Texas Agricultural Extension Service

Groundwater Quality Protection for Livestock Feeding Operations

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Introduction

The primary constituents of livestock and poultry manure that can contaminate groundwater include pathogenic organisms, nitrates and ammonia. Other constituents such as potassium, sodium, chloride and sulfate also may leach through the soil and impair the quality of an aquifer. Phosphorus and organic solids are not usually sources of groundwater pollution because of their limited leaching potential.

Potential point sources of groundwater contamination in livestock feeding operations include open, unpaved feedlots, runoff holding ponds, manure treatment and storage lagoons, silos and manure stockpiles. Insecticide spray equipment, dipping vats and disposal sites for waste pesticides, rinsates or containers also may contribute to localized groundwater contamination. This is especially true if pesticide use or disposal occurs near the well-head, because of the possibility of direct entry of runoff or infiltration around or through well casings or abandoned wells.

Nonpoint pollution sources include fields used for land application of manure and wastewater, manure accumulations around livestock watering locations, and intermittently-used stock pens. Livestock grazing operations, from sparse rangelands to intensively-stocked pastures, can influence the water quality of streams and aquifers. The nonpoint source pollution potential of pastured livestock depends in part upon the stocking density, length of grazing period, average manure loading rate, uniformity of manure spreading by grazing livestock, and disappearance of manure with time. Because livestock concentrations (animal density) vary widely across Texas, manure voided varies from less than 0.1 to more than 7 dry tons per acre per year. Nitrogen deposition from grazing cattle ranges from approximately 1 to 200 pounds per acre per year for sparse rangelands and intensively-grazed improved pastures, respectively.

This publication summarizes research results and management strategies for groundwater pollution control for open feedlots, holding ponds and lagoons, and land on which manure and wastewater are applied.

Feedlot Surfaces

Research in several states, in climates ranging from arid to humid, has determined that an active feedlot surface develops a compacted manure/soil interfacial layer (usually 2 to 4 inches thick) which provides an excellent moisture seal. This compacted manure/soil layer reduces the water infiltration rate to less than 0.002 inches per hour, or as little as 3 percent of the infiltration rate of the underlying soil (Mielke et al., 1974; Mielke and Mazurak, 1976). This zone of low infiltration restricts the leaching of salts, nitrates and ammonium into the subsoil and underlying groundwater (Schuman and McCalla, 1975A). This interfacial layer is usually dark brown or black, often resembling charcoal, perhaps because of its iron sulfide content (Norstadt et al., 1975). It is composed of bacterial cells, organic matter, degradation products and soil particles.

Self-Sealing of Soil Surface

If an undisturbed anaerobic layer of compacted manure is left above the manure/soil interfacial layer, formation and leaching of nitrate are retarded in favor of denitrification (Stewart et al., 1967; Chang el al., 1973). With this type of anaerobic condition, nitrate is converted to nitrogen gas which is released to the atmosphere rather than being leached to subsoil and

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groundwater. The soil profile which best retards nitrate and nitrite movement and retains salts near the soil surface was found to be sandy topsoil above a clay loam subsoil (Norstadt and Duke, 1982).

McCalla and Elliot (1971) found that reducing conditions are present 1 to 5 feet beneath a cattle feedlot, as evidenced by the presence of methane and carbon dioxide and the oxygen levels in the soil air beneath feedlots as compared to a cropped field. Reducing conditions, coupled with the presence of organic matter, promote denitrification and protect against nitrate leaching.

To avoid disrupting the surface seal provided by the manure/soil interfacial layer, feedlot personnel should be taught the correct use of manure collection machines (wheel loaders or elevating scrapers) to "harvest manure" rather than "cleaning pens." Leaving an undisturbed manure pack also will result in collecting the highest quality manure for crop fertilization or energy generation (Sweeten et al., 1985). Feedlots that have been abandoned without manure removal may be more likely to pollute groundwater than active feedlots (Madison and Brunett, 1984).

