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Observations of Grass Community Dynamics in Short Duration Grazing Systems in West Texas

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ABSTRACT

Short duration grazing (SDG) has played a major role in grazing management practices in North America over the past 2 decades. Among other things, implementation of SDG (i.e., cell grazing) reportedly improves livestock distribution within the grazing unit and improves range condition. The objective of this study was to evaluate density and frequency of the herbaceous vegetation as affected by distance from cell center, as well as changes in density and frequency over a 9-year period. Vegetation of the study area is considered a semidesert grass-shrub complex dominated by black grama (*Bouteloua eriopoda* Torr., Torr.) and multiple-stemmed honey mesquite (*Prosopis glandulosa* Torr.). Following implementation of SDG, density and frequency of herbaceous vegetation differed at various distances from the cell center. The spatial variability in plant response suggests that implementation of SDG did not result in uniform forage utilization. Secondly, there was an increase in density and frequency of perennial grasses over the 9 years of the study. The increase in plant density and frequency may be related to SDG but it is likely that a principal cause of the positive response was favorable precipitation levels received during the study period.

KEYWORDS: SDG, cell grazing, black grama, *Bouteloua eriopoda*, density, frequency

In the early development of short duration grazing (SDG) and similar grazing systems, proponents suggested that uniform utilization of grazing land could be achieved by proper implementation of SDG (Savory and Parsons, 1980). Although Savory (1983) has since refuted claims that uniform utilization can be achieved under SDG, he still states that distribution of grazing can be improved through properly managed SDG methods (Savory, 1988). Recent research questions the idea that SDG improves or results in uniform livestock distribution and utilization (Kirby et al., 1986; Pitts and Bryant, 1987; Nelson et al., 1989; Walker et al., 1989a; Walker et al., 1989b; McKown et al., 1991). Nevertheless, numerous producers and land managers still believe that uniform distribution and forage utilization will be

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achieved with the implementation of SDG or other grazing strategies that rely on high stock densities (Stan Reinke, Natur. Res. Conserv. Service, pers. comm.).

We believe that existing paradigms held by land managers and producers concerning livestock distribution and utilization warrant evaluation of SDG on a long-term basis, especially in semiarid and arid ecosystems where soil water and nutrients are limited. Thus, the objective of our study was to determine spatial and temporal dynamics of herbaceous vegetation in terms of density and frequency in two SDG systems over a 9-year period. Development and evaluation of the objective is based on the assumption that similar utilization by livestock of plants at various distances from the cell center should result in a similar pattern of plant response (i.e., density and frequency) within cell pastures.

STUDY AREA

The study was conducted on two sites of the Anderson Ranch in Winkler and Ward counties of the Trans Pecos Region of Texas. The sites were owned by the University of Texas Lands/Surface Interests and leased for grazing by Mike Harrison. The area was classified as a semidesert grass-shrub complex (Nelson, 1934; Paulsen and Ares, 1962). Average annual precipitation was 11 inches with 80% of the precipitation occurring from May to October. Temperatures ranged from a daily minimum of 13°F in January to an average maximum of 95°F in July. The frost-free period averaged 233 days. The area was dominated by shallow sandy loam to deep noncalcareous sandy soils which had good infiltration rates and were well drained.

The major native grasses on the Anderson Ranch were perennials including black grama (*Bouteloua eriopoda* Torr. Torr.), dropseeds (*Sporobolus contractus* Hitchc., *Sporobolus flexuosus* Thurb. Rydb.), plains bristlegrass (*Setaria leucopila* Scribn. & Merr., K., Schum.), bush muhly (*Muhlenbergia porteri* Scribn.), fluffgrass (*Erioneuron pulchellum* H. B. K.), and threeawns (*Aristida* spp. L.). The primary woody plant was multiple-stemmed honey mesquite (*Prosopis glandulosa* Torr.); however, creosotebush (*Larrea tridentata* DC., Cov.), catclaw (*Acacia greggii* Gray), threadleaf groundsel (*Senecio douglasii* DC.), and broom snakeweed (*Gutierrezia sarothrae* Pursh, Britt. & Shinners) were also common. Short-lived perennial and annual forbs were abundant during intermittent wet periods, but generally made up a minor portion of the plant cover.

Sandwell Cell

Nine pastures were arranged in a wagon-wheel design in the Sandwell Cell, which covered 7,606 acres. Each pasture was about 840 acres and 2 miles long. Sandwell Cell was dominated by shallow soils classified as Sharvana sandy loam (thermic Petrocalcic Ustalfic Paleargids). The Sandwell Cell was native rangeland dominated by black grama and multiple-stemmed honey mesquite. The cell was stocked with a cow/calf herd at 49 acres per animal unit year (AUY) throughout the study. The grazing cycle was 90 days with 10- to 12-day grazing periods.

Harrison Cell

The Harrison Cell encompassed 8,006 acres with eight pastures of nearly equal size arranged in a wagon-wheel design. Each pasture was about 1,000 acres and 2 miles long. Harrison was dominated by a shallow, gravelly loam soil in the Simona series (thermic Typic Paleorthids). In 1977-78, the Harrison site was rootplowed and seeded to a mixture of 75% Lehmann lovegrass (*Eragrostis lehmanniana* Nees) and 25% plains bristlegrass, dropseeds, and sideoats grama (*Bouteloua curtipendula* Michx., Torr.). Although a good stand of Lehmann lovegrass established, substantial re-establishment of native plant species like black grama and fluffgrass had occurred by 1983. The Harrison Cell was stocked with a cow/calf herd at 40 acres per AUY throughout the study. The overall grazing cycle was similar to that of Sandwell with a 90-day grazing cycle and 10- to 12-day grazing periods.

METHODS

In January 1983, three pastures within each cell were selected for measurement of spatial and temporal changes in vegetation under SDG. Selected pastures were generally equal in size and were considered to represent the respective cells in terms of dominant soils and vegetation. Beginning near the cell center and extending toward the periphery of each pasture, eight permanent transects were located systematically at 1322-ft intervals. Each transect line was 164 ft long and situated perpendicular at 105 ft from a paddock fence radiating out from the cell center.

Beginning with the establishment of the cells in 1983, vegetation was sampled annually. A modified belt transect system (Schmutz et al., 1982) was used to estimate density and frequency. The methodology involved systematic placement of a 0.33 ft^2-quadrat at 3.28-ft intervals along a tape measure stretched between opposite ends of the transect. At each quadrat placement, the number of individual plants of each species was recorded for plant density (plants ft^{-2}) and frequency (%) determination. Before observations were recorded each year, procedures for identifying individual plants were standardized among observers and years. Individual grass plants are often difficult to distinguish, especially if they reproduce vegetatively (Bonham, 1989). Consequently, we adopted a procedure of identifying an individual plant as vegetation growing from an individual tussock.

Both cells were analyzed separately because initial botanical composition and stocking rates differed. Repeated measures analysis of variance was used to determine differences in density and frequency among the eight distances (treatments) across the three pastures (replicates) within each cell averaged over time (Hicks, 1993). Test of sphericity determined that multivariate analysis rather that univariate should be utilized (SAS, 1985). Least squares analysis was performed on treatment and interaction effects when $P \leq 0.10$. Significant year differences were identified using multivariate analysis procedure for a paired contrast between years (SAS, 1985), which limits year comparisons to contrasts between two consecutive years (e.g., 1983 vs. 1984, not 1983 vs. 1985).

RESULTS

Distance from Cell Center

Analyses of the first year data (1983), collected prior to implementation of SDG, indicated that density and frequency of the major perennial grass species were similar among the treatments (i.e., distance from cell center) for both cells. Hence, there did not appear to be existing patterns in plant density or frequency at the onset of the study.

Sandwell Cell

Black grama was the dominant perennial grass species as it composed more than 77% of the total perennial grass density in the Sandwell Cell. Other prevalent grasses were threeawns at a low relative density of 4.7%. Density and frequency for black grama differed among lines in the Sandwell Cell (Table 1). Black grama density was higher near the cell center (line 1 = 2.89 plants ft^{-2}) than for the remaining lines, while black grama density for lines midway through the pasture (4 and 5 = 0.90 plants ft^{-2}) was lower than all other lines except for line 3. Black grama frequency for line 1 (78.0%) was higher than lines 2 through 6.

There was a year by line interaction for density of total grasses and threeawns. For the first 5 years of the study, density of total grasses was generally similar in the front and back part of the paddocks but higher than total grass density for the middle lines. During the last 4 years of the study, however, density for line 1 was generally higher than all other lines, including those in the back part of the paddocks. As for density of threeawns, all lines had similar densities from 1983 through 1986, whereas density varied among lines from 1987 through 1991.

Frequency for threeawns and total grasses differed among lines in the Sandwell Cell (Table 1). Frequency of total grasses was similar for the lines at the front and back parts of the paddocks while the lowest frequencies were recorded for lines 4 and 5 (61.1 and 62.9%, respectively). Frequency of black grama followed the same pattern as total grasses, whereas threeawn frequency by line was considerably different. Frequency of threeawns peaked in the middle lines at 14.8% and reached its lowest point towards the front part of the paddock at 1.4%.

Harrison Cell

Lehmann lovegrass was the dominant perennial grass in the Harrison Cell as it composed about 26.1% of the total perennial grass density. The secondary grass species were black grama and threeawns with relative densities of about 15.5% and 15.2%, respectively. Density and frequency of black grama, threeawns, and total grasses were similar for all lines. Lehmann lovegrass, however, tended to decrease in density as distance from cell center increased (Table 2). There was a year by line interaction for Lehmann lovegrass frequency which was related to the inconsistency of significant differences among lines over time. Frequency was generally higher for lines 1 through 5 than for lines 6 through 8 (Table 2). During the majority of the study (1983 through 1988), lines 1 and 2 tended to have the highest frequency. Frequency for 1990, was highest for lines 4 and 5.

Table 1. Density (plants ft^{-2}) and frequency (%) for the major perennial grass species by line in the Sandwell Cell. Means are averaged over years.

Species	Line†							
	1	2	3	4	5	6	7	8
Density								
Black grama	2.9 a‡	1.6 b	1.5 bc	0.9 c	0.9 c	1.7 b	2.1 b	2.0 b
Frequency								
Black grama	78 a	50 bcd	49 bcd	31 d	35 cd	54 bc	71 ab	68 ab
Threeawns	4 cd	1 d	10 ab	15 a	11 ab	6 bcd	9 bc	9 bc
Total grass	83 ab	68 bc	71 bc	61 c	63 c	69 bc	82 ab	98 a

†Density and frequency were estimated along lines at intervals of 1,322 ft from the cell center.
‡Within a row, means followed by different letters are different ($P<0.1$).

Table 2. Density (plants ft^{-2}) and frequency (%) for the major perennial grass species by line in Harrison Cell. Means are averaged over years.

Species	Line†							
	1	2	3	4	5	6	7	8
Density								
Leh. lovegrass	1.0 a‡	0.8 ab	0.5 bcd	0.7 abc	0.6 abcd	0.2 d	0.3 cd	0.4 bcd
Frequency								
Leh. lovegrass	41	40	26	33	31	8	12	24

†Density and frequency were estimated along lines at intervals of 1,322 ft from cell center.
‡Within a row, means followed by different letters are different ($P<0.1$).

Sandwell Cell

Density and frequency of black grama differed over time in the Sandwell Cell (Table 3). Black grama density and frequency peaked in 1989 and then declined to lower levels in 1990 and 1991 levels. Density and frequency of threeawns also changed over the course of the study. Frequency increased over time peaking in1991 at 16.8% (Table 3). Analysis of density of threeawns, however, indicated a year by line interaction. Line 2 did not change over time while density for the remaining lines increased. There was a year by line interaction for total grass density. The interaction reflected the small change in density that occurred in lines 6, 7, and 8 over the course of the study while density increased for lines 1 through 5 over the study period.

Table 3. Density (plants ft^{-2}) and frequency (%) for the major perennial grass species from 1983 to 1991 in the Sandwell Cell. Means are averaged over lines.

Species	Year								
	83	84	85	86	87	88	89	90	91
Density									
B. grama	1.5*	1.0*	1.3*	1.8*	1.8	1.7*	2.3*	1.8	1.9
Frequency									
B. grama	48*	37*	42*	57	59*	64*	66*	59	57
Threeawns	4	3*	5*	6	9*	12*	8	8*	17

*Within a row, a mean with an asterisk is different ($P<0.1$) than the mean of the following year.

Harrison Cell

Density of black grama, Lehmann lovegrass, threeawns, and total grasses increased over time in the Harrison Cell (Table 4). Density for the major grasses peaked in the period from 1989 to 1991. Density of total grasses reached its highest level in 1988 before declining in 1989. Lehmann lovegrass increased from 0.20 plants ft^{-2} in 1983 to 0.73 plants ft^{-2} in 1991, while total grasses increased from 1.23 to 2.52 plants ft^{-2} over the same period. Frequency of black grama and total grasses did not change throughout this study. Frequency of threeawns did increase, reaching its highest level in 1991 (Table 4). The year by line interaction which occurred for frequency of Lehmann lovegrass was significant. Frequency of Lehmann lovegrass for lines 1 and 2 peaked between 1987 and 1988, while lines 3 through 7 peaked between 1990 and 1991. Lines 1 and 2 declined to the level reported in 1991.

Table 4. Density (plants ft^{-2}) and frequency (%) for the major perennial grass species from 1983 to 1991 in the Harrison Cell. Means are averaged over lines.

Species	Year								
	83	84	85	86	87	88	89	90	91
Density									
B. grama	0.3*	0.2	0.2*	0.3	0.2*	0.4	0.5	0.4	0.4
L. lovegrass	0.2*	0.1*	0.4*	0.5*	0.6*	0.7	0.7*	1.0*	0.7
Threeawns	0.2	0.2	0.2*	0.3*	0.4	0.3	0.3	0.5*	0.6
Total grass	1.2	1.4	1.4*	2.2*	2.3*	2.9*	2.4	2.5	2.5
Frequency									
Threeawns	11	10	10*	19*	25	21*	18*	21*	30

*Within a row, a mean with an asterisk is different ($P<0.1$) than the mean of the following year.

DISCUSSION

Distance from Cell Center

If SDG results in uniform utilization within pastures, then one might expect uniformity of plant response at various distances from cell center, assuming climate and soils are similar. Results of our study indicate that changes in density and frequency of some of the major perennial grass species varied spatially within the experimental pastures (Tables 1 and 2). Our findings are consistent with others which suggest uniform utilization by grazing livestock is not achieved under SDG (Kirby et al., 1986; Pitts and Bryant, 1987; Soltero et al., 1989).

Density of grasses was relatively high near both cell centers. Heavy grazing pressure often causes bunchgrasses to break, and results in increased density and lower basal cover (Nelson, 1934; Hickey, 1961; Butler and Briske, 1988). Vigor of these smaller plants is generally lower and the plants are more susceptible to grazing (Briske, 1991). As measured in 1990 and 1991, basal area of individual grass plants in the front portions of the pastures was less than that of grass plants of the same species further from the cell center (Scott and Schacht, unpublished data). Visual observations also indicated that although plant density was higher in the front portions of the pastures, individual plants were considerably smaller. Collectively, these results suggest that heavy use was occurring in the front of pastures, probably because of proximity of water.

The apparent low utilization of plants in the back of pastures was probably due to distance from water. Stuth (1991) indicated that forage utilization decreases dramatically after 0.5 miles from water with the outer limit of cattle and sheep grazing at approximately 1 mile. Pastures in both Sandwell and Harrison cells were approximately 2 miles long, and consequently, the back of the pastures may have exceeded the area available for grazing. Nevertheless, Squires (1981) described some groups of cows that travelled as far as 5.5 miles from water to forage. Livestock often forage in disparate locations because of preferences for particular areas (e.g., habitats) within the environment (Scott et al., 1995), which may explain the observations of Squires (1981). Livestock may also learn the schedule of movements in a SDG system. Managers report that livestock are usually "waiting at the gate" when its time to move into a new cell pasture. In the Sandwell and Harrison cells cattle were moved on a regular basis from one pasture to the next through gates near the cell centers; therefore, livestock grazing distribution was probably also affected by movement procedures employed in the two cells.

Pasture configuration may have influenced livestock distribution and utilization patterns. Pastures in the two cells were triangular-shaped and arranged in a wagon-wheel design, with watering facilities at the cell centers. It is possible that higher levels of utilization in the front portion of pastures were the result of pasture design rather than factors relating to SDG. Nevertheless, most SDG units utilize a wagon-wheel design with triangular-shaped pastures. Our findings regarding plant responses at varying distances should be applicable to the majority of SDG units.

Change Over Time

The increase in density and frequency of the major perennial grass species could be interpreted as a result of implementation of SDG. The cells were established during relatively dry years when annual precipitation was below the annual long-term average of 11 inches. During the study period, annual precipitation was relatively high especially from 1984 through 1987. Following 1987, annual precipitation declined to below-average levels in 1989 before increasing again in 1990. Nelson (1934) reported years of above-average rainfall preceded increases in herbaceous plant density by 1 to 2 years in the semidesert region of western Texas and southern New Mexico. In our study increases in density and frequency of major perennial grass species generally occurred 1 to 2 years after above-average annual precipitation (Figures 1 and 2). Therefore, increases in density and frequency over time may be attributed to above-average annual precipitation rather than SDG, or possibly a combination of both factors.

Finally, average stocking rate for the two cells (45 acre per AUY) was about 32% higher than the long-term stocking rate previously used on the Anderson Ranch under continuous grazing (Gary Loftin, Manager, Anderson Ranch, pers. comm.). Control of intensity and frequency of defoliation of key forage species is a basic principle of intensively-managed grazing systems such as SDG (Vallentine, 1990). When properly managed, intensively-managed grazing systems reportedly allow for higher levels of utilization and stocking rates because length of grazing and recovery periods match the needs of the key species (Waller et al., 1986). Perennial grasses in our study responded favorably to relatively high stocking rates and SDG as they increased in density and frequency over the study period. Other studies in Texas and Oklahoma, however, report varying results concerning vegetation response to SDG at higher stocking rates (Ralphs et al. 1990; Gillen et al. 1991). Moreover, our study did not provide the resolution to separate the effect of above-average precipitation

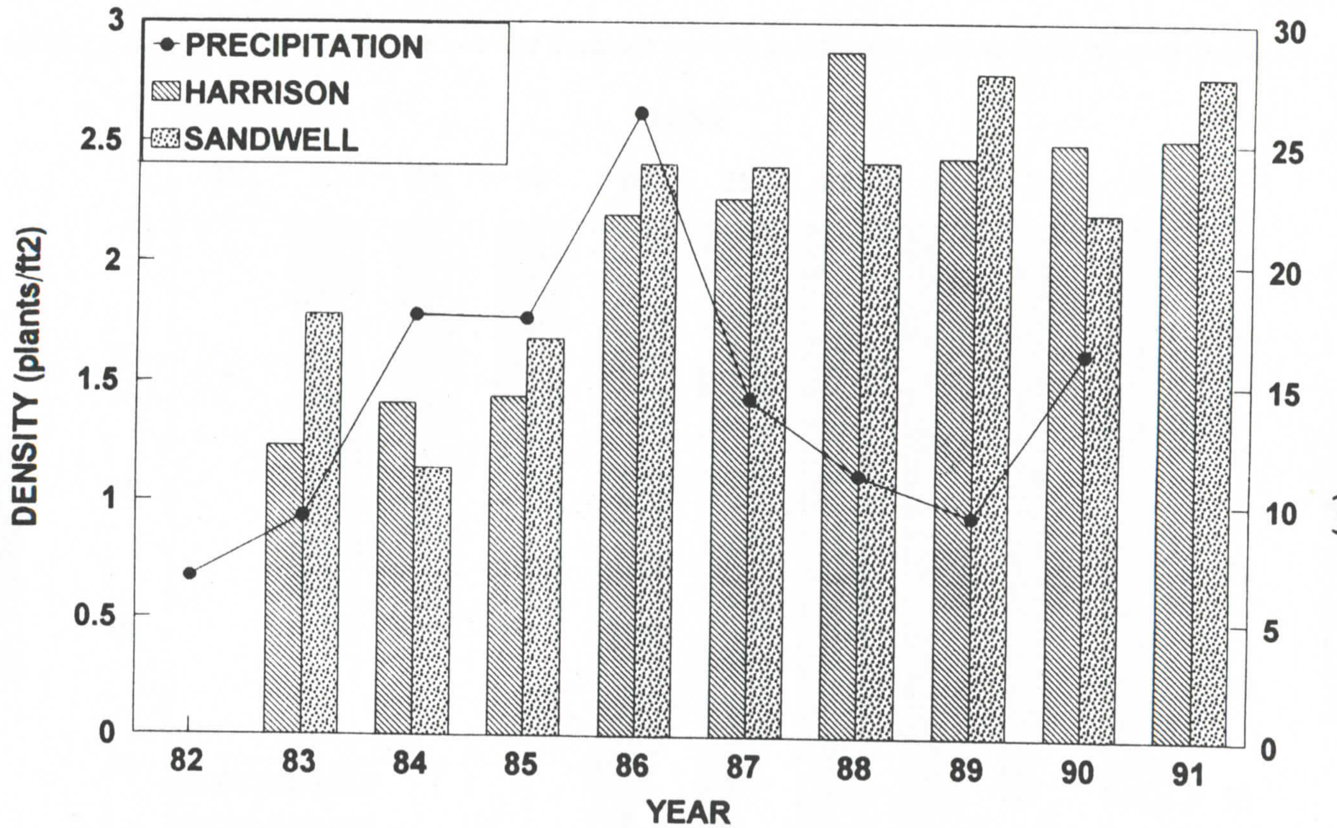

Figure 1. Total grass density for the two cells compared to annual precipitation received during the study period.

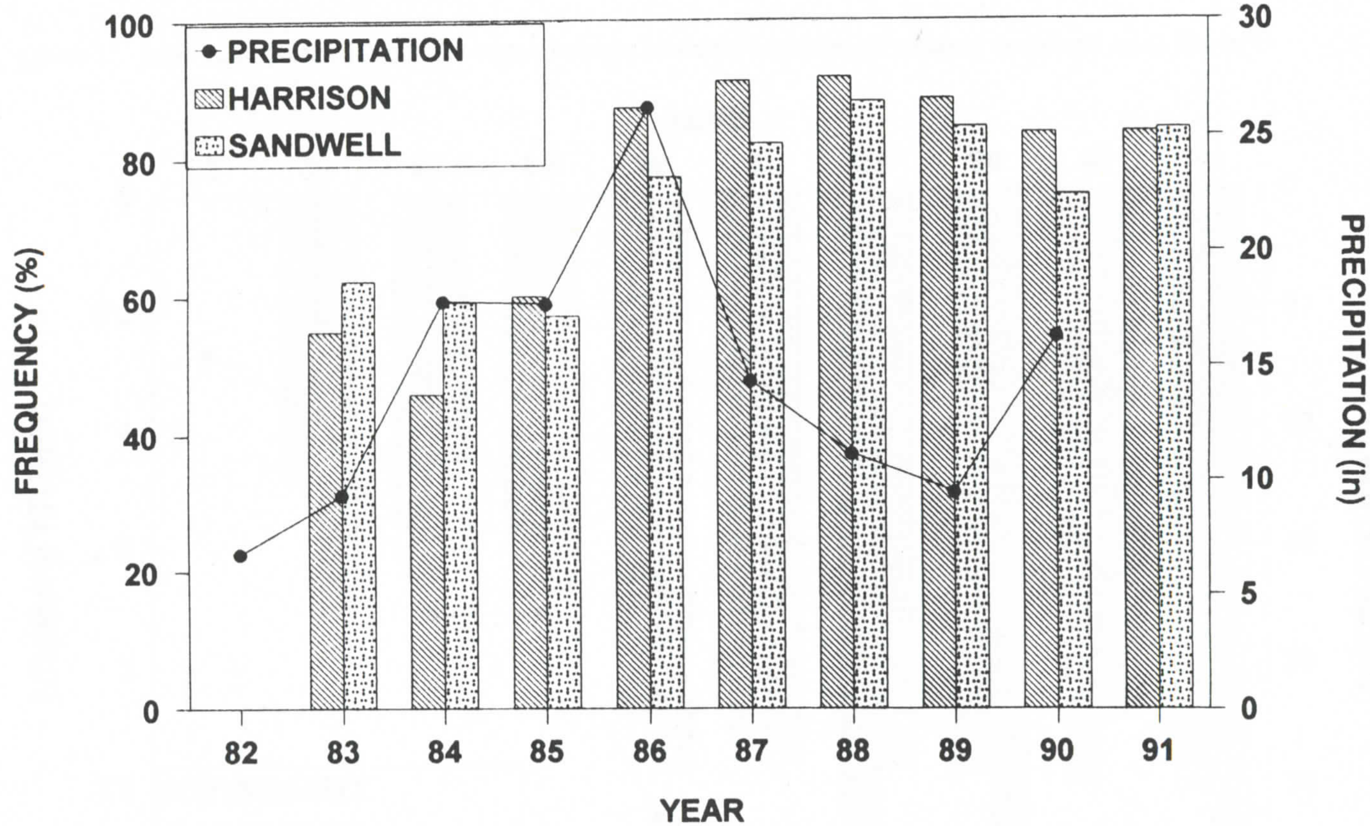

Figure 2. Total grass frequency for the two cells compared to annual precipitation received during the study period.

from SDG. Consequently, further research is needed to determine if relatively high stocking rates can be maintained with SDG over an extended period of time without causing range degradation, especially during periods of below-average precipitation.

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Tenderization of Caprine Carcasses with Injection of Calcium Chloride

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ABSTRACT

This study evaluated the effects of calcium chloride ($CaCl_2$) on the tenderness of caprine meat. Data from nine Spanish goats (*Capra hircus*) were evaluated to determine tenderness using shear force values and sensory evaluation. The longissimus muscle (LD) and psoas major (PM) were removed immediately after slaughter, and 0.2 M of $CaCl_2$ was injected into each at the rate of 0.1 ml g^{-1} (0.1 pints lb^{-1}). Samples were heat-seal packaged and tumbled for 2 hours. Samples were then placed in the cooler and aged for 48 hours. After freezer storage, the meat was thawed and the LD was cut into 1-inch steaks starting from the posterior end. Three 0.5-inch cores were taken from each steak and sheared once. The PM was left whole and three 0.5-inch cores were taken and sheared once. Warner-Bratzler shear force and sensory evaluations were conducted. A significant difference ($P<0.05$) in shear force was found in the LD meat. Sensory evaluations for tenderness expressed panelists' ability to detect a difference between treatments and preferences ($P<0.05$) for meat injected with $CaCl_2$.

KEYWORDS: goat, meat

Because palatability is a major concern of consumers purchasing meat products, producers are constantly searching for new ways to improve meat tenderness. Recently, it was shown that lamb and beef carcasses can be tenderized by the infusion of $CaCl_2$ (Koohmaraie et al., 1989; Koomaraie et al., 1990). Although this method has been effective in lamb and beef carcasses (Koohmaraie et al., 1991), it has yet to be studied with caprine carcasses. In addition, no research has been conducted using injection and tumbling of meat as a means to disperse $CaCl_2$ throughout the meat. If proven to be effective, this may be a practical way to disperse $CaCl_2$ and increase the marketability (tenderness) of Spanish goats.

The terms "Spanish goat" and "brush goat" refer to goats that are mongrel animals descended from most of the major milk goats (Ensminger and Parker, 1986). These goats come in a variety of colors and patterns. Both males and females have horns, a few being polled.

Spanish goats are known for their ability to exist largely upon brush and still yield acceptable quantities of edible meat (Dollahite, 1972). Goat meat is similar in nutritive value to beef and lamb, but contains less fat (Ensminger and Parker, 1986).

The purpose of this study was to show that the combined effect of a $CaCl_2$ (0.2 M

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solution) injection and the tumbling of caprine meat immediately after slaughter will result in postmortem tenderization.

METHODS AND MATERIALS

This research was conducted at the Sul Ross State University Meat Science Laboratory in Alpine, Texas. For this experiment, nine Spanish goats were on feed for 5 months (dry lot), then slaughtered (10 to 14 months of age, 86 to 155 lbs.). Immediately after slaughter, the longissimus muscle (LD) and the psoas major (PM) were removed, weighed and then injected with a 0.2 M solution of calcium chloride at the rate of 0.1 ml g^{-1} (0.1 pint lb^{-1}). Additives used in this study for injection were food grade calcium chloride ($CaCl_2$) and distilled water (H_2O).

The LD and the PM were removed from each side of the fresh carcasses. The pair from the right side was designated as the control and the pair from the left side as the treatment. Both groups were weighed, and a 0.2 M solution of $CaCl_2$ was injected into the treatment pair. Muscles were sealed into nonvacuum plastic bags and tumbled for 2 hours in the cooler at 42°F. At the end of the tumbling period, both groups were stored in the cooler for 48 hours and then transferred to the freezer (-10°F).

