

RESPONSE OF SEVEN CROPS AND TWO SOILS TO APPLICATION OF BEEF CATTLE FEEDYARD EFFLUENT

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ABSTRACT. A greenhouse experiment was conducted to evaluate yield and nutrient uptake following land application of beef cattle feedyard effluent. Effluent from a large commercial feedyard was applied to seven crops planted in 210 pots containing Pullman clay loam (PCL) or Amarillo fine sandy loam (AFSL). The crops evaluated were forage sorghum, wheat, corn silage, alfalfa, bromegrass, bermudagrass, and Jose tall wheatgrass. Each crop and soil type received five effluent application treatments representing 0%, 25%, 50%, 100%, and 200% of the annual crop nitrogen requirement and about 0%, 20%, 40%, 80%, and 160% of the annual crop phosphorus requirement over the growing period, which ranged from 4 to 12 months. Dry matter yield increased with increasing application rates for all crops except alfalfa in the AFSL, with minimal differences in dry matter yield for the PCL. For the PCL, all crops except corn silage had foliage crude protein concentrations equal to or greater than published values. For the AFSL, forage sorghum, wheat, and corn silage had foliage crude protein concentrations less than typical. In the PCL at the highest application rate, phosphorus uptake rates in the foliage were wheat (16 kg/ha), alfalfa (36 kg/ha), bromegrass (41 kg/ha), Jose tall wheatgrass (37 kg/ha), forage sorghum (47 kg/ha), corn silage (57 kg/ha), and bermudagrass (112 kg/ha). In the AFSL at the highest application rate, phosphorus uptake rates in the foliage were wheat (10 kg/ha), bromegrass (12 kg/ha), alfalfa (17 kg/ha), forage sorghum (17 kg/ha), Jose tall wheatgrass (20 kg/ha), corn silage (22 kg/ha), and bermudagrass (41 kg/ha). Soil characteristics including electrical conductivity and sodium were generally higher after application of effluent for both soil types, although the changes were more pronounced in the AFSL than the PCL.

Keywords. Manure, Effluent, Runoff, Feedlot, Feedyard, Crops, Land application.

The Texas High Plains is a semiarid environment with annual precipitation of 46 cm (18 in.) and potential annual evaporation of 190 cm (75 in.). The Texas High Plains has one of the highest concentrations of cattle in feedlots in the United States. There are 104 feedlots of capacity greater than 5,000 head, feeding about 6.8 million cattle annually in the region (SPS, 1999). These feedlots produce 16 million metric tons (36 billion lbs) of wet manure annually (Parker et al., 1997).

Beef cattle feedlots in the Texas High Plains are constructed as open lots with earthen pen surfaces. Precipitation falling on the pen surfaces comes into direct contact with manure and is either absorbed or runs off. State regulations require feedlots to have retention facilities to control the runoff (effluent). Ponds must be sized according to a water balance that takes into account the effluent volume, process-generated wastewater, evaporation, and irrigation. In addition, all ponds must have adequate capacity to contain effluent from the 25-yr, 24-h rainfall event (TNRCC, 1999).

Feedlot effluent is produced at the rate of about 10.4 cm/yr (4.1 in./yr) from the pen areas (Sweeten, 1996). From the estimated 4,900 to 7,300 ha (12,000 to 18,000 acres) of feed pens and associated drainage areas, about 4.9 to 7.4 million m³ (4,000–6,000 acre-ft) of feedlot effluent are produced per year in the region. Evaporation is a primary method for controlling effluent levels in storage ponds. However, during high precipitation periods, there is a need to drain storage ponds as soon as practical to maintain retention capacity. The most common method of draining is to apply the effluent to adjacent cropland and pastureland.

The effluent offers an alternative water and nutrient source, but contains elevated salt and nutrient concentrations (Tchobanoglous and Burton, 1991; Sweeten, 1994; Smith et al., 1993). When applied at excessive rates, effluent can have negative effects on soils and crops. Excessive soil nitrates and salts can lead to leaching of nutrients into groundwater (Linsley et al., 1992). Excessive soil nutrients can reduce crop yields and produce elevated crop nutrient concentrations, leading to health problems for grazing animals (National Science Foundation, 1996). In addition, high sodium concentrations can cause dispersion of clay soils, resulting in surface sealing and reduced infiltration rates (Bohn et al., 1985).