Nutrient Leaching

Concentrations of nitrate and ammonia decrease rapidly within the top foot (30 cm) of the feedlot soil layer (**Figure 1**) (Schuman and McCalla, 1975B). Soil water samples taken at about 3 feet beneath cattle feedlots showed concentrations of NO_3, P, Mg and salinity similar to those under adjacent cropland (Alego et al., 1972; Elliott et al., 1972; Schuman and McCalla, 1975B; Dantzman et al., 1983).

Miller (1971) measured groundwater quality in the Ogallala Aquifer beneath 80 cattle feedlots in the Texas High Plains. He determined that about one-fourth had contributed to nitrate levels that approached or exceeded the U.S. Environmental Protection Agency's drinking water standard of 10 ppm NO_3-N in the immediate vicinity of the feedlots. Seepage rates were estimated at 2 to 20 x 10^{-6} cm per second (0.003 to 0.03 inches per hour) under feedlot surfaces and playas used for runoff collection.

Borman (1981) monitored water quality in a shallow alluvial aquifer, by means of 19 observation wells placed around a 90,000 head feedlot, from feedlot startup through 4 years of operation. Chloride concentrations increased slightly in one well downgradient from a runoff retention pond. Leachate had percolated to 5 feet beneath the feedlot but not to 20 feet. The observed changes in groundwater quality were slight, which was attributable to an impermeable manure pack, soil clogging under the cattle pens, limited recharge, denitrification in the unsaturated zone, and soil clogging at the bottom and sides of an unlined runoff retention pond.

Kreitler (1975) has developed a technique for differentiating between the nitrate in soil and groundwater caused by animal wastes and that caused by commercial fertilizer or resulting from natural soil material. The method uses N-15 isotope as a tracer.

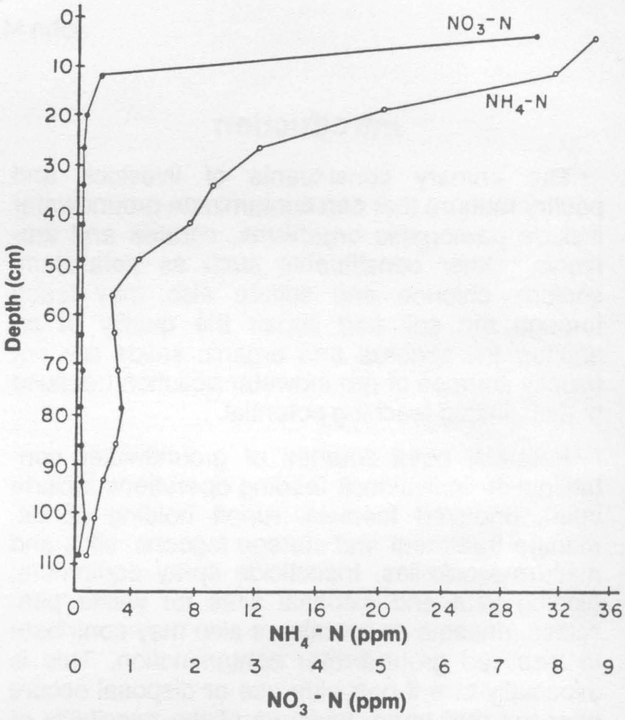

Figure 1. Ammonia and nitrate nitrogen present in a feedlot soil profile (Schuman and McCalla, USDA-ARS, 1975B).

Holding Ponds and Lagoons

Self-Sealing

Seepage from livestock waste treatment lagoons and runoff holding ponds has been studied by researchers for at least 2 decades. In essence, it has been determined that bacterial cells and fine organic matter generally clog soil pore spaces along the bottoms and sides of lagoons and holding ponds (Barrington and Jutras, 1985), making them effectively "self-sealing" (Davis et al., 1973).