The LD and PM were removed from the freezer and thawed for 24 hours at 42°F. Each LD was sliced from the posterior end into 1-inch steaks. The PM were left whole. The meat was cooked in a preheated (350°F) Blodgette Type CTB-1 convection oven. All samples were cooked to an internal temperature of 150°F before being removed.

For sensory evaluation, a seven-member trained sensory panel (Gross and Stanfield, 1976) evaluated broiled caprine meat steaks. The panelists evaluated the steaks for tenderness at room temperature. A 6-point scale (6=highly acceptable and 1=highly unacceptable) was used in evaluating the product tenderness.

A mechanically powered Warner-Bratzler Shear was used to objectively measure tenderness. Shear force was estimated with steaks from the control and experimental groups. After cooking, 0.5-inch cores were taken. From each LD steak, four cores were taken with a hand-held coring device. From each PM, three cores were taken. Each core was sheared once.

A paired t distribution (Zar, 1984) analysis was used to determine significant differences ($P<0.05$) between means for shear values. The Duo-Trio Differentiation test was analyzed based on the number of correct responses compared to the total number of responses (Stone and Sidel, 1985). A chi-square analysis (Zar, 1984) was used to determine significant differences ($P<0.05$) between means for the taste panel ratings. The data were analyzed using the SPSS (1988) implementation of the paired t distribution and chi-square analyses.

RESULTS AND DISCUSSION

Shear Force

Results of the paired t distribution analysis showed a significant difference ($P<0.05$) in the shear-force values between the control and the treatment groups of the LD (Table 1). Lowered shear-force values indicated an increase in tenderness of the injected samples. The analysis of the PM (Table 2) showed significance ($P<0.05$), with the control being more tender than the injected. However, in the PM this significance is of little practical importance to consumers as the muscle is naturally tender without treatment. St. Angelo (1991) reported that when lamb carcasses are infused with 0.3 M $CaCl_2$ mechanical shear-force measurements are significantly reduced when compared to control lambs. In addition, it has been shown (Boleman et al., 1993) that a 0.3 M solution of $CaCl_2$ at 10% by weight 1-hour postmortem is effective in lowering shear-force values.

Table 1. Paired t test table of shear force values for 0.2 M $CaCl_2$ injected and non-injected (control) meat of the longissimus muscle.

Treatment	Number of pairs	DF	Mean (lb) ±SD	SE of Mean	2-tail Sig.
0.2 M $CaCl_2$			7.9602 ±2.4190	.233	
	108	107			.0001
Control			10.7991 ±2.6410	.254	

Table 2. Paired t test table of shear force values for 0.2 M $CaCl_2$ injected and non-injected (control) meat of the psoas major.

Treatment	Number of pairs	DF	Mean (lb) ±SD	SE of Mean	2-tail Sig.
0.2 M $CaCl_2$			5.0333 ±2.0540	.342	
	36	35			.027
Control			4.1833 ±1.4710	.245	

Sensory Evaluation

In the analysis of the Duo-Trio Differentiation test, there were 47 correct responses out of 63. Upon analysis of data, a highly significant difference ($P<0.001$) in treatments was found. This indicated that panelists were able to detect a difference between $CaCl_2$ injected meat and non-injected LD meat.

Results of the chi-square analysis (Table 3) of the tenderness ratings showed a significant difference ($P<0.05$). Seventy-six percent of the panelists rated the $CaCl_2$ injected meat as slightly acceptable or above, compared to the non-injected meat where 51% was rated as slightly acceptable or above.

Table 3. Chi-square analysis† for taste panel acceptance in LD muscle.

	Rating‡					
Treatment	1	2	3	4	5	6
0.2 M $CaCl_2$	1	3	11	15	23	10
Control	1	10	20	14	11	7

†Chi-square likelihood ratio = 11.5; df = 5; P-value = 0.042.
‡Ratings: 1 = highly unacceptable and 6 = highly acceptable.

CONCLUSION

The injection of $CaCl_2$ in the LD of Spanish goats had an effect on tenderness when compared to meat containing no $CaCl_2$. Shear force values were reduced in the LD and sensory panel acceptability was increased.

This study indicates that successful tenderization of Spanish goat meat can be increased significantly when $CaCl_2$ is injected and tumbled postmortem. Thus, it is believed that the potential marketability of this product may be enhanced through a more rapid method of tenderization prior to the onset of rigor mortis. This finding will enable the Spanish goat industry to guarantee a tender and calcium-fortified product.

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Economic Comparison of Pig Feedlot Housing Facilities in the Southern High Plains of Texas

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ABSTRACT

An economic analysis of two pig feedlot enterprises was conducted using low- and high-investment facilities. Pigs housed in the low-investment facility consumed 10% more feed and gained 13% more weight than pigs housed in the high-investment facility. Results indicate that pork producers in the Southern High Plains of Texas could increase rates of return by building a low-cost facility for finishing feeder pigs. The results were qualified, however, because only one seasonal production cycle was investigated.

Although cattle feeding is a major industry in the Southern High Plains of Texas (SHPT), there are few pig finishing facilities. Climate, land costs, and availability of feed grains in this area create an environment in which finishing feeder pigs should be a viable enterprise. A feeder pig finishing enterprise (rather than farrow-to-finish) requires relatively low amounts of labor while not requiring the special skills and facilities needed to manage a breeding herd. Feeder pig finishing, regardless of the type of facility used, requires substantial operating capital for the purchase of feeder pigs and feedstuffs.

Costs vary among types of finishing facility, but are relatively lower for a feeder pig operation than for a farrow-to-finish operation. Two basic options were considered for pig finishing facilities. The first option was a low-investment facility with a sheltered area on a dirt lot having an expected life of 10 years. The second option required a higher investment with a curtain-sided confinement building useful for 25 years.

Considering the potential differences in the pig growth performance and building investment costs, we were interested in determining which facility would be the better investment. To study this question, a joint project with Texas Tech University, the Texas Department of Agriculture, and the Texas Pork Producers was established. The study investigated pig growth in low- and high-investment facilities and developed economic data to compare the alternate investments.

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MATERIALS AND METHODS

Facilities

The low-investment facility consisted of a shelter with a roof and a back wall enclosing a 10 X 10 ft area on a dirt lot measuring 10 X 64 ft. Wheat straw bedding (36 bales) was provided during the last 45 days of the trial when the average daily temperatures fell below 70°F.

The high-investment facility consisted of an enclosed finishing building with mechanical ventilation. Pens measured 14 X 12 ft with concrete slatted flooring throughout. Waste was removed using an automated flush system.

Pens in both types of facilities were provided with two, three-hole self-feeders and one nipple waterer. Pigs in the high-investment facilities had access to an additional nipple waterer as a result of pen modifications required to accommodate the pig group size selected for this study. All pens in each facility were equipped with a mist sprayer to cool the animals when the outdoor temperature exceeded 85°F. Each facility was equipped with an automatic feed system, thus labor requirements were similar. The only energy used in the low-investment facility was electricity for heat strips wrapped around the water lines to prevent freezing. The high-investment facility used propane heaters and electric fans and lights. Because the energy usage for each facility was not monitored for this study, it was assumed that each facility consumed similar levels of energy. Although the authors recognized that this assumption favors high-investment facilities, they proposed conducting a sensitivity analysis for this cost comparison if the results warranted. Both facilities were located at the Texas Tech Swine Farm near New Deal, Texas.

Animals

A total of 239 crossbred barrows and gilts from two genetic stocks were used to compare the performance of pigs raised in the different facilities. One hundred and twenty pigs, purchased from a commercial breeder, were from a three-way rotational cross involving Duroc, Hampshire and Yorkshire (DHY) breeds. Originating from the Texas Tech Swine Farm, 120 pigs resulted from a four-way rotational cross using Duroc, Hampshire, Yorkshire and Landrace (DHYL) breeds. A total of 119 pigs was assigned to the low-investment facility and 120 pigs were assigned to the high-investment facility. Twenty pigs were placed per pen with a total of six pens per facility. The integrity of each genetic source was maintained and represented by three pens in each facility. The average initial weight of the pigs was 53 lb with an average purchase cost of $95.21 per cwt. The trial was conducted from August through November of 1990.

For the first 30 days the pigs were fed a 16% crude protein (CP) grower ration. All diets were based on sorghum-soybean meal, which met or exceeded NRC (1988) recommendations. After the initial 30 days, the pigs started the finishing phase, weighing an average of 94.35 lb. The pigs were fed a 14% CP finishing ration for this phase and feed intake was measured. All pigs were weighed in groups every 30 days. After 86 days on the finishing diet, all pigs were taken off trial and each pig was individually weighed. A uniform group, of 166 pigs with an average weight of 244.8 lbs was sold to a commercial packer. The remaining pigs were marketed locally within a 41 day period when they weighed an average of 248 lb.

Statistical analyses were conducted on the finishing performance data. The data were analyzed as a two-factor factorial: genetic source and investment facility. The pen was the experimental unit. Data were analyzed using the General Linear Model (SAS, 1990).

RESULTS AND DISCUSSION

Performance and carcass data are presented in Table 1. Pigs from the two sources (DHY vs. DHYL) did not differ in performance, regardless of facility ($P > 0.05$). Death loss was similar ($P > 0.10$) among pigs in the two housing systems with four deaths (3.4%) in the low-investment facility and three deaths (2.5%) in the other facility. Because of environmental factors (e.g., low temperatures), animals housed in the low-investment facility consumed significantly more feed (6.1 vs. 5.5 lb day^{-1}). Higher consumption resulted in a heavier finished pig ($P < 0.01$) (243.9 lb. vs. 223.7 lb) in the low-investment facility.

Table 1. Performance and carcass data for pigs in two types of facilities (low or high-investment).

Performance†	Low	High	Standard Error
Number	119.0	120.0	-
Starting wt, lb‡	52.8	52.8	-
Start of finishing, lb§	94.4	94.3	2.53
Final weight, lb¶#	243.9	223.7	4.72
Average daily gain, lb#	1.7	1.5	0.02
Feed intake, lb per day††	6.1	5.5	0.11
Feed:gain ratio	3.5	3.7	0.10

†Collected on the finishing phase for all pigs with pens as experimental units.
‡Grower phase was 30 days.
§Finishing phase was 86 days.
¶Carcass data were collected on 166 head consisting of pigs that weighed an average of 244.8 lb. Carcass data were not available for pigs marketed locally.
#Difference between facilities, $P < 0.01$.
††Difference between facilities, $P < 0.05$.

Using the information contained in Table 1, returns for feeding 239 pigs during a production period in the low- and high-investment facilities are reported in Tables 2 and 3. Because pigs are rough on buildings, we assumed an annual repair cost of 2% of the building cost (Boehlje and Eidman, 1984). Each production period consisted of 116 days in which the pigs were housed in the facilities and 30 days in which the facilities were cleaned and quarantine measures taken. Thus, each production period consists of 146 days. Death loss of 3% resulted in 232 pigs marketed, but it was assumed that all 239 pigs which began the production period consumed feed throughout the period. The average price received for barrows and gilts in Omaha, Nebraska at the time of sale was $53.71 per cwt (USDA, 1992).

Table 2. Net returns for feeding 239 pigs in a low-investment facility for one production period.†

Revenue from sale of pigs	
(232 pigs * 2.44 cwt * $53.71/cwt) =	$30,404.16
Costs	
Variable:	
Purchased pigs (239 pigs * 53 lb/pig * $0.9521/lb) =	$12,060.25
Feed (84.56 ton * $123.26/ton) =	$10,422.87
Bedding-wheat straw bales (36 bales * $2.50/bale) =	$90.00
Building repairs (assumes 2% of building cost) =	$282.20
sub-total =	$22,855.32
Fixed:	
Building dep. ($14,110.18 * 1/10 years * 1/2.5 periods) =	$564.40
Equipment dep. ($8,332.16 * 1/8 years * 1/2.5 production periods) = 416.61	
sub-total =	$981.02
Interest‡	
@ 4% on Direct Expenses (0.04 * $22,855.32 * 0.5) =	$457.11
@ 4% on Indirect Expenses (0.04 * $981.01 * 0.5) =	$19.62
sub-total =	$476.73
@ 8% on Direct Expenses (0.08 * $22,855.32 * 0.5) =	$914.21
@ 8% on Indirect Expenses (0.08 * $981.01 * 0.5) =	$39.24
sub-total =	$953.45
@ 12% on Direct Expenses (0.12 * $22,855.32 * 0.5) =	$1,371.32
@ 12% on Indirect Expenses (0.12 * $981.01 * 0.5) =	$58.86
sub-total =	$1,430.18
Net returns	
@ 4% ($30,404.16 - $22,855.32 - $981.01 - $476.73) =	$6,091.09
@ 8% ($30,404.16 - $22,855.32 - $981.01 - $953.45) =	$5,614.37
@ 12% ($30,404.16 - $22,855.32 - $981.01 - $1,430.18) =	$5,137.64

†Labor and utility expenses are not considered. A death loss of 3% is assumed for marketing purposes. From the estimates presented in Table 1. Based on a uniform feeding period of 116 days. Salvage value is assumed to be zero (Boehlje and Eidman, 1984).
‡Interest per year = (purchase price + salvage value)/2 * interest rate.

Table 3. Net returns for feeding 239 pigs in a high-investment facility for one production period.†

Revenue from sale of pigs		
(232 pigs * 2.24 cwt * $53.71/cwt) =		$27,912.01
Costs		
Variable:		
Purchased pigs (239 pigs * 53 lb/pig * $0.9521/lb) =		$12,060.25
Feed (76.24 ton * $123.26/ton) =		$9,397.34
Building repairs (assumes 2% of building cost) =		$806.19
	sub-total =	$22,263.78
Fixed:		
Building dep. ($40,309.30 * 1/25 years * 1/2.5 periods) =		$644.95
Equipment dep. ($8,332.16 * 1/8 years * 1/2.5 production periods) =		$416.61
	sub-total =	$1,061.56
Interest‡		
@ 4% on Direct Expenses (0.04 * $22,263.78 * 0.5) =		$445.28
@ 4% on Indirect Expenses (0.04 * $1,061.56 * 0.5) =		$21.23
	sub-total =	$466.51
@ 8% on Direct Expenses (0.08 * $22,263.78 * 0.5) =		$890.55
@ 8% on Indirect Expenses (0.08 * $1,061.56 * 0.5) =		$42.46
	sub-total =	$933.01
@ 12% on Direct Expenses (0.12 * $22,263.78 * 0.5) =		$1,335.83
@ 12% on Indirect Expenses (0.12 * $1,061.56 * 0.5) =		$63.69
	sub-total =	$1,399.52
Net returns		
@ 4% ($27,912.01 - $22,263.78 - $1,061.56 - $466.51) =		$4,120.17
@ 8% ($27,912.01 - $22,263.78 - $1,061.56 - $933.01) =		$3,653.66
@ 12% ($27,912.01 - $22,263.78 - $1,061.56 - $1,399.52) =		$3,187.16

†Labor and utility expenses are not considered. A death loss of 3% is assumed for marketing purposes. From the estimates presented in Table 1. Based on a uniform feeding period of 116 days. Salvage value is assumed to be zero (Boehlje and Eidman, 1984).

‡Interest per year = (purchase price + salvage value)/2 * interest rate.

Feed consumption data were not collected during the grower phase of the trial. Because feed costs are a major factor in the cost of pig production, the expected feed intake listed in the NRC (1988) was used to estimate the amount of feed consumed during this phase. Actual feed consumption data were used to calculate the cost of feed during the finishing phase. The price of the grower diet was $133.20 per ton and the finishing diet cost $121 per ton. The grower diet accounted for 18.5% of total feed costs, with the finishing diet accounting for the remainder. Thus, a weighted average was used to obtain an average feed price of $123.26 per ton over the entire trial period. Given the feed intake values reported in Table 1, 239 pigs during the 116 day grower and finisher phases consumed 84.56 and 76.24 tons in the low- and high-investment facilities, respectively.

Fixed costs reflect the depreciation of buildings and equipment. The low-investment facility was expected to last 10 years while the high-investment facility was expected to last 25. Equipment such as waterers, feeders, and an automated feeding system were depreciated over 8 years for both facilities. The automated feeding system consisted of one bulk feed tank and an auger system for each facility. By allowing 146 days for one cycle of 239 pigs to reach market weight, 2.5 cycles of pigs could go through the facilities per year. For each year of depreciation, it was assumed that 598 pigs would be marketed. The actual cost of the low-investment facility (building = $14,110.18; equipment = $8,332.16) was used because the facility was built within the last two years. The cost of the high-investment facility (building = $40,309.30; equipment = $8,332.16) was estimated at 1992 prices.

Simple interest charges were calculated for variable and fixed costs at three annual rates of 4, 8 and 12%. The 4% interest rate was used to represent the opportunity cost of those producers who spend cash to invest in facilities. Because the future cost for borrowing funds to invest in facilities is unknown, the 8% and 12% interest rates were included for comparison purposes. Given the costs and revenues presented in Tables 2 and 3, the net returns for the low-investment facility were greater than those for the high-investment facility by 47.8% to 61.2%, depending on the interest rate used.

Other factors affecting the profit margin of a finishing pig operation are feed costs and pig purchase price. Net returns, with varying feed cost and the pig purchase price, are reported in Tables 4 and 5. In Table 4 the price of feed is varied at $20 increments from $100 per ton to $200 per ton. Table 5 reports net returns as the purchase price of feeder pigs is varied at $.10 increments from $.75 per lb to $1.15 per lb. Additionally, net returns are reported in Table 6 at 8% interest rates when varying both feed cost and pig purchase price. Results found in Tables 4, 5, and 6 indicate that the low-investment facilities generated the higher revenue whether feed cost, initial purchase price of the pigs, or both were varied. While selling price also affects the profit or loss margin, unless a producer uses marketing options, little control over selling price can be exerted and therefore selling price was not varied.

Table 4. Net returns for both facilities with varying feed costs and interest rates†.

Feed Cost	Low			High		
($/ton)	4%	8%	12%	4%	8%	12%
100	8097	7660	7223	5929	5498	5067
120	6372	5901	5430	4374	3912	3451
140	4647	4142	3637	2818	2326	1834
160	2922	2383	1845	1263	741	218
180	1197	625	52	(292)	(845)	(1398)
200	(528)	(1134)	(1741)	(1848)	(2431)	(3015)

†From estimates presented in Tables 2 and 3. Purchase price was $0.9521 per lb.

Table 5. Net returns for both facilities with varying purchase price of weaned pigs and interest rates†.

Purchase Price ($/lb)	Low 4%	Low 8%	Low 12%	High 4%	High 8%	High 12%
0.75	8702	8277	7851	6731	6316	5901
0.85	7410	6959	6509	5439	4999	4558
0.95	6118	5642	5166	4147	3681	3215
1.05	4826	4325	3823	2855	2364	1873
1.15	3534	3007	2480	1563	1047	530

†From estimates presented in Tables 2 and 3. Feed cost was $123.26 per ton.

Table 6. Net returns at 8% interest rate for both facilities with varying purchase price of weaned pigs and feed costs†.

Feed Cost	Low 0.75	Low 0.85	Low 0.95	Low 1.05	Low 1.15	High 0.75	High 0.85	High 0.95	High 1.05	High 1.15
$/ton	----------	----------	----------	----------	-----	$/lb -----	----------	----------	----------	----------
100	10322	9005	7688	6370	5053	8160	6843	5526	4208	2891
120	8563	7246	5929	4611	3294	6575	5257	3940	2622	1305
140	6805	5487	4170	2853	1535	4989	3671	2354	1037	(281)
160	5046	3728	2411	1094	(224)	3403	2086	768	(549)	(1867)
180	3287	1970	652	(665)	(1983)	1817	500	(818)	(2135)	(3452)
200	1528	211	(1107)	(2424)	(3741)	231	(1086)	(2403)	(3721)	(5038)

†From estimates presented in Tables 2 and 3.

CONCLUSIONS

Pigs housed in low-investment facilities consumed more feed while gaining proportionately more weight than similar pigs housed in high-investment facilities. Given the feed efficiency observed in the low-investment facility, producers will increase their investment returns by investing in low cost facilities. Additionally, we found that by varying the interest rate, feed cost, or initial purchase price of the pigs, the low-investment facility continued to produce the greatest net revenue. Three price variables which are important for producers to monitor are purchase price of pigs, feed costs, and the price received for market hogs. A change of any of these prices could change the results of this study.

Caution is suggested in the use of the economic data. First, some expenses were assumed constant, in particular, utilities. Also, the season of the year that pigs are fed may greatly influence production data. Perhaps the pigs fed in the low-investment facility will be less efficient in feed conversion during the winter. Previous research (Tribble and Orr, 1978) compared the performance of pigs raised in confinement with those raised on dirt lots. In a trial conducted from December to March, pigs in confinement grew 15% faster and had a 7% improvement in feed efficiency than those pigs raised on dirt lots. Death and morbidity losses may also be greater in pigs fed in the low-investment facility in the winter. These factors could potentially reverse the present findings, and therefore deserve study.

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Cotton Gin Plant Compliance with Air Pollution Regulations in Texas

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ABSTRACT

Recent air pollution legislation affects stationary sources such as cotton gins. This study estimated the increase in gin plant costs that resulted from compliance with various levels of air pollution control and the associated impact on returns. Because investment in air pollution control differs by gin plant size and level of pollution control, five plant sizes were examined in combination with control systems that reduce per bale emissions from 4 lb per bale to 2.24, 1.60 and 1.06 lb per bale. Cost increases and rates of return were affected by gin plant size, level of control technology, plant volume, and method of harvest (picked or stripped).

The Clean Air Act of 1963 was the first major federal involvement in air pollution regulation in the US. This act was subsequently amended in 1967, 1970, 1977, and 1990 and, in general, increased federal involvement in air pollution regulation. The Clean Air Act of 1970 required that emission standards be established for stationary sources of air pollution. These standards were to be established on an industry-by-industry basis and were to consider the cost of air pollution control. The established standards were to represent the "best available control technology" (BACT) available to the industry. The Federal Clean Air Act (FCAA) amendments of 1990 represented a further strengthening of the Clean Air Act and ended more than a decade of Congressional stalemate over air pollution regulations in the US (Smith, 1992). The 1990 legislation represents an important change in air pollution regulation, in particular, as it affects stationary sources such as cotton gins.

Air pollution regulations are implemented at the state level; the implementing agency in Texas is the Texas Natural Resources Conservation Commission (TNRCC), known as the Texas Air Control Board (TACB) prior to September 1993. Cotton gins in Texas are regulated under the nuisance rule (General Rules, Section

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101.4), which states:

> No person shall discharge from any source whatsoever one or more air contaminants or combination thereof, in such concentration and of such duration as are or may tend to be injurious to or to adversely affect health or welfare, animal life, vegetation, or property, or as to interfere with the normal use and enjoyment of animal life, vegetation, or property.

About 160 cotton gin plants in Texas (40%) have not been grandfathered or permitted by the TNRCC. Those gins in isolated locations with favorable community acceptance and no past nuisance compliance violation history will be required to invest in a minimum level of control which is defined as baseline "best available control technology" (BACT). Gin plants which require more control than BACT (the minimum level of control) must propose additional controls to the TNRCC. The complement of control equipment finally required of a particular plant is the result of negotiations between the TNRCC and gin plant management.

OBJECTIVES

The TNRCC has some flexibility and discretion in administering the clean air statutes by considering the trade-offs between economic and environmental impacts. In particular, the regulation states that a plant will use the best available control technology with consideration being given to its technical practicability and economic reasonableness (TACB, 1992). The term "economic reasonableness" is undefined in law or regulations.

The cost of upgrading selected gin plants with an air pollution control system may be substantial and in some cases may place financial burden on the firm. In view of these concerns, the objectives of this study were to (1) estimate the impact on gin plant costs that result from compliance with various levels of air pollution control and (2) estimate the economic impact on gin plant firms that result from investments in required air pollution control devices. The analysis was designed to evaluate economic impacts that result from incorporating technology that increasingly lowers a plant's emission rate.

METHODS

Investments in air pollution control were expected to differ by gin plant size and level of pollution control. In this study, five plant size categories were established based on bale per hour (bph) capacity. These include: $\leq$ 10 bph; 11 to 15 bph; 16 to 25 bph; 26 to 34 bph; and $\geq$ 35 bph. In addition, three control systems were included in the analysis and represented technology that reduced total per bale emissions from the current 4 lb per bale to 2.24, 1.60, and 1.06 lb per bale, respectively. Costs were estimated for each plant size category, which reflected current control technology (4 lb per bale). Based on current gin revenue schedules, rates of return were estimated and subsequently compared with returns from plants, which reflected upgrading to the three levels of air control (emissions rate of 2.24, 1.60, and 1.06 lb per bale). The calculated rates of return were compared with a predetermined critical or required rate of return to identify plant sizes whose financial viability were threatened by required investments in air pollution control. The required rate of return is that which is thought necessary to attract capital into the cotton ginning industry. Investment in air pollution control is expected to reduce profitability (returns) of gin plant operations as a result of increases in fixed and variable costs and, in some cases, reduce returns to levels that threaten a firm's economic viability.

Gin plant costs were estimated with a computerized economic-engineering model (GINMODEL) which was initially developed by the Economic Research Service of the USDA and more recently updated and maintained in the Department of Agricultural Engineering at Texas A&M University (Shaw et al., 1977; USDA, 1977). An input data file was developed for each plant size category that reflected existing plants and their air pollution control technology (4 lb per bale emission rate). Then for each plant size, the investment in air pollution control and additional connected horsepower associated with the three air pollution control systems were estimated and the new cost relationships generated. Rates of return were generated for each plant size category at alternative volumes. The model was validated with cost data provided by COBANK, the Bank for Cooperatives in Austin, Texas. In general, GINMODEL costs approximated the actual cost data and therefore were judged adequate to carry out study objectives (Childers et al.,1994).

RESULTS

Air Pollution Control Systems and Effect on Costs

The three air pollution control systems examined in this study were BBACT (Baseline Best Available Control Technology), BACTD1 (Best Available Control Technology Design 1), and BACTD2 (Best Available Control Technology Design 2). BBACT, BACTD1, and BACTD2 were designed to reduce emissions from the current 4 lb per bale to 2.24, 1.60, and 1.06 lb per bale, respectively. Controls used to reduce emissions to 2.24 lb per bale (BBACT), as described by the TNRCC, include high efficiency cyclones (1D-3D or 2D-2D) on all centrifugal fan exhausts and small mesh screens on all lint cleaner condenser drums and battery condensers. Technologies used to reduce the emission rates to 1.60 lb per bale (BACTD1) and 1.06 lb per bale (BACTD2) were estimated by Parnell and Yarlagadda in the Department of Agricultural Engineering at Texas A&M University (Yarlagadda et al., 1994; USDA, 1993; Mihalski et al., 1993). BACTD1 includes 2D-2D or 1D-3D cyclones on all centrifugal fan exhausts, the replacement of axial fans with centrifugal fans, and the replacement of condenser drums with 2D-2D cyclones. BACTD2 includes a pre-separator/1D-3D cyclone system on all fan exhausts. The capital investment associated with each air pollution control system was estimated using data and procedures prescribed by Cooper and Alley. Unit costs in combination with estimated airflow rates (cubic feet per minute) were used to estimate total capital investment for the BBACT, BACTD1, and BACTD2 control systems in gin plants processing picked and stripped cotton. For plants processing picked cotton, estimates of capital investment ranged from $56,000 for the smallest plant ($\leq$ 10 bph) upgrading to a BBACT system to $333,000 for the largest plant size ($\geq$ 35 bph) upgrading to a BACTD2 system (Table 1). Similarly, for plants processing stripped cotton, estimates of capital investment ranged from $64,000 for the smallest plant (≤ 10 bph) upgrading to a BBACT system to $366,000 for the largest plant size (≥ 35 bph) upgrading to a BACTD2 system (Table 2).

Table 1. Total capital investment for BBACT, BACTD1 and BACTD2, picked cotton.

Gin Size Capacity†	BBACT	BACTD1	BACTD2
bph		$	
≤10	56,000	76,000	107,000
11-15	65,000	91,000	129,000
16-25	95,000	135,000	197,000
26-34	136,000	195,000	289,000
≥35	156,000	225,000	333,000

†Representative plants in the five gin size categories are 10, 12.5, 20, 30 and 35 bales per hour, respectively.

Table 2. Total capital investment for BBACT, BACTD1 and BACTD2, stripped cotton.