Although many studies have been performed on land application of dairy, swine, and poultry manure and effluent, there has been limited research using beef cattle effluent. Beef cattle effluent has considerably different waste characteristics than effluent from dairies and swine operations. At beef cattle feedyards in the Texas panhandle, animals deposit manure directly on the open-lot earthen surface, and the manure is scraped and removed every 120 to

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365 days. Precipitation that falls on the feedyard surface is either absorbed by the manure pack or results in overland flow (effluent) that is eventually captured by the storage pond. Effluent characteristics can vary from feedyard to feedyard depending on precipitation, dilution, and manure characteristics (Lehman, 1972; Sweeten, 1994).

Wallingford et al. (1974) applied beef feedlot effluent to corn silage over four consecutive years on silty clay loam soil using furrow irrigation. Effluent application rates were 0, 7, 13, 22, and 37 cm/yr. The electrical conductivity (EC) of the effluent ranged from 1.0 to 12.8 mmhos/cm. Accumulation of nutrients and salts (NO₃-N, P, K, and Na) was observed in the top 30 cm of soil for all treatments, and NO₃-N and Na were detected to 100 cm depth at the highest application rate. Maximum yield and uptake of N and P were observed at the 13 cm/yr and 22 cm/yr application rates. In northeast Kansas, Olson et al. (1982) applied beef feedlot effluent to bromegrass at four application rates (2.5, 5.1, 7.6, and 10.2 cm/yr) for four years to determine the effectiveness of the grass in removing nitrogen. Yields and nitrogen uptake increased initially with increasing wastewater application rates, but decreased with time due to effects of excessive moisture. Olson found that removal of nitrogen by bromegrass is significant if crop yields are high, but concluded that bromegrass was not the best crop because yields were reduced by excessive moisture.

Farmers and feedlot operators in the Texas High Plains have asked for assistance in determining effluent application rates that maximize crop production, recover nutrients, minimize negative effects on the environment, and fulfill regulatory requirements. As a result, researchers from the Cooperative Research, Education, and Extension Triangle

(CREET) near Amarillo, Texas, have initiated several land application experiments to provide answers to the many land application questions posed by these producers. This research presents results of a greenhouse study designed to obtain preliminary information on the effects of land applying feedlot effluent to two soils and seven crops. The objectives of the study were: 1) to determine plant growth and nutrient uptake rates for each of the seven crops at various effluent application rates, and 2) to determine effects of land applying feedlot effluent on soil characteristics.

MATERIALS AND METHODS

Feedlot effluent was applied in a greenhouse study to seven crops and two widely different soil types (Miller, 1999). The crops were forage sorghum (*Sorghum bicolor*), wheat (*Triticum aestivum ssp. vulgare*), corn silage (*Zea mays ssp. indentata*), alfalfa (*Medicago sativa*), bromegrass (*Bromus catharticus*), bermudagrass (*Cynodon dactylon*), and Jose tall wheatgrass (*Agropyron elongatum*). The soils were Pullman clay loam (fine, mixed, superactive, thermic Torrertic Paleustolls) and Amarillo fine sandy loam (fine-loamy, mixed, thermic Aridic Paleustalfs). Both soils are common to the Texas panhandle. Chemical characteristics of the soils are shown in table 1. Effluent treatments were designed to meet 0%, 25%, 50%, 100%, and 200% of the annual crop nitrogen requirement, as recommended by Martin et al. (1976). This corresponded to about 0%, 20%, 40%, 80%, and 160% of the annual crop phosphorus requirement. Primary nutrient application rates for each treatment are summarized in table 2.

Table 1. Characteristics of soils, feedlot effluent, and supplemental irrigation water (groundwater).

Parameter	Amarillo Fine Sandy Loam	Pullman Clay Loam	Feedlot Effluent	Groundwater
NO ₃ -N (mg/kg or mg/L)	7	20.7	0.42	1.02
Total N (mg/kg or mg/L)	445.3	1524	260	NA
Total P (mg/kg or mg/L)	159.6	1008.3	35.8	NA
Plant-available P (mg/kg or mg/L)	11.3	113.6	NA	NA
K (mg/kg or mg/L)	200.6	986	647	4
Mg (mg/kg or mg/L)	259.6	364	67.9	34
Ca (mg/kg or mg/L)	1780	2136.3	51.5	52
Na (mg/kg or mg/L)	57.3	68	131	40
pH	7	5.5	7.69	7.6
S (mg/kg or mg/L)	24.6	55	NA	51
Electrical Cond. ^[a] (μS/cm)	108.2	250	5340	636

^[a] Soil electrical conductivity measured on solution of 1 part soil to 2 parts water by weight.
NA= not analyzed.

Table 2. Primary nutrient application rates (kg/ha).

