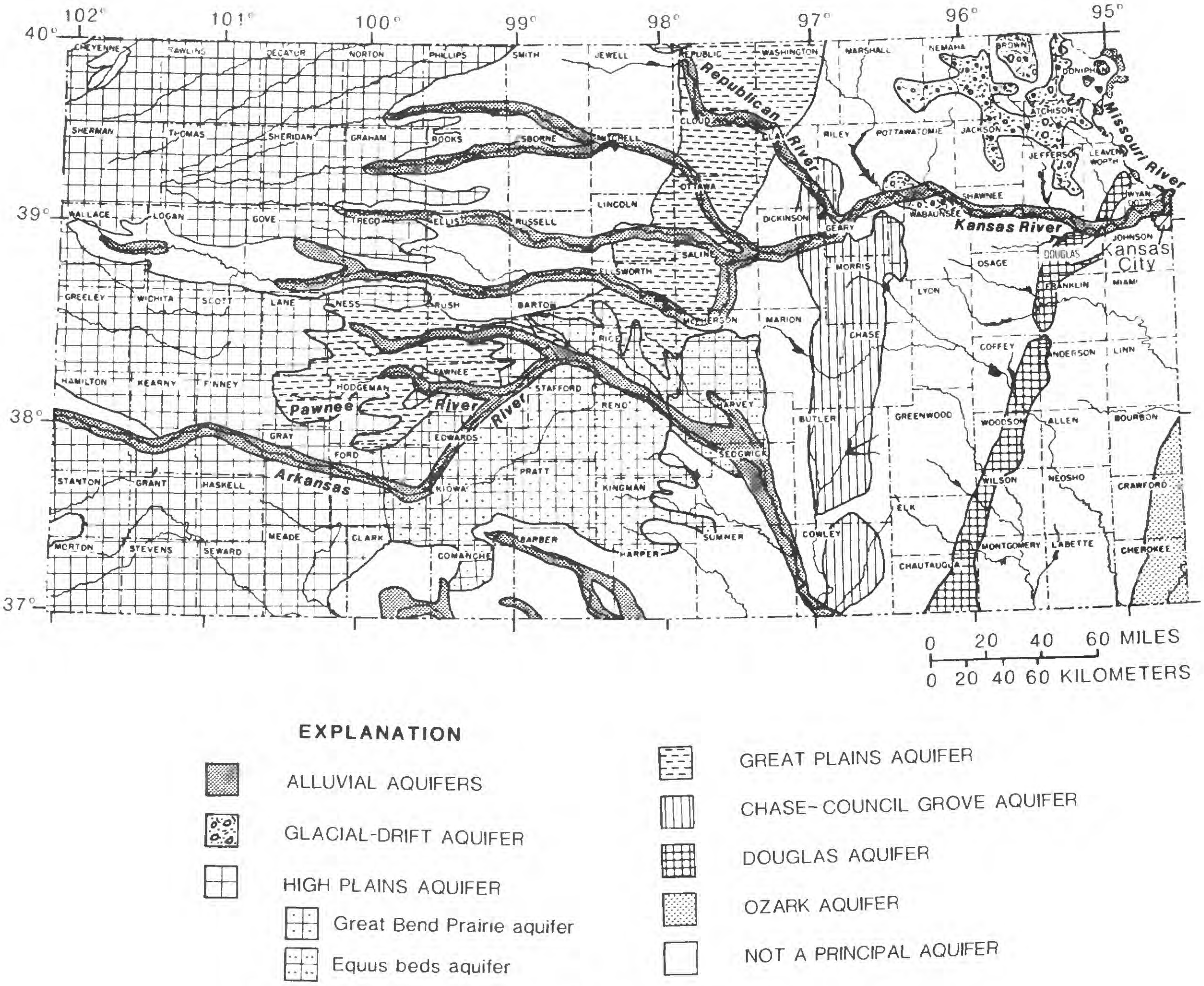

Figure 2. Principal aquifers (modified from Bevans and others, 1985).

southeastern Kansas. This aquifer consists of dolomite of the Arbuckle Group of Cambrian and Ordovician age, which yields 30 to 150 gallons per minute. Depth to the aquifer is greater than 300 feet, and because it is confined, the probability of it being contaminated by agricultural activity is slight.

Many small-yielding domestic wells throughout the State either are dug or drilled into saturated clay, shale, and limestone at locations where there are no major aquifers. These shallow wells are very susceptible to contamination by nitrate and other agricultural chemicals, especially in the eastern part of the State where precipitation is greater.

Climate

The climate of Kansas becomes drier going from east to west across the State, as indicated by the map showing average annual precipitation, 1951-80 (fig. 3). The extreme southeastern part of the State receives an average of more than 40 inches of precipitation annually and in many years can be classified as having a humid climate. The western tier of counties averages less than 20 inches of annual precipitation, and in some years can be classified as having an arid climate. Precipitation reports for Kansas are provided by the National Oceanic and Atmospheric Administration for the nine reporting districts indicated in figure 3. Average annual

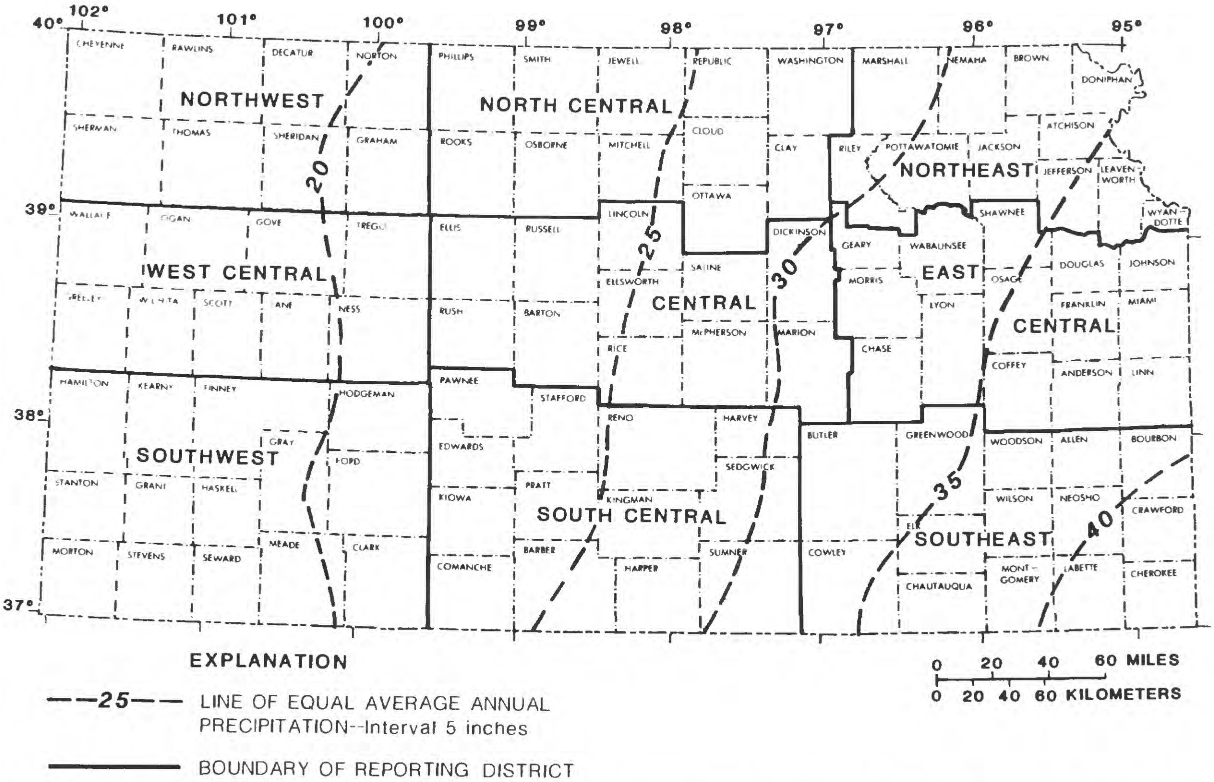

Figure 3. Average annual precipitation, 1951-80, and precipitation reporting districts of the National Oceanic and Atmospheric Administration.

Table 1. *Average annual precipitation, 1951-80, for nine reporting districts*
[Data from National Oceanic and Atmospheric Administration, 1983]

District (fig. 3)	Average annual precipitation (inches)
Northwest	19.88
North-central	26.30
Northeast	34.33
West-central	19.58
Central	27.66
East-central	35.38
Southwest	18.56
South-central	26.28
Southeast	36.50

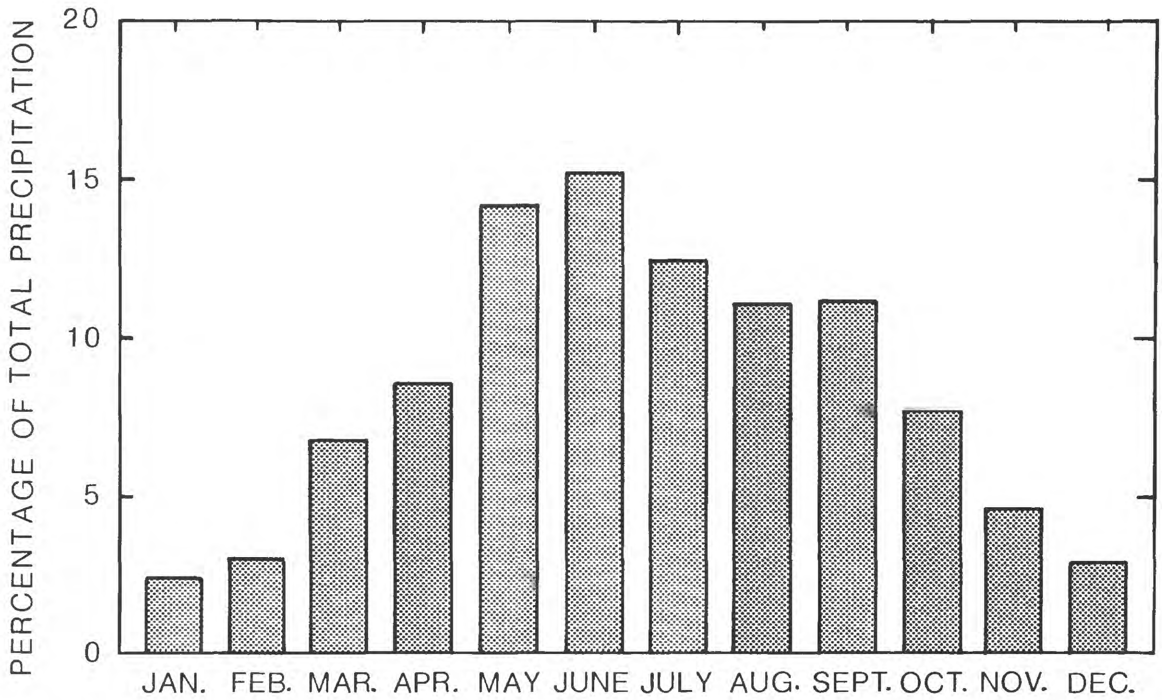

Figure 4. Average monthly precipitation in Kansas as a percentage of total average annual precipitation, 1951-80.

precipitation for these reporting districts is given in table 1, and figure 4 shows the average monthly precipitation as a percentage of each district's annual average. More than 70 percent of the average annual precipitation occurs during the growing season (April through September). Summers are hot with temperatures in the 90's and occasionally over 100°F. Winters usually have extended periods of subfreezing temperatures. Loss of water to the atmosphere (evapotranspiration) is dependent upon temperature, humidity, solar radiation, and the availability and type of live vegetation.

If adequate precipitation is not available, irrigation may be used to supply water for plant growth. The number of irrigated acres for 1984 for the nine reporting districts is shown in table 2. During those periods when rainfall or irrigation rates are greater than the rate of evapotranspiration, a surplus of water occurs, and the soil-moisture reservoir is recharged. If the soil becomes saturated, deep percolation to the ground-water reservoir and (or) runoff occurs. Most generally, deep percolation occurs during the nongrowing season when evapotranspiration is at a minimum, or during excessive application of irrigation water.

Soil

The soil of Kansas has developed from various rocks and minerals with different origins. Many of the soil types in the State have developed from underlying geologic formations, which are mainly limestone, shale, and sandstone. Various soil types in northeast Kansas were derived from parent material that was carried into the State by the pre-Illinoian glaciation. Other soil types developed from alluvial deposits along rivers, and some extensive areas are mantled with eolian soil that was imported by the wind.

Soil contains solid mineral particles that are a result of many years of weathering of the parent materials and is mixed with varying amounts of organic material. Soil also contains varying amounts of water and gases. The total volume of the soil is about one-half soil material and one-half pore space (Foth, 1978). This pore space is the channel for movement or storage of soil moisture.

Soil material is divided into three major groups--sand, silt, and clay. These groups or textural classes are based on particle size, as shown in table 3. A textural classification system developed by the U.S. Department of Agriculture Soil Survey Staff (1951) is shown in figure 5.

Table 2. *Number of irrigated acres in 1984 for nine reporting districts*
[Kansas State Board of Agriculture, 1985]

District (fig. 3)	Irrigated land (acres)
Northwest	422,000
North-central	165,000
Northeast	25,000
West-central	350,000
Central	137,000
East-central	51,000
Southwest	1,800,000
South-central	479,000
Southeast	38,000

Soil-moisture characteristics are described as follows. Field capacity is the soil-moisture content after free water has been drained by gravity. Most soil is at field capacity within a few hours to a few days after a rain or irrigation. Soil moisture that is less than field capacity is removed by evaporation or by plant transpiration. As additional water is removed, the force required to remove the water increases until plant roots can no longer withdraw water from the soil. The plant leaves then become permanently wilted. At this point (the permanent wilting point), some water remains in the soil, but it can not be recovered by the plants. The difference in the quantity of water at field capacity and at the permanent wilting point is called available water--soil moisture that is usable for plant growth. The influence of soil texture on field capacity, permanent wilting point, and available soil moisture is shown for three typical soil types in table 4.