Gin Size Capacity†	BBACT	BACTD1	BACTD2
bph		$	
≤10	64,000	80,000	113,000
11-15	77,000	98,000	139,000
16-25	112,000	148,000	216,000
26-34	158,000	216,000	316,000
≥35	182,000	249,000	366,000

†Representative plants in the five gin size categories are 10, 12.5, 20, 30 and 35 bales per hour, respectively.

Introduction of air pollution controls affected depreciation, interest, property insurance, property tax, repair, and electrical expenses. Total depreciation and interest expense were determined with the standard present value annuity formula (GINMODEL) based on expected years of life and the representative average interest rate for capital investments (9.8%) in the Fall of 1993. Property insurance was determined by multiplying capital investment in the air pollution control systems by the co-insurance percentage and the insurance rate, while taxes were estimated by multiplying investment by the property tax rate. Electrical charges were based on rate schedules of utility companies in Texas.

To provide insight regarding the increase in costs that result from investment in air pollution equipment, the additional per bale costs associated with upgrading a ≤ 10 bph plant to BBACT was calculated for a plant processing 8,000 bales of stripped cotton (Table 3). The upgrade involved an investment of $64,000 and an increase in connected electrical horsepower from 536 to 722. Per bale cost increased by $2.74 per bale. About 80% of the increase in costs was accounted for by electricity (39%), interest on borrowed capital (27%), and depreciation (15%) (Table 3).

Table 3. Estimated increases in per bale costs that result from upgrading small plant (≤10 BPH) to BBACT stripped cotton†.

Cost Component	Pre-Control	Post-Control	Marginal Increase
	-------------------------$/bale------------------------------		
Depreciation	1.22	1.63	0.41
Capital Interest	1.71	2.45	0.74
Working Interest	0.70	0.72	0.02
Property Insurance	0.14	0.21	0.07
Property Taxes	0.55	0.78	0.23
Repairs	0.33	0.53	0.20
Electricity	3.39	4.46	1.07
Sub-total	8.04	10.78	2.74
Other	40.58	40.58	0.00
Total	48.62	51.36	2.74

†All per bale costs are calculated at an annual volume of 8,000 bales.

In general, the introduction of air pollution control had the expected effect on gin plant costs (Tables 4 and 5). First, per bale gin plant costs increased with the introduction of air pollution controls and with the adoption of control systems which increasingly lowered per bale emissions. For example, a plant in the 16 to 25 bph size category processing 16,000 bales of picked cotton would experience a cost increase of $1.46 per bale by introducing BBACT (emission rate of 2.24 lb per bale); however, by introducing BACTD1 (emission rate of 1.60 lb per bale) and BACTD2 (emission rate of 1.06 lb per bale), respective cost increases of $2.53 per bale and $3.80 per bale were expected (Table 4). Second, for a particular plant size, the increase in per bale cost associated with the introduction of air pollution control was reduced as plant volume increased. For example, the 16 to 25 bph plant processing 10,000 bales of picked cotton would expect costs to increase $2.16 per bale with the introduction of BBACT, but at an output of 20,000 bales, per bale costs were projected to increase a more modest $1.28 per bale. Third, for a particular control system, large plants operating at a specified utilization level

Table 4. Estimated per bale costs for each gin plant size under pre-control and the increase in per bale cost under BBACT, BACTD1 and BACTD2 at alternative volumes, picked cotton.

Plant Size Category	Volume and Per Bale Costs									
≤ 10 bph										
Volume (bales)	800	1600	2400	3200	4000	4800	5600	6400	7200	8000
Pre-Control Cost ($/bale)	148.49	90.35	71.37	62.35	57.48	54.42	52.70	51.48	51.22	51.00
Cost Increase ($/bale)										
BBACT	14.37	7.20	4.91	3.77	3.09	2.63	2.30	2.05	1.95	1.78
BACTD1	20.34	10.23	7.10	5.54	4.60	3.97	3.53	3.19	3.04	2.82
BACTD2	28.56	14.63	10.23	8.03	6.71	5.83	5.20	4.72	4.52	4.20
11-15 bph										
Volume (bales)	1200	2400	3600	4800	6000	7200	8400	9600	10800	12000
Pre-Control Cost ($/bale)	181.56	104.88	79.55	67.13	59.96	55.37	52.26	50.06	48.70	47.74
Cost Increase ($/bale)										
BBACT	11.29	5.67	3.88	2.99	2.45	2.09	1.83	1.64	1.56	1.43
BACTD1	16.20	8.38	5.87	4.62	3.86	3.36	2.99	2.73	2.60	2.43
BACTD2	22.95	12.02	8.48	6.71	5.64	4.93	4.42	4.04	3.87	3.62
16-25 bph										
Volume (bales)	2000	4000	6000	8800	10000	12000	14000	16000	18800	20000
Pre-Control Cost ($/bale)	181.24	101.59	75.22	62.15	54.41	49.33	45.77	43.16	41.54	39.97
Cost Increase ($/bale)										
BBACT	9.63	4.96	3.40	2.63	2.16	1.84	1.62	1.46	1.38	1.28
BACTD1	14.25	7.56	5.32	4.21	3.53	3.09	2.77	2.53	2.42	2.27
BACTD2	20.85	11.11	7.86	6.24	5.26	4.61	4.15	3.80	3.64	3.42

Table 4. (continued)

Plant Size Category	Volume and Per Bale Costs									
26-34 bph Volume (bales)	3000	6000	9000	12000	15000	18000	21000	24000	27000	30000
Pre-Control Cost ($/bale)	176.56	97.31	71.03	57.99	50.23	45.12	41.52	38.87	37.23	35.61
Cost Increase ($/bale)										
BBACT	9.18	4.73	3.24	2.49	2.05	1.75	1.54	1.38	1.31	1.20
BACTD1	13.64	7.23	5.09	4.02	3.38	2.95	2.65	2.41	2.31	2.16
BACTD2	20.32	10.80	7.63	6.03	5.08	4.45	3.99	3.65	3.50	3.27
≥ 35 bph Volume (bales)	5000	10000	15000	20000	25000	30000	35000	40000	45000	50000
Pre-Control Cost ($/bale)	175.21	96.13	69.89	56.84	49.07	43.94	40.53	38.07	36.25	34.91
Cost Increase ($/bale)										
BBACT	6.42	3.34	2.31	1.80	1.49	1.29	1.19	1.07	1.04	0.96
BACTD1	9.75	5.29	3.80	3.05	2.61	2.31	2.17	1.99	1.95	1.84
BACTD2	14.49	7.88	5.68	4.58	3.92	3.47	3.26	3.01	2.94	2.78

Table 5. Estimated per bale costs for each gin plant size under pre-control and the increase in per bale cost under BBACT, BACTD1, and BACTD2 at alternative volumes, stripped cotton.

Plant Size Category	Volume and Per Bale Costs									
≤ 10 bph										
Volume (bales)	800	1600	2400	3200	4000	4800	5600	6400	7200	8000
Pre-Control Cost ($/bale)	152.56	84.41	75.43	66.41	61.55	58.48	56.76	55.54	55.29	55.06
Cost Increase ($/bale)										
BBACT	17.79	9.07	6.40	5.06	4.26	3.73	3.35	3.06	2.93	2.74
BACTD1	27.06	14.19	10.13	8.11	6.89	6.08	5.50	5.07	4.87	4.59
	31.88	17.02	12.30	9.94	8.52	7.58	6.91	6.40	6.17	5.84
11-15 bph										
Volume (bales)	1200	2400	3600	4800	6000	7200	8400	9600	10800	12000
Pre-Control Cost ($/bale)	185.62	108.94	83.62	71.20	64.03	59.43	56.32	54.13	52.76	51.80
Cost Increase ($/bale)										
BBACT	13.86	7.25	5.13	4.07	3.44	3.03	2.72	2.49	2.39	2.24
BACTD1	18.39	9.98	7.27	5.92	5.10	4.57	4.18	3.89	3.76	3.57
BACTD2	25.93	14.13	10.28	8.36	7.21	6.45	5.90	5.48	5.30	5.03
16-25 bph										
Volume (bales)	2000	4000	6000	8800	10000	12000	14000	16000	18800	20000
Pre-Control Cost ($/bale)	185.30	105.65	79.28	66.21	58.47	53.39	49.83	47.22	45.60	44.03
Cost Increase ($/bale)										
BBACT	11.87	6.34	4.49	3.57	3.02	2.65	2.39	2.19	2.10	1.97
BACTD1	16.58	9.17	6.70	5.47	4.72	4.23	3.88	3.61	3.49	3.32
BACTD2	23.93	13.19	9.61	7.82	6.74	6.02	5.51	5.13	4.96	4.71

Table 5. (continued)

Plant Size Category	Volume and Per Bale Costs									
26-34 bph										
Volume (bales)	3000	6000	9000	12000	15000	18000	21000	24000	27000	30000
Pre-Control Cost ($/bale)	180.62	101.37	75.10	62.05	54.29	49.18	45.58	42.93	41.29	39.67
Cost Increase ($/bale)										
BBACT	11.13	5.93	4.19	3.32	2.80	2.45	2.21	2.02	1.94	1.81
BACTD1	15.92	8.77	6.37	5.18	4.47	3.99	3.65	3.39	3.28	3.11
BACTD2	23.19	12.71	9.21	7.46	6.42	5.72	5.22	4.84	4.67	4.43
≥ 35 bph										
Volume (bales)	5000	10000	15000	20000	25000	30000	35000	40000	45000	50000
Pre-Control Cost ($/bale)	179.27	100.19	73.95	60.90	53.13	48.00	44.60	42.13	40.31	38.97
Cost Increase ($/bale)										
BBACT	7.91	4.30	3.10	2.50	2.13	1.89	1.77	1.64	1.60	1.51
BACTD1	11.58	6.59	4.92	4.09	3.59	3.25	3.08	2.90	2.85	2.72
BACTD2	16.87	9.53	7.08	5.86	5.13	4.64	4.39	4.12	4.04	3.86

experienced more modest increases in per bale costs than smaller plants operating at the same utilization level. As an example, the ≥ 35 bph plant operating at 80% utilization (40,000 bales) would expect costs to increase $3.01 per bale if BACTD2 were introduced when processing picked cotton whereas the 26 to 34 bph plant and the 16 to 25 bph plant operating at the 80% utilization level would expect costs to increase $3.65 per bale and $3.80 per bale, respectively (Table 4). Finally, the increase in per bale costs for a plant processing stripped cotton were approximately $0.50 to $3.00 per bale higher than for plants processing picked cotton (Tables 4 and 5). This was the result of greater investment in air pollution control equipment and the need for additional connected horsepower in plants processing stripped cotton.

Air Pollution Control Systems and Effect on Returns

Rates of return after taxes were calculated for each gin plant size category under pre-control (current), and the BBACT, BACTD1, and BACTD2 air pollution control systems. Rates of return were based on projected costs, federal corporate taxes (Internal Revenue Service, 1992), and ginning revenue information taken from a USDA survey of gins (Glade et al., 1993) and data provided by COBANK in Austin, Texas. These data showed gins equipped with a universal-density (UD) press had an estimated revenue of $59.25 and $63.25 per bale when processing picked and stripped cotton, respectively. Since the ≤ 10 bph gin plant did not typically have a UD press, they were assumed to have an estimated revenue of $51.45 and $55.45 per bale when processing picked and stripped cotton, respectively. The Dun and Bradstreet publication, Industry Norms and Key Business Ratios, showed the simple rate of return on cotton ginning industry assets to average 14.7%; accordingly, this value was selected as the required rate of return. The required rate of return (14.7%) was based on a five year average (1988-1992) and included an annual sample of about 190 cotton ginning enterprises. Investments in air pollution control, which forced returns on gin plant investment below the required rate (14.7%), were judged to jeopardize the long-run economic viability of the cotton ginning enterprise.

Expected outcomes were shown by the rate of return analyses (Tables 6 and 7). First, introducing air pollution control decreased a gin plant's rate of return on investment, and, in general, those controls which increasingly lowered the emission rate tended to lower rates of return. For example, a plant in the 16 to 25 bph category processing 18,800 bales of picked cotton under pre-control conditions (emission rate of 4 lb per bale) experienced a rate of return on investment of 15.36%, but when upgraded to BBACT (emissions rate of 2.24 lb per bale), this plant's return on investment declined to 13.18%. When upgraded to BACTD1 (emissions rate of 1.6 lb per bale) and BACTD2 (emissions rate of 1.06 lb per bale), the returns declined to 12.12 and 10.76%, respectively (Table 6). Second, regardless of the control technology, a gin plant earned a higher rate of return at higher volume levels. As an example, a gin in the 16 to 25 bph capacity range processing 10,000 bales of picked cotton experienced a rate of return on investment of 2.99% under pre-control conditions, whereas at 18,800 bales the return increased to 15.36%. Third, large plants tended to experience higher rates of return than smaller plants when compared at specified utilization levels. As an example, a plant in the ≥35 bph category operating at 80% of capacity (40,000 bales) under BBACT generated a return of 13.64%, whereas plants in the 26 to 34 and the 16 to 25 bph categories

Table 6. Estimated simple rate of return on investment for each gin plant size under pre-control, BBACT, BACTD1 and BACTD2 at alternative volumes, picked cotton.

Plant Size Category	Volume and Rates of Return									
≤ 10 bph										
Volume (bales)	800	1600	2400	3200	4000	4800	5600	6400	7200	8000
Rate of Return (%)										
Pre-Control	-17.25	-13.83	-10.62	-7.75	-5.36	-3.17	-1.56	-0.04	0.31	0.68
BBACT	-17.31	-14.33	-11.58	-9.12	-7.09	-5.22	-3.86	-2.59	-2.41	-2.07
BACTD1	-17.14	-14.34	-11.83	-9.60	-7.76	-6.08	-4.88	-3.76	-3.69	-3.46
BACTD2	-17.83	-15.20	-12.84	-10.75	-9.04	-7.49	-6.41	-5.39	-5.48	-5.32
11-15 bph										
Volume (bales)	1200	2400	3600	4800	6000	7200	8400	9600	10800	12000
Rate of Return (%)										
Pre-Control	-19.57	-14.60	-9.74	-5.04	-0.57	3.17	6.54	9.33	11.50	13.47
BBACT	-19.39	-14.89	-10.53	-6.31	-2.29	1.32	4.45	7.17	9.17	10.95
BACTD1	-19.60	-15.29	-11.11	-7.08	-3.23	0.38	3.37	6.07	8.07	9.81
BACTD2	-19.61	-15.56	-11.65	-7.88	-4.29	-0.85	2.06	4.72	6.65	8.35
16-25 bph										
Volume (bales)	2000	4000	6000	8800	10000	12000	14000	16000	18800	20000
Rate of Return (%)										
Pre-Control	-17.74	-12.32	-6.97	-1.69	2.99	6.50	9.59	12.64	15.36	18.51
BBACT	-17.70	-12.72	-7.82	-2.98	1.53	5.09	7.94	10.74	13.18	15.98
BACTD1	-17.88	-13.10	-8.38	-3.73	0.73	4.32	7.10	9.78	12.12	14.74
BACTD2	-17.96	-13.44	-8.99	-4.60	-0.26	3.32	6.06	8.59	10.76	13.21

Table 6. (continued)

Plant Size Category	Volume and Rates of Return									
26-34 bph Volume (bales)	3000	6000	9000	12000	15000	18000	21000	24000	27000	30000
Rate of Return (%)										
Pre-Control	-15.61	-10.13	-4.70	0.57	4.40	7.62	10.90	14.32	17.40	19.93
BBACT	-15.72	-10.64	-5.60	-0.61	3.34	6.33	9.30	12.47	15.29	17.71
BACTD1	-15.90	-11.00	-6.14	-1.34	2.74	5.65	8.50	11.52	14.21	16.59
BACTD2	-16.05	-11.40	-6.79	-2.23	1.92	4.78	7.50	10.30	12.83	15.15
≥ 35 bph Volume (bales)	5000	10000	15000	20000	25000	30000	35000	40000	45000	50000
Rate of Return (%)										
Pre-Control	-15.63	-9.94	-4.30	1.10	4.64	8.17	11.66	15.07	18.41	21.65
BBACT	-15.72	-10.33	-4.99	0.27	3.84	7.13	10.40	13.64	16.76	19.82
BACTD1	-15.88	-10.65	-5.47	-0.32	3.34	6.50	9.66	12.80	15.79	18.75
BACTD2	-16.23	-11.14	-6.09	-1.08	2.79	5.83	8.89	11.94	14.83	17.71

Table 7. Estimated simple rate of return on investment for each gin plant size under pre-control, BBACT, BACTD1 and BACTD2 at alternative volumes, stripped cotton.

Plant Size Category	Volume and Rates of Return									
≤ 10 bph										
Volume (bales)	800	1600	2400	3200	4000	4800	5600	6400	7200	8000
Rate of Return (%)										
Pre-Control	-17.26	-13.85	-10.66	-7.79	-5.42	-3.23	-1.63	-0.13	0.22	0.59
BBACT	-17.86	-14.93	-12.30	-9.96	-8.05	-6.30	-5.07	-3.92	-3.87	-3.65
BACTD1	-18.13	-15.52	-13.19	-11.14	-9.48	-7.98	-6.96	-6.03	-6.19	-6.13
BACTD2	-18.31	-15.89	-13.75	-11.87	-10.38	-9.04	-8.17	-7.37	-7.68	-7.74
11-15 bph										
Volume (bales)	1200	2400	3600	4800	6000	7200	8400	9600	10800	12000
Rate of Return (%)										
Pre-Control	-19.58	-14.62	-9.78	-5.09	-0.62	3.12	6.49	9.27	11.45	13.41
BBACT	-19.77	-15.36	-11.10	-6.98	-3.06	0.58	3.63	6.38	8.40	10.18
BACTD1	-19.92	-15.76	-11.73	-7.85	-4.16	-0.64	2.32	5.03	7.02	8.75
BACTD2	-20.02	-16.15	-12.41	-8.81	-5.39	-2.13	0.83	3.34	5.29	7.04
16-25 bph										
Volume (bales)	2000	4000	6000	8800	10000	12000	14000	16000	18800	20000
Rate of Return (%)										
Pre-Control	-17.75	-12.33	-6.99	-1.72	2.95	6.47	9.55	12.60	15.31	18.45
BBACT	-18.01	-13.11	-8.28	-3.51	1.01	4.63	7.46	10.21	12.61	15.31
BACTD1	-18.20	-13.54	-8.95	-4.43	0.03	3.65	6.45	9.05	11.30	13.83
BACTD2	-18.35	-13.98	-9.67	-5.42	-1.23	2.46	5.30	7.74	9.81	12.18

Table 7. (continued)

Plant Size Category	Volume and Rates of Return									
26-34 bph										
Volume (bales)	3000	6000	9000	12000	15000	18000	21000	24000	27000	30000
Rate of Return (%)										
Pre-Control	-15.61	-10.14	-4.73	0.54	4.38	7.59	10.86	14.27	17.35	20.70
BBACT	-15.97	-10.95	-5.98	-1.05	3.01	5.98	8.90	12.01	14.78	17.86
BACTD1	-16.18	-11.39	-6.64	-1.93	2.25	5.16	7.95	10.85	13.47	16.40
BACTD2	-16.40	-11.86	-7.37	-2.92	1.26	4.22	6.85	9.53	11.98	14.74
≥ 35 bph										
Volume (bales)	5000	10000	15000	20000	25000	30000	35000	40000	45000	50000
Rate of Return (%)										
Pre-Control	-15.64	-9.96	-4.33	1.08	4.61	8.14	11.61	15.03	18.36	21.60
BBACT	-15.92	-10.60	-5.32	-0.08	3.56	6.80	10.02	13.21	16.28	19.31
BACTD1	-16.11	-10.99	-5.92	-0.88	2.94	6.00	9.08	12.15	15.07	17.97
BACTD2	-16.30	-11.40	-6.54	-1.72	2.28	5.17	8.08	11.01	13.77	16.53

under comparable conditions experienced returns of 12.47 and 10.74%, respectively (Table 6). In addition, under analogous conditions, the rates of return for plants processing picked cotton were slightly higher than returns for plants processing stripped cotton (Tables 6 and 7).

When the two largest plant sizes (26 to 34 and ≥ 35 bph) were operating at 100% capacity and processing either picked or stripped cotton, they generated returns in excess of the rate required (14.7%) to upgrade to an emission level of 1.06 lb per bale (BACTD2). But as shown by information in Table 6, no other plant size generated adequate returns to upgrade to this low emission rate. At peak volume (100% utilization), the rate of return was adequate to upgrade the 16 to 25 bph plant to an emission rate of 1.60 lb per bale (BACTD1) when processing picked cotton and to upgrade to an emission rate of 2.24 lb per bale (BBACT) when processing stripped cotton. Returns were insufficient for the ≤ 10 bph plants and the 11 to 15 bph plants to add air pollution controls. When plant utilization declined to 90% and the plant was processing picked cotton, the ≥ 35 bph plant generated returns that were adequate to upgrade to an emission rate of 1.06 lb per bale (BACTD2) while returns for the 26 to 34 bph plant would permit upgrading to an emission level of 2.24 lb per bale (BBACT) (Table 6). However, when processing stripped cotton and operating at 90% utilization, the ≥ 35 bph plant generated returns that allowed upgrading to an emission rate of only 1.60 lb per bale (BACTD1), whereas returns for the 26 to 34 bph plant would permit upgrading to an emissions rate of 2.24 lb to bale (BBACT) (Table 7).

SUMMARY AND CONCLUSIONS

Analysis regarding gin plant costs showed (1) per bale costs increased with introduction of air pollution controls, and controls which increasingly lowered per bale emission rates increased per unit processing costs; (2) for a particular gin plant size, the increase in per bale cost associated with introduction of air pollution control was reduced as plant volume increased; and (3) for a particular air pollution control system, large gin plants operating at a particular utilization level experienced more modest increases in per bale costs than smaller plants operating at similar utilization levels.

In general, the rates of return were inversely related to per bale plant costs. In particular, (1) introducing air pollution controls decreased a plant's rate of return on investment, and rates of return decreased as controls introduced increasingly lowered emission rates; (2) regardless of the air pollution control system, a gin plant earned a higher rate of return at higher volume levels; and (3) large plants tended to experience higher rates of return than smaller plants when compared at specified utilization levels.

The following observations were made regarding the ability of Texas gin plants to invest in air pollution controls:

(1) Neither the ≤ 10 bph nor the 11 to 15 bph plants had returns which permit investment in air pollution controls when processing picked or stripped cotton.

(2) The 16 to 25 bph plant, when processing picked cotton and operating at 100% utilization, had returns which permit investment in BACTD1 (1.60 lb per bale emission rate). However, when processing stripped cotton,

returns permitted investment in only BBACT (2.24 lb per bale emission rate) for the 16 to 25 bph plant. Upgrading was not feasible when the 16-25 bph plant operated at less than the 100% utilization level.

(3) The 26 to 34 bph plant, processing picked or stripped cotton at 100% utilization, had returns that permitted investment in BACTD2 (1.06 lb per bale emission rate). At 90% utilization, plants processing picked or stripped cotton upgraded to only BBACT (2.24 lb per bale emission rate). No investment in air pollution control was permitted when utilization levels fell below 90%.

(4) In the largest plant size category (≥ 35 bph), plants processing picked or stripped cotton and operating at 100% of capacity had returns which permitted upgrading to BACTD2 (1.06 lb per bale emission rate), whereas at 90% utilization, plants processing picked cotton upgraded to BACTD2 (1.06 lb per bale emission rate). But when processing stripped cotton, returns allowed upgrading to only BACTD1 (1.60 lb per bale emission rate). No investment in air pollution control was warranted when utilization levels were below 90%.

In conclusion, gin plant's rate of return on investment was unfavorably affected by the introduction of air pollution controls. Many Texas plants operate at comparatively low utilization levels and, as such, careful attention must be given to a plant's historic variability in processing levels when prescribing air pollution controls since their economic viability is sensitive to these investments.

This study had several shortcomings which should be noted. First, it was assumed that gin revenue schedules were unchanged with investments in air pollution controls. If ginning charges increased as a result of the higher cost, then the calculated rates of return were underestimated. Second, in the long run, new innovations may lower air pollution control costs and create uses for the removed pollutants. In which case, the unfavorable effects on the cotton ginning industry may be overstated by this study.

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Values of Stress Resistance Genes Relative to Dry Weight Accumulation in Wheat Seedlings

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ABSTRACT

Biotic stresses on winter wheat (*Triticum aestivum* L.) seedlings can be extremely damaging. Many genes for resistance to insects and pathogens have been introduced into wheat; however, no quantitative estimates are available regarding the effectiveness of such genes with regard to seedling traits. In this study we used closely related lines derived from backcrossing using a single recurrent parent to assist in estimating genotypic values for four resistance genes: *Pm17*, for resistance to powdery mildew; *Gb2*, for resistance to biotype 'C' greenbug; and two sources of resistance to biotype 'E' greenbug, *Gb3* and *Gb6*. All genes were present in the TAM-105 background. The genotypes were evaluated for dry matter accumulation during a 5-week period, beginning at the two-leaf stage. For each greenbug resistance gene, two initial infestation rates were examined, 0.5 and 5.0 aphids per plant. Powdery mildew damage to susceptible seedlings developed more slowly than did greenbug damage at either infestation rate. Resistance conferred by *Pm17* was completely effective in maintaining seedling dry weight in inoculated vs. uninoculated plants, while greenbug infestation of any of the resistant genotypes at 5.0 aphids per plant resulted in significantly reduced dry matter accumulation, compared to uninfested control plants by the end of the study. In TAM-105, which is susceptible to both greenbug biotypes, reduced dry weight occurred earlier when infested with biotype 'E' than with biotype 'C'. Also, while both TAM-105 and TAM-107 are susceptible to biotype 'E', when infested with that biotype, TAM-105 exhibited reduced dry weight sooner than did TAM-107, which possesses biotype 'C' resistance. These results suggest that biotype 'E' is the more damaging of the two biotypes, but that biotype 'C' resistance confers some delay in development of symptoms to biotype 'E'.

KEYWORDS: gene value, greenbug, powdery mildew

The effects of many stress agents on plants are most severe when stress occurs at early growth stages. This is particularly true for biotic stresses such as insect infestation or disease (Kieckhefer and Kantack, 1988; Duczek, 1989; Kieckhefer and Gellner, 1992; Verma et al., 1976). Slow rates of growth or partial stand loss resulting from these stresses limit the ability of the crop to recover later, even if

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natural or artificial controls are subsequently imposed. In the case of winter wheat, such stresses can be very damaging economically, due to its lengthy vegetative growth period and the common farming practice of using that vegetation for winter pasture for grazing by ruminants. As the economic value of winter grazing can be greater than that of the wheat grain (Shipley and Regier, 1972), decreased rates of seedling dry matter accumulation can be particularly costly.

Backcross breeding programs aimed at introgressing stress resistance genes into agronomically suitable genomic backgrounds have resulted in the development of closely related genotypes differing principally by their resistance genes (Porter et al., 1987; Tuleen et al., 1992). The value of such resistance genes would be expected to vary depending upon environment. The availability of closely related lines differing for specific resistance genes, in combination with controlled environments, thus provides an opportunity to measure gene values. This study was undertaken to evaluate the variation in seedling dry matter accumulation among closely related wheat lines specifically attributable to resistance genes.

MATERIALS AND METHODS

Two cultivars, one germplasm line and a breeding line of winter wheat (*Triticum aestivum* L. em. Thell) were used in this study. One of the cultivars, 'TAM-107', and the germplasm line, 'TX85C5820-5', were backcross products of the second cultivar, 'TAM-105'. TAM-107 carries biotype 'C' greenbug (*Schizaphis graminum*{Rondani}) resistance (*Gb2*) and powdery mildew (*Erysiphe graminis*{DC.f. *tritici* Em. Marchal}) resistance (*Pm17*) derived from rye (*Secale cereale* L.) cv. 'Insave', both present on a 1A:1R chromosome arm translocation, inherited through the wheat cultivar, 'Amigo' (Sebesta and Wood, 1978). TX85C5820-5 carries resistance (*Gb6*) to both biotype 'C' and biotype 'E' greenbugs, but is susceptible to powdery mildew, even though it contains the identical chromosome arm translocation, also from 'Insave' rye (Tuleen, et al., 1992). TAM-105 is susceptible to both greenbug biotypes as well as to powdery mildew. The breeding line used, TXGH12588-105, has pedigree (TAM-105 *4/Amigo)*5//'Largo', and it possesses powdery mildew and biotype 'C' greenbug resistances present on the translocated chromosome arm, as well as biotype 'E' resistance (*Gb3*) inherited from Largo (Tyler et al., 1987).

