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Suitability of Biodiesel from Winter Safflower on the Southern High Plains

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ABSTRACT

Winter safflower is considered a potential feedstock for biodiesel production that can be grown on the Texas High Plains. It requires fewer inputs than current irrigated crops, and could be grown on semi-arid or marginal land. The potential of winter safflower for biofuel production is analyzed using a life-cycle assessment of the energy inputs and greenhouse gas (GHG) emission impacts during the seed and biodiesel production processes. In addition, this study identifies the factors that have the greatest impact on GHG emissions and the likelihood that winter safflower would be adopted by farmers on the High Plains. Finally, a safflower production model that includes GHG emissions was developed, and this model was used to determine how potential GHG emissions policies might change resource use by farmers. It was found that expected carbon prices are not likely to affect demand for irrigation by safflower farmers.

KEY WORDS: winter safflower, life-cycle greenhouse gas emission, biofuel

INTRODUCTION

The increasing emission of greenhouse gases (GHG), like carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) has raised great concerns about potential global warming effects, which has led to recognition of the need to reduce anthropogenic GHG emissions worldwide. Transportation through the combustion of fossil fuels is a major source of GHG emissions, accounting for about 26% of total U.S. greenhouse gas emissions in 2010 (EPA 2010). Biofuel derived from biomass is often advocated as a significant contributor to possible solutions to the need for a sustainable transportation fuel. Such a substitution immediately addresses the issue of reducing the use of non-renewable resources like fossil fuels and the impact on climate change, especially carbon dioxide and the resulting greenhouse effect. However, biofuels must be derived from feedstocks produced with much lower life-cycle GHG emissions than traditional fossil fuels and with little or no competition with food production if biofuel use is to realize local environmental and societal benefits (Tilman et al. 2009).

Winter safflower is a potential feedstock for biodiesel production that could be grown on the Texas High Plains. It requires fewer inputs in terms of irrigation and fertilizer than current irrigated crops, and could be grown on marginal or semi-arid land. Use and development of winter safflower biodiesel is believed to reduce GHG emissions.

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In addition, it could also benefit agricultural economies by providing an important new source of income for farmers while lowering dependence on fossil fuel supplies. However, the production of winter safflower requires fossil fuel inputs and emits greenhouse gases. Thus, it is crucial to measure the greenhouse gas emissions over the entire life-cycle of biodiesel production to assess the overall environmental benefits. Generally, the less a biofuel depends on fossil energy, the more potential it has for diversifying the total fuel supply. On the other hand, the degree to which a biofuel relies on fossil energy for its production is one of many criteria that may be used by policymakers and others to evaluate and compare various biofuels.

This report presents a life-cycle assessment (LCA) of the energy inputs and GHG emission impacts of safflower biodiesel relative to those of petroleum diesel and gasoline. The LCA of safflower biodiesel is a cradle-to-grave analysis of the energy and environmental impacts of making a product, which provides a tool to quantify the total required energy from different sources and the overall energy efficiency of safflower biodiesel production processes. This analysis estimates the consumption of total energy, fossil energy, petroleum oil and emissions of GHGs. The LCA of safflower biodiesel in this analysis accounts for emissions in four stages of production:

(1) feedstock cultivation, including energy inputs to produce fertilizer and other chemicals, safflower farming and harvest;
(2) feedstock transportation from farms to processing plants;
(3) oil extraction and biodiesel conversion; and
(4) biodiesel distribution from plants to refueling stations.

The report assumes a hexane extraction method to extract oil from safflower seeds, and transesterification is used to convert oil into biodiesel. Oil extraction and transesterification result in the production of two important coproducts, meal and crude glycerin, respectively, and a mass-based allocation method is used to account for the energy associated with co-products. This method is commonly used because it is easy to apply and provides reasonable results (Vigon et al. 1993). Next, the influence of individual parameters on the overall study results is determined through several sensitivity analyses. The four selected parameters are yield, fertilizer usage, irrigation levels, and transportation distances. Each set of parameters is tested individually, while the others are held at their base case values. In response to governmental policies which aim to reduce GHG emissions, profit-maximizing famers will shift toward biofuel crops cultivation when profits from biofuel crops exceed profits from production of food crops. For example, in response to instruments that make energy sources with low GHG emissions increasingly profitable, such as biofuels, farmers will profit from this increase in relative price of biofuel crops. The final step in this analysis is to analyze farmers' production decisions corresponding to different carbon policies. In order to do that, a production function of safflower and GHG emissions are developed, as well as a related profit function to evaluate possible incentives to change behaviors.

