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Economic Impacts of Precision Farming in Irrigated Cotton Production

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ABSTRACT

Spatial optimal nitrogen fertilizer application levels and net revenues in irrigated cotton production were derived. Results indicate that precision farming can improve the profitability, and potentially reduce the environmental damages associated with nitrogen fertilizer use in irrigated cotton production.

KEY WORDS: precision farming, agricultural profitability, environmental impact

Increased use of fertilizers, pesticides, and other chemicals has contributed to the enhancement of agricultural productivity in recent decades. Currently, production agriculture is facing challenges, such as increasing costs of production, shortage of irrigation water, and increased public concern on the impacts of agricultural production on the environment. To survive in the highly competitive world market of agricultural commodities, agricultural producers must produce high quality products at low prices, while employing environmentally friendly practices. One way to accomplish these objectives is to adopt precision farming technology.

Traditionally, optimal fertilizer use in agriculture has assumed spatial and temporal field homogeneity with respect to soil fertility, soil moisture, pest populations, and crop characteristics. That is, decision rules for optimal fertilizer use do not account for field heterogeneity. Precision farming, precision agriculture, or site-specific management recognizes the variability of such factors within fields and seeks to optimize variable input use under these conditions. Robert et al. (1995) states that precision farming for site-specific management is an advanced information technology based agricultural management system designed to identify, analyze, and manage site-soil spatial and temporal variability within fields for optimum profitability, sustainability, and protection of the environment. The development of precision farming practices is closely related to several new technologies that have been utilized in agricultural production in recent years. These new technologies involve the use of microcomputers, microprocessor based control systems, satellite positioning technologies, and different kinds of sensors. With the support of these technologies, spatial soil testing, variable rate application of fertilizers, variable rate spraying, and yield mapping are becoming available.

The primary objective of this study was to evaluate the economic implications of precision farming practices with respect to nitrogen fertilizer use in irrigated cotton production in the Southern High Plains of Texas (SHPT), as compared to conventional whole-field farming practices. In particular, a dynamic optimization model that introduces an inter-temporal nitrate-nitrogen carry-over function is used to derive and evaluate optimal nitrogen application rates, yield, and the net present value of returns for a 10-year planning horizon.

The SHPT is a semi-arid region located in the northwestern portion of Texas. It encompasses approximately 22 million acres in 42 counties. Cotton is the most important crop produced in the areas in terms of both acreage and crop value. Annual cotton plantings vary between 2.6 and 3.3 million acres in a 25-county region within the SHPT, with approximately 50 percent of these acres being irrigated (Yu et al. 1999). The soil types in the SHPT include: hard lands, composed of fine-textured clays and clay loams, which represent 54% of the area; mixed lands, composed of medium-textured loams and loamy sands, which represent 23% of the area; and sandy lands, composed of coarse-textured sand, which also represents 23% of the area.

MATERIALS AND METHODS

Contemporary studies have shown that both nitrogen and phosphorous fertilizer application and residual fertility have positive impacts on cotton yields (Segarra et al. 1989, Carter et al. 1974, Onken and Sunderman 1972, Yu et al. 2000). Westerman and Kurtz (1972) discussed nitrogen residual in the soil in relation to soil types. They found that total nitrogen (nitrogen application plus nitrogen residual) is higher in heavy soils as compared to sandy soils. They also found that two-thirds of the nitrogen residual is in the top 10 centimeters of the soil.

The research discussed in this manuscript combines new technologies to address the impacts of nitrogen fertilizer application and nitrogen residual on irrigated cotton production under different levels of initial soil fertility, and soil and location characteristics in the long run. A dynamic optimization model is developed to evaluate the relationship between the optimal decision rules for nitrogen application and nitrogen residual, and other soil and location properties. In this model cotton yield is a function of total nitrogen available. Total nitrogen available is equal to applied nitrogen plus nitrogen residual in the soil at a given time. Nitrogen residual at a given time is a function of previous nitrogen application and previous levels of nitrogen residual. Specifically, the structure of the optimization model used is:

$$\text{Max } Z = \sum_{t=0}^{n} \{[P_t \cdot Y_t(NT_t, W_t, X_1, X_2, \ldots, X_n) - CP_t \cdot NA_t - CW_t \cdot W_t]\cdot(1+r)^{-t}\} \quad (1)$$

Subject to:

$$NT_t = NA_t + NR_t, \quad (2)$$

$$NR_{t+1} = f_t[NA_t, NR_t], \quad (3)$$

$$NR_0 = NR(0), \quad (4)$$

and $NA_t, NR_t \geq 0$ for all t.

Where Z is the per-acre net present value of returns to risk, management, overhead, and all other cotton production inputs except for nitrogen and irrigation water in \$/acre; n is the length of the decision-maker's planning horizon in years; P_t is the price of cotton in year t (\$/lb.); Y_t is the cotton yield function in year t (lbs./acre); NT_t is the total nitrogen available to the crop in year t (lbs./acre); W_t is irrigation water applied in year t (inches);

X_1, X_2, …, X_n are other variables that influence the crop yield; CP_t is the price of nitrogen in year t ($/lb.); NA_t is nitrogen applied in year t (lbs./acre); CW_t is price of irrigation water in year t ($/acre inch); NR_t is nitrogen residual in year t (lbs./acre); and r is the discount rate.

Equation (1) is the objective function, or performance measure, of the optimization model. Equation (2) is an equality constraint that adds the applied nitrogen to the nitrogen residual at time t, and it used in equation (1) to calculate the cotton yield at time t. Equation (3) is the equation of motion that updates nitrogen residual. Equation (4) is the initial condition on the level of nitrogen residual at the beginning of the planning horizon.

The primary source of data for this study was from an experiment conducted at the Texas Agricultural Experiment Station in Lamesa, Texas, in 1998. The experiment originally included 104 field locations, but only 100 locations were considered in the analysis because of missing data. At each location, the nitrogen residual level in the soil at a depth of 0 to 90 centimeters was measured on June 3, 1998. Using MapInfo, a desktop mapping software that provides a mapping technique for calculating and displaying the trends of data that vary over geographic space (Vertical Mapper Manual), the pre-season nitrogen residual levels in the 100 locations are shown in Figure 1. The nitrogen residual levels in the top soil at a depth of 0 to 90 centimeters ranged from 0 to 283.14 pounds per acre at the beginning of the season.

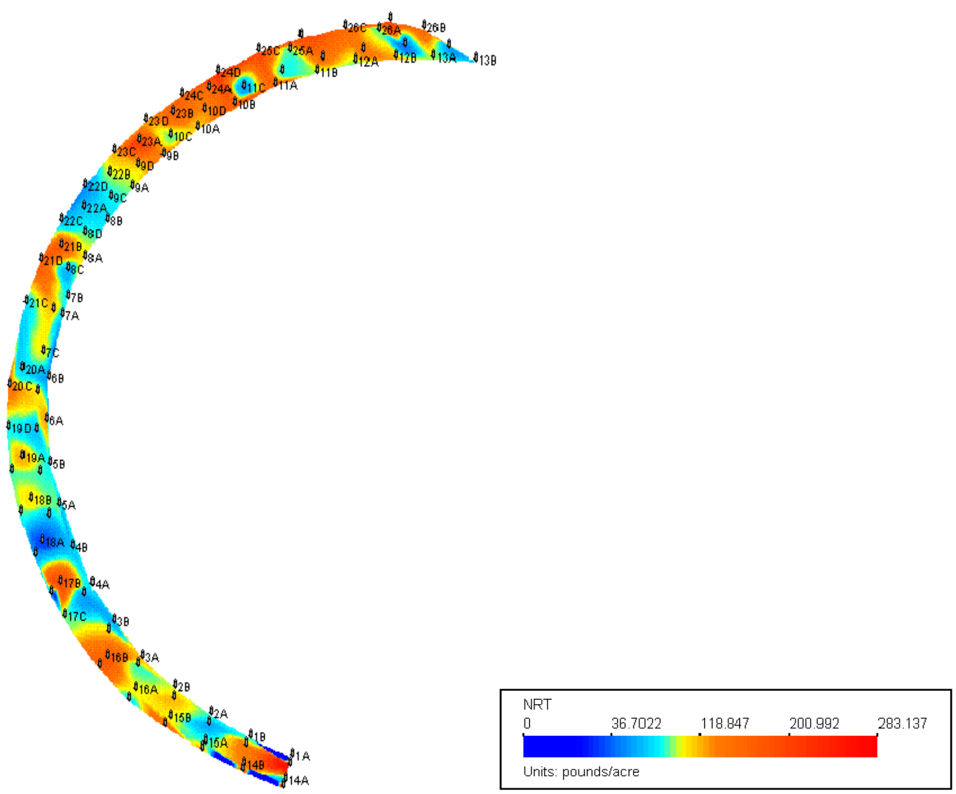

Figure 1. NO_3-N Pre-Season Residual Map from 0 to 90 Centimeters of Soil Depth, Lamesa, Texas, 1998.

The entire experimental field was treated equally, except for irrigation water, which was applied at two different levels of evapotranspiration (ET), 50% ET and 75% ET, and three different rates of nitrogen fertilizer (0, 80, and 120 pounds per acre). Other production inputs, such as pesticides, phosphorus fertilizer, and herbicides, were applied at the same rates across the experiment.

At the end of the growing season, a cotton stripper equipped with sensors and a Global Position System (GPS) was used to harvest the cotton. The yield data were downloaded into a computer and analyzed using MapInfo. Figure 2 shows the cotton lint yields in the 100 field locations, which ranged from 392.63 pounds per acre to 1086.67 pounds per acre. Notice that the inner portion of the field had relatively lower yields, as compared to the outer portion. This is likely explained by the lower water application level (50% ET) in this portion of the field.

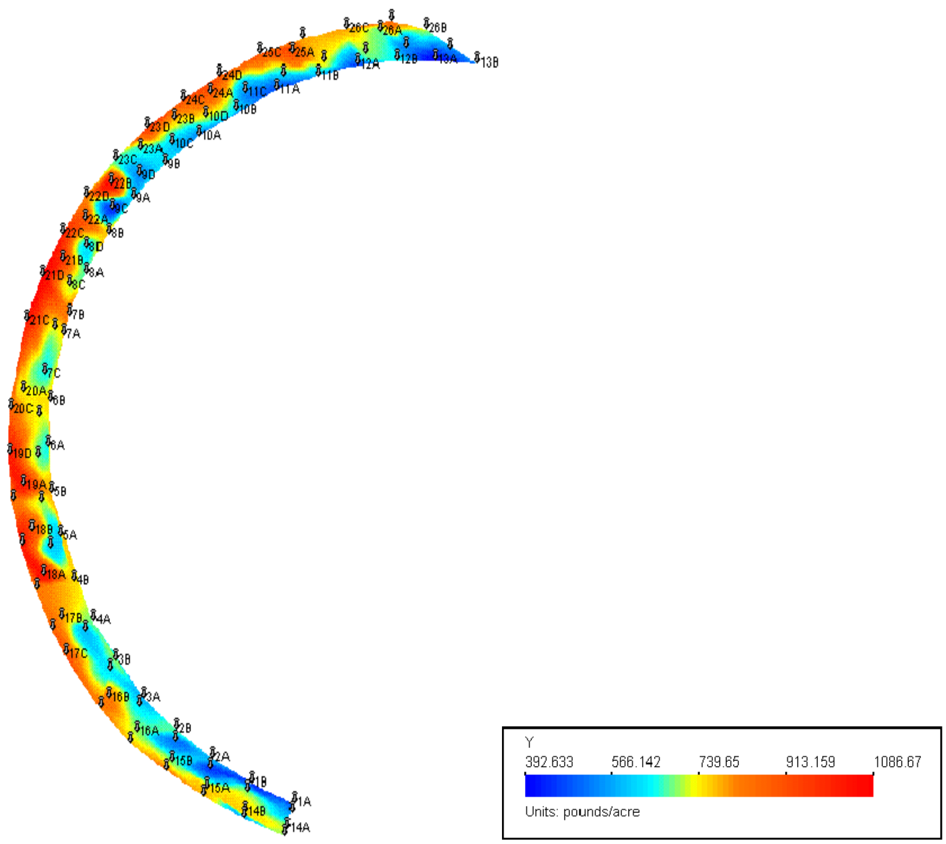

Figure 2. Spatial Cotton Yield Map, Lamesa, Texas, 1998.

The nitrogen residual level at a depth of 0 to 90 centimeters was measured again at each of the 100 locations on November 19, 1998, after the cotton was harvested. Post-harvest nitrogen residual levels ranged from 19.01 pounds per acre to 407.67 pounds per acre (Figure 3).

RESULTS

The cotton yield production function was estimated using GLM (General Linear Models) procedures (SAS 1982), assuming several functional forms including the double logarithmic, semi-logarithmic, Mistscherlich-Spillman, quadratic, and cubic. The quadratic functional form was found to best fit the data and provide economically sound results. The estimated cotton yield production function used in the analysis is:

$$Y = \underset{(3.06)}{257.40} + \underset{(9.66)}{5.05*10^{-1}}*NT*W*SD - \underset{(-8.33)}{7.03*10^{-5}}*NT*NT*ELEV*CL + \underset{(3.67)}{28.03}*PN \qquad (5)$$

$$R^2 = 0.5321$$

Where Y is cotton lint yield in lbs./acre; NT is total nitrogen available to the crop (lbs./acre), which equals the nitrogen applied (NA) during the cotton growing season plus the nitrogen residual (NR) in the soil at the beginning of the season; W is the water available to the crop at either 50% or 75% ET; SD and CL represent the sand and clay percentage in the soil; ELEV is the elevation of the location in feet and; PN is the number of plants per acre. The numbers in parenthesis below the parameter estimates in equation (5) are *t*-values, which indicate that the terms NT*W*SD, and NT^2 *ELEV*CL were significant at the 0.0001 level; the PN term is statistically significant at the 0.0005 level; and the intercept term is statistically significant at 0.005 level.

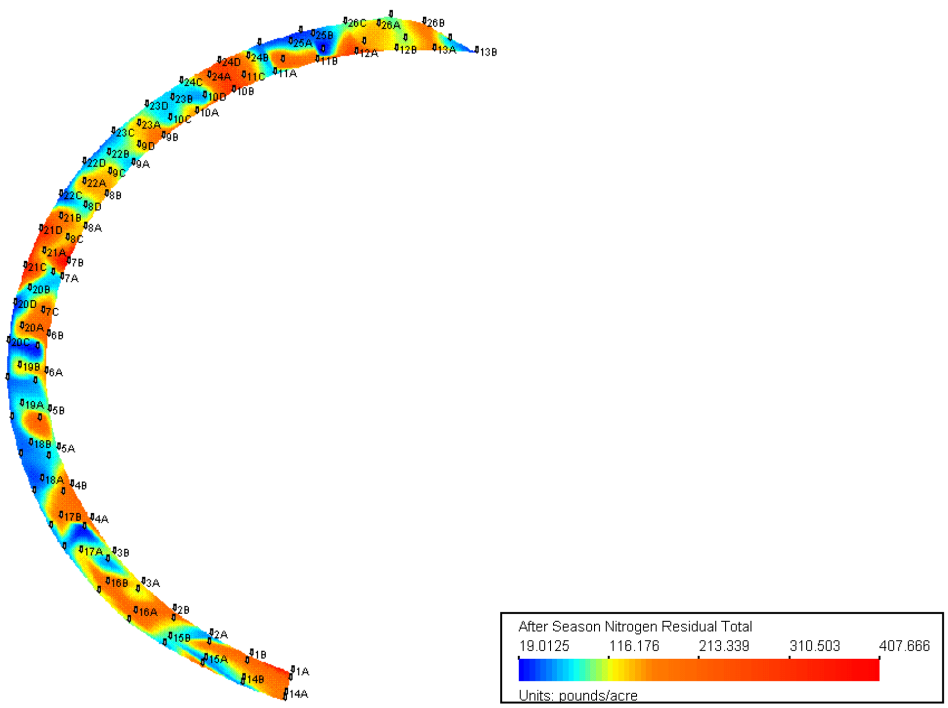

Figure 3. NO_3-N After-Season Residual Map from 0 to 90 Centimeters of Soil Depth, Lamesa, Texas, 1998.

The estimated production function suggests that there are significant interaction effects among nitrogen fertilizer, water, elevation, and soil properties (including the available clay and sand percentage in the soil) in explaining cotton yields. The R^2 value indicates that 53.21% of the variation in the observed cotton lint yields was explained by the independent variables included in the regression.

Based on the information of pre-season and post-season nitrogen residual (NR_t and NR_{t+1}) in the soil, and the nitrogen application level (NA_t) during the cotton growing season, the nitrogen carry-over function was estimated to be:

$$NR_{t+1} = \underset{(0.30)}{4.28} + \underset{(4.21)}{4.74*10^{-1}} NA_t + \underset{(3.01)}{4.17*10^{-1}} NR_t \qquad (6)$$
$$R^2 = 0.2932.$$

Where the variables NR and NA are defined as before and the *t*-values are reported in parenthesis. All the parameters in equation (6), except the intercept term are statistically significant at the 0.05 level. The R^2 value indicates that 29.32% of the variation in the observed post-season nitrogen residual can be explained by the nitrogen application level during the cotton growing season and pre-season nitrogen residual level.

The dynamic optimization model was solved under two scenarios. The first scenario represents the optimality conditions under the precision input application technology. This was done to mimic possible scenarios of fertility that could be faced under precision farming practices within fields. That is, under precision farming practices, optimal input decision rules according to spatial differences within fields would be desired. For this scenario, 100 optimization models were built for the 100 locations within the field with their associated pre-season nitrogen residual levels, and soil and location characteristics (elevation, and the available sand and clay percentage in the soil).

The second scenario represents the optimality conditions under conventional input application technology, i.e., whole-field farming. For this scenario, because water was applied at only two different levels (50% ET and 75% ET) in the experiment, water was introduced as a dummy variable in the mathematical model. In order to mimic possible scenarios of fertility that could be faced under whole-field farming practices, the 100 locations were separated into two groups (50 locations for each group), according to their water application levels. Average initial nitrogen residual level, and average soil and location characteristics were calculated for each group and used in the optimization model.

The optimization model given by equations (1) through (4) was solved for all combinations of the following conditions: (1) a ten-year planning horizon, (2) a 5% discount rate (r = 0.05), (3) a water price of $2.68/inch, (4) a cotton lint price of $0.60/lb., (5) a nitrogen fertilizer price of $0.30/lb., and (6) 100 locations with their corresponding initial nitrogen residual levels for precision farming practices, and the two ET groups described above with average initial nitrogen residual levels for whole-field farming practices.

As expected, the optimal decision rules for applying nitrogen fertilizer varied across periods in the planning horizon for a given nitrogen and cotton price combination at the different levels of nitrogen residual and soil and location characteristics. However, because a stable optimal decision rule is desirable to simplify management, an additional constraint of equating nitrogen applications across time periods within the planning horizon was introduced for each given nitrogen and cotton price combination and initial nitrogen soil fertility.

Solutions to the 102 optimization models (100 models for scenario one [precision farming practices], and 2 models for scenario two [whole-field farming practices]) were obtained using GAMS (General Algebraic Mathematical System), and are presented in Tables 1 and 2. These two tables list total optimal levels of nitrogen applications, total per-acre net present value of returns above nitrogen and water costs, and the tenth year after-season nitrogen residual level for each location for the ten-year planning horizon assumed for the evaluation of both precision farming practices and whole-field farming practices. Also, a comparison of the revenue and crop yield change associated with the two farming practices at each location is presented in Tables 1 and 2.

Table 1. A Comparison of Precision Farming and Whole-Field Farming Scenarios under 50% ET.

		Precision-Farming Practices					Whole-Field Farming Practices					Difference			
Number	PLOT	Total Revenue	Total Yield	Total NA	NR10	TFP	Total Revenue	Total Yield	Total NA	NR10	TFP	Revenue Change	Yield Change	TFP Change	NR10 Change
1	1A	3125.53	6945.56	454.24	44.24	15.29	3125.27	6951.78	466.98	45.27	14.89	0.0082%	-0.0896%	0.40	-1.03
2	1B	3223.90	7172.54	503.77	48.26	14.24	3221.77	7148.55	466.98	45.27	15.31	0.0661%	0.3356%	-1.07	2.99
3	2A	3105.08	6907.49	458.83	44.61	15.05	3104.97	6911.37	466.98	45.27	14.80	0.0035%	-0.0562%	0.25	-0.66
4	2B	3147.80	6997.32	466.19	45.21	15.01	3147.80	6997.74	466.98	45.27	14.99	0.0000%	-0.0060%	0.02	-0.06
5	2C	3147.51	7017.51	500.34	47.98	14.03	3145.73	6997.39	466.98	45.27	14.98	0.0566%	0.2876%	-0.96	2.71
6	2D	3185.77	7100.39	512.18	48.94	13.86	3182.55	7070.92	466.98	45.27	15.14	0.1009%	0.4167%	-1.28	3.67
7	3A	3012.92	6658.12	338.87	34.87	19.65	2982.34	6665.68	466.98	45.28	14.27	1.0252%	-0.1135%	5.37	-10.40
8	3B	3267.61	7315.79	604.17	56.41	12.11	3242.11	7193.93	466.98	45.27	15.41	0.7865%	1.6940%	-3.30	11.14
9	3C	3114.56	6926.71	459.27	44.64	15.08	3114.46	6930.43	466.98	45.27	14.84	0.0031%	-0.0537%	0.24	-0.63
10	3D	3276.02	7314.79	571.08	53.73	12.81	3260.18	7228.55	466.98	45.27	15.48	0.4858%	1.1930%	-2.67	8.45
11	4A	3083.21	6846.84	426.88	42.01	16.04	3080.31	6860.83	466.98	45.27	14.69	0.0940%	-0.2039%	1.35	-3.26
12	4B	3177.70	7084.91	514.83	49.16	13.76	3174.21	7053.44	466.98	45.27	15.10	0.1099%	0.4462%	-1.34	3.89
13	4C	3152.12	7016.56	482.51	46.53	14.54	3151.72	7007.94	466.98	45.27	15.01	0.0127%	0.1229%	-0.47	1.26
14	4D	3097.47	6870.22	418.71	41.35	16.41	3093.53	6887.80	466.98	45.27	14.75	0.1273%	-0.2554%	1.66	-3.92
15	5A	3292.24	7340.59	558.86	52.74	13.13	3279.89	7266.14	466.98	45.28	15.56	0.3765%	1.0245%	-2.42	7.46
16	5B	3297.82	7369.63	592.29	55.45	12.44	3276.09	7259.51	466.98	45.27	15.55	0.6633%	1.5168%	-3.10	10.18
17	5C	3275.45	7328.85	597.26	55.85	12.27	3251.45	7213.93	466.98	45.27	15.45	0.7382%	1.5931%	-3.18	10.58
18	5D	3448.97	7766.38	758.09	68.91	10.24	3352.63	7419.08	466.98	45.27	15.89	2.8737%	4.6812%	-5.64	23.64
19	6A	3700.20	8368.33	937.11	83.46	8.93	3499.16	7700.29	466.98	45.28	16.49	5.7453%	8.6755%	-7.56	38.18
20	6B	3278.67	7346.56	617.84	57.52	11.89	3247.89	7207.67	466.98	45.27	15.43	0.9479%	1.9269%	-3.54	12.25
21	6C	3068.12	6811.33	419.31	41.40	16.24	3064.13	6827.15	466.98	45.27	14.62	0.1300%	-0.2317%	1.62	-3.87
22	6D	3051.42	6759.77	387.04	38.78	17.47	3040.23	6779.07	466.98	45.27	14.52	0.3682%	-0.2847%	2.95	-6.49
23	7A	3290.97	7371.52	621.19	57.79	11.87	3259.90	7228.66	466.98	45.27	15.48	0.9531%	1.9763%	-3.61	12.52
24	7B	3090.20	6850.20	408.26	40.50	16.78	3083.95	6867.88	466.98	45.27	14.71	0.2028%	-0.2574%	2.07	-4.77
25	7C	3376.63	7559.69	650.43	60.17	11.62	3334.76	7375.03	466.98	45.28	15.79	1.2554%	2.5040%	-4.17	14.90
26	7D	3711.83	8428.23	998.08	88.40	8.44	3459.98	7635.12	466.98	45.27	16.35	7.2790%	10.3877%	-7.91	43.13
27	8A	3465.98	7806.40	773.26	70.15	10.10	3366.31	7440.38	466.98	45.27	15.93	2.9610%	4.9194%	-5.84	24.87
28	8B	3253.24	7262.43	559.54	52.79	12.98	3240.60	7188.98	466.98	45.27	15.39	0.3902%	1.0217%	-2.42	7.52
29	8C	3188.14	7104.86	511.36	48.87	13.89	3185.02	7076.00	466.98	45.27	15.15	0.0979%	0.4078%	-1.26	3.60
30	8D	3398.72	7640.85	715.68	65.47	10.68	3326.27	7363.83	466.98	45.27	15.77	2.1783%	3.7619%	-5.09	20.20
31	9A	3310.52	7403.86	609.65	56.86	12.14	3283.91	7273.70	466.98	45.27	15.58	0.8102%	1.7894%	-3.43	11.59
32	9B	3041.16	6726.68	360.73	36.65	18.65	3020.66	6742.74	466.98	45.28	14.44	0.6788%	-0.2382%	4.21	-8.63
33	9C	3170.96	7056.91	488.91	47.05	14.43	3170.19	7043.99	466.98	45.27	15.08	0.0240%	0.1834%	-0.65	1.78
34	9D	2993.00	6610.89	328.96	34.07	20.10	2955.14	6605.85	466.98	45.27	14.15	1.2809%	0.0764%	5.95	-11.21
35	10A	3078.81	6815.01	383.60	38.51	17.77	3066.17	6834.40	466.98	45.28	14.64	0.4121%	-0.2837%	3.13	-6.77
36	10B	3105.75	6881.70	406.81	40.39	16.92	3099.39	6901.22	466.98	45.28	14.78	0.2053%	-0.2830%	2.14	-4.89
37	10C	3061.11	6779.66	386.59	38.75	17.54	3049.76	6799.42	466.98	45.28	14.56	0.3723%	-0.2907%	2.98	-6.53
38	10D	2929.05	6458.29	285.08	30.50	22.65	2863.28	6420.67	466.98	45.27	13.75	2.2971%	0.5859%	8.90	-14.77
39	11A	2964.18	6537.95	295.95	31.39	22.09	2905.97	6513.51	466.98	45.28	13.95	2.0028%	0.3752%	8.14	-13.89
40	11B	3133.88	6962.79	454.35	44.25	15.32	3133.63	6968.98	466.98	45.27	14.92	0.0081%	-0.0889%	0.40	-1.03
41	11C	2846.37	6256.84	223.56	25.50	27.99	2708.39	6096.40	466.98	45.27	13.05	5.0948%	2.6316%	14.93	-19.77
42	11D	3115.09	6930.13	464.30	45.05	14.93	3115.08	6931.47	466.98	45.27	14.84	0.0004%	-0.0194%	0.08	-0.22
43	12A	3124.82	6950.67	464.45	45.07	14.97	3124.81	6951.93	466.98	45.27	14.89	0.0003%	-0.0181%	0.08	-0.21
44	12B	2962.14	6540.79	314.65	32.91	20.79	2918.46	6532.77	466.98	45.28	13.99	1.4967%	0.1227%	6.80	-12.37
45	12C	2932.02	6456.98	266.09	28.96	24.27	2844.85	6388.85	466.98	45.28	13.68	3.0641%	1.0664%	10.58	-16.31
46	12D	3009.41	6650.73	336.57	34.69	19.76	2978.43	6659.79	466.98	45.28	14.26	1.0402%	-0.1360%	5.50	-10.59
47	13A	3127.30	6948.52	452.17	44.07	15.37	3126.94	6955.47	466.98	45.27	14.89	0.0116%	-0.0999%	0.47	-1.20
48	13B	3059.53	6801.36	430.34	42.29	15.80	3057.17	6814.34	466.98	45.27	14.59	0.0774%	-0.1905%	1.21	-2.98
49	13C	3152.03	7013.57	478.26	46.19	14.66	3151.82	7007.42	466.98	45.27	15.01	0.0067%	0.0878%	-0.34	0.92
50	13D	3056.25	6787.15	418.30	41.32	16.23	3052.08	6802.74	466.98	45.27	14.57	0.1368%	-0.2291%	1.66	-3.95
Average		3169.58	7057.22	493.34	47.41	15.38	3138.43	6980.02	466.98	45.27	14.95	0.9812%	1.0476%	0.44	2.14

Table 2. A Comparison of Precision Farming and Whole-Field Farming Scenarios under 75% ET.

		Precision-Farming Practices					Whole-Field Farming Practices					Difference			
Number	PLOT	Total Revenue	Total Yield	Total NA	NR10	TFP	Total Revenue	Total Yield	Total NA	NR10	TFP	Revenue Change	Yield Change	TFP Change	NR10 Change
51	14A	3794.05	8640.43	791.22	71.60	10.92	3790.00	8656.34	841.69	75.70	10.28	0.1068%	-0.1837%	-10.28	-75.70
52	14B	4260.92	9732.97	1055.80	93.09	9.22	4203.61	9507.67	841.69	75.70	11.30	1.3632%	2.3697%	-11.30	-75.70
53	14D	3996.01	9099.31	880.60	78.86	10.33	3993.76	9075.47	841.69	75.70	10.78	0.0561%	0.2627%	-10.78	-75.70
54	15A	4007.47	9140.50	906.95	81.00	10.08	4001.18	9096.44	841.69	75.70	10.81	0.1574%	0.4844%	-10.81	-75.70
55	15B	3690.76	8362.82	669.68	61.74	12.49	3638.75	8345.95	841.69	75.71	9.92	1.4294%	0.2021%	-9.92	-75.71
56	15C	4007.39	9098.49	836.79	75.31	10.87	4007.35	9100.89	841.69	75.70	10.81	0.0010%	-0.0264%	-10.81	-75.70
57	15D	4006.72	9102.32	845.14	75.98	10.77	4006.70	9100.57	841.69	75.70	10.81	0.0005%	0.0193%	-10.81	-75.70
58	16B	3948.75	8943.12	769.33	69.83	11.62	3940.11	8964.39	841.69	75.71	10.65	0.2194%	-0.2373%	-10.65	-75.71
59	16C	3657.18	8314.84	700.74	64.25	11.87	3621.12	8305.81	841.69	75.70	9.87	0.9958%	0.1087%	-9.87	-75.70
60	16D	3833.80	8694.40	745.16	67.87	11.67	3818.46	8713.43	841.69	75.71	10.35	0.4018%	-0.2184%	-10.35	-75.71
61	17A	3549.86	8047.83	610.66	56.94	13.18	3437.88	7922.29	841.69	75.70	9.41	3.2572%	1.5847%	-9.41	-75.70
62	17B	3731.21	8465.23	706.55	64.73	11.98	3699.10	8466.36	841.69	75.70	10.06	0.8680%	-0.0133%	-10.06	-75.70
63	17C	3804.41	8662.61	785.64	71.15	11.03	3799.09	8677.52	841.69	75.70	10.31	0.1400%	-0.1718%	-10.31	-75.70
64	17D	4218.01	9647.62	1041.60	91.93	9.26	4163.81	9442.62	841.69	75.70	11.22	1.3018%	2.1711%	-11.22	-75.70
65	18A	3922.39	8974.16	915.87	81.72	9.80	3914.58	8923.63	841.69	75.70	10.60	0.1994%	0.5662%	-10.60	-75.70
66	18B	3979.95	9037.48	827.74	74.57	10.92	3979.64	9043.90	841.69	75.70	10.74	0.0078%	-0.0710%	-10.74	-75.70
67	18C	3858.63	8765.58	774.76	70.26	11.31	3850.78	8781.07	841.69	75.70	10.43	0.2040%	-0.1764%	-10.43	-75.70
68	18D	4183.80	9522.96	952.56	84.70	10.00	4165.83	9431.41	841.69	75.70	11.21	0.4314%	0.9707%	-11.21	-75.70
69	19A	4011.64	9131.76	873.42	78.28	10.46	4010.04	9113.43	841.69	75.70	10.83	0.0399%	0.2012%	-10.83	-75.70
70	19B	4083.53	9312.84	942.47	83.88	9.88	4069.13	9234.12	841.69	75.70	10.97	0.3538%	0.8525%	-10.97	-75.70
71	19C	4318.93	9865.67	1074.60	94.61	9.18	4248.77	9607.65	841.69	75.70	11.41	1.6513%	2.6855%	-11.41	-75.70
72	19D	3905.64	8878.18	812.94	73.37	10.92	3904.33	8889.79	841.69	75.70	10.56	0.0335%	-0.1305%	-10.56	-75.70
73	20A	4582.87	10484.25	1218.90	106.33	8.60	4414.09	9953.09	841.69	75.70	11.83	3.8235%	5.3366%	-11.83	-75.70
74	20B	4485.16	10253.62	1169.30	102.31	8.77	4357.95	9828.51	841.69	75.70	11.68	2.9191%	4.3253%	-11.68	-75.70
75	20C	3804.58	8621.23	718.55	65.71	12.00	3778.01	8629.78	841.69	75.71	10.25	0.7035%	-0.0990%	-10.25	-75.71
76	20D	4053.70	9251.47	939.99	83.68	9.84	4040.04	9175.95	841.69	75.70	10.90	0.3381%	0.8230%	-10.90	-75.70
77	21A	4304.57	9784.03	984.65	87.31	9.94	4275.63	9651.19	841.69	75.71	11.47	0.6769%	1.3763%	-11.47	-75.71
78	21B	4068.96	9241.58	870.46	78.04	10.62	4067.70	9224.25	841.69	75.71	10.96	0.0310%	0.1878%	-10.96	-75.71
79	21C	3865.85	8806.80	824.99	74.34	10.68	3865.41	8813.82	841.69	75.70	10.47	0.0114%	-0.0796%	-10.47	-75.70
80	21D	4278.08	9731.92	994.16	88.09	9.79	4248.02	9587.84	841.69	75.71	11.39	0.7075%	1.5026%	-11.39	-75.71
81	22A	3581.52	8164.48	710.87	65.07	11.49	3553.31	8167.42	841.69	75.70	9.70	0.7941%	-0.0360%	-9.70	-75.70
82	22B	4185.63	9562.44	1023.00	90.43	9.35	4143.54	9385.83	841.69	75.70	11.15	1.0156%	1.8817%	-11.15	-75.70
83	22C	4072.67	9302.79	958.42	85.18	9.71	4053.38	9207.89	841.69	75.70	10.94	0.4758%	1.0307%	-10.94	-75.70
84	22D	4194.47	9638.94	1124.20	98.64	8.57	4103.64	9316.33	841.69	75.70	11.07	2.2133%	3.4629%	-11.07	-75.70
85	23A	4322.63	9853.54	1048.00	92.46	9.40	4268.19	9635.78	841.69	75.70	11.45	1.2755%	2.2599%	-11.45	-75.70
86	23B	4071.06	9269.10	914.50	81.62	10.14	4063.54	9216.78	841.69	75.70	10.95	0.1850%	0.5676%	-10.95	-75.70
87	23C	4014.81	9154.19	919.45	82.02	9.96	4006.90	9097.48	841.69	75.71	10.81	0.1972%	0.6235%	-10.81	-75.71
88	23D	3872.93	8833.76	856.78	76.93	10.31	3872.61	8825.61	841.69	75.70	10.49	0.0083%	0.0924%	-10.49	-75.70
89	24A	3584.25	8120.49	622.84	57.93	13.04	3497.05	8054.65	841.69	75.71	9.57	2.4935%	0.8174%	-9.57	-75.71
90	24B	3580.23	8107.09	599.98	56.09	13.51	3477.37	8033.04	841.69	75.71	9.54	2.9579%	0.9218%	-9.54	-75.71
91	24C	3693.89	8360.46	642.09	59.50	13.02	3623.99	8329.76	841.69	75.71	9.90	1.9290%	0.3685%	-9.90	-75.71
92	24D	4293.69	9746.43	958.35	85.19	10.17	4275.23	9643.77	841.69	75.71	11.46	0.4317%	1.0646%	-11.46	-75.71
93	25A	3557.44	8075.08	641.75	59.47	12.58	3487.07	8030.04	841.69	75.70	9.54	2.0180%	0.5608%	-9.54	-75.70
94	25B	3850.58	8771.81	826.81	74.49	10.61	3850.25	8778.58	841.69	75.70	10.43	0.0084%	-0.0771%	-10.43	-75.70
95	25C	3791.03	8593.04	708.42	64.89	12.13	3762.84	8611.19	841.69	75.71	10.23	0.7492%	-0.2108%	-10.23	-75.71
96	25D	4304.37	9798.72	1019.80	90.17	9.61	4264.74	9620.87	841.69	75.71	11.43	0.9291%	1.8486%	-11.43	-75.71
97	26A	3503.20	7946.14	606.41	56.60	13.10	3399.79	7848.77	841.69	75.70	9.33	3.0417%	1.2406%	-9.33	-75.70
98	26B	4004.62	9104.11	858.05	77.03	10.61	4004.21	9095.05	841.69	75.70	10.81	0.0102%	0.0996%	-10.81	-75.70
99	26C	4154.56	9461.01	959.12	85.24	9.86	4136.48	9361.92	841.69	75.71	11.12	0.4371%	1.0584%	-11.12	-75.71
100	26D	3955.26	8968.38	791.10	71.60	11.34	3951.35	8988.42	841.69	75.71	10.68	0.0990%	-0.2230%	-10.68	-75.71
Average		3976.07	9048.96	860.62	77.24	10.73	3942.13	8970.29	841.69	75.70	10.66	0.8740%	0.8395%	-10.66	-75.70

Economic Implications

The optimal spatial nitrogen application rates for the assumed ten-year planning horizon under precision farming are depicted in Figure 4. These rates range from 20.59 pounds per acre to 122.76 pounds per acre per year. There is no clear relation between the optimal nitrogen application map (Figure 4) and the pre-season nitrogen residual map (Figure 1). Under conventional whole-field farming practices, the optimal nitrogen application rates are 46.70 pounds per acre per year for the 50% ET water application, and 84.17 pounds per acre per year for the 75% ET water application scenario.