Plants were grown from seed in vermiculite in 8x8x8 cm plastic pots. Fifteen seeds were germinated in each pot. Populations were thinned to ten plants per pot prior to initiating treatments. Mixed fluorescent and incandescent lighting was provided (about 300 $\mu Em^{-2}sec^{-1}$ at pot level) in a growth chamber, using a 12 h photoperiod. At the two-leaf stage, plants were either infested with biotype 'C' or biotype 'E' greenbugs (at a rate of either 0.5 or 5.0 apterous adults per plant) or inoculated with powdery mildew, by dusting with conidia from previously infected plants. An equal number of uninfested and uninoculated plants were grown as the control group. On the day of inoculation/infestation, and on every third day following, for a period of 36 days, 3 replicate pots were harvested from each treatment group. Plants were gently washed with water after harvest, to remove aphids or mycelia. Total above-ground plant material from each pot was oven dried, and then weighed to the nearest mg.

The genetic value of each resistance gene was estimated by subtracting the difference between treated seedling dry weights and the untreated seedling dry weights in the resistant genotype from the same difference in the susceptible genotype for any individual time interval. In each case, the most appropriate comparisons are between the most closely related genotypes so that epistatic effects are minimized. In the case of the biotype 'E' resistance derived from Largo (*Gb3*), that comparison would be between the resistant breeding line, TXGH12588-105, and the susceptible variety, TAM-107. For the biotype 'E' resistance derived from Insave rye (*Gb6*), the appropriate comparison is between TX85C5820-5 and TAM-105. For biotype 'C' resistance (*Gb2*) and for powdery mildew resistance (*Pm17*), both derived from Amigo, the appropriate comparison is between TAM-107 and TAM-105.

The experiment was analyzed as a factorial design, with 4 genotypes x 6 treatments x 13 harvest dates and 3 replications. Dry weight data were log transformed prior to analysis of variance, and mean separation, when appropriate, was accomplished by Waller's variation of Duncan's multiple range test or by least significant difference (LSD).

RESULTS AND DISCUSSION

Seedling dry weights over the duration of the experiment are summarized in Table 1, from which several important results can be derived. 1) Over the first 9 days of the experiment, no genotypes or treatments differed significantly ($P=0.05$) from each other. 2) Highly significant ($P<0.01$) differences were found among the genotypes, and among the treatments, after 9 days of treatment. 3) Most significant variation among treatments was attributable to the response of known susceptible genotypes. 4) Significant differences were observed between the treated and untreated plants on greenbug-resistant genotypes exposed to the biotypes for which they express resistance, at the higher infestation rate, near the end of the study. 5) In TAM-105, which is susceptible to all the stress agents examined in the study, the effects of biotype 'E' greenbug were observed sooner and were significantly more damaging in dry matter accumulation than were those resulting from biotype 'C' infestation. 6) Both greenbug treatments were significantly more damaging to dry matter accumulation by TAM-105 than was powdery mildew inoculation. 7) Dry matter accumulation in TAM-105 infested with biotype 'E' greenbug departed significantly from the untreated control sooner than did similarly treated TAM-107, though both of those genotypes are biotype 'E' susceptible.

The relationship among genotypes with respect to dry matter accumulation was largely as expected, based upon known resistance or susceptibility. That is, susceptible genotypes showed evidence of reduced dry weight gain sooner, and more dramatically than did resistant genotypes. This was true for all stress agents examined. The results also point out that resistance is not absolute, at least not for greenbug resistance, in that if resistant seedlings were exposed to enough aphids, under conditions favorable for greenbug development and reproduction, those plants eventually succumbed. This result may also apply to loss of dry weight in resistant lines exposed to powdery mildew, at times longer than were examined here, although in this study we observed no visible symptoms of powdery mildew in

Table 1. Seedling dry weights of four related wheat genotypes exposed to greenbug or powdery mildew treatments.

Days After Treatment	Treatment[†]	Genotype				F test[‡]
		TAM105	TAM107	TX85C5820-5	TXGH12588-105	
0	Control	0.21[§]	0.19	0.25	0.22	ns
	Mildew	0.20	0.18	0.23	0.20	ns
	C 0.5	0.25	0.20	0.22	0.25	ns
	C 5.0	0.23	0.17	0.24	0.21	ns
	E 0.5	0.25	0.18	0.26	0.22	ns
	E 0.5	0.21	0.20	0.22	0.19	ns
3	Control	0.22	0.21	0.27	0.26	ns
	Mildew	0.22	0.22	0.28	0.27	ns
	C 0.5	0.25	0.21	0.30	0.25	ns
	C 5.0	0.21	0.22	0.27	0.28	ns
	E 0.5	0.24	0.20	0.29	0.29	ns
	E 5.0	0.26	0.23	0.26	0.28	ns
6	Control	0.28	0.25	0.29	0.32	ns
	Mildew	0.30	0.26	0.31	0.30	ns
	C 0.5	0.30	0.27	0.30	0.29	ns
	C 5.0	0.33	0.28	0.32	0.33	ns
	E 0.5	0.36	0.28	0.33	0.33	ns
	E 5.0	0.32	0.29	0.30	0.34	ns
9	Control	0.36	0.33	0.33	0.36	ns
	Mildew	0.32	0.30	0.34	0.32	ns
	C 0.5	0.35	0.35	0.36	0.38	ns
	C 5.0	0.32	0.31	0.35	0.39	ns
	E 0.5	0.35	0.34	0.35	0.40	ns
	E 5.0	0.28	0.32	0.34	0.35	ns
12	Control	0.42	0.41	0.39	0.39	ns
	Mildew	0.44	0.36	0.40	0.40	ns
	C 0.5	0.41	0.39	0.40	0.42	ns
	C 5.0	0.28	0.37	0.38	0.41	*
	E 0.5	0.37	0.38	0.41	0.42	ns
	E 5.0	0.18	0.33	0.39	0.39	*
15	Control	0.47	0.49	0.44	0.45	ns
	Mildew	0.51	0.42	0.42	0.44	ns
	C 0.5	0.42	0.44	0.45	0.41	ns
	C 5.0	0.22	0.43	0.43	0.47	**
	E 0.5	0.26	0.37	0.42	0.44	*
	E 5.0	0.10	0.21	0.44	0.45	**
18	Control	0.52	0.54	0.46	0.51	ns
	Mildew	0.50	0.48	0.48	0.49	ns
	C 0.5	0.40	0.51	0.48	0.47	*
	C 5.0	0.17	0.49	0.49	0.50	**
	E 0.5	0.20	0.29	0.47	0.46	**
	E 5.0	-[¶]	0.08	0.48	0.48	**

Table 1. (continued)

Days After Treatment	Treatment†	Genotype				F test‡
		TAM105	TAM107	TX85C5820-5	TXGH12588-105	
21	Control	0.53	0.57	0.53	0.56	ns
	Mildew	0.51	0.55	0.44	0.56	ns
	C 0.5	0.36	0.55	0.52	0.58	*
	C 5.0	0.09	0.54	0.50	0.54	**
	E 0.5	0.14	0.24	0.51	0.51	**
	E 5.0	-	-	0.51	0.47	ns
24	Control	0.60	0.62	0.57	0.61	ns
	Mildew	0.44	0.59	0.50	0.63	*
	C 0.5	0.20	0.60	0.58	0.57	**
	C 5.0	-	0.55	0.55	0.55	ns
	E 0.5	0.09	0.20	0.56	0.62	**
	E 5.0	-	-	0.57	0.60	ns
27	Control	0.62	0.65	0.63	0.64	ns
	Mildew	0.40	0.64	0.36	0.66	**
	C 0.5	0.17	0.58	0.60	0.62	**
	C 5.0	-	0.62	0.61	0.61	ns
	E 0.5	0.03	0.11	0.64	0.66	**
	E 5.0	-	-	0.61	0.62	ns
30	Control	0.64	0.63	0.66	0.73	ns
	Mildew	0.38	0.68	0.41	0.69	**
	C 0.5	0.04	0.62	0.64	0.68	**
	C 5.0	-	0.59	0.68	0.60	ns
	E 0.5	-	0.05	0.67	0.69	**
	E 5.0	-	-	0.64	0.58	ns
33	Control	0.70	0.68	0.69	0.79	ns
	Mildew	0.29	0.72	0.25	0.74	**
	C 0.5	-	0.66	0.70	0.76	ns
	C 5.0	-	0.57	0.66	0.65	ns
	E 0.5	-	-	0.70	0.71	ns
	E 5.0	-	-	0.62	0.65	ns
36	Control	0.76	0.71	0.81	0.84	ns
	Mildew	0.22	0.73	0.17	0.79	**
	C 0.5	-	0.72	0.75	0.80	ns
	C 5.0	-	0.61	0.73	0.68	ns
	E 0.5	-	-	0.77	0.78	ns
	E 5.0	-	-	0.64	0.64	ns
LSD (P=0.05)		0.16	0.11	0.14	0.18	

†Greenbug treaments were one of the two biotypes, C and E, each applied at two rates, 0.5 and 5.0 aphids per plant, in pots (replicates) containing ten seedlings each.

‡Analysis of variance conducted within each treatment and date of harvest (among genotypes): ns = nonsignificant; *, ** = significant (P=0.5, 0.01).

§Data are means of three replicates (ten plants per replicate).

¶All plants died; these entries were not included in subsequent data analyses.

resistant lines. We also observed differences among the susceptible lines in time of onset of symptoms, and rate of dry weight loss. This was particularly noticeable for the comparison of TAM-105 and TAM-107 exposed to biotype 'E' greenbug. While plants of both lines were susceptible, and eventually died, both symptoms and reduced dry weight gain occurred earlier in TAM-105 than in TAM-107. Possibly, the biotype 'C' resistance in TAM-107 is mildly inhibitory to biotype 'E' greenbugs.

Calculation of the values of specific resistance genes (Table 2) is permitted by the close relationship among these lines, so that neither epistasis nor genotype x environment interaction is likely to confound interpretation of the results. These calculations permit evaluation of the relative effectiveness of each resistance gene to the appropriate stress agent, at least within the genetic background provided by TAM-105. It could be viewed that the least effective resistance was that provided by *Pm17* since the difference between plants carrying resistant vs. susceptible alleles at this locus was less than that for the other loci examined. This is reflected by lower estimates of genetic value for this gene than for the three greenbug resistance loci. On the other hand, during the time period evaluated in the current study, *Pm17* provided absolute immunity to the pathogen, a result not observed for greenbug infestation of any of the sources of greenbug resistance. These results likely relate to the longer period of time required for occurrence of mildew damage than for greenbug damage, so in that sense the comparison may be misleading. Still, the results show that under conditions optimal for the development of either stress agent on wheat seedlings, the greenbug resistances are more valuable. Estimates of genetic value did not differ greatly between the two biotype 'E' greenbug resistance sources, when exposed to similar inoculation levels, although significant differences between control plant dry weight and heavily infested TXGH12588-105 did occur six days earlier than similar significant differences in TX85C5820-5. Estimates of genetic value for the biotype 'C' resistance conferred by *Gb2* were generally smaller than those for either of the biotype 'E' resistance genes, indicating that, at least in the TAM-105 background, any biotype 'E' resistance may be more beneficial than biotype 'C' resistance.

The results of this study suggest that greater attention should be paid to economic threshold values for seedling wheat. This study was conducted under controlled conditions which were near optimal for development of the insects or mildew. Such conditions can prevail in winter wheat fields planted early to permit winter grazing. The higher rate of initial greenbug infestation used in this study was approximately equal to that currently recommended for spray treatment (Boring and Patrick, 1994), while the lower infestation rate was 4- to 10-fold less than the recommended treatment level for seedling wheat. Both levels produced significant reductions in seedling dry weight gain within 2 weeks on susceptible wheat, however. Such dry weight reductions are the observable result of very early structural damage (Morgham et al., 1994), so that even if aphids are removed at the recommended time, the damage may persist, as suggested by measurements of root length and dry weight (Burton and Burd, 1993). Because most wheat in the south central US is grazed by livestock, it is also important in these areas to consider the potential for damage to forage quality in determining spraying recommendations. Perhaps the value of resistance genes to producers may be enhanced by understanding differences in forage quality under seedling infestation.

Table 2. Estimates of genetic value for resistance to greenbug and powdery mildew in wheat seedling dry weight accumulation.

Resistance Gene	Treatment Level†	Days after Treatment 0	3	6	9	12	15	18	21	24	27	30	33	36
Gb2	High	NS‡	NS	NS	NS	.121KL§	.208J	.344G	.419EF	---¶	---	---	---	---
	Low	NS	NS	NS	NS	NS	NS	.107L	.153K	.320G	.406F	.595B	.651A	---
Gb3	High	NS	NS	NS	NS	NS	.299HI	.415EF	---	---	---	---	---	---
	Low	NS	NS	NS	NS	NS	.137KL	.287I	.332GH	.486D	.604B	---	---	---
Gb6	High	NS	NS	NS	NS	NS	.288I	.470D	---	---	---	---	---	---
	Low	NS	NS	NS	NS	NS	.129KL	.296HI	.353G	.465D	.577B	---	---	---
Pm17	-	NS	NS	NS	NS	NS	NS	NS	NS	.151K	.224J	.330GH	.448DE	.533C

†Greenbug infestation rates were 0.5 aphids per plant (low) or 5.0 aphids per plant (high).
‡NS = non significant ($P > .05$).
§Means followed by the same capital letter are not significantly different by Waller-Duncan test (K ratio = 100).
¶All susceptible plants died.

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Effects of Various Levels of Sodium Chloride and Hexametaphosphate on Restructured Beef Steaks During Cooler Storage

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ABSTRACT

Restructured beef steaks were prepared from boneless chucks. This study evaluated the effects of salt, phosphate and length of cooler storage on restructured beef steaks. Samples were manufactured with four sodium chloride and phosphate combinations (treatments) 0% and 0%, 0% and 0.5%, 2% and 0%, and 2% and 0.5%. Water was added (3%) at the time of mixing. The product was formulated in a mixer for 15 minutes. The four treatments were passed through a patty machine (3/1 head) and then stored at 4°C for 0, 3, 6, and 10 days. Various quality attributes of restructured beef steaks were studied. Restructured beef steaks with salt had lower ($P<0.05$) water-holding capacity (WHC) values (higher water binding capacity) than controls or those manufactured with phosphate alone. The taste panelists detected significantly ($P<0.05$) improved juiciness and cohesiveness with 2% sodium chloride. Percent moisture and the Warner-Bratzler shear force values did not differ significantly among treatments or storage periods.

In recent years, much interest has been shown in the processing of lower value and tougher cuts of meat into higher value meat items. Current restructuring technologies offer new methods of beef chuck utilization which include the use of sodium chloride, phosphate and a variety of additional non-meat ingredients. These ingredients can be used to produce an increasing variety of portion-controlled meat products from the beef chuck that can be formed into different shapes with a desired texture and tenderness.

MATERIALS AND METHODS

Two-piece boneless vacuum packaged chucks (#115, National Association of Meat Purveyors, 1992) were used in this study. Three replications of the study were conducted. The muscles were ground through a coarse grinder plate (2.5 cm) and then through a fine plate (0.3 cm). The ground meat was placed in polyethylene bags and stored for 4 hours at 4°C. The meat formulation consisted of 90% lean and 10% fat with 3% water added. Analysis was determined by using a modified Babock analysis (AOAC, 1990). From this meat block the four separate treatments

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were formulated.

The four formulation treatments were 1) No added sodium chloride or phosphate (control), 2) 0.0% sodium chloride with 0.5% phosphate added, 3) 2.0% sodium chloride with 0.0% phosphate, and 4) 2.0% sodium chloride with 0.5% phosphate.

Each treatment was mixed 15 minutes in a Leland food mixer (Leland Detroit Co. Detroit, MI). The phosphate was a commercial grade sodium hexametaphosphate while the salt was a commercial grade of sodium chloride. Each bulk formulation was passed through a Hollymatic patty machine using a 3/1 head. These steaks were wrapped in plastic film and stored at 4°C until evaluated.

Proximate composition for moisture was determined in duplicate on the raw sample using the oven drying method (AOAC, 1975). The cooking procedure for all restructured steaks was in a Blodgett convection oven. All samples (sensory and objective measurements) were cooked to an internal temperature of 34°C before being turned and cooked to a final internal temperature of 68°C.

For sensory evaluation, a seven-member trained sensory panel (Gross and Stanfield, 1976) evaluated broiled restructured beef steaks. Each panel was randomly served samples from each treatment. The cooked restructured steaks were evaluated for appearance, flavor, cohesiveness, juiciness, and tenderness. An 8-point scale (8=excellent, 1=extremely poor) was used in evaluating product quality.

Water holding capacity (WHC) was determined by the filter paper press method, (high WHC values represent low WHC) as developed and used by Hamm (1960). Shear force (kg) was estimated with steaks from each formulation treatment and storage period. Steaks were placed in a Blodgett convection oven and were broiled to an internal temperature of 68°C. The cooked steaks were placed in a 2°C to 0°C cooler for 45 minutes before testing. This provided adequate firmness to better ensure uniform cores (Will and Henrickson, 1976). From each steak, three 1.25 cm diameter cores were taken at three pre-selected sites on the steak. Each core was sheared three times using the Warner-Bratzler Shear.

Data were analyzed by Analysis of Variance (Barr et al., 1979) using a completely random design (Steele and Torrie, 1980) with split-plot treatment arrangements. Where significant differences were found, means were separated by Duncan's multiple range test (Snedecor and Cochran, 1980). Significant differences were accepted at the 5% level.

RESULTS AND DISCUSSION

In this experiment, there was no difference ($P>0.05$) in percent moisture between raw steak samples (Table 1). Likewise, phosphate data showed little influence on moisture retention (Cassidy, 1977).

Sensory panelists detected no difference ($P>0.05$) for tenderness from restructured beef steak among treatments (Table 2), thus, the addition of sodium chloride and phosphate had slight effect on tenderness. Likewise, no significant differences ($P>0.05$) in tenderness were detected among the formulations and treatments storage period. Tenderness scores remained relatively constant throughout the storage period.

Table 1. Raw meat percent moisture mean values by NaCl/PO_4 combinations and storage days. Means did not differ significantly ($P>0.05$).

Treatment NaCl, PO_4	Cooler Storage (days)			
	0	3	6	10
0%, 0%	70.35	69.87	69.75	69.43
0%, 0.5%	70.50	70.34	70.31	69.93
2%, 0%	70.49	69.89	70.19	69.75
2%, 0.5%	70.63	69.53	69.96	69.84

Sensory panelists, however, detected differences ($P<0.05$) in appearance, flavor, cohesiveness, and juiciness among restructured beef steak treatments. Restructured steaks with 2% sodium chloride and 0.5% phosphate were juicier, more flavorful and more cohesive than the other combinations. Juiciness and appearance scores were slightly increased by phosphate treatment. As previously stated, sensory panelists detected differences ($P<0.05$) in appearance score between treatments (Table 2). However, the appearance score decreased ($P<0.05$) over the storage time. Sodium chloride (2%) increased ($P>0.05$) sensory panelists scores for cohesiveness. Siegel and Schmidt (1979) and Macfarlane et al., (1977) reported that NaCl is a primary factor in the development of this property. This product resembled a solid piece of meat in appearance and texture. Cohesiveness scores remained relatively consistent during cooler storage (Table 2).

Analysis of taste panel data indicated differences ($P<0.05$) in juiciness scores between treatments for restructured beef steaks (Table 2). However, there was a tendency for sensory panelist scores for juiciness to decrease ($P<0.05$) over the storage time (Table 2). Longer storage times for restructured beef steaks decreased flavor scores. This trend might indicate slight influences on oxidation during the storage period. This observation was previously reported by Okerman and Organisciak (1979).

All sensory factors (flavor, cohesiveness and juiciness) showed general improvement with the 2% sodium chloride, 0.5% phosphate combination. Neer and Mandigo (1977) also reported that panelists preferred restructured meat product containing sodium chloride and phosphate in comparison to the control.

Mean values of water-holding capacity (Table 3) showed that control and 0.5% phosphate samples had higher ($P>0.05$) water-holding capacity (WHC) values than steaks containing sodium chloride. Juiciness increased at the 2% level of sodium chloride. This was expected since sodium chloride has been shown to increase water-holding capacity. These results agree with those reported by Neer and Mandigo (1977). Their study found that juiciness improved as percent of NaCl was increased in the cured pork product.

Table 2. Mean values of sensory evaluation by $NaCl/PO_4$ combinations and storage days.[†] Sensory evaluations were made with an 8-point scale (8=excellent, 1=extremely poor).

	%NaCl, %PO_4				Cooler storage (days)			
	0, 0	0, 0.5	2, 0	2, 0.5	0	3	6	10
Appearance[†] (color)	4.50[‡]a	4.87a	4.97a	5.39a	5.35a	5.40a	4.85a	3.92a
Flavor	4.00a	4.23a	5.40b	5.80b	4.51a	4.55a	4.79a	4.46a
Cohesiveness	3.70a	4.00a	5.43b	6.00b	3.56a	4.76a	5.42b	5.41b
Juiciness	3.77a	3.83a	4.90b	5.03b	3.67a	5.38b	5.37ab	5.35a
Tenderness	5.20a	4.73a	5.60a	5.83a	5.24a	5.40a	5.40a	5.75a

†n=7 for sensory evaluation.

‡Within a row, means from the various $NaCl/PO_4$ combinations or storage days followed by the same letter did not differ significantly ($P > 0.05$).

Shear force values (Table 4) indicated no significant differences (P > 0.05) between treatment and storage period. Since these data were in agreement with sensory panel results, it was concluded that restructured steaks have acceptable tenderness.

Sodium chloride addition to restructured beef steaks increased sensory panel acceptability and water-holding capacity, whereas phosphate had little effect on sensory panel scores or percent moisture of the product. The combination of sodium chloride and phosphate improved the sensory properties over that of 0.5% phosphate or control steaks. Cooler storage for up to 10 days did not significantly affect the sensory properties, percent moisture, water-holding capacity or shear value in restructured beef steaks derived from the bovine chuck.

Table 3. Mean values of water-holding capacity (WHC) by NaCl/PO_4 combinations and storage days.†

Treatment	Cooler Storage (days)			
%NaCl, %PO_4	0	3	6	10
0, 0	19.48‡a	20.32a	21.03a	22.26a
0, 0.5	20.84a	19.61a	19.87a	19.61a
2, 0	9.35b	11.03b	11.48b	10.58b
2, 0.5	11.35b	11.55b	13.16b	12.97b

†Ratio (cm^2) of total juice area to meat film area (high number indicates low WHC).
‡Within a column, means followed by the same letter did not differ significantly (P > 0.05).

Table 4. Mean values of Warner-Bratzler shear force (kg) by NaCl/PO_4 combinations and storage days. Means did not differ significantly (P > 0.05).

Treatment	Cooler Storage (days)			
NaCl, PO_4	0	3	6	10
0%, 0%	1.52	1.37	1.97	2.21
0%, 0.5%	1.40	1.39	1.78	1.77
2%, 0%	1.48	1.25	1.72	1.42
2%, 0.5%	1.41	1.47	1.49	1.41

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Effect of Polymethylolcarbamide (Urea Formaldehyde Condensation Polymer) on Growth and Tissue Formaldehyde Residues in Shrimp

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ABSTRACT

Toxicity of the urea formaldehyde resin pellet binder polymethylolcarbamide (Basfin[R]) was determined in 28-day feeding trials conducted in tanks with *Penaeus vannamei* Boone, 1931. Levels of polymethylolcarbamide ranging from 0.25 to 8% did not affect shrimp survival. However, growth of shrimp fed feeds containing more than 0.5% polymethylolcarbamide was less than that of shrimp fed control feeds without polymethylolcarbamide. Growth was reduced 58% by feed containing 8% polymethylolcarbamide, and 19 to 27% by feeds containing 1 to 4% polymethylolcarbamide. In a separate trial, growth was reduced 29 and 30% by feeds containing 0.5 and 1% polymethylolcarbamide, respectively. Growth was reduced by polymethylolcarbamide both in feeds that were extruded without heating using alginate as the binder, and in feeds that were bound by polymethylolcarbamide with the addition of steam, heat and pressure. Formaldehyde residues in muscle increased linearly with polymethylolcarbamide level in feed. However, at levels of polymethylolcarbamide recommended by manufacturers for pellet binding, predicted levels of formaldehyde in shrimp tissues would be lower than those reported in stored fish and shrimp. Under conditions of semi-intensive pond culture where natural foods were present, a 28-day feeding trial conducted in outdoor pens indicated that growth and survival were not affected by 0.5% polymethylolcarbamide.

KEYWORDS: toxicity, pellet binder, feeding trial, *Penaeus vannamei*

Polymethylolcarbamide is a urea formaldehyde polymer that has been marketed by BASF Aktiengesellschaft under the trade name Basfin[R] as a binder for pelleting mixed feedstuffs. It is also the major component of AQUA-TEC, marketed by Uniscope, Inc. as a pellet binder and waterproofing agent for use in fish and shrimp feeds, and of MAXI BOND, marketed by AGresearch, Inc. as a binder for all

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feeds. Manufacturer claims indicate that the addition of polymethylolcarbamide makes pelleted feeds harder, more durable, and more resistant to abrasion (BASF, 1983a). Increased stability of pellets in water due to polymethylolcarbamide has been reported in carp (BASF, 1983a) and in crustacean feeds (Boonyaratpalin, 1984; Uniscope, 1987, 1988a, 1988b, 1988c).

Although amounts of free formaldehyde in polymethylolcarbamide are relatively small, acid hydrolysis in the digestive system could release formaldehyde and urea. However, radio tracer studies with rats indicate that the primary path of polymethylolcarbamide elimination is fecal excretion and that renal and respiratory excretion are relatively minor (Grubenbecher and Kargarotos, 1983). This suggests that polymethylolcarbamide is excreted intact rather than metabolized, because the primary routes of elimination for free formaldehyde would be respiration and for free urea would be renal excretion. At the low rates that the binder is used in feeds, BASF (1983a) concludes that the urea and formaldehyde have no toxicological significance. Levels up to 0.5% in piglet feeds and up to 1% in broiler feeds, do not exert any adverse effects (BASF, 1983a).

Data describing the effects of polymethylolcarbamide on growth and survival have not been reported for penaeid shrimp. The objectives of this study were to (i) evaluate the effects of polymethylolcarbamide levels on the growth and survival of *Penaeus vannamei* in tanks, (ii) measure formaldehyde residues in shrimp tissues, (iii) determine if polymethylolcarbamide, when used under conditions similar to commercial applications, has adverse effects on growth and survival, and (iv) determine if effects of polymethylolcarbamide levels recommended for commercial feeds are present under conditions of semi-intensive pond culture where natural foods are additionally present.

MATERIALS AND METHODS

Three 28-day growth trials were conducted in indoor tanks where shrimp had access to dry feeds only. The first growth trial was designed to determine if high levels of dietary polymethylolcarbamide affect growth and survival, and to measure tissue levels of formaldehyde residues. Polymethylolcarbamide levels used in this trial were 0, 1, 2, 4, and 8%. The second growth trial was designed to determine the effects of dietary levels similar to those used in commercial feeds. Polymethylolcarbamide levels used in the second trial were 0, 0.25, 0.50, and 1.00%. The third growth trial was designed to determine if polymethylolcarbamide affected growth and survival when ingredients were conditioned at high temperature and pressure before extrusion. Levels of polymethylolcarbamide in the feeds were 0 and 1%. A fourth 28-day growth trial was conducted in pens within a pond where the shrimp had access to the substrate and natural foods as well as dry feeds. Polymethylolcarbamide levels used in the feeds for the pen study were 0 and 0.5%.

For the third growth trial, *Penaeus vannamei* postlarvae were obtained from Laguna Madre Shrimp Farms and grown to a suitable size. For all other growth trials, juvenile *P. vannamei* were obtained from the Texas A&M University Shrimp Mariculture Facility in Corpus Christi. For the first and second growth trials conducted in tanks, shrimp were acclimated for a minimum of 3 days before stocking. For the pond trial, which was conducted at the Texas A&M Mariculture Facility in Corpus Christi, the shrimp were stocked directly into the pens.

Table 1. Composition of feeds without polymethylolcarbamide. Values of ingredients and components represent percentages of diets on a dry weight basis.