As soil moisture decreases, more force is required to remove water from the soil. The amount of force it takes to remove the water (moisture stress) is also a function of soil

Table 3. *Soil-texture classification*
[U.S. Department of Agriculture Soil Survey Staff, 1951]

Texture classification	Particle size (millimeters)
Stone or gravel	Greater than 2.0
Very coarse sand	1.0 - 2.0
Coarse sand	0.5 - 1.0
Fine sand	0.10 - 0.25
Very fine sand	0.05 - 0.10
Silt	0.002 - 0.05
Clay	Less than 0.002

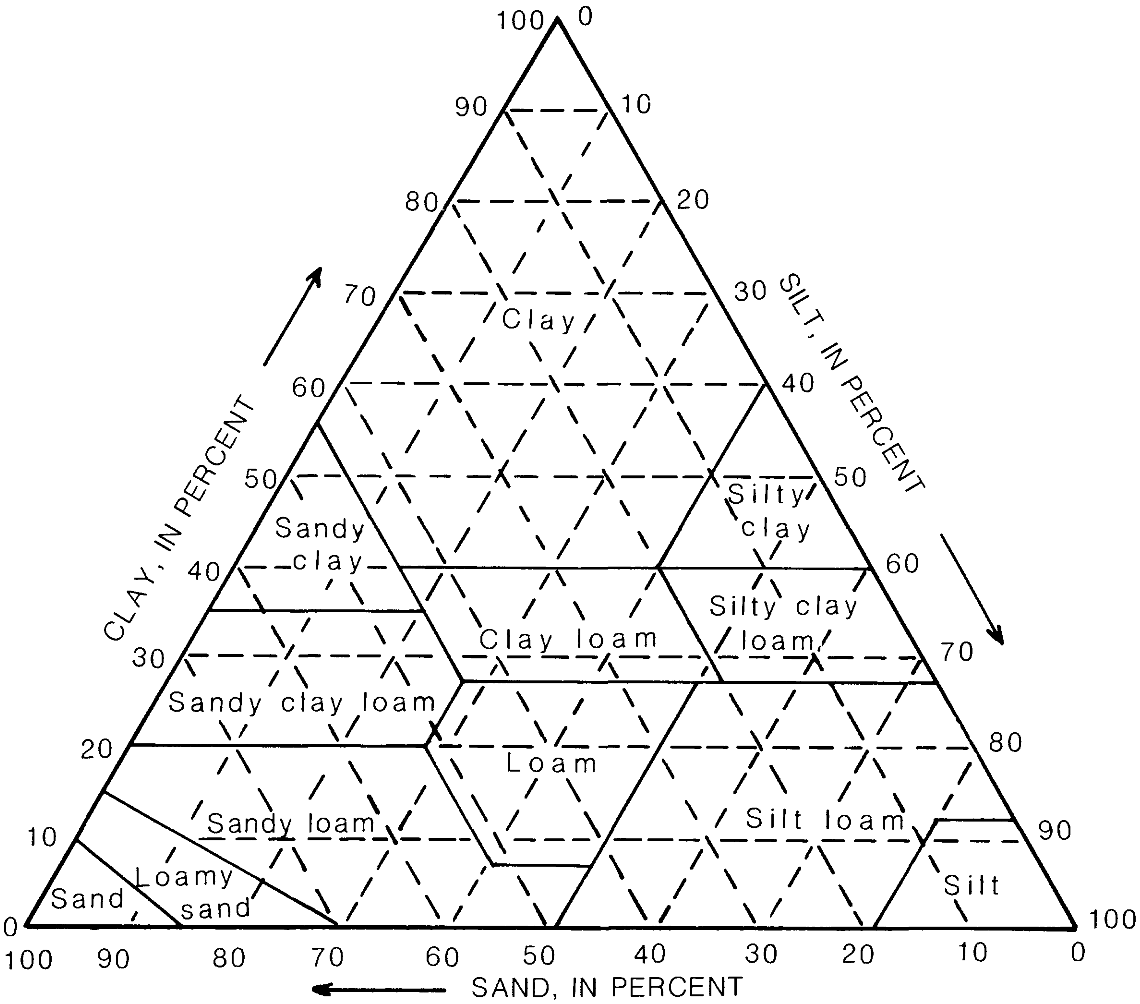

Figure 5. Classification of soil textures (U.S. Department of Agriculture Soil Survey Staff, 1951).

Table 4. *Typical soil-moisture levels for three soil textures*

Texture	Field capacity (inches per foot)	Permanent wilting point (inches per foot)	Available moisture (inches per foot)
Sandy	1.2	0.2	1.0
Loamy	2.2	.5	1.7
Clay	3.6	1.2	2.4

texture. A set of typical soil-moisture-release curves is shown in figure 6. Available soil moisture is released more easily from sand than from clay. Although finer textured soil holds more water, it also holds it more tightly than coarser soil. Thus, coarser soil can transmit a much larger quantity of water and chemicals than finer soil. Coarser soil often overlies shallow aquifers, such as those in south-central and southwestern Kansas and in the alluvial river valleys.

Excessive leaching occurs most frequently in coarse-textured soil. If water from rainfall or irrigation is applied to this soil in amounts greater than its field capacity, this water can drain rapidly through the soil and leach any soluble chemicals into the ground water. Annual moisture used by crops grown in Kansas is shown in table 5.

Coarse-textured soil that is very susceptible to leaching also is most often irrigated. This soil type usually occurs in conjunction with a coarse-textured unsaturated zone and a shallow water table. Water drains easily through sandy soil, thus frequent irrigation is required to maintain the moisture content necessary for crop growth. Excessive irrigation can produce significant chemical leaching losses. Intense rainfall during May through July can cause nitrogen-leaching losses from spring-seeded crops. However, intense rainfall does occur at other times of the year and can have an impact on winter-wheat production as well, particularly on coarse-textured soil.

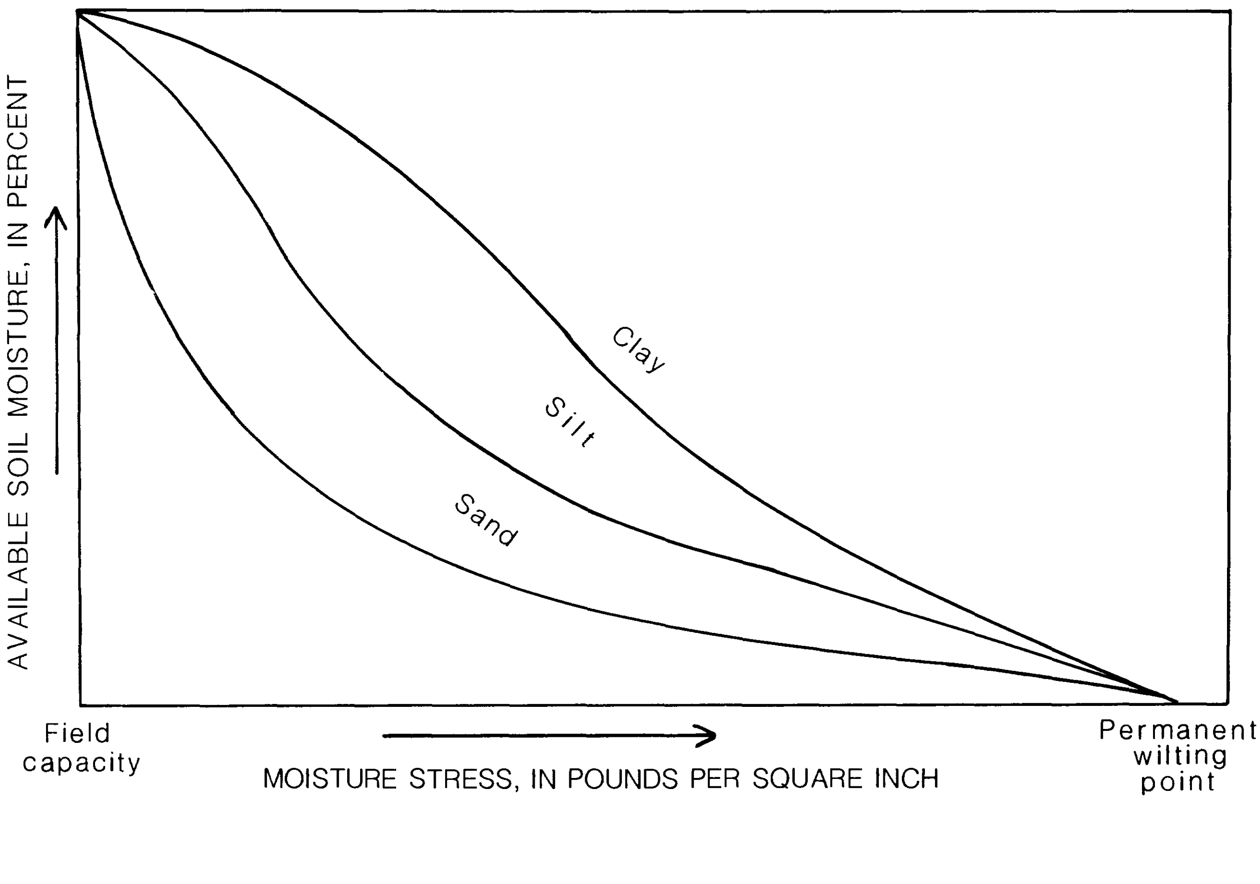

Figure 6. Typical soil-moisture-release curves for three common soil types (Foth, 1978).

Table 5. *Annual crop-moisture use for typical Kansas crops*
[Kansas State University, 1982]

Crop	Moisture use (inches)
Corn	24-26
Soybeans	20-22
Grain sorghum	18-20
Wheat	15-18

In general, the greater the percentage of sand in the soil the more susceptible it will be to leaching. Soil is grouped into four classes of leachability (Kissel and others, 1982):

Class 1 - Sand, fine sand, coarse sand, and loamy coarse sand, with permeability ranging from 6 to 20 inches per hour.

Class 2 - Loamy fine sand, coarse sandy loam, and sandy loam, with permeability ranging from 2 to 6 inches per hour.

Class 3 - Loam, very fine sandy loam, silt loam, and fine sandy loam, with permeability ranging from 0.6 to 2 inches per hour.

Class 4 - Clay loam, silty clay loam, silty clay, sandy clay, and clay, with permeability less than 0.6 inch per hour.

As soil types differ across the State, leachability classes vary accordingly. A map showing leachability classes of Kansas soil is shown in figure 7. The entire soil profile was considered in selection of the leachability class for a particular soil type. The finest textured horizon or the most-limiting layer (smallest permeability) becomes the deciding factor in class selection (Kissel and others, 1982). The leachability map shows that the majority of classes 1 and 2 are in south-central or southwestern Kansas. However, important agricultural areas that have class 1 or 2 soil types are located also in the many river valleys throughout the State. Because of the scale of figure 7, this detail could not be shown. The number of acres in each leachability class in Kansas is listed in table 6.

AGRICULTURAL AND CHEMICAL FACTORS AFFECTING GROUND-WATER QUALITY

Agricultural Land Use

Farmers in Kansas use a variety of agricultural practices that may be important factors affecting the leaching of agricultural chemicals. These practices are related to climate, in general, and specifically to the depth of soil moisture available for plant growth. The eastern one-third of the State has adequate precipitation to grow most crops, whereas the western two-thirds of the State commonly uses supplemental irrigation. In areas where irrigation water is not available, crops must be grown under dryland conditions, completely dependent upon moisture stored in the soil.

The most common crop grown under dryland conditions in Kansas is winter wheat. Fall preparation for planting wheat involves tillage to reduce plant residues on the soil surface and preparation of the soil seedbed. Fertilizers, herbicides, and insecticides typically are applied before planting. Farmers often increase soil-fertility levels by surface or near-surface applications of fertilizer early in the spring. If

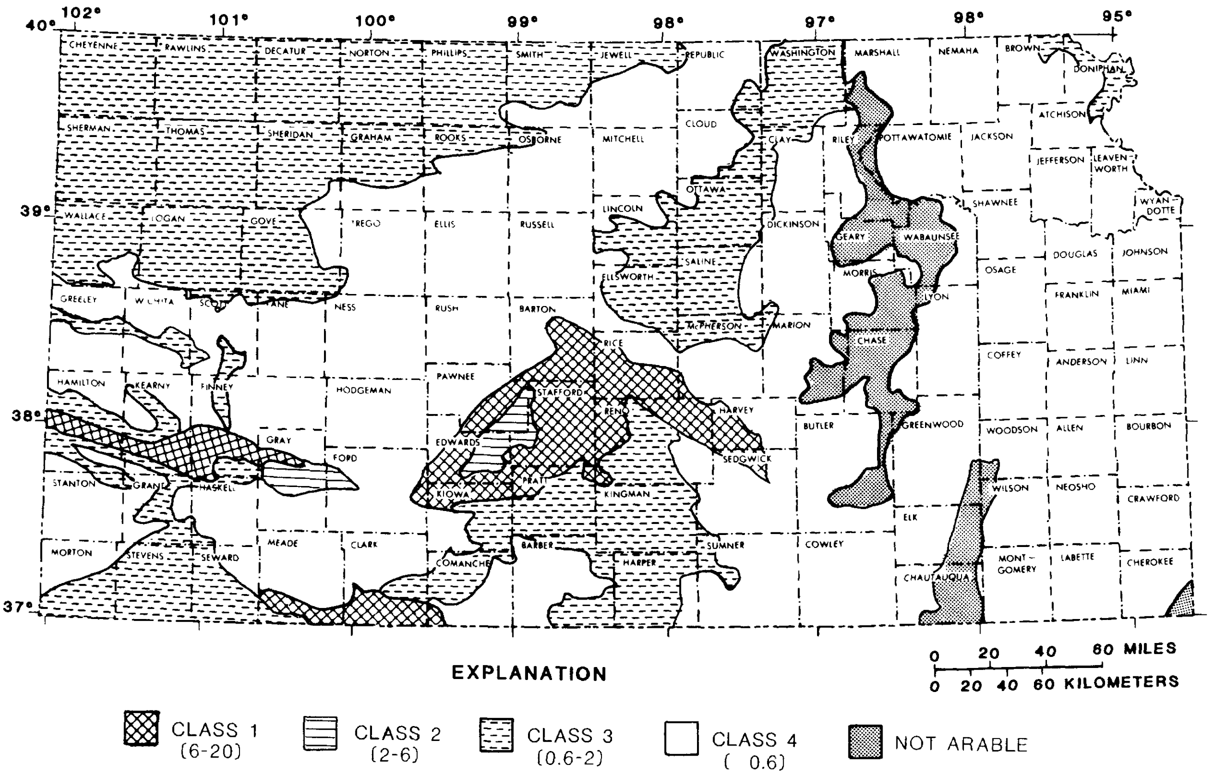

Figure 7. Distribution of leachability classes of Kansas soil (modified from Kissel and others, 1982).

Table 6. *Number of acres in each leachability class in Kansas*
[Kissel and others, 1982]

Leachability class	Number of acres
Class 1	1,210,000
Class 2	1,770,000
Class 3	12,500,000
Class 4	15,500,000

weed or insect problems occur during the early spring months, additional herbicide or insecticide applications may be necessary. Wheat is harvested during the early summer months, and the soil is allowed to lie idle until preparation for planting is started in the fall.

For areas of the State with adequate precipitation or irrigation, intensive agricultural practices are used to grow row crops, such as corn, grain sorghum, and soybeans. Typically, the preparation of fields is started after the soil has thawed in the spring. Fields are tilled by disking to loosen the soil, and large quantities of nitrogen-containing fertilizers are applied. A short time before planting, herbicides and insecticides are applied and tilled into the soil surface. Further weed growth may require cultivation or application of a postemergent herbicide to the crop. Harvesting of row crops occurs during the late summer and fall. After harvest, crop residues left in the field are disked into the soil. Crop residues are incorporated into the soil by a chisel or plow in the fall, and the soil-residue mixture is allowed to accumulate winter moisture until the next spring. The freezing and thawing process breaks up soil particles and crop residue so that by planting time in the spring a fairly homogeneous mixture of soil and organic material exists.