	Treatment 1			Treatment 2			Treatment 3			Treatment 4			Treatment 5		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
Forage sorghum	0	0	0	70	10	81	140	19	163	280	38	325	560	76	650
Wheat	0	0	0	35	5	41	70	10	81	140	19	163	280	38	325
Corn silage	0	0	0	62	9	73	125	17	145	250	34	290	500	69	581
Alfalfa	0	0	0	89	12	103	178	24	206	355	49	412	710	98	825
Bromegrass	0	0	0	46	6	54	92	13	107	185	26	215	370	51	430
Bermudagrass	0	0	0	62	9	73	125	17	145	250	34	290	500	69	581
Jose tall wheatgrass	0	0	0	46	6	54	92	13	107	185	26	215	370	51	430

The crops were grown in 20.3 cm diameter pots filled with 6.4 kg of dry soil. Prior to filling, the soil was heated to 185° C to kill weed seeds. Each treatment was replicated three times, resulting in a total of 210 pots to accommodate the seven crops, two soils, and five effluent application rates.

Beef feedyard effluent was collected from a runoff storage pond at a large commercial beef cattle feedlot (table 1), and was applied from 4 to 12 times in equal time intervals over the growing season (table 3). Effluent was applied over equal time intervals to simulate real-life conditions in which the primary goal of land application is to remove effluent from the storage pond to provide storage for future runoff, and the secondary goal is to apply at rates that minimize potential for off-site transport of nutrients whether from surface runoff or from deep leaching. Applying effluent over the growing season attempts to accomplish both goals. Fresh effluent was collected before each application, and was applied within 24 hours of collection. Effluent was applied every 30 days for all crops. The first application occurred no earlier than three weeks after germination. In addition to effluent application, all pots were irrigated to meet crop water requirements every three to four days throughout the growing period using groundwater (table 1) from the West Texas A&M University Nance Ranch well. Irrigation water and effluent were applied slowly over a 30-minute period, so that no leaching occurred from any of the pots.

All seven crops were planted on 8 June 1998. Seed planting rates, sowing depths, and harvest dates are summarized in table 3. The forage sorghum and corn silage were harvested once at the end of the growing season, and all other crops were harvested several times throughout the growing season. Each crop was clipped at 7.6 cm (3 in) from the ground surface. Alfalfa was harvested at 10% bloom, and bromegrass was harvested at 25% bloom.

After each harvest, crop dry matter yield was determined by oven drying. The dried foliage was ground to pass a 2 mm sieve, and was analyzed for total phosphorus (Kjeldahl digest using ICP) and total nitrogen (Kjeldahl digest with a Technicon Auto Analyzer II). All analyses were performed by the Texas A&M University Soil, Water, and Forage Testing Laboratory in College Station, Texas.

The soil was analyzed before the experiment for total N (Kjeldahl digest with a Technicon Auto Analyzer II), total P (Kjeldahl digest using ICP), pH and electrical conductivity (1 part soil to 2 parts water by weight), and NO₃-N (Lachat Instruments QuickChem 8000). In addition, plant-available P, K, Ca, Mg, Na, and S were measured by ICP on ammonium acetate-ethylenediaminetetraacetic acid (NH₄OAc-EDTA) extracts per the "TAMU Method" (Hons et al., 1990). At the completion of the experiment, three soil cores (3.8 cm diameter and 15 cm length) were collected from each pot and composited. Each composite soil sample was analyzed for the same parameters as before the experiment.

Statistical analyses consisted of analysis of variance (ANOVA) and least significant difference (LSD) comparisons among treatments. All statistical analyses were performed using SPSS Version 5.0 .

RESULTS AND DISCUSSION

DRY MATTER YIELDS

In the Pullman clay loam (table 4), there were no significant differences among the treatments for forage sorghum, wheat, corn silage, alfalfa, or bromegrass . Bermudagrass showed a significantly higher yield between the fourth and fifth treatment but no differences among the

Table 3. Planting, harvesting, and effluent application information for each crop.