METHODS AND PROCEDURES

This section describes the methods and data used to construct the four stages of the biodiesel life-cycle: feedstock cultivation, feedstock transportation, oil extraction with biodiesel conversion, and product distribution.

Feedstock Cultivation. According to Lai (2004), production, formulation, storage, distribution of carbon-based inputs, and application with tractorized equipment lead to combustion of fossil fuel and use of energy from alternate sources, which also emits CO_2 and other GHGs into the atmosphere. Table 1 below lists the energy required (on a per-acre basis) for safflower seed production. The energy used for planting the seed and other farm activities, such as land preparation, fertilizer and pesticide application, irrigating, and harvesting is included in total farm fuels and electricity estimates. The fuel required for hauling the safflower after harvest is also included in the fuel estimates. The farm input data for safflower production were obtained through crop trials conducted at Texas Tech University (Oswalt, 2008), which were the most recent data available at the time of this study. In addition, all energy inputs were converted to British thermal units (Btu) using low-energy heating values.

Table 1. Annual energy requirements for agricultural inputs before allocating coproduct credits.

Inputs	Usage	Energy Required (Btu/gal)
Urea	50.00 (Lbs/acre)	878.12
Diesel	3.84 (Gal/acre)	7,250.15
Electricity	130.84 (kWh/acre)	6,508.75
Herbicides	1.50 (Lbs/acre)	2,504.81
Total		17,141.83

Crop systems emit N_2O directly, produced through nitrification and denitrification in the cropped soil, and also indirectly, when N is lost from the cropped soil as some form other than N_2O (that is, NO_x, NH_3, or NO_3) and later converted to N_2O off the farm (Adler et al.,2007). Thus, estimation of direct and indirect N_2O emissions from safflower farming requires two important parameters: the amount of nitrogen from fertilizer application and the amount of nitrogen in the aboveground biomass left in the field after harvest and in the belowground biomass (i.e., roots).

According to IPCC (2006) estimates, aboveground biomass for safflower is 91% of the yield (on a dry-matter basis). Aboveground biomass has a nitrogen content of 0.8%. Belowground biomass is about 19% of aboveground biomass, with a nitrogen content of 0.8%. The total amount of nitrogen in safflower biomass that is left in fields per acre of safflower harvested is calculated as shown in the following equation[1]:

*2000 lbs/acre * 85% (dry matter content of safflower) * (91%* 0.8% + 19% * 0.8%) = 14.96 lb N/acre.* *(1)*

IPCC (2006) sets the default value at 1% of N applied to soils for direct N_2O emissions from soil. On the other hand, to estimate indirect N_2O emissions, two additional emission factors are required: one associated with volatilized and re-deposited N, and the second associated with N lost through leaching or runoff. According to the IPCC (2006) estimate, the fractions of N that are lost through volatilization is 10%, with a range of 3-30%. The emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces is 1%, with a range of 0.2-5%. The fraction of N losses by leaching and runoff is estimated to be 30%, with a range of 10-80%. The other emission factor of leached and runoff nitrogen to N in N_2O emissions is 0.75%, with a range of

0.05–2.5%. Thus, the total direct and indirect N_2O emissions (in carbon equivalent) from managed soils are calculated as follow[2]:

*14.96 lb N/acre * (1% + 10% * 1% +30% * 0.75%) * 44/28 = 0.31 lbs/acre. (2)*

Adding urea to soils during fertilization leads to a loss of CO_2 that was fixed in the industrial production process, and it is estimated by[3]:

*50 lbs/acre * 0.20 * 44/12 =36.67 lbs/acre (3)*

where 0.20 represents an overall emission factor for urea (IPCC, 2006).

Feedstock Transportation. To estimate energy requirements and GHG emissions from the transport of safflower seeds from the fields on the Southern High Plains of Texas to biodiesel conversion facilities, we assume the average energy used for transporting is 1.13 MJ per kg of safflower seeds (Sheehan et al. 1998). The estimation was based on the total distance of 320 miles, which includes the distance for trucking safflower seeds from the field to the nearest biodiesel conversion facilities located in Dallas, TX, and the distance to get the biodiesel to its final destination.