Agricultural Chemical Use

Fertilizers

For centuries crop production has been improved by the addition of natural substances, such as manures, lime, marl, ashes, and bone, to the soil. Certain plants, called legumes, that utilize nitrogen-fixing bacteria were grown periodically to add nitrogen to the soil. With the advent of mechanized farming, much more land was placed in production, and natural fertilizers could not keep pace with crop production. As a result, nutrient depletion and soil erosion occurred. Crop production increased significantly with the commercial production of synthetic fertilizers because growth was limited only by the ability of the plant to absorb the fertilizers and by available moisture. Nutrients from abundant crop residues, combined with excessively applied fertilizers, can accumulate in ponds, rivers, lakes, and ground water. H. D. Foth (1978) estimated that industrially fixed nitrogen equals natural worldwide terrestrial fixation and that the biosphere is gaining about 9 million metric tons more nitrogen than it is losing. Large concentrations of nitrogen in ground water can be a result of intensive agricultural activity.

Any organic or inorganic substance of natural or synthetic origin that supplies one or more of the nutrient elements essential for the growth and reproduction of plants can be considered a fertilizer. Generally, these substances contain nitrogen, phosphorus, or potassium. The common commercial fertilizers containing nitrogen, phosphorus, or potassium are listed in table 7. Other nutrient elements and chemical radicals combined within a fertilizer also can affect water quality, depending on the soil's chemical characteristics.

Nitrogen--Of the three major fertilizer compounds (nitrogen, phosphorus, or potassium), nitrogen compounds are by far the most extensively used chemicals. Because nitrogen compounds form nitrates that are water soluble, any excess that is not utilized by the growing plants is available for leaching. Leached nitrogen is an economic loss for the farmer, and a potential contaminant to the ground-water system. The farmer must solve the problem of maintaining maximum yields while minimizing nitrogen loss by leaching. The amount of nitrogen leached is a function of soil properties (including chemical and biological factors), amount of water available for leaching, the amount of nitrogen available in the soil, and of course, the composition and properties of the fertilizer. Excessive rates of nitrogen application lead to dissolved nitrogen in the nitrate form (NO_3^-), which is the form of nitrogen most readily used by plants and is one of the most common contaminants indentified in ground water (Freeze and Cherry, 1979).

Several methods of reducing nitrogen leaching are available. These include time and method of fertilizer application, application rates, management of irrigation, and application of nitrogen-release inhibitors; however, all methods are affected by unpredictable weather fluctuations.

Table 7. *Common fertilizers and their chemical formulas*
[Love, 1979]

Fertilizer	Material	Chemical formula
Nitrogen	Anhydrous ammonia	NH_3
Do.	Urea	$CO(NH_2)_2$
Do.	Ammonium nitrate	NH_4NO_3
Do.	Ammonium sulfate	$(NH_4)_2SO_4$
Do.	Diammonium phosphate	$(NH_4)_2HPO_4$
Do.	Sodium nitrate	$NaNO_3$
Do.	Potassium nitrate	KNO_3
Phosphorus	Rock phosphate	$Ca_{10}F_2(PO_4)_6$
Do.	Concentrated superphosphate	$Ca(H_2PO_4)_2$
Do.	Phosphoric acid	H_3PO_4
Do.	Diammonium phosphate	$(NH_4)_2HPO_4$
Potassium	Muriate of potash	KCl
Do.	Sulfate of potash	K_2SO_4
Do.	Potassium nitrate	KNO_3
Do.	Potassium metaphosphate	KPO_3

Research conducted at Kansas State University, Manhattan, Kans. (Kissel and Virgil, 1985), has shown that varying the timing and method of nitrogen application has consistently given good results (table 8). The application of nitrogen fertilizer closer to the time that it is actually needed by the crop can reduce nitrogen losses. Two or three smaller surface applications (postemergence) of nitrogen that can be used by the crop within 3 weeks is preferable to a large single application. The additional costs of extra trips across the field can be offset by savings on nitrogen. However, field compaction by equipment used for the extra trips can retard plant growth. This method reduces the amount of fertilizer available to leach through the soil profile with excess precipitation. Incorporation of fertilizer broadcast on the surface into the top layer of soil by disking is recommended where feasible. This method reduces the chance for movement by surface runoff or volatilization loss.

Nitrogen application rates vary across the State, depending on crop, soil, and precipitation. Rates of nitrogen application recommended by the Kansas Cooperative Extension Service are listed in table 9 (Whitney, 1976).

Irrigation water can be applied at a rate that will minimize deep percolation. This can be done by irrigating more often at a slower rate with a sprinkler system or by surge flooding. Surge flooding utilizes pulses of water in a furrow instead of continuous flow. The objective of the surge-flooding method is to keep the moisture content of the wetted soil profile just below field capacity, slow the downward percolation of water, and keep the nitrogen where the plants can utilize it.

The use of nitrification inhibitors as a nitrogen management tool has increased in recent years. Inhibitors are used to slow the conversion of ammonium (NH_4^+) to the nitrate (NO_3^-) form of nitrogen that can be utilized by plants. Nitrification inhibitors that have been tested in Kansas are as follows:

1. Carbon disulfide,

2. Sodium trithiocarbonate,

Table 8. *Nitrogen application rates for alternative timing of application*
[Modified from Kissel and Virgil (1985). Values are in percent of total nitrogen applied]

Crop	Soil texture	Time of application: Preplant, Fall[1]	Preplant, Spring	At planting[2]	Postemergence (Surface application)
Corn and sorghum (irrigated)	Medium and fine		100		Optional
		100			Do.
			50	50	Do.
		50		50	Do.
				90	10
	Coarse		100		Optional
			50	50	Do.
					Do.
Corn and sorghum (nonirrigated)	Medium and fine		100		Optional
		100			Do.
			50	50	Do.
		50		50	Do.
				90	10
	Coarse		100		Optional
			50	50	Do.
				90	10
Wheat[3] (irrigated and non-irrigated)	Medium and fine	100			Optional
				90	10
		50		50	Optional
	Coarse			90	10
		50		50	Optional

[1] Fall preplant applications should not be made on soils subject to flooding or soils that are poorly drained and stay extremely wet most springs.

[2] Base the use on the need for phosphorus as a starter.

[3] Preplant applications on wheat may result in excessive fall growth unless wheat is pastured or seeding delayed. Surface applications should be made before March 15.

Table 9. *Nitrogen application rates recommended by Kansas Cooperative Extension Service for different locations and crops*
[Data from Whitney, 1976. Values in pounds per acre]

Crop	Area of State	Medium- and fine-textured soils		Sandy-textured soil	
		Fallowed	Continuous cropped	Dryland	Irrigated
Corn[1]	Entire		100-200	100-200	160-220
Sorghum	Eastern		80-160	80-160	120-180
	Central	30-60	40-80	40-80	120-180
	Western[2]	0-40		30-40	120-180
Wheat[3]	Eastern		40-70	40-70	50-80
	Central	20-40	30-60	40-60	50-80
	Western[2]	0-40		25-50	50-80
Soybeans	Entire	None	None	None	None

1 These recommendations are for both grain and silage production. Dryland corn is not recommended in central and western Kansas.

2 Recommendations are based on sufficient subsoil moisture at planting time. If subsoil moisture is insufficient at planting time, then nitrogen application rates shown for western Kansas under dryland conditions should be reduced.

3 If wheat is pastured extensively, then add 2 to 30 pounds per acre to nitrogen recommendations.

3. Ammonium dithiocarbamate,

4. Potassium ethyl xanthate, and

5. 2-chloro-6-(trichloromethyl)-pyridine (nitrapyrin).

Of these products, the first four were not effective in inhibiting nitrification under the conditions that existed at the locations where they were applied. Nitrapyrin was effective in inhibiting nitrification in all studies (Maddux and others, 1985). Nitrapyrin was best at inhibiting nitrification on coarse-textured soil where leaching can be significant. Tests have shown inhibition of nitrification for periods of 4 to 6 weeks (Barnes and others, 1982; 1983). Nitrapyrin retards the growth of bacteria that produce nitrate, allows a more efficient use of nitrogen fertilizer for plant growth, and effectively reduces nitrate concentrations available for leaching into ground water. Nitrapyrin can be used as a deterrent to leaching from unexpected excess precipitation and to extend the interval between fractional fertilizer applications.

Phosphorus and Potassium--Phosphorus and potassium have very limited movement in the soil and virtually remain in the area of application. For row crops and small grains, phosphorus and potassium generally are incorporated into the seedbed prior to planting or applied at planting. With reduced-tillage practices being used on many farms, the application of phosphorus and potassium can create problems. For these nutrients to be effectively utilized by row crops and small grains, they must be incorporated into the root zone. With no-till practices, the phosphorus and potassium may be supplied at planting or incorporated in large quantities every 2 to 3 years.

Phosphorus and potassium application rates usually are based on soil tests that determine the background concentrations for these constituents. For soils that are deficient in phosphorus, application rates vary from 20 pounds per acre for western dryland wheat to 80 pounds per acre for irrigated corn and grain sorghum used for silage. Potassium application rates range from 20 to 140 pounds per acre for soil that is deficient in potassium.

Lime--Lime (primarily calcium carbonate, but may contain magnesium carbonate) is used to treat soil that is acidic. The type of lime to use, whether calcic ($CaCO_3$) or dolomitic ($MgCO_3$), is determined by the calcium-magnesium balance in the soil when the initial pH determinations are made. Soil pH is a measure of soil acidity (less than pH 7) or alkalinity (greater than pH 7) and is used to determine the need for the application of lime, which helps to neutralize acidic soil and increase crop production. The amount of lime needed is determined by the use of a buffer solution applied to a soil sample. The amount of lime required depends on factors, such as amount and type of clay, organic matter, and soluble aluminum content in the soil. Effective neutralization of soil acidity depends on thorough mixing of the lime with the soil. An application of the recommended rate of lime may be sufficient to maintain a satisfactory soil pH for several years. Additional lime needs should be determined by regular testing of the soil every 3 years.

Increased crop production on irrigated sandy soil in south-central and western Kansas frequently has resulted in soil pH values of less than 7. These small pH values may be the result of excessive nitrogen applications; 1 pound of ammonium nitrate may require as much as 6 pounds of lime to prevent an increase in acidity and to maintain optimum conditions for nitrification. Small pH values also may be the result of increased organic content from crop residues and soil leaching. Solubility and leaching of many chemicals in the soil vary according to the pH of the soil water.

Pesticides

A major survey of pesticide usage in Kansas was conducted in 1978 by the Cooperative Extension Service at Kansas State University and the Kansas Crop and Livestock Reporting Service (Nilson and Johnson, 1980). Information was collected in two separate surveys, one for crops and another for pasture and rangeland. Farmers were asked to report acreage and specific pesticide treatments for each crop and land use. Approximately 12,000 farmers, farming a total of nearly 2 million acres, responded to the survey. The reported data were extrapolated using the estimated crop acreage in the nine reporting districts (fig. 3) to determine area and statewide application of specific pesticides. The extrapolated area treated with each pesticide then was multiplied by the label-recommended rate of application to determine the estimated quantity of active ingredient applied. The 1978 pesticide-usage values are summarized in table 10. Table 18 in the "Supplemental Information" section at the end of this report lists pesticide usage by reporting district.

During 1978, Kansas farmers applied approximately 28.1 million pounds of active pesticide ingredients. Herbicides accounted for 85 percent of the total (23.8 million pounds) and insecticides for 15 percent (4.3 million pounds). Approximately 10 million acres were treated with herbicide at an average rate of 2.4 pounds per acre, and 4 million acres were treated with insecticides at a rate of 1 pound per acre. More than 30 percent of the 20 million acres in crops received herbicides, with a total of 18.3 million pounds applied. The remaining 5.5 million pounds of herbicides were applied to 2.6 million acres (12 percent) of pasture and rangeland. All the insecticides were applied to cropland, with

Table 10.--*Pesticide usage on crops and pasture or rangeland in Kansas, 1978*
[Data from Nilson and Johnson, 1980]

Pesticide class	Common name	Trade name	Area applied[1] (acre)	Percent-age of crop	Mean rate (pounds per acre)	Total applied (pounds)
			Corn			
Herbicides	--	--	1,559,900	86	3.97	6,185,800
	Atrazine	AAtrex	1,392,600	77	1.63	2,266,000
	EPTC	Eradicane	349,000	19	4.25	1,482,000
	Butylate	Sutan+	290,300	16	4.50	1,305,000
	Alachlor	Lasso	300,800	17	2.02	606,400
	Cyanazine	Bladex	143,300	7.8	1.91	273,100
	Propachlor	Ramrod	48,700	2.7	3.55	172,900
	2,4-D[2]	--	69,400	3.8	.45	31,200
	Metolachlor	Dual	12,800	.70	2.16	27,600
	Dicamba	Banvel	29,800	1.6	.34	10,000
	Pendimethalin	Prowl	4,600	.25	1.30	6,000
	Glyphosate	Roundup	1,600	.09	3.50	5,600
Insecticides	--	--	1,479,800	81	1.53	2,268,300
	Carbofuran	Furadan	387,100	21	1.00	390,300
	Terbufos	Counter	330,800	18	1.00	330,800
	Fonofos	Dyfonate	323,500	18	1.00	323,500
	Phorate	Thimet	294,800	16	1.07	314,300
	Carbaryl	Sevin	130,100	7.1	2.34	304,700
	Heptachlor	--	103,300	5.7	2.00	206,600
	Propargite	Comite	110,900	6.1	1.67	185,200
	Parathion[3]	--	168,800	--	--	--
	Toxaphene	--	32,500	1.8	2.91	94,700
	Oxydemetonmethyl	Metasystox-R	146,600	8.1	.57	83,600
	Disulfoton	Di-Syston	69,000	3.8	1.00	69,000
			Grain sorghum			
Herbicides	--	--	3,249,600	69	2.76	8,983,400
	Propachlor	Ramrod	1,074,000	23	3.36	3,607,600
	Atrazine	AAtrex	2,079,400	44	1.66	3,448,000
	Propazine	Milogard	651,500	14	1.32	857,600
	Terbutryn	Igran	381,300	8.1	1.75	666,000
	2,4-D[2]	--	611,100	13	.44	268,700
	Cyanazine	Bladex	94,300	2.0	1.24	117,300

Table 10. *Pesticide usage on crops and pasture or rangeland in Kansas, 1978*--Continued