Crop	Planting Date	Seed Planting Rate (per pot)	Sowing Depth (cm)	Harvested on Day(s)	100% of Annual Crop Nitrogen Requirement (kg/ha)	Total Effluent Applied at 100% of Annual Crop Nitrogen Requirement (cm)	Number of Effluent Applications per Growing Season ^[a]
Forage sorghum (<i>Sorghum bicolor</i>)	6/98	6 seeds	3	128	280	10.8	4
Wheat (<i>Triticum aestivum</i> ssp. <i>vulgare</i>)	6/98	7 seeds	5	49, 70, 98, 126, 154	140	5.4	5
Corn silage (<i>Zea mays indentata</i>)	6/98	2 seeds	5	128	250	9.7	4
Alfalfa (<i>Medicago sativa</i>)	6/98	0.10 g	1	63, 92, 147, 202, 371	355	13.6	12
Bromegrass (<i>Bromus catharticus</i>)	6/98	10 seeds	1	49, 63, 106, 146, 201, 371	185	7.2	12
Bermudagrass (<i>Cynodon dactylon</i>)	6/98	0.04 g	1.2	49, 70, 98, 126, 154, 182, 210, 237, 264, 292, 348, 377	250	9.7	12
Jose tall wheat-grass (<i>Agropyron elongatum</i>)	6/98	13 seeds	0.5	63, 90, 118, 146, 174, 202, 377	185	7.2	12

^[a] Effluent was applied every 28 to 30 days.

first four treatments. The Jose tall wheatgrass showed significant increases in dry matter yield across all treatments.

In the Amarillo fine sandy loam (table 5), forage sorghum, wheat, corn silage, bromegrass, bermudagrass, and Jose tall wheatgrass had significantly higher yields at the higher effluent application rates. Only alfalfa did not show a significant increase in dry matter yield, probably because alfalfa is a legume and was able to fix its own nitrogen at the lower effluent application rates. Effluent application had a greater effect on changes in dry matter yield in the Amarillo fine sandy loam than in the Pullman clay loam. Dry matter yields were higher in the Pullman clay loam than in the Amarillo fine sandy loam for all crops because the Pullman clay loam is a more fertile soil than the Amarillo fine sandy loam.

NUTRIENT UPTAKE IN FOLIAGE

Nitrogen uptake generally increased with increasing effluent application rate in both soil types. However, responses were less prevalent in the Pullman clay loam, as wheat, alfalfa and bromegrass showed no significant differences in nitrogen uptake across the various effluent application rates. The ratio of nitrogen uptake rate with effluent application to that with no effluent application (percent difference) was higher in the Amarillo fine sandy loam than in the Pullman clay loam (tables 6 and 7). Nitrogen uptake in the Pullman clay loam was in many cases more than two times that in the Amarillo fine sandy loam across all treatments. There were no significant differences in nitrogen uptake across treatments for alfalfa in either soil type, again probably because alfalfa fixes nitrogen.

Table 4. Dry matter yields (kg/ha) for crops grown in Pullman clay loam.

	Trt 1 0% N	Trt 2 25%N	Trt 3 50% N	Trt 4 100% N	Trt 5 200% N
Forage sorghum	20,300 a	20,900 a	21,200 a	22,100 a	20,500 a
Wheat	3,300 a	3,300 a	3,700 a	3,100 a	3,500 a
Corn silage	20,300 a	24,300 a	22,400 a	22,400 a	23,800 a
Alfalfa	10,800 a	10,100 a	8,600 a	12,000 a	11,800 a
Bromegrass	13,800 a	12,000 a	12,000 a	14,100 a	14,800 a
Bermudagrass	20,700 a	20,800 a	20,300 a	23,100 a	33,000 b
Jose tall wheatgrass	7,500 a	8,100 ab	8,100 ab	9,700 b	12,000 c

^[a] Using LSD comparisons, means with different letters in a row are significantly different at $\alpha = 0.05$.

Table 5. Dry matter yields (kg/ha) for crops grown in Amarillo fine sandy loam.

	Trt 1 0% N	Trt 2 25%N	Trt 3 50% N	Trt 4 100% N	Trt 5 200% N
Forage sorghum	12,100 a	13,900 a	14,400 a	14,200 a	19,000 b
Wheat	800 a	1,100 ab	1,200 ab	1,600 bc	2,200 c
Corn silage	8,300 a	9,300 a	10,700 a	9,300 a	14,600 b
Alfalfa	6,900 a	6,400 a	6,600 a	6,300 a	7,600 a
Bromegrass	3,000 a	3,700 a	4,000 a	6,000 b	6,100 b
Bermudagrass	7,600 a	8,100 a	10,600 b	14,200 c	17,900 d
Jose tall wheatgrass	1,600 a	2,300 ab	2,600 b	3,600 c	5,800 d

Table 6. Total nitrogen uptake in foliage (kg/ha) for crops grown in Pullman clay loam.