After several months of storage, coefficients of permeability of the bottom soil of ponds storing liquid manure, wastewater and runoff from livestock operations have usually been from one to three orders of magnitude (i.e., 10 to 1000 times) lower with wastewater than with clean water (Robinson, 1973; Lehman and Clark, 1975; Barrington and Jutras, 1983). Where the bottoms and sides of manure storage ponds and lagoons have moderate to fine-textured soil (such as silt, clay loam or clay), the final permeability coefficient is usually of the order of magnitude of 10^{-6} centimeters per second (cm/sec), or 0.0014 inches per hour (in/hr) (**Figure 2**) (Barrington and Jutras, 1985). However, final permeabilities of a sand usually exceed 10^{-6} cm/sec (0.0014 in/hr) (Dye et al., 1984). Cattle manure has generally shown better self-sealing properties than swine manure (Barrington and Jutras, 1985).

Livestock manure and wastewater provide significant beneficial self-sealing on the bottoms and sides of lagoons and holding ponds. However, this phenomenon should not be counted on as the sole means of protecting groundwater, and lagoons and holding ponds should be placed in relatively impermeable subsoils (Dye et al., 1984).

Many feedlots in Texas are built on playa lakes, which have clay bottoms (Randall Clay) several feet thick underlain by much more permeable soil material (of Pleistocene origin) which resembles caliche. Lehman and Clark (1975) determined that undisturbed cores of the clay surface soil in playas had permeability values with clear water of 2.8×10^{-5} cm/sec (0.04 in/hr), as compared to 1.1 x 10^{-3} cm/sec (1.6 in/hr) for the buried Pleistocene materials. However, the addition of feedyard runoff reduced permeabilities to only 5.6×10^{-7} cm/sec (8.3×10^{-4} in/hr) for the Randall clay after 10 days, and to 1.7×10^{-6} cm/sec (0.0025 in/hr) for the underlying soil within 45 days.

Nutrient and Salt Leaching

Lehman et al. (1970) investigated the leaching of feedyard runoff contaminants below a playa lake bottom. Nitrogen compounds did not move

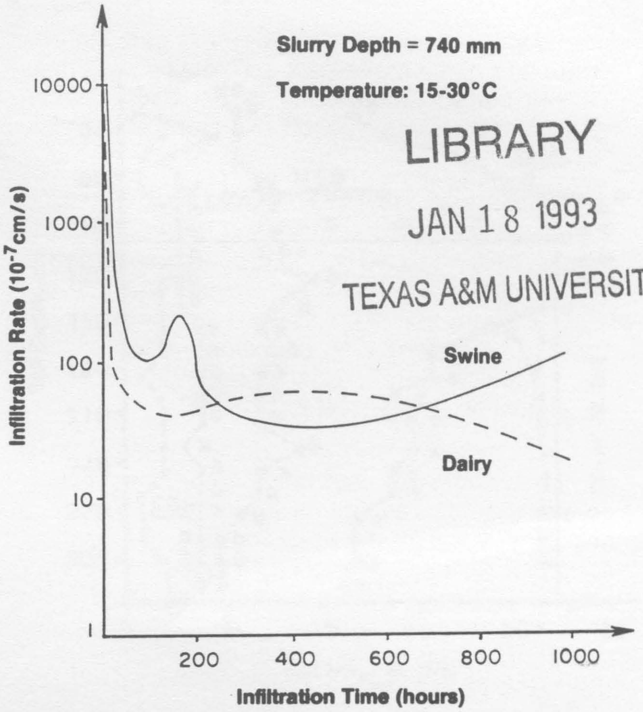

Figure 2. Infiltration rates for swine and dairy manure slurries over coarse sand (Barrington and Jutras, 1985).

below 3 feet. At 2 feet and below, the nitrate and nitrite concentrations were only slightly higher than for playas not receiving feedyard runoff (**Table 1**).

The feedlot playa study was repeated 5 years later by Clark (1975). Results in **Figures 3 and 4** show that both nitrate and chloride concentrations decreased drastically within the top meter of soil. Below 1 meter (3.3 feet), nitrate concentrations were lower than the public drinking water standards of 10 mg/l nitrate-nitrogen.