Biodiesel Production. The production of biodiesel from safflower seeds occurs in two stages: seeds are first treated to remove the oil, and then the oil is converted into biodiesel. The first stage, the removal of the oil from the safflower seeds, is often called crushing, and the most common method used to convert the oil into biodiesel is a process known as transesterification.

Oil Extraction. Safflower seeds contain 28% oil by weight. Two main methods used for extraction of the safflower seed oil are identified as mechanical extraction and solvent extraction, and the latter is more commonly used. The standard solvent extraction process uses n-hexane that is produced from petroleum. Most of the n-hexane used in oil extraction is recovered and recycled, with some inevitable loss (Huo et al. 2008). After extraction, the oil is filtered through a filter press and is then ready for the conversion to bio-diesel.

Table 2 presents the inputs required for the extraction of safflower seed oil using a continuous solvent extraction process. Due to a lack of availability of data on safflower seed-specific extraction processes, this study uses proxy data for the continuous solvent extraction of oil from multiple bio-feedstocks using hexane as the solvent (Whitaker and Heath 2009). It is assumed that the oil is extracted via solvent extraction with an efficiency of 95%.

Table 2. Fossil energy requirements for safflower seed oil extraction before allocating coproduct credits, per ton of input.

Inputs	Equivalent Energy Required	Units
Electricity	50	kWh
Hexane	8	lbs
Steam	560	lbs
Water	2876	gal

Transesterification. Transesterification is the process used to make biodiesel fuel, which is the reaction of a fat or oil with an alcohol to form esters and glycerol in the presence of a catalyst. Methanol and ethanol are used most frequently among all alcohols that can be used in the transesterification process, especially methanol because of its low cost and its physical and chemical advantages (Ma and Hanna, 1999). After biodiesel is derived, the remaining material is then distilled to recover the methanol and most of the water which are reused to avoid waste and reduce input costs. The glycerin is also refined to be used in the production of various other products (Pradhan et al. 2009).

Natural gas and electricity are required as energy inputs during the transesterification process, and the data used in this study is based on a comprehensive survey by the National Biodiesel Board (NBB) of its 230 member companies from biodiesel production in the U.S. (National Biodiesel Board, 2009), since no published data was found for the methanol-based biodiesel transesterification safflower seed oil. The data provided by the survey represent the most accurate depiction of the energy used to produce biodiesel, and are intended to replace all data currently in use for the modeling of the life-cycle GHG and energy impacts of biodiesel production in the U.S. The survey returned one data set that represents the industry average for transesterification of all biodiesel feedstocks used in the survey results, the inputs required during extraction, the recovery of the excess methanol, and treatment of the glycerin are listed in Table 3.

Table 3. Base case data inputs for methanol-based biosiesel transesterification via safflower seed oil, per ton of biodiesel.

Inputs	Equivalent Energy Required	Units
Safflower Seed Oil	2120	lbs
Electricity	57	kWh
Natural Gas	1.12	MJ
Methanol	196	lbs
Sodium Methylate	50	lbs
Sodium Hydroxide	1.98	lbs
Potassium Hydroxide	0.14	lbs
Hydrochloric Acid	56	lbs
Sulfuric Acid	0.28	lbs
Citric Acid	0.74	lbs
Glycerin Output	248	lbs

Calculating Co-product Credits for Biodiesel. The energy used to produce the meal portion and the crude glycerin that is produced during the transesterification stage must be excluded from the life-cycle assessment. Sheehan et al. (1998) used a mass-based allocation method in their study to allocate total energy used to only the production of soybean biodiesel. We choose this method because it is easy to apply and provides reasonable results, which simply allocates energy to the various co-products by their relative weights. Thus, the energy used to produce biodiesel can be calculated in the following way: Energy input allocation for biodiesel = $E_1f_1 + E_2f_2 + E_3$ *(4)*
where E_1 is energy input for agriculture, safflower seeds transport and crushing; f_1 is the mass fraction of safflower seeds oil used to produce biodiesel; E_2 is the energy used during transesterification; f_2 is mass fraction of the transesterified oil used to produce biodiesel; and E_3 is energy input for biodiesel transport.