Pesticide class	Common name	Trade name	Area applied[1] (acre)	Percent-age of crop	Mean rate (pounds per acre)	Total applied (pounds)
			Grain sorghum--Continued			
Herbicides						
	Glyphosate	Roundup	2,700	0.05	3.50	9,500
	Dicamba	Banvel	34,700	.74	.25	8,700
Insecticides	--	--	1,862,600	40	.81	1,515,500
	Toxaphene	--	112,000	2.4	3.35	375,400
	Disulfoton	Di-Syston	380,400	8.1	.96	364,200
	Carbaryl	Sevin	126,600	2.7	2.03	257,500
	Phorate	Thimet	188,800	4.0	1.00	188,800
	Parathion[3]	--	270,800	5.8	.51	138,500
	Carbofuran	Furadan	129,800	2.8	.82	106,900
	Malathion	--	35,200	.75	1.19	42,000
	Heptachlor	--	731,000	16	.04	30,700
	Dimethoate	Cygon	16,500	.35	.33	5,500
	Lindane	--	64,000	1.4	.04	2,700
	Oxydemetonmethyl	Metasystox-R	7,300	.16	.33	2,400
	Demeton	Systox	4,100	.09	.25	1,000
			Wheat			
Herbicides	--	--	1,085,700	10	.61	665,900
	2,4-D[2]	--	1,024,200	9.1	.63	641,700
	Dicamba	Banvel	124,000	1.1	.13	15,500
	Bromoxynil	Brominal	23,000	.21	.38	8,700
Insecticides	--	--	516,000	5.0	.72	372,700
	Toxaphene	--	74,900	.66	4.40	330,200
	Heptachlor	--	239,800	2.1	.06	14,400
	Parathion[3]	--	17,900	.16	.50	8,950
	Malathion	--	7,300	.06	1.00	7,300
	Lindane	--	78,600	.70	.06	4,700
	Endosulfan	Thiodan	6,700	.06	.50	3,350
	Carbaryl	Sevin	2,000	.02	1.50	3,000
	Endrin	--	1,400	.01	.25	350
	Dimethoate	Cygon	1,000	.01	.42	400

Table 10. *Pesticide usage on crops and pasture or rangeland in Kansas, 1978*--Continued

Pesticide class	Common name	Trade name	Area applied[1] (acre)	Percent-age of crop	Mean rate (pounds per acre)	Total applied (pounds)
			Soybeans			
Herbicides	--	--	1,161,400	78	1.94	2,255,600
	Alachlor	Lasso	404,900	27	2.29	925,200
	Trifuralin	Treflan	551,200	37	1.25	691,000
	Metribuzin	Sencor	449,600	30	.43	193,300
	Chloramben	Amiben	53,300	3.6	2.00	106,600
	Linuron	Lorox	92,900	6.3	1.00	92,900
	Bentazon	Basagran	67,600	4.6	1.00	67,600
	Pendimethalin	Prowl	38,500	2.6	1.11	42,900
	Profluralin	Tolban	43,700	3.0	.87	37,900
	Oryzalin	Surflan	50,800	3.4	.72	36,600
	Bifenox	Modown	22,600	1.5	1.45	32,800
	Naptalam	Alanap	9,800	.66	2.25	22,000
	Dinoseb	--	--	--	--	--
	Glyphosate	Roundup	1,200	.08	3.50	4,200
	Fluchloralin	Basalin	1,800	.12	1.00	1,800
	Dinitroamine	Cobex	1,600	.11	.50	800
Insecticides	--	--	30,800	2.0	1.45	44,700
	Toxaphene	--	15,300	1.0	2.05	31,400
	Carbaryl	Seven	2,800	.19	2.24	6,300
	Parathion[3]	--	6,600	.45	.50	3,300
	Malathion	--	2,200	.15	1.13	2,500
	Dimethoate	Cygon	1,200	.08	1.00	1,200
			Alfalfa			
Herbicides	--	--	59,100	6.0	1.52	90,000
	Simazin	Princep	38,400	3.7	1.20	46,100
	Propham	Chem-Hoe	7,600	.72	3.50	26,600
	EPTC	Eptam	1,900	.11	.80	960
	Profluralin	Tolban	4,700	.45	1.00	4,700
	Benefin	Balan	3,000	.29	1.13	3,400
	Diuron	Karmex	1,800	.17	1.60	2,900
	Terbacil	Sinbar	1,200	.11	.80	960
	2,4-DB	Butyrac	600	.06	1.00	600

Table 10. *Pesticide usage on crops and pasture or rangeland in Kansas, 1978*--Continued

Pesticide class	Common name	Trade name	Area applied[1] (acre)	Percentage of crop	Mean rate (pounds per acre)	Total applied (pounds)
			Alfalfa--Continued			
Insecticides	--	--	139,500	13	0.71	99,000
	Carbofuran	Furadan	57,800	5.5	.49	28,200
	Malathion	--	16,500	1.6	1.38	22,800
	Parathion[3]	--	34,500	3.3	.51	17,500
	Methoxychlor	--	4,900	.5	1.17	5,700
	Methidation	Supracide	7,900	.8	.50	3,950
	Azinophosmethyl	Guthion	4,200	.4	.75	3,150
	Dimethoate	Cygon	4,900	.5	.53	2,600
	Diazinon	--	3,200	.3	.70	2,200
	Phosmet	Imidan	1,900	.2	1.0	1,900
	Trichlorfon	Dylox	800	.08	1.0	800
			Pasture and rangeland			
Herbicides	--	--	2,581,900	12	2.13	5,505,800
	2,4,-D[2]	--	2,306,700	11	1.69	3,906,700
	2,4,5-T	--	719,800	3.4	2.07	1,488,700
	Dicamba	Banvel	29,800	.14	2.00	59,600
	2,4,5-T	Silvex	24,200	.11	2.00	48,500
	Picloram	Tordon	600	0	4.00	2,400
			Fallow			
Herbicides	--	--	210,600	3.00	.79	167,300
	2,4-D[2]	--	134,900	1.9	.64	86,400
	Atrazine	AAtrex	67,700	1.00	1.00	67,700
	Cynazine	Bladex	5,200	.07	2.40	12,500
	Paraquat	--	2,800	.04	.25	700

1 The "area applied" includes acres where a pesticide is used alone or in combination. A given area may receive multiple pesticides; therefore, the sum of individual chemicals does not equal the total area of application for the category.

2 Includes ester and amine formulations.

3 Includes both ethyl and methyl parathion and encapsulated forms.

20 percent of the planted acreage receiving treatment.

In terms of total quantity, atrazine was the most extensively used pesticide, with 5.8 million pounds applied. However, in areal extent, 2,4-D was used most extensively, being applied to more than 4 million acres. The most popular herbicide for application to pasture and rangeland was 2,4-D, while atrazine was used extensively on corn and grain sorghum. No insecticide approached the level of usage of the major herbicides in either areal extent or quantity. During 1978, seven herbicides were applied in quantities exceeding 1 million pounds, but no insecticide application exceeded 1 million pounds.

A few selected herbicides and insecticides accounted for the vast majority of usage. Thirty-five different herbicides were used, but the top 10 in usage accounted for 94 percent of the total quantity applied. Twenty-three insecticides were used, but the 10 most used accounted for more than 99 percent of the total quantity applied.

Knowledge of crops grown in a given area can give a good indication of the pesticides used and the approximate quantities used. Pesticides were used to the greatest extent on corn. Eighty-six percent of all corn acreage received herbicides, and 81 percent received insecticides. Each acre of corn treated for weed control received an average application of nearly 4 pounds of herbicides compared to the average of all crops of 2.4 pounds per acre. However, the largest total quantity of pesticides was applied to grain sorghum. Pesticides were utilized least on wheat, with only 10 percent of the planted acreage treated for weed control and 5 percent for insect control. For each crop, typically four or five herbicides and insecticides accounted for the majority of treated acreage. In the case of wheat, fallow, and pasture and rangeland, 2,4-D was applied to 89 percent of the acreage treated for weed control.

The 1978 survey of pesticide usage (Nilson and Johnson, 1980) also provided herbicide data compiled by reporting districts (fig. 3). Comparable data on insecticide usage were not compiled. Usage of major herbicides is presented for each of the nine reporting districts in table 18 in the section on "Supplemental Information." Only 8 to 10 herbicides are tabulated for each district, but in each case those tabulated represented more than 90 percent of total herbicide usage in the district.

In the three western reporting districts, atrazine dominated herbicide usage in terms of both acreage and total quantity applied. Across western Kansas, herbicides for corn production were in greatest use during 1978. Atrazine was applied to about 80 percent of all corn acreage in western Kansas, with the largest percentage in northwest Kansas (89 percent). Atrazine also was applied to approximately 30 percent of western Kansas grain-sorghum acreage. EPTC was used on about 25 percent of the corn acreage in western Kansas, and propazine was applied to about 25 percent of the grain sorghum. Alachlor was applied to 25 percent of all corn acreage in northwest Kansas, but is was not used extensively in the remainder of western Kansas.

A significant difference between the western and the central reporting districts was the predominance of 2,4-D use in the central reporting districts. Corn was not a major crop in central Kansas, and the considerable use of 2,4-D on grain sorghum, wheat, and especially pastureland, made it surpass atrazine in both acreage and total quantity applied throughout central Kansas. Atrazine was the primary herbicide used on corn and grain sorghum in central Kansas, but propachlor also was used extensively on grain sorghum. Alachlor was used more extensively in central Kansas than in western Kansas. Herbicides were utilized to a much greater extent in north-central Kansas than in the remainder of central Kansas. In fact, total herbicide usage in north-central reporting districts nearly equaled the combined totals of the central and south-central districts.

The character of herbicide usage in eastern Kansas differs somewhat from the rest of the State, due primarily to cropping patterns. Soybeans were a major crop in eastern Kansas, and herbicide usage included trifluralin, metribuzin, and alachlor, which are used primarily or exclusively on soybeans. Atrazine and 2,4-D were the most extensively used herbicides in eastern Kansas, with usage of these two chemicals nearly equal in each of the three eastern reporting districts. Atrazine was applied to approximately three-fourths of the acreage planted to both corn and grain sorghum; whereas 2,4-D was used primarily on grassland and to some extent on corn, grain sorghum, and wheat. Throughout eastern Kansas, propachlor was the third most-used herbicide, and alachlor was fourth. Propachlor was applied to approximately 40 percent of grain-sorghum acreage, and alachlor was used on 25 to 30 percent of both corn and grain-sorghum acreage. It is important to note that in eastern Kansas, as in central Kansas, the northernmost reporting district relied the most on herbicides. Northeast Kansas was the only reporting district in which any single herbicide was applied in excess of 1 million pounds. In northeast Kansas, 2,4-D, atrazine, and propachlor were all used in quantities exceeding 1 million pounds.

Overall, the three eastern reporting districts, plus north-central Kansas, had the greatest reliance on herbicides during 1978. Herbicide usage in these four areas, which encompass approximately 40 percent of the agricultural land in Kansas, was at least 60 percent of the statewide total. This greater dependence on herbicides is due primarily to differences in cropping patterns and climate. It is important to note that the districts reporting significant herbicide usage also have shallow and very vulnerable ground-water supplies.

Total pesticide usage in the State increased only slightly since 1978, based on a comparison of major crop acreages for 1978 and 1984, the latest year of published crop-production statistics (Kansas State Board of Agriculture, 1985). Major crop acreages, total and irrigated for 1978 and 1984, are listed in table 11. The total acreage planted to the four major crops (corn, grain sorghum, wheat, and soybeans) increased by 8 percent, slightly over 1.5 million acres. Much of this added acreage came from placing marginal land into production, which could require additional herbicides. The greatest increase was the additional 2 million acres for wheat, an 18-percent increase. The mean rate of herbicide application to wheat was 0.61 pound per acre for insecticides, 0.72 pound per acre. Both rates were the smallest application rates for any of the major crops. Soybean acreage increased 14 percent, up 210,000 acres, and grain sorghum increased slightly. The largest change was the total acreage planted to corn, which decreased by 40 percent, 770,000 acres, with more than one-half of that total decrease in irrigated acreage. This decrease was largely an effect of the conservation of irrigation water in the western two-thirds of the State. Corn had the largest rate of pesticide application of the major crops. However, the increased wheat and soybean acreages (2.2 million acres) offset the decreased corn acreage (0.77 million acres) in relation to total weight of pesticides used. A slight decrease in the use of atrazine statewide could be inferred from this analysis. Irrigated wheat acreage increased 125 percent (522,000 acres), and irrigated grain-sorghum acreage increased 30 percent (94,000 acres). Total irrigated acreage was up 12 percent, an increase of 264,000 acres.

Chemical Properties of Pesticides--The leaching of pesticides in the soil is dependent on the sorptive characteristics of the compound and soil. Sorptive characteristics significantly affect the physical leaching of pesticides within a soil-water matrix. The sorptive properties of pesticides generally correlate well with the organic carbon content of soil, which usually decreases with depth. Sorption of organic solutes from water to soil is related to the aqueous solubility of the solute, with the least-soluble organic compounds being the most sorbed onto the soil. The adsorption partition coefficient (Kd) can be computed from the organic content of the soil and either the solubility or the octanol-water distribution coefficient by the equations (Carsel and others, 1984):

$$\log Koc = 3.64 - (0.557 \times \log Sol), \quad (1)$$

or

$$\log Koc = 1.00 (\log Kow) - 0.21, \quad (2)$$

and

$$Kd = Koc \frac{(\text{percent organic carbon})}{100}, \quad (3)$$

where Koc = organic-carbon distribution coefficient;

Sol = solubility, in milligrams per liter;

and

Kow = octanol-water distribution coefficient.