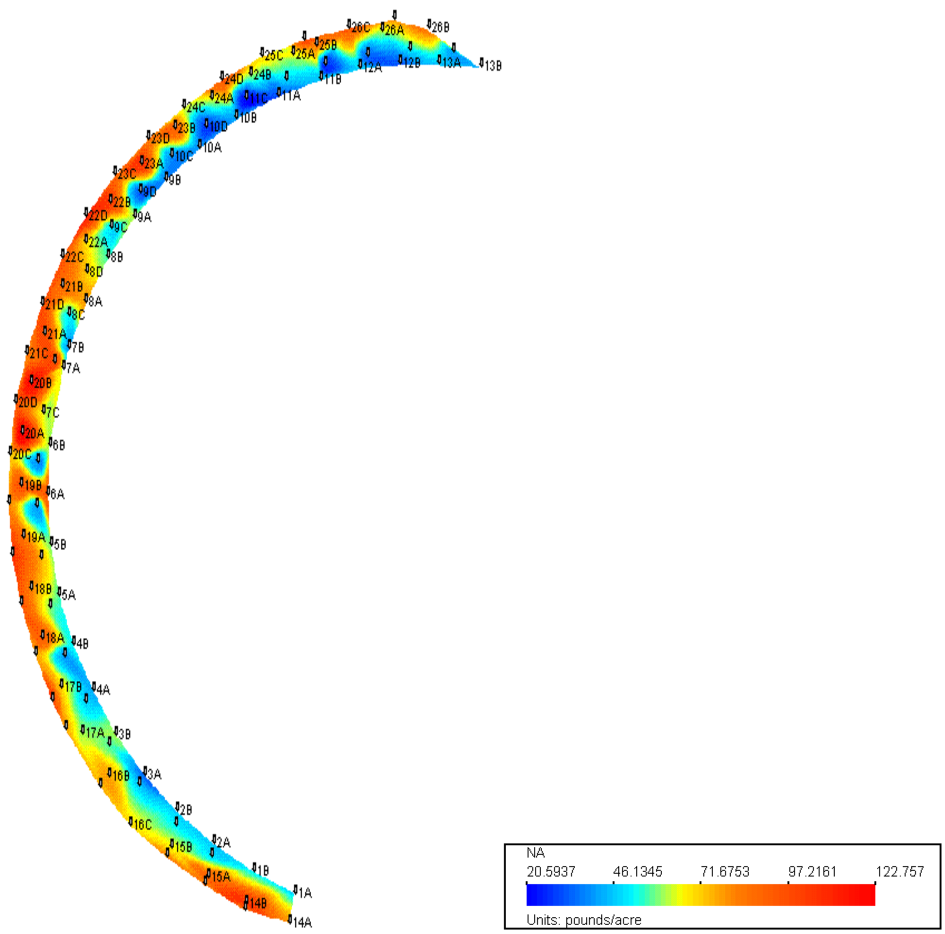

Figure 4. Optimal Levels of Spatial Nitrogen Application Map on a Per-Acre and Per-Year Basis for a Ten-Year Planning Horizon, Lamesa, Texas, 1998.

Tables 1 and 2 list the total cotton lint yields under the two nitrogen application technologies. Under precision farming practices, cotton yield ranged from 6,176.88 to 8,428.23 pounds per acre under 50% ET and 7,946.14 to 10,526.62 pounds per acre under 75% ET over a ten-year planning horizon. Under whole-field farming practices, total cotton yield ranged from 6,029.95 to 7,700.29 pounds per acre under 50% ET, and 7,848.77 to 9,995.83 pounds per acre under 75% ET over a ten-year planning horizon.

By comparing the yield difference at each field location under the two technologies, it was found that the average total yield for the ten-year planning horizon would increase by 1.11%, from 6,980.02 pounds per acre with conventional whole-field to 7,057.22 pounds per acre with precision farming under the 50% ET scenario. Under the 75% ET scenario, total yield would increase by 0.88%, from 8,970.29 pounds per acre (conventional whole-field farming practices) to 9,048.96 pounds per acre (precision farming practices). The yield percentage difference from precision farming ranged from a decrease of 0.29% (Location 10C) to an increase of 10.39% (Location 7D) under 50% ET, and from a decrease of 0.24% (Location 16B) to an increase of 5.34% (Location 20A) under 75% ET (Figure 5). 72% of the field locations show a yield increase, and 28% of the field locations show a yield decrease.

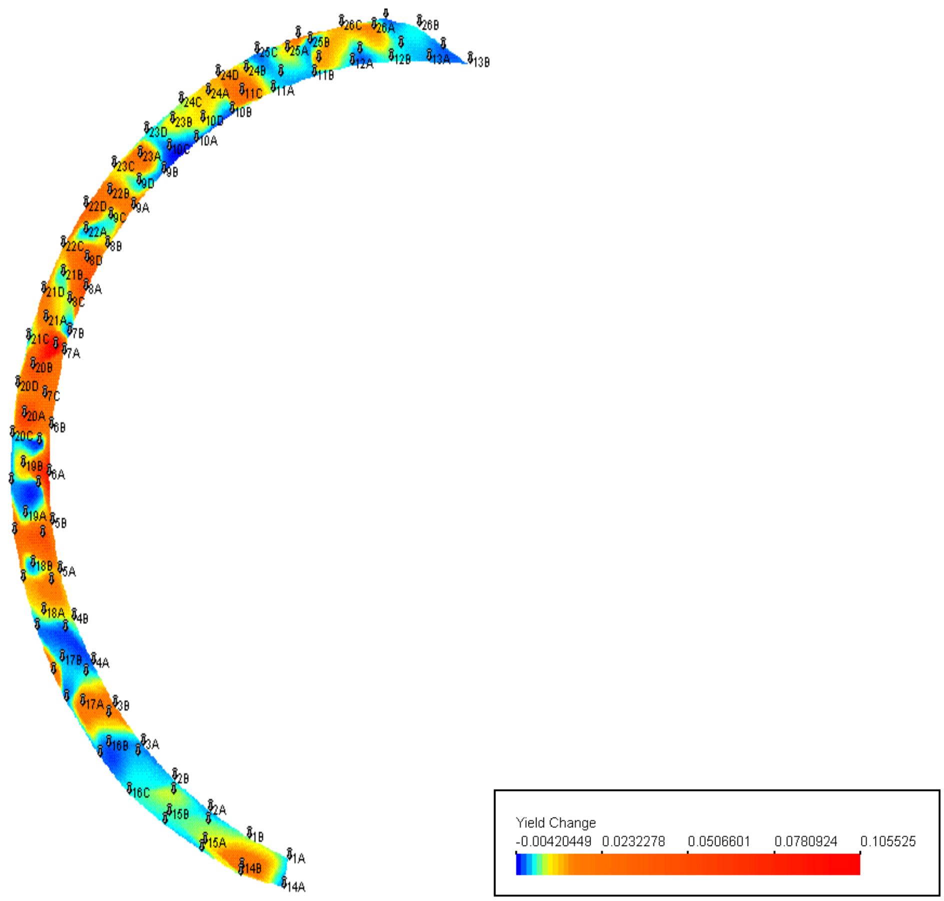

Figure 5. Yield Change for a Ten-Year Optimization Model (Precision Farming and Conventional Whole-Field Farming), Lamesa, Texas, 1998.

Net revenues above nitrogen fertilizer and water costs were also calculated under the two technologies (Tables 1 and 2). Spatial net revenue levels for the ten-year planning horizon ranged from $2,846.37 per acre (Location 11C) to $3,711.83 per acre (Location 7D) under 50% ET, and from $3,503.20 per acre (Location 26A) to $4,582.97 per acre (Location 20A) under 75% ET (Figure 6). The outer side of the field shows higher net revenues than in the inside of the circle. This is a direct result of higher levels of irrigation water applied on the outer locations. Under conventional whole-field farming, spatial net revenue levels for the ten-year planning horizon ranged from $2,708.39 per acre (Location 11C) to $3,499.16 per acre (Location 6A) under 50% ET, and from $3,399.79 per acre (Location 26A) to $4,414.09 per acre (Location 20A) under 75% ET.

In summary, the average net revenue during the ten-year planning horizon would be improved by 0.99%, from $3,138.43 per acre under conventional farming to $3,169.58 per acre under precision farming practices at 50% ET; and by 0.86%, from $3,942.13 per acre under conventional whole-field farming practices to $3,976.07 per acre under precision farming practices at 75% ET. The percentage change in net revenue above nitrogen fertilizer and water at each location in the field is shown in Figure 7. Change ranged from an increase of 0.00% (location 2B) to an increase of 7.28% (location 7D) under 50% ET, and from an increase of 0.0005% (location 15D) to an increase 3.82% (location 20A) under 75% ET. Note, however, that at every location in the field an increase in net revenue would be expected from the adoption of precision farming practices. A summary comparison of the previously discussed results is presented in Table 3.

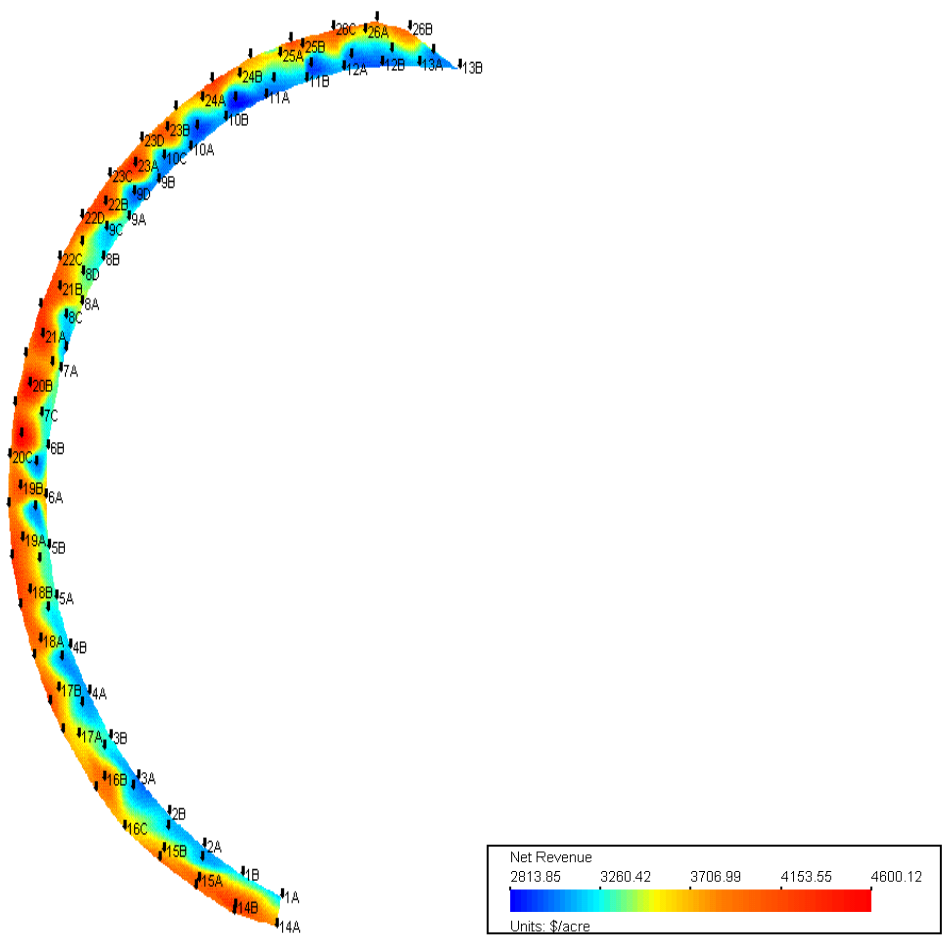

Figure 6. Spatial Net Revenue Above Nitrogen and Water Costs for a Ten-Year Optimization Model For Precision Farming Practices, Lamesa, Texas, 1998.

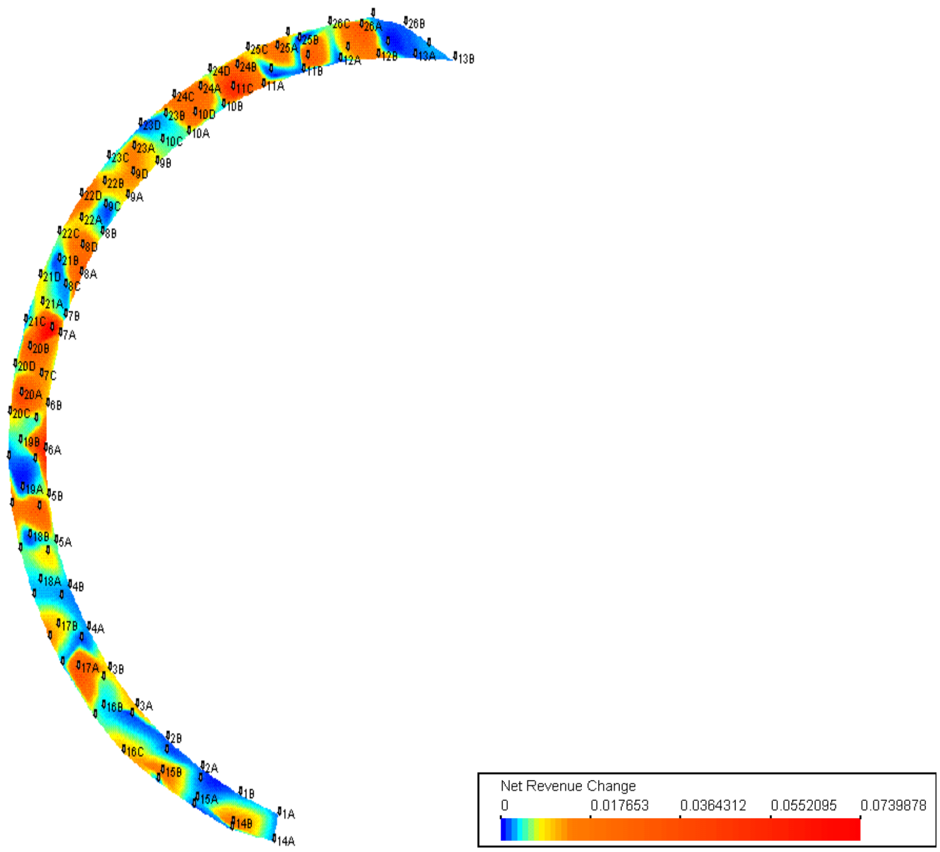

Figure 7. Spatial Net Revenue Change to Nitrogen Use (Precision Farming and Conventional Whole-Field Farming), Lamesa, Texas, 1998.

Table 3. Comparison of Precision Farming Practices and Conventional Whole-Field Farming Practices in Irrigated Cotton Production at Lamesa, Texas, 1998.

Applied Water Level		Precision Farming	Whole-Field Farming	Change
50% ET	Average Nitrogen Applied (lbs./a.)	49.33	46.70	5.33%
	Average Lint Yield (lbs./a.)	7057.22	6980.02	1.11%
	Average Net Revenue above Nitrogen and Water Costs ($/acre)	3169.58	3138.43	0.99%
75% ET	Average Nitrogen Applied (lbs./a.)	86.06	84.17	2.20%
	Average Lint Yield (lbs./a.)	9048.96	8970.28	0.88%
	Average Net Revenue above Nitrogen and Water Costs ($/acre)	3976.07	3942.13	0.86%

Productivity of Precision Farming verses Whole-Field Farming

Productivity, in its broadest sense, refers to the efficiency of a production process. In economics, it is commonly expressed as *total factor productivity* (TFP), which is the ratio of total output to total inputs used in the production process. TFP can be measured in an index form (Ahearn et al. 1998). If the ratio is increasing, this implies that productivity has improved, i.e., more output can be obtained from a given level of inputs.

Tables 1 and 2 also contain the TFP at each location in the field under the two nitrogen application technologies being evaluated. At 50% ET, the TFP change from whole-field to precision farming ranges from a decrease of 7.91 units (Location 7D) to an increase of 14.93 units (Location 11C). On the average, at 50% ET, precision farming increases TFP by 0.44 units. This means that precision farming practices increase cotton yield by an additional 0.44 pounds per acre for every pound of nitrogen fertilizer use, compared to whole-field farming practices. At the same time, precision farming builds up the average nitrogen residual level in the soil at the end of the tenth growing season by an average amount of 2.14 pounds per acre.

Table 2 shows that at 75% ET, the TFP change from whole-field to precision farming ranges from a decrease of 3.22 units (Location 20A) to an increase of 3.97 units (Location 24B). On the average, precision farming increases TFP by 0.07 units. That is, precision farming increases cotton yield by an additional 0.07 pounds per acre for every pound of nitrogen fertilizer use, as compared to whole-field farming practices. Also, at 75% ET, precision farming practices build up the average nitrogen residual level in the soil at the end of the tenth growing season by an additional 1.54 pounds per acre.

Tables 1 and 2 also show that there is an opposite relationship between the changes in TFP and the changes in the nitrogen residual level in the soil after the tenth season. If TFP increases, nitrogen residual level decreases, and vice versa. Both Tables 1 and 2 show that there are some locations in the field in which precision farming practices result in a lower TFP.

Under whole-field farming the average nitrogen residual levels at the end of the tenth season are 45.27 pounds per acre under 50% ET and 75.70 pounds per acre under 75% ET. Under precision farming practices, nitrogen residual levels are quite different depending on the location, perhaps due to the soil and location characteristics. Under dynamic optimization, if there is potential to increase net revenues in the future at a given location, precision farming practices would build up the nitrogen residual levels in that location. Because extra nitrogen fertilizer is applied to build up the after-season nitrogen residual levels, it is expected that TFP will decrease in that location. If future net revenues are not likely to increase in a given location, precision farming practices will lower their nitrogen residual levels, and TFP is expected to increase at those locations.

In short, precision farming practices can not only improve productivity, i.e., nitrogen use efficiency, but can also help to build up nitrogen residual in the soil at the end of the cotton growing season and improve the distribution of nitrogen residual levels across locations in the field.

CONCLUSIONS AND DISCUSSION

Overall, this analysis revealed that precision spatial utilization of nitrogen fertilizer, as compared to conventional whole-field farming, would result in an increase in crop yield, net revenue, and productivity on a per acre basis. This study found that nitrogen fertilizer could be used more efficiently, implying higher yields, net revenue, and output per unit of input used under precision farming practices, as compared to conventional whole-field farming practices. More importantly, it was found that precision farming practices would either build up or lower nitrogen residual levels at the end of the growing season, according to the net revenue potential of different locations.

This can improve yields, net revenue and input use efficiency, and have the potential to decrease the negative environmental impacts of agricultural production.

Net revenues do not show a sufficient increase as a result of adopting precision farming practices. This is partially explained by the fact that the experimental field did not have much variability on its initial soil nitrogen residual levels, and other spatial and soil properties. Future studies should be conducted to evaluate the relationship between the net revenue and the degree of variability in these factors. It is important to point out, however, that precision farming can effectively be used to determine "measurement zones" within fields where the benefits of precision farming would be sufficient.

Also, because of information limitations, this study only considered variable costs associated with the use of nitrogen fertilizer and water application and did not consider the fixed costs associated with the adoption of precision farming practices. For precision farming to be profitable in the future, this technology should also be used to control the variable application of other inputs, including seed, phosphorus fertilizer, potassium fertilizer, pesticide, herbicide, and other inputs. The application of multiple inputs could help to lower the average fixed costs of precision farming. Future studies should incorporate more variable inputs and consider the fixed costs of precision farming.

REFERENCES

Ahearn, M, J. Yee, E. Ball, and R. Nehring. "Agricultural Productivity in the United States." Economic Research Service*, USDA*. January (1998): AIB-740.

Carter, J. N., M. E. Jensen, and S. M. Bosman. 1974. "Determining Nitrogen Fertilization Needs for Sugarbeets From Residual Soil Nitrate and Mineralizable Nitrogen." Agronomy J. 66(1): 319-23.

Onken, A. B., and H. D. Sunderman. "Applied and Residual Nitrate-Nitrogen Effects on Irrigated Grain Sorghum Yield." Soil Science Society of America Proceedings 36(1972): 94-97.

Robert, P. C., R. H. Rust, and W. E. Larson. Proceedings of site-specific management for agricultural systems (second international conference). American Society of Agronomy Inc., Crop Science Society of America, Inc., and Soil Science Society of America, Inc. (1995): xiii.

SAS User's Guide: Statistics. SAS Institute Inc. 1982.

Segarra, E., D. E. Ethridge, C. R. Deussen, and A. B. Onken. 1989. "Nitrogen Carry-over Impacts in Irrigated Cotton Production, Southern High Plains of Texas*."* Western Journal of Agricultural Economics, 14(2): 300-309.

Vertical Mapper Manual. Vertical Mapper for MapInfo, Version 1.50.

Westerman, R. L., and L.T. Kurtz, 1972. "Residual Effects if N-labeled Fertilizers in a Field Study." Soil Science Society of America Proceedings, 36: 91-94.

Yu, M., E. Segarra, and D. Nesmith. 1999. "Spatial Utilization of Phosphorus: Implications for Precision Agriculture Practices." Proceedings of Beltwide Cotton Conferences. Pg. 299-302.

Yu, M., E. Segarra, H. Li, R. J. Lascana, C. Chilcutt, L. T. Wilson, K. Bronson, and S. Searcy. 2000. "The Economics of Precision Agricultural Practices in Cotton Production." Proceedings of Beltwide Cotton Conferences. Pg. 369-374.

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Pyrithiobac Combinations Control Red Morningglory (*Ipomoea coccinea*) and Devil's-claw (*Proboscidea louisianica*) in Non-Transgenic Cotton (*Gossypium hirsutum*)

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ABSTRACT

Standard and reduced rates of pyrithiobac, prometryn, and diuron applied preemergence (PRE) alone and in combination and followed by pyrithiobac POST were evaluated for red morningglory and devil's-claw control in non-transgenic cotton. Preemergence applications of prometryn or diuron controlled red morningglory no more than 27% and devil's-claw no more than 47%. Preemergence combinations of prometryn or diuron plus pyrithiobac controlled red morningglory and devil's-claw as much as 75%. Prometryn or diuron plus pyrithiobac followed by pyrithiobac postemergence (POST) controlled red morningglory 88 to 91% and devil's-claw 81 to 100%. Red morningglory control was similar with reduced rates (0.8 lb ai/A) of prometryn or diuron plus pyrithiobac PRE followed by a reduced rate (0.047 lb ai/A) of pyrithiobac POST. Cotton yields were greatest when PRE combinations were followed by pyrithiobac POST.

KEYWORDS: cotton 'Paymaster HS-26', devil's-claw, diuron, *Gossypium hirsutum* L., preemergence herbicide combinations, *Proboscidea louisianica* (Mill.) Thellung, prometryn, pyrithiobac, red morningglory, weed management

INTRODUCTION

Morningglory (*Ipomoea* spp.) infests approximately 1,000,000 acres of Texas cotton and may cause complete crop loss at populations of one or more plants per 6 feet of row (Keeley et al. 1986). Savoy et al. (1993) reported that no single herbicide treatment provided season-long morningglory control in cotton. In addition, herbicides

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applied preplant incorporated (PPI) did not control morningglory (Holshouser and Chandler 1988, Savoy et al. 1993) and PRE herbicides only provided early-season control or suppression (Smith and Chandler 1991). Applications of MSMA plus methazole, fluometuron, or cyanazine applied postemergence-directed (PDIR) following a soil-applied herbicide program has effectively controlled most morningglories (Savoy et al. 1993, Thullen and Keeley 1994, Wilcut et al. 1997); however, methazole and cyanazine are not currently registered for use in cotton and fluometuron has a history of cotton injury on lighter soils. In addition, Wilcut et al. (1996) reported that producers prefer to make POST applications instead of PDIR applications in small cotton.

Devil's-claw is a problem weed in Southwestern cotton production (Dowler 1992). Lack of devil's-claw control resulted in stripper harvest complications and reduced lint yield by 74% when populations reached 1 plant per foot of row (Mercer et al. 1987). Herbicides applied PRE in cotton have limited activity on devil's-claw, and POST herbicides lose effectiveness once this weed reaches 4 inches in height (Smith et al. 1973). Although there are PDIR herbicides available that effectively control many difficult to control broadleaf weeds in cotton (Buchanan 1992), often the necessary height differential between the crop and weed is difficult to establish.

Pyrithiobac has POST activity on devil's-claw (Prostko and Chandler 1998) and morningglory spp. (Keeling et al. 1993a, Jordan et al. 1993), but control has been inconsistent on the Texas Southern High Plains (Light et al. 1999). Developing a weed-control strategy that provides consistent control of these weed species would be of considerable benefit to cotton producers in the Texas Southern High Plains. Therefore, research was conducted to evaluate standard and reduced rates of pyrithiobac, prometryn, and diuron applied PRE alone and in combination and followed by pyrithiobac POST for red morningglory and devil's-claw control in non-transgenic cotton.

MATERIALS AND METHODS

Field experiments were conducted in 1997 and 1998 on the Texas Agricultural Experiment Station near Lubbock, TX and on private land near Hart, TX. Soils at Lubbock and Hart were an Acuff sandy clay loam (fine-loamy, mixed, superactive, thermic Aridic Paleustolls) with 0.8% organic matter and a pH of 7.8 and a Pullman clay loam (fine, mixed, superactive, thermic, Torrertic Paleustolls) with 1.5 % organic matter and a pH of 7.5, respectively. The Lubbock site contained natural infestations of devil's-claw estimated 60 days after planting (DAP) at 2 plants/ft^2 in non-treated control plots, while the Hart location contained natural infestations of red morningglory estimated 60 DAP at 6 plants/ft^2 in the non-treated control plots. Trifluralin at 0.8 lb ai/A was applied preplant and incorporated over all test areas to control annual grasses and Palmer amaranth (*Amaranthus palmeri* S. Wats.). Cotton, Paymaster HS-26, was planted in 40-inch rows at a seeding rate of 12 lb/A at each location in 1997 and 1998. Planting dates near Lubbock were May 8, 1997 and May 7, 1998 and May 15, 1997 and May 4, 1998 near Hart. Traditional production practices were implemented at each location.

Herbicide treatments were applied to plots 4 rows by 30 feet in length using a tractor-mounted, compressed-air sprayer equipped with Teejet[1] 80015VS flat-fan nozzles calibrated to deliver 10 gallons per acre. Prometryn at 0.8 and 1.2 lb ai/A (reduced and standard rates, respectively), diuron at 0.8 or 1.2 lb ai/A (reduced and standard rates,

[1]Spraying Systems Co., North Avenue and Schmale Road, Wheaton, IL 60188.

respectively), and pyrithiobac at 0.032, 0.047, and 0.063 lb ai/A (reduced and standard rates) were applied PRE alone. Tank-mix combinations of prometryn at 0.8 or 1.2 lb ai/A or diuron at 0.8 or 1.2 lb ai/A plus pyrithiobac at 0.032 or 0.047 lb ai/A also were applied PRE. Tank-mix combinations of prometryn or diuron (0.8 or 1.2 lb ai/A) plus pyrithiobac at 0.032 lb ai/A were applied PRE and followed by pyrithiobac applied POST at 0.047 or 0.063 lb ai/A. Pyrithiobac applied PRE alone at 0.032 lb ai/A was also followed by pyrithiobac POST at either 0.047 or 0.063 lb ai/A. All POST pyrithiobac treatments included crop oil concentrate[2] at 1% (v/v). Pyrithiobac was applied POST to 1 to 3-leaf devil's-claw (1 to 4 inches in height) or to 1 to 3-leaf red morningglory (2 to 4 inches in height). Cotton size at the POST application was 2 to 3-leaf (3 to 5 inches in height). Rainfall totaled approximately 20 inches in 1997 and 13 inches in 1998 at both locations. Due to the more adequate rainfall in 1997, no supplemental irrigation was applied at either location that year. However, each experiment was furrow irrigated in May, June, and July 1998 totaling approximately 12 inches.

The experimental design was a randomized complete block with three replications. Weed control and crop injury were estimated visually on a scale of 0 to 100% (where 0 = no control or injury and 100 = complete control or cotton death). Weed control was estimated 41 and 73 days after planting (equivalent to 2 and 7 weeks after POST treatments) at both locations. Crop injury (stunting and chlorosis) was estimated at 14 and 30 days after POST applications. Yields were obtained by hand-harvesting 2 rows by 13 feet in length within the center of each plot. Harvested samples were ginned and lint yield determined. Percentage data were subjected to arcsine square root transformation before performing analysis of variance. Non-transformed data are presented in the tables based on the analyses of transformed data for weed control. Data were not combined over years because treatment by year interactions occurred for both red morningglory and devil's-claw. Means were separated using Fisher's Protected LSD test at $p \leq 0.05$.

RESULTS AND DISCUSSION

Red Morningglory Control. In 1997, cool and wet soil conditions increased the soil activity of PRE herbicides and perhaps the residual activity of pyrithiobac POST compared to 1998. However, individual treatments of prometryn, diuron, or pyrithiobac applied PRE still did not effectively control red morningglory (30 to 62%) early-season (41 DAP) in 1997 (Table 1). Combinations of prometryn plus pyrithiobac were more effective at controlling red morningglory than most combinations of pyrithiobac plus diuron. Prometryn plus pyrithiobac (regardless of rates) controlled red morningglory 83 to 87%, in contrast to 62 to 67% control from preemergence combinations of diuron plus pyrithiobac at 0.032 lb ai/A. Excellent red morningglory control (92 to 98%) was observed when PRE combinations (prometryn or diuron plus pyrithiobac) were followed by pyrithiobac POST.

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[2]Agri-Dex, 83% paraffin based petroleum oil with 17% polyol fatty acid esters and polyethoxylated derivatives thereof. Helena Chemical Co., 6075 Poplar Ave., Suite 500, Memphis, TN 38119.

Table 1. Effects of prometryn, diuron, and pyrithiobac on red morningglory control in cotton near Hart, TX, 1997 and 1998.

			Days after planting			
	Application		1997		1998	
Treatment[a]	Rate	Timing[b]	41	73	41	73
	- lb ai/A-		----------------	%	----------------	
Prometryn	0.8	PRE	37	8	29	2
Prometryn	1.2	PRE	52	27	38	5
Diuron	0.8	PRE	30	10	34	5
Diuron	1.2	PRE	32	10	38	5
Pyrithiobac (pyr)	0.032	PRE	45	29	34	17
Pyrithiobac	0.047	PRE	58	40	38	18
Pyrithiobac	0.063	PRE	62	48	47	2.5
Prometryn + pyr	0.8+0.032	PRE	83	62	49	28
Prometryn + pyr	0.8+0.047	PRE	83	75	57	38
Prometryn + pyr	1.2+0.032	PRE	85	64	57	41
Prometryn + pyr	1.2+0.047	PRE	87	73	61	47
Diuron + pyr	0.8+0.032	PRE	67	50	42	20
Diuron + pyr	0.8+0.047	PRE	78	66	49	30
Diuron + pyr	1.2+0.032	PRE	62	42	44	23
Diuron + pyr	1.2+0.047	PRE	80	63	47	42
Pyr fb pyr	0.032 fb 0.047	PRE fb POST	86	80	98	84
Pyr fb pyr	0.032 fb 0.063	PRE fb POST	92	88	98	85
Prometryn + pyr fb pyr	0.8+0.032 fb 0.047	PRE fb POST	92	85	100	90
Prometryn + pyr fb pyr	0.8+0.032 fb 0.063	PRE fb POST	93	85	99	89
Prometryn + pyr fb pyr	1.2+0.032 fb 0.047	PRE fb POST	96	90	99	89
Prometryn + pyr fb pyr	1.2+0.032 fb 0.063	PRE fb POST	98	88	100	91
Diuron + pyr fb pyr	0.8+0.032 fb 0.047	PRE fb POST	98	90	97	87
Diuron + pyr fb pyr	0.8+0.032 fb 0.063	PRE fb POST	96	91	100	88
Diuron + pyr fb pyr	1.2+0.032 fb 0.047	PRE fb POST	97	90	98	88
Diuron + pyr fb pyr	1.2+0.032 fb 0.063	PRE fb POST	98	89	99	89
LSD (0.05)			8	10	8	8

[a]Abbreviations: fb, followed by; POST, postemergence; PRE, preemergence; Pyr, Pyrithiobac.
[b]All POST pyrithiobac treatments included crop oil concentrate at 1% (v/v).

Overall, late-season (73 DAP) red morningglory control was greater from preemergence combinations that included the higher rate of pyrithiobac (0.047 lb ai/A) compared to combinations that included the lower rate. Pyrithiobac combinations with prometryn were generally more effective than pyrithiobac combinations with diuron. Red morningglory was controlled 73 to 75% by combinations of prometryn plus pyrithiobac at 0.047 lb ai/A. Less control (62 to 64%) was observed from prometryn plus the reduced rate of pyrithiobac (0.032 lb ai/A), which was similar to control from diuron plus the full rate of pyrithiobac (63 to 66%). Pyrithiobac PRE followed by pyrithiobac POST at 0.063 lb ai/A controlled red morningglory 88%, which was greater than any PRE combination alone. Red morningglory control from PRE combinations followed by pyrithiobac POST was similar (85 to 91%) to pyrithiobac PRE followed by pyrithiobac POST.

In 1998, PRE treatments of prometryn, diuron, or pyrithiobac applied individually did not provide effective early-season red morningglory control (29 to 47%) 41 DAP. Preemergence combinations of diuron plus pyrithiobac were similar to pyrithiobac applied PRE alone at 0.063 lb ai/A. Increased red morningglory control (57 to 61%) was observed from PRE combinations of prometryn and pyrithiobac (when either was applied at their higher rate) compared to other PRE treatments.

In contrast to 1997, no PRE treatment controlled red morningglory greater than 47% at 73 DAP. However, all PRE treatments followed by pyrithiobac POST controlled red morningglory at least 84% in 1998.