	Trt 1 0% N	Trt 2 25%N	Trt 3 50% N	Trt 4 100% N	Trt 5 200% N
Forage sorghum	117 a	135 a	120 a	148 a	234 b
Wheat	100 a	102 a	110 a	104 a	117 a
Corn silage	109 a	133 ab	154 bc	147 ac	251 d
Alfalfa	456 a	423 a	345 a	513 a	497 a
Bromegrass	220 ab	233 ab	204 a	248 ab	289 b
Bermudagrass	310 a	299 a	359 a	360 a	519 b
Jose tall wheatgrass	132 a	149 ab	161 b	194 c	243 d

^[a] Using LSD comparisons, means with different letters in a row are significantly different at $\alpha = 0.05$.

Table 7. Total nitrogen uptake in foliage (kg/ha) for crops grown in Amarillo fine sandy loam.

	Trt 1 0% N	Trt 2 25%N	Trt 3 50% N	Trt 4 100% N	Trt 5 200% N
Forage sorghum	26 a	35 ab	44 bc	57 c	123 d
Wheat	18 a	23 a	26 ab	37 b	63 c
Corn silage	30 a	30 a	39 a	44 a	114 b
Alfalfa	274 a	252 a	275 a	276 a	320 a
Bromegrass	52 a	54 a	62 a	92 b	90 b
Bermudagrass	68 a	73 a	95 a	143 b	233 c
Jose tall wheatgrass	25 a	33 a	39 ab	55 b	97 c

^[a] Using LSD comparisons, means with different letters in a row are significantly different at $\alpha = 0.05$.

In the Pullman clay loam, increasing effluent application did not affect phosphorus uptake significantly in forage sorghum, wheat, corn silage, alfalfa, or bromegrass (table 8), while bermudagrass and Jose tall wheatgrass exhibited significant increases in phosphorus uptake rates. Phosphorus uptake rates were up to three times higher in the Pullman clay loam than in the Amarillo fine sandy loam, probably because plant-available phosphorus concentrations were ten times higher in the Pullman clay loam at the beginning of the experiment than in the Amarillo fine sandy loam. Phosphorus uptake rates in the Amarillo fine sandy loam increased with increasing effluent application in corn silage, bromegrass, bermudagrass, and Jose tall wheatgrass, with minimal differences in forage sorghum, wheat, or alfalfa (table 9).

Because crops grown with feedlot effluent will eventually be used as animal feed, the crude protein concentration of the

Table 8. Total phosphorus uptake in foliage (kg/ha) for crops grown in Pullman clay loam.

	Trt 1 0% N	Trt 2 25%N	Trt 3 50% N	Trt 4 100% N	Trt 5 200% N
Forage sorghum	33 a	32 a	34 a	36 a	48 a
Wheat	15 a	16 a	18 a	14 a	16 a
Corn silage	53 ab	60 ab	47 a	66 b	57 ab
Alfalfa	33 a	32 a	27 a	39 a	37 a
Bromegrass	35 a	33 a	34 a	39 a	42 a
Bermudagrass	57 a	67 ab	70 ab	82 b	114 c
Jose tall wheatgrass	24 a	29 ab	32 b	33 b	42 c

^[a] Using LSD comparisons, means with different letters in a row are significantly different at $\alpha = 0.05$.

Table 9. Total phosphorus uptake in foliage (kg/ha) for crops grown in Amarillo fine sandy loam.

	Trt 1 0% N	Trt 2 25%N	Trt 3 50% N	Trt 4 100% N	Trt 5 200% N
Forage sorghum	10 a	10 a	10 a	14 a	17 a
Wheat	3 a	4 a	3 a	5 a	10 a
Corn silage	16 b	12 a	14 ab	14 ab	22 c
Alfalfa	12 a	11 a	13 a	14 a	18 a
Bromegrass	8 a	8 a	8 a	11 b	11 b
Bermudagrass	19 ab	17 a	22 b	30 c	41 d
Jose tall wheatgrass	5 a	6 a	9 b	11 c	17 d

^[a] Using LSD comparisons, means with different letters in a row are significantly different at $\alpha = 0.05$.

crops is important. Crude protein concentrations were calculated as a direct percentage of the total nitrogen concentration in the forage (Hutcheson and Hutcheson, 1996), and are compared against typical crude protein percentages for crops grown under adequate nutrient concentrations in table 10. In the Pullman clay loam, all crops except corn silage and wheat had foliage crude protein concentrations equal to or greater than published values.

For the Amarillo fine sandy loam, forage sorghum, wheat, and corn silage had foliage crude protein concentrations less than typical. This suggests that the nutrient concentrations in the effluent were not provided when the crop needed them, or nutrient availability in the effluent was not as high as assumed. While these crude protein values are lower than typical, they are still high enough to be considered quality feed, as most cattle forages have excessive protein concentrations and the extra is passed through the animal and excreted (National Science Foundation, 1996).