Ingredient	Growth trial 1 & 2	Growth trial 3	Growth trial 4
Wheat starch†	21.3		21.1
Soybean meal‡	25.0	39.3	15.0
Wheat Middlings†		29.6	
Casein†	10.9		14.4
Soy protein (α-protein)†	10.9		14.4
Shrimp head meal§	6.2		5.0
Fish meal¶	6.2	20.0	5.0
AIN mineral mixture 76†	6.8	0.1	10.7
Calcium phosphate (dibasic)#		1.0	
Fish oil (menhaden)¶	3.9	1.0	5.5
Soybean lecithin (oil not removed)†	1.0	0.5	0.5
Cholesterol†	0.5	0.3	0.3
Vitamin mixture†,§§	2.0	2.6	2.0
Choline chloride#		0.1	
Ascorbic acid†	0.3		0.3
Ascorbic acid polyphosphate††		0.3	
Fish solubles¶	1.0		1.0
Cellulose (Alphacel)†	1.3	2.0	2.2
Sodium Alginate‡‡	2.0	2.0	2.0
Sodium hexametaphosphate#	1.0	1.0	1.0
Component			
Protein	40.0	40.4	40.0
Lipid	8.0	5.6	8.0
Fiber	4.0	4.1	4.0
Ash	13.0	10.3	15.0
Nitrogen free extract	35.0	39.6	33.0

†ICN Biomedicals, Inc., Costa Mesa, CA.
‡Producers Cooperative Association, Bryan, TX.
§Blum and Bergeron, Inc., Houma, LA.
¶Zapata-Haynie Corporation, Hammond, LA.
#VWR Scientific, Houston, TX.
††Vitamin Technologies International, Buhl, ID.
‡‡Kelco, Chicago, IL.
§§30 g/kg para-Amino benzoic acid (B_X), 1 g/kg D-Biotin (H), 1 g/kg Butylated hydroxylanisole, 1 g/kg Cholecalciferol (D_3, 400000 I.U./g), 75 g/kg Choline chloride, 1 g/kg Cyanocobalamin (B_{12}), 5 g/kg Folic acid (M), 180 g/kg Inositol, 2 g/kg Menadione (K_3), 26 g/kg Nicotinic acid, 15 g/kg D-Pantothenic acid (calcium salt), 3 g/kg Pyridoxine hydrochloride (B_6), 2 g/kg Retinyl palmitate (A), 8 g/kg Riboflavin (B_2), 498 g/kg Sucrose, 5 g/kg Thiamine mononitrate (B_1), 22 g/kg DL-alpha-Tocopherol acetate (E, 250 I.U./g).

Formulations of feeds and calculated proximate analyses are shown in Table 1. All control formulations without polymethylolcarbamide were complete feeds that were known from previous growth trials to produce satisfactory growth and survival of *Penaeus vannamei* in tanks without other supplemental feeds. The 1% polymethylolcarbamide feed used in the third growth trial was made by substituting 1% cellulose and 1% polymethylolcarbamide for 2% alginate in the control formulation. In the other growth trials, levels of polymethylolcarbamide were varied by substituting polymethylolcarbamide for equal amounts of wheat starch in the control formulations.

In commercial applications, the binding characteristics of polymethylolcarbamide are activated by the addition of steam and heat to the feed mix (BASF, 1983a). However, heat and pressure treatment of feeds containing the higher levels of polymethylolcarbamide used in the first growth trial (up to 8%) would produce very hard feeds that are unpalatable to shrimp. To reduce differences in water stability of the feeds due to the level of polymethylolcarbamide, all feeds, with the exception of the 1% polymethylolcarbamide feed used in the third growth trial, were prepared with alginate as a binder and extruded without heating (Meyers, 1980). These feeds were extruded through a 3.2 mm diameter die and dried at 50 to 60°C to a water content of less than 10%. The 1% polymethylolcarbamide feed used in the third growth trial was pelleted by Daishowa Chemicals, Inc. Ingredients used in the 1% polymethylolcarbamide feed were conditioned for 20 to 30 sec in a pellet conditioning chamber by heating with steam at 207 mla (30 psi) to 88°C. This feed was extruded through a 3.2 mm diameter die, held for 10 min without cooling, and cooled in a forced air drying oven to room temperature. All dried feeds were broken to an appropriate length (3 to 10 mm) and stored at -10°C.

The first two tank trials were conducted in 0.23 m^2 tanks containing 136 L of seawater. The third tank trial was conducted in 0.06 m^2 tanks containing 17 L of seawater. In the three tank trials, seawater was recirculated through tanks from a 58,500 L seawater system at respective rates of 83, 167, and 70% of tank volumes per hour. Daily exchange in the recirculating seawater system averaged 10%. A 12 h light:12 h dark photoperiod was maintained throughout growth trials. Stocking densities were 35 per m^2 (12 per tank) in the first two experiments, and 114 per m^2 (7 per tank) in the third experiment.

In tank trials, shrimp were fed in excess four times daily at 6 hour intervals (06:00, 12:00, 18:00, and 24:00) to make intact feed pellets continuously available to shrimp and at the same time minimize the amount of excess feed left in tanks. The amount fed each day was divided into four equal feedings at 6 hour intervals. Uneaten food was partially removed by the flow of water through the tanks as the feed pellets disintegrated. Residual feed pellets, exuviae, and dead shrimp were manually removed on a daily basis by siphoning. Although the amount of food presented daily to each shrimp did not differ between dietary treatments, feed rates (as percentages of the weights of the shrimp) varied between dietary treatments because of differences in growth between treatments. Daily feed rates in the three tank experiments ranged from 20 to 41, 20 to 25, and 18 to 74%, respectively.

The pen growth trial was conducted in 1 m^2 square pens at a seawater depth of 0.76 m. Pens were constructed of 4 x 15.9 mm polyethylene mesh, Aquanet[R] XV-1110, InterNet[C] Incorporated. Daily exchange of sea water in the pond was 2%. Shrimp were stocked at a density of 60 m^{-2} and fed at a daily rate of 3% of their weight as estimated from maximum growth rates obtained under similar conditions in previous growth trials. The amount fed per day was divided equally among four separate feedings at 6 hour intervals (06:00, 12:00, 18:00, and 24:00). Although the amount of feed presented to shrimp did not differ between dietary treatments, feed rates increased up to a level of 4% during the growth trial due to a lower than expected growth rate.

In tank trials, salinity, temperature, and dissolved oxygen were measured daily and ammonia, nitrite, and nitrate were measured weekly. In the pond trial, salinity, maximum and minimum temperatures, and morning and afternoon dissolved oxygen were measured daily. Salinity was controlled by the addition of fresh water. Average weights of shrimp were determined at the beginning and end of growth trials by dividing the total weight of shrimp in the tank by the number of shrimp. Growth of shrimp was expressed in terms of instantaneous growth rates (IGR) given by the following equation.

$$IGR = 100 \times (\ln(Weight_{final}/Weight_{initial}))/28 \text{ days}$$

Formaldehyde residues in muscle tissue were determined by the laboratory of Dr. Chavez at the McDonald Campus of McGill University, Ste Anne de Bellevue, Quebec, Canada and provided for this manuscript by BASF Aktiengesellschaft (Kohler, 1986).

One-way analysis of variance (ANOVA) and Student-Newman-Kuels *a posteriori* comparison of means were used to determine significant differences in survival and growth due to levels of polymethylolcarbamide in the feed. Differences in concentration of formaldehyde residues in shrimp tissues were analyzed by linear regression of tissue levels onto levels of polymethylolcarbamide in the feed. The critical probability value used to determine significance was $P = 0.05$.

RESULTS

Water quality parameters are given in Table 2 for the tank experiments and in Table 3 for the pen experiment. Water quality parameters were stable within experiments and adequate for growth and survival of shrimp. Within experiments,

Table 2. Water quality parameters for tank experiments. Values represent mean ± standard deviation for number of replicates in parentheses.

Parameter	Experiment 1	Experiment 2	Experiment 3
Salinity (ppt)	31 ± 1 (29)	24 ± 1 (29)	29 ± 1 (28)
Temperature (°C)	28 ± 1 (29)	28 ± 1 (29)	29 ± 1 (28)
Oxygen (ppm)	6.0 ± 0.4 (29)	6.0 ± 0.2 (29)	7.7 ± 0.6 (28)
Ammonia (ppm N)	0.11 ± 0.08 (3)	0.06 ± 0.02 (4)	0.04 ± 0.01 (4)
Nitrite (ppm N)	0.04 ± 0.02 (3)	0.21 ± 0.08 (4)	0.03 ± 0.03 (4)
Nitrate (ppm N)	0.25 ± 0.25 (3)	1.19 ± 0.15 (4)	not determined

survival did not differ among shrimp fed different levels of polymethylolcarbamide (P = 0.3315 in tank experiment 1, P = 0.2466 in tank experiment 2, P = 0.9807 in tank experiment 3, and P = 0.5222 in the pen experiment). Means ± standard deviations (number of replicates) for percentages of survival were 95 ± 6 (40), 88 ± 8 (40), 66 ± 11 (25), and 57 ± (17) in the respective experiments.

Table 3. Water quality parameters for pen experiment. Values represent mean ± standard deviation for number of replicates in parentheses.

Salinity (ppt)	35 ± 2 (28)
Daily maximum temperature (°C)	29 ± 2 (28)
Daily minimum temperature (°C)	25 ± 2 (28)
Morning dissolved oxygen (ppm)	6 ± 1 (28)
Afternoon dissolved oxygen (ppm)	9 ± 2 (27)

Growth of shrimp fed diets containing polymethylolcarbamide are shown in Figure 1. The first tank experiment indicated that dietary polymethylolcarbamide levels of 1% or above reduced growth of shrimp. In addition, growth of shrimp fed a diet containing 8% polymethylolcarbamide was significantly lower than that of shrimp fed diets containing 1, 2 and 4% polymethylolcarbamide. Differences in growth between shrimp fed diets containing 1, 2, and 4% polymethylolcarbamide were not significant. In the second tank experiment, dietary polymethylolcarbamide levels similar to those used in commercial feeds reduced growth. Instantaneous growth rates of shrimp fed 0.5 and 1% polymethylolcarbamide were significantly lower than those of shrimp fed feed without polymethylolcarbamide. In the third tank experiment, 1% polymethylolcarbamide feed also reduced growth. Instantaneous growth rates of shrimp fed a feed bound with 2% alginate were greater than those of shrimp fed a feed bound with 1% polymethylolcarbamide under conditions similar to commercial applications. In contrast to results obtained in the second indoor tank experiment, growth of shrimp fed a diet containing 0.5% polymethylolcarbamide in outdoor pens did not differ from that of shrimp fed a diet without polymethylolcarbamide.

In tank experiment 1, mean weight gains per shrimp were reduced 58% by the 8% polymethylolcarbamide feed relative to the weight gain (4.1 g) of shrimp fed the feed without polymethylolcarbamide. Mean weight gains were reduced 19 to 26% by feeds containing 1, 2 and 4% polymethylolcarbamide. In tank experiment 2, the mean weight gain (2.36 g) of shrimp fed feed without polymethylolcarbamide was reduced 29 and 30% by feeds containing 0.5 and 1% polymethylolcarbamide, respectively. In tank experiment 3, the mean weight gain (1.71 g) of shrimp fed feed without polymethylolcarbamide was reduced 30% by feed containing 1% polymethylolcarbamide.

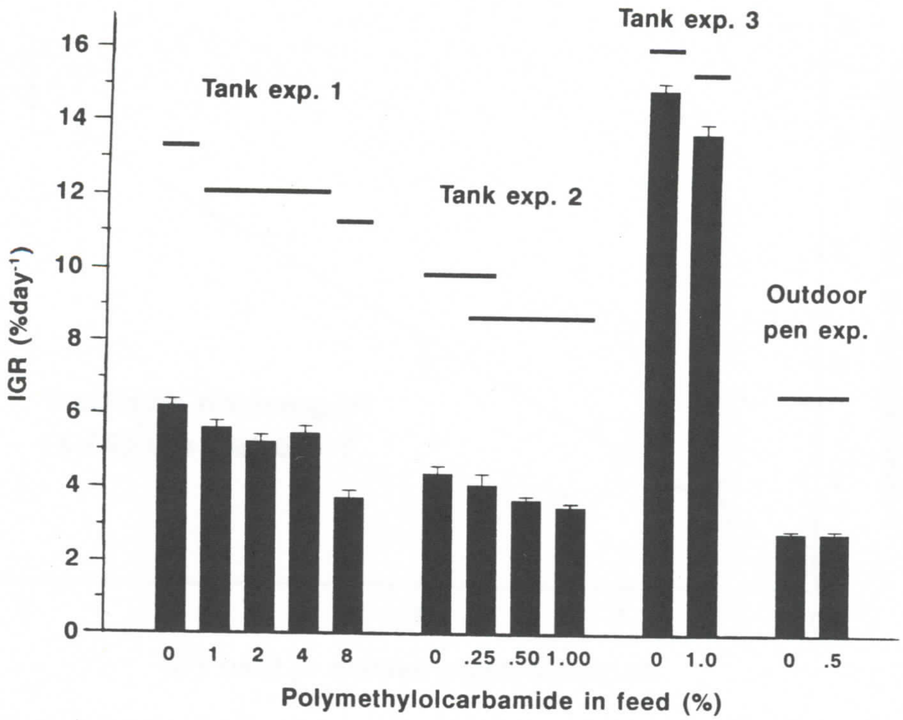

Figure 1. Effect of polymethylolcarbamide on instantaneous growth rate (IGR) of *Penaeus vannamei* in percent growth per day. Natural foods were available to shrimp in the outdoor pen experiment but not in tank experiments 1, 2, and 3. Vertical bars represent means of 8 replicates except for 0% polymethylolcarbamide in the pen experiment where 9 replicates were used and tank experiment 3 where 7 replicates were used. Error bars represent standard errors of means. Means under a continuous horizontal line are not significantly different.

At the end of the first tank experiment, muscle tissue of shrimp was collected for analysis to determine if formaldehyde residues accumulated from the polymethylolcarbamide in the feed (Figure 2). Regression of tissue formaldehyde residues onto polymethylolcarbamide levels in the feed indicated that tissue formaldehyde was linearly proportional to polymethylolcarbamide in the feed and described by the regression equation shown in Figure 2. Deviations from linear regression were not significant ($P = 0.7549$). To test the significance of linear regression of tissue formaldehyde onto polymethylolcarbamide in the feed, the mean square for linear regression was tested over the pooled mean squares for deviations from linear regression and for variation within feed levels according to rules proposed by Bancroft (1964). Linear regression was highly significant ($P < 0.0001$).

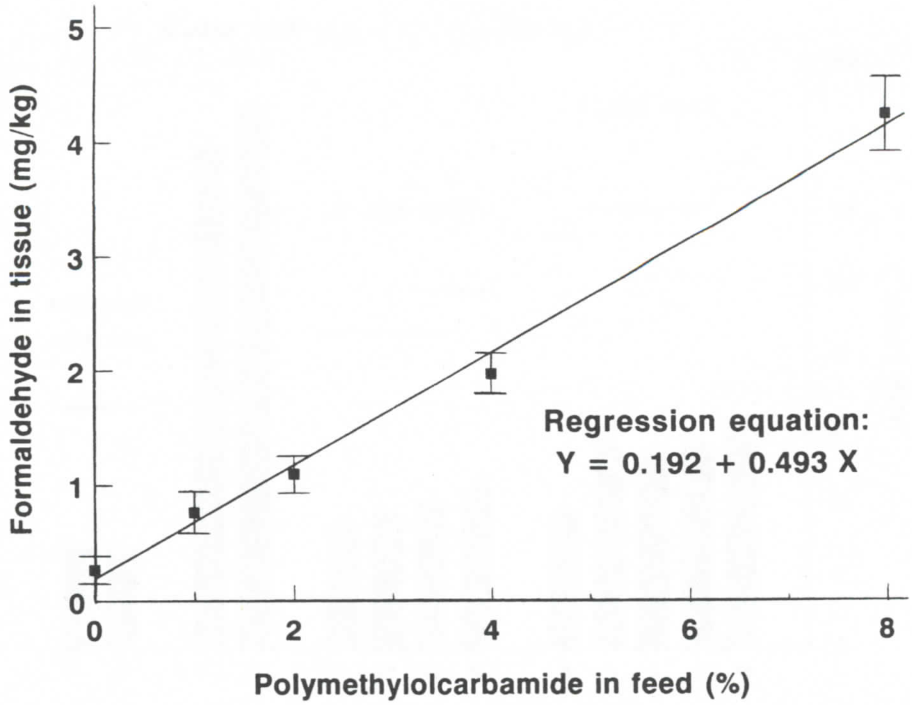

Figure 2. Effect of polymethylolcarbamide in feed on residual formaldehyde in muscle tissue of *Penaeus vannamei* on a dry weight basis. Data are means of 8 replicates and error bars represent standard errors of means.

DISCUSSION

Data presented in this study indicate that polymethylolcarbamide levels at or above 0.5% can reduce growth of shrimp. Reductions in growth may occur at levels below 0.5% but were beyond the resolution of the experimental design.

Instantaneous growth rates were lowest in the pen experiment and highest in the third tank experiment. The major reasons for differences in growth rates between experiments were differences in the size of shrimp used. Means $\pm$ standard deviations (number of replicates) for initial weights were 2.38 $\pm$ 0.42 g (100) in the pen experiment, and 0.89 $\pm$ 0.12 g (40) and 0.93 $\pm$ 0.11 g (40) in the first two indoor tank experiments. In the third tank experiment, the mean initial weight was estimated from a random sample of shrimp at stocking as 0.026 g. Other factors that may have contributed to lower growth in the outdoor pen experiment were higher stocking densities and lower seawater temperatures at night. Diurnal variations in water temperature did not occur in the indoor experiments.

Data presented in this study for the pen experiment indicate that under conditions where shrimp have access to natural foods, growth was not reduced by the presence of 0.5% polymethylolcarbamide. However, feeding rates and feed quality were not equivalent in the tank and pen experiments because feeding rates were higher in the tanks, and because formulated feeds may be supplemented with natural foods in outdoor pens. Notwithstanding these differences, growth in the pen experiment was not limited by the availability or quality of formulated feeds. In preliminary experiments conducted to establish optimal feeding rates for similar feeds in the pen experimental system, higher daily feeding rates ranging from 5 to 10% did not increase growth of shrimp stocked at the same density and biomass. Stable isotope studies conducted in similarly constructed pens by Anderson et al. (1987) indicated that pond productivity contributed 53 to 77% of the carbon in growth of shrimp with a final biomass of 86 to 96 g m^{-2}. Although final biomass in the present pen study was greater (177 to 182 g m^{-2}) than that reported by Anderson et al. (1987), natural foods were also important in the present study. In the pen experiment, the most probable explanation for the lack of reduction in growth by the feed containing 0.5% polymethylolcarbamide is that availability of natural foods reduced dietary intake of polymethylolcarbamide relative to the indoor tank experiments even where the percentage of polymethylolcarbamide in the formulated feeds was the same.

Recommended practical application rates for use of polymethylolcarbamide as a binder in feeds for terrestrial animals are 0.1 to 0.3% (BASF, 1983b; Uniscope, n. d.). Levels reported to be suitable and effective for pellet binding in shrimp feed are 0.4 to 0.5% (Boonyaratpalin, 1984) and 0.5 to 0.75% (Uniscope, 1989). There was no indication from the results of this study that polymethylolcarbamide reduced growth when used at recommended levels for semiintensive pond culture. However, as culture methods are intensified and amounts of pelleted feed consumed by shrimp increase relative to the availability of natural foods, growth may be decreased by polymethylolcarbamide levels that have no effect in less intensive culture. Under these conditions, economic advantages of using polymethylolcarbamide as a pellet binder would have to be weighed against its negative effect on growth.

Concerns about formaldehyde residues in tissues of shrimp grown on feeds bound with polymethylolcarbamide are unwarranted. Low levels of formaldehyde are present in many foods, including shrimp. In the first tank experiment, muscle tissues of shrimp fed feed without polymethylolcarbamide contained a mean formaldehyde concentration of 0.27 mg kg^{-1} on a dry weight basis, or 0.06 mg kg^{-1} on a wet weight basis (dry weight = 23.9% of wet weight). Formaldehyde is also formed in shrimp and fish from the decomposition of trimethylamine oxide to dimethylamine and formaldehyde as the result of deterioration during processing or storage (Amano and Yamada, 1964; Castell and Smith, 1973). At 1 to 4°C, formaldehyde levels on a wet weight basis in defrosted muscle of fish were 20 mg kg^{-1} in *Gadus macrocephalus* after 2 days of storage, and 50 mg kg^{-1} in *Hexagrammos stelleri* after 4 days of storage (Amano and Yamada, 1964). For old frozen fillets stored under poor conditions, Castell and Smith (1973) reported a formaldehyde concentration of 0.85 mmole per 100 g of muscle, a level equivalent to 255 mg kg^{-1} on a wet weight basis. In shrimp, postmortem storage for 72 hours at 7°C and one year at -20°C produced formaldehyde residues on a wet weight basis of 1.2 and 1 mg kg^{-1}, respectively (Hose and Lightner, 1980). Using the regression equation in Fig. 2, predicted muscle formaldehyde residues in shrimp that were fed diets containing 0.5 % polymethylolcarbamide in tanks would be 0.44 mg kg^{-1} on a dry weight basis or 0.10 mg kg^{-1} on a wet weight basis. At levels of polymethylolcarbamide recommended for pellet binding, levels of formaldehyde in shrimp tissues would be lower than those reported in stored fish and shrimp.

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Cost of Production Impacts of Restricted Pesticide Use on Fruits and Vegetables

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ABSTRACT

This study estimated the impacts of reduced chemical use on fruit and vegetable crops. Specifically, the yield and per unit cost impacts of eliminating the use of insecticides, fungicides, and herbicides were evaluated, as well as the impacts of an approximate 50% reduction in the number of applications. Nine crops were studied, but the impacts on three crops (onions, sweet corn, and oranges) are discussed in this article. The impacts were generally substantial but highly variable among regions and crops. The fresh market crops tended to experience larger yield reductions than the processed market crops. Sweeping pesticide use reduction involving more than one pesticide category would have more adverse (synergistic) impacts on yield than strategies targeted toward a particular pesticide group.

The 1990s will likely represent a crossroad on the issue of pesticide use in agriculture. Congress amended the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) in 1988 to require that all pesticides and their uses registered before November 1984 be reregistered to comply with current standards by the end of 1997. It is widely believed that this re-registration requirement could limit the availability of certain pesticides, especially for minor crop uses. The result would likely lead to substantial reductions in productivity for fruit and vegetable crops. The issue is not only the potential removal of a label. As important is the concern that the costs of re-registration may be so substantial that manufacturers would find it prohibitively unprofitable to produce and market certain pesticides. The burden of proof, therefore, may be so costly that certain pesticides would not be available as crop protectants because of regulation costs rather than any science-based concerns about efficacy, residues, or health.

The pesticide issue was made more complex by the decision of the Ninth Circuit Court of Appeals when it ruled that zero tolerance of carcinogenic pesticide residues was inconsistent with the Environmental Protection Agency (EPA) negligible risk policy for pesticide approval under section 409 of the Federal Insecticide, Fungicide,

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and Rodenticide Act (FIFRA) for pesticide labeling. The Clinton administration has proposed a policy which would eliminate consideration of economic benefits in the pesticide review and approval process and establish a standard for registration of "reasonable certainty of no harm" (Browner, et al., 1993).

In the re-registration process, consideration has been given to the impact on productivity, yield, and output levels of a loss of a specific chemical for proposed uses on specified crops. Few studies, however, have been completed on the impact of eliminating a large number of pesticides, a scenario that might occur as a result of the re-registration process. Likewise, little is known about the potential impact of reducing the level of pesticide use from current practices to perhaps 50% of current practices, a change that has been suggested as a possible environmental policy goal.

Previous studies of the impacts of substantial reductions in chemical use fall into the following categories:

1. Studies of the impacts of chemical use approaching zero levels have been completed for major program crops (Knutson et al., 1990; Smith et al., 1990). These studies excluded fruits and vegetables, whereas this study addresses that deficiency.
2. Studies have been conducted of the impacts of imposing relatively high levels of taxes on fertilizer and pesticides as a means of discouraging use. The most recent of these studies (Rendleman, 1993) implies higher levels of farmer responsiveness to increased fertilizer and pesticide prices than had been indicated previously. Questions regarding the long-run impact on the competitiveness of US agriculture have not been studied.
3. Studies of the indirect environmental and economic costs associated with pesticides have been conducted. Included in such assessments are analyses of pesticide impacts on human health, domestic animals, crop pollination and honeybee losses, groundwater and surface water contamination, fish and wildlife, and microorganism losses (Pimental et al., 1991, 1992).
4. Studies of the impacts of eliminating individual chemicals have been completed in conjunction with FIFRA reregistration and related EPA/USDA/FDA regulatory requirements.
5. Studies of the impacts of eliminating individual chemicals or groups of chemicals have been completed on experimental plots throughout the US. The results of such studies need to be considered in drawing conclusions regarding the broader implications of substantial chemical use reduction under commercial conditions, but they are not necessarily the final answer because of the limited purposes for which each experiment was conducted.
6. Studies of organic or sustainable agriculture farms (Cacek and Langer, 1986; Dabbert and Madden, 1986) may have the potential for approximating actual farming conditions more closely than experimental plots. Organic farms and those employing practices identified under the sustainable agriculture umbrella, however, also must be interpreted carefully inasmuch as they are generally conducted on a case farm basis as opposed to widespread commercial applications. In addition, it is not unusual for such farms to use organic chemicals, which have likewise come under question by EPA for their potential adverse impact on health and the environment.
7. Result demonstrations conducted by the Extension Service closely

approximate controlled changes in pesticide use under actual farming conditions. Such studies may be the best source of information on current chemical use farming practices. A coordinated compilation of such demonstrations are difficult to assemble, however.

OBJECTIVES

The overall objective of this study was to estimate the impacts of reduced chemical use on fruit and vegetable crops. Specific objectives were:

1. To evaluate the yield and cost of production impacts of zero use of insecticides, fungicides, and herbicides on a set of fruits and vegetables that collectively represent no less than 80% of the value of fruit and vegetable production in the US.
2. To evaluate the yield and cost of production impacts of approximately a 50% reduction in the number of applications of insecticides, fungicides, and herbicides for the same set of fruits and vegetables.
3. To draw implications for the trade-offs involved in chemical use policy decisions related to fruits and vegetables.

While studies of zero use of pesticides have been posited as irrelevant to the policy issue of chemical use on major program crops (Ayer and Conklin, 1990), they quite clearly are not irrelevant in the case of minor use crops where:

1. The options for control of particular pests have declined, with only one or two chemicals pesticides now available.
2. The pesticide manufacturers, in effect, are limited procedurally (and economically) on the number of crops for which a chemical can be registered if any carcinogenic effects are found.
3. The existence of proposals that would enforce strict compliance to the zero tolerance criterion contained in the Delaney clause (EPA) threaten the use of pesticides on a wide array of crops.

The interest in the 50% reduction option results from the contention by Doering (1991) and others (Ayer, 1991) that the zero option is not only unrealistic but also represents maximum impact. In addition, Doering asserts that the yield response curve associated with reduced chemical use is concave, meaning that there could be substantial reductions in pesticide use with little impacts on yield.

Estimating the impacts of a zero and 50% pesticide application rate provides some insight into the shape of the yield and unit cash cost curve as chemical use is reduced from current commercial farming practices to zero chemical use. In other words, this procedure determines whether the greatest yield reductions are likely achieved in the initial move from the current number of applications to an approximate 50% reduction in the number of applications or in the second move from 50% to zero use. This information is useful in addressing the Doering hypothesis. While having one observation between zero use and commercial practice may not be definitive in determining the exact shape of the yield response curve, it should be decisive on whether the tendency is toward concavity as hypothesized by Doering.

MATERIALS AND METHODS

The current fruit and vegetable study employs a modified application of the procedures developed in the Knutson et al., (1990) study of zero chemical use in program crops. The specific crops on which yield and cost estimates were made accounted for more than 82% of the value of US fruit and vegetable production in 1992. The crops were selected in a manner that represented a cross section of the different levels of chemicals utilized under normal commercial farming conditions. The fruit and vegetable crops analyzed in the study included potatoes, oranges, tomatoes, grapes, apples, lettuce, onions, sweet corn and peaches.

Estimates were made of the yield and unit cash costs of production for the 50% reduction in number of applications and for zero chemical use under the following four chemical use reduction scenarios:

1. No herbicides including growth regulators that generally involve applications of micro quantities of compounds classified as herbicides.
2. No fungicides, natural or synthetic, including fumigants. While fumigants are primarily a means of disease control, they may also act to reduce both insect and weed populations.
3. No natural, synthetic, biological, or chemical insecticides;
4. No herbicides, insecticides, or fungicides as defined above; hereinafter referred to as no pesticides.

Leading horticultural scientists were asked to make these estimates considering the related changes in cultural practices that needed to be made in each of the major production regions. The initial responsibility of each horticultural scientist was to specify a baseline set of horticultural practices for the crop in the region being studied. These practices included the typical number and timing of pesticide applications under normal weather conditions. After specifying the baseline practices, the scientist also indicated any changes in cultural practices occurring as a result of the pesticide reduction scenarios that would minimize the adverse yield and cost impacts.