Table 11. *Total and irrigated crop acreages during 1978 and 1984*

Reporting district (fig.3)	Crop	Total acreage (thousands of acres) 1978[1]	1984[2]	Irrigated acreage (thousands of acres) 1978[1]	1984[2]
Northwest	Corn	240	133	198	107
	Sorghum	107	451	43	82
	Wheat	1,257	1,373	21	84
	Soybeans	1	47	<1	<1
West-central	Corn	190	62	136	46
	Sorghum	218	436	58	82
	Wheat	1,348	1,456	57	106
	Soybeans	4	15	<1	<1
Southwest	Corn	555	313	493	266
	Sorghum	783	934	356	415
	Wheat	2,039	2,354	297	611
	Soybeans	18	70	<1	<1
North-central	Corn	111	88	80	71
	Sorghum	704	605	18	33
	Wheat	1,334	1,543	2	10
	Soybeans	34	103	<1	<1
Central	Corn	62	42	33	23
	Sorghum	607	530	42	44
	Wheat	1,727	1,793	6	16
	Soybeans	37	52	<1	<1
South-central	Corn	124	84	102	71
	Sorghum	608	634	100	147
	Wheat	2,633	2,848	34	112
	Soybeans	66	116	<1	<1
Northeast	Corn	268	183	10	10
	Sorghum	573	408	3	3
	Wheat	244	508	<1	<1
	Soybeans	295	342	<1	<1
East-central	Corn	190	112	17	20
	Sorghum	498	440	3	9
	Wheat	235	533	<1	<1
	Soybeans	513	434	<1	<1
Southeast	Corn	80	33	2	5
	Sorghum	502	362	5	7
	Wheat	483	892	<1	<1
	Soybeans	552	551	<1	<1

Table 11. *Total and irrigated crop acreages during 1978 and 1984*--Continued

Reporting district (fig.3)	Crop	Total acreage (thousands of acres) 1978[1]	1984[2]	Irrigated acreage (thousands of acres) 1978[1]	1984[2]
Total	Corn	1,820	1,050	1,071	619
	Sorghum	4,700	4,800	628	872
	Wheat	11,300	13,300	417	939
	Soybeans	1,520	1,730	<1	<1
Total	All	19,340	20,880	2,116	2,380

1 Kansas State Board of Agriculture, 1980.

2 Kansas State Board of Agriculture, 1985.

Table 12 is a compilation of available data on solubility, octanol-water distribution coefficient, half-life, and acute oral toxicity (LD_{50}) for selected pesticides. Pesticides detected in Kansas ground water are labeled with footnote 3. Half-life of a pesticide is the time that expires until the mass becomes one-half of the mass of the initial parent compound by chemical degradation. The parent compound may decompose into other organic compounds, which have different chemical properties. Half-life is quite variable and is dependent on soil pH, soil moisture, temperature, microbial activity, and sunlight. Toxicity can be expressed as the LD_{50}, which is a statistical estimate of the acute oral dosage necessary to kill 50 percent of a large population of laboratory animals under stated conditions. The smaller the LD_{50}, the more toxic the chemical.

Pesticide-Soil Interactions--Pesticides have complex interactions with soil and other environmental factors. Atrazine, the most commonly used pesticide in Kansas, has been chosen to exemplify the variety of possible pathways for leaching and degradation. Atrazine is a selective herbicide for use on a variety of crops, orchards, and ornamental and terrestrial noncrop and forestry sites. Atrazine is applied by using ground-spray equipment, aircraft, or center-pivot irrigation systems. Many studies involving atrazine have been conducted to investigate degradation rates in various soil types under different conditions, the metabolites generated by degradation, and the leaching and mobility of the parent substance. These various degradation factors for atrazine vary according to soil type, pH, temperature, moisture levels, light conditions, microbial activity, and whether the soil/water system is aerobic or anaerobic.

Under aerobic conditions, 38 percent of the applied atrazine degraded to hydroxy-atrazine in sandy load, 40 percent in silty clay loam, and 47 percent in silty loam after 8 weeks at 30 °C (Harris, 1967). Atrazine labeled with carbon-14 is moderately to significantly mobine in soil ranging in texture from gravelly sand to clay, as

Table 12. *Chemical properties and toxicity of selected pesticides*[1]

Pesticide	Trade name	Type of pesticide	Solubility in water at 20-25 degrees Celsius (milligrams per liter)	Octanol-water distribution coefficient (logarithm)	Half-life (days)	Acute oral toxicity, LD_{50}[2] (milligram per kilogram)
Alachlor[3]	Lasso	Herbicide	220	2.78	26-70	1,800
Atrazine[3]		do.	70	2.45	67-365	1,750
Benzene	--	Insecticide	1,430	--	--	3.8
Biomacil[3]	Hyvar	Herbicide	815	2.02	365+	5,200
Butylate	Sutan	do.	45	--	365+	4,000
Carbaryl	Sevin	Insecticide	120	2.56	8-12	250
Carbofuran	Furadan	do.	700	2.44	13-127	2
Chlordane	--	do.	insoluble	--	--	343
Chlorpyrifos[3]	Dursban	do.	2	4.97	--	145
Cyanazine[3]	Bladex	Herbicide	171	2.24	14-20	182
Dicamba	Banvel	do.	very slight	0.48	4.5-94	1,707
Dicloram	Tordan	do.	430	.30	28-526	3,750
Endrin	--	Insecticide	insoluble	--	--	7
EPTC	Eradicane	Herbicide	365	--	7	1,631
Fonofos	Dyfonate	Insecticide	insoluble	--	--	3
Heptachlor epoxide	--	do.	insoluble	--	--	147
Lindane	--	do.	insoluble	--	--	88
Metalachlor[3]	Dual	Herbicide	530	--	15-50	2,780
Methoxychlor	--	Insecticide	insoluble	--	--	6,000
Metribuzine[3]	Sencor	Herbicide	1,200	--	7-28	2,200

Table 12. *Chemical properties and toxicity of selected pesticides*[1]--Continued

Pesticide	Trade name	Type of pesticide	Solubility in water at 20-25 degrees Celsius (milligrams per liter)	Octanol-water distribution coefficient (logarithm)	Half-life (days)	Acute oral toxicity, LD_{50}[2] (milligram per kilogram)
Pramitol[3]	Prometon	Herbicide	750	--	--	2,980
Propachlor	Ramrod	do.	700	1.61	28-52	710
Propazine[3]	Mitogard	do.	8.6	2.94	285-588	>5,000
Simazine[3]	Princep	do.	insoluble	1.94	18-365	5,000
Terbufos	Counter	Insecticide	15	2.22	--	1.6
Terbutryn	Ingran	Herbicide	25	--	21-70	2,500
Toxaphene[3]	--	Insecticide	insoluble	3.27	217	90
Trifluralin[3]	Treflan	Herbicide	24	4.75	10-384	500
1,2 Dichloro-ethane	EDC	Insecticide	120	--	--	670
2,4-D[3]	--	Herbicide	insoluble as acid; soluble as a salt; esters soluble in oil	2.81	7-28	375
2,4,5-T[3]	Silvex	do.	1.4	--	--	500

[1] Windholz, 1983; Carsel and others, 1984; Nilson and others, 1987; Sine, 1988.

[2] LD_{50} is a statistical estimate of the dosage necessary to kill 50 percent of a large population of laboratory animals under stated conditions. The smaller the LD_{50}, the more toxic the chemical.

[3] Pesticides detected in Kansas ground water as of September 1986.

determined by soil thin-layer chromatography, column leaching, and adsorption/desorption batch equilibrium tests. Based on soil thin-layer chromatography tests, atrazine was intermediately mobine in loam, sandy-clay loam, silty loam, silty-clay loam, and silty-clay soils, and mobile in sandy-loam soil; while the degradation hydroxy-atrazine had little mobility in sandy loam and silty-clay-loam soil (Helling, 1971). Rapid adsorption and desorption of atrazine in a clay-loam soil were determined to be affected markedly by soil pH within the range of 3.9 to 8.0 but were not affected appreciably by temperature changes within the range of 10 to 40 °C (McCormick and Hilbold, 1966). Atrazine degraded in sandy soil at 23 °C, with a half-life of more than 125 days at 4-percent water-holding capacity, 37 days at 35 percent water-holding capacity, and 36 days at 70 percent water-holding capacity (Hurl and Kibler, 1976). Atrazine undergoes rapid photodegradation in water with a half-life of approximately 25 hours (Burkhard and Guth, 1976). Atrazine was stable in aerobic ground-water samples incubated for 15 months at 10 or 25 °C in the dark (Weidner, 1974). Phytotoxic residues of atrazine persisted for more than 24 weeks at 10 °C and for less than 12 weeks at 35 °C (Lavy, 1974).

The combination of degradation factors can make the prediction of the leaching and fate of atrazine quite complex. The half-life increases as the sand content increases and as soil temperature decreases. Sunlight enhances the degradation of atrazine. Therefore, atrazine applied to minimal or no-tillage agricultural plots may be slower to degrade than plots that are tilled. Greater moisture content in the soil aids in degradation of the chemical, but once atrazine reaches the water table, it appears to be more stable.

The increased stability of atrazine in a saturated environment may be related to decreased oxygen concentration, decreased organic carbon concent, low stable temperature, and decreased microbial activity. The leaching of atrazine in the soil is related to soil type and pH. Soil type includes particle size, cation-exchange characteristics of the clay portion, and organic carbon content. Development of humic acids or lime application can alter soil pH substantially from year to year.

Because it is a polar molecule, the metabolite hydroxy-atrazine has chemical properties that are quite different from atrazine. This is true for most of the other pesticides and their metabolites. Each chemical has unique properties that affect leaching and fate.

DRINKING-WATER STANDARDS

The quality of public drinking water in Kansas is regulated by the Kansas Department of Health and Environment (1986) and the U.S. Environmental Protection Agency (1986a,b). These agencies have set standards for public-water supplies that can be used also to evaluate "private" drinking-water supplies, which frequently come from shallow domestic wells. These water-quality standards are divided into primary and secondary standards. Primary standards apply to those constituents that have health implications. Secondary standards apply to constituents that affect the aesthetic properties and desirability of water for drinking and domestic uses but are not believed to have health effects. However, some constituents or contaminants of ground water are not included in either primary or secondary standards because adequate knowledge is not available on the effect on humans for all substances that could contaminate ground water. For these reasons, desirable concentrations in drinking water have been suggested by various health organizations or have been derived from available toxicological data. The data are presented in tables 13 to 15.

Inorganic Constituents

Inorganic constituents are defined in the following paragraphs, and a summary of standards for these constituents is given in table 13.

Total hardness--Calcium and magnesium are the principal minerals contributing to total hardness. Water with less than 50 mg/L (milligrams per liter) total hardness (as $CaCO_3$) is considered soft water. Hard water requires more soap or detergent for laundering and has a tendency to develop scale deposits, especially when heated above 140 °F. A total hardness greater than 400 mg/L is considered excessive (U.S. Environmental Protection Agency, 1986b).

Table 13. *Summary of drinking-water standards and recommended limits for inorganic constituents*

Constituent	Unit of measurement	Drinking-water standard Primary[1]	Secondary[2]	Suggested limit[3]
Total hardness ($CaCO_3$)	milligrams per liter	--	400	--
Calcium (Ca)	do.	--	--	75-200
Magnesium (Mg)	do.	--	--	50-150
Sodium (Na)	do.	--	--	100
Potassium (K)	do.	--	--	100
Total alkalinity ($CaCO_3$)	do.	--	--	60-300
Chloride (Cl)	do.	--	250	--
Sulfate (SO_4)	do.	--	250	--
Nitrate (as N)	do.	10	--	--
Fluoride (F)	do.	4.0	2.0	--
pH	standard units	--	6.5-8.5	--
Turbidity	nephelometric turbidity units, NTU	1[4]	--	--
Specific conductance	microsiemens per centimeter at 25 degrees Celsius	--	--	1,500
Dissolved solids	milligrams per liter	--	500	--
Total phosphorus	do.	--	--	5.0
Silica (SiO_2)	do.	--	--	50
Ammonia (as N)	do.	--	--	0.1
Iron (Fe)	do.	--	.3	--
Manganese (Mn)	do.	--	.05	--

[1] U.S. Environmental Protection Agency, 1986a.
[2] U.S. Environmental Protection Agency, 1986b.
[3] Kansas Department of Health and Environment, 1986.
[4] Treated surface water.

Sodium--Sodium is an essential nutrient. The dietary requirement for sodium is less than 1,000 milligrams per day for adults. However, adults in the United States typically have a total sodium intake of 3,000 to 4,000 milligrams per day. There is a great deal of evidence that excessive sodium intake contributes to an age-related increase in blood pressure in genetically susceptible people. Therefore, the suggested limit for sodium in drinking water has been set at 100 mg/L (Kansas Department of Health and Environment, 1986). Persons on a sodium-restricted diet may require water with a sodium concentration less than this guideline, but persons not susceptible to high blood pressure can tolerate sodium well in excess of the suggested limit. Ion-exchange water softeners add quantities of sodium to softened water.

Potassium--The concentration of potassium normally detected in drinking water has no health or aesthetic effects on drinking-water users.

Alkalinity--The alkalinity of water is a measure of its capacity to neutralize acids. Bicarbonate and carbonate are the major contributors to alkalinity, but borates, silicates, hydroxide, and phosphates also contribute. The relationship of pH, calcium, and alkalinity determine whether a water is corrosive or whether it will deposit calcium carbonate.

The Kansas Department of Health and Environment (1986) suggests the alkalinity of treated water be at least 60 mg/L to prevent corrosiveness.

Chloride--The secondary drinking-water standard for chloride is 250 mg/L because some people can detect a salty taste at that concentration. Chloride has no serious health effect at this concentration. Corrosion of metal is accelerated as chloride concentration increases.

Sulfate--The secondary drinking-water standard for sulfate is 250 mg/L because of the bitter taste and laxative effects of excessive sulfate. Sulfate also accelerates corrosion of metal.

Nitrate--The primary drinking-water standard for nitrate, reported as nitrogen, is 10 mg/L. Excessive nitrate consumption by infants; less than 1 year in age may result in infant cyanosis, also called methemoglobinemia or "blue baby syndrome." A nitrate concentration of 10 mg/L is considered safe for infants however, adults can tolerate much larger concentrations without ill effects. Since 1940, 20 cases of methemoglobinemia reported in Kansas have been associated with water supplies containing 30 to 180 mg/L nitrate as nitrogen. Young animals may be at greater risk than humans, as their dietary intake of nitrate is generally greater. Ruminants (cattle, sheep, and so forth) are most sensitive to nitrate.

Fluoride--The primary drinking-water standard for fluoride is 4.0 mg/L; the secondary standard is 2.0 mg/L. A fluoride concentration of approximately 1.0 mg/L helps prevent dental cavities. At concentrations less than 0.7 mg/L, fluoride will not be of any benefit. At concentrations greater than 2.0 mg/L, fluoride may cause mottling of the teeth. Bone changes can occur if drinking water contains 8 to 20 mg/L of fluoride, and if fluoride exceeds 20 mg/L, crippling fluorosis can occur after long-term consumption.

pH--Standard units of pH, which is the negative log of the hydrogen-ion concentration, extend from zero (very acidic) to 14 (very alkaline), with 7 being neutral. The desirable pH range for drinking water is from 6.5 to 8.5. A pH of less than 6.0 or more than 10.0 could indicate the presence of a contamination source.

Turbidity--Turbidity in water is the suspended material that causes a beam of light to scatter. Turbidity can be aesthetically and physiologically significant because it can provide a medium for bacterial growth. The drinking-water standard for treated surface water is a maximum 2-day average of 5 nephlometric turbidity units (NTU) and a maximum average of 1 NTU over a 30-day period. No standards have been established for ground water.

Specific conductance--Conductance is a numerical expression of the ability of water to conduct an electric current. Because the number, which is expressed as microsiemens per centimeter at 25 °C (microsiemens), depends on the concentration of the dissolved minerals, conductance indicates the degree of mineralization in the water. Specific conductance greater than 1,500 microsiemens is considered excessive.

Dissolved solids--Dissolved solids is a measure of the dissolved material in water. Concentrations of dissolved solids greater than 500 mg/L are objectionable because of a mineral taste and possible health effects. Water containing more than 1,000 mg/L dissolved solids can be expected to accelerate corrosion.