Table 10. Crude protein percentages for the highest effluent application rate (TRT 5) compared to typical crude protein percentages for crops grown under adequate nutrient concentrations.

	Amarillo Fine Sandy Loam	Pullman Clay Loam	Typical ^[a]
Forage sorghum	4.1	7.1	7 – 11
Wheat	13.1	21.3	27
Corn silage	4.9	6.6	8.6 – 9.2
Alfalfa	26.2	26.5	18.9 – 20.1
Bromegrass	10.8	12.3	9.3
Bermudagrass	8.2	9.8	7.2 – 12.6
Jose tall wheatgrass	10.5	12.8	8.4

^[a] Undersander, 1992; Amos et al., 1996; National Science Foundation, 1996.

Table 11. Soil chemical characteristics initially and at the completion of the experiment for the highest effluent application rate (TRT 5) in Pullman clay loam.

	EC ($\mu\text{S}/\text{cm}$)	TKN (mg/kg)	$\text{NO}_3\text{-N}$ (mg/kg)	Total P (mg/kg)	Plant-available P (mg/kg)	Na (mg/kg)	Ca (mg/kg)	Mg (mg/kg)
Initial soil	250	1524	21	1008	114	68	2136	364
Forage sorghum	217	1410	5.3	964	124	345	2000	389
Wheat	250	1518	33	991	122	375	2024	406
Corn silage	195	1467	12.3	1058	168	402	2242	512
Alfalfa	1092	1525	76	866	235	1998	2172	494
Bromegrass	1192	1435	19	835	191	2197	2012	392
Bermudagrass	760	1376	1.3	948	201	1904	2136	451
Jose tall wheatgrass	870	1574	1	946	175	1662	1931	398

SOIL CHARACTERISTICS

Soil salinity is a universal threat in arid areas where irrigation waters contain a significant amount of dissolved salts (Hoffman et al., 1983). Electrical conductivity is generally a reliable index of salt concentration. In the Pullman clay loam, there was little change in soil electrical conductivity for forage sorghum, wheat, and corn silage. However, alfalfa, bromegrass, bermudagrass, and Jose tall wheatgrass had EC values 3 to 4 times that of the initial soil (table 11). The cause of the higher EC values in these soils could be because these crops had longer growing seasons and received more supplemental irrigation water. The supplemental irrigation water had a much lower EC than the effluent (table 1); however, because no leaching occurred, it still probably contributed to increasing the EC of the soil. Soil nitrate concentrations in the PCL were highest for the alfalfa, at 76 mg/kg compared to 21 mg/kg initially. Soil sodium concentrations were higher in all crops than in the initial soil, with minimal differences in calcium and magnesium (table 11).

In the Amarillo fine sandy loam, soil EC values were noticeably higher post-harvest in the alfalfa, bromegrass, bermudagrass, and Jose tall wheatgrass. Alfalfa had the highest EC and sodium concentration. Soil sodium concentrations were higher in all crops than in the initial soil. Alfalfa exhibited considerably higher soil sodium, calcium, and magnesium than all other crops (table 12). Though the cause of this increase is unknown, it does suggest that alfalfa may not be a good long-term choice for effluent application if salts are of concern.

NUTRIENT MASS BALANCE

Nutrient mass balances for nitrogen and phosphorus are presented in tables 13–16. The balances were calculated knowing the initial and final soil nutrient concentrations, the nutrients removed by the plants, and nutrients added with effluent application. Positive balances indicate an unaccounted loss of nutrients due to volatilization, leaching, or laboratory/sampling errors. Negative balances indicate an unaccounted gain of nutrients due to nitrogen fixation or laboratory/sampling errors. A change in the soil nutrient concentration of 50 mg/kg equates to a change of about 100 kg/ha in the nutrient balance, while at a dry matter yield of 10,000 kg/ha, a change in nutrient content of 1% corresponds to a change of 100 kg/ha in the nutrient balance.

Table 12. Soil chemical characteristics initially and at the completion of the experiment for the highest effluent application rate (TRT 5) in Amarillo fine sandy loam.