For most crops, a horticultural economist was asked to work with the horticultural scientist for the purpose of converting the changes in yields and cultural practices into unit cash costs of production for each of the eight chemical use reduction scenarios in each of the major production regions. Preference was given to a horticultural economist located at the same university as the lead horticultural scientist for each crop. The budgets utilized were identified, evaluated, and modified by the horticultural economist based upon the baseline production practices specified by the horticultural scientist. The budgets were analyzed only from the perspective of changes in variable costs. In other words, the cash costs represented in the budgets do not include fixed or overhead costs which are substantial in fruit and vegetable production. Since some of the fixed costs (e.g., requirements for management or machinery replacement) may increase under one or more of the reduced pesticide scenarios, the unit cost results must be considered conservative.

The major points included in the instructions given the scientists for making the yield and cost estimates were as follows:

1. The zero pesticide use option covers all pesticides, organic or inorganic. While a distinction was considered between organic and inorganic pesticides, it was concluded that the distinction from a safety perception and public policy perspective has become sufficiently clouded that the zero

option should be as pure as possible. For cases in which biological pesticides (such as Bt) have become common, the scientists may have provided an indication of the magnitude of impact associated with the elimination of such pesticides as a basis for comparison.

2. The 50% reduction in applications option was made with the understanding that the scientists were to eliminate those applications and those pesticides having the least impact on yields following intensive IPM methods. In all cases, however, the pesticides were to be applied at the rates indicated on the labels. In cases with only one application of a pesticide, the 50% reduction option was declared not applicable (NA) unless the horticultural scientist chose to specify an alternative strategy that was feasible.
3. Current budgets for the geographic areas studied were used as a baseline for the estimates of yields and costs. From this baseline for each budget item, notes were requested from the scientists on the factors, sources, and reasoning that formed the basis for each change from the baseline practices for each chemical use reduction option.
4. Yields were estimated in terms of marketable quality product on commercial farm applications. The scientists were urged to draw on all available research and related information to make this yield decision as objectively as possible. For example, organic farm yields could be a benchmark for making the zero option estimates to the extent that organic pesticides were also removed. What constitutes a marketable yield was left to the judgment of the horticultural scientist interacting with the economist. For example, while consumers arguably might buy wormy sweet corn, apples, peaches or tomatoes in the absence of any alternative, the scientist was instructed to consider and apply current industry standards as influenced by consumer preferences.
5. Changes in cultural practices (e.g., number of trips through the field), crop rotation, amount of labor utilized, and the cost of repairs were specified by the scientists.
6. Synergistic effects such as the impacts of more weeds on insect or fungi problems were considered.
7. If storage was a major consideration (as in potatoes, onions, or apples), the impacts of reducing and eliminating post-harvest applications of growth regulators or sprout inhibitors on marketable yield were considered.
8. Estimates were made in consultation with scientists located in each region analyzed. Sometimes the lead horticultural scientist had experience in more than one region. In other cases, separate lead scientists were retained for each region. In other words, substantial effort was made to accurately capture regional differences in the impacts of reduced chemical use.

RESULTS

The yield and cost impacts generally were substantial but highly variable among regions and crops (Tables 1, 2, 3, and 4). Due to space limitations, it is not possible to discuss the details of all nine of the fruit and vegetable crops studied. Results from three crops that are important to the Southern Region (two vegetables

Table 1. Summary of yield reductions per acre for fresh and processed fruits and vegetables, 1992.

Crop	Herbicides		Fungicides		Insecticides		Pesticides	
	Zero use	50% use	Zero use	50% use	Zero use	50% use	Zero use	50% use
Potatoes								
Idaho	30	15	15	10	25	NA	50	20
North Dakota	30	15	50	15	50	10	65	35
Maine	25	15	100	25	50	25	100	70
Oranges								
Florida	0	0	50	17	15	8	63	25
California	15	15	25	24	0	0	36	35
Tomatoes								
Florida	27	NA	70	28	100	30	100	50
California	25	10	10	4	22	9	37	17
Grapes								
California	50	25	97	44	58	36	66	68
New York	12	5	37	12	10	4	26	21
Apples								
Washington	20	15	6	3	100	14	100	30
Michigan	60	30	100	90	100	75	100	100
Lettuce								
California	13	NA	47	27	53	13	67	14
Onions								
Idaho	46	15	20	NA	12	8	60	45
California	35	25	30	10	10	NA	60	45
Texas	25	10	60	40	40	15	80	60
Sweet Corn								
Florida	8	NA	60	20	100	15	100	30
Wisconsin	50	20	NA	NA	13	7	63	30
Peaches								
California	1	0	45	30	40	25	75	45
Georgia/S.C.	20	0	100	80	100	60	100	100

NA = Not applicable (50% reduction was not possible because only one application is currently used).

Table 2. Summary of total costs per acre for fresh and processed fruits and vegetables, 1992.

Crop	Baseline	Herbicides		Fungicides		Insecticides		Pesticides	
		Zero use	50% use	Zero use	50% use	Zero use	50% use	Zero use	50% use
Potatoes									
Idaho	$744.66	$837.54	$760.78	$744.14	$723.26	$759.08	NA	$781.41	$778.58
North Dakota	$343.62	$403.76	$380.96	$358.34	$330.22	$324.70	$325.90	$365.78	$410.78
Maine	$828.53	$993.30	$867.30	NC	$845.92	$882.16	$830.06	NC	$968.90
Oranges									
Florida	$2,224.93	$2,618.25	$2,236.77	$1,495.72	$1,968.47	$1,903.46	$2,068.19	$1,587.87	$1,826.93
California	$3,874.12	$3,775.86	$3,488.08	$3,811.78	$3,882.85	$3,587.06	$3,730.50	$3,332.74	$3,348.79
Tomatoes									
Florida	$8,450.67	$7,267.36	NA	$4,648.94	$6,951.99	NC	$6,990.41	NC	$5,747.16
California	$891.16	$1,210.67	$1,037.13	$905.03	$905.22	$913.47	$911.06	$1,195.80	$1,098.92
Grapes									
California	$3,826.78	$2,304.48	$3,264.52	$1,508.82	$3,338.80	$2,598.95	$3,110.63	$901.08	$2,667.84
New York	$820.93	$877.81	$840.32	$882.83	$754.93	$822.13	$813.55	$809.30	$760.84
Apples									
Washington	$2,733.25	$3,678.35	$2,733.92	$2,803.32	$2,768.29	NC	$288.79	NC	$2,854.51
Michigan	$1,330.75	$1,521.99	$1,373.87	NC	$811.16	NC	$876.85	NC	NC
Lettuce									
California	$3,755.00	$3,725.00	NA	$2,715.00	$3,265.00	$2,385.00	$3,495.00	$2,310.00	$2,845.51
Onions									
Idaho	$2,076.76	$1,781.91	$2,075.68	$1,701.84	NA	$1,997.30	$1,995.75	$1,309.92	$1,410.61
California	$3,781.85	$3,383.76	$3,403.85	$3,123.25	$3,601.75	$3,495.85	NA	$2,518.84	$2,855.14
Texas	$3,781.85	$2,245.60	$2,386.16	$1,439.58	$1,841.48	$1,853.38	$2,231.91	$1,129.37	$1,626.62
Sweet Corn									
Florida	$1,402.66	$1,357.01	NA	$898.79	$1,230.32	NC	$1,206.62	NC	$1,073.35
Wisconsin	$270.34	$251.38	$264.59	NA	NA	$266.46	$275.63	$242.64	$261.54
Peaches									
California	$2,118.00	$2,161.00	$2,127.00	$1,832.00	$1,975.00	$1,787.00	$1,919.00	$1,568.00	$1,836.00
Georgia/S.C.	$2,078.00	$1,791.00	$2,098.00	NC	$934.00	NC	$1,213.00	NC	NC

NA = Not applicable (50% reduction was not possible because only one application is currently used).

NC = No Crop (100% yield loss).

Table 3. Summary of total costs per unit for fresh and processed fruits and vegetables, 1992.

		Herbicides		Fungicides		Insecticides		Pesticides	
Crop	Baseline	Zero use	50% use	Zero use	50% use	Zero use	50% use	Zero use	50% use
Potatoes									
Idaho	$0.0257	$0.0411	$0.0308	$0.0301	$0.0277	$0.0348	NC	$0.0530	$0.0336
North Dakota	$0.0280	$0.0348	$0.0272	$0.0432	$0.0236	$0.0391	$0.0263	$0.0631	$0.0384
Maine	$0.0377	$0.0602	$0.0464	NC	$0.0613	$0.0602	$0.0419	NC	$0.1468
Oranges									
Florida	$0.0537	$0.0632	$0.0540	$0.0723	$0.0573	$0.0314	$0.0653	$0.1031	$0.0588
California	$0.1564	$0.1794	$0.1657	$0.2043	$0.2064	$0.1448	$0.1506	$0.2088	$0.2088
Tomatoes									
Florida	$0.2414	$0.2844	NA	$0.4428	$0.2759	NC	$0.2853	NC	$0.3284
California	$0.0144	$0.0260	$0.0186	$0.0162	$0.0152	$0.0189	$0.0161	$0.0306	$0.0214
Grapes									
California	$0.2187	$0.2634	$0.2487	$3.4448	$0.3407	$0.3536	$0.2777	$8.8785	$0.4691
New York	$0.0800	$0.0972	$0.0882	$0.1366	$0.0636	$0.0890	$0.0626	$0.1924	$0.0939
Apples									
Washington	$0.0781	$0.1314	$0.0921	$0.0852	$0.0815	NC	$0.0980	NC	$0.1165
Michigan	$0.0665	$0.1902	$0.0961	NC	$0.4056	NC	$0.1754	NC	NC
Lettuce									
California	$0.1001	$0.1146	NA	$0.1368	$0.1187	$0.1363	$0.1075	$0.1748	$0.1423
Onions									
Idaho	$0.0415	$0.0660	$0.0488	$0.0425	NA	$0.1454	$0.0434	$0.0655	$0.0513
California	$0.0945	$0.1301	$0.1135	$0.1115	$0.1000	$0.0971	NA	$0.1574	$0.1298
Texas	$0.1071	$0.1331	$0.1179	$0.1800	$0.1325	$0.1373	$0.1165	$0.2510	$0.1807
Sweet Corn									
Florida	$0.1028	$0.1081	NA	$0.1646	$0.1127	NC	$0.1040	NC	$0.1124
Wisconsin	$0.0225	$0.0419	$0.0276	NA	NA	$0.0254	$0.0246	$0.0539	$0.0311
Peaches									
California	$0.0623	$0.0645	$0.0626	$0.0960	$0.0830	$0.0676	$0.0753	$0.1845	$0.0982
Georgia/S.C.	$0.1732	$0.1866	$0.1748	NC	$0.3892	NC	$0.2527	NC	NC

NA = Not applicable (50% reduction was not possible because only one application is currently used).

NC = No Crop (100% yield loss).

Table 4. Summary of percentage change in total costs per pound for fresh and processed fruits and vegetables, 1992.

	Herbicides		Fungicides		Insecticides		Pesticides	
Crop	Zero use	50% use	Zero use	50% use	Zero use	50% use	Zero use	50% use
Potatoes								
Idaho	59.89	19.95	17.33	7.92	35.60	NA	109.87	30.69
North Dakota	67.14	30.66	107.31	13.26	87.85	26.20	202.83	84.34
Maine	59.79	23.10	NC	36.08	112.86	11.27	NC	289.65
Oranges								
Florida	17.68	0.53	34.45	6.59	1.85	1.04	91.86	9.48
California	14.70	5.96	30.65	32.01	-7.41	-3.70	33.54	33.55
Tomatoes								
Florida	17.80	NA	83.38	14.26	NC	18.17	NC	36.02
California	81.14	29.31	12.84	5.81	31.41	12.35	112.99	48.57
Grapes								
California	20.44	13.74	1475.32	55.80	64.70	27.01	3045.56	114.53
New York	21.51	7.75	70.69	4.50	11.28	3.23	140.42	17.32
Apples								
Washington	68.22	17.87	9.11	4.41	NC	22.90	NC	49.20
Michigan	185.93	47.49	NC	509.55	NC	163.56	NC	NC
Lettuce								
California	14.46	NA	35.57	18.57	36.10	7.40	84.55	42.06
Onions								
Idaho	58.89	17.59	2.43	NA	9.29	4.46	57.69	23.50
California	37.65	20.01	17.98	5.82	2.71		66.51	37.27
Texas	24.24	10.01	49.34	27.35	28.17	8.81	134.31	68.74
Sweet Corn								
Florida	5.16	NA	60.19	9.64	NC	1.23	NA	9.37
Wisconsin	85.97	22.34	NA	NA	12.65	9.24	139.34	38.21
Peaches								
California	3.55	0.42	57.27	33.21	40.62	20.81	196.13	57.61
Georgia/S.C.	7.74	0.96	NC	124.74	NC	45.93	NC	NC

NA = Not applicable (50% reduction was not possible because only one application is currently used).
NC = No Crop (100% yield loss).

and one fruit crop) are discussed, however, to provide insight in to the variation that exists among crops, regions, and the relative importance of each class of pesticides studied. The discussion that follows focuses on onions, sweet corn, and oranges.

Onions

The major production areas identified for this study are the California Imperial Valley where Imperial Sweet spring onions are produced, South Texas where spring onions are produced, and the Idaho-Oregon Malheur Valley region where storage onions are produced. These three production areas account for about 60% of US production of dry onions.

Estimated per acre yield reductions associated with zero pesticide use ranged from 60% in Idaho and California to 80% in Texas. A 50% reduction in the number of applications would result in an estimated 45% reduction in yield per acre in California and Idaho and 60% in Texas (Table 1).

These results suggest that the greatest proportional reduction in yield would be associated with the first 50% reduction in pesticide applications. Using Idaho storage onions as an example, the initial 50% reduction in the number of pesticide applications would lead to a 45% reduction in the estimated yield per acre, while removing the remaining 50% of the pesticide applications would reduce the estimated yield by an additional 15%.

In Texas, the initial 50% reduction in the number of applications would result in the estimated yield per acre falling 13,500 pounds per acre from 22,500 lb to 9,000 lb. Eliminating all pesticide use would lead to an additional yield reduction of only 4,500 pounds. The initial 50% reduction in pesticide use, therefore, resulted in an estimated yield reduction three times greater than that produced by removing the remaining pesticide applications.

While all the reduced pesticide scenarios would result in lower total cash costs per acre than indicated by the baseline budget using conventional commercial farming practices, the estimated cash cost per pound of onions produced would be greater in all cases for each pesticide use reduction scenario (Table 3). The total estimated cash cost increase would go from 4.2 to 6.6 cents per pound in Idaho, 10.7 to 25.1 cents per pound in Texas, and 9.5 to 15.7 cents per pound in California. The total cash cost per pound would, therefore, increase by a projected 67% in California, 58% in Idaho, and 134% in Texas (Table 4).

Herbicides

Eliminating herbicide use scenario would appear to have the largest adverse impact on yields in Idaho and California, reducing the estimated yields by 46 and 35% respectively (Table 1). Despite a doubling of hand weeding, Idaho farmers would experience a projected decline from 50,000 lb per acre to 27,000 lb (Table 1).

The lead scientist felt that California farmers would be unable to keep up with the increased weed population despite two additional cultivations, two weed shreddings, and 5 additional hand weedings. As a result, spring onion yields would drop from an estimated 40,000 to 26,000 lb. Since hand weeding often disturbs the bulbs and disrupts or even curtails plant growth, hand weeding would be a less than perfect substitute for applying herbicides. Under the 50% herbicide reduction scenario, the estimated yield reduction would be comparatively less (15% in Idaho where pre-emergence herbicides were retained (post-emergence applications were eliminated) and hand weeding was nearly doubled. On the other hand, California would experience an estimated 25% yield reduction in spite of retaining pre-emergence herbicides and tripling the amount of hand weeding.

The zero use herbicide scenario projected that yields in Texas would drop by 25% Despite twice as much cultivation and three times more hand weeding, yields would fall from 22,500 to 16,875 lb. Under the 50% scenario, however, Texas would retain pre-emergence herbicides, increase cultivation by about 50% and increase hand weeding by 60% This would result in a projected yield reduction of only 10%.

Eliminating herbicides would increase the cash cost of growing onions in Idaho by an estimated 59% from 4.2 to 6.6 cents per pound. This compares to estimated increases of 38% in California and 24% in Texas. A 50% reduction in herbicide applications would increase the cash cost per pound by a projected 10% in Texas, 18% in Idaho, and 20% in California.

The yield reductions and unit cash cost increases probably understate the full impact of reduced herbicide use because of the reduction in the marketable size of onions caused by increased competition with weeds for moisture and nutrients. As a consequence, this reduction would also affect the quantity determined aspects of market price available to the producer.

Fungicides

The study revealed that reducing fungicide use would likely have the most adverse impact on yields in the more humid Texas climate. Eliminating fungicides would result in Texas spring onion yields declining by an estimated 60% from 22,500 to 9,000 lb per acre. Even with fungicide use cut in half, Texas yields would drop by an estimated 40% to 13,500 lb per acre.

In Idaho the estimated yield would decline by 20% from 50,000 to 40,000 lb per acre under the zero reduction scenario. With only the one application of fumigants, the 50% reduction option would not be applicable. In California, the zero fungicide application option would reduce the yield by an estimated 30% from 40,000 lb to 28,000, while the 50% reduction from two applications to one would result in a 10% yield reduction.

The higher cost associated with zero fungicide use would range from an estimated low of 2% in Idaho (less humid climate) to 49% in Texas. This represented an increase of less than 1 cent per pound in Idaho to more than 5 cents per pound in Texas. With fungicide applications cut by half, the cash cost increase would range from a projected 6% in California to 27% in Texas.

Insecticides

Texas spring onions would be the crop most adversely affected by reduced insecticide use. Estimated yields under the zero insecticide use option would fall by an estimated 40% from 22,500 to 13,500 lb. Reducing the number of insecticide applications from five to two would reduce the yield by an estimated 15% to 19,150 lb.

The estimated yield reduction in Idaho with no insecticides was approximately 12% while cutting applications from the normal two to one would reduce the estimated yield by 8% to 46,000 lb. California, with only one insecticide application, would experience a projected 10% yield reduction under the zero scenario. Since California used only one application, the 50% reduction scenario would not be applicable.

The 40% yield reduction experienced by Texas onions in the no insecticide scenario would result in an estimated 28% increase in the cash cost of production from 10.7 to 13.7 cents per pound. This compares with projected increases of only 9% in Idaho and 3% in California. In contrast, the projected cost per pound would increase by only 4% in Idaho and 9% in Texas after a 50% reduction in normal insecticide applications.

Summary

In all the pesticide reduction cases, the projected yield reductions would be substantial. Under the zero pesticide scenario, the onion yield reduction in all three regions would average an estimated 64%. That figure would drop to 48% if applications were cut by half.

These estimates indicate substantial regional differences with South Texas consistently being the most adversely affected area, except in the loss of herbicides, and Idaho being the least adversely affected, except in the loss of herbicides. The largest estimated yield reductions would result from the loss of herbicides, except in Texas where the loss of fungicides would cause the largest yield reduction.

Estimated unit cost increases would be in the range of 20 to 70% across the chemical use scenarios. Per unit costs in Texas, however, would probably more than double without pesticides.

Although this study does not analyze the impacts of reduced yields and higher costs on the prices and gross receipts to growers, a yield reduction in some scenarios also would mean a reduction in the marketable size of onions. This reduction would be due primarily to the compounding effects of weeds, diseases, and insects on the size of the onion plant leaf area. The consequence would be an increase in the price of large onions relative to small onions.

Each scenario eliminating herbicides assumes that labor can be hired at the normal rate to reduce the weed population. Constraints on labor availability could make it impossible to hire these laborers in some areas. To maintain current onion production under either the no pesticide option or the 50% reduction in applications, onion acreage would have to increase nationwide from 25 to 50%. This increase would mean reduced production of other crops.

Alternatively, imports would need to be increased to meet domestic demand. This increase would likely result in higher consumer prices and provide little assurance of the conditions under which the imported onions were grown.

Sweet Corn

The major production areas identified for this study were Florida and Wisconsin. Florida produces an estimated 30% of the sweet corn utilized in the fresh market. Wisconsin is believed to be representative of the broader Corn Belt region, where sweet corn is grown primarily for processing. While Wisconsin accounts for 23% of the processed sweet corn production, the broader Corn Belt region accounts for about 50%.

Substantial differences in both yield and cash cost impacts were indicated between Florida fresh and Wisconsin processed sweet corn. The study revealed that zero pesticide use would reduce the yield per acre by an estimated 63% in Wisconsin and 100% in Florida (Table 1). In other words, without pesticides, no sweet corn of commercially acceptable quality would be produced in Florida due to the loss of insecticides. Moreover, any scenario that eliminates insecticides in Wisconsin would reduce or possibly eliminate exports of processed products because the resulting lower quality product would not meet the quality standards required by importers.

A 50% reduction in the number of pesticide applications would result in an estimated 30% reduction in yield per acre in both Wisconsin and Florida. These results suggest that from the perspective of all pesticides in Wisconsin, the yield reductions would be shared somewhat equally between the first 50% pesticide reduction and the second 50%.

In Florida, however, the greatest reduction would take place with elimination of the second 50% of the pesticide applications. With a 50% reduction, the Florida yield would fall 30% from an estimated 13,650 lb per acre to 9,550 lb. When the remaining pesticides were removed, zero yield is estimated. This sequential comparative effect of a 50% and 100% reduction would be similar for both fungicides and insecticides, meaning that the second 50% reduction would have the greatest impact. The second 50% of applications may be viewed as necessary in order to avert the risk of losing a crop in which the pre-harvest cash investment in the crop would be more than $670 per acre.

While both the zero and 50% scenarios for Florida indicate lower total cash costs per acre than those indicated by the baseline budget using conventional commercial farming practices (Table 2), the cash cost per pound of sweet corn would be higher in all cases when a crop was produced. For example, under the 50% pesticide option, the total estimated cash cost would fall from $1,403 to $1,073 per acre. However, the total cash cost per pound would increase by 9% in Florida from 10.3 cents to 11.2 cents per pound (Table 3). Because no production would occur under the no pesticide option in Florida, this cost comparison cannot be made (NC). In such instances, the term "NC" in the figures means no crop was produced.

In Wisconsin, the estimated cash cost per acre for all pesticide use reduction scenarios would be less than the baseline option using conventional farming practices, but not substantially less. Like Florida, the cash cost per pound in Wisconsin also would be higher with a lower yield per acre. For example, the baseline cash cost would decrease from $270 per acre (2.25 cents per pound) to $243 per acre (but increase to 5.4 cents per pound) under the zero pesticide option.

Herbicides

In Florida, weeds do not represent nearly as great a threat to reduced sweet corn production as do insects and diseases. For example, the withdrawal of herbicides would reduce the yield by only an estimated 8% under the zero reduction scenario. A 50% reduction would not be possible (already at the minimum application level) and is represented by "NA" in the tables and figures. In Wisconsin, the estimated yield loss would be a much higher 50% from 12,000 lb to 6,000 lb per acre. The 50% reduction in herbicide use would be accomplished in Wisconsin by selective application on areas most vulnerable to weeds and by placing less emphasis on conservation tillage, which would increase soil erosion. This approach would be an environmental trade-off. The lead scientists for this chapter also noted that cultivation would be an imperfect alternative to herbicides due to the risk of crop failure in a wet year.

For both the 50% reduction in herbicides and the zero option, the cash cost of growing sweet corn would decrease on a per acre basis and increase on a per pound basis in both regions. For example, with no herbicides, Table 2 indicated the estimated cash cost in Wisconsin would decrease from $270 per acre (2.25 cents per pound) under baseline to $251 per acre (but increase 4.2 cents per pound). Increased cultivation combined with the lower yield would be the primary contributing factors to the higher unit cost, thus raising some concern about effectiveness. Eliminating herbicide applications would increase the estimated per unit cash cost of growing sweet corn in Florida by only 5% or less than 1 cent per pound.

Fungicides

Fungicides are not commonly used on sweet corn in Wisconsin. However, fungicides are essential in Florida for the prevention of foliar diseases and for harvesting a marketable product. Therefore, reductions in fungicide use would have an adverse impact on sweet corn yields in the more humid Florida climate where sweet corn yields would be reduced by 60% in the absence of fungicides. This would be below the threshold for harvesting the crop since industry norms indicate the crop would not be harvested if more than 35% of the ears were unmarketable. In such instances, a 100% loss would likely be declared. If the remaining 40% of the crop were harvested, however, a 60% increase (6.2 cents) would occur in the cost per pound.

In the 50% fungicide reduction scenario, the yield loss in Florida would be reduced to 20% but more scouting for the detection of disease and more sorting to remove diseased ears in packing would be required. The result would be a drop in the yield from an estimated 13,650 lb to 10,920 lb per acre. The estimated unit cash cost associated with a 50% reduction in applications of fungicides in Florida would be almost 10% higher, rising from 10.3 cents to 11.3 cents per pound.

Insecticides

For sweet corn, insecticides are essential for production in Florida. Therefore, Florida sweet corn production would be adversely affected by reduced insecticide use, and no commercial production is estimated if the zero insecticide use option were used.

This substantial loss was estimated because of the severe damage that ears would experience and the inability of producers to cull out the infested ears so that consumers could reasonably be expected to buy the resulting product. Reducing the number of insecticide applications by 50% would reduce the estimated yield by 15% from 13,650 to 11,600 lb.

The Wisconsin estimated yield with no insecticides would be reduced 13%, dropping from 12,000 lb to 10,500 lb per acre. However, this might result in the product not meeting export standards, thus limiting the market to only domestic outlets. The 50% reductions in applications would result in an estimated 7% yield decline.

The estimated 15% yield reduction experienced by Florida sweet corn producers with a 50% reduction in insecticide application would result in about 1% increase in the expected unit cash cost of production. In contrast, an estimated 13% yield reduction in Wisconsin under the zero insecticide option would increase cost by approximately 13%. The increase in cost would be only 9% if half of he normal insecticide application were used. With no production in Florida in the absence of insecticides, unit cash costs could not be calculated.

Summary

Using weighted averages, sweet corn yield per acre estimates for the production regions of Florida and Wisconsin (with application to Minnesota and Illinois) would fall by 78% without pesticides and 30% if pesticide applications were cut in half. Except for the herbicide scenario, yield reduction estimates would be much larger in Florida than in Wisconsin due to climate and soil conditions and the strict aesthetic and quality requirements of the fresh market.

Because of varied growing conditions, the impacts of different pesticide groups would be substantially different between corn produced for the fresh market and that used by the processed market. In Florida, for example, sweet corn could not likely be produced commercially without insecticides. On the other hand, Wisconsin does not use fungicides to any significant degree in producing sweet corn for the processed market.

The absence of pesticides would create an estimated crop reduction of 63% in Wisconsin, but it would result in a total crop loss in Florida, which produces about 30% of the US production for the fresh market. Although Wisconsin's losses would not be as severe, the estimated cash cost per pound would still increase by 139% under the zero option.

Marketability would be a major concern in both growing areas. Failing to meet quality standards would threaten export markets for Wisconsin growers while Florida producers would face the unwillingness of consumers to buy diseased or insect-infested ears of corn in the fresh market.

Because consumers have demonstrated they are less inclined to buy corn when the end has been clipped to eliminate worm damage, buyers currently will reject a whole truckload of sweet corn based on one or two worm-infested crates. As a result, farmers would have no alternative but to walk away from worm-infested fields.

Oranges

Oranges normally rank as the largest of the fruit crops in terms of value of sales in the US. In 1992, however, the orange industry was still recovering from a series of freezes that destroyed many trees in California, Florida, and Texas. As a result, US orange sales totaled only about $1.6 billion in 1992 and accounted for 12% of fruit and vegetable sales. The major production areas analyzed in this study were California and Florida, which account for about 98% of the value of US production.

Florida produces almost exclusively for the processed (juice) market and accounts for virtually all US orange juice production. California, on the other hand, produces oranges primarily for the fresh market, accounting for 76% of the fresh orange market. Although no California oranges are grown intentionally for juice, about 20 to 30% do not make grade and are processed for juice. The specific area in California for which these estimates are made is the San Joaquin Valley, which represents about 60% of the California production. California estimates are representative of navel orange production only.

Estimating the yield and cost impacts of reduced pesticide use in oranges presents some unique problems. One of the major impacts of pesticide use reduction in oranges for the fresh market is the reduced quality of the marketed products. Specifically, as pesticide usage is decreased, the proportion of the oranges that grade out as #2 quality and juice grade would increase even though the yield may not change by a large percentage. This may result in significantly lower producer returns. While returns to growers are not the primary focus of this analysis, these implications are mentioned in this chapter when they are particularly relevant.