Devil's-claw Control. Prometryn, diuron, or pyrithiobac (0.032 and 0.047 lb ai/A) PRE did not effectively control devil's-claw (37 to 60%) early-season in 1997 (Table 2). Increasing the rate of pyrithiobac to 0.063 lb ai/A increased devil's-claw control to 70% 41 DAP. Similar control (63 to 77%) was observed from PRE combinations of prometryn or diuron plus pyrithiobac. All PRE treatments followed by pyrithiobac POST (regardless of rate) increased devil's-claw control ≥ 99% 41 DAP (2 weeks after the pyrithiobac POST treatment).

Table 2. Effects of prometryn, diuron, and pyrithiobac on devil's-claw control in cotton near Lubbock, TX, 1997 and 1998.

	Application		Days after planting			
			1997		1998	
Treatment[a]	Rate	Timing[b]	41	73	41	73
	- lb ai/A-		---------------%-------------			
Prometryn	0.8	PRE	37	18	5	0
Prometryn	1.2	PRE	43	26	16	0
Diuron	0.8	PRE	55	47	33	0
Diuron	1.2	PRE	50	43	38	0
Pyrithiobac (pyr)	0.032	PRE	45	24	24	0
Pyrithiobac	0.047	PRE	60	55	27	0
Pyrithiobac	0.063	PRE	70	64	35	0
Prometryn + pyr	0.8+0.032	PRE	73	55	53	18
Prometryn + pyr	0.8+0.047	PRE	77	70	47	20
Prometryn + pyr	1.2+0.032	PRE	70	54	51	17
Prometryn + pyr	1.2+0.047	PRE	75	75	62	25
Diuron + pyr	0.8+0.032	PRE	63	53	53	12
Diuron + pyr	0.8+0.047	PRE	67	64	54	17
Diuron + pyr	1.2+0.032	PRE	63	56	56	15
Diuron + pyr	1.2+0.047	PRE	76	70	54	25
Pyr fb pyr	0.032 fb 0.047	PRE fb POST	100	99	96	63
Pyr fb pyr	0.032 fb 0.063	PRE fb POST	100	98	97	82
Prometryn + pyr fb pyr	0.8+0.032 fb 0.047	PRE fb POST	100	97	96	75
Prometryn + pyr fb pyr	0.8+0.032 fb 0.063	PRE fb POST	99	97	97	77
Prometryn + pyr fb pyr	1.2+0.032 fb 0.047	PRE fb POST	99	96	97	81
Prometryn + pyr fb pyr	1.2+0.032 fb 0.063	PRE fb POST	100	100	97	84
Diuron + pyr fb pyr	0.8+0.032 fb 0.047	PRE fb POST	99	96	98	80
Diuron + pyr fb pyr	0.8+0.032 fb 0.063	PRE fb POST	100	99	97	80
Diuron + pyr fb pyr	1.2+0.032 fb 0.047	PRE fb POST	100	100	99	82
Diuron + pyr fb pyr	1.2+0.032 fb 0.063	PRE fb POST	100	100	98	83
LSD (0.05)			6	9	9	5

[a]Abbreviations: fb, followed by; POST, postemergence; PRE, preemergence; Pyr, Pyrithiobac.
[b]All POST pyrithiobac treatments included crop oil concentrate at 1% (v/v).

Pyrithiobac PRE applied at 0.47 or 0.63 lb ai/A controlled devil's-claw more effectively than prometryn or diuron 73 DAP. Preemergence combinations including pyrithiobac at 0.047 lb ai/A or greater controlled devil's-claw 67 to 77%, while all other

PRE combinations controlled devil's-claw ≤ 56%. Both the standard (0.063 lb ai/A) and reduced (0.047 lb ai/A) rates of pyrithiobac POST following any PRE treatment maintained effective devil's-claw control (96 to 100%) 73 DAP.

In 1998, individual PRE treatments did not control devil's-claw (≤ 38%) 41 DAP. Early-season devil's-claw control improved to 47 to 62% when either prometryn or diuron was combined with pyrithiobac applied PRE. Preemergence combinations followed by pyrithiobac POST controlled devil's-claw 96 to 98% 41 DAP (2 weeks after the pyrithiobac POST treatment). By 73 DAP, no individual PRE treatment or PRE combination provided more than 25% devil's-claw control in 1998. However, any PRE combination followed by pyrithiobac POST (regardless of rate) controlled devil's-claw 75 to 84%.

Cotton Response. Although some reports suggest pyrithiobac can cause a transient chlorosis ("yellow flash") 5 to 7 d after POST applications (Keeling et al. 1993b), no cotton injury was observed following any individual PRE treatment, PRE combination, or sequential PRE/POST treatment in 1997 or 1998 (data not shown). Dotray et al. (1996) reported similar results.

Red morningglory site: Overall lint yields in 1997 were reduced due to damaging hail 14 d after cotton emergence. No lint was produced from plots that received a single PRE treatment of prometryn, diuron, or pyrithiobac (at 0.032 lb ai/A) due to severe weed pressure and subsequent competition (Table 3). However, plots that received pyrithiobac PRE at 0.047 or 0.063 lb ai/A produced 85 to 92 lb lint/A. Plots treated with PRE combinations of prometryn or diuron plus pyrithiobac or pyrithiobac PRE followed by pyrithiobac POST increased lint yields 16 to 170 lb/A compared to pyrithiobac alone at 0.063 lb ai/A. Combinations of prometryn or diuron plus pyrithiobac PRE followed by pyrithiobac POST increased lint yields 65 to 254 lb/A compared to PRE combinations alone.

Similar to findings by Patterson et al. (1991), higher cotton yields were associated with POST applications of pyrithiobac in 1998. Pyrithiobac PRE followed by pyrithiobac POST increased yields 99 to 221 lb/A compared to PRE combinations of prometryn or diuron plus pyrithiobac. The greatest lint yields recorded at Hart in 1998 (749 to 816 lb/A) were produced in plots treated with PRE combinations of prometryn or diuron plus pyrithiobac followed by pyrithiobac POST.

Devil's-claw site in Lubbock: Despite increased rainfall at Lubbock in 1997, below average heat- unit accumulation[3] (699 fewer heat units in 1997 compared to 1998) resulted in reduced yields. No yield differences were recorded in 1997 between plots that received prometryn, diuron, or pyrithiobac applied PRE alone. Rate-dependent yield increases were recorded from PRE combinations of prometryn or diuron plus pyrithiobac compared to prometryn, diuron, or pyrithiobac alone. Preemergence treatments followed by pyrithiobac POST yielded 455 to 578 lb lint/A, which was equal to or greater than yields produced from plots which received only a PRE treatment.

In 1998, no lint was harvested from plots treated only with prometryn or diuron PRE. Pyrithiobac PRE alone produced 100 to 158 lb lint/A. Lint yields were increased 72 to 193 lb/A with the addition of prometryn or diuron to pyrithiobac PRE compared to

[3]Heat units obtained at http://achilleus.tamu.edu/data/weather/weather.html from Texas Agricultural Experiment Station, Soil Physics Department, Lubbock, TX.

pyrithiobac PRE alone. When PRE combinations of prometryn or diuron plus pyrithiobac were followed by pyrithiobac POST, lint yields increased 150 to 396 lb/A compared to sequential PRE/POST applications of pyrithiobac.

Table 3. Cotton lint yields from prometryn, diuron, and pyrithiobac treatments near Hart and Lubbock, TX, 1997 and 1998.

	Application		Hart		Lubbock	
Treatment[a]	Rate	Timing[b]	1997	1998	1997	1998
	- lb ai/A-		------------------lb lint/A---------------			
Prometryn	0.8	PRE	0	142	281	0
Prometryn	1.2	PRE	0	231	289	0
Diuron	0.8	PRE	0	136	264	0
Diuron	1.2	PRE	0	224	287	0
Pyrithiobac (pyr)	0.032	PRE	0	241	264	100
Pyrithiobac	0.047	PRE	85	301	290	124
Pyrithiobac	0.063	PRE	92	275	301	158
Prometryn + pyr	0.8+0.032	PRE	109	297	396	293
Prometryn + pyr	0.8+0.047	PRE	237	355	429	286
Prometryn + pyr	1.2+0.032	PRE	137	331	392	253
Prometryn + pyr	1.2+0.047	PRE	252	358	435	246
Diuron + pyr	0.8+0.032	PRE	108	272	411	243
Diuron + pyr	0.8+0.047	PRE	138	317	489	230
Diuron + pyr	1.2+0.032	PRE	150	321	337	239
Diuron + pyr	1.2+0.047	PRE fb POST	255	369	426	275
Pyr fb pyr	0.032 fb 0.047	PRE fb POST	230	468	455	356
Pyr fb pyr	0.032 fb 0.063	PRE fb POST	211	493	559	435
Prometryn + pyr fb pyr	0.8+0.032 fb 0.047	PRE fb POST	362	749	458	585
Prometryn + pyr fb pyr	0.8+0.032 fb 0.063	PRE fb POST	356	787	470	594
Prometryn + pyr fb pyr	1.2+0.032 fb 0.047	PRE fb POST	340	797	577	612
Prometryn + pyr fb pyr	1.2+0.032 fb 0.063	PRE fb POST	324	796	578	591
Diuron + pyr fb pyr	0.8+0.032 fb 0.047	PRE fb POST	320	788	489	692
Diuron + pyr fb pyr	0.8+0.032 fb 0.063	PRE fb POST	342	709	524	620
Diuron + pyr fb pyr	1.2+0.032 fb 0.047	PRE fb POST	356	806	568	608
Diuron + pyr fb pyr	1.2+0.032 fb 0.063	PRE fb POST	346	816	565	752
LSD (0.05)			71	99	153	106

[a]Abbreviations: fb, followed by; POST, postemergence; PRE, preemergence; Pyr, Pyrithiobac.
[b]All POST pyrithiobac treatments included crop oil concentrate at 1% (v/v).

This research suggests that PRE combinations of prometryn or diuron plus pyrithiobac followed by pyrithiobac POST can effectively control red morningglory and devil's-claw in non-transgenic cotton. Reduced rates of prometryn or diuron plus pyrithiobac followed by reduced rates of pyrithiobac POST controlled red morningglory as effectively as standard rates. Although PRE combinations of pyrithiobac with either prometryn or diuron increased control of red morningglory and devil's-claw compared to standard rates of prometryn or diuron alone, this control was still unacceptable by most standards. Effective, season-long control of red morningglory and devil's-claw was achieved when PRE treatments were followed by pyrithiobac POST.

REFERENCES

Buchanan, G. A. 1992. Trends in weed control methods. In C. G. McWhorter and J. R. Abernathy, eds. Weeds of Cotton: Characterization and Control. Memphis, TN. The Cotton Foundation: pp. 47-72.

Dotray, P. A., J. W. Keeling, C. G. Henniger, and J. R. Abernathy. 1996. Palmer amaranth (*Amaranthus palmeri*) and devil's-claw (*Proboscidea louisianica*) control in cotton (*Gossypium hirsutum*) with pyrithiobac. Weed Technol. 10:7-12.

Dowler, C. C. 1992. Weed survey - Southern states: Broadleaf crops subsection. Proc. South. Weed Sci. Soc. 45:392-407.

Holshouser, D. L. and J. M. Chandler. 1988. Management systems for morningglories in cotton. Proc. South. Weed Sci. Soc. 41:87.

Jordan, D. L., R. E. Frans, and M. R. McClelland. 1993. Total postemergence herbicide programs in cotton (*Gossypium hirsutum*) with sethoxydim and DPX-PE350. Weed Technol. 7:196-201.

Keeley, P. E., R. J. Thullen, and C. H. Carter. 1986. Influence of planting date on growth of ivyleaf morningglory (*Ipomoea hederacea*) in cotton (*Gossypium hirsutum*). Weed Sci. 34:906-910.

Keeling, J. W., C. G. Henniger, and J. R. Abernathy. 1993a. Broadleaf weed control in cotton with DPX-PE350. In D. J. Herber and D. A. Richter, eds. Proceedings Beltwide Cotton Conference. Memphis, TN. National Cotton Council of America. p. 1529.

Keeling, J. W., C. G. Henniger, and J. R. Abernathy. 1993b. Effects of DPX PE350 on cotton (*Gossypium hirsutum*) growth, yield, and fiber quality. Weed Technol. 7:930-933.

Light, G. G., P. A. Dotray, and J. R. Mahan. 1999. Thermal dependence of pyrithiobac efficacy in *Amaranthus palmeri*. Weed Sci. 47:644-650.

Mercer, K. L., D. S. Murray, and L. M. Verhalen. 1987. Interference of unicorn-plant (*Proboscidea louisianica*) with cotton (*Gossypium hirsutum*). Weed Sci. 35:807-812.

Patterson, M. G., B. E. Norris, Jr., and J. W. Everest. 1991. Evaluation of DPX-PE350 for weed control in cotton. Proc. South. Weed Sci. Soc. 44:76.

Prostko, E. P. and J. M. Chandler. 1998. Devil's-claw (*Proboscidea louisianica*) and smellmelon (*Cucumis melo* var. *dudaim*) control in cotton (*Gossypium hirsutum*) with pyrithiobac. Weed Technol. 12:19-22.

Savoy, B. R., D. L. Holshouser, K. L. Smith, and J. M. Chandler. 1993. A system for morningglory (*Ipomoea* spp.) control in cotton (*Gossypium hirsutum* L.). Weed Technol. 7:615-618.

Smith, D. T., R. C. Berner, and A. W. Cooley. 1973. Devil's-claw - Herbicidal Control. College Station, TX: Texas Agricultural Experiment Station Prog. Rep. 3202.

Smith, K. L. and J. M. Chandler. 1991. Effectiveness of norflurazon and prometryn combinations for preemergence control of annual morningglory. In D. J. Herber and D. A. Richter, eds. Proceedings Beltwide Cotton Conferences. Memphis, TN: National Cotton Council of America. p. 964.

Thullen, R. J. and P. E. Keeley. 1994. Control of ivyleaf morningglory (*Ipomoea hederacea*) in cotton (*Gossypium hirsutum*) by combinations of methods. Weed Technol. 8:772-776.

Wilcut, J. W., H. D. Coble, A. C. York, and D. W. Monks. 1996. The niche for herbicide-resistant crops in U.S. agriculture. In S. O. Duke, ed. Herbicide-Resistant Crops: Agricultural, Environmental, Economic, Regulatory, and Technical Aspects. Boca Raton, FL: CRC Press. p. 213-230.

Wilcut, J. W., D. L. Jordan, W. K. Vencill, and J. S. Richburg, III. 1997. Weed management in cotton (*Gossypium hirsutum*) with soil-applied and post-directed herbicides. Weed Technol. 11:221-226.

Genetic Analysis of Quercetin in Onion (*Allium cepa* L.) 'Lady Raider'

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ABSTRACT

Onion bulbs (*Allium cepa* L.) uniform in color, size, shape, and maturity were selected from breeding line 97-50 of the Texas Tech University onion improvement program and were designated breeding line 'Lady Raider'. Bulbs in this line are pearlized, red in color, grano shaped, and are in the short-day onion class, which matures in Lubbock in early summer. In a 1999 grow-out, bulbs of this phenotype were analyzed spectrophotometrically for quercetin content, as measured by total flavonol (TF) content. Quercetin is of interest in the onion industry because of its health-related properties. There had been no previous selection for TF in this line. Values in this parent population were normally distributed and ranged from 79 - 431 mg/kg. Bulbs were grouped by TF concentration into high (>232 mg/kg), medium (203-223 mg/kg), or low (<203 mg/kg) populations and designated P_{OH}, P_{OM}, and P_{OL}, respectively. The populations were caged separately in 2000 and allowed to sib-pollinate, forming three Sib-one (S_1) populations. These populations were designated as Sib-one high (S_{1H}), Sib-one medium (S_{1M}), and Sib-one low (S_{1L}) based upon the parent population from which it was generated. Flavonol concentrations of the P_O populations were compared to those of the S_1's. TF frequencies for all populations were normally distributed and TF ranges differed. TF values of the S_1 populations ranged from 228 - 675 mg/kg. The TF mean of each P_O population was significantly different from that of each S_1 population. Flavonol content in the S_1 generation segregated into classes similar to those of P_O populations, indicating that TF's can be manipulated through selective breeding.

KEY WORDS: flavonols, quercetin, onion, *Allium cepa*, breeding, selection

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Onions are high in phytochemicals, groups of compounds produced by plants that are metabolized but not synthesized by animals (Campbell 1996). Flavonols are a major class of phytochemicals that provide color, texture, and taste (Harborne 1986). The flavonol of interest in this study is quercetin. It is found in many different fruits and vegetables in varied concentrations. Onion (*Allium cepa* L.) ranked highest in quercetin content in a survey of 28 vegetables and 9 fruits (Herrmann 1976, Hertog and Hollman 1996). Quercetin is reported to have protective effects in reducing the risk of cardiovascular disease (Hertog and Hollman 1996, Keli et al. 1996, Knekt et al. 1996), it functions as an anti-cancer agent (Leighton et al. 1992, Knekt et al. 1997) and has promise to be an antioxidant agent (Deschner et al. 1991) because of its antiprostanoid, anti-inflammatory responses and decreased rate of DNA degradation (Formica and Regelson 1995). Quercetin levels tend to be highest in red and yellow onions and lowest in white onions (Patil et al. 1995, Lombard et al. 2002). Amounts of quercetin in onions vary with bulb color, type, and variety (Leighton et al. 1992, Patil and Pike 1995, Lombard 2000).

Regardless of onion bulb pigmentation, quercetin concentration is highest in the outer rings (Patil and Pike 1995). Onion is an intensely selected crop, for which characteristics such as bulb shape, size, color, and single centers are chosen by breeders (Rabinowitch and Brewster 1990). Due to the potential health benefits of quercetin, its importance in onion, and varietal differences, quercetin is a trait of interest in onion breeding programs. There are no reports of breeding for increased levels of quercetin. Here we report our results after one generation of selective breeding for quercetin content in one line of a short-day onion. This information could be useful for breeders of *A. cepa* looking for ways to increase quercetin levels in their crop.

EXPERIMENTAL PROCEDURES

Parental population. In 1997 onion bulbs uniform in color, size, shape, and maturity were selected from breeding line 97-50 of the Texas Tech University (TTU) onion improvement program and formed the breeding line 'Lady Raider'. Bulbs were planted into the field at the TTU Erskine Street Farm Fall 1997 and upon flowering the following spring were mass pollinated in a crossing cage. Seeds were harvested Summer 1998 and January 1999 were sown into flats filled with equal parts greenhouse potting mix (peat:perlite) and sand in the TTU Horticulture Gardens Greenhouse under day temperatures of 25-30°C and night temperatures of 20°C. Flats were moistened with city water until seedlings had two true leaves, whereupon every other watering plants were fertilized with a dilute solution of 20-20-20. Flats were kept moist but not saturated. March 1999 when seedlings were approximately 90 days of age they were transplanted to the TTU Erskine Street Farm. Bulbs were harvested in early summer when 50% of the tops were down. The line was evaluated for phenotype and bulbs with pearlized, rose-red color, grano shape, and in the short-day onion class were selected. Individual bulbs were evaluated for quercetin content following Lombard et al. (2002). Previous studies have shown that 96% of a tissue extract measured spectrophotometrically for TF content (mg/kg) is quercetin (Lombard et al. 2002). We report here levels of quercetin as TFs. Outer, inedible portions from bulbs were removed. Onions were quartered and one quartered section was weighed then frozen in liquid nitrogen. Frozen tissue was ground to a fine powder using a coffee grinder (Braun®, Boston, MA) and quercetin was extracted from 20 g ground onion powder in 80 ml of 80% EtOH by filtering twice through number

8 (Fisher Scientific, Houston, TX) and grade 42 (Whatman, Clifton, NJ) filter paper. Filtrate was collected into 2 ml Eppendorf tubes and stored at -20°C until analysis. Ethanolic extracts were thawed, vortexed, and diluted 10:1 with 80% EtOH to a total of 5 ml. Absorbance (AU) readings were made in duplicate at 362 nm using a Spectronic Genesys 5 (Waltham, MA) spectrophotometer and recorded as mg/kg total flavonols (TF). These onions formed the initial population (P_o). Individuals from the P_o were grouped into one of three categories based upon the TFs observed: high (> 230 mg/kg), medium (208 – 230 mg/kg), or low (< 208 mg/kg).

Selected populations. Bulbs from each sub-population were kept in their respective groups and planted back to the field fall 1999. Upon flowering, bulbs from each population were mass pollinated separately in crossing cages, creating seed for three sibbed (sister or sibling) (S_1) populations. Summer 2000 seed from the sibbed onions were harvested separately and, based on their parentage, were designated as sib population S_{1H} (high), S_{1M} (medium), or S_{1L} (low). This seed was sown in the TTU Horticultural Greenhouse January 2001 and transplanted to the TTU Erskine Farm (Lubbock, TX) spring 2001 as above. Sib-one bulbs were harvested in early summer, selected for phenotype and analyzed as were the previous populations following Lombard et al. (2002) with the following adjustment: rather than quartering the onions, three core samples approximately 4 mm x 6 mm each, were taken from equal distant locations on the perimeter of the onion. Coring minimizes the rotting that follows larger, quartered sampling. Smaller samples still provided adequate tissue for accurate spectrophotometric readings, while increasing the likelihood of more bulbs surviving replanting in the field for vernalization and larger populations the following spring. Means within and between parent and sib-one populations were analyzed using a pooled t-test and corrected pooled t-value.

RESULTS AND DISCUSSION

Values of TFs in the three P_o ranged from 79 - 431 mg/kg and when plotted, followed a normal distribution (not shown). TF values of the S_1 populations ranged from 228 - 675 mg/kg (Table 1).

Table 1. Total flavonols of parental (P_0) and 1st sibbed (S_1) generation progeny selections of 'Lady Raider' onion.

Population	Sample Size	Total Flavonols (mg/kg)		
Parental		Range	Mean	Std. Error
P_{OL}	22	79 – 195	142	6.81
P_{OM}	6	203 - 223	219	3.57
P_{OH}	11	232 - 431	302	17.63
Sib-one				
S_{1L}	92	228 - 445	287	6.02
S_{1M}	30	228 - 565	392	15.47
S_{1H}	43	272 - 675	456	15.44

When TFs of the S_1 populations were plotted against their P_o parental population, the values for TFs had shifted but were clearly distinguished in the three populations. Some of the shift in TF values from the parental to sibbed progeny may be attributed to genetic variation, but the shift is most likely due to the tissue from which the extract came. Tissue analyzed from the P_o populations was taken from a quartered sample extending into the innermost rings of the bulb, including the inner rings, while tissue from the S_1 progeny came from the outermost scales only (after removal of outer dry skin), hence the tissue sampled likely had relatively higher quercetin levels. Quercetin has been reported to be in highest concentration in the outer rings (Patil et al. 1995). However, all individuals from S_1 populations were treated alike and segregated into three distinct groups as in the parental populations. From the P_0 population with the lowest TFs (P_{1L}) was generated the lowest S_1 population (S_{1L}), likewise from the medium P_0 population (P_{0M}) was generated the medium levels of the S_1 population (S_{1M}), and from the P_0 population with the highest levels of the (P_{0H}) was generated the highest levels of the S_1 populations (S_{1H}). TF values observed in the sib-one population, 228 mg/kg to 675 mg/kg, exceeded those of the parent population (range 79 mg/kg to 431 mg/kg). T-tests revealed means of sibbed populations were significantly different from each other and from the parent population (Table 2).

Table 2. Calculated t- values for means of total flavonols within and between parent and sib-one populations of 'Lady Raider' onion * values significantly different ($P<0.05$).

	P_{OL}	P_{OM}	P_{OH}	S_{1L}	S_{1M}	S_{1H}
P_{OL}		4.66*	10.19*	47.55*		
P_{OM}	4.66*		2.77*		4.05*	
P_{OH}	10.19*	2.77*				4.82*
S_{1L}	47.55*				7.69*	12.35*
S_{1M}		4.05*		7.69*		2.84*
S_{1H}			4.82*	12.35*	2.84*	

Flavonol concentration means for the sib-one populations mirror those of the parent populations. S_{1H} has the highest TF flavonol mean (456 mg/kg), S_{1M} mid-range (329 mg/kg), and S_{1L} the lowest (286 mg/kg).

Onions are an out-crossing species and heterozygous at many loci. Varietal differences (Leighton et al. 1992) and high coefficients of variation in quercetin levels between onion varieties (Lombard 2000) have been reported. Spectrophotometrically obtained total flavonol (TF) data from parent and sib-one populations of 'Lady Raider' reveal continuous, quantitative data and from these data we suggest that TFs are governed by more than one gene. As such, quercetin in onion is likely highly heritable and selection for TFs for increased levels can be achieved.

REFERENCES

Campbell, N.A. 1996. Biology, 4th Ed. Benjamin/Cummings Publishing Co., Inc., Menlo Park. p. 22-24.

Deschner, E.E., J. Ruperto, G. Wong, and H.L. Newmark. 1991. Quercetin and rutin as inhibitors of azomethanol-induced colonic neoplasia. Carcinogenesis 12:1193-1196.

Formica, J.V. and W. Regelson. 1995. Review of the biology of quercetin and related bioflavonoids. Food Chemistry and Toxicology 12:1061-1080.

Harborne, J.B. 1986. Nature, distribution and function of plant flavonoids, p. 15-24. In Cody, V., E. Middleton, Jr. and J.B. Harborne (eds.). Progress in Clinical and Biological Research, Vol.213. Alan R. Liss, New York.

Herrmann, K. 1976. Flavonols and flavones in food plants: a review. Journal of Food Technology 11:433-448.

Hertog, M.G.L. and P.C.H. Hollman. 1996. Potential health effects of the dietary flavonol quercetin. Euro. J. of Clin. Nutr. 50: 63-71.

Keli, S.O., M.G.L. Hertog, E.J.M. Feskens, and D. Kromhout. 1996. Dietary flavonoids, antioxidant vitamins, and incidence of stroke. Arch Intern. Med. 154: 637-642.

Knekt, P., R. Järvinen, A. Reunanen, and J. Maatela. 1996. Flavonoid intake and coronary mortality in Finland. BMJ. 312: 478-481.

Knekt, P., R. Järvinen, R. Seppänen, M. Heliövaara, L. Teppo, E. Pukkala, and A. Aromaa. 1997. Dietary flavonoids and the risk of lung cancer and other malignant neoplasms. Amer. J. Epidem. 146: 223-230.

Leighton, T., C. Ginther, L. Fluss, W.K. Harter, J. Cansado, and V. Notario. 1992. Molecular characterization of quercetin and quercetin glycosides in Allium vegetables phenolic compounds in food and their effects on health II. ACS Symposium Series. 507: 220-238.

Lombard, K.A. 2000. Investigation of the flavonol quercetin in onion (Allium cepa L.) by high-performance liquid chromatography (HPLC) and spectrophotometric methodology. M.S. Thesis. Texas Tech University.

Lombard, K.A., E. Geoffriau, and E. Peffley. 2002. Flavonoid quantification in onion (*Allium cepa* L.) by spectrophotometric and HPLC analyses. Hort Science 37(4):682-685.

Patil, B.S. and L.M. Pike. 1995. Distribution of quercetin content in different rings of various coloured onion (*Allium cepa* L.) cultivars. Journal of Horticultural Sciences 70(4): 643-650.

Patil, B.S., L.M. Pike, and K.S. Yoo. 1995. Variation in the quercetin content in different colored onions (*Allium cepa* L.). Journal of the American Horticulture Society 120(6): 909-913.

Rabinowitch, H.D. and J.L. Brewster. 1990. Onions and allied crops volume I: botany, physiology, and genetics onions and allied crops, vol I. CRC, Boca Raton. pp. 273.

Effects of Prickly Pear Control (Prescribed Fire x Herbicide) on Three Important Food Plants of Northern Bobwhite: An Observation

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ABSTRACT

Millions of acres of Texas rangelands have been infested by prickly pear cactus (*Opuntia* spp.). Because prickly pear is perceived as a nuisance plant to livestock producers, many landowners control prickly pear through a tandem of prescribed fire and an aerial application of picloram (4-amino-3,5,6-trichloropicolinic acid). While the effectiveness of such a practice has been documented, its effects on important wildlife food plants has received little attention. The objective was to compare density of 3 important food plants for northern bobwhite (*Colinus virgnianus*) between a burned-only and burned-and-sprayed area. A 1,198-ac pasture was burned in February 1998, and subsequently sprayed with picloram a 400-ac portion in April. Density for ragweed (*Ambrosia psilostachya*), croton (*Croton* sp.), and snow-on-the-mountain (*Euphorbia marginata*) was determined by randomly sampling 40 circular plots (20 in. radius) in both treatment areas during July 1998. Ragweed had a higher mean density in the burned-only area (19.8 plants/yd^2) compared to the burned-sprayed (1.3 plants/yd^2; *P* = 0.0001). Croton also had a higher mean density in the burned-only area (1.6 plants/yd^2) than in the burned-sprayed (0.2 plants/yd^2; *P* = 0.02). There was no difference in snow-on-the-mountain mean density between burn-only (0.3 plants/yd^2) and burned-sprayed (0.3 plants/yd^2; *P* = 0.5). Because forbs represent important food plants for wildlife, further research is needed to document the immediate and long-term impacts of picloram-treated sites.

KEYWORDS: Bobwhite, brush control, cactus, forb, northern bobwhite, picloram, prescribed fire, prickly pear

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Prickly pear cactus (*Opuntia* spp.; hereafter prickly pear) has invaded approximately 25 million acres of Texas rangelands (Lundgren et al. 1981). Prickly pear is perceived as a serious range management problem (Lundgren et al. 1981), especially in the Rolling Plains ecoregion of Texas (Scifres 1980:1-40). Dense stands of prickly pear interfere with forage utilization and livestock movement and handling (Ueckert 1997). Ingestion of prickly pear fruit also may cause ulceration and bacterial infection in the lips, tongue, palate, and gastrointestinal tracts of livestock, while the seeds may cause rumen impaction (Merrill et al. 1980). Therefore, many landowners advocate the control of prickly pear.

Prickly pear control often is achieved through prescribed fire and a subsequent aerial spraying of the herbicide picloram (4-amino-3,5,6-trichloropicolinic acid). This tandem of prescribed fire and picloram spraying is very effective in controlling prickly pear, achieving 98% mortality of prickly pear (Ueckert et al. 1988). While the effectiveness of prickly pear control has been documented, its effect on important wildlife food plants has received little or no attention.

In conjunction with prickly pear mortality, picloram is considered highly effective for control of broad-leaf herbaceous plants (i.e., forbs) on rangeland (Scifres 1980:165-170), resulting in a phenomenon referred to as "forb shock". The duration of forb shock is unknown for picloram; however, for other herbicides it can last at least 1 growing season after application (Scifres and Mutz 1978). Forbs represent important food plants for several wildlife species, such as northern bobwhite (*Colinus virginianus*; Lehmann, 1984:165–176), wild turkeys (*Meleagris gallopavo*; Hurst 1992), mourning doves (*Zenaida macroura*; Lewis 1993), and white-tailed deer (*Odocoileus virginianus*; Verme and Ullrey 1984). Thus, the reduction in forb abundance following prickly pear control might be detrimental to wildlife populations, depending on several factors such as the amount of area treated and degree of forb reduction.

The objective was to document immediate impacts (0-3 months post treatment) of prickly pear control on abundance of 3 important food plants for northern bobwhites (hereafter, bobwhites). Bobwhites were chosen as the case-study species because of their economic importance as a game bird.

MATERIALS AND METHODS

Study Area

This study was conducted on a private ranch located in Shackelford County, Texas, which lies at the junction of 2 ecoregions (Hernández 1999). The majority of the county (>75%) is found within the Rolling Plains ecoregion, while the far eastern portion of the county is contained within the Cross Timbers and Prairies ecoregion (Gould 1975). Mean annual rainfall in the Rolling Plains ranges from 22 to 30 in. (Correll and Johnston 1979). Soils vary from coarse sands to redbed clays and shales (Gould 1975). The general aspect of the landscape is a honey mesquite (*Prosopis glandulosa*) savannah. However, honey mesquite has increased its density over much of the region in the last 50 years, with prickly pear as a codominant over many areas (Scifres 1980:1-40).

Data Collection and Analysis

A 1,198-ac pasture was burned in February 1998 under prescriptions according to Natural Resource Conservation Service guidelines. The area was prescribed burned during morning hours (8-10 AM) using a headfire, which was conducted in 65º F, 35% humidity, and 10 mph wind speeds. In April 1998, a 400-ac portion was aerially sprayed with picloram at a rate of 0.25 lb/ac. In July 1998, 40 circular plots (20 in. radius) were randomly sampled in the burned-only and burned-sprayed areas. A non-treated area (i.e. control) was not sampled because in heavily-infested areas, prickly pear control is warranted in order to improve rangeland condition or manage wildlife habitat. Under this context, land stewards have to decide between the more effective method of controlling prickly pear (i.e., prescribed fire x picloram) or the more traditional method (i.e., prescribed burning only). Because the impacts realized on wildlife habitat by each method is an important consideration in this decision process, the intent was to document how each method impacted wildlife habitat, namely density of 3 important bobwhite food plants. Thus, no untreated area was sampled and the burned-only area represents the statistical control.

Forty random plots were selected in each area from a 55 yd. x 55 yd. grid overlain on a map of the study site. At each plot, the number of individual plants were counted for 3 forb species: western ragweed (*Ambrosia psilostachya*), croton (*Croton* sp.), and snow-on-the-mountain (*Euphorbia marginata*). These 3 species were selected because they represent important and common food plants for bobwhites in this ecoregion (Jackson 1972).

Density of the selected fobs was analyzed between treatments using Wilcoxon rank sums test (Daniel 1987) the data were not normally distributed. All results are reported as $\bar{x} \pm$ S.E. and consider results significant at $\alpha = 0.05$.

RESULTS

Ragweed was more dense in the burned-only area (19.8 ± 3.2 plants/yd^2) compared to the burned-sprayed area (1.3 ± 0.8 plants/yd^2 ; P = 0.0001). Croton also had a higher density in the burned-only (1.6 ± 0.5 plants/yd^2) than in the burned-sprayed (0.2 ± 0.1 plants/yd^2; P = 0.02). Lastly, there was no difference in snow-on-the-mountain density between burned-only (0.3 ± 0.1 plants/yd^2) and burned-sprayed (0.3 ± 0.1 plants/yd^2; P = 0.5).

DISCUSSION

Chemical control of prickly pear through the tandem treatments of prescribed fire and aerial spraying of picloram reduced forb density for 2 of 3 species. A significant difference in density was observed between treatments in ragweed and croton, but not snow-on-the-mountain. Results correspond with other research (McCarty and Scifres 1972), which indicates that picloram can effectively control ragweed. However, the response of individual forb species vary considerably to herbicides, which might explain why only 2 forb species were affected in this study. Blaisdell and Mueggler (1956) reported that only 13 of 38 forb species were moderately (34-66% kill rate) to severely (67-100% kill rate) damaged on a sagebrush (*Artemesia* spp.) community treated with 2,4-D . This varying susceptibility of plants to herbicides can be explained by stage of plant development at the time of treatment (Brady 1971).

Herbicides generally penetrate younger leaves more rapidly than older foliage (Scifres 1980) and are more effective during rapid vegetative growth and maximum emergence (McCarty and Scifres 1972). As plants age, species formerly killed by herbicides may be only slightly affected later (Scifres 1980). Because the forb species monitored in this study may have been at different development stages, the effect that picloram had on forb density possibly varied in this study.

A more critical question to consider is what impact the reduction in forb density actually has on wildlife populations. The answer to this question is a function of the effectiveness of the treatment in reducing forb density (i.e, which forb species are affected and the degree and duration of forb shock) and the scale of the treatment. Naturally, this relationship will vary by wildlife species. The focus is on bobwhites for the purpose of this discussion.

Food availability (as measured in kilograms of seed produced per hectare) generally is not considered limiting for bobwhites (Guthery 1997). However, forb shock resulting from prickly pear control may reduce temporarily (i.e., 0-2 years) food availability. Ragweed and croton densities were documented as being lower in the burned-sprayed area compared to the burned-only area. Ragweed and croton are important seed-producing plants for bobwhite in the Rolling Plains of Texas (Jackson 1972). Furthermore, density and structure of herbaceous plants influences the abundance of phytophagus insects (Lawton 1983). Insects represent an important food item for bobwhite chicks and breeding adults (Stoddard 1931:159-164, Rosene 1969:108). Therefore, reduction of forb density and potentially insect abundance following prickly pear control might be detrimental to bobwhites.