	EC ($\mu\text{S}/\text{cm}$)	TKN (mg/kg)	$\text{NO}_3\text{-N}$ (mg/kg)	Total P (mg/kg)	Plant-available P (mg/kg)	Na (mg/kg)	Ca (mg/kg)	Mg (mg/kg)
Initial soil	108	445	7.0	160	11	57	1780	260
Forage sorghum	250	423	11.7	179	17	392	1758	345
Wheat	183	429	7.7	170	10	361	1636	303
Corn silage	333	423	8.0	169	13	398	1811	338
Alfalfa	1069	475	69	152	30	3074	2844	571
Bromegrass	678	474	4.7	153	13	1724	1502	259
Bermudagrass	388	459	1.0	135	11	1486	1737	304
Jose tall wheatgrass	690	413	1.7	156	12	1378	1388	250

Table 13. Nitrogen balance (kg/ha) for crops grown in Pullman clay loam.^[a]

	Trt 1 0% N	Trt 2 25%N	Trt 3 50% N	Trt 4 100% N	Trt 5 200% N
Forage sorghum	-17	-39	158	293	550
Wheat	-37	-93	-14	73	175
Corn silage	265	317	207	327	361
Alfalfa	-204	-188	111	-136	211
Bromegrass	-287	-333	-350	-4	256
Bermudagrass	296	377	406	408	272
Jose tall wheatgrass	-130	-274	-104	-25	29

[a] Positive balance indicates unaccounted loss of nutrient (volatilization, leaching, or laboratory variation). Negative balance indicates unaccounted gain of nutrient (nitrogen fixation or laboratory variation).

Table 14. Nitrogen balance (kg/ha) for crops grown in Amarillo Fine Sandy Loam.^[a]

	Trt 1 0% N	Trt 2 25% N	Trt 3 50% N	Trt 4 100% N	Trt 5 200% N
Forage sorghum	-46	67	139	255	480
Wheat	51	81	101	198	249
Corn silage	-12	64	143	249	429
Alfalfa	-510	-346	-237	-104	331
Bromegrass	45	69	97	64	223
Bermudagrass	-13	34	75	97	240
Jose tall wheatgrass	-45	53	191	242	336

[a] Positive balance indicates unaccounted loss of nutrient (volatilization, leaching, or laboratory variation). Negative balance indicates unaccounted gain of nutrient (nitrogen fixation or laboratory variation).

Table 15. Phosphorus balance (kg/ha) for crops grown in Pullman clay loam.^[a]

	Trt 1 0% N	Trt 2 25%N	Trt 3 50% N	Trt 4 100% N	Trt 5 200% N
Forage sorghum	89	-14	93	63	115
Wheat	229	131	87	139	55
Corn silage	162	67	7	9	-86
Alfalfa	437	366	345	339	340
Bromegrass	56	32	38	211	349
Bermudagrass	211	235	268	153	73
Jose tall wheatgrass	70	77	36	72	131

[a] Positive balance indicates unaccounted loss of nutrient (volatilization, leaching, or laboratory variation). Negative balance indicates unaccounted gain of nutrient (nitrogen fixation or laboratory variation).

Table 16. Phosphorus balance (kg/ha) for crops grown in Amarillo Fine Sandy Loam.^[a]

	Trt 1 0% N	Trt 2 25%N	Trt 3 50% N	Trt 4 100% N	Trt 5 200% N
Forage sorghum	-35	8	15	2	22
Wheat	-34	-13	-7	14	8
Corn silage	-63	-11	-24	-4	29
Alfalfa	45	70	60	35	96
Bromegrass	39	59	54	51	54
Bermudagrass	5	29	7	34	77
Jose tall wheatgrass	21	28	47	49	42

[a] Positive balance indicates unaccounted loss of nutrient (volatilization, leaching, or laboratory variation). Negative balance indicates unaccounted gain of nutrient (nitrogen fixation or laboratory variation).

There was a general trend of increasing nitrogen loss with increasing application rate in both the Pullman clay loam and the Amarillo fine sandy loam (tables 13 and 14). In the Amarillo fine sandy loam, only 8 of the 35 nutrient mass balances were negative, indicating gain of nitrogen (table 14), and four of these were for alfalfa, which can be explained by nitrogen fixation. The other four ranged from -12 to -46 kg/ha, which are relatively small numbers and could be due to laboratory and sampling variation.

CONCLUSIONS

Effluent application produced no detrimental effect on crop yields, and in some cases increased yields. Alfalfa and bermudagrass had the highest nutrient uptake rates in both soil types, and therefore would be best suited where there is a limited land base. Increases in soil salinity were smallest for forage sorghum, wheat, and corn, but this condition was probably the result of shorter growing seasons rather than direct influences of the crops. The N and P uptake rates measured during this research should provide useful information for use in nutrient management plans in the Texas panhandle. Additional field studies are needed to determine long-term effects of land application of beef cattle feedlot effluent.