A second problem involves the long-run impact of reduced pesticide use on the survival of trees in the orchard. The estimates in this report consider the five-year average impact of reduced pesticide use on orange yields and costs. The scientists emphasized that the longer-run detrimental effects on the trees are difficult to measure but nonetheless important.

Substantial differences exist between California and Florida oranges in both yield and cost impacts. Yield reductions per acre associated with zero pesticide use would be an estimated 36% in California and 63% in Florida. A 50% reduction in the number of applications would result in an estimated 25% reduction in yield per acre in Florida and a corresponding 35% yield reduction in California.

These results suggest that in Florida, the greatest yield reduction would occur with the second 50% pesticide reduction. That is, in Florida the estimated yield reduction is 10,350 pounds with a 50% reduction in pesticides. When the remaining 50% of the pesticides were removed, the estimated yield would drop an additional 15, 650 pounds per acre. In California, however, the greatest yield reduction would occur with the first 50% reduction in pesticide applications (35% reduction). In fact, removing the second 50% of the applications would result in only one additional percentage point estimated reduction in yield.

While both the zero and 50% pesticide reduction scenarios for Florida indicate lower total cash costs per acre than the baseline budget using conventional commercial farming practices (Table 2), the cash cost per pound would be substantially higher in all but the insecticide case of zero pesticide use. It would be only marginally higher, however, with a 50% reduction in pesticides. Specifically, under the zero pesticide option in Florida, the total estimated cash cost would fall from $2,225 to $1,588 per acre (Table 2). However, the total cash cost per pound would increase by 92% from 5.4 cents to 10.3 cents per pound. With a 50% reduction in applications, the cost per pound would rise by more than 9% to 5.9 cents per pound.

In California, the cash cost per acre for the zero pesticide use reduction scenarios would be lower than the baseline option using conventional farming practices. However, the cash cost per unit would rise due to declines in yield per acre. For example, even though the baseline cost would fall from $3,874 per acre to $3,333 per acre under the zero pesticide option, the estimated per unit cost would increase from more than 15 cents per pound to nearly 21 cents per pound.

Herbicides and Growth Regulators

In Florida, weeds do not represent as great a threat to orange production as fungi. Withdrawing herbicides would not reduce the yield but would require substantially increased cultivation. In California, the yield would drop an estimated 15% from 24,776 lb to 21,052 lb per acre under the zero herbicide/growth regulator option, with all the decrease resulting from elimination of growth regulators. To mitigate the impact that reduced herbicides may have on yields, current water and nitrogen rates would have to double.

A 50% reduction in herbicide use in Florida could be accomplished by reducing the size of the treatment band from the normal 12 to 14 ft to 6 to 7 ft, while increasing mechanical mowing. In both scenarios in Florida, it would be possible to accomplish weed control with no sacrifice in yield per acre. For the zero option, however, grove work would have to be increased about 25 fold from $20 per acre under the baseline to more than $490 per acre. Additionally, the altering of band widths would require the purchase of wider mowers or expanded reach mowers that would increase long-term capital expenditures.

For both the 50% reduction in herbicide applications and the zero option, the cash cost of growing oranges would increase on both a per acre and a per pound basis in Florida. With no herbicides, for example, the cost would increase from $2,225 per acre (5.4 cents per pound) under the baseline to $2,618 per acre (6.3 cents per pound, Table 3). Increased grove work would be the primary contributing factor to the higher cost. With a 50% reduction in herbicide use, the cash cost per pound would increase marginally by less than 1% (Table 4).

In California, the total cash cost would increase 15% under the zero option and 6% under the 50% herbicide/growth regulator option. Although the impacts of reduced herbicides and growth regulators are combined for this analysis, the scientists emphasized that the effects of each in orange production in California would be different. In other words, almost all of the yield reductions occurring in the herbicide scenarios stem from the reduction in the use of growth regulators rather than the decrease in herbicide use.

Fungicides

Eliminating fungicide use would result in an estimated 50% reduction (21,000 lb) in Florida orange yields. Under the 50% fungicide reduction scenario in Florida, the fall fungicide applications would be eliminated, resulting in an estimated 17% yield decline (7,000 lb).

In California, eliminating fungicides from the normal application level would cause the yield to decline by an estimated 25% from 24,776 to 18,658 lb per acre under the zero option. Scientists in California also noted, however, that foreign buyers for export markets would not be willing or able to deal with the excessive levels of rot and spoilage that would occur as a result of the time required for transportation after eliminating post-harvest fungicides. These oranges would be diverted to the domestic market, causing downward pressure on domestic prices. On average, the percent of crop grading #1 would fall from an estimated 50 to 41% under either fungicide scenario. Juice grade oranges would increase from an estimated 31 to 37 % under the fungicide reduction scenarios.

The unit cash cost associated with zero fungicide use would increase by an estimated 34% in Florida from 5.4 to 7.2 cents per pound. With fungicide applications 50% of normal, the cost increase would be nearly 7%. The estimated California cost increase would approach 31 % under the no fungicide option, rising from 15.6 cents to about 20.4 cents per pound.

Insecticides

Mites are classified as insects in this study and are the major insect problem in Florida oranges. Miticides are likewise classified as insecticides. By using a zero insecticide option and eliminating three applications of a miticide, Florida orange production would be reduced by 16% from 41,400 lb to 34,776 lb.

Reducing the number of insecticide applications by 50% through eliminating the postbloom application and limiting the fall application to every other year would reduce the estimated yield by 8% to 38,088 lb.

The California yield would not be greatly affected by eliminating insecticides, although there would be a major adverse effect on the quality of oranges marketed. For navel oranges, researchers estimated that as much as 25 to 30% of the fruit would move from grade #1 to grade #2, and 10% would move from grade #2 to juice. While this would be the only case in which the cash cost per pound would fall, the return to the grower could be expected to fall by even more due to discounting related to reduced marketable quality.

The projected 16% yield reduction that would be experienced by Florida oranges with no insecticides would result in a 2% increase per pound in the unit cash cost of production. With 50% of the normal insecticide applications, the cash cost per pound would increase less than 1%.

Summary

The largest yield reductions would result from the loss of insecticides and fungicides in Florida and from the loss of herbicides and fungicides in California. Orange yields in both Florida and California, which account for 98% of the value of US orange production, would be reduced by an estimated weighted average of 55% under the zero pesticide option and 28% if insecticides and fungicides applications were cut by half. Florida would be the most adversely affected if pesticides were eliminated. Under the zero option, Florida yields per acre would drop 63% and the total cash cost per pound to growers would rise by 92%.

For both production areas, scientists indicated that insect and disease problems could be expected to take their toll over a longer time period by eventually causing trees to become nonproductive and die. Thus, the estimates in this study are believed to be highly conservative. In addition, the adverse impacts of reduced pesticide use on product quality (especially California fresh navel production) may substantially reduce potential returns to growers, impacting the long-run stability and competitiveness of the domestic orange industry.

DISCUSSION

This study follows an earlier study that used similar methodology to evaluate the impact of pesticide use reduction on the major program crops. Although the results for fruits and vegetables are similar to the program crop study, they are more dramatic in that some fruit or vegetable crops would be completely wiped out in certain regions as a result of the absence of pesticides.

The major difference between this study and the earlier study is the inclusion of a 50% pesticide reduction option for fruits and vegetables. The results suggest that a substantial variation exists from crop-to-crop in regard to whether the largest incidence of yield reduction would occur in the first 50% decrease or in the final 50%.

The need to proceed with caution on policies involving the elimination or substantial reduction of pesticides was a major conclusion in the earlier study of major program crops. This inference is even more important in a study of fruits and vegetables because the number of pesticide options are often very limited and the potential yield reductions are large.

Further research and technological innovations will be required before significant reductions in pesticide use will be possible without substantial yield reductions and large cash cost increases. The nation's policymakers will likely want to consider all economic, environmental, nutritional and social tradeoffs as they consider pesticide policy changes that will impact every link of America's food chain for years to come.

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Production of *Spirulina platensis* from Growth Media Containing Anaerobically Digested Cattle Waste

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ABSTRACT

The marine microalga, *Spirulina platensis*, was cultured in growth media that included various concentrations of digested cattle waste effluent from a pilot anaerobic digester system. The anaerobically digested cattle waste was diluted with either a synthetic sea salt solution or a diluted oilfield brine solution and culture growth rates were monitored over time. Media treated with digested cattle waste were significantly superior for *Spirulina* growth rate (with yields up to 785 mg dry weight L^{-1} d^{-1}) as compared to the control treatment replicates (with yields up to 235 mg dry weight L^{-1} d^{-1}), which contained no cattle waste. We also demonstrated that *Spirulina* could be cultured in diluted oilfield brine. However, the amount of contaminant algae rose as the concentration of anaerobically digested cattle waste increased in the growth medium.

KEYWORDS: growth rate, Instant Ocean, oilfield brine

The use of animal wastes to culture microalgae is particularly desirable in areas such as the High Plains of West Texas where intensive production of cattle is accompanied by the accumulation of large amounts of wastes. For cattle feedlots and dairies, government regulations have become stricter and now are at a zero discharge level. Failure to comply with these regulations has led to many producers receiving fines from the Environmental Protection Agency (EPA). Mitchell and Richmond (1988) successfully grew *Spirulina platensis* in media prepared from Zarouk medium treated with various concentrations of leachate of raw cattle waste. Pieterse et al. (1982) produced an average of 10 g m^{-2} d^{-1} dried algal material in an

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integrated system treating wastes from a cattle feedlot in South Africa. Pal and Amla (1992) have reported the need for additional nitrogen input when *S. platensis* was produced in a sewage-based media. *Spirulina* culture also required a source of alkaline brine for maximum protection. Some algae farms located near oceans have used filtered sea water to dilute animal wastes. However, inland locations such as the High Plains of West Texas must identify a source of saline water abundant enough and suitable for culturing marine microalgae. Potential sources of saline water are ground water that is high in salinity, and thus not suitable for conventional agriculture, and oilfield brine that can be diluted to the desired salinity with fresh water.

Many systems have been designed for the production of algal biomass, ranging from highly automated operations designed to culture a specific microalga, using a completely defined inorganic chemical medium, to open, outdoor ponds that commonly use some form of organic waste to produce a less specific product (Lee et al., 1992; Radmer and Parker, 1994). This waste grown product has been referred to as "albazoid" (algae, bacteria, zooplankton and detritus) to accurately describe its composition (Richmond, 1986; Soeder, 1986). The culture of microalgae from inorganic chemical media and CO_2 yields a practically monoalgal product of food grade quality that commands a relatively high price. The purchase of nutrients and CO_2 account for as much as 30-40% of the operations cost for food grade microalgal culture (Shelef et al., 1978). Obviously, inclusion of the food grade product in animal feeds would not be cost effective. However, culture of algal biomass from organic nutrients such as cattle (Kilani, 1992; Pieterse et al., 1982), swine (Canizares and Dominguez, 1993; Canizares et al., 1993) or poultry waste may provide a high protein product suitable for use in animal feeds due to lower production costs. This study concentrated on developing growth media for production of an algal culture dominated by *S. platensis*, using resources locally available in West Texas, when possible, for future application in outdoor production ponds.

MATERIALS AND METHODS

Anaerobically Digested Cattle Waste

All cattle waste used in this study was collected from Lubbock Feedlots, Inc., Lubbock, Texas. A pilot digester system was constructed to prepare anaerobically digested cattle waste (ADCW) for research purposes. The system consisted of four 500-liter fiberglass silos to which 30 liters of cattle waste diluted to 3% volatile solids was added daily to yield a 17-day retention time. The silos were sealed and the liquid agitated by recirculating methane produced as a product of microbial digestion to suspend solids in the digester. The effluent was centrifuged at 1500 x gravity to reduce suspended solids and frozen for storage.

Culture Conditions

Experiments were inoculated from a laboratory stock *S. platensis* culture. This culture was dominated by *S. platensis* but also include some *Oscilatoria* spp., a filamentous blue-green alga. We will refer to cultures as *Spirulina* cultures, even though they were not monoalgal. The laboratory culture was maintained under semi-continuous culture conditions to maintain the cells in an exponential growth phase. This was accomplished by removing a portion of the culture daily and replacing it with an equal amount of fresh medium, while keeping the culture at about 30-35°C under a fluorescent light source.

Replicate cultures were grown in 500-mL Erlenmeyer flasks plugged with cotton to protect cultures from airborne contaminants. Each replicate was maintained at a volume of 200 mL. The flasks were placed on a rotary shaker at 120 revolutions min^{-1} and illuminated at a light intensity of about 0.756 lumen cm^{-1} by fluorescent light in a white light chamber. Light intensity was measured with a Simpson (Elgin, Illinois) model 408 illumination level meter. A diel cycle (16 hours light to 8 hours dark) was maintained by an automatic timer and light chamber temperature ranged from 25-32°C.

Experimental Design

Experiments consisted of four replicates in each treatment category in a completely randomized design (CRD). Each replicate started as 175 mL of the appropriate growth medium and 25 ml from the laboratory stock culture as an inoculum. The 25-mL inoculum in a total volume of 200 mL yielded a starting culture density of 12.5% of the dry weight of the stock culture for each replicate. The cultures were allowed a 48-hour initial growth interval with no sampling occurring.

Fifty milliliters were removed from each replicate for evaluation after 48, 72, 96, 120 and 144 hours. Fresh medium was added to replace the medium that was removed for evaluation and the replicates were placed back on the shaker table. Parameters measured were pH, temperature, and dry weight per volume (mg L^{-1}) of biomass. The pH and temperature were measured with a Cole Parmer (Chicago, Illinois) Model 5986-60 pH and temperature meter. Dry weight was determined by filtering the cells from 25 mL of culture medium through a 0.45-μm membrane filter in a Whatman glass fritted vacuum filtration apparatus. The filters were dried at 105°C overnight and then weighed. Dry weight in milligrams per liter was used to determine growth rate of algae for each replicate as a measure of growth for each 24-hour period.

The daily dry weight and growth rate values were analyzed by analysis of variance (ANOVA) and a Fisher's protected least significant difference (LSD) means separation test to determine significant differences ($P < 0.05$). Also, a standard hemocytometer was used to determine the amount of single celled contaminant algae present in each treatment after 144 hours.

Synthetic Sea Salts

This experiment was conducted to determine the optimum concentration of ADCW in a synthetic sea salt (Instant Ocean; Sarrebourg, France) solution. The experiment consisted of four replicates in each of five treatment categories. All replicates contained 1 g urea L^{-1} , 0.10 g K_2HPO_4 L^{-1} and 6 g $NaHCO_3$ L^{-1} to insure that nitrogen (N), phosphorus (P) and carbon (C) would not be limiting factors for culture of *Spirulina*. Additionally, each replicate contained 8 g synthetic sea salt L^{-1} to yield a salinity, as total dissolved solids, of 15 g L^{-1}. The five experimental treatments were 0 (control), 12.5, 25, 50 and 100% ADCW (% of total volume).

The remainder of the medium was composed of water purified by a 1-μm sediment filter, a 1-μm carbon filter and a 0.05-μm membrane filter. Starting pH was 8.37 for the control replicates, 8.35 for the 12.5% and the 25% ADCW replicates, and 8.33 for the 50% and the 100% ADCW replicates. Stock culture density was 465 mg L^{-1} and 25 mL was used as the starting inoculum. Therefore, the starting culture density was 58 mg L^{-1} for each 200-mL replicate.

Oilfield Brine

This experiment was conducted to determine the feasibility of a *Spirulina* growth medium consisting of diluted oilfield brine and ADCW. The diluted oilfield brine solution consisted of 80% purified fresh water, 10% ADCW, 10% oilfield brine (175 g total dissolved solids L^{-1}) and 100 mg L^{-1} IGP-HCB6 (Industrial Grain Products; Lubbock, Texas), a commercially available product containing petroleum degrading bacteria. The pH was 7.84 and salinity was 20 g L^{-1}. The cattle waste present in the solution served as a nutrient source for the bacteria that were included to degrade residual hydrocarbons present in the brine. The solution was placed on a magnetic stirrer and was aerated at a temperature of 28.5-30.6°C for 48 hours. The solution was then treated with 4 g Na_2CO_3 L^{-1} , which immediately caused the solution to turn milky and flocculate heavily. The suspended, flocculated solids were precipitated with 80 mg $Al_2(SO_4)_3$ L^{-1}, which resulted in a clear, straw-tinted solution with a pH of 7.39 and salinity of 18 g L^{-1}. This solution was treated with an additional 4 g Na_2CO_3 L^{-1} and 80 mg $Al_2(SO_4)_3$ L^{-1} to repeat the flocculation, precipitation process, resulting in a pH of 9.82 and a salinity of 19 g L^{-1}. The solution was filtered through a 0.45-μm membrane filter and stored in a glass aspirator bottle. A growth experiment was performed with this solution serving as the diluent for ADCW. Treatment levels were 0% ADCW (control) and 25% ADCW with the remainder of the growth medium containing diluted oilfield brine solution. There were four replicates for both treatment levels. The treatments were supplemented with urea at 1 g L^{-1}, 0.10 g K_2HPO_4 L^{-1}, and 6g $NaHCO_3$ L^{-1}. Starting pH was 8.87 for the control replicates and 8.88 for the 25% ADCW replicates. Stock culture density was 500 mg L^{-1} and 25 mL was used as the starting inoculum. Therefore, the starting culture density was 62.5 mg L^{-1} for each 200-mL replicate.

RESULTS

Synthetic Sea Salts

After an initial 48-hour growth period, all treatments prepared with synthetic sea salts and ADCW had developed into rapidly growing cultures. Culture dry weight increased as concentration of ADCW increased. There was some decline in daily growth rates in all treatments. However, all treatments, except for the 100% ADCW replicates were growing at a high rate by the completion of the experiment. After 144 hours of culture, all treatments that included ADCW had significantly higher final daily growth rates and dry weights than the control. During the 144-hour period, temperature and pH did not vary with treatment. Treatments, three, four and five all had final dry weights in excess of 1,000 mg L^{-1}. However, growth rate is ultimately the deciding factor for treatment performance. The 25% ADCW and 50% ADCW treatments had significantly higher final growth rates than all the other treatments (Figure 1). Contaminant load (unicellular algae mL^{-1}) after 144 hours of culture were, 6.6 x 10^5 for the control, 8.7 x 10^5 for the 12.5% ADCW treatment, 1.6 x 10^6 for the 25% ADCW treatment, 2.2 x 10^6 for the 50% ADCW treatment and 3.9 x 10^6 for the 100% ADCW treatment.

Diluted Oilfield Brine

Spirulina in control and ADCW treated cultures grew quickly and by the 48-hour point had treatment mean dry weights in excess of 300 mg L^{-1} (Figure 2). Additionally, both peaked for mean daily growth rate after about 72 hours. However, both control and ADCW treated replicates showed a steady increase in growth rate after an initial drop following the growth rate peak. The ADCW treated replicates had a significantly higher final dry weight upon completion of the experiment. Contaminant load (unicellular algae per milliliter) after 144 hours, as determined by a standard hemocytometer count on a pooled treatment sample, was 0 for the control and 4.8 x 10^4 for the treated culture. All growth media used were supplemented for P with 0.10 g K_2HPO_4 L^{-1}. Above this level, formation of a white flocculant occurred in media formulated with synthetic sea salt. No cultures showed signs of P-limited growth, such as change in trichome size or shape.

DISCUSSION

Nutrient Balance

Ideally, the sole limiting factor for an algal culture should be solar irradiance. However, this is seldom the case in any algal culture, since as the biomass increases and is removed from the pond, the macro- and micro-elements required for optimum growth are present in diminished quantities. Therefore, large outdoor cultures should be monitored constantly. Richmond (1986) used the level of nitrogen as a guideline for adding, in equivalent amounts, the entire formula of the growth medium. This is a relatively easy method to maintain a nutrient balance in a food grade algal culture with a defined inorganic medium. However, when animal waste is used to increase the nutrient level, the concomitant increase in organic matter (particulate and dissolved) serves to increase contamination by undesirable biota such as heterotrophic unicellular algae (i.e., *Chlorella spp.*) and their predators (i.e., cladocerans, ciliates, rotifers, etc.). This results in a complicated food chain that leads to either a decrease in the output of the desired species or total loss of the *Spirulina* culture. For a medium that contains all required macro- and micro-nutrients, there is no significant difference between mean daily growth rate for the 25% ADCW treatment and the 50% ADCW treatment even though the 25% treatment had a much lower contaminant load. The treatment with the lower contaminant load should contain more *Spirulina* biomass per unit volume and thus be a more valuable product. To maintain a cattle waste based culture dominated by *Spirulina*, it is important to add organic and inorganic nutrients to supply N, P, and C while keeping the concentration of organic waste as low as possible.

The maximum daily average growth rate of 785 mg L^{-1} is the equivalent of 785 g dry weight m^{-3}. In a commercial production pond of 0.3-m depth, this

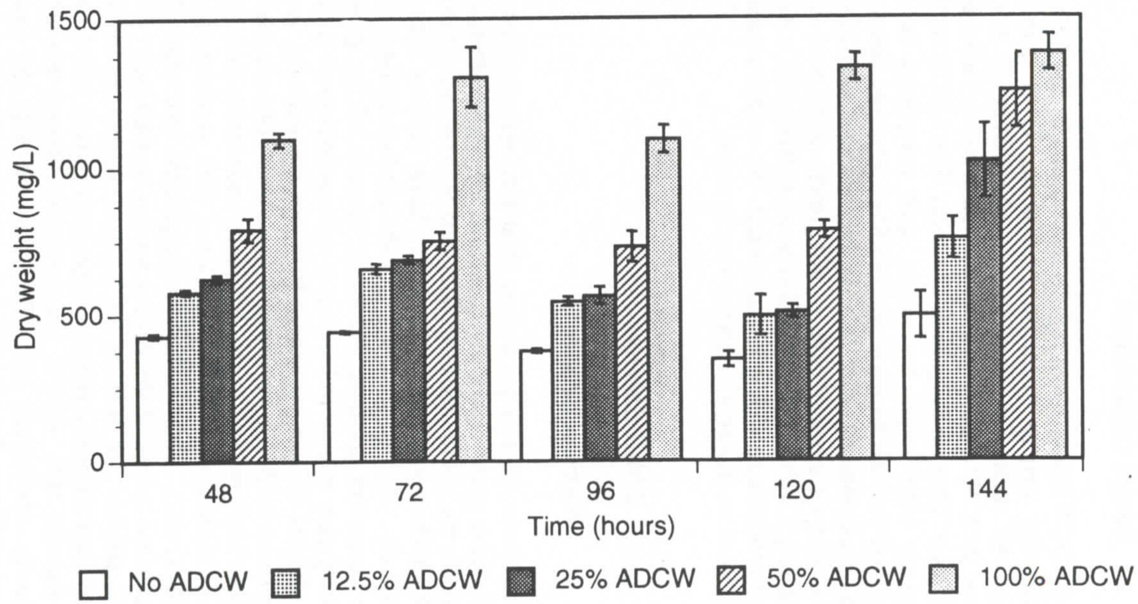

Figure 1. Mean dry weight and standard error (mg L^{-1}, n=4) of *Spirulina* after 48, 72, 96, 120, and 144 hours of culture in growth media formulated with synthetic sea salts and 0, 12.5, 25, 50, and 100% anaerobically digested cattle waste (ADCW). For ADCW of 0%, pH was 9.11-9.15, and temperature was 31.5-32.3°C; for 12.5% ADCW, pH was 9.02-9.22, and temperature was 32.4-32.9°C; for 25% ADCW, pH was 8.92-9.12, and temperature was 33.0-33.4°C; for 50% ADCW, pH was 8.86-8.99, and temperature was 32.2-33.3°C; for 100% ADCW, pH was 8.76-8.87, and temperature was 32.2-34.4°C.

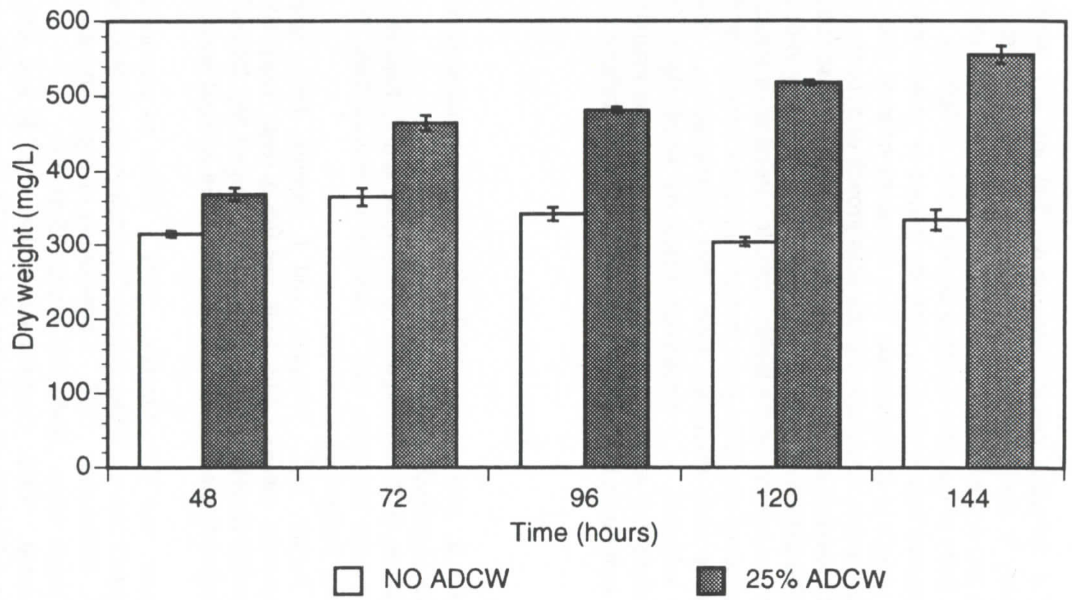

Figure 2. Mean dry weight and standard error (mg L^{-1}, n=4) of *Spirulina* after 48, 72, 96, 120, and 144 hours of culture in growth media formulated with diluted oilfield brine and 0, and 25% anaerobically digested cattle waste (ADCW). For ADCW of 0%, pH was 9.34-9.41, and temperature was 31.3-35.9°C; for 25% ADCW, pH was 9.35-9.47, and temperature was 31.8-36.4°C.

concentration of *Spirulina* would be the equivalent of 235.5 g m^{-2}--well beyond the typical 10-20 g m^{-2} and the extraordinary 54 g m^{-2} achieved by some commercial producers (Richmond & Becker 1986). It is unknown if similar rates can be achieved in large scale production, but at least we know that the biological potential exists if contaminant algae can be controlled.

Recommendations

As the density of a *Spirulina* culture rises above 500 mg dry weight L^{-1}, photosynthetic efficiency is diminished. Therefore, instead of removing a fixed amount of the culture and replacing with fresh medium daily, we recommend that the culture be diluted daily to maintain a culture concentration of 500 mg L^{-1}. Dry weight should be measured before dilution, with the output or growth rate being equivalent to the dry weight in milligrams per liter minus the original 500 mg L^{-1}. This modification in procedure would allow continuous growth of *Spirulina* without the adverse effects of crowding and shading caused by extremely dense cultures.

Outdoor culture of *Spirulina* in diluted oilfield brine will be necessary to determine if *Spirulina* can indeed be cultured in the highly variable natural environment of an outdoor pond and to produce quantities great enough to prepare experimental diets. Laboratory cultures have some protection from gross contamination. However, outdoor cultures are subjected to a continuous attack by weed algae, such as *Chlorella spp*. Therefore, we recommend that outdoor cultures be established to develop management techniques to maintain a dominant *Spirulina* culture.

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Herbicide Efficacy in Peanuts Grown Under Reduced Tillage Systems

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ABSTRACT

The use of reduced tillage systems in peanuts (*Arachis hypogaea* L.) from 1987 to 1989 resulted in weed problems, which in many instances required the use of a postemergence herbicide. When herbicides were applied prior to tillage, Pursuit (imazethapyr) tank-mixed with Roundup (glyphosate) or Gramoxone (paraquat) provided excellent control of southern crabgrass (*Digitaria ciliaris* Koel.) and Palmer amaranth (*Amaranthus palmeri* S. Wats.), while Texas panicum (*Panicum texanum* Buckl.) control was erratic. Under irrigated and rainfed conditions, a postemergence treatment of Poast, (sethoxydim) and Blazer (acifluorfen) provided the most consistent control of annual grasses and broadleaf weeds at six locations in South Texas. Prowl (pendimethalin) + Dual (metolachlor) provided the most consistent control (>85%) of annual grasses and yellow nutsedge (*Cyperus esculentus* L.) when applied immediately before irrigation. When Prowl + Dual was applied 7 days prior to irrigation, annual grass control was reduced by 14 to 16%.