The potential for groundwater contamination is increased (Lehman and Clark, 1975) when playa

Table 1. Nitrate, nitrite and ammonium-nitrogen concentrations beneath playa used for feedlot runoff collection (Lehman, Stewart and Mathers, 1970).

	Feedlot Playa* (3 obs. wells)			Non-Feedlot Playa (2 wells)	
Depth Feet	Nitrate	Ammonium	Nitrite	Nitrate	Nitrite
0	12.8	58.7	2.8	--	--
1	225	18.4	3.2	7.8	0.34
2	6.2	5.7	0.13	2.8	0.16
3	3.7	3.1	0.05	2.8	0.16
4	3.0	3.3	0.03	2.5	0.13
5	3.4	3.5	0.02		
6-13	0.3-2.7	1.1-2.8	0.02-0.12		

* Average of 3 center observation wells.

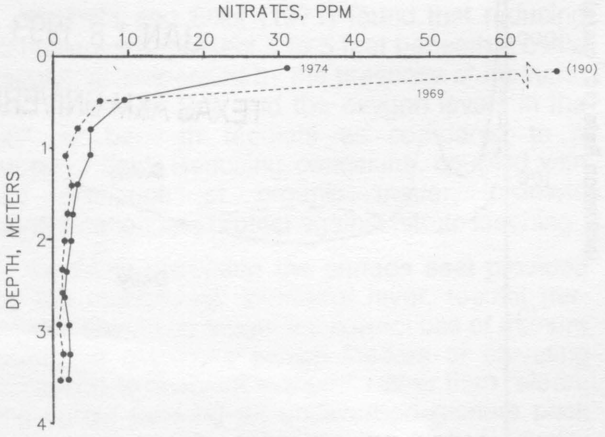

Figure 3. Nitrates (NO_3-N), dry-weight basis (110°C), beneath a feedyard playa, 1969 and 1974 (Clark, 1975).

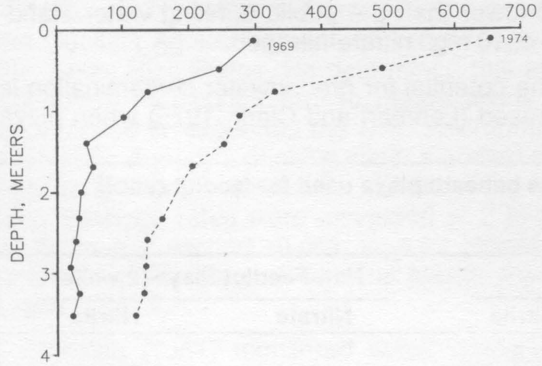

Figure 4. Chlorides, dry-weight basis (110°C), beneath a feedyard playa, 1969 and 1974 (Clark, 1975).

lake bottoms are excavated below the Randall clay layer. When excavation must be done, the clay should be stockpiled and reapplied to a compacted depth of 1 foot or more over the bottom and sides of the pond to serve as a clay liner (TWC, 1987).

Monitoring wells placed near livestock waste treatment lagoons and holding ponds have been used to determine the distribution of groundwater contaminants caused by lagoon seepage (Collins et al., 1975; Ciravolo et al., 1979; Sewell, 1978; Ritter et al., 1981; Phillips and Culley, 1985). Nutrient or salt concentrations in shallow groundwater sometimes increase in the immediate vicinity of lagoons or holding ponds. However, these initial increases usually diminish after several months. Results of studies with monitoring wells are reasonably consistent with the observed reductions in permeability caused by self-sealing.

Regulatory Requirements for Soil Material

The Texas Water Commission (TWC, 1987) adopted a regulation that governs confined, concentrated livestock and poultry feeding operations. In order to protect groundwater from seepage from lagoons and holding ponds, the TWC regulation requires that all wastewater retention facilities be constructed of compacted or in-situ soil materials at least 12 inches thick and with low permeability. The soil material must meet or exceed the following criteria:

- liquid limit of 30 percent or more;
- plasticity index of 15 or more; and
- fraction passing a number 200 mesh sieve of 30 percent or more.