REFERENCES

- Amos, H. E., M. B. Smith, and M. A. Froetschel. 1996. Protein and amino acid losses during ensiling: Influence of forage type, maturity and preservation. In *1996 Annual Report*, 127–136. University of Georgia Animal and Dairy Science.
- Bohn, H. L., B. L. McNeal, and G. A. O'Conner. 1985. *Soil Chemistry*, 2nd ed. New York, N.Y.: John Wiley and Sons.
- Hoffman, G. J., R. S. Ayers, E. J. Doering, and B. L. McNeal. 1983. Salinity in irrigated agriculture. In *Design and Operation of Farm Irrigation Systems*, 145–185. M. E. Jensen, ed. St. Joseph, Mich.: ASAE.
- Hons, F. M., L. A. Larson–Vollmer, and M.A. Locke. 1990. NH_4OAc –EDTA extractable phosphorus as a soil test procedure. *Soil Sci.* 149(5): 249–256.
- Hutcheson, D. P., and J. P. Hutcheson. 1996. Feeds and feeding. In *Cattle Feeding: A Guide to Management*, 113–128. R. C. Albin and G. B. Thompson, eds. Amarillo, Tex.: Trafton Printing, Inc.
- Lehman, O. R. 1972. Playa water quality for groundwater recharge and use of playas for impoundment of feedyard runoff. In *Proceedings of the Playa Basin Symposium*, 25–30. L. V. Urban and A. W. Wyatt, eds. Lubbock, Texas: Texas Tech University.
- Linsley, R. K., J. B. Franzin, D. L. Freyberg, and G. Tohobanoglous. 1992. *Water Resources Engineering*. New York, N.Y.: McGraw Hill.
- Martin, J. H., W. H. Leonard, and D. L. Stamp. 1976. *Principles of Field Crop Production*. New York, N.Y.: Macmillan Publishing Co.
- Miller, B. L. 1999. A greenhouse study of land application of cattle feedlot effluent. M.S. thesis, Division of Agriculture, December 1999. Canyon, Texas: West Texas A&M University.
- National Science Foundation. 1996. *Nutrient Requirements of Beef Cattle*. Washington, D.C.: National Academy Press.
- Olson, R. V., R. V. Terry, W. L. Powers, and C. W. Swallow. 1982. Disposal of feedlot lagoon water by irrigating brome grass: I. Crop removal of nitrogen. *J. Environ. Qual.* 11(2): 267–272.
- Parker, D. B., B. W. Auvermann, B. A. Stewart, and C. A. Robinson. 1997. Agricultural energy consumption, biomass generation, and livestock manure value in the Southern High Plains. In *Proceedings of Workshop #1, Livestock Waste Streams: Energy and Environment*, 1–18. Austin, Tex.: Texas Renewable Energy Industries Association.
- Smith, S. J., B.A. Stewart, A. N. Sharpley, J. W. Naney, T. McDonald, M. G. Hickey, and J. M. Sweeten. 1993. Nitrate and other nutrients associated with playa storage of feedlot wastes. Bulletin B–5081. College Station, Tex.: Texas Agricultural Extension Service.
- SPS. 1999. *Cattle–Feeding Capital of the World: 1999 Fed Cattle Survey*. Amarillo, Texas: Southwestern Public Service Co.
- Sweeten, J. M. 1994. Water quality associated with playa basins receiving feedlot runoff. In *Proceedings of the Playa Basin Symposium*, 161–174. L. V. Urban and A. W. Wyatt, eds. Lubbock, Tex.: Texas Tech University.
- _____. 1996. Cattle feedlot manure and wastewater management practices for water and air pollution control. In *Cattle Feeding: A Guide to Management*, 62–84. R. C. Albin and G. B. Thompson, eds. Amarillo, Texas: Trafton Printing, Inc.
- TNRCC. 1999. Control of Certain Activities by Rule, Subchapter B, Concentrated Animal Feeding Operations, Pollution Prevention Plans. Texas Administrative Code, Title 30, Section 321.39. Austin, Tex.: Texas Natural Resource Conservation Commission.
- Tchobanoglous, G., and F. L. Burton. 1991. *Wastewater Engineering: Treatment, Disposal, and Reuse*. New York, N.Y.: McGraw–Hill.
- Undersander, D. 1992. *Alternate Forage Crops*. Forage Research and Extension Article No. FC–17.1. Madison, Wis.: University of Wisconsin.