It is recommended that landowners consider an approach of prickly pear management instead of prickly pear eradication. Perhaps, landowners should manage prickly pear with prescribed fire and picloram only in areas of heavy infestations (i.e., solid, expanse stands of prickly pear). Periodic (every 5-7 years) prescribed fire by itself might be used to manage prickly pear in areas of lower infestation (Ueckert 1997). This management approach would allow landowners to manage cactus density while maintaining adequate bobwhite habitat at the landscape scale.

The impacts of prickly pear control (prescribed fire x picloram) on wildlife populations need to be investigated in greater detail. Specifically, research is needed to document the impacts of prickly pear control on seed production and insect abundance, as well as on the duration of forb shock on treated sites.

REFERENCES

Blaisdell, J. P., and W. F. Mueggler. 1956. Effect of 2,4-D on forbs and shrubs associated with big sagebrush. J. Range Manage. 9:38-40.

Brady, H. A. 1971. Spray date effects on behavior of herbicides on brush. Weed Sci. 19:200-204.

Correl, D. S., and M. C. Johnston. 1979. Manual of the Vascular Plants of Texas. Univ. Tex. Dallas, Richardson, Tex.

Daniel, W. W. 1987. Biostatistics: A foundation for analysis in the health sciences. Fourth ed. John Wiley and Sons, New York, NY.

Gould, F. W. 1975. Texas plants–a checklist and ecological summary. Tex. Agric. Exp. Sta. Misc. Publ. 585, College Station, Tex.

Guthery, F. S. 1997. A philosophy of habitat management for northern bobwhites. J. Wildl. Manage. 61:291-301.

Hernández, F. 1999. The value of prickly pear cactus as nesting cover for northern bobwhite. Ph.D. Diss., Texas A&M Univ.-Kingsville, Kingsville, Tex., Texas A&M Univ., College Station, Tex.

Hurst, G. A. 1992. Foods and feeding. P. 66-83 In: J. G. Dickson (ed). The Wild Turkey: Biology and Management. Stackpole Books, Harrisburg, Penn.

Jackson, A. S. 1972. Handbook for bobwhite quail managements in west Texas Rolling Plains. Tex. Parks Wildl. Bull. 48.

Lawton, J. H. 1983. Plant architecture and the diversity of phytophagus insects. Ann. Rev. Entomol. 28:23-29.

Lehmann, V. W. 1984. Bobwhites in the Rio Grande Plain of Texas. Texas A&M Univ. Press, College Station, Tex.

Lewis, J. C. 1993. Foods and feeding ecology. P. 181-204 In: T. S. Baskett, M. W. Sayre, R. E. Tomlinson, and R. E. Mirarchi (eds). Ecology and Management of the Mourning Dove. Stackpole Books, Harrisburg, Penn.

Lundgren, G. K., R. E. Whitson, D. N. Ueckert, F. E. Gilstrap, and C. W. Livingstron, Jr. 1981. Assessment of the prickly pear problem on Texas rangelands. Tex. Agric. Exp. Sta. Misc. Publ. 1483.

McCarty, M. K., and C. J. Scifres. 1972. Herbicidal control of western ragweed in Nebraska pastures. J. Range Manage. 25:290-292.

Merrill, L. B., C. A. Taylor, Jr., R. Dusek, and C. W. Livingston. 1980. Sheep losses from range with heavy prickly pear infestation. P. 1-99 In: D. N. Ueckert and J. E. Houston (eds). Rangeland resources research. Tex. Agric. Exp. Sta., Austin, Tex.

Rosene, W. 1969. The bobwhite quail: its life and management. Rutgers Univ. Press, New Brunswick, N. J.

Scifres, C. J., and J. L. Mutz. 1978. Herbaceous vegetation changes following applications of tebuthiuron for brush control. J. Range Manage. 31:375-378.

Scifres, C. J., and M. M. Kothmann. 1976. Site relations, regrowth characteristics, and control of lotebush with herbicides. J. Range Manage. 29:154-157.

Scifres, C. J. 1980. Brush Management: principles and practices for Texas and the southwest. Texas A&M Univ. Press, College Station, Tex.

Stoddard, H. L. 1931. The bobwhite quail: its habits, preservation and increase. Charles Scribner's Sons, New York, N. Y.

Ueckert, D. N. 1997. Prickly pear ecology. P. 33-42 In: D. Rollins, D. N. Ueckert, C. G. Brown (eds). Brush sculptors. Tex. Agric. Ext. Serv., San Angelo, Tex.

Ueckert, D. N., J. L. Peterson, R. L. Potter, J. D. Whipple, and M. W. Wagner. 1988. Managing prickly pear with herbicides and fire. Tex. Agric. Exp. Sta. Consol. Prog. Rep. 4570:10-15.

Verme, L. J., and D. E. Ullrey. 1984. Physiology and nutrition. P. 91-128 In: L. K. Halls (ed). White-Tailed Deer Eecology and Management. Stackpole Books, Harrisburg, Penn.

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Relationship Between Landscape Aspect and Playa Alignment on the Texas High Plains

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ABSTRACT

Playas (ephemeral lakes) of the Texas High Plains (THP) appear to be aligned when observed on small scale maps or aerial photographs. Playa orientation, however, has eluded spatial description and the landscape topography relationships are unknown. This study examined the relationship between landscape aspect and playa alignment for 23 THP counties. Landscape topography was evaluated using aspect direction as determined from 100 ft (~33m) contours presented on U. S. Geological Survey 1:250,000 topographic quadrangle maps. Playa alignment was evaluated with the Hough transform using a Linear Evaluation of Actual Points Program (LEAPP). Playa alignment from LEAPP correlated with landscape aspect from USGS map contours with a correlation coefficient of 0.17. Playas were aligned with aspect direction by quadrant for 13 of the 23 THP counties evaluated. For those 13 counties, the average aspect was 112 degrees for the contour method compared to 117 degrees for the LEAPP method indicating a relationship between landscape aspect and playa alignment.

KEYWORDS: Hough transform, Linear Evaluation of Actual Points Program, Texas High Plains.

INTRODUCTION

One of the most interesting geomorphic features on the Texas High Plains (THP) is the ephemeral lake known as a playa. These transient wetlands provide critical wildlife habitat throughout the region (Bolen et al. 1989). Playa lakes are defined in terms of the fine-textured soils that typically occupy the lowest elevational position in the otherwise flat topography (Zartman and Allen 1999). Most playa soils were historically mapped as Randall clay (fine, smectitic, thermic Ustic Epiaquerts). Current efforts by the Natural Resources Conservation Service have remapped and reclassified many of the playas making the ubiquitous Randall soil just one of several playa lake soils. Competing soil series are the Ranco, Rosston and Ustibuck while similar soils are the Chapel, McLean, Lazbuddie, Lockney and Sparenburg.

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Playas appear to be aligned when viewed from the air or on small-scale aerial photographs and maps. Finley and Gustavson (1981) noted this linear orientation of playas and speculated that underlying geologic structures may control playa location. Reeves (1990) stated that most playas formed from a combination of eolian activity at the soil surface and dissolution and subsidence of underlying geologic strata. Gustavson et al. (1995) attributed playa formation to complex pedogenic, geologic and biological processes.

Zartman and Fish (1989, 1992) evaluated playa alignment by several different methods. Linear regression worked quite well ($r^2 \geq 0.98$) when the playas were within 5 km of draws (Zartman and Fish 1992). Their work, however, suggested no significant linear relationships away from the natural drainage ways. Using a geostatistical approach, Zartman and Fish (1989) reported almost east-west (275 degrees) and north-south (350 degrees) lineation of playas on a subset of the playas of Castro County, Texas. Playa analysis of the whole county showed the strongest linear spatial distribution was along an axis of approximately west-northwest through east-southeast (Zartman and Fish 1992).

The efforts of Zartman and Fish (1989, 1992) were very time intensive and may include human bias in pattern interpretation. Recent efforts in pattern recognition have utilized the Hough transform (HT) to evaluate natural shapes for lineament detection (Samal and Edwards 1997, Wang and Howart 1990). HT is a mathematical means to identify straight lines (Hough 1962). A principal application of the HT has been by the military (Casasent and Krishnapuram 1987, Krishnapuram and Casasent 1989, Kiryati and Bruckstein 1991, Yankowich and Farooq 1998). Cross (1988) used the HT to detect circular geological features while Cross and Wadge (1988) determined geological lineaments. Wang and Howarth (1990) and Karnieli et al. (1996) used HT for automatic lineament detection of geologic features. Zartman et al. (2000) developed the LEAPP algorithm to use the Hough transform to analyze linear features.

Our hypothesis was that the playa alignment should be related to landscape aspect on the THP. Our objective was to quantify the relationship between landscape aspect direction using USGS maps and playa alignment through LEAPP.

MATERIALS AND METHODS

Twenty-three Texas counties within the Texas High Plains (THP) form the study area (Fig. 1).

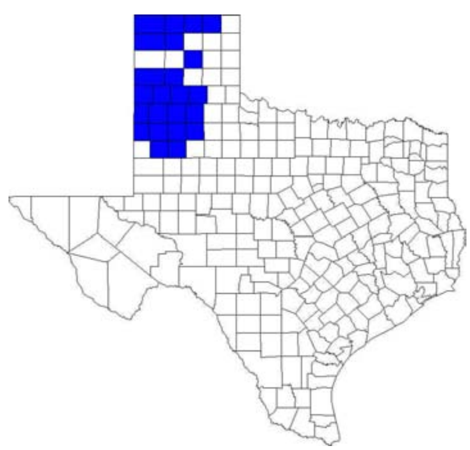

Figure 1. Counties evaluated for landscape aspect and playa alignment.

Playa location data from Fish et al. (1999) were analyzed for playa alignment using the LEAPP algorithm written in C^{++} (Zartman et al. 2000). Those playa locations were expressed in Albers equal area projection grid coordinates for the playa center of mass to the nearest 50 m. Primary data sources for the playas were Landsat imagery and Natural Resources Conservation Service (Soil Conservation Service) County Soil Survey Reports. United States Geological Survey 1:250,000 topographic quadrangle maps for the THP were used to determine the surface aspect topography. Aspect data were manually computed using the perpendicular angle to the chord of the median 100 foot (~33m) contour of the USGS map for that particular county in the THP. For counties split between the THP and the Rolling Plains (Brisco, Crosby and Floyd), only the contours from the THP areas were used. Directional attributes were reported in compass angle from 0° (North) through 90° (East) to 180° (South). Statistical analysis of means, standard deviations and correlation were performed in Excel.

RESULTS AND DISCUSSION

While the general aspect orientation of the Texas High Plains (THP) is towards the southeast, individual counties have their own aspects. Our general hypothesis was that the aspect direction of the county would determine the dominate playa orientation. To evaluate this premise, we evaluated the landscape aspect and dominate playa alignment for each of the 23 THP counties within the study area (Table 1).

Table 1. Best playa lineation angle using the LEAPP program or landscape aspect determined from USGS topographic maps by county on the Texas High Plains.

County	LEAPP angle	Contour angle
Bailey	93	162
Briscoe	139	120
Carson	83	33
Castro	111	152
Cochran	176	103
Crosby	60	130
Dallam	92	11
Deaf Smith	83	143
Floyd	163	112
Hale	3	122
Hansford	91	62
Hartley	119	170
Hockley	103	105
Lamb	103	159
Lubbock	2	127
Lynn	133	119
Moore	74	45
Ochiltree	45	27
Parmer	174	147
Randall	89	122
Sherman	83	130
Swisher	41	120
Terry	89	128

Based upon the aspect directions determined from the USGS maps, 18 of the 23 counties sloped to the southeast, while the remaining five counties sloped to the northeast. Mean contour aspect direction angle for all the counties in the study was 111 degrees (southeast) with a standard deviation of 45 degrees. For those counties that sloped to the southeast, the aspect orientation angle was 132 degrees with a standard deviation of 20 degrees. For the five counties that sloped to the northeast, the aspect orientation angle was 36 degrees with a standard deviation of 19 degrees.

Lineation as determined by LEAPP, was almost equally divided between those playas oriented to the northeast (11) and those oriented towards the southeast (12). Mean LEAPP angle for all counties in the study was 93 degrees (east) with a standard deviation of 46 degrees. The 12 counties with playa orientation to the southeast had an average orientation angle of 125 degrees and a standard deviation of 32 degrees. The 11 counties that had playas oriented towards the northeast, the average angle was 59 degrees with a standard deviation of 33 degrees.

Individual playa alignments and topographic aspect relationships were complex. When all 23 THP counties were evaluated, the landscape aspect and playa lineation had a correlation coefficient of 0.17. The average angles as determined by the two methods were similar (111 vs. 93 degrees). This seems to be, however, an artifact because the average absolute difference in angle between the two methods was 46 degrees. The median difference was 50 degrees and the mode was 51 degrees. Some counties differed greatly in aspect directions (Swisher varied by 79 degrees). While others such as Hockley County, were very similar with the county aspect angle of 105 degrees which agrees with the LEAPP angle of 103 degrees. Lubbock County would appear to differ greatly in orientation angle (2 vs. 127 degrees). The LEAPP orientation of two degrees can be alternatively be thought of as 182 compass degrees. Therefore, the angular differences in Lubbock County are actually only 55 degrees. Additionally, the playa orientation of two degrees for Lubbock County may reflect the presence of the Blackwater Draw. While a correlation coefficient of 0.17 is small, it indicated some spatial relationship between the lineation of the playas and the county aspect direction.

Thirteen of the 23 THP counties had similar quadrant directional aspects determined by contour evaluation and playa alignment angle as determined by LEAPP. For those 13 counties, the contour angle was 112 degrees whereas the LEAPP angle was 117 degrees. The standard deviation of 49 degrees for the contour method and 40 degrees for LEAPP method were also similar. In most instances (10 of 13), these counties sloped to the southeast. For counties that sloped to the southeast, the two methods, however, were negatively correlated (-0.48) with one another. This indicated that while counties and playas sloped the same general direction, specific slopes were not well matched. The remaining three counties (Carson, Moore and Ochiltree) sloped predominately to the northeast probably reflecting the influence of the Canadian River. For these three counties, the contour and LEAPP methods were positively correlated (0.59). This indicated both surface topography and playa alignment were probably influenced by the Canadian River escarpment.

CONCLUSIONS

Surface topography was related to playa alignment in some, but not all, of the areas studied. So far as we could determine, there was no overall pattern of landscape aspect and playa alignment throughout the THP. While the absolute correlation coefficient between the contour method using 1:250,000 topographic quadrangle maps and LEAPP for playa orientation overall was low (0.17), 13 of 23 counties had similar quadrant orientations. For those 13 counties, compass angles determined by the two methods were remarkably similar (112 for contour and 117 degrees for LEAPP). This knowledge may allow us to better understand the origin of playas as well as to better understand the possible consequences of current or projected uses of these critical wildlife habitats.

REFERENCES

Bolen, E. G., L. M. Smith and H. L. Schramm, Jr. 1989. Playa Lakes: Prairie wetlands of the Southern High Plains. BioSci. 39:615-623.

Casasent, D. and R. Krishnapuram. 1987. Detection of target trajectories using the Hough transform. Applied Optics 26:247-251.

Cross, A. M. 1988. Detection of circular geological features using the Hough transform. Int. J. Remote Sensing. 9(9): 1519-1528.

Cross, A. and G. Wadge. 1988. Geological lineament detection using the Hough transform. Int. Geosci. and Remote Sensing Symp. Pp. 1779-1782. Edinburgh, U. K.

Finley, R. J. and T. C. Gustavson. 1981. Lineament analysis based on Landsat imagery, Texas panhandle. TX. Bureau Econ. Geol. Circular 85-5.

Fish, E. B., E. L. Atkinson, C. H. Shanks, C. M. Brenton and T. R. Mollhagen. 1999. Playa Lakes Digital Database for the Texas Portion of the Playa Lakes Joint Venture Region. Tech. Pub #T-9-813 (CD-ROM) College of Ag. Sci. and Nat. Res., Texas Tech University, Lubbock, TX.

Gustavson, T. C., V. T. Holliday and S. D. Hovorka. 1995. Origin and development of playa basins, sources of recharge to the Ogallala aquifer, Southern High Plains, Texas and New Mexico. Rtp. of Investigations No. 229. Bureau Econ. Geol. Austin, TX 44p.

Hough, P. V. C. 1962. Method and means for recognizing complex patterns. U. S. Patent 3069654.

Karnieli, A., A. Meisels, L. Fisher and Y. Arkin. 1996. Automatic extraction and evaluation of geologic linear features from digital remote sensing data using a Hough transform. Photo. Eng. And Remote Sensing 62(5):525-531.

Kiryati, N. and A. M. Bruckstein. 1991. On navigating between friends and foes. IEEE Trans. on Pattern Analysis and Machine Intelligence. 13:602-606.

Krishnapuram, R. and D. Casasent. 1989. Hough transform detection of 3-D curves and target trajectories. Applied Optics. 28:3479-3486.

Reeves, C. C., Jr. 1990. A proposed sequential development of lake basins, Southern High Plains Texas and New Mexico. In, Gustavson, T. C. (ed.), Geologic framework and regional hydrology: Upper Cenozoic Blackwater Draw and Ogallala Formations, Great Plains. Pp.209-232 Bureau of Econ. Geol. Univ. of Texas. Austin, TX.

Samal, A. and J. Edwards. 1997. Generalized Hough transform for natural shapes. Patt. Recog. Lett. 18:473-480.

Wang, J. and P. J. Howarth. 1990. Use of the Hough transform in automated lineament detection. IEEE. Trans. Geosci. and Remote Sen. 28:561-566.

Yankowich, S. W. and M. Farooq. 1998. Hough transform based multisensor, multitarget, track initiation technique. Opt. Eng. 37:2064-2077.

Zartman, R. E and B. L. Allen. 1999. MLRA 77: Southern High Plains. P. 73-109. In H. Don Scott (ed.) Water and Chemical Transport in Soils of the Southeastern United States. Ark. Ag. Expt. Sta. Special Report 197. 388.p.

Zartman, R. E and E. B. Fish. 1989. Size, distribution, and orientation pattern of playa lakes in northwestern Castro County, Texas. Tx. J. of Agr. and Nat. Res. 3:31-33.

Zartman, R. E and E. B. Fish. 1992. Spatial characteristics of playa lakes in Castro County, Texas. Soil Science 153:62-68.

Zartman, R. E, C. Kroeker and E. B. Fish. 2000. Linear Evaluation of Actual Points Program (LEAPP). Tx. J. Agr. and Nat. Res. 13:45-50.

Learning Style, Preparation Techniques, and Success of Secondary Students Participating in a Nursery/Landscape Career Development Event

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ABSTRACT

The purpose of this study was to determine if a relationship existed between self-perceived learning styles of selected students and preparation techniques and success in Career Development Events (CDE). A tutorial website was developed to assist secondary Agricultural Science teachers and their students in preparing for the 2002 Texas Nursery/Landscape Career Development Event. Data were gathered using the Ways of Knowing Learning Style Inventory. Participants were self-selected for the survey based on their participation in a Nursery/Landscape CDE and their use of the CDE website tutorial. Most participants in the Nursery/Landscape CDE were white females aged 16-18. Regardless of gender, the most widely used training method for the CDE was videos/slides, followed closely by greenhouse/garden centers. Most had not used the CDE website tutorial. Frequencies indicated that males utilized the website tutorial to a greater extent than females, and yielded higher individual scores in the CDE than females. Most participants who used the website tutorial accessed the site from a school computer. The majority of participants were Concrete Active learners; however, participants who abstractly perceived learning performed better overall in the Nursery/ Landscape CDE.

KEYWORDS: Agricultural Education, Learning Styles

INTRODUCTION

Educators believe that studying the manner in which individuals learn is at the heart of educational enhancement. Learning style is thought to shape student educational performance (Kolb 1976, Dorsey and Pierson 1984, Cano et al. 1992a, Cano et al. 1992b, Torres and Cano 1994, Cano and Garton 1994, Whittington and Raven 1995, and Garton et al. 1997). Whittington and Raven described learning style as "the predominant and preferred manner in which individuals take in, retain, process, and recall information" (1995, p. 10). Since learning styles impact how effectively individuals learn in certain circumstances, educators should be responsive to cognitive technique variations (Shih and Gamon 2001). Agricultural education researchers (Cano et al. 1992a, Cano et al. 1992b, Cano and Garton 1994, Whittington and Raven 1995) determined the diversity of learning styles for Agriculture Science Teachers as well as preservice Agriculture Science Teachers. It stands to reason that secondary agriculture students are equally unique individuals with diverse learning styles. To that end, research suggested that learning styles might be an influential component in achieving success at the secondary level as both students and agricultural teachers embrace new technology.

Marrison and Frick (1993) affirmed the dramatic increased use of microcomputers in secondary schools across the nation. They recommended "….computer modules should be used by agricultural education teachers to supplement or replace a portion of traditional classroom instruction" (p. 37). Meeting the needs and goals of these students in the 21st century was an essential commitment of the Agriculture Science Teacher. Web-enhanced instruction was a viable means of promoting active learning. Such innovative approaches allowed the opportunity to individualize instruction to accommodate differences in educational goals, abilities, and learning styles. Another appeal of web-enhanced instruction was the convenience of accessing information at any time and from any place.

The model for Agricultural Science stressed the importance of classroom and laboratory instruction along with application through Supervised Agricultural Experience (SAE), incentives and FFA. These students were expected to participate in Career Development Events (CDE) to enhance learning. The importance of competition for students as a learning tool and the impact competition had on student self-esteem was generally held.

In 2002, Texas had 1460 Agriculture Science Teachers with over 100,000 students and 56,000 FFA members (Texas FFA background and info. n.d.). Traditionally, secondary agriculture students competing in the Nursery/Landscape CDE had prepared using live greenhouse plants, reference texts, and previous contest materials. While use of the Internet in Agriculture instruction at the secondary level had rapidly increased, it was still a relatively new practice. Research indicated students were more successful in classes if teachers used a variety of methods to address the different learning styles of students. However little research was found relating the impact of students' learning styles and students' preferred preparation techniques for Career Development Events. Therefore, a need existed to determine if learning styles and preparation techniques influenced success in a Career Development Event.

The purpose of this study was to determine if a relationship existed between self-perceived learning styles of selected students and preparation techniques and success in Career Development Events.

MATERIALS AND METHODS

Website tutorial. A tutorial website was developed to assist secondary Agricultural Science teachers and their students in preparing for the Nursery/Landscape CDE. The website tutorial included photographs of the 100 plants in the identification portion of the CDE, categorized by common and scientific name. Additionally, the website included the 200 questions from which the State CDE exam was taken; the answer key; a class of four landscape designs with accompanying site analysis, family profile, placing and justification. A link to the website was posted on the SWT Agriculture Department website: www.swt.edu/agriculture. Information regarding the website was made available to Texas Agricultural Science teachers via a postcard mailing and electronic mail. Additionally, information about and access to the site was available via links from the Texas FFA website as well as the unified CDE registration website for the state. The use of the materials as primary or supplemental study aids was left to the discretion of each participating Agriculture Science teacher or student.

Instrument. The Ways of Knowing Learning Style Inventory (Pierson and Frost, 1992) was used for the study. The inventory is a self-description survey, on which respondents rank four words in nine different items, based on their perceptions of the primary way they learn. Figure 1 provides an overview of the learning style categories. A section was added to the instrument to elicit responses from respondents regarding selected demographic information and use of the website as a study aid. The developers of The Ways of Knowing instrument report a reliability of 0.90 (Dorsey and Pierson 1984, Pierson and Frost 1992).

Concrete Active (CA) • Left brain preference and emphasizes concreteness and activeness • Likes to do things and will take risks. • Works well with people • Becomes aware through the senses and is extroverted • Generally employed in business-related occupations	**Abstract Reflective (AR)** • Right brain preference and emphasizes abstractness and reflectiveness • Likes to create theoretical models • Uses inductive reasoning to solve problems • Theory-oriented • Becomes aware through intuition and is introverted • Generally employed in science-related occupations
Concrete Reflective (CR) • Right brain preference and emphasizes concreteness and reflectiveness • Likes to create and has great imaginative ability • People-oriented and emotional • Becomes aware through the senses and is introverted • Generally employed in service-related occupations	**Abstract Active (AA)** • Left brain preference and emphasizes abstractness and activeness • Likes to make practical applications • Uses deductive reasoning to solve problems • Thing-oriented and not emotional • Becomes aware through intuition and is extroverted • Generally employed in technical-related occupations

Figure 1. Characteristics of learning style types as defined in the Ways of Knowing Learning Style Inventory (Pierson and Frost 1992).

Population. The target population was all students in Texas training for the 2002 Nursery/Landscape CDE. A sample representing the population was chosen from the students attending the SWT Invitational CDE in March 2002. The SWT Invitational CDE has historically drawn participants from across the state of Texas who were preparing for the Texas Nursery/Landscape CDE.

Method. The researchers provided the survey instrument to respondents during a rotational down period of the CDE. At the time voluntary completion of the instrument was requested, instructions were given and confidentiality was assured. Students who had not used the website were assigned to the control group, while students who had used the website, regardless of frequency, were assigned to the treatment group. The data were analyzed using the Statistical Package for the Social Sciences (SPSS) for Windows Release 10.0 (SPSS 1999). Statistical procedures included descriptive statistics, frequencies and analysis of variance.

RESULTS

Sixty responses were gathered of which 45 were female and 15 were male (Table 1). Demographic information indicated that the CDE participants included approximately equal numbers of fifteen through eighteen year olds. The overwhelming majority of respondents were Caucasian, although Native American, African American, and Hispanic responses were also reported (1, 1, and 10, respectively). This level of response was adequate for supplying ideas for the given population, but was not intended for generalizations to other populations.

When asked about training methods, regardless of gender, the most widely used training method for the SWT Nursery/Landscape CDE was videos/slides, followed closely by greenhouse/garden centers (Table 1). Most had not used the SWT CDE website tutorial. Videos and slides were used by 55 (92%) of the contestants, while 50 (83%) indicated training at a greenhouse or garden center. Contestants also reported using textbooks (52%) and living laboratories (10%). However, only eighteen (30%) reported using the SWT CDE website.

Table 1. Number of male and female survey participants indicating various training methods used to prepare for the Southwest Texas State University Career Development Event.

Characteristic	Female	Male	Total
Training Methods			
Greenhouse/Garden Center	36	14	50 [a]
Videos/Slides	41	14	55 [a]
Textbooks	24	7	31 [a]
Living Laboratory	2	4	6 [a]
SWT CDE Website	12	6	18 [a]

[a] More than one training method was reported

The majority of both female (73.3%) and male (60.0%) respondents indicated they had not used the SWT website in preparation for the CDE (Table 2). However, 18 of the 60 contestants reported they had used the website, with none reporting having visited the site more than 10 times. Although a larger percentage of males (40%) than females (27%) reported using the website, the difference was not statistically significant ($p = 0.905$). Respondents were asked to note the access location and frequency of use of the Southwest Texas State University CDE website (Table 3). A greater percentage of both females and males (15.6% and 20.0%, respectively) reported accessing the website from school.

Table 2. Frequency and percentages of reported website use of male and female survey participants at the Southwest Texas State University Career Development Event.

	Female		Male		Total	
No. of Uses	Freq.	%	Freq.	%	Freq.	%
0	33	73.3	9	60.0	42	70.0
1-5	10	22.3	6	40.0	16	26.6
6-10	2	4.4	0	0.0	2	3.4

Table 3. Frequency and percentages of reported website access locations of male and female survey participants at the Southwest Texas State University Career Development Event.

	Female		Male		Total	
Location	Freq.	%	Freq.	%	Freq.	%
Home	1	2.2	2	13.3	3	5.0
School	7	15.6	3	20.0	10	16.7
Both Home and School	4	8.9	1	6.7	5	8.3
No Access	33	73.3	9	60.0	42	70.0

A majority of both female (55.6%) and male (53.3%) respondents were discovered to be Concrete-Active learners based on the way they completed the Ways of Knowing instrument (Table 4). A vast majority of the respondents preferred to actively process information, while only 20 percent indicated they were more reflective in their processing style. More female respondents perceived information concretely than abstractly. Male respondents were fairly evenly split regarding the way they perceived information for learning.

Table 4. Frequency and percentages of learning style types of male and female survey participants at the Southwest Texas State University Career Development Event.

	Female		Male		Total	
Learning Style	Freq.	%	Freq.	%	Freq.	%
Concrete Active (CA)	25	55.6	7	46.7	32	53.3
Concrete Reflective (CR)	6	13.3	0	0.0	6	10.0
Abstract Reflective (AR)	3	6.7	3	20.0	6	10.0
Abstract Active (AA)	11	24.4	5	33.3	16	26.7

When comparisons were made between the CDE scores of males and females, a statistically significant difference was found (Table 5). The maximum possible individual score for the Nursery/Landscape CDE was 900. The mean score for the male participants was almost 100 points higher than the mean score for the female respondents (514 and 418, respectively).

Table 5. Results of an analysis of variance comparing male and female survey respondents to Southwest Texas State University Career Development scores.

Gender	N	Mean Score	SD	df	F	p
Female	45	418.04[a]	122.735	1	5.409	0.006**
Male	15	514.07[a]	159.102			

[a] Scores range from 0 to 900 with higher numbers indicating more positive scores.
**p<0.01

When looking at the frequencies of participants' use of the website, broken out by learning style, the Concrete Active and the Abstract Active learners, the most common styles in this study, appeared to have used the website most (Table 6). However, an analysis of variance revealed no statistically significant difference (p = 0.27) between the four learning styles and use of the website. Interestingly, the Abstract Active learners were the most evenly split group between website use and website non-use.

Table 6. Frequency and percentages of learning style types of survey participants and the use of the Southwest Texas State University Career Development Event training website.

	Website Use		No Website Use	
Learning Style	Frequency	Percentage	Frequency	Percentage
Concrete Active (CA)	8	25.0	24	75.0
Concrete Reflective (CR)	1	16.7	5	83.3
Abstract Reflective (AR)	2	33.3	4	66.7
Abstract Active (AA)	7	43.8	9	56.2

A multivariate analysis of variance revealed statistically significant differences in comparisons of respondents' different learning styles and the individual CDE scores (Table 7). Individuals who reported AR and AA, indicating an abstract learning style, scored on average over 100 points higher at the contest, compared to CR or CA, indicating concrete learning styles. The group of students with abstract reflective learning styles had the highest individual mean scores, while the group of students with concrete reflective learning styles had the lowest individual mean scores.

Table 7. Results of an analysis of variance comparing different learning styles of respondents to Southwest Texas State University Career Development scores.

Self-Perceived Learning Style	N	Mean Score	SD	df	F	p
Concrete Active (CA)	32	397.75	101.906	3	2.961	.040*
Concrete Reflective (CR)	6	389.67	137.609			
Abstract Reflective (AR)	6	535.67	168.985			
Abstract Active (AA)	16	515.19	151.461			

Note. Scores range from 0 to 900 with higher numbers indicating more positive scores.
$*p<0.05$

CONCLUSIONS

Past research indicated agriculture students were more likely to be Concrete Active learners. This held true for the participants in this study. Agricultural education researchers have stressed the importance of addressing the way agriculture students perceive information, however it may be just as important to address the way agricultural students process information. Since the overwhelming majority of FFA members participating in the study were Active in the way they process information, teachers and coaches should let students try out new ideas as active participants in the learning process.

Using computers with Internet capability, participants were able to access the SWT CDE website tutorial from home as well as school. Availability of such resources should provide additional impetus for secondary Agricultural Science Teachers to incorporate technology in their teaching. Students will be more likely to use such learning aids at home if they were introduced to them in a school setting. Furthermore it allows the Agriculture Science Teacher to, in effect, go home with each student for the purpose of extending and reinforcing learning and preparing for Career Development Events.

Although this study pointed to a group of participants with a certain learning style as having more success in a Career Development Event, the researchers stress it was not their intent to indicate Agricultural Science Teachers should select teams based on learning styles in order to win contests. On the contrary, it is the contention of these researchers that all students can be successful in Career Development Events. Teachers can better prepare their students by addressing the preferred learning style and providing learning opportunities to complement a student's preferred style.

In the SWT Nursery/Landscape CDE, the Abstract Reflective learners scored highest. The nature of the CDE requires analysis and judgments with limited artistic expression. It would be interesting to replicate the study with participants in a Floriculture CDE where the artistic expression is a larger component of the scoring. Additional research is also necessary to investigate relationships of team members with different learning styles. The researchers plan a follow-up study with a larger population to assess the impact of learning style on the use of the CDE website tutorial as a training aid.

REFERENCES

Cano, J. and B. L. Garton. 1994. The relationship between agriculture perservice teachers' learning styles and performance in a methods of teaching agriculture course. Journal of Agricultural Education, 35(2), 6-10.

Cano, J., B.L. Garton and M. R. Raven. 1992. Learning styles, teaching styles and personality styles of perservice teachers of agricultural education. Journal of Agricultural Education, 33(1), 46-52.

Cano, J., B. L. Garton and M. R. Raven. 1992. The relationship between learning and teaching styles and student performance in a methods of teaching agriculture course. Journal of Agricultural Education, 33(3), 16-21.

Dorsey, O. L. and M.J. Pierson. 1984. A descriptive study of adult learning styles in a nontraditional educational program. Lifelong Learning: An Omnibus of Practice and Research. 7(8),8-11.

Garton, B. L., G.W. Thompson and J. Cano. 1997. Agriculture teachers and students: in concert or conflict? Journal of Agricultural Education, 38(1), 38-45.

Kolb, D. A. 1976. Learning Style Inventory Self-scoring Test and Interpretation Booklet. McBer and Co., Boston.

Marrison, D. L. and M. J. Frick. 1993. Computer multimedia instruction versus traditional instruction in post-secondary agricultural education. Journal of Agricultural Education, 34(1), 31-38.

Pierson, M. J. and C. J. Frost. 1992. Ways of knowing. [Cyber courses]. Retrieved Nov. 18, 2002 from Southwest Texas State University, Occupational Education Dept. Web Site: http://www.oced.swt.edu

SPSS. 1999. SPSS 10.0 for Windows^{TM}. Prentice Hall Englewood Cliffs, New Jersey.

Shih, C. and J. Gamon. 2001. Student Learning Styles, Motivation, Learning Strategies, and Achievement In Web-Based Courses. Retrieved Oct. 01, 2001 from Wake Forest University International Center for Computer Enhanced Learning. Web Site: http://iccel.wfu.edu/publications/journals.

Texas FFA background and info. (n.d.).Retrieved Nov. 18, 2002 from Texas FFA Web Site: http://www.txaged.org/tfa-fact.html.

Torres, R.M. and J. Cano. 1994. Learning styles of students in a college of agriculture. Journal of Agricultural Education, 35(4), 61-66.

Whittington, M.S. and M. R. Raven. 1995. Learning and teaching styles of student teachers in the northwest. Journal of Agricultural Education, 36(4), 10-17.

Phosphorus Reductions in Runoff and Soils from Land-Applied Dairy Effluent Using Chemical Amendments: An Observation

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ABSTRACT

Field application of dairy effluent at nitrogen (N) agronomic rates generally leads to an over-application of phosphorus (P). A build up of soil P then occurs that can increase the soluble P in rainfall-runoff. Increases in runoff soluble P can cause surface water quality problems, because P is generally the limiting nutrient to algal growth in freshwater systems. Chemical amendments may reduce P solubility from effluent application fields by binding P into less soluble forms. This demonstration was conducted to display the impacts of two amendments, alum and gypsum, to soils and runoff using simulated rainfall conditions on a field historically used for dairy effluent application. Large decreases in soluble P in runoff and soil extractable P were seen on the alum-amended plot compared to the control. On the gypsum-amended plot, changes in soluble P concentrations in runoff were not observed, although small but notable decreases in soil P were indicated. These results indicate that alum may be a suitable chemical amendment for reducing soluble P from dairy effluent application fields. Long-term, replicated studies under natural rainfall conditions are needed to evaluate the impact of alum not only on runoff and soil P concentrations but also on forage quality and yield.