Total phosphorus--Phosphate is a nutrient that in concentrations normally detected in water has no physiological significance. The recommended State limit is based on the fact that concentrations greater than 5.0 mg/L may indicate contamination from human or animal wastes.

Ammonia--Ammonia is the biologically reduced form of nitrogen and can occur naturally in surface and ground water. At concentrations normally found, it has no health effects. It may cause unpleasant odors at concentrations greater than 0.03 mg/L. Concentrations greater than 0.1 mg/L may indicate contamination from surface pollutants, such as septic-tank leaching fields.

Silica--Silica is the oxidized form of the element silicon and occurs in small concentrations in most natural waters. Silica has no physiological significance to humans but can cause crusting deposits on well screens or pumps, piping, or water heaters. Concentrations greater than 50 mg/L may cause an undesirable cloudy appearance.

Iron--Iron is objectionable because of taste, red staining of porcelain fixtures and laundry, and deposition in plumbing. The secondary drinking-water standard for iron is 0.3 mg/L.

Manganese--The secondary drinking-water standard for manganese is 0.05 mg/L. Manganese in concentrations greater than 0.05 mg/L is objectionable because of unpleasant taste, black staining of porcelain fixtures and laundry, and deposition in plumbing. Manganese produces no significant health effects.

Trace Elements

Trace elements are also inorganic constituents of ground water, but they have added significance in that most are toxic to humans and animals in large concentrations. Trace elements are present in the soil and geologic formations of Kansas, but due to their small solubility in water, only trace concentrations normally are found. The solubility of trace elements in synthetic-organic compounds can be greater than in water and are, therefore, of concern when agricultural chemicals are applied. Table 14 lists the primary and secondary drinking-water standards for trace elements.

Pesticides

Drinking-water standards have been established for only a few pesticides even though toxicity information is available for most formulations. The long-term human-health effects of many pesticides are unknown. Health advisory levels in drinking water and any known long-term effects are given in table 15. Chronic health effects may occur after long-term consumption of water containing a pesticide at 10 to 100 times the health advisory level.

PRELIMINARY GROUND-WATER-QUALITY ASSESSMENT

Many ground-water samples from wells throughout the State were examined for agricultural chemical contamination. Data included an extensive study of selected chemical constituents in water from 766 wells representing all Kansas counties from 1976-81 (Spruill, 1983). A random farmstead well survey (Koelliker and others, 1987) examined 103 wells in several counties for selected chemical constituents during 1985-86. Also included in the preliminary ground-water-quality assessment were selected pesticide analyses of ground-water samples collected from wells determined to be located in areas that may be susceptible to rapid rates of leaching. These additional samples were collected from 56 wells during 1985-86.

Kansas Ground-Water-Quality Monitoring Network, 1976-81

Information from the 766 wells sampled from 1976-81 (Spruill, 1983) revealed widespread contamination of ground water by nitrate-nitrogen. Fourteen percent of the samples had nitrate-nitrogen concentrations exceeding the drinking-water standard or maximum contaminant level (MCL) of 10 mg/L (U.S. Environmental Protection Agency, 1986a). In Spruill's report (1983), the State was divided into 14 regions on the basis of geohydrologic factors to show regional variance. The geohydrologic regions and the percentage of sampled wells in which nitrate-nitrogen concentrations exceeded the MCL are shown in figure 8. Table 16 lists the statistical distributions within each region.

As a result of years of nitrogen application to the soil, nitrate contamination has occurred in ground water in each of the 14 geohydrologic regions in the State (fig. 8). The 10-mg/L drinking-water standard for nitrate-nitrogen was exceeded occasionally in 13 of the 14 regions. Median nitrate-nitrogen concentrations exceeded 3 mg/L in seven of the regions; concentrations greater than 50 mg/L occurred in four of the regions. Regions 2, 5, and 9 had the largest percentages of wells with ground water containing nitrate-nitrogen concentrations exceeding the MCL (30, 22, and 20 percent, respectively). Ground water exceeding the MCL occurred in 9 to 20 percent of

Table 14. *Summary of drinking-water standards and chronic health effects for trace elements*

Trace element	Drinking-water standard Primary[1] (milligrams per liter)	Drinking-water standard Secondary[2] (milligrams per liter)	Chronic health effects[3]
Arsenic (As)	0.05	--	Suspected carcinogen; blackfoot disease; pigmentation changes; fatigue,energy loss; accumulates in skin, bone, and muscle.
Barium (Ba)	1.0	--	Accumulates in liver, lungs, and spleen.
Cadmium (Cd)	.01	--	Bronchitis, emphysema, anemia; accumulates in liver and kidneys.
Chromium (Cr)	.05	--	Dermatitis; skin and nasal ulcers; accumulates in spleen, bones, kidney, and liver.
Copper (Cu)	--	1.0	Copper in drinking water has no health significance because the concentrations required to produce health effects exceed the maximum possible concentrations.
Lead (Pb)	.05	--	Nervous system, kidney, and blood disorders.
Mercury (Hg)	.002	--	Headaches; giddiness; kidney damage (ulceration).
Selenium (Se)	.01	--	Depression, nervousness, giddiness, dermatitis, gastrointestinal disturbance, dental decay, garlic-breath odor; accumulates in hair and nails.
Silver (Ag)	.05	--	Blue-gray discoloration of the skin, mucous membranes, and eyes; cosmetic effects only.

Table 14. *Summary of drinking-water standards and chronic health effects for trace elements*--Continued

Trace element	Drinking-water standard Primary[1] (milligrams per liter)	Secondary[2] (milligrams per liter)	Chronic health effects[3]
Zinc (Zn)	--	5.0	Irritability, muscular stiffness, loss of appetite, nausea; essential trace element; protects against lead and cadmium toxicity.

1 U.S. Environmental Protection Agency, 1986a.

2 U.S. Environmental Protection Agency, 1986b.

3 Kansas Department of Health and Environment, 1986. Chronic health effects may appear in sensitive individuals after long-term consumption at concentrations 10 to 100 times the established standards.

the wells in regions 1, 4, 6, 7, 8, 11, and 13. The median nitrate concentration (5.6 mg/L) was largest in region 8. This region also had the most favorable hydrologic agricultural factors for the leaching of chemicals to ground water (permeable soil, sandy unconsolidated lithology, shallow water table, and intensive agricultural activity). However, every region except region 3 had wells in which sample concentrations exceeded the MCL for nitrate-nitrogen.

Ground-water samples from the 766 wells were analyzed for the six pesticides for which a MCL exists. These chemicals were endrin, lindane, methoxychlor, and toxaphene, which are insoluble insecticides, and 2,4-D and silvex, which are herbicides and, as acids, are also insoluble. The insolubility of the six pesticides in water is the primary reason that only one compound, silvex, was detected in only one well of the 766 tested. That one sample indicated a concentration of 0.2 µg/L (microgram per liter), which is the detection limit for silvex. There were no analyses for the more soluble pesticides.

Kansas Farmstead-Well Survey, 1985-86

A random scheme to draw a sample of 103 wells from a population of over 40,000 farmstead wells was designed and carried out during 1985 and 1986 (Koelliker and others, 1987). Samples were analyzed for 20 pesticides, 29 volatile organic compounds (VOC), and 21 inorganic compounds, including nitrate-nitrogen. Of the wells sampled, 9 percent had detectable pesticides, 2 percent had detectable VOC, and 37 percent had inorganic chemicals exceeding the MCL.

Nitrate-nitrogen concentrations greater than 10 mg/L were found in 28 percent of the wells sampled. Farmstead wells in the northeast, north-central, and south-central reporting districts of the State (fig. 3) had a higher probability of nitrate-nitrogen contamination, with mean concentrations of 14.98, 11.61, and 9.06 mg/L, respectively. Atrazine was found in four wells; 2,4-D and 2,4,5-T were found together in one well; alachlor and 1,2-dichloroethane in one well; and tordon and benzene in one well each. Regional analysis of pesticide distribution was not possible.

Table 15. *Health advisory levels for pesticides in drinking water*
[Data from Kansas Department of Health and Environment, 1986]

Pesticide	Trade name	Acceptable daily intake[1] (milligrams per kilogram)	Health advisory level[2] (micrograms per liter)	Drinking-water standard[3] (micrograms per liter)	Chronic health effects[4]
Alachlor	Lasso	--	15	--	Known animal carcinogen; affects central nervous system; liver and kidney degeneration.
Aldrin	Aldex	--	0.031	--	Known animal carcinogen; bioaccumalated; central nervous system disorders.
Atrazine	AAtrex	0.0215	150	--	Reduced hemoglobin levels; reduced body weight.
Chlordane		--	.22	--	Known animal carcinogen; bioaccumulated; liver damage.
DCPA	Dacthal	.032	224		Unknown.
DDT		--	.42	--	Known animal carcinogen; liver damage; bioaccumulated.
Dieldrin	Dieldrex	--	.019	--	Known animal carcinogen; central nervous system disorders; reproductive disorders; bioaccumulated.
Metolachlor	Dual	.0025	17.5	--	Reduced body weight; little data available.

Table 15. *Health advisory levels for pesticides in drinking water*--Continued

Pesticide	Trade name	Acceptable daily intake[1] (milligrams per kilogram)	Health advisory level[2] (micrograms per liter)	Drinking-water standard[3] (micrograms per liter)	Chronic health effects[4]
PCB	Arochlor 1260	--	1.61	--	Suspected animal carcinogen; liver enlargement and damage; facial acne; facial redness and swelling; bioaccumulation in mother's milk.
Propachlor	Ramrod	0.100	700		Reduced body weight; increased liver weight; little data available.
Metribuzin	Sencor	.025	175	--	Liver and kidney damage; little data available.
Endrin		.000045	0.32	0.2	Suspected animal carcinogen; liver, kidney, brain, and adrenal damage; bioaccumulated; central nervous system disorders.
Lindane		--	.265	4	Known animal carcinogen; affects central nervous system; liver and kidney degeneration.
Methoxychlor		.05	340	100	Reduced body weight; little data available.

Table 15. *Health advisory levels for pesticides in drinking water*--Continued

Pesticide	Trade name	Acceptable daily intake[1] (milligrams per kilogram)	Health advisory level[2] (micrograms per liter)	Drinking-water standard[3] (micrograms per liter)	Chronic health effects[4]
Toxaphene		0.0016	11	5	Affects central nervous system; restlessness, hyperexcitability; kidney inflammation and degeneraation.
2,4-D		.01	70	100	Gastrointestinal irritation; increased weight and swelling of the liver; reduced kidney function; blood disorders.
2,4,5-TP	Silvex	.0075	52	10	Liver and kidney damage; suspected to cause fetal disorders.
2,4,5-T		.10	700	--	Decreased body weight; reproductive effects; little data available.

1 Acceptable Daily Intake - expressed in milligrams of contaminant per kilogram of body weight per day. Acceptable daily intake is based on the dosage of chemical(s) that produced no adverse health effects in chronic toxicity tests, usually involving animals. Acceptable daily intake includes an appropriate safety factor that depends on the amount and quality of toxicity data available. Acceptable daily intakes have not been established for known or suspected human carcinogens because it has not been determined that there is any threshold dosage below which there is no risk of cancer.

2 Health advisory level is the suggested concentration in drinking water that produces no adverse health effect with lifetime consumption of the water. It is calculated assuming the average human weighs 155 pounds and consumes 2 quarts of water daily and allowing that 20 percent of the acceptable daily intake is consumed in water. For known or suspected carcinogens, the health advisory level is based on intake rate that increases the risk of cancer by no more than 1 in 100,000 with lifetime consumption.

3 Primary drinking-water standards have been established for six of the older pesticides with a significant toxicity data base.

4 Chronic health effects may occur after long-term consumption of water containing a pesticide at 10 to 100 times the health advisory level.

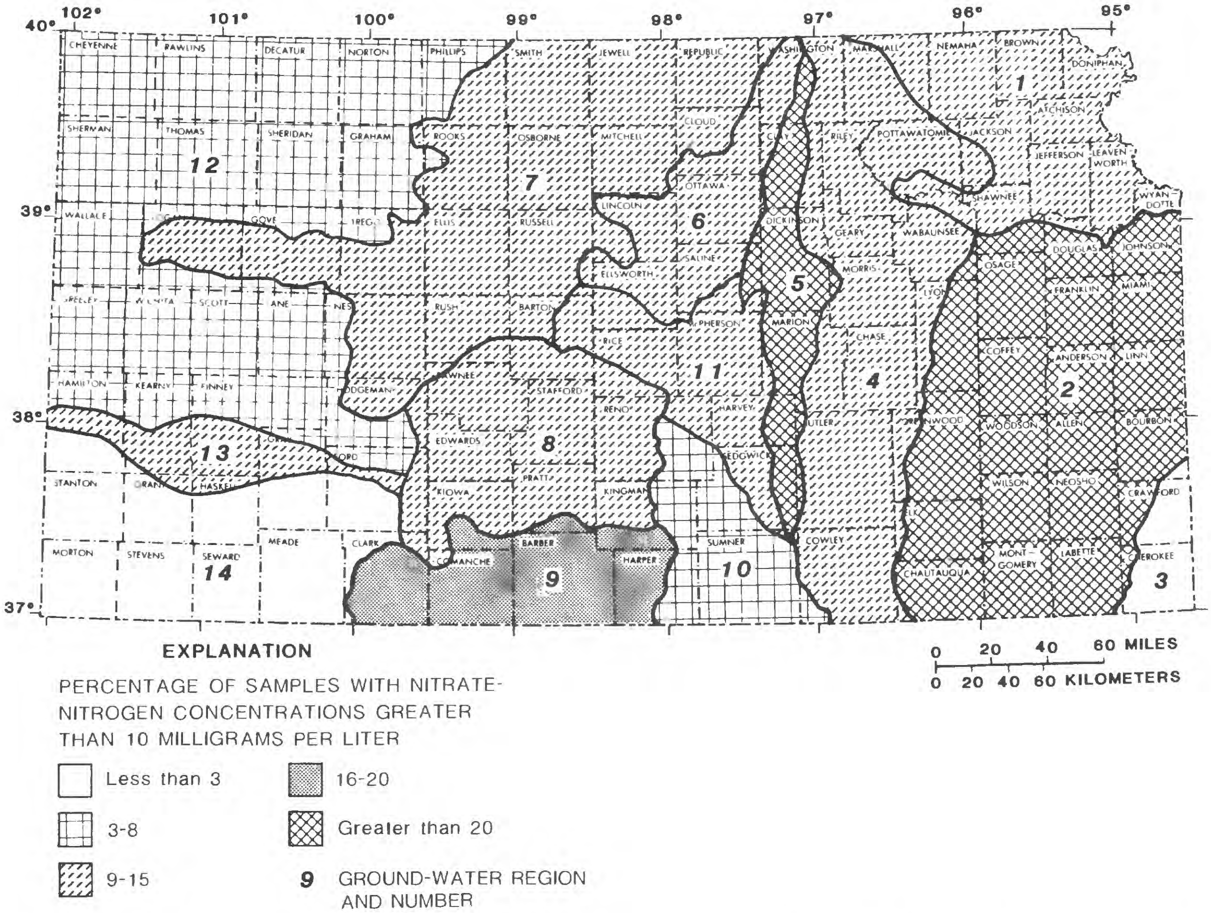

Figure 8. Ground-water regions and percentage of ground-water samples with dissolved nitrate-nitrogen concentrations exceeding drinking-water standard of 10 milligrams per liter.