Many lagoons also are required by individual permits to have clay liners with a permeability coefficient of 1×10^{-7} cm/sec.

If these soil standards for lagoons and holding ponds are followed, combined with the benefit of self-sealing from stored manure and wastewater, groundwater should be adequately protected. And, cumbersome requirements such as monitoring wells or impermeable membrane liners should not be needed.

Land Application of Wastes

It is essential that livestock manure and wastewater be collected, stored and applied to land in such a way as to prevent discharge to surface water (TWC, 1987). The hourly application rate for wastewater should be uniformly less than the soil infiltration rate to prevent surface runoff. Also, manure and wastewater should be applied to soils at annual rates that match expected plant uptake of nutrients and crop yield goals to ensure that groundwater contamination will not occur.

Yields from Manure Application

With proper manure fertilization rates, such as 10 tons of feedlot manure per acre, crop yields usually equal or exceed the yields from commercial fertilizer, as shown in **Table 2** (Mathers and Stewart, 1984). Yields with manure are often sustained for several years longer than with commercial fertilizer because of the slower release of residual nutrients and micronutrients (Lund et al., 1975; Lund and Doss, 1980).

Nutrient Accounting Balance

With proper manure application rates, most of the applied nutrients can be accounted for in increased crop harvest or increased weight gain of pastured cattle. Excessive manure application rates usually do not increase yields appreciably, but they do increase the soil nitrate levels to more than 10 ppm NO_3-N (**Figures 5 and 6**) (Reddell, 1974; Matthews and Stewart, 1984; Westerman et al., 1983).

Some research projects have documented crop nutrient uptake as a percent of applied nutrients. For example, Westerman et al. (1978) determined that the uptake of nitrogen, phosphorus and potassium (N-P-K) by coastal bermudagrass was 74, 41 and 74 percent, respectively, when swine lagoon effluent was applied at rates matching the recommended soil nitrogen (N) needs. But plant uptake of N-P-K was only 33, 17 and 32 percent when N application was four times the soil/plant requirements. The remaining 67 percent of the N applied remained in the soil and some had leached below the root zone (**Figure 5**). When manure applications greatly exceed crop nutrient requirements, nitrate-nitrogen accumulates in the root zone (Murphy et al., 1972; Manges et al., 1975; Reddell et al., 1974) and it may be subject to leaching. This soil accumulation of nitrate-nitrogen is illustrated in **Figures 6 and 7** (Mathers and Stewart, 1971). Further research is needed on how nutrients in soils leach, volatilize, denitrify or are used by crops in typical livestock and crop production systems in Texas.

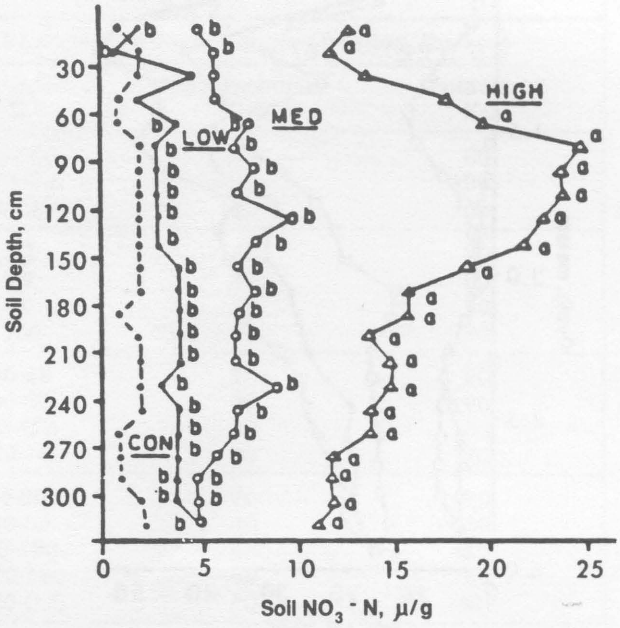

Figure 5. Effect on soil nitrate (NO_3-N) of lagoon effluent irrigation rates of 0, 4.7, 9.4 and 18.9 in/yr (control, low, medium and high, respectively) for 6 years (Westerman et al., 1983).