KEYWORDS: soluble reactive phosphorous, alum, gypsum, waste management, water quality

Rainfall runoff from animal waste application fields is coming under ever increasing scrutiny as a nonpoint source of pollution, especially as a source of phosphorus. Animal wastes are generally applied at a nitrogen (N) uptake rate for crops, leading to an over-application of phosphorus (P) in relation to crop uptake. For example, the N to P ratio in dairy manure is about 3:1, while most plants uptake N and P at a ratio of about 10:1 (Gilliam 1995). This over application of P has been associated with high P concentrations in rainfall runoff (e.g., Reddy et al. 1979, Sharpley et al. 1993) and linked to increasing P concentrations in receiving stream waters (McFarland and Hauck 1999). The over application of P on land does not generally have a negative impact on the growth of crops, although excessive P in the soil has been noted to decrease the ability of

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some plants to uptake micronutrients, particularly iron and zinc (Provin and Pitt 1999). In contrast, excessive P in surface waters can lead to negative impacts. Most freshwater systems are P limited with respect to algal growth (Gibson 1997). As additional P is added to lakes and streams via rainfall-runoff from waste application fields, the growth of algae and other aquatic plants may increase to undesirable levels impairing the use of water as fisheries, for recreation, and by industry and municipalities. The presence of excessive algae can physically cause filtration, aesthetic, and transportation problems, and also may cause chemical problems with regard to oxygen depletion (Boyd 1990) and the release of undesirable compounds generally associated with the decomposition of dead algae (Martin and Cook 1994, Codd 1995).

While most P that moves from agricultural fields to surface waters is sediment bound (NRC 1993), the application of manure to land, particularly when applied to the same field for many years, can increase the amount of soluble P moving in rainfall-runoff (Sharpley et al. 1993). Soluble P is largely readily available to algae for growth, while only a portion of sediment-bound P is readily available for algal uptake (Sharpley and Smith 1992). In controlling the runoff of P from fields, the reduction of soluble P losses may need to be considered separately from the reduction of sediment-bound P. Many erosion control practices, such as no-till, can greatly decrease the concentration of total P in field runoff, but may do little to control runoff of soluble P (e.g., Andraski et al. 1985, Baker and Laflen 1982).

One potential practice for controlling the runoff of soluble P from manure application fields involves the use of chemical amendments. Chemical amendments, such as gypsum and alum, have been used extensively in treating P in municipal wastewaters (Yeoman et al. 1988, Tchobanoglous and Burton 1991). Only recently have efforts focused on the transfer of this technology to animal wastes. Several laboratory studies have shown the potential promise of chemical amendments in reducing soluble P associated with animal manure (Anderson et al. 1995, Jones and Brown 2000, Moore and Miller 1994, Shreve et al. 1996), but only a few studies have evaluated the impact of chemical amendments on reducing P in runoff in the field (Edwards et al. 1999, Shreve et al. 1995). The purpose of this project was to demonstrate in the field using simulated rainfall the impacts of applying alum and gypsum as chemical amendments to a field historically used for dairy effluent.

MATERIALS AND METHODS

Three 8-ft by 10-ft plots were located on a dairy waste application field in Erath county, Texas. Plots were oriented with the slope along the long axis. Plots were labeled A (alum amendment), G (gypsum amendment), and C (control). The slope was 5.4 percent for plot A, 6.4 percent for plot C, and 5.9 percent for plot G. Soil type was a Windthorst (subgroup *Udic Paleustalfs*) according to the Erath County Soil Survey (USDA-SCS 1973). The soil was classified as a sandy loam based on a soil texture analysis for a 0-6 inch sample with 60 percent sand, 30 percent silt, and 10 percent clay. The field was typically maintained in a sorghum (*Sorghum bicolor*)-wheat (*Triticum* spp.) rotation with dairy effluent historically applied using a center pivot irrigation system. Plots were installed after sorghum planting in mid-May 2001.

During the study, the dairy operator did not apply manure or effluent to the field-plot area. The dairy operator did apply nitrogen (N) fertilizer (33-0-0) in late-May at a rate of about 100 lb/ac N. No commercial N was to have been applied to the field-plot area, but a miscommunication occurred between researchers and the dairy operator and his field personnel. The realization that commercial N had been applied to the field-plot area did not occur until after effluent was applied on the demonstration plots. This demonstration trial, thus, represents an over application of N above agronomic rates, which is not recommended. Although the focus of this demonstration is on P, the demonstration results also indicate the potential consequences of over applying N.

Effluent was applied on June 8, 2001 at the N agronomic rate assuming two cuttings of sorghum requiring 140 lb/ac N and 26 lb/ac P. Effluent application rates were calculated assuming 50 percent availability of total-N (TN) from the effluent. Forty gallons (21,200 gal/ac or 0.78 ac-inch) of effluent were applied to each plot based on results of an effluent sample collected on May 21, 2001 from the operator's secondary wastewater storage pond (1590 ppm TN and 363 ppm total P [TP]). At an application rate of 40 gallons per plot, 0.119 lb TP should have been applied via effluent to each plot. Samples taken of the effluent at the time of application (June 8) returned much lower nitrogen and phosphorus values than measured on May 21. The effluent applied measured 875 ppm TN, 86.9 ppm TP, 4.36 ppm orthophosphate-phosphorus (PO_4-P), 244 ppm ammonia-nitrogen (NH_3-N), and 4.1 ppm aluminum (Al) and had a pH of 7.9 standard units. Based on the laboratory analysis of the effluent applied, 0.028 lb TP and 0.0014 lb PO_4-P were applied to each plot. Assuming 50 percent nitrogen losses, only 0.146 lb TN were applied rather than 0.264 lb TN as calculated from the May 21 sample. The difference between the effluent sample taken on May 21 and the samples taken on June 8 indicate changes in nutrient concentrations within the secondary wastewater storage pond. No rainfall events occurred between May 21 and June 8, but the dairy operator was drawing down his primary wastewater storage pond into the secondary pond and irrigating from the secondary pond during this period. Because laboratory analyses generally take about two weeks to obtain, this indicates that dairy farmers may be in the position of applying more or less nutrients than expected if they do not frequently sample their wastewater storage ponds.

Chemical amendments of alum or gypsum were incorporated into the soil prior to effluent application. The stoichiometric equivalent of each amendment was calculated assuming all P in the May 21 effluent sample was in a soluble form available for binding with aluminum or calcium cations. The generalized reaction equations for calculating amendment dosage rates are provided below (Tchobanoglous and Burton, 1991):

$$Al_2(SO_4)_3{*}14H_2O + 2PO_4^{3-} \Leftrightarrow 2AlPO_4 + 3SO_4^{-2} + 14H_20$$

$$3HPO_4 + 5Ca^{+2} + 4OH^- \Leftrightarrow Ca_5(OH)(PO_4)_3 + 3H_2O$$

To bind all the P in the applied effluent (0.119 lb P based on the May 21 effluent sample), 1.15 lb alum were required and 1.27 lb gypsum assuming a 20.3 percent calcium equivalent in the gypsum. The stoichiometric rate was multiplied by 10 to allow for a binding reaction of amendments with P in the soil. Initial soil concentrations for extractable P averaged 417 ppm for a 0-6 inch sample using the TAMU extraction method (Hons et al. 1990). The dosage rate applied was 11.5 lb alum to plot A and 12.7 lb gypsum to plot G.

Three rainfall-simulation trials were conducted; one pretreatment and two posttreatment. The first simulation trial occurred on June 1, 2001 prior to the application of effluent or amendments. After the initial simulation trial, the surface of the plots was roughed up with a rake between the rows of sorghum to facilitate infiltration of the effluent and allow greater contact of the amendments with the soil. The second trial was conducted on June 11, three days after effluent and amendment application. The third trial was conducted on June 13. Plots were prewetted to saturation about 24 hrs prior to each simulation trial. A rainfall simulator as described by Humphry et al. (2002) was used producing continuous flow at a rate of three inches per hour. Rainfall events were continued for 30-minutes once runoff was established. Time to runoff and volume of runoff at five-minute increments were recorded for each plot during each rainfall simulation trial as well as total volume of runoff from each plot.

Total runoff volume was collected in separate barrels for each plot. After each rainfall simulation, each barrel was thoroughly mixed and two one-liter samples were extracted. The laboratory analyses of these two samples were averaged as duplicates in the results. These samples were analyzed for PO_4-P, TP, total Kjeldahl nitrogen (TKN), nitrite-nitrogen plus nitrate-nitrogen (NO_2-N+NO_3-N), NH_3-N, total suspended solids (TSS), and Al (Table 1), except in the third simulation trial. In the third simulation trial, Al was analyzed only for plots A and C for comparison purposes. Changes in Al runoff concentration were not expected on plot G with the gypsum amendment. Measurements of pH and conductivity were made of the runoff water captured in each barrel using a multiprobe instrument. A water sample of the simulated rainfall was collected and analyzed to determine background concentrations of N and P. The rainfall simulation water was groundwater obtained from a well on the dairy where the demonstration project was conducted. Concentrations within the simulated rainwater were 0.03 ppm NH_3-N, 0.25 ppm NO_2-N+NO_3-N, 0.23 ppm TKN, 0.006 ppm PO_4-P, <0.065 ppm TP, < 4 ppm TSS, and < 1.0 ppm Al. The simulated rainwater had a pH of 7.5 and conductivity of 651 μmhos/cm.

Table 1. Analysis methods and laboratory method detection limits (MDLs) for water quality and soil constituents analyzed by TIAER's laboratory.

Constituent	Method	Source	MDL (mg/L)
--------Water Samples--------			
NH_3-N	EPA 350.1	EPA (1983)	0.015
NO_2-N+NO_3-N	EPA 353.2	EPA (1983)	0.015
TKN	EPA 351.1,2	EPA (1983)	0.12
PO_4-P	EPA 365.2	EPA (1983)	0.004
TP	EPA 365.4	EPA (1983)	0.065
TSS	EPA 160.2	EPA (1983)	4
Al	EPA 3050B, EPA 7020	EPA (1997)	1
--------Soil Samples--------			
TKN	EPA 351.2	EPA (1983)	not applicable
Water Extractable P	SSSA, p. 891	SSSA (1996)	not applicable
Total P	EPA 365.4	EPA (1983)	not applicable
Aluminum	EPA 3050B, EPA 7020	EPA (1997)	not applicable

Prior to each simulated rainfall event, soil samples were collected at depths of 0-2 inches and 0-6 inches using standard soil probes. The holes made by the probes were filled using soil from the area surrounding each plot prior to simulating rainfall. Soil samples were dried for 48 hours, roughly ground to break up large clods, and then split for separate analyses by TIAER's laboratory and by the Texas A&M Soil, Forage, and Water Testing Laboratory in College Station. All soil samples were analyzed for water extractable P (water ext-P), TP, and TKN by TIAER's laboratory (Table 1). Soil samples from all three plots from trials 1 and 2 were also analyzed for Al and from plot A for trial 3. Splits of each soil sample were sent to the Texas A&M laboratory to obtain an analysis of extractable P using the TAMU method based on Hons et al. (1990). As part of the routine analysis at the Texas A&M laboratory, measurements of pH, NO_3-N, calcium (Ca), sulfur (S), and salinity are also presented.

RESULTS

The pretreatment results represent plot conditions prior to treatment with dairy effluent or any chemical amendments. Compared to pretreatment conditions, PO_4-P concentrations in runoff during the first posttreatment trial decreased over 90 percent with the alum amendment (Table 2). During the first posttreatment trial, an increase of 65 percent occurred on the control plot, while the gypsum amended plot indicated an increase of only 40 percent compared to pretreatment conditions. During the second posttreatment trial, runoff from the alum amended plot still showed a considerable decrease in PO_4-P concentrations compared to pretreatment levels, while the control and gypsum plots indicated PO_4-P runoff concentrations only slightly higher then pretreatment conditions.

Table 2. Runoff P and N constituent concentrations for pre- and posttreatment rainfall simulation events.

Treatment	Trial	PO_4-P (ppm)	TP (ppm)	NH_3-N (ppm)	NO_2-N +NO_3-N (ppm)	TKN (ppm)
Alum	Pre	0.66	13.3	0.33	0.65	55.1
	Post 1	0.04	12.9	1.96	0.68	45.7
	Post 2	0.07	14.3	0.40	1.88	56.5
Control	Pre	0.40	7.4	0.11	0.48	26.4
	Post 1	0.66	6.5	0.56	0.68	19.1
	Post 2	0.48	6.4	0.14	1.32	22.9
Gypsum	Pre	0.54	12.1	0.14	0.43	41.4
	Post 1	0.76	14.4	0.93	0.96	36.9
	Post 2	0.57	11.1	0.12	1.61	30.5

Posttreatment 0-2 inch soil samples also showed decreases in TAMU ext-P on the alum amended plot (Table 3). For a 0-6 inch soil sample, the alum amendment decreased soil TAMU ext-P concentrations by 11 percent compared to pretreatment levels. Notable decreases also occurred in posttreatment water ext-P concentrations for soils within the alum and gypsum amended plots compared to pretreatment conditions, particularly for the 0-2 inch soil samples. In contrast on the control plot, a slight increase in water ext-P occurred in the 0-2 inch soil layer. The alum amendment was by far the most effective in reducing water ext-P with over a 90 percent reduction in the 0-2 inch soil layer and about an 80 percent reduction in the 0-6 inch soil layer. The gypsum amendment reduced water ext-P by about 50 percent in the 0-2 inch layer and between 4 to 21 percent in the 0-6 inch layer in the two posttreatment trials.

Table 3. Soil P and N concentrations for pre- and postreatment rainfall simulation trials.

Treat-ment	Depth (in)	Trial	Water ext-P (ppm)	TAMU ext-P (ppm)	TP (ppm)	NO_3-N (ppm)	TKN (ppm)
Alum	0-2	Pre	40.5	215	372	44	1,880
		Post 1	2.9	161	464	125	1,570
		Post 2	2.2	155	460	139	1,700
Alum	0-6	Pre	42.7	209	398	62	2,030
		Post 1	10.7	187	439	106	1,650
		Post 2	7.2	185	438	109	1,550
Control	0-2	Pre	33.1	237	411	30	1,850
		Post 1	39.8	259	474	89	1,740
		Post 2	42.0	251	467	62	1,510
Control	0-6	Pre	32.5	210	422	41	1,930
		Post 1	37.8	250	445	75	1,360
		Post 2	35.2	262	395	67	1,300
Gypsum	0-2	Pre	45.2	335	523	25	1,980
		Post 1	21.4	334	529	80	1,520
		Post 2	22.4	340	539	59	1,520
Gypsum	0-6	Pre	35.8	270	431	38	1,810
		Post 1	28.2	296	563	75	1,490
		Post 2	34.5	325	518	51	1,400

In contrast to PO_4-P, TP concentrations in runoff showed relatively little difference between the three rainfall simulation trials on a given plot (Table 2). The percent change between posttreatment and pretreatment trials was less than 20 percent in all cases. Between plots notably higher TP concentrations were indicated for the alum and gypsum amended plots compared to the control plot. These higher runoff concentrations of TP from the alum and gypsum amended plots are partially associated with higher TSS concentrations measured in runoff (Tables 2 and 4), although this relationship does not appear to be linear (Figure 1). When TP concentrations in runoff were adjusted for TSS concentrations, the alum amended plot showed the lowest TP concentrations per unit of TSS in runoff, while the gypsum amended plot showed the highest TP concentrations per unit of TSS (Table 5). While differences in runoff TP concentrations between pretreatment and posttreatment trials were relatively small, a distinct change in soil TP concentrations occurred (Table 3). Soil TP concentrations increased from pretreatment to posttreatment on all three plots. As expected, the P applied with the effluent and already in the soil does not go away with treatment, but the alum amendment chemically binds much of the soluble P into a more insoluble form that is less likely to move without the movement of sediment.

Table 4. Runoff TSS, Al, conductivity, and pH values for pre- and posttreatment rainfall simulation events.

Treatment	Trial	TSS (ppm)	Al (ppm)	Conductivity (µmhos/ cm)	pH
Alum	Pre	11,200	220	672	8.0
	Post 1	12,700	266	974	7.0
	Post 2	15,200	314	1070	7.4
Control	Pre	4,090	106	662	8.1
	Post 1	3,640	100	675	8.2
	Post 2	3,520	79	677	8.4
Gypsum	Pre	5,640	117	670	8.1
	Post 1	7,340	139	1410	8.0
	Post 2	5,030	na	1320	8.1

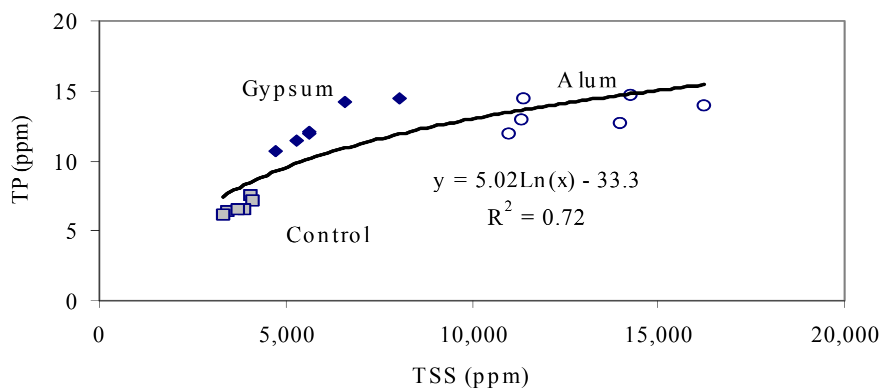

Figure 1. Relationship of TP to TSS in simulated runoff. Squares represent data from control plot, diamonds data from the gypsum-amended plot, and circles data from the alum-amended plot.

Table 5. TP, Al, and TKN as a percent of TSS in runoff.

Treatment	Trial	TP per unit TSS	Al per unit TSS	TKN per unit TSS
Alum	Pre	0.12%	1.96%	0.49%
	Post 1	0.10%	2.09%	0.36%
	Post 2	0.09%	2.06%	0.37%
Control	Pre	0.18%	2.59%	0.64%
	Post 1	0.18%	2.73%	0.52%
	Post 2	0.18%	2.25%	0.65%
Gypsum	Pre	0.21%	2.07%	0.73%
	Post 1	0.20%	1.89%	0.50%
	Post 2	0.22%	not measured	0.61%

Aluminum concentrations in runoff showed a very close linear relationship with TSS concentrations (Figure 2). An increase in Al runoff in the posttreatment trials on the alum-amended plot appeared to occur (Table 4), but when Al concentrations were adjusted for TSS, basically no change in Al concentrations was apparent between the alum or control plots (Table 5). Background soil aluminum concentrations across plots averaged 5,550±685 ppm for the 0-2 inch layer and 6,220±276 ppm for the 0-6 inch layer (Table 6). On the alum amended plot, a 25 percent increase in aluminum was indicated in the 0-2 inch layer after treatment. A similar increase was noted on the control plot. In the 0-6 inch soil layer, a slight increase in Al concentrations occurred on the alum amended plot, while decreases were noted on the control and gypsum amended plots.

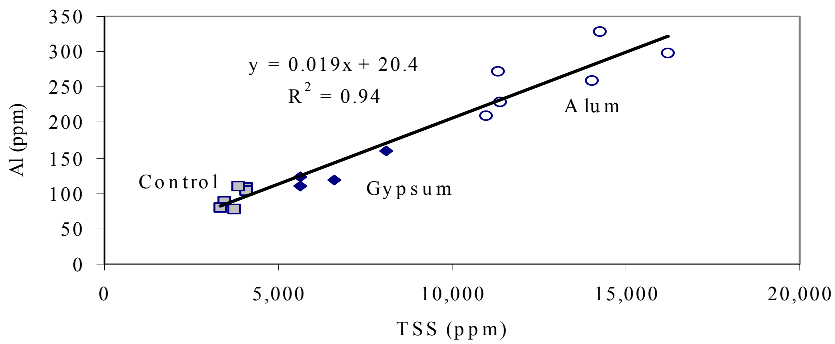

Figure 2. Relationship of Al to TSS in simulated runoff. Squares represent data from control plot, diamonds data from the gypsum-amended plot, and circles data from the alum-amended plot.

Table 6. Soil pH, Al, Ca, salt and S concentrations for pre- and postreatment rainfall simulation trials.

Treatment	Depth (in)	Trial	pH	Al (ppm)	Ca (ppm)	Salt (ppm)	S (ppm)
Alum	0-2	Pre	7.6	6,320	12,600	482	39
		Post 1	7.4	7,920	11,200	3,830	1,600
		Post 2	7.2	6,560	13,300	3,070	1,410
Alum	0-6	Pre	7.5	6,510	11,500	562	38
		Post 1	7.4	6,790	44,400	2,630	677
		Post 2	7.3	7,250	14,300	2,360	913
Control	0-2	Pre	7.6	5,000	12,900	408	53
		Post 1	8.2	6,090	11,600	963	67
		Post 2	8.1	na	11,700	582	69
Control	0-6	Pre	7.5	6,200	11,800	414	37
		Post 1	7.8	4,840	11,700	728	45
		Post 2	7.7	na	12,500	599	57
Gypsum	0-2	Pre	7.4	5,340	10,700	365	44
		Post 1	7.6	5,810	12,200	3,450	2,280
		Post 2	7.4	na	13,000	2,080	1,660
Gypsum	0-6	Pre	7.4	5,960	9,700	408	44
		Post 1	7.4	5,210	8,500	2,350	683
		Post 2	7.3	na	10,800	1,530	648

While the focus of this demonstration project was on phosphorus, nitrogen constituents also need to be considered in any evaluation of nutrient runoff. The amendments were expected to have little impact on nitrogen constituents, although it was thought that potential changes in soil pH brought about by the amendments might influence dynamics between N constituent forms. TKN comprised 95 percent or more of total-N in runoff from all rainfall simulations and showed some decreases in concentration with posttreatment simulation trials within plots (Table 2). Between plots, very notable differences in runoff TKN concentrations occurred. As with Al and to a lesser degree TP, TKN concentrations were strongly tied to TSS concentrations (Figure 3). Concentrations of TKN adjusted for TSS indicated a slight decrease in the first posttreatment trial compared to the pretreatment trial, but only minor differences between plots (Table 5). Clear decreases in soil TKN concentrations were indicated for both the 0-2 inch and 0-6 inch samples in comparing pretreatment with posttreament trials (Table 3).

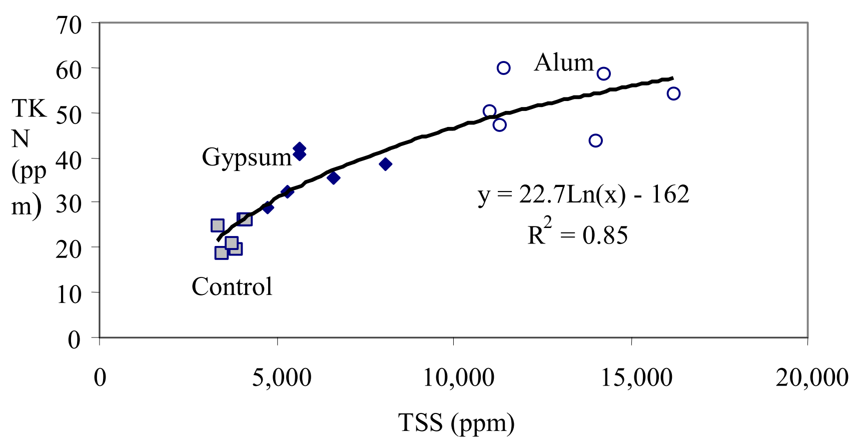

Figure 3. Relationship of TKN to TSS in simulated runoff. Squares represent data from control plot, diamonds data from the gypsum-amended plot, and circles data from the alum-amended plot.

For NH_3-N a fairly notably increase in runoff concentration occurred in the first posttreatment trial on the alum amended plot compared the control and gypsum amended plots (Table 2). In comparing NH_3-N with NO_2-N+NO_3-N concentrations between the first and second posttreatment trials, the nitrification of NH_3-N to NO_2-N+NO_3-N was quite apparent (Table 2). While NH_3-N and NO_2-N concentrations were not measured in the soil, soil NO_3-N concentrations increased with effluent application in the first posttreatment trial regardless of plot treatment (Table 3). On average across plots, soil NO_3-N in the first posttreatment trial increased 240 percent in the 0-2 inch layer and 84 percent in the 0-6 inch layer in comparison to pretreatment conditions. In the second posttreatment trial, decreases in soil NO_3-N concentrations were apparent in all but the alum-amended plot compared to the first posttreatment trial. This decrease in soil NO_3-N was likely in response to the ready movement of the nitrate ion in water and its transport through the soil column after the two simulated intense rainfall events.

A pretreatment pH value across plots averaged 8.07 $\pm$ 0.03 standard units. During the posttreatment trials, a notable decrease in runoff pH occurred on the alum-amended plot, while a slight increase was noted on the control plot (Table 4). Runoff from the gypsum-amended plot showed a fairly constant pH across all three trials. The pH decrease on the alum-amended plot was greatest for the first posttreatment simulation trial. This decrease in pH may explain the relatively high NH_3-N runoff concentrations associated with that trial on the alum-amended plot. Total ammonia nitrogen or NH_3-N as measured in the laboratory is comprised of NH_3 and NH_4^+ ions in equilibrium. The fraction of total ammonia nitrogen represented by NH_3 and NH_4^+ is a function of pH. The NH_4^+ form is more common at lower pH values and is not subject to volatilization loss, while the NH_3 form is more common at higher pH values and is subject to volatilization loss. Because more of the ammonia on the alum amended plot would be in the nonvolatile NH_4^+ form, more ammonia was available for movement in runoff in the first posttreatment trial and also for oxidation to NO_3-N. NO_3-N runoff and soil concentrations increased notably in the second posttreatment trial on the alum-amended plot. Changes in runoff pH, in general, appeared to follow noted changes in soil pH. For 0-2 inch and 0-6 inch samples, soil pH showed a slight decrease on the alum-amended plot, a notable increase on the control plot, and no change on the gypsum-amended plot (Table 6).

Conductivity in runoff increased notably from the alum and gypsum amended plots, while conductivity remained constant in runoff from the control plot (Table 4). Increases in conductivity were accompanied by large increases in soil salinity as noted by increased S concentrations, particularly in the 0-2 inch soil layer within the alum and gypsum amended plots (Table 6). The soils associated with this demonstration project were highly calcareous (Table 6). No notable increase in Ca was apparent on the gypsum-amended plot. Ca concentrations overall averaged 11,700 $\pm$ 1,350 ppm.

CONCLUSIONS AND RECOMMENDATIONS

Alum as a soil amendment demonstrated very large decreases in soluble P in runoff (as represented by PO_4-P) and soil extractable-P using a water extraction method. A smaller, but notable decrease, was indicated for soil extractable P using the TAMU method. The smaller percent change in soil extractable P noted with the TAMU method versus the water method occurs, because the TAMU extraction method involves acids that break some P bonds with other particles, thus, representing a mixture of soluble and particulate P from the soil. The TAMU extraction method for P was developed to estimate the quantity of plant-available P in the soil for making fertilizer recommendations. The water extraction method represents only the soluble P pool from the soil and is thought to be a better indicator of soluble P available for movement during rainfall-runoff events (Pote et al. 1996).

The results using gypsum were not as clear. Changes in the percent PO_4-P in runoff from the gypsum plot were fairly similar to the control plot, although increases in TAMU ext-P from the soil were not as high on the gypsum plot as on the control plot. The gypsum-amended plot also indicated notable decreases in water ext-P from the 0-2 inch and 0-6 inch soil layers, while the control plot showed notable increases in both cases. It appears that alum may be a more useful soil amendment for controlling soluble P runoff from dairy effluent application fields than gypsum for the calcareous soil used in this demonstration project.

Because this was only a short-term demonstration, long-term, replicated field studies are necessary to more fully assess the value of gypsum or alum as amendments. Further studies are also warranted to evaluate the impact of alum and gypsum amendments on crop establishment and growth before these amendments can be recommended for controlling soluble P in runoff, particularly with regard to soil salinity. Erosion control measures should also be implemented in conjunction with any amendment application for the control of TP, Al, TKN, and TSS in field runoff.

These results also must be considered within the context of the rainfall simulation methods used and the conditions of the individual plots at the time of the simulation trials. The three inches per hour simulated rainfall is a rate recommended for standardization of studies being conducted under the Natural Resource Conservation Commission's National Soil P Project relating soil test P to runoff P in benchmark soils of the United States (D.R. Edwards, personal communication 1998). However, this rainfall rate represents a relatively high rate for the study area (Erath County) and has a return frequency in Erath County of over 10 years for a 1-hr rainfall (3-inch rain) and about 2 years for a 30-minute rainfall (1.5-inch rain). A more typical lower intensity rainfall rate would be expected to produce less runoff and have less energy for transport of sediment-bound nutrients.

Potential costs to producers for chemical amendments will vary with the phosphorus level in their effluent and soils and the degree of phosphorus control desired. In this demonstration project, alum was applied at a rate of 8.6 tons/ac and gypsum at a rate of 7.7 tons/ac. According to a representative from General Chemical Corporation (a major alum manufacturer), the cost for dry alum ranges from about $200 to $250 per ton depending on the supplier. Liquid alum can be purchased for about $180 per ton of active ingredient but may cost more in shipping, because liquid alum is more difficult to transport than dry alum. Gypsum, containing about 20 percent calcium, costs about $60 per ton. Given the rates used on the demonstration plots and prices listed above, using these amendments would cost about $1,900/ac for dry alum and $460/ac for gypsum, not including the cost of application. As with most chemicals, discount prices should be available for bulk purchases, but will depend on the amount needed and negotiations with specific suppliers. These costs must be considered highly preliminary. The long-term effectiveness of chemical amendments must be determined before reliable cost estimates can be made.

REFERENCES

Anderson, D.L., O.H. Tuovinen, A. Faber, and I Ostrokowski. 1995. Use of soil amendments to reduce soluble phosphorus in dairy soils. Ecological Engineering 5:229-246.

Andraski, B.J., D.H. Muller, and T.C. Daniel. 1985. Phosphorus losses in runoff as affected by tillage. Soil Science Society of American Journal 49:1523-1527.

Baker, J.L. and J.M. Laflen. 1982. Effect of crop residue and fertilizer management on soluble nutrient runoff losses. Transactions of the American Society of Agricultural Engineers 25:344-348.

Boyd, C.E. 1990. Water Quality in Ponds for Aquaculture. Birmingham Publishing Co., Birmingham, AL.

Codd, G.A. 1995. Cyanobacterial toxins: Occurrence, properties and biological significance. Water Science & Technology 32:149-156.

Edwards, D.R., P.A. Moore, Jr., S.R. Workman, and E.L. Bushee. 1999. Runoff of metals from alum-treated horse manure and municipal sludge. Journal of the American Water Resources Association 35:155-165.

EPA, Environmental Protection Agency. 1997. Test Methods for Evaluating Solid Waste, Physical/Chemical Methods. Office of Solid Waste, Washington, D.C. EPA SW-846.

EPA, Environmental Protection Agency. 1983. Methods for Chemical Analysis of Water and Wastes. Environmental Monitoring and Support Laboratory, Office of Research and Development, USEPA, Cincinnati, Ohio. EPA-600/4-79-020, Revised March 1983.

Gibson, C.E. 1997. The Dynamics of Phosphorus in Freshwater and Marine Environments, pp. 119-136. In: Phosphorus Loss from Soil to Water, H. Tunney, O.T. Carton, P.C. Brookes, and A.E. Johnston (eds.). Centre for Agriculture and Bioscience International, New York, NY.

Gilliam, J.W. 1995. Phosphorus control strategies. Ecological Engineering 5:405-414.

Hons, F.M., L.A. Larson-Vollmer, and M.A. Locke. 1990. NH4Oac-EDTA-extractable phosphorus as a soil test procedure. Soil Science 149:249-256.

Humphry, J.B., T.C. Daniel, D.R. Edwards, and A.N. Sharpley. 2002. A portable rainfall simulator for plot-scale runoff studies. Applied Engineering in Agriculture 18:199-204.

Jones, R.M. and S.P. Brown. 2000. Chemical and settling treatment of dairy wastewater for solids separation and phosphorus removal, pp. 132-141. In: Animal, Agriculture and Food Processing Wastes, Proceedings of the Eighth International Symposium, October 9-11, 2000, Des Moines, Iowa, J.A. Moore (ed.). American Society of Agricultural Engineers, St. Josesph, MI.

Martin, A. and G.D. Cooke. 1994. Health risks in eutorphic water supplies. LakeLine 14:24-26.

McFarland, A.M.S. and L.M.Hauck. 1999. Relating agricultural land uses to in-stream stormwater quality. Journal of Environmental Quality 28:836-844.

Moore, P.A., Jr. and D.M. Miller. 1994. Decreasing phosphorus solubility in poultry litter with aluminum, calcium, and iron amendments. Journal of Environmental Quality 23:325-330.

NRC, National Research Council. 1993. Phosphorus in the Soil-Crop System, pp. 283-312. In: Soil and Water Quality: An Agenda for Agriculture. National Academy Press, Washington, D.C.

Pote, D.H., T.C. Daniel, A.N. Sharpley, P.A. Moore, Jr., D.R. Edwards, and D.J. Nichols. 1996. Relating extractable soil phosphorus to phosphorus losses in runoff. Soil Science Society of America Journal 60:855-859.

Provin, T.L. and J.L. Pitt. 1999. Phosphorus — Too Much and Plants May Suffer. Texas Agricultural Extension Service, College Station, TX, L-5249 (February 1999).

Reddy, K.R., R. Khaleel, M.R. Overcash, and P.W. Westerman. 1979. Phosphorus — A potential nonpoint source pollution problem in land areas receiving long-term application of wastes, pp. 193-212. In: Best Management Practices for Agriculture and Silviculture, R.C. Loehr, D.A. Haith, M.F. Walter, and C.S. Martin (eds.). Ann Arobor Science, Ann Arbor, MI.

Sharpley, A.N., T.C. Daniel, and D.R. Edwards. 1993. Phosphorus movement in the landscape. Journal of Production Agriculture 6:492-500.

Sharpley, A.N. and S.J. Smith. 1992. Prediction of bioavailable phosphorus loss in agricultural runoff. Journal of Environmental Quality 21:32-37.

Shreve, B.R., P.A. Moore, Jr., D.M. Miller, T.C. Daniel, and D.R. Edwards. 1996. Long-term phosphorus solubility in soils receiving poultry litter treated with aluminum, calcium, and iron amendments. Communications in Soil Science and Plant Analysis 27:2493-2510.

Shreve, B.R., P.A. Moore, Jr., T.C. Daniel, D.R. Edwards, and D.M. Miller. 1995. Reduction of phosphorus in runoff from field-applied poultry litter using chemical amendments. Journal of Environmental Quality 24:106-111.

SSSA, Soil Science Society of America. 1996. Methods of Soil Analysis, Part 3: Chemical Methods. Soil Science Society of America, Madison, WI.

Tchobanoglous, G. and F.L. Burton. 1991. Metcalf & Eddy: Wastewater Engineering Treatment, Disposal, and Reuse, 3rd Ed. McGraw-Hill, Inc., New York, NY.

USDA-SCS. 1973. Soil Survey of Erath County, Texas. U.S. Department of Agriculture-Soil Conservation Service, Cartographic Division, Soil Conservation Service, USDA, Washington, D.C.

Yeoman, S., T. Stephenson, J.N. Lester, and R. Perry. 1988. The removal of phosphorus during wastewater treatment: A review. Environmental Pollution 49:183-233.

Determining Particle Density in Dairy Manure Compost

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ABSTRACT

To accurately determine the bulk density of composted products, particle density must be precisely quantified. A submersion technique developed for use in soil science was adapted by utilizing hexane (a low density solvent) to facilitate particle submersion. Two composts were subjected to multiple treatments to determine the precision of the method. The inexpensive methods produced repeatable results that will aid compost producers in quantifying their products.