According to personal contact information, 28% of the total energy used for safflower agriculture, transport, and crushing is allocated to the oil used to make biodiesel, and 72%is allocated to the meal. Following transesterification, 90.6%of the total energy used to convert safflower seed oil into biodiesel is allocated to biodiesel and 9.4%is allocated to glycerin. In addition, the coproduct energy value of glycerin must be deducted from safflower agriculture, crushing, and transport, so that f_1 in equation (1) = 0.254 = (0.28 * 0.906), and f_2 = 0.906. All the energy used to transport biodiesel is allocated to biodiesel.

RESULTS

The results for safflower seed-derived biodiesel are compared to the baseline fuel, conventional petroleum diesel, based on three metrics: net changes in life-cycle GHG emissions, net energy value (NEV), and the net energy ratio (NER).

Net Energy Value and Net Energy Ratio. Two widely used types of energy efficiency are reported here. NEV is the difference between the energy output of the final biodiesel product and the fossil energy required to produce the biodiesel. A positive NEV indicates that this biofuel has a positive energy balance. NER is defined as the ratio of the final fuel product energy to the amount of fossil energy required to make the fuel, which identifies the degree to which a given fuel is or is not renewable. The base case energy requirements for safflower seed-derived biodiesel are presented in Table 4. After allocating energy by co-products, the total energy required to produce a gallon of biodiesel is 18,410 Btu. The NEV is about 99,886 Btu per gallon. The estimated NER is 6.4.

Table 4. Base case energy use for biodiesel and adjusted by energy efficiency factors.

Life-Cycle Inventory	Fossil Energy Use (Btu/gal of Biodiesel)	
	Total	Biodiesel Fraction
Feedstock Cultivation	17,142	4,800
Safflower Seeds Transport and Biodiesel Distribution	8,507	2,382
Safflower Seeds Oil Extraction	26,534	7,430
Biodiesel Conversion	4,192	3,798
Total Energy Input for Biodiesel Adjusted for Co-products		18,410
Biodiesel Total Energy Content		118,296
Net Energy Value (Btu Out – Btu In)		99,886
Net Energy Ratio (Btu Out/Btu In)		6.4

From a policy perspective, these are important considerations. Policy makers want to understand the extent to which a fuel increases the renewability of the energy supply. The estimated NEV and NER indicate that the safflower seed biodiesel production process generates more energy than it requires, and, in that sense, is sustainable. Another implication of the NER is the question of the effects on climate change of safflower seed biodiesel production. Specifically, it implies that higher fossil energy ratios imply lower net CO_2 emissions (Sheehan et al. 1998).

GHG Emissions. Table 5 presents CO_2-equivalents of GHGs (including CO_2, CH_4 and N_2O) emitted during the irrigated production of safflower seed-derived biodiesel. In addition, considering that safflower has the potential to be planted on non-irrigated cropland (14 inches of growing season rainfall are assumed), where irrigation infrastructure is typically not available, it is meaningful to examine the CO_2-equivalents of GHGs emitted when no irrigation is applied. The results are displayed in Table 6.

Table 5. CO_2 -equivalents of GHG emissions for biodiesel derived from irrigated safflower and adjusted by energy efficiency factors.

Activities	CO_2 Emissions *(kg CO_2 /mmBTU)*
Feedstock Cultivation	6.66
Safflower Seeds Transport and Biodiesel Distribution	1.12
Oil Extraction and Biodiesel Conversion	13.87
Total	21.65

Table 6. CO_2 -equivalents of GHG emissions for biodiesel when irrigation is not required.

Activities	CO_2 Emissions *(kg CO_2 /mmBTU)*
Feedstock Cultivation	3.42
Safflower Seeds Transport and Biodiesel Distribution	1.12
Oil Extraction and Biodiesel Conversion	13.87
Total	18.41

To clearly show the GHG reduction benefit of safflower biodiesel, Table 7 presents the changes in GHG emissions of the biodiesel relative to petroleum diesel, and shows that safflower seed-derived biodiesel production and use reduces net life-cycle greenhouse gas emissions by approximately 78% in the U.S. compared with conventional diesel. As indicated by the results, base case LCA calculations indicate that biodiesel produced from safflower seeds will lead to reduction of greenhouse gas and petroleum consumption compared with petroleum diesel. As outlined in the Energy Independence and Security Act of 2007, safflower seed biodiesel qualifies as an “advanced biofuel” and as a “biomass-based diesel,” and would qualify to meet fuel standards in those categories in the United States. In addition, a recent life-cycle GHG emissions was conducted for soybean biodiesel (Pradhan et al. 2012). This study reported that soybean biodiesel reduced GHG emissions by 81.2% compared to petroleum diesel, which is slightly higher than the 78% GHG reduction of safflower-based biodiesel. Thus, it is considered that winter safflower is still a promising energy crop especially in places lack of water irrigation.