Table 16. *Dissolved nitrate-nitrogen concentrations in Kansas ground-water supplies, 1976-81* [Data from Spruill, 1983]

Ground-water region (fig.8)	Number of samples	Quartile values of nitrate-nitrogen concentrations (milligrams per liter)				Percentage greater than drinking-water standard[1]
		1st	2nd (median)	3rd	4th (maximum)	
1	71	0.1	1.5	7.0	89	13
2	82	.7	4.0	13	120	30
3	10	0	0	0	.6	0
4	60	1.2	3.9	7.8	15	11
5	18	.2	2.7	10	28	22
6	62	.3	2.8	6.1	87	14
7	112	.4	2.8	6.6	56	14
8	62	3.7	5.6	8.7	29	11
9	25	.6	2.7	8.0	41	20
10	24	.9	3.2	7.4	13	8
11	53	.6	3.4	5.8	26	10
12	95	3.1	4.5	6.0	32	6
13	28	.3	2.7	6.7	21	11
14	48	.1	3.2	3.9	13	2

[1] U.S. Environmental Protection Agency (1986a)

Additional Sampling, 1985-86

The presence of nitrate-nitrogen contamination in Kansas ground water has been proven by the fact that nearly 16 percent (137 of 869) of the wells tested by the ground-water-quality monitoring network and the Kansas farmstead well survey had nitrate-nitrogen concentrations exceeding the MCL. However, only 1 percent (10 of 869) had detectable levels of pesticides. One explanation of the small number of positive pesticide detections was that the samples were tested for a limited number and type of pesticides. The ground-water testing from 1976-81 (Spruill, 1983) included only four insecticides and two herbicides, all of which were insoluble in water. Only 5 of the 20 pesticides examined by Koelliker and others (1987) were soluble in water. The economics of sample analysis helped dictate the compounds that were chosen. An additional sampling scheme was needed to economize analysis costs while maintaining the number of samples.

The additional sampling scheme consisted of sampling ground water from wells located in areas susceptible to leaching and having that sample analyzed for only the pesticides that were used nearby. This technique was used to sample 56 wells during 1985-86 in areas that had permeable soil (class 1 or 2) and shallow water tables (less than 30 feet below land surface). These areas were the Kansas River basin alluvium and parts of south-central Kansas. The samples were analyzed for the triazine group of herbicides (atrazine, cyanazine, simazine, propazine, and trifluralin), alachlor, metolachlor, and metribuzin.

Of the 56 wells sampled, 11 wells (20 percent) had pesticide concentrations exceeding detection limits. The wells with positive detections are listed in table 17. Eleven samples of ground water from nine wells contained atrazine, with concentrations ranging from less than 0.1 to 46 µg/L. Four samples from three wells contained cyanazine in concentrations ranging from 0.7 to 3.7 µg/L. Propazine (0.2 µg/L) and simazine (0.1 µg/L) were detected in only one sample (Sedgwick County, south-central Kansas). Three other herbicides were also detected: alachlor (1.9 µg/L); metolachlor (6.0 µg/L in water from one well, 43 and 55 µg/L in two water samples from another well); and metribuzin (14 µg/L) in one sample.

Because the largest concentrations of atrazine (46 µg/L), cyanazine (3.7 µg/L), metolachlor (55 µg/L), and the only detectable concentrations of metribuzin (14 µg/L) and alachlor (1.9 µg/L) were from water at only one site--the Hesston agronomy farm, approximately in the center of the State--it is uncertain how serious the problem of large concentrations of these herbicides is throughout the State.

Table 17. *Pesticides detected in Kansas ground water, 1985-86*

Location of well (latitude-longitude)	Date	Pesticide	Concentration (micrograms per liter)
Hesston agronomy farm			
(38°07'59"-97°26'24")	11/05/85	Atrazine	34
		Metolachlor	55
		Cyanazine	3.0
	03/27/86	Atrazine	46
		Metolachlor	43
		Metribuzin	14
		Cyanazine	3.7
		Alachlor	1.9

Table 17. *Pesticides detected in Kansas ground water, 1985-86*--Continued

Location of well (latitude-longitude)	Date	Pesticide	Concentration (micrograms per liter)
Topeka agronomy farm			
(39°05'00"-95°46'07")	10/03/85	Atrazine	0.7
	05/23/86	Atrazine	Trace
Wakarusa River valley			
(38°56'05"-95°08'56")	11/01/85	Atrazine	1.9
Republican River valley, Junction City			
(39°05'57"-96°49'06")	11/27/85	Cyanazine	1.1
Kansas River valley, Manhattan			
(39°08'17"-96°34'14")	12/18/85	Atrazine	.3
Smoky Hill River, Enterprise			
(38°54'44"-97°07'02")	11/26/85	Cyanazine	.7
Sedgwick County			
(38°29'32"-97°21'46")	08/15/85	Atrazine	.1
(38°43'56"-97°24'29")	08/12/85	Atrazine	.2
		Propazine	.2
		Simazine	.1
(38°51'11"-97°28'11")	08/13/85	Atrazine	.2
(38°52'10"-97°31'03")	08/12/85	Atrazine	.4
(38°53'48"-97°28'19")	08/14/85	Atrazine	.3
		Metolachlor	6.0

NEED FOR FUTURE STUDY

Problem

Because of the complexities associated with pesticide leaching through the soil, its transformation and degradation, and the multitude of combinations of soil, water, and chemicals, the scope of the potential contamination problem in Kansas has remained poorly defined. There are many different individual soil types in Kansas that range from impermeable clay to very porous sand. Water available for infiltration also varies greatly, with the southeastern part of the State receiving more than 40 inches of rainfall annually to less than 20 inches along the western border. Crops vary from short-grass pastures to row crops. Application rates of the more common pesticides are such that degradation of aquifers in the future may be much more severe than the degradation that already has been detected as indicated by the preliminary assessment of ground-water samples from potential problem areas.

The hypothesis that pesticide residuals and degradation products are being concentrated in the unsaturated zone needs to be tested. The extent of the present contamination of ground water could be much worse than the data indicate. The research effort would include intensive onsite and laboratory studies at an optimum network of experimental sites that are representative of major agricultural areas in Kansas and much of the Nation.

Major Objectives

The research effort would better define the characteristics of pesticide leaching and persistence from the land surface through the unsaturated zone into the saturated zone. The dynamics of the physical and chemical processes are complex and are difficult to evaluate. However, these processes can be grouped into six major categories that have become the objectives of the future study:

1. Determine field values of decay rates for selected pesticides.

2. Determine the spacial and temporal distribution of pesticide residues and their degradation products in the surface soils, unsaturated zone, and ground water.

3. Determine infiltration and ground-water-recharge rates.

4. Determine the extent of short-term (monthly) and long-term (yearly) pesticide leaching for various soil types, and the effects of precipitation timing and(or) application of irrigation water on leaching rates.

5. Determine the effect of chemigation (addition of fertilizers and pesticides to irrigation waters) on the leaching of pesticides to the ground water.

6. Compare measured results of pesticide decay and leaching with estimates produced by the numerical Pesticide Root Zone Model (Carsel and others, 1984) and the LEACH handbook (Dean and others, 1984) for validation of these tools for use at other locations.

The study would include a sufficient number of experimental sites representing a range of soil types, from sandy loam to clay, and climate, from subhumid to semiarid. Pesticides studied would include the most commonly used herbicides--atrazine, metolachlor, alachlor, 2,4-D, and trifluralin.

Determination of pesticide decay rates would be limited by the environmental and soil conditions present at the experimental sites. This limitation also applies in determining the distribution of pesticides from the surface to the water table. Onsite data acquired during at least two growing seasons would be used in the testing of the Pesticide Root Zone Model and the LEACH handbook estimates. An investigation of chemigation, which is the injection of agricultural chemicals into irrigation water, would focus on center-pivot systems and a single herbicide, such as atrazine.

Approach

The objectives of this study would be accomplished by a detailed study of pesticide leaching and persistence on agricultural lands in Kansas. A network of experimental sites currently exists in the form of the Kansas State University agronomy farms and experimental stations (fig. 9). These farms and stations are at locations that represent large agricultural regions of Kansas. Research at these farms and stations is conducted on agricultural practices that are characteristic of each area, such as crop patterns, pesticide application, and irrigation techniques. Detailed soil analyses have been conducted for most fields, and meticulous pesticide records have been maintained for more than two decades at some sites. Pesticides are applied accurately with special sprayers so that initial concentrations can be determined. Each farm or station has a soil scientist with equipment to aid in soil sampling and soil-property interpretations. Another very important aspect of using the farms and stations is that most have complete weather stations permanently installed, and data are available for evapotranspiration calculations. Also, the sites have the capability for soil-moisture monitoring.

Sites would be selected in fields at agronomy farms planted to corn, grain sorghum, soybeans, or wheat that had received applications of the herbicides atrazine, metolachlor, alachlor, 2,4-D, or trifluralin. In the fields selected for study, soil profiles would be sampled at various depths and at various times during the year. These soil samples would be analyzed for pesticide concentration, soil pH, organic carbon content, particle-size distribution, and moisture content. Water in the unsaturated zone would be sampled by suction lysimeters and analyzed for pesticide and chloride concentrations, pH, and specific conductance.

The infiltration of precipitation or irrigation water would be estimated from infiltrometer and evaporation data. Recharge to the ground-water system would be estimated from data collected by tensiometers, soil-moisture blocks, neutron-moisture meters, and observation wells. From measurements of the amount of water infiltrating the soil surface and the amount reaching the water table as recharge, and with the aid of conservative tracers, the adsorption/desorption phenomena of pesticides in the unsaturated part of the soil profile would be determined.

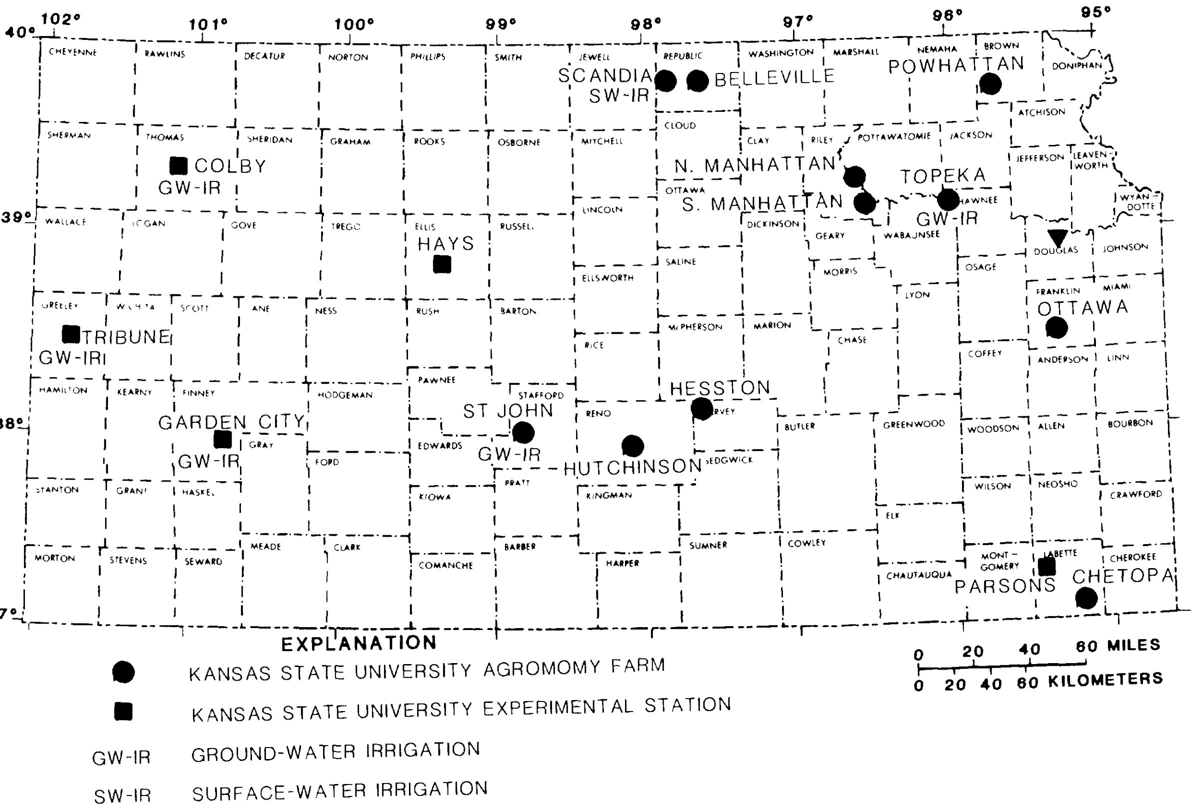

Figure 9. Location of Kansas State University agronomy farms and experimental stations.

Ground-water samples would be collected and analyzed for several inorganic constituents, including major ions, nitrate, ammonia, and organic constituents (including several classes of pesticides). Onsite water-quality measurements would include pH, water temperature, and specific conductance. Soil samples would be analyzed for particle-size distribution and hydraulic properties. The data would be used to relate constituent concentrations to particle-size distribution. The half-life of selected pesticides would be estimated from residual pesticide-concentration data from the soil, soil-water, and ground-water samples.

Soil and ground water in fields where chemigation is practiced would be sampled before the irrigation season and then immediately after cessation of irrigation in the late summer. Amounts of chemicals applied, approximate amounts of applied water, precipitation data collected at nearby rain gages, and type of irrigation equipment would be noted.

Results of the analyses of the pesticide residues in soil samples and water samples obtained at the test sites would be compared to results obtained from generalized data and the numerical Pesticide Root Zone Model and the LEACH handbook. If the data determined onsite do not agree with the model and LEACH estimates, detailed site data would be used to calibrate the Pesticide Root Zone Model for each site. As necessary, the model would be modified to better represent conditions in Kansas. The model then would be used to define the contamination potential for given locations throughout the State.

CONCLUSIONS

An assessment of the hydrologic factors, agricultural factors, and chemical factors that may affect the leaching of agricultural chemicals to ground water was conducted to evaluate the extent and severity of agricultural chemical contamination of ground-water resources in Kansas. The climate of a particular area determines the length of the growing season and the availability of water, at the surface and in the ground, for the growth of plants. Climate, together with surficial geology, soil type, and principal aquifers, determines the types of crops to be planted, types of tillage, conservation and irrigation practices, and affects the quantity and method of application of agricultural chemicals.