Table 2. Crop yields from feedlot manure application, Bushland, Texas 1969-80. USDA-ARS.

Manure Treatment	Number of Years: Manure Applied	Number of Years: Recovery No manure	Average Yields, lbs/acre/yr: Sorghum Grain 1969-'73	Average Yields, lbs/acre/yr: Corn 1975, '77, '79	Average Yields, lbs/acre/yr: Wheat 1976, '78, '80
0	11	0	4,490	8,350	1,400
0 (N)	11	0	6,440	13,390	4,050
0 (NPK)	11	0	6,410	13,560	4,290
10	11	0	6,640	13,920	3,430
30	11	0	6,490	13,400	4,530
60	5	6	6,360	14,340	4,000
120	5	6	5,120	13,950	4,260
240	3	8	900	15,260	4,330
240	1	10	330	12,100	2,810

Source: Mathers, A.C. and B.A. Stewart. 1984, *Transactions of the ASAE*, 27(4).

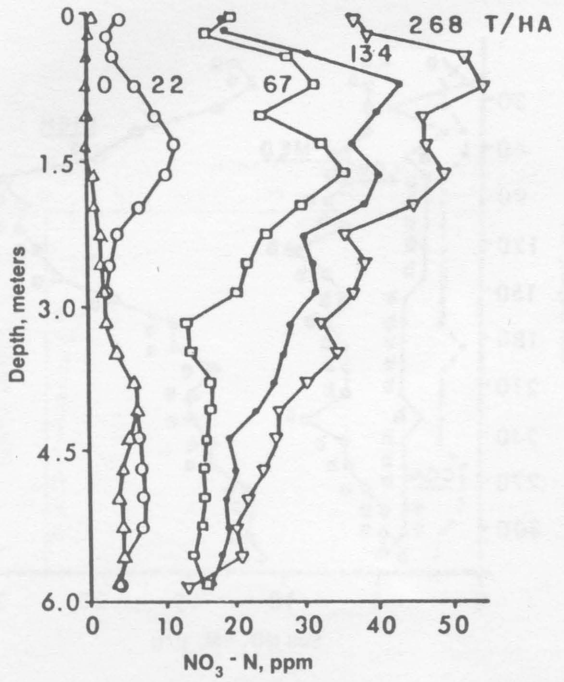

Figure 6. Total amount of nitrate-nitrogen accumulated in 20-foot soil profiles following two cropping seasons with the indicated amounts of manure applied each year (0, 10, 30, 60 and 120 tons/acre or 0, 22, 67, 134 and 268 metric tons/hectare) (Stewart and Mathers, 1971).

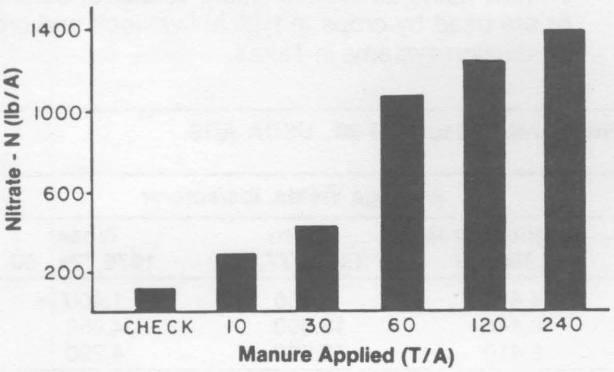

Figure 7. Nitrate-N in pullman clay loam soil after five annual applications of manure at indicated rates to irrigated grain sorghum (Mathers et al., 1975).

Soil Testing

Much of the agricultural soil in Texas is low in available nitrogen, organic matter and micronutrients and could benefit from manure application. Technical guides to proper manure application are readily available (Gilbertson et al., 1979). Fertilizer recommendations for specific crops are available from county Extension agents and agronomists (**Table 3**).