Table 7. Life-cycle GHG emissions for safflower-based biodiesel and petroleum diesel.

Fuel	CO_2 Emissions (kg CO_2/mmBTU)	Percent Change from Diesel
Diesel	97	----
Safflower-based Biodiesel	21.65	-78%

The data on life-cycle GHG emissions for diesel were obtained from U.S. (2010).

Sensitivity analyses. Several sensitivity analyses were conducted to determine the influence of individual parameters on the overall study results. The base case scenario focuses on existing agricultural technology and transportation distance of winter safflower within a short-term time horizon. However, sensitivity analysis allows to consider the potential for near-term improvements. The four selected input parameters are crop yield (that is, pounds of safflower seed per acre), fertilizer usage, irrigation levels, and transportation distances. Each parameter is tested individually while others are held at their base case values. The results identify which input parameters have the greatest impact on the net life-cycle GHG emissions.

According to Whitaker and Heath (2009), the normalized local sensitivity coefficient (known as elasticity) can be interpreted as the fractional change in model output resulting from a percentage change in model input. Equation 5 represents the calculation of the normalized local sensitivity coefficient (dimensionless):

$$(\partial C_j / C_j) / (\partial \lambda_i / \lambda_i) = (\lambda_i / C_j) * (\partial C_j / \partial \lambda_i) \quad (5)$$

where, C is the set of model output or total GHG emissions per gallon of biodiesel determined as described above, *j* representing a specific output, and λ is the set of model input parameters, with *i* representing a specific input parameter. The influence of an individual parameter on model results is indicated by the absolute magnitude of the coefficient. Coefficients with absolute magnitudes of greater than one indicate that a percentage change in the input parameters will lead to a greater percentage change in the model output. Coefficients less than one indicate parameters with a relatively insignificant impact on overall model results. The results of normalized local sensitivity coefficients displayed in Table 8 identify yield as the parameter with the greatest influence on life-cycle GHG emissions, followed by irrigation level. However, absolute values of all these coefficients are less than one, indicating that model outputs are less sensitive to these parameters. Safflower yield has a negative normalized local sensitivity coefficient which indicates a negative relationship between yield and life-cycle GHG emissions. If safflower yield per acre increases from the base case value, life-cycle GHG emissions of safflower-based biodiesel will decrease. In contrast, an increase in irrigation level will lead to an increase in life-cycle GHG emissions as indicated by the positive local sensitivity coefficient. Results of normalized local sensitivity coefficients indicate that fertilizer and transport distance have relatively minimal impacts on GHG emissions with coefficients of less than 0.1.

Table 8. Normalized local sensitivity coefficients for life-cycle GHG emissions for safflower-based biodiesel.

Parameter	Sensitivity Scenario		Normalized Local Sensitivity Coefficient
Yield	High seed yield	Set to high end of estimated range.	-0.2
Irrigation	Less irrigation	Set to low end of estimated range.	0.15
Fertilizer	Low fertilizer level	Set to low end of estimated range.	0.03
Transport	Reduced distance	Reduced distance of travel by 100 miles.	0.05

Producer Profit Analysis. Under the American Clean Energy and Security Act (ACES) that passed the U.S. House of Representatives recently, it is possible to create a cap and trade system for greenhouse gas emissions and new markets for agriculture to be created. Under ACES, capped entities (that is, greenhouse gas emitters) could purchase offsets to meet compliance obligations in lieu of reducing emissions themselves; in total, domestic and international offsets would be allowed up to a total of 2 billion metric tons of GHG emissions annually (Larsen 2009). This creates opportunities for farmers to participate in a new market and generate increased revenue as the legislation looks to the agricultural community to serve as offset providers. Consequently, biofuel crops cultivation is considered as one of the possible manners for providing offsets and also increasing profits. The purpose of the last part of this study is to analyze the costs and revenue from safflower production, as well as farmers' planting decisions under a cap and trade market to provide useful implications. In order to do that, a production function of safflower is estimated, where production is a function of fertilizer and water; production functions of GHG emissions from fertilizer application and irrigation process are also developed. Finally, a related profit function is developed to evaluate possible incentives to change behaviors.