Keywords: compost, particle density, dairy manure

INTRODUCTION

It has been widely accepted that compost provides chemical and physical benefits to soils. Although compost products vary and must be carefully tested to determine their exact nature, numerous laboratory trials with different products have successfully quantified the beneficial effects (Cornell University Composting 2003).

As compost use increases, source materials and the quality of the final product have become more regulated by federal, state and local agencies. Once considered an inexact science, quantifying the physical, chemical and biological properties of compost has become more exact. In 2001, the U.S. Composting Council (USCC) and United States Department of Agriculture (USDA) jointly produced *Test Methods for the Examination of Composting and Compost (TMECC)* to establish standards for precise methodologies to be used in compost analysis and to address many of the variable characteristics of compost. While the TMECC guidelines specifically address bulk density and air capacity, they do not specify a procedure for determining the particle density of composted solids (Thompson 2001). The Texas Department of Transportation (TxDOT) and the Texas Commission for Environmental Quality (TCEQ) have recently set forth new specifications for compost used on large state or federally-funded projects within Texas. Under the new specification, compost suppliers must comply with the USCC Seal of Testing Assurance (STA) program, which mandates a variable compost testing frequency based on the tonnage generated annually by each individual producer.

As such, the accurate quantification of particle density (as a component of bulk density) is vitally important for gravimetric compost measurements. For other media such as soil, particle density is often assumed to be 2.65 g/cm^3, the density of quartz (Brady and Weil 2002). However, compost particle density is more inconsistent due to variation in source materials.

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Concisely stated, the method employs the submersion of a known mass of compost in hexane to determine the volume of the compost solids (Figure 1). While hexane was used because of its low density (0.66 g/cm^3), the premise of the method remains valid for many other low density liquids. The use of a low density liquid causes particles that are normally buoyant in water to sink, facilitating an accurate measurement of the compost solids volume.

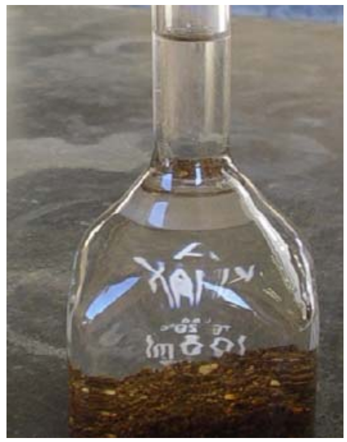

Figure 1. Compost submerged in hexane.

The goal of this project was to test this approach for the estimation of compost particle density and to determine the precision of the method across variable products.

MATERIALS AND METHODS

The physical properties of compost are similar to those of highly organic soils. As such, the method described below is adapted from Blake and Hartge (1986), a commonly employed method of determining soil particle density. Simply defined, density is the mass per unit volume of a given substance and is typically reported as grams per cubic centimeter (g/cm^3) or kilograms per cubic meter (kg/m^3) (Hillel 1998). While bulk density assesses the solid, liquid, and gaseous components of a material, particle density only addresses the solids. The key difference between the methodology employed by Blake and Hartge and that proposed for compost concerns the liquid for submergence. While soil particles, with particle densities commonly in excess of 1.0 g/cm^3, are easily submerged in distilled water, many compost particles are somewhat buoyant and as a result will not settle out of suspension so that an accurate measurement of displaced volume can be determined. Given this, hexane was selected as an inexpensive, low density liquid that allows for compost particle settling.

For this study, diary compost was collected from two locations in Erath County, Texas. The mass and volume of compost solids were quantified independently using the same sample. Prior to analysis, compost was oven dried at 70°C for 48 hours to remove moisture. Dried samples were ground to reduce the size of large aggregates. Next, 10-20 g of compost was placed in a 100 ml volumetric flask and weighed on a Mettler AE200 top loading balance to an accuracy of ±0.0001 g. To displace gases from the compost sample, the flask was brought to volume with hexane, completely submersing the compost. While tilted at an angle, the flask was gently swirled (Figure 2).

Figure 2. Agitating compost via swirling in a square based flask.

Square-based flasks appeared to be most efficient at agitating the submerged compost. After mixing, the flask was again brought to volume with hexane and the weight of the compost/hexane mixture was recorded. Samples from both locations were independently tested fifteen times using the aforementioned method. Compost particle density was calculated using equation 1:

$$\rho_p = \rho_h (W_c) / [W_c - (W_{ch} - W_h)] \quad \text{Eq. 1}$$

where ρ_p = Compost density (g/cm^3),
ρ_h = Density of hexane (g/cm^3),
W_c = Weight of oven-dried compost (g),
W_{ch} = Weight of compost and hexane (g),
W_h = Weight of 100 ml of pure hexane (g).

RESULTS AND DISCUSSION

As expected, the particle density of both compost samples was less than the assumed particle density of soil. Particle density of Compost A ranged from 2.22 g/cm^3 to 2.39 g/cm^3 with an average of 2.31 g/cm^3 and a standard deviation of 0.0475 (Table 1). Particle density of Compost B ranged from 2.19 g/cm^3 to 2.32 g/cm^3 with an average of 2.27 g/cm^3 and a standard deviation of 0.0364 (Table 1). It should be noted that the obtained values are somewhat higher than expected, but can likely be tied to the presence of carbonates and other inorganic media such as soil particles contained within the compost samples. Such carbonates and inorganic compounds are often inadvertently incorporated into compost through mechanical operations such as scraping of the soil surface during mixing or aeration processes and through eolian deposition of mineral soil.

Table 1. Particle density of two dairy manure composts from Erath County, TX.

Replication	Compost A	Compost B
	---------------------g/cm3------------------	
1	2.37	2.19
2	2.31	2.28
3	2.33	2.27
4	2.37	2.28
5	2.39	2.26
6	2.35	2.23
7	2.31	2.26
8	2.32	2.28
9	2.32	2.31
10	2.29	2.32
11	2.26	2.29
12	2.22	2.31
13	2.28	2.28
14	2.29	2.23
15	2.25	2.23
Mean	2.31	2.27
Std. Error	0.0123	0.0094

CONCLUSIONS

The hexane submersion method of compost particle density measurement offers an expeditious, accurate means of analysis. As a component of compost bulk density, the determination of compost particle density is vitally important in assessing the mass and/or volume of compost. Such information is germane not only to regulatory issues, but production, shipment, storage, blending and application of composted products.

REFERENCES

Blake, G.R. and K.H. Hartge. 1986. Methods of Soil Analysis: Part 1-Physical and Mineralogical Methods 2nd ed. American Society of Agronomy. Madison, WI.

Brady, N.C. and R.R. Weil. 2002. The Nature and Properties of Soils 13th ed. Prentice Hall. Upper Saddle River, NJ.

Cornell University Composting. 2003. The Science and Engineering of Composting [Online]. Available at http://www.cfe.cornell.edu/compost/science.html (Verified 10 Feb. 2003).

Hillel, D. 1998. Environmental Soil Physics. Academic Press. San Diego, CA.

Thompson, W.H. (ed.) 2001. Test Methods for the Examination of Composts and Composting. U.S. Gov't Print Office, Washington, DC.

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Electricity Rates, Input Use and Irrigated Cotton Profitability: A Hedonic Versus Traditional Profit Maximization Approach

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ABSTRACT

The impact of increasing energy cost on the optimal level of nitrogen and irrigation water use is examined for two irrigated cotton production management strategies using LEPA irrigation. The first strategy is a traditional production management strategy where the optimal per acre application rate is the rate that maximizes expected profit based on a fixed expected cotton lint price and known lint yield response to applied nitrogen and irrigation water. Under the second production strategy, cotton producers are assumed to maximize a hedonic profit function that explicitly considers the tradeoff between lint yield and lint quality attributable to alternative nitrogen and irrigation application rates, and the net effect the tradeoff has on per acre profit. The hedonic production approach, which manages for both quality and quantity, was found to be the more profitable producer strategy and used less fertilizer and less irrigation water.

KEYWORDS: Hedonic profit function, cotton, energy cost, irrigation cost

Though the deregulation of the electric power industry in Texas promises lower electric prices for consumers in aggregate, a number of studies indicate deregulation may lead to higher prices in rural areas of the country due to the limited ability of many rural regions to import electricity from producers outside their region (Northcutt 2001, Johnson 1999, Chernoff and Sanchez 1998). Johnson (1999) estimated that 55% of all irrigated Texas High Plains (THP) farms use electricity as their power source. Higher electricity costs will increase the cost of lifting groundwater and pressurizing irrigation systems and decrease already slim farm profit margins for those producers utilizing electricity as their power source. This is especially critical to THP cotton producers, who farm 60% of all irrigated land in the THP, and are considering switching from natural gas to electric energy given that natural gas pumping cost has risen by nearly five-fold, in some areas of the THP, in the last two years (Lubbock Avalanche Journal June 1, 2003).

A common strategy for dealing with shrinking profit margins is to increase yields by increasing factor input use and/or altering the production technology. However, such strategies will not increase profits when the additional costs exceed the additional revenue generated by the yield enhancement strategy. Recent studies indicate a superior approach to increasing cotton profitability is to broaden management practices beyond yield considerations, and include quality considerations in identifying profit-maximizing input use regimes (Denning et al. 2002, Green et al. 1999, Morrow and Krieg 1990). But, the relative additional profitability gains, or potential losses from this broadened management perspective is unknown in the case of changing factor input prices.

This research examines the potential economic benefit that can be captured by cotton producers if they adjust their management practices from a yield focus to a joint yield and quality focus for purposes of mitigating expected increases in electric energy prices. We specifically examine how per acre gross revenue and selected irrigation related variable cost items optimally respond to potential increases in energy cost under two alternative management strategies. The first strategy assumes producers simultaneously manage for both lint yield and lint quality, whereas in the second management strategy producers are assumed to follow tradition and manage solely for lint yield, and ignore the impact yield optimizing use rates have on lint quality. We also examine the capacity of revenue premiums for increased lint quality to partially, or totally, offset yield-related revenue decreases that may occur under reduced irrigation application rates. The sensitivity of the results to climatic conditions is also examined.

DATA AND METHODS

The data used to estimate the impact of per acre water and fertilizer input levels on cotton quality attributes was collected by Allen and Krieg (2000) from three field experiments conducted in Lubbock County, Texas, in 1997, 1998 and 1999. This data set contained 1,033 paired observations on lint yield, seed yield, turnout, micronaire, staple length, and fiber strength values corresponding to varying irrigation water/nitrogen application rates, phosphorous fertilizer application methods and rates, seed varieties, and weather conditions (i.e. accumulated heat units and rainfall during the cotton growing season).

Supplemental irrigation water, applied through a LEPA system, ranged from 3 to 14 acre-inches. Nitrogen was applied through the irrigation system at a rate of 6 pounds per acre-inch of applied water as recommended by Morrow and Krieg (1990). Three different phosphorous application methods were evaluated: pre-plant, side-dress, and fertigation at rates ranging from 0 to 73 pounds per acre. All water/fertilization application combinations were repeated for eleven cottonseed varieties: Paymaster HS 26, Paymaster HS 200, Delta Pine 2156, Paymaster Tejas, HOL 101, HOL 338, All-Tex Atlas, AFD Explorer, AFD Rocket, All-Tex Toppick, and All-Tex Xpress.

Temperature and rainfall measurements were collected at the research site. The experiment received less-than-average rainfall (8.5 inches) and close-to-average heat unit accumulation (1161C) in 1997. In 1998, a dry year, the plots received little rainfall (5.4 inches) and a relatively high heat unit accumulation (1544C). During 1999, the experiment received below average heat unit accumulation (1022C) and rainfall (6.3 inches). Heat unit accumulations were calculated from daily temperature data during the THP cotton-growing season, which extends from May to September.

Cotton yield and lint quality attributes were measured at each experimental plot by hand harvesting all cotton bolls within a sample area of 1/1000 of an acre. The harvested bolls were ginned and a sample of the ginned cotton from each plot was sent to the International Textile Center of Texas Tech University to determine the values of its lint quality attributes. Staple length, strength, and micronaire were measured using High Volume Instrument (HVI) tests. A complete discussion of the empirical data is found in Allen and Krieg (2000).

Modeling Procedure. In prior research, Britt et al. **(**2002) used Allen and Kreig=s data set in an econometric analysis to estimate the impact irrigation application level, fertilization level, and climatic condition have on per acre cotton lint yield, and the seven lint quality attributes for which price premiums and discounts are applied. This study merges their estimated production relationships for cotton quality attributes with price estimates for yearly average lint price, and price premiums and discounts paid for specific cotton quality attributes. The price premium and discount values were estimated using the Daily Price Estimation System (DPES). The DPES is a computerized, econometrically based, price analysis system maintained and operated by the Department of Agricultural and Applied Economics at Texas Tech University. The DPES uses a hedonic modeling approach to statistically estimate the quality premium and discount values for the West Texas and East Texas/Oklahoma cotton marketing regions on a daily basis. In any given marketing year the DPES estimates daily and average annual premiums and discounts for seven lint quality attributes: (1) leaf grade, (2) color grade, (3) staple length, (4) strength, (5) micronaire, (6) bark, and (7) other extraneous matter. Price premiums are paid for attributes whose quality exceeds a specified baseline quality level, and price discounts are used to adjust base price downward for attributes that are below the baseline quality level. When each of the seven lint quality attributes is at their respective baseline value the producer receives the base price because no quality adjustment is made to the base price. The average premium or discount value associated with the level of each quality attribute as determined by the 1998 DPES marketing year equations is used in this analysis (Hoelscher et al. *1*999). The 1998 marketing year was selected because the average premium and discount values generated by the DPES equations in this marketing year are representative of the average premiums and discounts for the seven lint quality attributes over the 1993-2001 period and thus allow the empirical results to be interpreted as an expected average value for each scenario considered (Misra 2002).

Hedonic Optimization Framework. Nonlinear mathematical programming was used to determine both the input use levels that maximize per acre profit and to simulate the relationships between input use levels, lint yield, lint quality, and producer lint price. The objective function was specified to simultaneously consider the impact fertilizer and water application rates have on both lint yield and lint quality, for a specified seasonal weather pattern, in the maximization of per acre profit. Models that explicitly consider the influence of quality attributes on the market price of a commodity are commonly referred to as hedonic models. The optimization framework allows additional water and fertilizer to be applied when it is more profitable to manage for yield than quality, and less water and fertilizer is applied, on the margin, when it is more profitable to manage for quality than yield. The nonlinear lint yield and quality response equations estimated by Britt et al. (2002) are embedded in the optimization model constraint set and used to link water and fertilizer application rates to yield and yield quality attributes. The level of each quality attribute, for a specific input regime, is internally passed to the 1998 DPES equation, an average pricing year, to calculate the quality adjusted per pound price received by producers. Hence, the premium and discount estimates are non-linear functions of the lint quality attributes, which in turn are a nonlinear function of input use levels, seed variety, and weather conditions. Thus, the hedonic optimization model endogenously determines the water and fertilizer application rates that maximize per acre profit for a given cost structure, production function, and set of weather conditions. In conceptual terms, the mathematical structure of the hedonic optimization procedure can be viewed as an eight equation system:

(1) Max Profit = P^H*Y^H - ERC - NERC

Where:

P^H = per pound hedonic price, and is endogenously estimated using the following general functional form: F(micronaire, strength, staple| other quality attributes fixed at appropriate base attribute values),

Y^H = is per acre hedonic lint yield,

ERC = G(cost applied irrigation water, cost electricity used, cost liquid nitrogen used), and

NERC = H(per acre cost of all fixed inputs and those variable inputs not in ERC).

Subject to:

(2) Y^H = I(water, liquid nitrogen, seed variety, heat units, rainfall | all other inputs fixed),

(3) Micronaire = J(water, liquid nitrogen, seed variety, heat units, rainfall | all other inputs fixed),

(4) Strength = K(water, liquid nitrogen, seed variety, heat units, rainfall | all other inputs fixed),

(5) Staple = L(water, liquid nitrogen, seed variety, heat units, rainfall | all other inputs fixed),

(6) $Water_x$ = M(electricity | given irrigation technology x),

(7) $Nitrogen_x$ = N(electricity | given irrigation technology x), and

(8) $Water_x$ # maximum acre-inch/per acre irrigation water applied using system x over the growing season.

Equation 1 is the objective, or profit, function that is to be maximized. Per acre profit is maximized when the difference between total revenue (TR) and the sum of electricity related variable costs (ERC) and non-electricity related costs (NERC) is as large as possible. In the hedonic model specification, per acre TR (P^H*Y^H) is calculated as the product of the endogenously determined per acre quantity of lint produced (Y^H) and the endogenously determined hedonic lint price (P^H). To isolate the impact changing electric rates are likely to have on cotton profitability, for a given irrigation technology, only those input cost items that vary with per acre energy use are allowed to vary in this analysis. Thus, ERC consists of the electricity expenditure required to apply the optimal per acre quantity of irrigated water, depreciation and maintenance of irrigation equipment used to deliver the optimal quantity of irrigation water, and the per unit cost of applying liquid nitrogen fertilizer at the optimal irrigation level. The application of liquid nitrogen fertilizer is treated as an electricity related variable cost because the experimental data which this analysis is based upon used fertigation to apply liquid nitrogen at a fixed rate per acre inch of applied irrigation water. NERC is defined as the per acre sum of all other variable cost items plus the traditional fixed cost items (machinery, irrigation system, land, etc.) and does not vary with the energy use level.

Constraint equations 2, 3, 4, and 5 capture the impact that changes in the per acre quantity of applied irrigation water, liquid nitrogen, heat units, and rainfall have on lint yield, measured in pounds, and the three most economically important qualitative lint attributes, micronaire, strength, and staple. The value of each of the three lint quality measures in combination with the 1998 base price endogenously determine the hedonic price per pound of lint

(P^H) and is the price variable in equation 1 (the profit function to be maximized). The four other lint quality attributes (leaf grade, color grade, bark, and other extraneous matter) are assumed to be at their respective base quality levels, the level for which no price discount is deducted nor a premium paid. The specific functional forms for equations 2, 3, 4, and 5 are reported in Britt et al. (2002).

Constraint equations 6 and 7 explicitly recognize that the quantity of irrigation water and nitrogen (liquid form) applied are a function of energy use. Consistent with the empirical data used to estimate the lint yield and lint quality response to applied water and nitrogen, the hedonic optimization model assumes fertigation is used to apply nitrogen to the crop. Equation 8 prevents the per acre quantity of applied irrigation water from exceeding the capacity of the irrigation system. The per-acre inch cost of applied water (C_W) is calculated as:

(9) C_W = Pumping Cost + Machinery Cost
= 0.164*[Pumping Lift + {2.31*Pumping Pressure}]*ECOST/KWH +
[0.003234*Pump Lift]

As shown in equation 9, pumping cost is a function of electricity cost per kwh (ECOST/KWH), pump lift, and pumping pressure. Machinery cost accounts for the maintenance, lube, and repairs of irrigation equipment and is estimated as a function of pump lift (Arabiyat, 1998). Per acre liquid nitrogen cost, the other energy related variable cost, is calculated as acre-inches of applied water multiplied by pounds of liquid nitrogen applied per acre-inch applied water, and this product is then multiplied by the per pound cost of liquid nitrogen.

Non-Hedonic Optimization Framework. The non-hedonic optimization framework is conceptually similar to the hedonic framework with two important exceptions. First, the lint quality equations for micronaire, strength, and staple length (equations 3, 4, 5) are excluded from the constraint set. Thus, in the non-hedonic approach irrigation and fertilizer application rates are allowed to influence lint yield only, and are incorrectly assumed to have no impact on cotton lint quality, and per pound lint price. The second change is directly related to the first, because quality is assumed to be unaffected by input use level, a fixed expected producer price coefficient is substituted for the endogenous price variable in equation 1 (P^H). Because the non-hedonic manager ignores the impact of input use levels on quality, the non-hedonic manager may receive a per unit price less than the expected price. The per pound price the non-hedonic manager actually receives is subsequently calculated by substituting the water and nitrogen application rates that maximize profits in the non-hedonic profit model specification into the hedonic model, and simulating the per pound lint price when these two inputs are used at their non-hedonically determined optimal levels. Thus, it is possible for a non-hedonic producer to achieve a higher per acre yield but receive a lower per pound market price under specific weather patterns and/or input use levels. The average lint price for the 1998 marketing year was used ($0.5807/lb) as producer expected price. The 1998 average marketing year base price was received when all seven lint quality attributes were at their respective base values, where neither a price discount is deducted for below average quality characteristics, nor a price premium paid for above average quality characteristics.

Representative Farm Assumptions. Analytic results are reported for a typical farm on the THP that uses seed variety Paymaster HS 26, the most common seed variety. Thus, the seed variety variable in equations 2, 3, 4, and 5 is fixed in this analysis. The average phosphorous pre-plant application rate of 40 pounds per acre is applied. Irrigation water is applied by a LEPA irrigation system that can apply a maximum of 15 acre-inches of water, per acre, in the growing season. Whole farm cotton budgets for the region were consulted and fixed costs (including all other non-irrigation related variable costs) were estimated to be $381 per acre (USDA 2000). With respect to the electricity related variable cost items, per pound nitrogen cost was set at the average 2001 price of $0.4125 for nitrogen, or $264 per ton of 32% solution, (NASS 20001) and is applied at the recommended rate of 6 pounds per acre inch of applied water (Morrow and Krieg 1990). The baseline electricity rate was set at $.0718/KWH, the average commercial price in 2001 for the THP. Pumping lift and pumping pressure were respectively set at 200 feet and 16.5 PSI, based on information provided by the High Plains Water District (1998).

Weather Scenarios. For purposes of examining the impact climatic conditions have on the relative profitability of hedonic versus non-hedonic management, both management strategies were examined for three weather scenarios. The three scenarios were derived after reviewing 87 years of historic temperature and precipitation data for Lubbock county (National Oceanic and Atmospheric Administration 2001, National Weather Service 2001). The first scenario represents an average weather year. In an average weather year the cotton crop receives 1275 heat units and 9.85 inches of rainfall within the growing season (May-September). The second weather scenario is representative of a cool and wet growing season where the crop receives 1100 heat units and 12.34 inches of rainfall. The third, and final, scenario is for a hot and dry growing season where the crop receives 1400 heat units and only 5.62 inches of rainfall.

Electricity Cost Scenarios. Given the uncertainty surrounding future electric rates in rural areas we present the relative profitability measures of the two alternative management scenarios, for four alternative price scenarios. The alternative electricity price scenarios are: (1) the average rate paid by commercial customers in 2001 ($.0718/kwh), (2) a 10% rate increase, (3) a 30% rate increase, and a 45% rate increase.

RESULTS

This section presents profit comparisons for both hedonic and non-hedonic profit management for the three weather scenarios and four potential electricity cost rates. Across all weather and price scenarios, hedonic management is never less profitable, and is generally more profitable, than non-hedonic management. From a theoretical perspective this is not surprising because, at its most basic level, the hedonic profit maximization approach provides producers with additional management choices, where one management choice remains the non-hedonic management choice. Even though a non-hedonic producer often mistakenly manages for an incorrect expected market price, the per pound price the producer receives at the time of sale is nevertheless a function of the lint=s hedonic quality attributes. Thus, while unlikely, it is possible that both management strategies can generate identical quality characteristics in some situations.

Average Weather Conditions. Under average weather conditions, hedonic profit management generated higher profits than non-hedonic management. Moreover, as electricity price is increased, the value of hedonic management increases relative to non-hedonic management. The hedonic benefit ranges from $5.32 per acre at the baseline electric rate and increases to $8.69 per acre when the baseline electric rate is increased by 45% (Table 1). Despite the fact that hedonic management provides a higher market price than non-hedonic management ($0.56/lb versus $0.55/lb) gross revenue is higher for non-hedonic management due to higher lint yields. Lint yields are higher for non-hedonic management because the non-hedonic manager applies the maximum per acre quantity of water (15 acre-inches/acre), whereas the hedonic manager applies less water (13.09 - 13.60 acre-inches depending on electricity price).

Table 1. Per Acre Revenue and Cost Comparisons of Hedonic Versus Non-Hedonic Cotton Management for a LEPA Irrigated Farm with a 200 Foot Pump: Average Weather Conditions.

Item	Base Cost ($0.0718/kwh)	Energy Cost Increase 10%	30%	45%
Profit Hedonic ($/ac)	209.27	205.78	198.85	193.71
Profit Non-Hedonic ($/ac)	203.95	199.74	191.33	185.02
Non-Hedonic Profit Loss ($/ac)	-5.32	-6.04	-7.52	-8.69
Applied Water: Hedonic (ac in/ac)	13.60	13.48	13.26	13.09
Applied Water: Non-Hedonic (ac in /ac)	15.00	15.00	15.00	15.00
Price Hedonic ($/lb)	0.56	0.56	0.56	0.56
Price Non-Hedonic ($/lb)	0.55	0.55	0.55	0.55
Yield Hedonic (lbs/ac)	1,156.55	1,153.93	1,148.81	1,145.07
Yield Non-Hedonic (lbs/ac)	1,183.66	1,183.66	1,183.66	1,183.66
Gross Revenue Hedonic ($/ac)	647.52	647.10	646.19	645.45
Gross Revenue Non-Hedonic ($/ac)	650.48	650.48	650.48	650.48
Hedonic Electricity Related Costs ($/ac)	80.61	83.68	89.70	94.10
Non-Hedonic Elec. Related Costs $/ac)	88.89	93.09	101.50	107.81

Note: In average weather conditions the crop receives 1275 heat units and 9.85 inches of rainfall over the growing season.

Despite the lower gross revenue for hedonic management, anywhere from $2.95 to $5.03 per acre (Table 2) depending upon the cost of electricity, hedonic management is more profitable because irrigated related variable cost is considerably less under hedonic management ($8.27 to $13.71 per acre). The hedonic management cost savings associated with applying less water, in combination with a slightly higher lint price are more than sufficient to offset the slight yield disadvantage of hedonic management.

Table 2. Per Acre Differences in Gross Revenue, Electricity Related Production Costs, and Profit for Non-Hedonic Cotton Production Relative to Hedonic Production for a LEPA Irrigated Farm with a 200 Foot Pump Lift: Average Weather Conditions.

Item	Base Cost ($0.0718/kwh)	Energy Cost Increase 10%	30%	45%
Increased Gross Revenue ($/ac)	2.95	3.37	4.29	5.03
Change in Electricity Related Costs ($/ac)				
Increased Energy Cost ($/ac)	3.91	4.68	6.36	7.76
Increased Irrigation Maint. Cost ($/ac)	0.90	0.98	1.13	1.23
Increased Fertilizer Cost ($/ac)	3.46	3.75	4.32	4.72
Total Extra Electricity Related Cost ($/ac)	8.27	9.41	11.81	13.71
Non-Hedonic Profit Reduction ($/ac)	-5.32	-6.04	-7.52	-8.69

Note: In average weather conditions the crop receives 1275 heat units and 9.85 inches of rainfall over the growing season.

Cool and Wet Weather Conditions. The overall empirical results for the cool and wet growing season scenario are generally similar to the average weather scenario except that the magnitude of the economic benefit is considerably larger for hedonic management. The hedonic profit management benefits range from $70.03 to $78.08 per acre (Table 3). As before the non-hedonic manager has higher yields because approximately 5 more inches of water is applied, per acre, than under hedonic management. While the additional water application serves to increase lint yield it does so at the expense of sacrificing lint quality. The per pound market price for lint under hedonic management is $0.58 regardless of electricity cost, but never exceeds $0.51 per pound under non-hedonic management (Table 3).

Table 3. Per Acre Revenue and Cost Comparisons of Hedonic Versus Non-Hedonic Cotton Management for a LEPA Irrigated Farm with a 200 Foot Pump Lift: Below Average Temperature and Above Average Rainfall.

	Base Cost	Energy Cost Increase		
Item	($0.0718/kwh)	10%	30%	45%
Profit Hedonic ($/ac)	242.72	239.83	234.45	229.96
Profit Non-Hedonic ($/ac)	164.63	163.78	161.28	159.93
Non-Hedonic Profit Loss ($/ac)	-78.08	-76.06	-73.17	-70.03
Applied Water: Hedonic (ac in/ac)	9.38	9.32	9.21	9.13
Applied Water: Non-Hedonic (ac in /ac)	14.85	14.68	14.40	14.16
Price Hedonic ($/lb)	0.58	0.58	0.58	0.58
Price Non-Hedonic ($/lb)	0.50	0.50	0.51	0.51
Yield Hedonic (lbs/ac)	1,141.28	1,139.83	1,137.14	1,135.28
Yield Non-Hedonic (lbs/ac)	1,221.40	1,220.34	1,218.36	1,216.54
Gross Revenue Hedonic ($/ac)	656.31	656.09	655.88	655.28
Gross Revenue Non-Hedonic ($/ac)	610.65	613.33	617.84	621.43
Hedonic Electricity Related Costs ($/ac)	55.58	57.83	62.29	65.60
Non-Hedonic Elec. Related Costs ($/ac)	88.01	91.12	97.42	101.79

Note: In the below average temperature and high rainfall weather scenario the crop receives 1100 heat units and 12.34 inches of rainfall over the growing season.

The superior lint quality associated with hedonic management more than offsets the yield reduction and hedonic management generates between $33.84 and $45.66 more revenue per acre than non-hedonic management (Table 4). Due to lower water use, electricity related variable cost is considerably less for the hedonic manager, ranging from $32.43 to $36.19 less per acre. Assuming a 45% increase in electricity cost, electricity expenditure by the hedonic manager is $20.47 less per acre than for the non-hedonic manager (Table 4).

Table 4. Per Acre Differences in Gross Revenue, Electricity Related Production Costs, and Profit for Non-Hedonic Cotton Production Relative to Hedonic Production for a LEPA Irrigated Farm with a 200 Foot Pump Lift: Below Average Temperature and Above Average Rainfall.

Item	Base Cost ($0.0718/kwh)	Energy Cost Increase 10%	30%	45%
Reduced Gross Revenue ($/ac)	-45.66	-42.77	-38.05	-33.84
Change in Electricity Related Costs ($/ac)				
Increased Energy Cost ($/ac)	15.34	16.54	18.92	20.47
Increased Irrigation Maint. Cost ($/ac)	3.54	3.47	3.36	3.26
Increased Fertilizer Cost ($/ac)	13.54	13.28	12.85	12.46
Total Extra Electricity Related Costs ($/ac)	32.43	33.29	35.23	36.19
Non-Hedonic Profit Reduction ($/ac)	-78.08	-76.06	-73.17	-70.03

Note: In the below average temperature and high rainfall weather scenario the crop receives 1100 heat units and 12.34 inches of rainfall over the growing season.

Hot and Dry Weather Conditions. The hot and dry weather scenario provides a situation where the hedonic management solution is identical to the non-hedonic solution (Table 5). Per acre profit is identical because the hot weather in combination with low rainfall necessitates that both managers maximize their use of applied water (both apply the maximum of 15 acre-inches per acre). Even though both managers apply the maximum quantity of available water, yields are as much 20% lower then they were in the prior two weather scenarios. This suggests that the additional revenue generated by increasing lint yields at low per acre production levels, is more profitable than managing for quality when yields are low due to water supply scarcity.

Table 5. Per Acre Revenue and Cost Comparisons of Hedonic Versus Non-Hedonic Cotton Management for a LEPA Irrigated Farm with a 200 Foot Pump Lift: Above Average Temperature and Below Average Rainfall.

Item	Base Cost ($0.0718/kwh)	Energy Cost Increase 10%	30%	45%
Profit Hedonic ($/ac)	133.86	129.65	121.24	114.93
Profit Non-Hedonic ($/ac)	133.86	129.65	121.24	114.93
Non-Hedonic Profit Loss ($/ac)		0.00	0.00	0.00
Applied Water: Hedonic (ac in/ac)	15.00	15.00	15.00	15.00
Applied Water: Non-Hedonic (ac in /ac)	15.00	15.00	15.00	15.00
Price Hedonic ($/lb)	0.59	0.59	0.59	0.59
Price Non-Hedonic ($/lb)	0.59	0.59	0.59	0.59
Yield Hedonic (lbs/ac)	979.43	979.43	979.43	979.43
Yield Non-Hedonic (lbs/ac)	979.43	979.43	979.43	979.43
Gross Revenue Hedonic ($/ac)	580.39	580.39	580.39	580.39
Gross Revenue Non-Hedonic ($/ac)	580.39	580.39	580.39	580.39
Hedonic Electricity Related Costs ($/ac)	88.89	93.09	101.50	107.81
Non-Hedonic Elec. Related Costs ($/ac)	88.89	93.09	101.50	107.81

Note: In the above average temperature and low rainfall weather scenario the crop receives 1400 heat units and 5.62 inches of rainfall over the growing season.

SUMMARY AND CONCLUSIONS

The optimization results revealed significant differences between hedonic and non-hedonic profitability. Not surprisingly, as economic theory would suggest, hedonic management is more profitable than non-hedonic profit maximization given the modeling assumptions. However, the magnitude of increased profitability value for hedonic management in a cool wet year was surprising, hedonic management generated $78.08 more profit per acre than non-hedonic management. Per acre energy related variable cost is also considerably less under hedonic management, and the per acre cost saving increases as electricity price increases. Moreover, assuming a 45% increase in the price of electricity and average weather conditions, energy related variable cost is $13.71 less per acre than under non-hedonic management and 56.6% of the cost savings is attributable to decreased electricity expenditures. In addition to the reported cost savings, the use of irrigation water is generally less under hedonic management, and is as much as 36.8% less under the cool and wet weather scenario (Table 3). Clearly input management decisions can have a profound influence on per acre profit, lint yield, lint quality, lint price, and production cost.

While these empirical results are consistent with the hedonic valuation literature, the magnitude of the reported differences between hedonic versus non-hedonic profit maximization are conditioned on the experimental data used to quantify the lint yield and lint quality response to applied water and nitrogen, and the 1998 DPES equation. The production response models were estimated by Britt *et al.* (2002), using three years of experimental data collected under intensive management practices in one Texas county. The reported results for lint yield and quality characteristics, and overall profitability, will likely vary with the various soil types and management practices of the Texas High Plains. However, from a theoretical perspective, hedonic profit maximization will always generate a per acre profit level greater than or equal to non-hedonic profit maximization for any given set of management practices. Finally, the empirical results were derived under the assumption that the producer had perfect knowledge of growing season rainfall and accumulated heat units. This assumption is heroic given current weather forecasting capabilities. But with the continuing advances in precision agriculture technology, the need for perfect weather forecasts will be greatly diminished, because precision agricultural techniques allow management to continuously adjust input use levels to compensate for changing weather conditions and facilitate hedonic profit maximization. Clearly additional economic research is needed to determine the on-farm plausibility of managing for hedonic characteristics. However, the economic incentive is there, and the agricultural payoff could be enormous.

REFERENCES

Allen, D. P., and D. R. Krieg. Maximizing Cottonseed Quality Through Nutrient Management Strategies. *2000 Beltwide Cotton Conference Proceedings*. National Cotton Council, Memphis, TN.

Arabiyat, Tallah (1998). Agricultural Sustainability in the Texas High Plains. Unpublished M.S. Thesis, Department of Agricultural and Applied Economics, Texas Tech University, Lubbock, Texas, 1998.

Britt, M.L., O.A. Ramirez, and Carlos Carpio. Quality, Weather, and Cotton Production. *Journal of Agricultural and Applied Economics*. 34(3): December 2002: 561-583.

Brown, J.E., D. E. Ethridge, D. Hudson, and C. Engels. An Automated Econometric Approach for Estimating and Reporting Daily Cotton Prices. *Journal of Agricultural and Applied Economics*. 27(2): Dec., 1995: 409-422.

Chernoff, H., and G. Sanchez. The Impact of Industry Restructuring on Electricity Prices. Catalog #F60198. American Gas Association. Arlington, VA. 1998.

Green, C.J., D.R. Krieg, and J.S. Reiter. Cotton Response to Multiple Applications of Nutrient Mixtures. *1999 Beltwide Cotton Conference Proceedings*. National Cotton Council. Memphis, TN: 1272-1273.

High Plains Water Conservation District. An Analysis of Irrigation Ditch Losses, Pump Plants, and the Cost of Pumping Water. Report 98-1, 1998.