KEYWORDS: strip-tillage, irrigation, rainfed

Peanuts have traditionally been grown in a well-prepared seedbed. Relatively little research has been conducted in peanuts using minimum-tillage production practices compared with other agronomic crops. Part of this lack of interest was due to a perceived need to moldboard-plow to bury crop residues to reduce the possibility of disease problems (Buchanan et al., 1982; Grichar and Boswell, 1986).

The use of minimum- and strip-tillage production practices in corn, grain sorghum, and soybeans has greatly reduced production costs (Adams et al., 1973; Fink and Wesley, 1974; Melville and Rabb, 1976; and Nelson, et al., 1977). These tillage production practices in peanut could result in considerable savings in

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energy, machinery, and labor requirements. Unger et al. (1977) reported that a crop residue on the soil surface could nearly eliminate erosion problems. Musick et al. (1975) reported that a heavy mulch comprised of irrigated wheat could increase soil water storage by 2.5 inches in an 11-month fallow period. The extra soil water could increase subsequent grain sorghum yield by approximately 1000 lb acre^{-1}.

Peanut yields under minimum- and no-tillage management have varied. Wright and Porter (1985) reported that no-tillage peanuts matured later than conventional-tilled peanuts and produced lower pod yields and grade than peanuts produced with conventional-tillage. Colvin et al. (1985) found that peanut yields were higher in several minimum-tillage systems compared with those produced by conventional-tillage methods. He found that peanut grade was not influenced by a minimum-tillage system. Hartzog and Adams (1985) reported that the elimination of deep tillage affected neither yield nor grade.

Varnell et al. (1976) stated that no-till peanuts reduced pod yield and quality. In comparison with conventional cultural practices, no-tillage reduced foliage, pod, and kernel yields by 58, 64, and 62%, respectively. In Texas, researchers (Boswell and Grichar, 1981a; Boswell and Grichar, 1981b; Grichar and Boswell, 1987; and Grichar and Smith, 1989) have reported yield reductions of 400 to 1500 lb acre^{-1} with the no-tillage system as compared with full-tillage, while minimum-tillage has been intermediate in yield.

The strip-tillage peanut production system is a conservation tillage system which offers potential for use by Texas peanut producers. This system offers an opportunity for peanut production on highly erodible soils by reducing wind and water erosion. It also offers the opportunity to cut the number of tillage trips across a field, thus reducing energy and labor inputs to the crop.

Acceptance of conservation tillage in most areas of the US has been hampered by less-than-adequate weed control (Hoefer et al., 1981; Kapusta, 1979; Richey et al., 1977). The introduction of new pre- and postemergence herbicides is beginning to ease weed control problems in soybeans (Elmore, 1987). However, problems with weed control still exist in reduced-tillage peanuts and need to be resolved.

The objectives of this research were to evaluate broadleaf signalgrass, southern crabgrass, Texas panicum, Palmer amaranth, wooly croton (*Croton capitatus* Michx.), and yellow nutsedge control and peanut yields in reduced tillage systems under irrigated and rainfed conditions. Additional studies were set up to evaluate various preemergence herbicides in combination with Roundup or Gramoxone to determine i) herbicide compatibility, ii) the possibility of obtaining burndown of existing vegetation and, iii) residual herbicide activity with preemergence herbicides. The effectiveness of using irrigation to incorporate dinitroaniline herbicides was also investigated.

MATERIALS AND METHODS

These studies were conducted throughout South and Central Texas, in areas where peanuts are normally grown. Oats (*Avena sativa* L.), ryegrass (*Lolium multiflorium* L.), or wheat (*Triticum aestivum* L.) was planted in the fall and allowed to grow to harvest time in the late spring, or shredded to a height of 10 to 12 inches prior to planting of peanuts.

Seedbeds were prepared with a Bush-hog Ro-till (Bush-Hog, Inc., Selma, AL) unit which tilled a 14 to 18 inch wide strip on 36 inch centers. The Ro-Till unit consisted of a subsoil shank which penetrated the soil to a depth of approximately 14 inches. Twin sets of fluted coulters were mounted on either side of these shanks. The subsoiler shank was used to open the soil and destroy any plowpan beneath the row. The fluted coulters were used to smooth the soil and break any large clods. Rolling crumblers mounted immediately behind the fluted coulters further smoothed and shaped the seedbed. The previous crop residue was left intact on the soil surface. Prowl at 1.5 pt acre^{-1} or Treflan (trifluralin) at 1.0 pt acre^{-1} was incorporated into the strip-tilled area during the tillage operation. Peanuts (var. Florunner) were planted at all locations in the prepared strip immediately after tillage at the rate of 90 to 95 lb acre^{-1}.

Existing vegetation in all tests, except for the herbicide combination studies, was killed with Roundup at 3 qt or Gramoxone at 1 to 2 qt acre^{-1}. These were applied either prior to, or immediately after the ro-till operation. Peanuts were then planted into the tillage strip with conventional planters.

Experimental design was a randomized complete block design with a plot length of 25 to 30 feet by two rows wide. Each test was replicated four or five times. All herbicide trials, except for the herbicide combination study, included an untreated check. All field plots had naturally moderate to high weed populations (3 to 8 plants ft^{-2}). Herbicide treatments were applied broadcast with a compressed-air, bicycle sprayer using Teejet (Spraying Systems Co., Wheaton, IL) 11002 flat fan nozzles which delivered a spray volume of 20 gal acre^{-1}.

Visual ratings of weed control were recorded at various intervals throughout the growing season. Ratings were based on a scale of 0 (no control) to 100 (complete weed control), relative to the untreated check. Peanut yields were determined by digging the pods when plants were 140 to 150 days old, air-drying in the field for 4 to 6 days, and harvesting individual plots with a combine. Weights were recorded after soil and trash were removed from samples. Ratings and peanut yields were subjected to an analyses of variance with Duncan's Multiple Range Test at the 5% level of significance.

All tests were irrigated regularly during the growing season except for the dryland trials located in Lee County. Leafspot and insect sprays were applied as recommended by the Extension Service.

Tank Mixes of Preemergence Herbicides with Roundup or Gramoxone

This study involved the use of various preemergence herbicides (Table 1) in tank mixes with Roundup or Gramoxone to determine i) herbicide compatibility, ii) the possibility of obtaining burndown of existing vegetation and, iii) residual herbicide activity with the preemergence herbicide (conducted in Lavaca and Frio Counties). The soil type at the Lavaca County location was a Tremona loamy fine sand (thermic Aquic Arenic Paleustalfs) with less than 1% organic matter. Soil on the producer's farm near Pearsall in Frio County was a Duval fine sandy loam (fine-loamy, mixed, hyperthermic Aridic Haplustalfs) with 1% organic matter. Herbicide treatments included Roundup alone at 1.0 lb ai acre^{-1} or in combination with Lasso (alachlor) at 3.0 lb ai acre^{-1}, Dual at 2.0 lb ai acre^{-1}, Pursuit at 0.094 lb ai acre^{-1}, or Alanap (Naptalam) at 2.0 lb ai acre^{-1}. Gramoxone at 0.75 lb ai acre^{-1} was applied alone or with the above mentioned herbicides.

Table 1. Herbicides evaluated in strip-tillage experiments.

Trade Name	Common Name	Chemical composition
Alanap	Naptalam	2-[(1-naphtalenylamino)carbonyl]benzoic acid
Basagran	bentazon	3-(1-methylethyl)-(1H)-2,1,3-benzothiadiazin-4(3H)-one, 2,2-dioxide
Blazer	acifluorfen	5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid
Butyrac	2,4-DB	4-(2,4-dichlorophenoxy)butanoic acid
Cobra	lactofen	(±)-2-ethoxy-1-methyl-2-oxoethyl 5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoate
Dual	metolachlor	2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)acetamide
Gramoxone	paraquat	1,1'-dimethyl-4,4'-bipyridinium ion
Lasso	alachlor	2-chloro-N-(2,6-diethylphenyl-N-(methoxymethyl)acetamide
Poast	sethoxydim	2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one
Prowl	pendimethalin	N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine
Pursuit	imazethapyr	(±)2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid
Rescue	naptalam+2,4-DB	see above
Roundup	glyphosate	N-(phosphonomethyl)glycine
Tough	pyridate	0-(6-chloro-3-phenyl-4-pyridazinyl S-octyl carbonothioate
Treflan	trifluralin	2,6-dinitro-N,N-dipropyl-4-(trifluoromethyl)benzenamine

Weed Control Under Irrigation

This study evaluated peanut weed control with various herbicides alone and in combination under irrigated conditions (conducted in Atascosa, Frio, and Lavaca counties). Soil in Atascosa County near Pleasanton was a Webb fine sandy loam (fine, mixed, hyperthermic Aridic Paleustalfs) with less than 1% organic matter. The soil type at the Lavaca County location was a Tremona loamy fine sand (thermic Aquic Arenic Paleustalfs) with less than 1% organic matter. Soil at the Frio County location was a Duval fine sandy loam (fine-loamy, mixed, hyperthermic Aridic Haplustalfs) with 1% organic matter. Herbicide treatments included Alanap at 2.0 lb ai acre^{-1} + Dual at 2.0 lb ai acre^{-1}, Alanap at 2.0 lb ai acre^{-1} + Lasso at 3.0 lb ai acre^{-1}, Dual at 1.5 and 3.0 lb ai acre^{-1}, Lasso at 3.0 lb ai acre^{-1}, Prowl alone at 0.75 lb ai acre^{-1} or in combination with Lasso at 3.0 lb ai acre^{-1} or Dual at 1.5 lb ai acre^{-1}, Poast at 0.3 lb ai acre^{-1} plus Blazer at 0.5 lb ai acre^{-1}, Dual at 1.5 lb ai acre^{-1} plus Cobra (lactofen) at 0.2 lb ai acre^{-1}, and Gramoxone at 0.125 lb ai acre^{-1} plus Basagran (bentazon) at 0.5 lb ai acre^{-1}.

Weed Control Under Dryland Conditions

This study evaluated peanut weed control with various herbicides alone and in combination under dryland conditions (conducted in Lee County). The soil in Lee County near Dime Box was a Demona loamy sand (clayey, mixed, thermic Aquic Arenic Paleustalfs) with 1% organic matter. This study included the same herbicide treatments as the weed control under irrigation study with the addition of Prowl at 0.75 lb ai acre^{-1} plus Poast at 0.3 lb ai acre^{-1}.

Weed Control with Incorporation by Irrigation

This study evaluated peanut weed control with Prowl, Treflan, or Prowl + Dual when incorporated with irrigation. Herbicide treatments included Prowl alone at 0.75 lb ai acre^{-1} and 1.0 lb ai acre^{-1}, Prowl at 0.75 lb ai acre^{-1} plus Dual at 2.0 lb ai acre^{-1}, and Treflan at 0.75 and 1.0 lb ai acre^{-1}.

RESULTS AND DISCUSSION

In general, weed control was difficult to obtain with soil applied herbicides in many of the strip-tillage plots, and required use of a postemergence herbicide in order to obtain satisfactory control.

Tank Mixes of Preemergence Herbicides with Roundup or Gramoxone

Roundup and Gramoxone alone provided good initial kill of the small grain cover crop (data not shown). However, the addition of Alanap to Gramoxone resulted in slower activity on existing vegetation. Activity time was doubled when Alanap was added to Gramoxone over that of Gramoxone alone for burndown effects to be seen on small grains (data not shown).

When Roundup or Gramoxone was mixed with a preemergence herbicide, subsequent growth of annual grasses was adequately controlled (>80%) with only a few herbicide treatments as shown by later season ratings (Table 2 and 3). At the Lavaca County location, Roundup or Gramoxone plus Pursuit provided the best overall control of southern crabgrass in 1987 and 1988 (Table 2). Pursuit is the first herbicide to provide residual control of purple (*Cyperus rotundus*) and yellow nutsedge and numerous broadleaf weed species (Grichar et al., 1992; Wilcut et al., 1994). However, many peanut producers are unaccustomed to rotational crop restrictions after Pursuit application (Anonymous, 1992; Wilcut et al., 1991a).

All herbicide combinations provided fair late-season control (66-78%) of broadleaf signalgrass [*Brachiaria platyphylla* (Griseb.) Nash] without any significant differences between herbicide combinations in 1987 (Table 2). In 1988, all herbicide treatments provided less than 70% late season control of broadleaf signalgrass. Work in the Virginia-North Carolina area showed that broadleaf signalgrass control was unacceptable with preplant incorporated (PPI) applications of Balan (benefin), Lasso, or Dual (Chamblee et al., 1982). Full season broadleaf signalgrass control required a PPI application of Balan followed by Dual applied at ground-cracking (Chamblee et al., 1982).

At the Frio County location, in 1987, under light weed pressure, Roundup and Gramoxone alone provided better than 80% control of Texas panicum and Palmer amaranth (Table 3). Addition of Pursuit to Roundup significantly improved Texas panicum control 14% over that of Roundup alone. In 1988, with heavy Texas panicum pressure, Gramoxone plus Lasso provided excellent late-season annual grass control (>90%). In 1988, when Roundup was added to Lasso, Texas panicum control was reduced (21%) from the Gramoxone plus Lasso treatment. Pigweed (*Palmer amaranth*) control in 1987 was greater than 85% with all herbicides (Table 3). In 1988, Roundup plus Pursuit provided up to 27% better pigweed control than other herbicide combinations. Pursuit has been found to be a cost-effective soil-applied herbicide that may reduce reliance on postemergence herbicides for annual broadleaf weed control (Wilcut et al., 1991b).

Peanut yields in 1987 were greater than 3500 lb acre^{-1} with all herbicide treatments. The Roundup + Dual treatment outyielded the Roundup alone treatment by 20% (Table 3). Yields reflect excellent weed control throughout the growing season and lack of problems at digging. Although weeds seriously reduce the yield of peanuts through competition, major losses also occur by weeds interfering with efficient harvesting (Buchanan et al., 1982). A heavy stand of weeds, especially grasses, made this operation almost impossible. The tight fibrous root system of the weeds become entwined with the peanut plant, and when this occurred many peanuts are stripped from the vine during digging operations. Peanuts that become detached from the plant remained unharvested in or on the soil. This harvesting loss was estimated to range from \$6 acre^{-1} in Alabama to \$15 acre^{-1} in Oklahoma and South Carolina (Wilcut et al., 1994).

Weed Control Under Irrigation

Various herbicides alone and in combination were evaluated for weed control in Frio, Atascosa, and Lavaca counties in 1988 and 1989 (Table 4). At all locations, the most consistent control was obtained with a postemergence application of Poast plus Blazer. Control was greater than 90% for Texas panicum, broadleaf signalgrass, Wooly croton and pigweed species when Poast and Blazer were applied

Table 2. Percent annual grass weed control† with a strip-tillage system in Lavaca County using various herbicide combinations applied prior to planting of peanuts.

Treatment	Rate	1987 (11 WAT)‡		1988 (15 WAT)	
		Southern crabgrass	Broadleaf signalgrass	Southern crabgrass	Broadleaf signalgrass
	lb ai acre^{-1}				
Roundup	1.0	0 d§	0 b	0 e	0 c
Gramoxone¶	0.75	0 d	0 b	0 e	0 c
Roundup + Lasso 4E	1.0 3.0	58 c	72 a	63 bc	52 ab
Roundup + Dual 8E	1.0 2.0	60 bc	70 a	67 bc	45 ab
Roundup + Pursuit 2AS	1.0 0.094	81 a	66 a	95 a	65 a
Roundup + Alanap L	1.0 2.0	63 bc	78 a	53 cd	47 ab
Gramoxone + Lasso 4E	0.75 3.0	54 c	70 a	55 cd	42 ab
Gramoxone + Dual 8E	0.75 2.0	60 bc	72 a	75 abc	37 b
Gramoxone + Pursuit 2AS	0.75 0.094	72 ab	74 a	89 b	66 a
Gramoxone + Alanap L	0.75 2.0	61 bc	74 a	32 d	31 b

†Control index: 0=no control; 100=complete control.
‡WAT=weeks after preemergence treatment.
§Means followed by the same letter are not significantly different at the 5% level of significance (Duncan's Multiple Range Test).
¶All Gramoxone treatments included a non-ionic surfactant (X-77) added at the rate of 4 oz acre^{-1}.

Table 3. Percent weed control† and 1987 peanut yield with a strip-tillage system in Frio County using various herbicide combinations applied prior to planting of peanuts.

Treatment	Rate	1987 (15 WAT)‡ Texas panicum	1987 (15 WAT)‡ Palmer amaranth	1988 (11 WAT) Texas panicum	1988 (11 WAT) Palmer amaranth	yield
	lb ai acre^{-1}					lb acre^{-1}
Roundup	1.0	83 b§	87 a	0 e	0 d	3728 bc
Gramoxone¶	0.75	90 ab	96 a	0 e	0 d	3978 abc
Roundup + Lasso 4E	1.0 3.0	95 ab	92 a	70 b	67 abc	3882 abc
Roundup + Dual 8E	1.0 2.0	91 ab	100 a	65 bc	62 bc	4463 a
Roundup + Pursuit 2AS	1.0 0.094	97 a	97 a	65 bc	87 a	4273 ab
Roundup + Alanap L	1.0 2.0	95 ab	96 a	50 cd	70 abc	4377 ab
Gramoxone + Lasso 4E	0.75 3.0	95 ab	100 a	91 a	76 abc	3936 abc
Gramoxone + Dual 8E	0.75 2.0	93 ab	97 a	45 d	70 abc	3541 c
Gramoxone + Pursuit 2AS	0.75 0.094	88 ab	98 a	62 bc	85 ab	3945 abc
Gramoxone + Alanap L	0.75 2.0	90 ab	95 a	57 bcd	60 c	4247 ab

†Control index: 0=no control; 100=complete control.
‡WAT=Weeks after preemergence treatment.
§Means followed by the same letter are not significantly different at the 5% level of significance Duncan's Multiple Range Test).
¶All Gramoxone treatments included a non-ionic surfactant (X-77) added at the rate of 4 oz acre^{-1}.

Table 4. Percent weed control[†] under a strip-tillage system with irrigation.

			1988			1989		
			Frio Co. (16 WAT)[‡]		Atascosa Co. (11 WAT)	Frio Co. (13 WAT)		Lavaca Co. (13 WAT)
Treatment	Rate	Appl. Time	Texas panicum	Wooly croton	Texas panicum	Texas panicum	Pigweed Spp.	Broadleaf Signalgrass
	lb ai acre^{-1}							
Check	-	-	0 d[§]	0 e	0 f	0 c	0 b	0 f
Alanap L+Dual 8E	2.0+2.0	Pre	76 bc	86 abc	30 cde	99 a	97 a	70 bc
Alanap L+Lasso 4E	2.0+3.0	Pre	76 bc	77 bcd	32 cde	99 a	98 a	30 ef
Dual 8E	1.5	Pre	70 c	8 abcd	15 ef	95 ab	100 a	36 e
Dual 8E	3.0	Pre	76 bc	6 bcd	37 bcde	98 a	99 a	66 bcd
Lasso 4E	3.0	Pre	70 c	72 cd	43 bcd	98 a	100 a	42 de
Prowl 4E	0.75	Pre	73 bc	65 d	52 bc	98 a	96 a	10 fg
Prowl 4E+Lasso 4E	0.75+3.0	Pre	80 bc	85 abc	58 b	99 a	100 a	45 cde
Prowl 4E+Dual 8E	0.75+1.5	Pre	88 ab	78 abcd	42 bcd	98 a	100 a	38 e
Poast 1.5E/ Blazer 2L[¶]	0.3/ 0.5	Post	93 a	97 a	97 a	98 a	100 a	97 a
Dual 8E+Cobra 2EC	1.5+0.2	Pre	83 abc	93 ab	27 de	92 b	97 a	51 bcde
Gramoxone+ Basagran 4E[#]	0.125+ 0.5	Post	72 bc	75 bcd	41 bcd	99 a	100 a	74 b

†Control index: 0=no control; 100=complete control.
‡WAT=weeks after preemergence treatment.
§Means followed by the same letter are not significantly different at the 5% level of significance (Duncan's Multiple Range Test).
¶Crop oil (Agridex) added at the rate of 1 qt acre^{-1}.
#Non-ionic surfactant (X-77) added at the rate of 4 oz acre^{-1}.

early in the growing season (weeds were less than 4 inches tall). Poast controls annual and perennial grasses but lacks residual control (Grichar and Boswell, 1986; Grichar and Boswell, 1989; Wilcut et al., 1994). Poast is most active if the grass weeds are not moisture stressed when treated (Wilcut et al., 1994). Blazer is widely used in the Virginia-North Carolina and the southwestern peanut regions of the US (Wilcut et al., 1994). Blazer controls many broadleaf weeds found in peanuts (Buchanan et al., 1982; Wilcut et al., 1994). Common lambsquarters (*Chenopodium album*), common ragweed (*Ambrosia artemisiifolia*), eclipta (*Eclipta prostrata*), pigweed species (*Amaranthus* spp.), and tropic croton (*Croton glandulosus*) are controlled with Blazer (Buchanan et al., 1982; Wilcut, 1991; Wilcut et al., 1994). Timeliness of application is critical for maximum efficacy, yields, and net returns (Buchanan et al., 1982; Wilcut and Swann, 1990).

Weed Control Under Dryland Conditions

Texas panicum control in 1988 was greater than 70% with all herbicide combinations (Table 5). Moisture conditions were excellent at planting and early in the growing season, but very little rain fell later in the season (less than 14 inches of rainfall from planting until peanut harvest).

In 1989, Prowl applied PPI followed by Poast applied postemergence (POST) and the POST treatment of Poast and Blazer provided excellent control of broadleafs and annual grasses (>85%). Prowl controlled Texas panicum 47%, while Prowl followed by Poast resulted in a 46% increase in grass control. Prowl alone did not effectively control wooly croton (*Croton capitatus*) or silverleaf nightshade (*Solanum elaeagnifolium*).

Peanut yields reflect the importance of reducing weed populations when moisture conditions are less than ideal. In both years, the POST treatment of Poast and Blazer produced the significantly highest yields (Table 5). Peanut yields with Poast and Blazer were increased by 38% and 163% in 1988 and 1989, respectively, over the untreated check. Poor overall yields in 1989 were the result of virtually no rainfall after peanuts were planted (less than 8 inches of rain during the growing season).

Weed Control with Incorporation by Irrigation

The need to incorporate dinitroaniline herbicides used in peanuts was the objective for this study conducted in 1989. The Prowl label states that it must be incorporated within 7 days of application (Anonymous, 1992). However, since hot and windy weather conditions are usually prevalent in South Texas during peanut planting, it was felt that this interval would not be acceptable to provide adequate weed control (authors personal observations). Herbicides were applied up to 7 days prior to irrigation to determine residual activity of Prowl, Treflan, or Prowl in combination with Dual.

Southern crabgrass control was better with Prowl and Treflan when applied immediately ahead of irrigation (0 day). As the time interval between herbicide application and irrigation increased, southern crabgrass control decreased (Table 6). With broadleaf signalgrass, the control was less than 60% with Prowl or Treflan. The interval between herbicide application and irrigation had no effect on signalgrass control. When Prowl and Dual were tank-mixed, control of broadleaf signalgrass

Table 5. Percent weed control[†] and peanut yield with a strip-tillage system in Lee County under dryland conditions.

			1988 (17 WAT)[‡]	1989 (12 WAT)		Yield	
Treatment	Rate	Appl Time	Texas panicum	Texas panicum	Broadleafs[§]	1988	1989
	lb ai acre^{-1}					lb acre^{-1}	
Check	-	-	0 d[¶]	0 e	0 c	761 ab	176 ab
Alanap L+Dual 8E	2.0+2.0	Pre	85 abc	45 bcd	91 a	747 ab	268 ab
Alanap L+Lasso 4E	2.0+3.0	Pre	95 ab	57 b	86 a	626 b	205 ab
Dual 8E	1.5	Pre	81 abc	48 bcd	90 a	910 ab	183 ab
Dual 8E	3.0	Pre	86 abc	40 bcd	90 a	816 ab	108 b
Lasso 4E	3.0	Pre	76 bc	42 bcd	93 a	736 ab	150 b
Prowl 4E	0.75	Pre	92 abc	47 bcd	66 b	684 ab	183 ab
Prowl 4E+Lasso 4E	0.75+3.0	Pre	90 abc	50 bcd	85 a	689 ab	225 ab
Prowl 4E+Dual 8E	0.75+1.5	Pre	73 c	52 bc	92 a	776 ab	271 ab
Poast/Blazer[#]	0.3/0.5	Post	98 a	88 a	98 a	1043 a	463 a
Gramoxone + Basagran[††]	0.125+0.5	Post	94 ab	20 de	96 a	706 ab	102 b
Dual 8E+Cobra 2EC	3.0+0.2	Pre	77 bc	25 cde	95 a	584 b	160 b
Prowl 4E/Poast	0.75/0.3	Pre/Post	-	93 a	87 a	-	331 ab

[†]Control index: 0=no control; 100=complete control.
[‡]WAT=weeks after preemergence treatment.
[§]Broadleafs=Mixed stand of wooly croton and silverleaf nightshade.
[¶]Means followed by the same letter are not significantly different at the 5% level of significance (Duncan's Multiple Range Test).
[#]Crop oil (Agridex) added at the rate of 1 qt acre^{-1}.
[††]Non-ionic surfactant (X-77) added at the rate of 4 oz acre^{-1}.

Table 6. Weed control[†] with Herbicide incorporation of Prowl, Treflan, and Dual with irrigation in Lavaca County in 1989.

Treatment	Rate	Appl time[§]	% Control (6 WAT)[‡] Broadleaf signalgrass	Southern crabgrass	Yellow nutsedge	Peanut yield
	lb ai $acre^{-1}$					lb $acre^{-1}$
Check	-	-	0 e[¶]	0 e	0 c	912 cd
Prowl 4E	0.75	0 day	25 de	67 abc	0 c	1075 bcd
Prowl 4E	1.00	0 day	45 bcd	67 abc	0 c	1147 bcd
Prowl 4E	0.75	2 day	32 cde	53 bcd	0 c	944 bcd
Prowl 4E	1.00	2 day	37 cde	61 bcd	0 c	1145 bcd
Prowl 4E	0.75	4 day	32 cde	58 bcd	0 c	1090 bcd
Prowl 4E	1.00	4 day	45 bcd	47 bcd	0 c	1068 bcd
Prowl 4E	0.75	7 day	35 cde	37 cd	0 c	996 bcd
Prowl 4E	1.00	7 day	41 bcd	32 d	0 c	852 d
Treflan 4E	0.75	0 day	35 cde	52 bcd	0 c	1260 abcd
Treflan 4E	1.00	0 day	57 abcd	81 ab	0 c	1505 abcd
Treflan 4E	0.75	2 day	32 cde	57 bcd	0 c	1095 bcd
Treflan 4E	1.00	2 day	30 de	60 bcd	0 c	1052 bcd
Treflan 4E	0.75	4 day	37 cde	37 cd	0 c	1088 bcd
Treflan 4E	1.00	4 day	30 de	52 bcd	0 c	1218 abcd
Treflan 4E	0.75	7 day	30 de	40 cd	0 c	846 d
Treflan 4E	1.00	7 day	50 abcd	57 bcd	0 c	1001 bcd
Prowl 4E+ Dual 8E	0.75 2.0	0 day	85 a	95 a	88 a	1708 ab
Prowl 4E+ Dual 8E	0.75 2.0	2 day	86 a	95 a	80 ab	1917 a
Prowl 4E+ Dual 8E	0.75 2.0	4 day	77 ab	79 ab	71 b	1658 abc
Prowl 4E+ Dual 8E	0.75 2.0	7 day	71 abc	79 ab	77 ab	1622 abcd

†Control index: 0=no control; 100=complete control.
‡WAT=weeks after preemergence treatment.
§Application time denotes interval between herbicide application and irrigation.
¶Means followed by the same letter are not significantly different at the 5% level of significance (Duncan's Multiple Range Test).

and southern crabgrass improved considerably. Also, this combination provided greater than 70% yellow nutsedge control. Yields reflected the competitive nature of the annual grasses. The Prowl plus Dual treatments provided a 78 to 110% yield increase over the untreated check.

These studies indicated that excellent weed control is possible in a reduced tillage system. However, a greater herbicide input is required. This included the use of postemergence herbicides to provide season long weed control. Presently cleared preemergence herbicides, which were effective in reduced tillage systems, did not provide full season control when used alone.

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