The data used to estimate safflower production function are from Engel and Bergman (1997), which is comprised of 45 observations of safflower yield, fertilizer and water. Although safflower yield is determined by numerous factors, the analysis focuses on two crucial input factors: fertilizer and irrigation water. A cubic functional form (Equation 6) was used to better describe the increasing and decreasing returns to scale as exhibited in the data:

$$Y = \alpha_0 + \alpha_1 w + \alpha_2 f + \alpha_3 w^2 + \alpha_4 f^2 + \alpha_5 w^3 + \alpha_6 f^3 + \alpha_7 wf + \alpha_8 w^2 f + \alpha_9 wf^2 \qquad (6)$$

where, Y denotes safflower yield (lbs/acre), f the total amount of nitrogen available to the crop (lbs/acre), and w total water available (inches/acre). Three interaction terms were included to capture the relationship between two input factors, but were ruled out by a joint significance test. The results of the production function estimation are presented in Table 9. The adjusted R-squared value of 0.83 indicates the estimated production function properly captured the underlying relationship between the two input factors, and t-values of coefficients are also acceptable at 10% significant level.

Table 9. Estimated parameter values of the safflower production function.

	intercept	w	f	w^2	f^2	w^3	f^3
Coefficients	4405	-1090	-8.68	86.43	0.12	-1.91	$-4.56*10^{-4}$
Standard Errors		636.65	6.78	46.76	0.10	1.10	$4.12*10^{-4}$
Adjusted R^2							0.83

Finally, the profit function of safflower is simply the difference between the revenue from production and total costs plus a carbon credit that farmers receive by reducing GHG emissions during their production of the fuel feedstock. Specifically, it is expressed as follows:

$$\pi = p * Y - (p_w * w + p_f * f + fixed\ costs) + p_c * (c_p - c\ (w, f) \quad (7)$$

where π denotes profit, p safflower price, Y denotes safflower yield per acre, p_w irrigation water price per inch, w irrigation water applied per acre, p_f fertilizer price per pound, f nitrogen fertilizer applied per pound. p_c is the per-unit carbon credit which farmers receive for reduced GHG emissions as compared to an equivalent unit of petroleum diesel[4]. c_p is carbon output of an equivalent amount of petroleum diesel, and $c(w, f)$ is carbon output caused by irrigation and fertilizer application which is estimated and expressed in the following equation[5]:

$$c(w, f) = 4.61 * w + 0.338 * f \quad (8)$$

Note that the change in carbon output calculated in equation 8 does not take into account the secondary effects of a change in fertilizer or irrigation – the change in yield that would change the resulting GHG emissions per unit of fuel value. We use the simplified equation 8 as an approximation to the functional relationship between input use intensity and carbon output. The yield effects of a change in irrigation or fertilizer application would tend to mitigate the change in carbon output for most values of water or fertilizer.

It is obvious from the profit equation that carbon enters simply as an additional cost of using water and fertilizer. So that the cost of water application can be expressed as:

$$cost_w = (p_w + p_c * 4.61) * w \quad (9)$$

Similarly, the cost of fertilizer application is:

$$cost_f = (p_f + p_c * 0.338) * f \quad (10)$$

Equation 10 shows an increase in the carbon price should affect the farmer's input demand in the same way as an increase in input price. That is to say, if the carbon price increases, farmers will decrease water and fertilizer usage to decrease GHG emissions to increase profits. This suggests that, instead of a simple increase in price (through increased demand) for the feedstock, the ability to carry the GHG policy instrument over to feedstock producers through a mechanism could have a positive effect on GHG emissions abatement as well as conservation of other scarce resources, such as water.