Producers should annually sample and test soils for nutrients. They should also measure the nutrient and salt concentrations in manure and wastewater in order to establish fertilization practices that both produce optimum crop yields and protect water quality. Soil testing is both a good agricultural practice and an excellent groundwater protection measure. Accurate soils analyses can be obtained at low cost from the Soil/Water/Plant Testing Laboratories of the Texas Agricultural Extension Service in College Station and Lubbock.

Summary

Feedlot surfaces should be managed to collect (harvest) manure frequently, yet to maintain an undisturbed layer of compacted manure and a manure/soil interfacial layer over the underlying soil surface. This will restrict leaching of nutrients and salts. When feedlots are closed, however, all manure should be removed.

A significant amount of self-sealing occurs in the soil at the bottoms and sides of storage lagoons and holding ponds as the soil is clogged with organic matter and bacterial cells. However, a complete seal is not formed. Therefore, compacted clay soils are needed to adequatedly control seepage, in accordance with state water pollution control regulations and permits.

Applying manure and wastewater according to crop nitrogen requirements will prevent groundwater contamination in most cases. However, excessive application rates can contaminate underlying aquifers with nitrate, ammonia, chloride and perhaps other substances.

Table 3. Crop yield goals versus nutrient recommendation, lbs/acre.

Crop	Yield Goal	Available Nutrient Recommendation, lbs/acre		
		Nitrogen N	Phosphorus P_2O_5	Potassium K_2O
Corn	75-99 bu/a	75-100	60	80
	100-149 bu/a	110-165	80	130
	150-200 bu/a	180-240	80	140
Cotton	1.0 bale/a	40	40	30
	1.5 bales/a	60	60	50
	2.0 bales/a	80	80	80
	2.5 bales/a	100	80	80
Grain Sorghum	1500-2000 lbs/a	30-40	20	20
	2000-4000 lbs/a	40-80	40	80
	4000-6000 lbs/a	80-120	60	100
	6000-8000 lbs/a	120-160	80	120
Wheat	20-30 bu/a	40-60*	20	20
	30-40 bu/a	60-80	40	30
	40-60 bu/a	80-120	40	40
	60-80 bu/a	120-160	60	60
	80-100 bu/a	160-200	60	60
Coastal Bermuda	Grazing only	100-160	50	90
	1 Cutting + Grazing only	160-220	50	150
	3 Cuttings	300-350	100	300
	4-6 Cuttings	400-600	130	400
Alfalfa	Non-irrigated, annually	20	60	120
	Irrigated; 6 T/a	20	100	120
	Irrigated; 8-12 T/a	20	140	200
Clover	Annually	20	80	120
	Sod seeded	20	80	120
	With ryegrass/small grains	40	80	120
Wheat	Light grazing**	160	60	60
	Moderate grazing	200	80	120
	Heavy grazing	240	80	120
Sorghum/Sudan	1 cutting or light grazing	80	40	40
	2 cuttings or medium grazing	160	60	60
	3 cuttings or heavy grazing	200	80	80

*If wheat will not be grazed, suggested N rates can be reduced 10 to 25 percent.

**Fertilizer rates suggested for grazing wheat pastures are for the higher rainfall, eastern one-third of Texas. Rates for all grazing intensities should be reduced by approximately 10 percent for each 50-mile increment west of 1-35 to compensate for decreasing annual rainfall.

Note: Actual fertilizer recommendations are based on the above crop requirements, minus soil nutrient levels identified by a soil test, resulting in recommendations which may be slightly to significantly lower than the nutrient levels listed in the table. For example: soils testing high in both phosphorus and potassium may require supplemental nitrogen only to produce 50 bushels of wheat. (Generally, no economic response to potassium fertilization would be expected west of I-35. The exception may be intensively managed coastal bermuda.)

Source: Texas Agricultural Extension Soil Testing Laboratories, College Station and Lubbock.

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