Hoelscher, K., D. Ethridge, and S. Misra. Texas-Oklahoma Producer Cotton Market Summary: 1997/98. 1999 Beltwide Cotton Conference Proceedings, National Cotton Council. Memphis, TN: 350-354.

Johnson, P. Electric Power Deregulation: Potential Impacts on Irrigated Crop Production on the Texas High Plains. *Texas Journal of Agriculture and Natural Resources*. 12(1999): 39-50.

Misra, S. Personal Communication. Department of Agricultural and Applied Economics. Texas Tech University, Lubbock, TX. September 2002.

Morrow, M. and D.R. Krieg. Cotton Management Strategies for a Short Growing Season Environment: Water-Nitrogen Considerations. *Agronomy Journal*. 84 (1990): 52-56.

Lubbock Avalanche Journal. Energy Costs Draining Irrigation Farmers Dry. Page 1, June 1, 2003.

National Agricultural Statistical Service. *Agricultural Prices*. Agricultural Statistics Board, U.S. Department of Agriculture.

National Oceanic and Atmospheric Administration. Min/Max Temperature at the Lubbock International Airport Weather Station from 1914-2000. National Climatic Data Center, Asheville, NC. 2001.

National Weather Service. *Lubbock Precipitation: 1911-Present.* Lubbock Weather Bureau, Lubbock, TX. 2001.

Northcutt, K. Deregulation: Texas Style. *Texas Co-Op Power*. Nov., 2001.

Texas Agricultural Statistics Service. *Texas Agricultural Statistics*. USDA, National Agricultural Statistics Service. Austin, TX. 2001.

Texas Tech University. Standardized Performance Analysis. Department of Agricultural and Applied Economics, Nov., 2001.

United States Department of Agriculture. *2000 Projected Costs and Returns Per Acre: Cotton, Sprinkler Irrigated*. Texas Agricultural Extension Service, Amarillo, TX.

United States Department of Agriculture. *1998 Texas Custom Rates Statistics*. Texas Agricultural Statistics Service, Austin, TX.

Occurrence of Feral Dogs (*Canis lupus familiaris*) in Northwest Texas: An Observation

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ABSTRACT

The distribution of feral dogs (*Canis lupus familiaris*) in Texas has not been well documented. This report discusses several observations of feral dogs in northwest Texas and the implications of these observations to cattle and wildlife.

KEYWORDS: *Canis lupus familiaris*, feral dogs, livestock, northwest Texas

Populations of feral dogs (*Canis lupus familiaris*) have been documented in many areas of the United States (Green and Gipson 1994). Because of their potential negative impacts to wildlife and livestock (Denney 1974, Boggess et al. 1978, Lowry and McArthur 1978), information concerning populations of feral dogs is important to biologists and the public. Despite reportedly occurring in all 50 states (Green and Gipson 1994), feral dogs have not been well documented in Texas. Additionally, specimens of feral dogs are poorly represented in museum collections, and no records are from northwest Texas. Populations of feral dogs in northwest Texas are reported, and a specimen collected for The Museum, Texas Tech University, is described.

In northwest Texas, free-ranging dogs, presumed to be feral, were observed by the authors on several occasions from 1998 to 2001. In past studies, dogs were considered feral if they did not wear collars, avoided human contact, and formed packs (Scott and Causey 1973, Gipson 1983, Daniels and Bekoff 1989). Although some dogs observed probably were not feral, subsequent information obtained by the authors suggested that most dogs were feral. Small packs (3-6 dogs) observed by the authors were always associated with cattle feedyards in northern Moore and southern Sherman counties. These observations were consistent with previous researchers that reported feral dog packs of 2-7 individuals (Beck 1973, Scott and Causey 1973, Nesbitt 1975, Gipson 1983).

On December 15, 2000, a female feral dog was collected on U.S. Highway 54, 5 km southwest of Stratford, Sherman County. This particular dog was observed by the authors earlier that week traveling with other feral dogs in a nearby field. Based on tooth wear (Gipson et al. 2000), this dog was approximately 3-4 years old. Inspection of her

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reproductive tract indicated she had never bred. Standard measurements were: total body length, 43.3 in; hind foot length, 7.3 in; tail length, 12.2 in; ear length, 4.3 in; shoulder height, 16.7; and body mass, 30.8 lb. The dog had dark mottled coloration, and thus was a mongrel, or mixed breed. Mongrel dogs often develop after a few generations of uncontrolled breeding among feral dogs (Green and Gipson 1994). This specimen (TTU 85505) is deposited in The Museum, Texas Tech University, Lubbock. Based on a search of records from museums in Texas and New Mexico, this is the first specimen of *C. lupus familiaris* from northwest Texas.

Because feral dogs appeared to be associated with cattle feedyards, the authors used a standard questionnaire to interview managers of 12 cattle feedyards in six counties to determine the status of feral dogs in other areas of northwest Texas (Table 1). The results of the questionnaire suggest that populations of feral dogs are not widespread in northwest Texas, however, isolated populations regularly occur in some areas (Table 1).

Table 1. Manager responses from 12 cattle feedyards in northwest Texas relative to feral dogs status for the previous 5 years. Pack sizes reportedly ranged from 3 to 5, but sometimes up to 10 feral dogs.

County	Observations of feral dogs	Observations ≥ 1 per month	Feral dogs in packs	Annual killings of feral dogs
Dallam	No	---	---	---
Dallam	No	---	---	---
Deaf Smith	Yes	Yes	Yes	Yes
Deaf Smith	No	---	---	---
Hansford	No	---	---	---
Hansford	Yes	No	No	No
Hansford	No	---	---	---
Hartley	Yes	No	No	No
Hartley	No	---	---	---
Moore	Yes	Yes	Yes	Yes
Moore	Yes	No	No	No
Sherman	Yes	Yes	Yes	Yes

Although populations of feral dogs can persist independent of humans in natural areas (Scott and Causey 1973, Green and Gipson 1994), most populations are dependent on human habitations for permanent sources of food and recruitment of new dogs. For example, populations of feral dogs were primarily dependent on large garbage dumps for food in Alabama (Scott and Causey 1973), Alaska (Gipson 1983), and Arizona (Daniels and Bekoff 1989). Similarly, populations of feral dogs were dependent on poultry carrion from large-scale poultry farms in Arkansas (Gipson and Sealander 1976) and Nebraska (Mahan et al. 1978). Feral dogs can reproduce in the wild (Green and Gipson 1994), however, many populations persist due to recruitment of free-ranging dogs from human habitation (Scott and Causey 1973).

Populations of feral dogs in northwest Texas were likely dependent on cattle carrion, because feral dogs occurred near feedyards where dead cattle often were left in carcass pits. It is unknown if feral dog populations reproduced; however, nearby towns likely were a source of free-ranging dogs to maintain populations. Absence or non-enforcement of dog control programs, leash laws, and spay or neuter programs in rural towns contribute to high dog numbers that are sources of feral dog populations (Daniels and Bekoff 1989). In addition to scavenging, feral dogs can be important predators of livestock (Denney 1974, Boggess et al. 1978). Feral dogs also can have negative impacts on wildlife by killing prey species, including deer, *Odocoileus hemionus* and *O.*

virginianus (Denney 1974, Lowry and McArthur 1978). In northwest Texas, feral dogs were not a serious threat to livestock as there were no reports of feral dogs killing livestock. However, feral dogs possibly had negative impacts on wildlife, especially in areas surrounding the towns where feral dogs regularly formed packs. Future research should attempt to determine the ecology of feral dogs in northwest Texas.

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REFERENCES

Beck, A. 1973. The ecology of stray dogs. York Press, Baltimore, Maryland.

Boggess, E. K., R. D. Andrews, and R. A. Bishop. 1978. Domestic animal losses to coyotes and dogs in Iowa. J. Wildl. Manage. 42:362-372.

Cooperative Extension Division, Univ. Nebraska, Lincoln; Great Plains Agricultural Council, Wildlife Committee; and U.S.D.A.-A.P.H.I.S. Wildlife Services, Washington, D.C.

Daniels, T. J. and M. Bekoff. 1989. Population and social biology of free-ranging dogs, *Canis familiaris*. J. Mammal. 70:754-762.

Denney, R. N. 1974. The impact of uncontrolled dogs on wildlife and livestock. Trans. N. Am. Wildl. Nat. Res. Conf. 39:257-291.

Gipson, P. S. 1983. Evaluation and control implications of behavior of feral dogs in interior Alaska. Vertebr. Pest Control Manage. Mater. 4:285-294.

Gipson, P. S. and J. A. Sealander. 1976. Changing food habits of wild *Canis* in Arkansas with emphasis on coyote hybrids and feral dogs. Am. Midl. Nat. 95: 249-253.

Gipson, P. S., W. B. Ballard, R. M. Nowak and L. D. Mech. 2000. Accuracy and precision of estimating age of gray wolves by tooth wear. J. Wildl. Manage. 64:752-758.

Green, J. H. and P. S. Gipson. 1994. Feral dogs. Pp C77-81, *in* Prevention and control of wildlife damage (S. E. Hygnstrom, R. M. Timm and G. E. Larson, eds.).

Lowry, D. A. & K. L. McArthur. 1978. Domestic dogs as predators on deer. Wildl. Soc. Bull. 6:38-39.

Mahan, B. R., P. S. Gipson, and R. M. Case. 1978. Characteristics and distribution of coyote X dog hybrids collected in Nebraska. Am. Midl. Nat. 100:408-415.

Nesbitt, W. H. 1975. Ecology of feral dog packs on a wildlife refuge. Pp 391-396, *in* The wild canids: their systematics, behavioral ecology, and evolution (M. W. Fox, ed.). Nostrand Reinhold Co., New York, New York, 508 pp.

Scott, M. D. and K. Causey. 1973. Ecology of feral dogs in Alabama. J. Wildl. Manage. 37:253-265.

Economic Evaluation of Short Season Bollgard® Cotton Cultivars on the Texas High Plains

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ABSTRACT

An economic evaluation was conducted on near isolines of cotton cultivars that did or did not contain Bollgard® technology for their usefulness in the defense of cotton bollworms *Helicoverpa* (=*Heliothis*) *zea* (Boddie), tobacco budworms *Heliothis virescens* (F.) and other insect pests at a northern and southern location of the Texas High Plains. The most intense insect pressure came from beet armyworms *Spodoptera exigua* (Hubner), an insect not targeted for Bollgard® control, in the southern location. Conventional insecticide applications saved an average 178 lb/ac of lint cotton, but were not economically feasible because of the cost and number of insecticide applications. The northern location did not result in any insect pest surpassing the economic threshold, especially those targeted for control with Bollgard®. The benefits of preventing secondary pests outbreaks from cotton aphids and other pests did not present itself in the two years and two locations of this study.

KEYWORDS: Cotton, Economics, Lint yield, Bollgard®, Insecticides, Bollworms, Budworms, Beet armyworms

Bollgard® cotton has been genetically modified to incorporate a recombinant DNA construct from the bacterium *Bacillus thuringiensis* Berliner subsp. *kurstaki* (Bt), which codes for δ-endotoxin proteins (Perlak et al. 1990, 1991). *Bacillus thuringiensis* is a naturally occurring soil bacterium that when ingested by certain lepidopteron larvae, is a safe alternative to controlling insect pests of cotton while reducing insecticide use and preserving beneficial insects (Armstrong et al. 2000). When ingested, *B. thuringiensis,* a crystalline protein (protoxin), is activated in the insect midgut, releasing toxic fragments that interact with the larval midgut epithelium, binding specifically to the brush border membrane vesicles (Gill et al. 1992). In susceptible insects, gut paralysis and cessation of feeding occur within minutes following ingestion of the δ-endotoxin protein (Dulmage et al. 1978).

Transgenic cotton varieties containing *Bacillus thuringeinsis* (Bt), have been available since 1996 for indeterminate varieties grown in the mid-south and southeast (Williams 1996), but shorter season, stripper-type varieties utilized on the Texas High Plains have only been available with the Bt technology since the 2000 growing season. In 1996, the first year of commercial availability, Bt cotton accounted for 1.85 million acres of total planted U.S. cotton acres (Williams 1997). By 1998, Bt cotton accounted for over a quarter of the total harvested U.S. cotton acres (Frisvold et al. 1999). Due to the lack of stripper varieties more suited for growing on the Texas High Plains, which accounts for approximately 40% of total U.S. cotton production, only an estimated 10% of the total Bt cotton acreage in the U.S. for the 2000 production season was produced on the Texas High Plains (Carpenter and Gianessi 2001).

Short season, stripper-type varieties with Bt have been in production for a short period of time on the Texas High Plains, therefore, there is limited information on fiber quality and lint yields. Efficacy evaluations for target lepidopteran pests within Texas have been positive in terms of controlling insect pests and preserving beneficials (Benedict et al. 1996). It should be pointed out that during the course of a normal production season; the southeastern cotton growing regions have higher lepidopterous insect pressure compared to the Texas High Plains.

The target insects that Bt cotton has provided effective control of on the Texas High Plains is the cotton bollworm *Helicoverpa (=Heliothis) zea* (Boddie) and the tobacco budworm *Heliothis virescens* (F.) complex, and in far West Texas the pink bollworm *Pectinophora gossypiella* (Saunders) Outside of these insect pests, Bt cotton does not control other insects such as thrips (Thysanoptera), boll weevils *anthonomus grandis* Boheman, cotton aphids *aphis gossypii* Glover, cotton fleahoppers *Pseudatomoscelis seriatus* (Reuter) and Lygus *Lygus* spp.

The Bt technology has been widely accepted on the Texas High Plains even though the economics of adoption have not been fully evaluated. The average number of insecticide applications for bollworm control is one per season (Rummel et al.1986). Therefore, the cost of the Bt technology would need to be less than the cost of one application of insecticide on average to justify the cost of the technology. Technology fees, loss of the ability to retain seed for the next year due to exclusive rights of the technology, and up-front costs of seed are some of the economic disadvantages associated with Bt cotton varieties. Ultimately, an economic evaluation of various cotton varieties grown at different locations and under different insect pressures would help in determining the cost-benefit ratios of Bt cotton production on the Texas High Plains.

Historically, the cotton bollworm, *Helicoverpa zea* (Boddie) and the tobacco budworm, *Heliothis virescens* (Fabricius) have caused less damage on the Texas High Plains than in other areas of the state (Rummel et al. 1986). Although the number of insecticide applications per acre may not be as high in the Texas High Plains as compared to other cotton production regions in the United States, the use of Bt cotton varieties may be an economical and safe means of controlling the bollworm/budworm complex.

The objectives of this research were to monitor the seasonal infestation levels of bollworm/budworms, boll weevils, secondary insect pests and beneficial insects in conventional stripper varieties versus newly released isolines of Bt stripper varieties; and to determine if the technology would pay for itself versus managing insects with conventional insecticides. All production costs, including the technology fees for Bollgard® and Roundup Ready®, and boll weevil eradication fees were used versus the return from lint yield and fiber quality as affected by insect damage.

MATERIALS AND METHODS

The cotton isolines used in this study are adapted to Texas High Plains growing conditions. Varieties with Bollgard® and Roundup Ready® technologies were compared to varieties with only the Roundup Ready® technology (Table 1). A northern experimental site near Halfway, TX in Hale County was used to evaluate 2200RR versus 2280BGRR and 2326RR versus 2326BGRR. The cultivars were planted in a randomized block design with four replications under a center pivot irrigation system. A more southern location near Denver City, TX in Gaines County was used to evaluate the previously mentioned cultivars with the addition of 9903RR and 4892BGRR, which are more intermediate cultivars that have a history of producing acceptable yields in more southern counties of the Texas High Plains. Four replications of each cultivar were planted at each site in a randomized block that included a split-plot where each cultivar was designated as treated or non-treated.

Table 1. Parental background of cotton cultivars containing the Bollgard® and Roundup Ready® technology and evaluated in 2000 and 2001.

Parental Background	Herbicide Resistance Trait[1]	Cry1Ac[2] + Herbicide Resistance Trait
HS200[3]	PM 2200RR	PM2280BG\RR
HS26[3]	PM2326RR	PM2326BG\RR
ST474[4]	ST4793RR	ST4892BG\RR

[1]Roundup Ready®; Monsanto Co., (St. Louis, MO).
[2]Bollgard®; Monsanto Co., (St. Louis, MO).
[3]Paymaster® variety (Delta & Pineland Co., Scott MS).
[4]Stoneville Pedigree Seed variety (Memphis, TN).

The treated designation implied that when any pest insect was determined to exceed the economic threshold, an insecticide application of choice would be used to control the insects versus non-treated plots where no control measures were used. Each plot was scouted according to the guidelines described by Sansone et al., 2000. Adult pheromone traps for beet armyworms, bollworms and budworms were placed at the perimeter of each location to monitor the movement of adults around the area. Sampling of the test plots started at emergence but economic pests were scouted on a weekly basis when fruiting structures appeared on the cotton plants.

Test plots were harvested with a two-row or four-row cotton stripper depending upon the availability of harvest equipment. Seed-cotton weights were taken with automated weigh buggies in the field. Sub-samples of seed cotton were ginned at the Texas A&M Experiment Station, Lubbock, Texas. Lint quality was determined by HVI analysis for micronaire, length, and strength characteristics for each sub-sample by the International Textile Center, Texas Tech University, Lubbock, Texas. Cotton yield data were analyzed using Proc ANOVA and means separated by Fishers LSD (SAS 1998). Statistical interactions for Bollgard® versus non-Bollgard®, insecticide treated versus non-treated, and the genetic background of the cotton varieties were also determined in the analysis of variance procedure.

An economic evaluation of the various varieties and insecticide treatments was made using returns above direct cash costs. The market price for cotton lint was estimated using the Daily Price Estimator System (DPES) for West Texas cotton for the 2000/2001 crop year. The DPES is based on an econometrically derived hedonic pricing equation that calculates the estimated premiums and discounts for various lint quality characteristics and adjusts the estimated base price to calculate the market price for cotton lint (Ward et al. 2002). Cottonseed value was based on $95/ton. Production expenses for seed, technology fees, herbicides, insecticides, fertilizer, irrigation, and crop insurance were based on actual expenditures at each experimental location. The Standardized Performance Analysis Database for the 2000 crop year was used to provide average expenses for labor, fuel, and repairs (Blackshear and Johnson 2001). Ginning expenses were calculated based on a 25% cotton lint turnout ratio.

RESULTS AND DISCUSSION

The first year of this study occurred during an epidemic outbreak of beet armyworms at the Denver City site as is indicative of the number of insecticide applications and the significant interaction for the treated versus non-treated test plots, regardless of the Bollgard® technology (Tables 2 & 3). Beet armyworms are not effectively controlled by Bollgard® cotton, but some suppression has been documented (Luttrell et al. 1999). Only two varieties, PM2280BGRR and ST4793R, from the treated plots resulted in positive returns for 2000 at the Denver City location. All other treatments and varieties resulted in losses ranging from $16.65 to $81.19 per acre (Table 3). Average lint yields for the treated varieties in 2000 were significantly higher at 549 compared to 373 lbs per acre for the non-treated varieties. The insecticides used to control beet armyworms are newer and more expensive which accounts for the losses in returns for Denver City in 2000. Another confounding factor at Denver City in 2000 was that ultra low volume applications of malathion were made on a weekly basis throughout the growing season which killed many of the predators of lepidoterous pests but did not control the beet armyworms. This allowed for extraordinarily high densities of beet army worms to develop.

Table 2. Insecticides[1] used in test plots that were treated when the economic threshold was exceeded for Bt and non-Bt cultivars evaluated for bollworm\budworm control, 2000 and 2001.

		Application Date		Application Rate (oz/ac)		
Insecticide	Brand	2000	2001	2000	2001	Cost $/ac
(Denver City)						
Aldicarb	Temik[2]	5/13	5/27	9.6	9.6	26.56
Emamectin	Denim[3]	7/17		0.15		11.19
Carboxylate	Fury[3]	7/28		0.54		6.35
Emamectin	Denim[3]	7/28		0.13		9.87
Chlorpyrifos	Lorsban[3]	8/9		11.0		7.31
Imidacloprid + Cyfluthrin	Leverage[3]	8/9		0.51 + 0.36		9.72
Carbofuran	Furadan[3]	8/25		1.76		2.19
Emamectin	Denim[3]			0.02		1.63
Acephate	Orthene[2]		7/10		2.5	3.00
Indoxocarb	Steward[3]		7/17		1.6	17.83
(Halfway)						
Aldicarb	Temik[2]	5/27	5/27	9.6	9.6	26.56
Oxamyl	Vydate[4]	7/3		1.14		2.91
Oxamyl	Vydate[4]	7/7		1.14		2.91
Oxamyl	Vydate[4]	8/29		1.52		3.86

[1]Boll weevil eradication applications of malathion ULV at a total cost of $12.00/ac are not shown in the table but are included in the production costs.
[2] Indicates that all test plots regardless of "treatment" designation were sprayed.
[3] Indicates that only the plots designated as "treated" were sprayed for beet armyworms.
[4] Vydate was used at Halfway for boll weevil control because Hale County was not voted in for eradication until 2001.

The 2001 insect season at Denver City was more normal than the previous year with only two applications of insecticides made in July. The first insecticide application of acephate was for cotton fleahoppers, another insect not affected by Bollgard®. The application of acephate allowed beet armyworm populations to increase because the non-selectivity acephate killed predators of the lepidopterous pests. This resulted in an economic density of beet armyworms which were then treated with indoxocarb.

The 2001 growing season at Denver City was more conducive to cotton production and the yields across all varieties were higher than in 2000. The genetic background for the less determinate varieties such as ST4793 and ST4892 resulted in higher yields than the more determinate varieties as indicated by the significant interaction for genetic background (Table 3). Returns above direct costs ranged from $268 to $480 per acre at Denver City in 2001. The cultivar ST4793R had the highest returns in both years of the study.

Table 3. Mean lint yield[1] for Bt and non-Bt cotton cultivars evaluated for bollworm\budworm control, and economic return in dollars/ac, Western Peanut Growers Farm, Gaines County, TX 2000 and 2001.

		2000		2001	
Cultivar	Treatment Designation	Yield (lb/ac)	Return ($/ac)	Yield (lb/ac)	Return ($/ac)
PM2200RR	T	480 b	(31.89)	992 bcde	357.73
PM2280BGRR	T	582 a	2.46	949 cde	310.99
PM2326RR	T	536 ab	(16.65)	1151 abc	445.10
PM2326BGRR	T	535 ab	(35.51)	941 cde	299.38
ST4793R	T	581 a	2.63	1306 a	480.58
ST4892BR	T	579 a	(25.39)	1267 a	337.66
PM2200RR	UT	343 d	(66.55)	831 e	268.20
PM2280BGRR	UT	387 d	(62.56)	930 cde	318.74
PM2326RR	UT	357 d	(63.48)	989 cde	369.87
PM2326BGRR	UT	381 d	(79.92)	886 de	299.38
ST4793R	UT	363 d	(80.37)	1183 ab	436.88
ST4892BR	UT	408 cd	(78.02)	1266 a	435.21
Denver City 2000		*Df*	*F*	*P>F*	
Genetic background[2]		2	2.2	0.145	
Bt vs no-BT[3]		1	7.52	0.013	
Trt vs no trt[4]		1	156.4	<0.001	
Transg*treat[5]		1	0.01	0.929	
Denver City 2001		*Df*	*F*	*P>F*	
Genetic background[6]		2	25.9	>0.001	
Bt vs no-BT[7]		1	3.76	0.068	
Trt vs no trt[8]		1	2.81	0.111	
Transgene*treat[9]		1	7.45	0.014	

[1] Column means followed by the same letter are not significantly different, LSD *P>0.05*.
[2]Interaction means for ST474, HS26, and HS200 were 543, 513 and 503 lbs/ac, respectively.
[3]Interaction means for Bt versus non-Bt in were 542 and 498 lbs/a, respectively.
[4]Interaction means for treated versus non-treated were 620 and 419 lbs/ac, respectively.
[5]Interaction means for transgenic by treatment, BGRR treated, BGRR non-treated, RR treated, and BGRR non-treated were 643, 440, 597 and 397 lbs/ac, respectively.
[6]Interaction means for ST474, HS26, and HS200 were 550, 451 and 421 lbs/ac, respectively.
[7]Interaction means for Bt versus non-Bt in were 489 and 459 lbs/a, respectively.
[8]Interaction means for treated versus non-treated were 487 and 461 lbs/ac, respectively.
[9]Interaction means for transgenic by treatment, BGRR treated, BGRR non-treated, RR treated, and BGRR non-treated were 451, 467, 523 and 455 lbs/ac, respectively.

Neither bollworms nor budworms, the insects more closely targeted for control with Bollgard® cotton, were an economic threat at Halfway and did not approach the economic threshold 2000 or 2001. The only insecticide applications were for boll weevil in 2000 with oxamyl because Hale County was not in a boll weevil eradication program (Table 4). Mean lint yields were very similar for 2000, with no significant differences across varieties or for treated versus non-treated test plots. This was a good indication that no insect pest threatened yield resulting in no treatment measures. Returns above direct costs in 2000 ranged from $108 to $168 per acre.

Table 4. Mean Lint Yield[1] for Bt and non-Bt cotton Varieties Evaluated For bollworm\budworm Control, and economic return in dollars/ac, Texas A&M Experiment Station, Hale County, TX - 2000 and 2001.

		2000		2001	
Cultivar	Treatment designation	Yield (lb/ac)	Return ($/ac)	Yield (lb/ac)	Return ($/ac)
PM2200RR	T	737 a	152.40	1063 c	347.30
PM2280BGRR	T	735 a	115.42	1073 c	346.84
PM2326BGRR	T	742 a	123.83	1159 a	399.37
PM2326RR	T	721 a	138.13	1113 abc	354.46
PM2200RR	UT	783 a	168.90	1084 bc	362.76
PM2280BGRR	UT	727 a	108.81	1077 bc	345.09
PM2326BGRR	UT	834 a	169.19	1128 ab	375.78
PM2326RR	UT	718 a	136.64	1097 bc	361.08
Halfway 2000		*df*	*F*	*P>F*	
Genetic background[2]		1	0.08	0.783	
Bt vs no-BT[3]		1	0.39	0.543	
Trt vs no trt[4]		1	1.00	0.336	
Transgene*treat[5]		1	0.08	0.780	
Halfway 2001					
Genetic background[6]		1	19.81	<0.001	
Bt vs no-BT[7]		1	3.19	0.099	
Trt vs no trt[8]		1	0.22	0.650	
Transgene*treat[9]		1	0.55	0.471	

[1] Column means followed by the same letter are not significantly different, LSD $P>0.05$.
[2] Interaction means for HS26, and HS200 were 751, and 742 lbs/ac, respectively.
[3] Interaction means for Bt versus non-Bt in were 757 and 737 lbs/ac, respectively.
[4] Interaction means for treated versus non-treated were 731 and 764 lbs/ac, respectively.
[5] Interaction means for transgenic by treatment, BGRR treated, BGRR non-treated, RR treated, and BGRR non-treated were 736, 778, 725 and 748 lbs/ac, respectively.
[6] Interaction means for HS26, and HS200 were 1128, 1078 lbs/ac, respectively.
[7] Interaction means for Bt versus non-Bt in were 1113 and 1093 lbs/ac, respectively.
[8] Interaction means for treated versus non-treated were 1106 and 1100 lbs/ac, respectively.
[9] Interaction means for transgenic by treatment, BGRR treated, BGRR non-treated, RR treated, and BGRR non-treated were 1112, 1106, 1091 and 1094 lbs/ac, respectively.

The results at Halfway for 2001 reflected a more favorable production season compared to 2000. Yields from all varieties and treatments were higher, resulting in returns ranging from $345 to $399 dollars per acre . The genetic background interaction for 2001 was significant for Halfway (Table 4). We believe this is analogous to the Denver City yields in 2001 and the result of a favorable production season with more natural rainfall.

The present study was conducted during years of light bollworm/budworm pressure and one year of outbreak infestations of beet armyworms at the Western Peanut Growers Farm near Denver City location in 2000. The Halfway location on average would require one application of insecticide for bollworm/budworm control, but none were required for 2000 or 2001. We believe that cultivars that contain the Bt technology will yield comparable or better than the parent lines, and provide the benefit of not disturbing natural predators and parasites of the cotton aphids and other insect pests. Cotton aphid outbreaks have been documented in the northern and southern high plains and can be expensive in terms of direct economic loss from feeding (Kidd et al. 1996) and from ginning problems as a result of sticky cotton (Hequet E., N. Abidi 2002). These added benefits did not display themselves in the two years of evaluation, but are benefits from the Bollgard® technology that should be very important as boll weevil eradication culminates.

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REFERENCES

Armstrong, J. S., J. L. Leser, and G. C. Kraemer. 2000. An inventory of the key predators of cotton pests on Bt and non-Bt cotton in west Texas. p.1030-1033. In Proc. Beltwide Cotton Conf., San Antonio, TX. 4-8 Jan. 2000. Natl. Cotton Counc. Am., Memphis, TN.

Benedict, J. H., E. S. Sachs, D. W. Altman, W. R. Deaton, R. J. Kohel, D. R. Ring, and S. A. Berberich. 1996. Field performance of cottons expressing transgenic Cry1A insecitcidal proteins for resistance to *Heliothis virescens* and *Heliocoverpa zea* (Lepidoptera: Noctuidae). J. Econ. Entomol. 89:230-238.

Blackshear, J. and P. Johnson. 2001. Profitability of Cotton Production in the Texas High Plains. p. 241-244. In Proc. Beltwide Cotton Conf., Memphis, TN.

Carpenter, J. E. and L P. Gianessi. 2001. Agricultural Biotechnology: Updated Benefit Estimates. Report prepared for the National Center for Food and Agricultural Policy.

Dulmage, H. T., H. M. Graham, and E. Martinez. 1978. Interaction between the tobacco budworm, *Heliothis virescens*, and the δ-endotoxin produced by the HD-1 isolate of *Bacillus thuringiensis* var. *kurstaki*: relationship between length of exposure to the toxin and survival. J. Invertebr. Pathol. 32:40-50.

Frisvold, G., R. Tronstad, and J. Mortenson. 1999. Economics of Bt Cotton. Arizona Cotton Field Day. http://ag.arizona.edu/arec/ext/btcotton/display.html.

Gill, S. S., E. A. Cowles, and P. V. Petrantonio. 1992. The mode of action of *Bacillus thuringiensis* endotoxin. Annu. Rev. Entomol. 37:615-636.

Hequet E. and N. Abidi. 2002. Processing sticky cotton: Implication of trehalulose in residue build-up. Journal of Cotton Science 67-90.

Kidd, P W., D. R. Rummel, and H. G. Thorvilson. 1996. Effect of cyhalothrin on field populations of the cotton aphid in the Texas High Plains. Southw. Entomol. 21:293-301.

Luttrell, R. G., L. Wan, and K Knighten. 1999. Variation in susceptibility of noctuid (Lepidoptera) larvae attacking cotton and soybean to purified endotoxin proteins and commercial formulations of *Bacillus thuringiensis*. J. Econ. Entomol. 92: 21-32.

Perlak, F. J., R. W. Deaton, T.A. Armstrong, R. L. Fuchs, S. R. Sims, J. T. Greenplate, and D.A. Fischoff. 1990. Insect resistant cotton plants. Biotechnology 8:939-943.

Perlak, F. J., R. W. Deaton, T. A. Armstrong, R. L. Fuchs, S. R. Sims, J.T. Greenplate, and D.A. Fischoff. 1991. Modification of the coding sequence enhances plant insect control protein genes. Proc. Natl. Acad. Sci. U.S.A. 88:3324-3328.

Rummel, D. R., J. F. Leser, J. E. Slosser, G. J. Puterka, C. W. Neeb, J. K. Walker, J. H. Benedict, M. D. Heilman, L. N. Namken, J. W. Norman, and J. H. Young. 1986. Cultural Control of *Heliothis* spp. In Southwestern U.S. Cropping Systems, pp. 38-53. In S. J. Johnson, E. G. King, and J. R. Bradley, Jr. [eds], Theory and tactics of *Heliothis* Population Management: I-Cultural and Biological Control. Southern Coop. Series Bull. 316.

Sansone, C. G., M Muegge, J. F. Leser and P. Kidd. 2000. Managing cotton insects in the High Plains, Rolling Plains and Trans-Pecos areas of Texas. Texas Cooperative Extension Bulletin E-6.

SAS Institute. 1998**.** SAS/STAT user's guide: release 7.00. SAS Institute, Cary, NC.

Ward, J., J. Nelson, S. Misra, and D. Ethridge. 2002. Texas-Oklahoma Producer Cotton Market Summary: 2000/2001. In Proc. Beltwide Cotton Conf., Memphis,TN.

Williams, Michael R. 1996. “Cotton Insect Losses, 1995.” Proceedings Beltwide Cotton Conference, (1996): 670-689.

Williams, Michael R. 1997. “Cotton Insect Losses, 1996.” Proceedings Beltwide Cotton Conference, (1997): 834-853.

Production and Natural Regeneration of Annual Medics in West-Central Texas

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ABSTRACT

Several annual *Medicago* species have been found to be well adapted to the soils and climates of other areas of Texas, but their adaptation to west-central Texas has not been studied. We evaluated the establishment, yield, and natural reseeding potential of *Medicago truncatula, M. lupulina, M. polymorpha, M. minima, and M. orbicularis* on a Rioconcho clay loam/Spur clay loam soil complex near San Angelo, Texas during 1998 – 2004. All annual medics established following seeding in mid November 1998 although sub-freezing temperatures in December 1998 caused considerable seedling mortality. With one irrigation in November 1998 and above-normal winter and spring rainfall, all species produced a good seed crop in spring 1999. The medics did not establish in autumn 1999 because of dry conditions, but good establishment occurred in autumn 2000 following 8 in. of rainfall and a single irrigation in November 2000. Frequencies of seedlings ranged from 61% for 'Jemalong' barrel medic (*M. truncatula*) to 90% for 'Devine' little bur medic (*M. minima*) in late March 2001. Forage yields in early May 2001 did not differ significantly among the species, but ranged from 1250 (± 590) lb/acre for 'Jemalong' barrel medic to 2640 (± 610) lb/acre for 'Estes' button medic (*M. orbicularis*). Yield from a late-October 2000 planting of 'Devine' little bur medic in May 2001 was 3060 (± 620) lb/acre. 'Devine' little bur medic and 'Estes' button medic exhibited later maturation and tended to produce more forage than the other species. Frequencies of medic seedlings in the November 1998 plantings were low (≤ 25%) while frequency of 'Devine' little bur medic in the October 2000 planting was high (63%) during February 2004 following multiple tillage operations and planting of wheat in September 2003. Annual medics appear to have potential for improvement of rangelands and pastures in west-central Texas, but should be expected to produce significant forage amounts only in years with above-normal, cool-season rainfall or under irrigation.

KEYWORDS: forage, legumes, *Medicago lupulina, Medicago minima, Medicago orbicularis, Medicago polymorpha, Medicago truncatula*, pasture

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INTRODUCTION

Very few desirable forage legumes are present on rangelands in west-central Texas and few have been available for planting in mixtures with grasses on rangelands or improved pastures. Identification of productive, palatable legumes adapted to the soils and climate of west-central Texas would be very beneficial for livestock and wildlife production because of their capacity to fix atmospheric nitrogen and improve the quality of animal diets. Several annual species in the *Medicago* genus, commonly called annual medics, have been shown to be well adapted to the soils and climates of other areas of Texas. The genus *Medicago* contains the well-known perennial *M. sativa* and *M. falcata*, which are commonly known as alfalfa. The annual species are less well known in the USA, and are native to western Asia and the Mediterranean region, though many of the annual species have become naturalized over much of the world (Heyn 1963). A leaflet (L-306), authored by E. M. True, Extension Agronomist at Texas A&M, entitled "Burclover" listed four annual medics as having potential in Texas. This leaflet is not dated, but its contents suggest that it may have been written in about 1956. This leaflet suggests that there were five species of annual medics under evaluation or released for use in Texas at that time. In 1957, the Texas Research Foundation at Renner released a button medic (*M. obicularis*) (Davis et al. 1957). This release, "button clover", was not named, and the currently named cultivar 'Estes' is believed to be a rediscovery of the material originally released as button clover by the Texas Research Foundation. In 1998, 'Armadillo' bur medic (*M. polymorpha*) was released from the Texas A&M University Agricultural Research Station at Beeville (Ocumpaugh 1999). 'Armadillo' was derived from a collection from Pasture 18 at the Beeville Research Station.