In general, the greater the percentage of sand in the soil the more susceptible it will be to leaching and to contamination by agricultural chemicals. Soil in Kansas has been grouped into four classes of leachability--from class 1, with the largest permeability, to class 4, with the smallest.

Of the three major fertilizer compounds (nitrogen, phosphorus, and potassium), nitrogen is the most extensively used. As a result of years of nitrogen application to the soil, nitrate-nitrogen contamination has occurred in the ground water of each of 14 geohydrologic regions in the State. The 10-mg/L drinking-water standard for nitrate-nitrogen was exceeded occasionally in 13 of the 14 regions, based on water samples collected from 1976-81 at 766 wells. Median nitrate-nitrogen concentrations exceeded 3 mg/L in seven of the regions; concentrations greater than 50 mg/L occurred in four of the regions. Phosphorus and potassium have very limited movement in the soil and virtually remain in the area of application.

Lime is used to treat soil that is acidic. Increased crop production on irrigated sandy soil in south-central and western Kansas frequently has resulted in soil pH values of less than 7. These small pH values may be the result of excessive nitrogen applications. One pound of ammonium nitrate may require as much as 6 pounds of lime to prevent an increase in acidity and to maintain optimum conditions for nitrification.

During 1978, about 23.8 million pounds of herbicides and 4.3 million pounds of insecticides were used in the State. Atrazine was the most extensively used herbicide, with 5.7 million pounds applied. However, in areal extent, 2,4-D was the most extensively used, being applied to more than 4 million acres. Atrazine was used extensively on corn and grain sorghum; 2,4-D, on pasture and rangeland. Use of each of seven herbicides exceeded 1 million pounds, but use of no single insecticide exceeded 1 million pounds.

One or more pesticides were detected in about 20 percent (11) of the 56 wells from which samples were collected during 1985-86 in areas susceptible to agricultural chemical leaching. The most common group of pesticides detected was the triazine herbicides--atrazine, cyanazine, propazine, and simazine. Eleven samples of ground water from nine wells contained atrazine, with concentrations ranging from less than 0.1 to 46 µg/L. Only two atrazine concentrations exceeded 2 µg/L (34 and 46 µg/L). Four samples contained cyanazine in concentrations ranging from 0.7 to 3.7 µg/L. Propazine (0.2 µg/L) and simazine (0.1 µg/L) were detected in only one sample (Sedgwick County, in south-central Kansas). Three other herbicides were also detected: alachlor (1.9 µg/L); metolachlor (6.0 µg/L in water from one well, 43 and 55 µg/L in two water samples from another well); and metribuzin (14 µg/L) in one sample.

Because the largest concentrations of atrazine (46 µg/L), cyanazine (3.7 µg/L), metolachlor (55 µg/L), and the only detectable concentrations of metribuzin (14 µg/L) and alachlor (1.9 µg/L) were from water at only one site--the Hesston agronomy farm, approximately in the center of the State--it is uncertain how widespread the problem of large concentrations of these herbicides is throughout the State. It is noteworthy that the herbicides 2,4-D, 2,4,5-T, picloram, and alachlor and the insecticides chlordane and heptachlor epoxide have been detected by other researchers in ground water from domestic-supply wells in the State.

A plan of a proposed study of the leaching and fate of pesticides in the saturated and unsaturated zones in Kansas includes a comprehensive investigation of pesticides in soil and ground water, data collection, process interpretation, and numerical modeling.

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SUPPLEMENTAL INFORMATION

Table 18. *Major herbicide usage during 1978, by reporting district*
[Data from Nilson and Johnson, 1980]

Common name	Trade name	Crop	Area[1] applied (acre)	Percentage of crop acreage	Total[2] applied (pounds)
		Northwest Kansas			
Atrazine	AAtrex	Corn	216,300	89	352,600
		Sorghum	65,500	34	108,700
		All	281,800		461,300
EPTC	Eradicane	Corn	78,000	32	330,700
Alachlor	Lasso	Corn	61,500	25	124,200
2,4-D	--	Corn	9,600	4	4,300
		Sorghum	11,000	6	4,800
		Wheat	113,600	9	71,600
		Pasture	9,800	1	16,600
		All	144,000		97,300
Propachlor	Ramrod	Corn	4,500	2	16,000
		Sorghum	15,300	8	51,400
		All	19,800		67,400
Cyanazine	Bladex	Corn	23,900	10	45,600
		Sorghum	11,200	6	13,900
		All	35,100		59,500
Propazine	Milogard	Sorghum	40,300	21	53,200
Terbutryn	Igran	Sorghum	18,200	10	31,900
Dicamba	Benvel	Corn	23,500	10	8,000
		Sorghum	6,200	3	1,600
		All	29,800	3	9,600

Table 18. *Major herbicide usage during 1978, by reporting district*
[Data from Nilson and Johnson, 1980]--Continued

Common name	Trade name	Crop	Area[1/] applied (acre)	Percentage of crop acreage	Total[2/] applied (pounds)
		North-Central Kansas			
2,4-D	--	Corn	4,000	4	1,800
		Sorghum	104,200	15	45,800
		Wheat	201,600	15	127,000
		Pasture	452,500	19	764,700
		All	762,400		939,300
Propachlor	Ramrod	Corn	9,400	9	33,400
		Sorghum	225,200	33	756,700
		All	234,600		790,100
Atrazine	AAtrex	Corn	73,300	67	119,500
		Sorghum	367,200	54	609,500
		All	440,500		729,000
EPTC	Eradicane	Corn	30,000	27	127,500
Propazine	Milogard	Sorghum	78,400	12	103,500
Cyanazine	Bladex	Corn	13,800	13	26,400
		Sorghum	9,900	1	12,300
		All	23,700		38,700
Alachlor	Lasso	Corn	5,300	5	10,700
		Soybeans	12,200	2	27,900
		All	17,500		38,600
Terbutryn	Igran	Sorghum	21,500	3	37,600
Dicamba	Banvel	Sorghum	6,600	1	1,700
		Wheat	22,400	2	2,900
		All	29,000		4,600

Table 18. *Major herbicide usage during 1978, by reporting district*
[Data from Nilson and Johnson, 1980]--Continued

Common name	Trade name	Crop	Area[1/] applied (acre)	Percentage of crop acreage	Total[2/] applied (pounds)
		Northeast Kansas			
2,4-D	--	Corn	17,500	7	7,900
		Sorghum	65,600	11	28,900
		Wheat	12,900	5	8,100
		Pasture	630,400	37	1,065,400
		All	726,400		1,110,300
Atrazine	AAtrex	Corn	202,000	77	329,300
		Sorghum	450,300	77	747,500
		All	652,200		1,076,800
Propachlor	Ramrod	Corn	12,200	5	43,300
		Sorghum	295,200	50	991,900
		All	307,400		1,035,200
Alachlor	Lasso	Corn	75,600	29	152,700
		Soybeans	105,400	38	241,400
		All	181,000		394,100
Butylate	Sutan+	Corn	52,900	20	238,100
EPTC	Eradicane	Corn	46,500	18	197,600
Trifluralin	Treflan	Soybeans	109,300	40	136,600
Metribuzin	Sencor	Soybeans	150,200	54	64,600
Cyanazine	Bladex	Corn	23,700	9	45,300
		Sorghum	5,600	1	6,900
		All	29,300		52,200
Chloramben	Amiben	Soybeans	21,900	8	43,800

Table 18. *Major herbicide usage during 1978, by reporting district*
[Data from Nilson and Johnson, 1980]--Continued

Common name	Trade name	Crop	Area[1/] applied (acre)	Percentage of crop acreage	Total[2/] applied (pounds)
		West-Central Kansas			
Atrazine	AAtrex	Corn	154,500	79	251,800
		Sorghum	56,400	27	93,600
		All	210,900		345,400
EPTC	Eradicane	Corn	67,000	34	284,800
2,4-D	--	Corn	2,400	1	1,100
		Sorghum	14,100	7	6,200
		Wheat	158,600	12	99,900
		Pasture	15,400	1	26,000
		All	190,500		133,200
Propazine	Milogard	Sorghum	66,000	31	87,100
Terbutryn	Igran	Sorghum	45,400	22	79,500
Cyanazine	Bladex	Corn	17,700	9	33,800
		Sorghum	26,600	13	33,000
		All	44,300		66,800
Butylate	Sutan+	Corn	9,000	5	40,500
Propachlor	Ramrod	Corn	600	<1	2,100
		Sorghum	6,100	3	20,500
		All	6,700		22,600

Table 18. *Major herbicide usage during 1978, by reporting district*
[Data from Nilson and Johnson, 1980]--Continued

Common name	Trade name	Crop	Area[1/] applied (acre)	Percentage of crop acreage	Total[2/] applied (pounds)
		Central Kansas			
2,4-D	--	Corn	5,700	9	2,600
		Sorghum	114,100	18	50,200
		Wheat	207,000	12	130,400
		Pasture	192,700	9	325,700
		All	519,500	9	508,900
Atrazine	AAtrex	Corn	24,100	39	39,300
		Sorghum	204,800	32	340,000
		All	228,900		379,300
Propachlor	Ramrod	Corn	1,500	2	5,300
		Sorghum,	56,000	9	188,200
		All	57,500		193,500
Propazine	Milogard	Sorghum	138,300	21	182,500
Terbutryn	Igran	Sorghum	63,000	10	110,300
Alachlor	Lasso	Corn	15,800	26	31,900
		Soybeans	8,400	29	19,200
		All	24,200		51,200
Cyanazine	Bladex	Corn	13,000	21	24,800
		Sorghum	10,200	2	12,600
		All	23,200		37,400
Butylate	Sutan+	Corn	7,200	12	32,400

Table 18. *Major herbicide usage during 1978, by reporting district* [Data from Nilson and Johnson, 1980]--Continued

Common name	Trade name	Crop	Area[1/] applied (acre)	Percentage of crop acreage	Total[2/] applied (pounds)
		East-Central Kansas			
Atrazine	AAtrex	Corn	122,700	71	200,000
		Sorghum	357,300	75	593,100
		All	480,000		793,100
2,4-D	--	Corn	15,400	9	6,900
		Sorghum	71,000	15	31,200
		Wheat	22,500	10	14,200
		Pasture	383,100	14	647,400
		All	492,000		699,800
Propaclor	Ramrod	Corn	5,900	3	20,900
		Sorghum	190,400	40	639,700
		All	196,300		660,600
Alachlor	Lasso	Corn	38,400	22	77,600
		Soybeans	130,900	29	299,800
		All	169,300		377,400
Trifluralin	Treflan	Soybeans	166,900	37	208,600
Butylate	Sutan+	Corn	41,100	24	185,000
EPTC	Eradicane	Corn	16,600	10	70,300
Metribuzin	Sencor	Soybeans	136,300	30	58,600
Cyanazine	Bladex	Corn	20,100	12	38,400
		Sorghum	9,400	2	11,700
		All	29,500		50,100
Linuron	Lorox	Soybeans	31,300	7	31,300

Table 18. *Major herbicide usage during 1978, by reporting district*
[Data from Nilson and Johnson, 1980]--Continued

Common name	Trade name	Crop	Area[1/] applied (acre)	Percentage of crop acreage	Total[2/] applied (pounds)
		Southwest Kansas			
Atrazine	AAtrex	Corn	437,100	78	712,500
		Sorghum	105,400	14	175,000
		All	542,500		887,500
Butylate	Sutan+	Corn	134,900	24	607,100
EPTC	Eradicane	Corn	98,900	18	420,300
2,4-D	--	Corn	8,800	2	4,000
		Sorghum	74,100	10	32,600
		Wheat	39,500	2	24,900
		Pasture	93,500	4	158,000
		All	215,900		219,500
Propazine	Milogard	Sorghum	157,900	21	208,400
Terbutryn	Igran	Sorghum	113,000	15	197,800
Propachlor	Ramrod	Corn	6,700	1	23,800
		Sorghum	26,300	3	88,400
		All	33,000	3	112,200
Cyanazine	Bladex	Corn	25,000	4	47,800
		Sorghum	7,600	1	9,400
		All	32,600		57,200
Alachlor	Lasso	Corn	18,500	3	37,400

Table 18. *Major herbicide usage during 1978, by reporting district*
[Data from Nilson and Johnson, 1980]--Continued

Common name	Trade name	Crop	Area[1/] applied (acre)	Percentage of crop acreage	Total[2/] applied (pounds)
		South-Central Kansas			
2,4-D	--	Corn	900	<1	400
		Sorghum	83,300	13	36,700
		Wheat	192,200	7	121,100
		Pasture	146,500	6	247,600
		All	422,900		405,800
Atrazine	AAtrex	Corn	97,100	75	158,300
		Sorghum	128,900	20	214,000
		All	226,000		372,300
Propachlor	Ramrod	Corn	4,000	3	14,200
		Sorghum	99,500	16	334,300
		All	103,500		348,500
Propazine	Milogard	Sorghum	133,500	21	176,200
Alachlor	Lasso	Corn	64,500	50	130,300
		Soybeans	11,600	14	26,600
		All	76,100		156,900
Terbutryn	Igran	Sorghum	70,700	11	123,700
Butylate	Sutan+	Corn	16,100	12	72,500
Trifluralin	Treflan	Soybeans	43,800	53	54,800
Dicamba	Banvel	Corn	200	<1	70
		Sorghum	6,000	1	1,500
		Wheat	50,900	2	6,600
		All	57,100		8,170

Table 18. *Major herbicide usage during 1978, by reporting district*
[Data from Nilson and Johnson, 1980]--Continued

Common name	Trade name	Crop	Area[1] applied (acre)	Percentage of crop acreage	Total[2] applied (pounds)
		Southeast Kansas			
2,4-D	--	Corn	4,900	6	2,200
		Sorghum	73,700	14	32,400
		Wheat	76,200	16	48,000
		Pasture	374,100	10	632,200
		All	528,900		714,800
Atrazine	AAtrex	Corn	65,500	80	106,800
		Sorghum	343,800	67	570,700
		All	409,300		677,500
Propachlor	Ramrod	Corn	3,800	5	13,500
		Sorghum	160,000	31	537,600
		All	163,800		551,100
Alaclor	Lasso	Corn	21,200	26	42,800
		Soybeans	136,600	27	312,800
		All	157,800		355,600
Trefluralin	Treflan	Soybeans	199,700	34	249,600
Butylate	Sutan+	Corn	13,300	16	59,900
Metribuzin	Sencor	Soybeans	135,900	23	58,400
Linuron	Lorox	Soybeans	31,800	5	31,800
Bentazon	Basagran	Soybeans	28,400	5	28,400

1 The "area applied" includes acres where a pesticide is used alone or in combination; a given area may receive multiple pesticides.

2 The "total applied" was derived by multiplying the "area applied" by the the statewide average application rate for each herbicide on each crop.