Today, there is a renewed effort in Texas to evaluate introduced and naturalized annual medics which may be incorporated into grazinglands to improve the quality of forage and reduce the need for protein supplement and nitrogen fertilizer required to maintain acceptable levels of livestock and wildlife production (Ocumpaugh and Stichler 2000). The purpose of this experiment was to determine: 1) the adaptation of five annual medics to the soils and climate of west-central Texas; 2) their forage yield potential; and 3) the ability of these species to re-seed naturally.

METHODS AND MATERIALS

The experiment was established on a Rioconcho clay loam/Spur clay loam complex near Carlsbad, about 16 miles northwest of San Angelo, Texas. The site had been graded and borders were constructed to facilitate flood irrigation with treated sewage effluent. The experiment was arranged as a randomized complete block design with three replications of each of five annual medics (Table 1). These species were described by Ocumpaugh and Stichler (2000). The site was disked then the plots were seeded with a hand-held broadcast seeder on November 18-19, 1998. All seeds were inoculated with a *Rhizobium* inoculant for annual medic species immediately prior to planting. Plots varied from 19 to 24 ft in width and from 300 to 475 ft in length. The plots were cultipacked after seeding and flood irrigated within 1 week. Competition from tall weeds was suppressed by shredding to a 5-inch stubble height during early spring 1999. The plots were not cultivated after the initial seedbed preparation until late August 2003. All plots were flood-irrigated in mid November 2000 and again in late March 2001. Rainfall was recorded from a rain gauge located near the study site.

Table 1. *Medicago* species and planting rates utilized in an experiment near Carlsbad, Texas on November 18-19, 1998.

Common Name	Scientific Name	Seeding rate (lb bulk seed/acre)[2]
'Jemalong' barrel medic	*M. truncatula*	10.0
'BEBLK' black medic[1]	*M. lupulina*	6.0[3]
'Armadillo' bur medic	*M. polymorpha*	10.0
'Devine' little bur medic[1]	*M. minima*	6.2[3]
'Estes' button medic	*M. orbicularis*	10.0

[1]Indicates experimental material, seed not commercially available.

[2]Medicago and clover seeds are marketed and planted on a bulk seed basis. Over 90% of the seeds are normally germinable.

[3]Inadequate seed supply to plant at a seeding rate of 10.0 lb bulk seed/acre.

Frequency of occurrence of annual medic plants was estimated in each plot from 200 random placements of a 2-in.-diameter circular quadrat on March 21, 2001. Frequency sampling combines density and dispersion characteristics of plants (Hyder et al. 1963). Standing crop of annual medic forage was estimated by clipping to a 1-in. stubble height in five, 2.69-ft^2 quadrats in each plot on May 7-8, 2001. The samples were oven-dried, then weighed to the nearest 0.1 gm. Plot means of these data were subjected to analysis of variance and means were separated by $LSD_{0.05}$.

'Devine' little bur medic (*M. minima*) was planted in a 1.1-acre plot adjacent to the replicated experiment on October 31, 2000. The plot, which had grown wheat during the winter of 1998-99, was disked then 'Devine' seeds were hand-broadcast seeded at 9.1 lb bulk seed/acre. Seeds were inoculated with a *Rhizobium* for annual medic species immediately prior to planting. A spike-tooth harrow was pulled over the plot twice to cover the seeds. The plot was irrigated in early November 2000 and on March 28, 2001. Standing crop of Devine little bur medic was estimated on this plot by clipping to a 1-in. stubble height in eight 2.69-ft^2 quadrats on May 8, 2001, followed by oven-drying and then weighing the samples.

The annual medic plots were not tilled again until late summer 2003, when they were chiseled and disked to prepare a seedbed for planting wheat. Wheat was planted with a drill in early September 2003. The wheat was grazed by cattle during November 2003 and the plots were flood irrigated in early December 2003. Frequency of occurrence of annual medic plants was estimated in each plot in the replicated experiment from 200 random placements of a 2-in.-diameter circular quadrat on February 11, 2004. Frequency of Devine little bur medic in the 1.1-acre plot seeded October 31, 2000 was estimated from three samples of 200 random placements of 2-in.-diameter circular quadrats the same day.

RESULTS AND DISCUSSION

The soil was relatively moist at time of planting in November 1998 and 9.45 in. of rain were received during November 1998 through May 1999 (Table 2). Good stands of all five species emerged, but stands were substantially reduced by a brief period of sub-freezing temperatures in December 1998. Dense growth of annual, cool-season forbs occurred on the plots in spring 1999, but shredding at a 5-in. stubble height allowed the medics to produce a seed crop. The plots were not grazed by livestock, but deer had access to the plots. The plots were not irrigated during the autumn of 1999 and no seedlings emerged during the fall of 1999 or winter of 1999-2000 due to inadequate rainfall (Table 2). Good stands of annual medic seedlings emerged in all plots in response to 8 in. of rainfall during September 25 through November 8, 2000 (Table 2) and a single irrigation in mid November 2000.

Table 2. Monthly rainfall (in.) at the annual medic site near Carlsbad, Texas during 1998 through 2003.

Month	Year					
	1998	1999	2000	2001	2002	2003
	- inches -					
January	0.40	1.25	0.20	1.45	0.65	0.15
February	0.60	0.00	0.10	1.00	1.70	1.80
March	3.10	2.50	0.80	1.50	1.30	1.70
April	0.00	1.50	0.10	0.65	0.35	0.00
May	3.10	2.85	0.35	1.50	0.20	1.40
June	1.00	5.40	6.55	0.95	2.20	5.75
July	0.00	3.25	0.00	0.45	5.70	1.00
August	2.65	0.45	0.00	2.15	1.20	2.00
September	0.00	0.10	0.75	2.85	2.40	5.45
October	2.70	0.55	5.10	0.65	5.30	3.15
November	0.50	0.00	2.15	3.15	0.80	0.55
December	0.85	0.35	0.60	0.20	1.70	0.00
Total	14.90	18.20	16.70	16.50	23.50	22.98

Frequencies of annual medics ranged from 61 to 90% in March 2001 (Table 3), indicating that the plant density was fairly high and that medic plants were fairly evenly distributed over the plots. 'Devine' little bur medic had the highest frequency (90%), although its frequency was not different from that of 'Estes' button medic (78%) or 'BEBLK' black medic (*M. lupulina)* (75%) ($P \leq 0.05$). The frequency of 'BEBLK' black medic (75%) was not significantly different from that of 'Armadillo' bur medic (69%) or that of 'Jemalong' barrel medic *(M. truncatula)* (61%) ($P \leq 0.05$) (Table 3).

Table 3. Mean frequency of occurrence of live plants of five annual medics on March 21, 2001 that had established during autumn 2000 from a seed crop produced in spring 1999 in an experimental planting near Carlsbad, Texas.

Annual medic	Frequency (%)
'Devine' little bur medic	90 a[1]
'Estes' button medic	78 ab
'BEBLK' black medic	75 abc
'Armadillo' bur medic	69 bc
'Jemalong' barrel medic	61 c

[1]Means followed by similar lower case letters are not significantly different at $P \leq 0.05$.

These data indicate that all species produced sufficient seeds during the spring of 1999 to produce fairly dense, uniform stands in the fall 2000/winter 2001, even though no seed crop was produced during the spring of 2000. It is interesting to note that 'Devine' little bur medic and 'BEBLK' black medic, which were seeded at 6.2 and 6.0 lb/acre, respectively, tended to have somewhat higher plant frequencies than 'Armadillo' bur medic and 'Jemalong' barrel medic, which were seeded at 10 lb/acre (Table 2). Deer grazing on the annual medics did not appear to be significant in the winter of 2000-2001, possibly because of an abundance of cool-season, annual vegetation on adjacent rangeland and wheat on adjacent cropland.

Yields in early May 2001 in the replicated experiment ranged from 1250 lb/acre for 'Jemalong' barrel medic to 2640 lb/acre for 'Estes' button medic (Table 4). Mean yields were not significantly different (F = 1.9; P = 0.1871) among the annual medics due to plot-to-plot variation within the species. Although standing crops of associated cool-season annual grasses and forbs were not estimated, it was clear that their abundance and biomass were greater on plots with low yields of annual medics.

Table 4. Estimated yield of five annual medics on May 7-8, 2001 that had reseeded naturally without tillage following planting in November 1998 near Carlsbad, Texas.

Annual medic	Mean yield (lb/acre)[1]	Standard deviation
'Estes' button medic	2640	610
'Devine' little bur medic	2060	540
'BEBLK' black medic	1730	360
'Armadillo' bur medic	1700	980
'Jemalong' barrel medic	1250	590

[1]Means were not significantly different ($P \leq 0.05$).

Estimated yield of 'Devine' little bur medic in early May 2001 on the plot seeded October 31, 2000 was 3060 ± 620 (s.d.) lb/acre. Few cool-season, annual grasses or forbs were present on this plot. The higher herbage yield of 'Devine' on the plot seeded October 31, 2000 compared to the yield on the adjacent plots seeded to this species in November 1998 may have been due to a greater annual medic plant density, more recent soil disturbance, or to less competition from associated annual grasses and forbs.

Visual observations of the plots on May 17, 2001 revealed that 'Jemalong', 'BEBLK', and 'Armadillo' medics were rapidly drying, that 'Devine' was beginning to dry up, but that 'Estes' button medic continued to be green and succulent. This suggests that 'Devine' little bur and 'Estes' button medics may continue to grow and provide quality forage later into the spring in west-central Texas compared to 'Jemalong', 'BEBLK', and 'Armadillo'.

About 7.7 in. of rain fell on the study site during September through October 2003 (Table 2). The wheat planted on the plots in September 2003 grew well, but establishment of the annual medics from the seed crop produced in spring 2001 was much less than we had expected based on establishment in autumn of 2000. Mean frequencies of the annual medics on February 11, 2004 ranged from 1% for 'BEBLK' black medic to 25% for 'Devine' little bur medic (Table 5), but the means were not significantly different (P = 0.16). These low frequency values indicated that medic plant densities were much lower than had been observed in March 2001. We also noticed in February 2004 that the distribution of medic plants in all plots tended to be patchy, rather than uniform. These plots had to be disked twice to prepare the seedbed for planting wheat. This tillage may have covered the annual medic seeds too deeply for optimal emergence. However, the mean frequency of 'Devine' little bur medic on the plot seeded in October 2000 was 63% (± 1.6 s.d.), so excessive tillage may not totally explain the low establishment of annual medics in 2003 in the replicated experiment. We speculate that seed production in spring 2001 may have been greater on the 'Devine' plot seeded in October 2000 than on the plots of other medic species seeded in November 1998. Tillage only about 2 in. deep is recommended for maintaining good stands of reseeding annual medics (Darcy Turner, Turner Seed Co., Breckenridge, TX, personal communication). No-till or minimum-tillage methods should be considered when planting wheat over annual medics.

Table 5. Mean frequency (%) of live plants of five annual medics growing in a mixture with wheat on February 11, 2004.

Species	Frequency (%)[1]
'Jemelong' barrel medic	13
'BEBLK' black medic	1
'Armadillo' bur medic	16
'Devine' little bur medic	25
'Estes' button medic	14

[1]Means were not significantly different (P = 0.1587).

CONCLUSIONS

All five annual medics appeared adapted to the soils at the study site and to the climate of west-central Texas, although the winters during this study period were relatively mild. A brief period of sub-freezing temperatures in December 1998 killed a substantial percentage of the seedlings that had emerged following planting in mid-November 1998, and some seedling mortality was observed following sub-freezing temperatures in the winter of 2000-01. Seeding earlier in the fall might give annual medic seedlings sufficient time to harden and become more cold tolerant. Additional observations are needed to determine if these annual medics would survive a severe winter in west-central Texas. All five species produced acceptable stands in the fall of 2000 from seeds produced in the spring of 1999. Establishment of all annual medics in the replicated experiment was limited (≤ 25% frequency) in autumn 2003, whereas, that of 'Devine' little bur medic in an adjacent plot seeded October 31, 2000 was very good (63% frequency). We believe that excessive tillage may have limited emergence of the medics in 2003 by covering the seeds too deeply. Better establishment of 'Devine' little bur medic in 2003 on the plot seeded in October 2000 may have been realized because of greater seed production on this plot in spring 2001.

With supplemental water from irrigation and above-normal, cool-season rainfall, the five annual medics exhibited substantial to excellent potential to produce forage, with yields ranging from 1250 to 3060 lb/acre. Two species, 'Devine' little bur and 'Estes' button medic, retained green and succulent forage later into the spring than did 'Jemalong' barrel, 'BEBLK' black, and 'Armadillo' bur medics. 'Estes' button and 'Devine' little bur medics also tended to have the potential for greater forage yields. Without supplemental irrigation, these annual medics would likely produce significant amounts of forage and might only be present during years with above-normal, cool-season rainfall in the west-central Texas environment. Without irrigation, the earlier maturing material may prove to be more sustainable, as it may allow these to mature and set seed sufficiently early to avoid the more stressful late spring temperatures. Research from Argentina, suggests that *M. minima* is very tolerant to water stress (Fedorenko et al. 1995), and we have observed this to be true in other testing done with the 'Devine' material. Results from this experiment are very encouraging relative to identifying annual legumes for improving rangelands, tame pastures, and wildlife habitats in west-central Texas.

The experiences from other trials at several locations in Texas and Oklahoma suggest that 'Jemalong' barrel medic will be the least likely to withstand extreme cold temperatures. Testing as far north as central Oklahoma suggests that 'Devine' little bur, and 'BEBLK' black medic will have the greatest winter hardiness.

REFERENCES

Davis, J.H., E.O. Gangstad, and H. L. Hackerott. 1957. Button clover: A reseeding winter annual legume for north central Texas. Bulletin 6. Hoblitzelle Agricultural Laboratory, Texas Research Foundation, Renner, TX.

Fedorenko, D.E.F., O.A. Fernadez, and C.A. Busso. 1995. The effect of water stress on top and root growth in *Medicago minima*. J. Arid Environ. 29: 47-54.

Heyn, C.C. 1963. The Annual Species of Medicago. Scripta Hierosolymitana, Publications of the Hebrew University, Jerusalem. 154 pages.

Hyder, D.N., C.E. Conrad, P.T. Tueller, L.D. Calvin, C.E. Poulton, and F.A. Sneva. 1963. Frequency sampling in sagebrush-bunchgrass vegetation. Ecology 44:740-746.

Ocumpaugh, W.R. 1999. Armadillo burr medic: A new legume variety for central and south Texas. Texas Forage and Grassland Council Advances. Vol. 12, No. 1. p. 1-3. Texas Forage and Grassland Council, Georgetown, Texas.

Ocumpaugh, W.R. and C. Stichler. 2000. Forages for south and south-central Texas. p. V-2 - V-12, In: Texas Beef Cattle Short Course. College Station, TX. August 7, 2000. "Forage Grazing School". Dept. of Animal Science, Texas A&M University and Texas Cooperative Extension, College Station, Texas.

Skills for Agricultural Science Teachers: School Administrator's Perspectives

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ABSTRACT

This study was conducted in order to assess what skills school administrators deem important for the Agricultural Science teachers to possess and what level of importance they place on each skill. The collection of data for this study took place in May 2000. The data collection instrument consisted of a direct mail questionnaire containing 49 separate phrases in regard to teachers' skills. The questionnaire was sent to all public school superintendents in 128 districts in Educational Service Center Regions 8 and 10. The skills were rated on a five point Likert-type scale with 1 being *Unimportant* and 5 being *Essential* and ranked according to their mean score. The study revealed that administrators perceive skills in the areas of leadership development and supervised experience programs, service to special populations, and instructional management as the most important skills needed by Agriculture Science teachers. Skills in production agriculture and natural resources were perceived as less important.

KEYWORDS: Agricultural science teachers, school administrators, teacher skill, teacher knowledge

The National Council for Agricultural Education (2001) defines agriculture education today as "a systematic program of instruction available to students desiring to learn about science, business, and technology of plant and animal production and/or about the environmental and natural resources system" (p. 1). The mission for agricultural education involves preparing students for careers and informed choices in agriculture, food, fiber, and natural resources systems. Agricultural educators attribute supervised experience programs (SEPs), classroom and laboratory instruction, and student participation in leadership organizations as a complete educational program in agriculture (National Council for Agricultural Education 2001, Stagg and Staller 1999).

Most people associate agriculture education today with livestock shows, leadership, and the National FFA Organization. The FFA continues to play a vital role in agricultural education since its establishment in 1928. According to Vaughn, Kieth, and Lockaby (1999), the FFA was established to allow competition between students in order to build self-esteem, develop social skills and values in the young, and keep vocational agriculture in the public schools system. Many agricultural educators believe that without the establishment of FFA, there would be no agricultural education in the public school system.

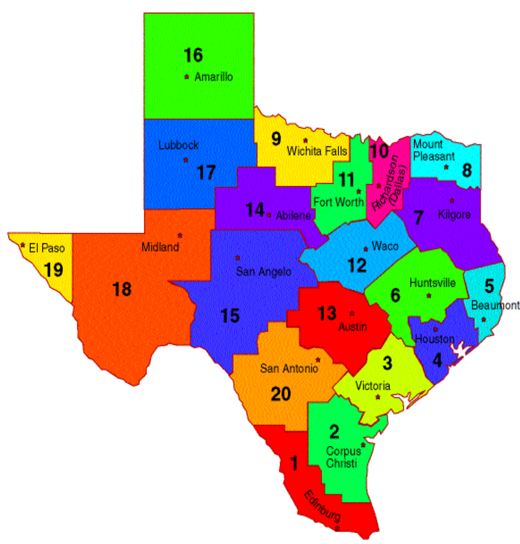
There have been many transitions in agricultural education since its beginning. Most notable are the changes from yearlong courses to semester courses, from manual food production to food technology and agribusiness, and from production projects to applied activities. There are also new requirements for secondary teachers and new curricula for the agricultural student. New curricula for Texas agricultural students include twenty-seven semester agriscience and technology courses. Larke and Norris (1988) stated that due to the continued change of Texas agricultural science curriculum, teachers have had to adapt to teaching unfamiliar curriculum in their classrooms.

Researchers have attempted as far back as the late 1880s to identify specific criteria that produce the most effective agricultural science teacher (Miller, Kahler, and Rheault 1989). Swortzel (1995) identified the following six roles as the primary criteria for the twenty-first century agricultural educator: facilitator of learning, understander of the learner, program developer, administrator, professional educator, and role model/mentor. However, because of the dramatic changes in agriculture, the fluctuation of content in agricultural education courses, and the changes in student enrollment related to agricultural courses, the role of the Agricultural Science teacher is difficult to put into one single definition.

The purpose of this study was to determine and identify what skills and roles Agricultural Science teachers should possess as perceived by school administrators and assess what level of importance they place on these skills.

MATERIALS AND METHODS

This study was conducted in order to determine what skills school administrators deem most important for Agricultural Science teachers and what level of importance they placed on these skills. The study was conducted in May 2000. It consisted of a direct mail questionnaire sent to all public school superintendents in 128 school districts in Texas ESC Regions 8 and 10 (Figure 1). The questionnaire contained 49 separate phrases pertaining to Agricultural Science teachers' skills. The skills were rated by each respondent on a Likert-type scale.

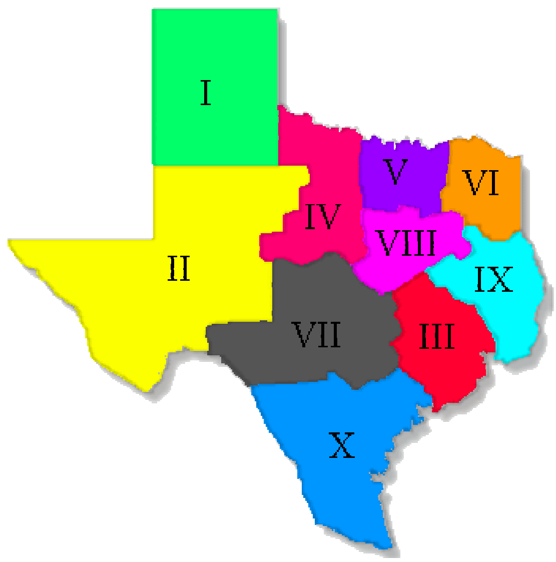


(adapted from Texas Education Agency, http://www.tea.state.tx.us/ESC/)

Figure 1. Educational Service Center Regions in Texas with Service Center Location

The population consisted of all public school systems in the Texas ESC Regions 8 and 10. The characteristics of the school districts were varied. Some of the school districts had multiple high school campuses while others consisted of a single campus. A small proportion of the school districts had middle school programs. There were also districts with no Agricultural Science program.

The sample consisted of the superintendent or his/her designee from 48 school districts in ESC Regions 8 and 80 school districts in ESC Region 10. All of the school districts in ESC 8 were representative of Agricultural Science programs in Area VI FFA (Figure 2). School districts in ESC Regions 10, with the exception of seven districts in Ellis County, are representative of programs in Area V FFA (Figure 2).



(adapted from Texas FFA, http://www.txaged.org/tfa-news.html)

Figure 2. Texas FFA Areas

The instrument consisted of 49 separate phrases to complete the sentence, "Agricultural Science teachers should be able to…" Each phrase was followed by a five-point Likert-type scale ranging from 1 (Unimportant) to 5 (Essential). Although not specifically expressed on the instrument, reviewers indicated that they understood that the higher the rating on the 1-5 scale, the more important the skill was.

Gay (1996) defined validity as "the degree to which a test measures what it is supposed to measure" (p. 624). Content validity of the instrument was based on an extensive review of literature related to administrators' and other agriculture stakeholders' perceptions of Agricultural Science teachers' responsibilities (Flint 1979, Nowadnick 1979, Cox and Zubrick 1986, Kotrlick and Drueckhammer 1987, Foster, Bell, and Erskine 1995, Russell, 1999).

Prior to data collection, a group of preservice and inservice Agricultural Science teachers and a former school administrator reviewed the instrument for content, readability, and applicability to the profession. Suggestions were considered and slight revisions were made to the instrument.

The collection of data occurred through a direct mail questionnaire using the previously discussed instrument. The questionnaire was sent to all public school superintendents in ESC Regions 8 and 10 during May of 2000. The superintendent of each district was mailed a cover letter explaining the purpose of the study, along with the questionnaire and a business reply envelope for returning the completed questionnaire. In the cover letter, superintendents were asked to complete the questionnaire or forward it to the administrator who was most familiar with the Agricultural Science program(s) in the district. The position of the person actually completing the questionnaire was unknown since the responses were anonymous.

A data collection period of six weeks was allowed for the questionnaire to be returned. Sixty-one were returned providing an overall response rate of 47.66%. Since no attempt was made to control for non-response error, generalization of these findings beyond the accepting sample should be made with caution. Data were analyzed to answer the following research question.

What level of importance do school administrators place on skills related to:

a. production and natural resources methods,
b. agricultural mechanization,
c. youth leadership development and SEPs,
d. instrument management,
e. information technology,
f. serving special populations, and
g. program and professional development?

Data were analyzed with Statistical Package for the Social Sciences (SPSS) version 10.0.

RESULTS AND DISCUSSION

The level of importance the school administrators placed on each skill is addressed in separate tables where each of the 49 skills have been placed in categories pertaining to one of the following curriculum areas: a) production and natural resources methods, b) agricultural mechanization, c) youth leadership development and SEPs, d) instructional management, e) information technology, f) serving special populations, and g) program and professional development.

The importance of skills ranked by school administrators in production and natural resource methods can be evaluated in Table 1. *Explain current farm production practices* ranked as highest priority followed by *select livestock for show projects* as second highest priority. Administrators ranked *select and apply pesticides* as the lowest priority.

Table 1. Summary of Responses to Production and Natural Resources Methods (n=61).

Skill	Mean*	SD
Explain current farm production practices	4.15	0.83
Select livestock for show project	4.10	0.91
Perform livestock skills	4.02	0.92
Clip/groom livestock for shows	3.89	0.88
Identify/evaluate soils for productivity	3.79	0.88
Operate greenhouse facilities	3.56	0.87
Demonstrate safe hunting practices	3.52	0.98
Develop greenhouse production schedules	3.51	0.85
Select/apply pesticides safely	3.48	1.06

*Based on a 1-5 Likert- type scale: 1= Unimportant, 5= Essential

Data were analyzed to determine administrators' perceptions of skills needed by Agricultural Science teachers in regard to agricultural mechanization. *Safely use hand and power tools* and *metal fabrication equipment* ranked as the two most important skills, respectively. *Agricultural mechanization* skill ratings are presented in Table 2.

Table 2. Summary of Responses to Agricultural Mechanization Skills (n=61).

Skill	Mean*	SD
Safely use hand and power tools	4.75	0.51
Use welding/metal fabrication equipment	4.49	0.65
Operate farm machinery/equipment	3.74	1.05
Repair household/farm plumbing systems	3.72	0.82
Maintain farm tractors/machinery	3.62	1.11
Install electrical wiring/fixtures	3.44	0.99

*Based on a 1-5 Likert- type scale: 1= Unimportant, 5= Essential

When considering youth leadership and development and SEPs, administrators perceived *supervise students on field trips and FFA activities* to be of highest priority followed by *demonstrate the use of parliamentary procedure* as second highest priority. Ratings of the administrators' perceptions of importance to all *youth leadership and SEP* skills can be found in Table 3.

Table 3. Summary of Responses to Youth Leadership Development (n=61).

Skill	Mean*	SD
Supervise students on field trips/activities	4.72	0.58
Demonstrate use of parliamentary procedure	4.36	0.86
Complete official FFA record books	4.33	0.85
Apply for FFA proficiency/chapter awards	4.30	0.78
Understand the customs/traditions of FFA	4.26	0.89
Complete Texas FFA Scholarship application	4.23	0.88
Teach public speaking	4.18	0.84

*Based on a 1-5 Likert- type scale: 1= Unimportant, 5= Essential

Administrators rated *manage the classroom environment* as the most important skill needed by Agricultural Science teachers in the category of instructional management. Following closely to this mean ranked score is *recognize safe and unsafe laboratory practices. Develop lesson plans and recognize different learning styles among students* were tied for third with a mean score of 4.57. *Use cooperative learning techniques* was ranked as the lowest priority. The results can be evaluated in Table 4.

Table 4. Summary of Responses to Instructional Management Skills (n=61).

Skill	Mean*	SD
Manage the classroom environment	4.82	0.43
Recognize safe/unsafe laboratory practices	4.79	0.49
Recognize different learning styles	4.57	0.62
Develop lesson plan	4.57	0.72
Use cooperative learning techniques	4.10	0.87

*Based on a 1-5 Likert- type scale: 1= Unimportant, 5= Essential

Responses to the importance of information technology skills are addressed in Table 5. Administrators perceived *locate sites on the world wide web (WWW)* as the single most important *information technology* skill needed by Agricultural Science teachers. *Create and maintain web pages* were perceived as the lowest priority skill.

Table 5. Summary Responses to Information Technology Skills (n=61).

Skill	Mean*	SD
Locate sites on the World Wide Web	4.31	0.81
Use computers to prepare FFA record books	4.16	0.76
Send/receive email and attachments	4.07	0.81
Use PowerPoint or similar software	3.49	0.89
Create and maintain web pages	3.02	1.04

*Based on a 1-5 Likert- type scale: 1= Unimportant, 5= Essential

Data were analyzed to conclude the order of importance for skills related to serving special populations (Table 6). *Modify instructional techniques for special education students* was perceived as most important. Ranking as lowest priority was *understand the admission-review-dismissal* process. *Work with students who are economically disadvantaged* fell between the highest and lowest priority skill.

Table 6. Summary of Responses to Serving Special Populations (n=61).

Skill	Mean*	SD
Modify instruction/special education students	4.57	0.62
Work with economically disadvantaged	4.44	0.67
Understand the A.R. D. process	4.34	0.73

*Based on a 1-5 Likert- type scale: 1= Unimportant, 5= Essential

In the area of program and professional development, administrators found *communicate with parents and community members* to be the most important skill needed by the Agricultural Science teacher. The least important skill was perceived to be *write applications for educational grants.* These findings are summarized in Table 7.

Table 7. Summary of Responses to Program and Professional Development Skills (n=61).

Skill	Mean*	SD
Communicate with parents/community	4.84	0.42
Collaborate with other teachers	4.62	0.64
Interpret school district policies	4.54	0.74
Conduct departmental inventory	4.44	0.67
Develop program budgets	4.41	0.72
Complete business forms (POs, travel, etc.)	4.36	0.90
Manage activity fund accounts	4.30	0.99
Serve as leader among school employees	4.18	0.81
Plan/manage fund raising activities	4.13	0.85
Chair/participate on faculty committees	3.97	0.87
Interpret TAAS/AEIS reports	3.70	0.95
Drive bus for FFA activities	3.56	1.19
Write applications for educational grants	3.21	0.97

*Based on a 1-5 Likert- type scale: 1= Unimportant, 5= Essential

CONCLUSION

Literature reviewed for this study included articles regarding the perceptions and attitudes of administrators, teachers, counselors, and other agricultural educators toward vocational agriculture, the vocational agriculture curriculum, and related programs. The roles and skills deemed important for the secondary Agricultural Science teacher were also addressed.

Flint (1979) suggested that in order to maintain a quality vocational agriculture program community involvement is one of the methods that should be implemented. He stated that this could be achieved by allowing speakers of agriculturally based business or farms in the classroom and using these sites for laboratory instruction. The data from this study supports Flint's findings. When all 49 instructional skills were ranked in descending order of importance, *communicate with parents and community members* ranked as the most important skill needed by Agricultural Science teachers. Respondents also found this as first priority when the skill was categorized in the curriculum area of *program and professional development*. Findings of this study also support those of a previous study by Nowadnick (1979) where being involved in public relations was listed as one of the six rules that should be followed by vocational agriculture programs in order to be successful.

Thompson (1986) studied the goals and objectives of the vocational agriculture program perceived to be important by superintendents, vocational agriculture program perceived to be important by superintendents, vocational agriculture teachers, and students. Among the ten statements listed in the survey was the need to develop competence in livestock and crop judging. Although respondents did not rank livestock judging as an important skill, *select livestock for show projects* ranked in the instructional category of production and natural resources methods as the second highest priority skill.

In a study conducted to compare the perceptions of agricultural teachers and principals on the importance of teachers activities in the vocational program, Cox and Zurbrick (1986) reported leadership development to be the most important instructional area in the future curriculum according to Nebraska teachers, principals, and superintendents. In a second study regarding the perceptions of agricultural education stakeholders toward important curriculum areas in the future, Russell (1999) reported that they also thought leadership to be the most important area in the future. Kotrlick and Drueckhammer (1987) reported that Agricultural Science teachers ranked agricultural mechanics and SEPs as the two most important programmatic factors in order to plan their program for the year 2000. Data from this study did not support findings of Kotrlick and Drueckhammer (1987) regarding agricultural mechanics. However, findings of this study support the points made by Foster et al. (1995) and Russell (1999) since all *youth leadership development and SEP* ranked in the top 25 of the 49 skills.

This study assessed the perception of school administrators toward skills deemed important for the Agricultural Science teacher. The level of importance the administrators placed on these skills was also assessed.

The top ten skills as perceived by school administrators for the Agricultural Science teacher to possess were ranked in descending order of importance and are as follows:

- communicate with parents and community members,
- manage the classroom environment,
- recognize safe and unsafe laboratory practices,
- safely use hand and power tools,

- supervise students on field trips and FFA activities,
- collaborate with other teachers,
- develop lesson plans,
- recognize different learning styles among students,
- modify instruction for students in special education, and
- interpret school districts policies.

Forty-nine skills were divided into seven separate curricular areas including: production and natural resources methods, agricultural mechanization, youth leadership development and SEPs, instructional management, information technology, serving special populations, and program and professional development. Administrators ranked four of the top ten skills in the area of instructional management and three of the top ten skills in program and professional development.

All skills in the curricular area of production and natural resources methods ranked in the bottom 25 of the 49 skills. Of the agricultural mechanization skills, only two ranked in the top 25; these consisted of *safely use hand and power tools* and *use welding/metal fabrication equipment*. All skills in youth leadership development and SEPs were ranked in the top 25 skills as well as all skills in serving populations. All but one instructional management skills were in the top 25.

Administrators perceived most skills in the curricular areas of leadership development and SEPs, serving special populations and instructional management to be of higher importance. Administrators perceived production and natural resources methods skills, agricultural mechanization skills, and information technology skills to be of lower importance by ranking most of those skills in the lower half. Perceptions on program and professional development skills were varied.

These findings can be beneficial to both preservice and inservice Agricultural Science teachers as well as teacher educators. Current and future teachers may use these findings to better understand the rationale that administrators use in making decisions affecting agricultural science programs. Teacher educators may also wish to place greater emphasis on these skills during preservice preparation of Agricultural Science teachers. Even though administrators in this study placed greater emphasis on leadership development than they did on production agriculture and natural resources, information technology, and agricultural mechanization, the latter should not be overlooked in teacher preparation

REFERENCES

Blezek, A.G. 1986. The prioritization of tasks of vocational agriculture instructors as perceived by state supervisors, teacher educators, and vocational agriculture instructors in Nebraska. *Journal of the American Association of Teacher Educators in Agriculture*, 27 (1): 45-52.

Cox, D. E. & Zurbrick, P. R. 1986. A comparative analysis of perceived importance of teacher activities associated with the program components of vocational agriculture. Journal of the American Association of Teacher Educators in Agriculture, 27 (3): 29-34.

Flint, G.H. 1979. Maintaining quality vo-ag programs-An administrator's view. Agricultural Educational Magazine, 51: 206, 210.

Foster, R., Bell, L., & Erkskine, N. 1995. The importance of selected instructional areas in the present and future secondary agricultural education curriculum as perceived by teachers, principals, and superintendents in Nebraska. Journal of Agricultural Education, 36, (3). 1-7.

Gay, L.R. 1996. Educational research: Competencies for analysis and application. (5th ed.). Englewood Cliffs, NJ: Prentice Hall, Inc.

Kotrlick, J.W. & Drueckhammer, D. 1987. The importance of selected external factors and programmatic components in planning vocational agriculture programs. Journal of the American Association of Teacher Educators in Agriculture, 28 (4): 26-31,49.

Larke, A. & Norris, R.J. 1988. Opinion leadership among teachers of Agricultural science in Texas. Journal of the American Association of Teacher Educators in Agriculture, 29 (4): 32-39.

Miller, W.W., Kahler, A.A. & Rheault, K. 1989. Profile of the effective vocational agricultural. Journal of Agricultural Education, 30 (2): 33-40.

National Council for Agricultural Education. 2001. About agricultural education. [Online]. http://www.teamaged.org/aged/htm.

Nowadnick, G. 1979. A successful vo-ag program-A principal's point of view. Agricultural Education Magazine, 51: 207.

Russell, D.H. 1999. Perception of urban agriculture education stakeholders toward curriculum (urban education, urban agriculture) (Doctoral dissertation, Iowa State University, 1999). Dissertation Abstracts International, 60, 04A.

Stagg, B. & Staller, B. 1999. Will FFA be a part of agricultural education in twenty years? Agricultural Education Magazine, 71: 2,19.

Sworzel, K.A. 1995. A program for the preparation of preservice agricultural education teachers for the twenty-first century. Columbus, OH: Ohio State University, Department of Agricultural Education. (ERIC Document Reproduction Service No. ED 389 676).

Thompson, D.E. 1986. Examining superintendents', vocational agricultural teachers' and vocational agriculture students' perceptions of vocational agriculture programs. Journal of the American Association of Teacher Educators in Agriculture. 27 (4): 37-41.

Vaughn, P.R., Kieth, L., & Lockaby, J. 1999. The FFA organization: Needed then & needed now. Agricultural Education Magazine, 71: 4-5.