To determine the magnitude of the possible effect of a carbon credit carried through to the farmer, a simple profit simulation and grid search is run to determine farmer responses to a positive value of p_c in equation 7. The nature of the production functional form makes developing factor demand equations difficult, since part of the first-order condition for profit maximization is a quadratic function of input variables, which, when solved, result in input demand functions that are undefined for a range of variable values. Instead, profit (equation 7) for a wide array of input values is calculated and the input use that maximizes profit is also identified. At baseline prices (and a zero value for p_c), positive farmer profits can be obtained for any safflower seed price greater than \$0.06 per pound[6]. This suggests that safflower seed oil is profitable from about a \$0.25 per pound market price (assuming 30% oil content of safflower seed and \$75/ton crushing costs), which is lower than the comparable prices for soybean oil (assuming a \$0.189/lb seed price and 19% oil content). Market prices for crude safflower oil are currently much higher than this, however, as refined safflower oil is typically sold as a specialty or gourmet cooking oil.

When the carbon credit value increases, that is, when p_c increases from zero, it is found that farmer input choice is relatively unresponsive to changes in carbon credit prices. The producer reduces water use at a rate of about 0.1 acre-in per \$0.12/kg CO_2 carbon credit. Currently, carbon credits in a carbon market are expected to range between \$15 and \$30 per metric ton CO_2, or \$0.015 and \$0.03 per kg. These prices are not high enough to induce safflower farmers to reduce input use.

CONCLUSION AND DISCUSSION

Base case analysis results indicate that biodiesel produced from winter safflower achieves a reduction in net life-cycle GHG emissions of 78% compared with conventional petroleum diesel. With a positive NEV of 99,886 Btu per gallon and NER of significantly greater than one, the safflower-derived biodiesel system yields more useful energy than is required during production, processing, and transport. These results suggest that the safflower-based biodiesel system under consideration could potentially achieve the identified sustainability goals of reducing net GHG emissions, displacing conventional petroleum diesel consumption, with a large net energy ratio. In addition, yield and irrigation level were identified as parameters to which life-cycle GHG emissions are most sensitive.

Finally, the profit function analysis reveals that winter safflower is a profitable feedstock for biodiesel production to grow on the Texas High Plains. However, even carefully designed carbon policy is not likely to induce feedstock producers to further decrease GHG emissions during production. Overall, the benefits of winter safflower biofuel to the nation of providing cleaner burning fuels that improve both regional and global air quality while improving soil and water quality are obvious. Combined with the improvements in farm economy, which can be expected with the production of energy on farms and increased income for local farmers, winter sunflower crop is expected to become increasing competitive in the future on the Texas High Plains.

Note that this study does not consider potential land use changes. Increased CO_2 emissions from potential land use changes are an important factor, but it is not included in the current analysis since reliable data on potential land use changes induced by safflower seed-based biodiesel production are not available. However, safflower is grown on semi-arid or marginal land. It is anticipated that there will be a neutral to positive net carbon sequestration as the areas are changed to hosting large-scale safflower plants.

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APPENDIX

Table A1. Enterprise budget summaries for dryland and irrigated winter safflower production.

Costs and Revenues	Dryland Safflower	Irrigated Safflower
Variable Cost ($/acre)	61.63	151.76
Total Ownership Costs ($/acre)	93.70	93.70
Land Rent ($/acre)	40.00	40.00
Total Costs ($/acre)	195.33	285.46
Yield(lb/acre)	678.40	1745.05
Seed Price($/lb)	0.20	0.20
Cost($/lb)	0.29	0.16
Total Revenue($/acre)	135.68	349.01
Net Revenue($/acre)	-59.65	63.55
Revenue Net of Variable Costs($/acre)	74.05	197.25

Source: Oswalt, S.; Texas Tech University.

ENDNOTES

[1] Safflower yield is 2000 lb/acre as estimated.
[2] 44/28 represents the conversion of nitrogen emissions to N_2O emissions.
[3] 44/12 represents the conversion of carbon emissions to CO_2 emissions.
[4] Currently, carbon credits are expected to be paid to biofuel producers. Here p_c is a hypothetical portion of the total offset that could be paid to farmers to induce additional carbon savings.
[5] This equation is estimated by summing the GHG emissions of these two activities together, and the coefficients are estimated by EPA.
[6] Assuming prices of water and fertilizer are $4.50/acre-in, $500/ton respectively, and that fixed costs are $80/acre.

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Habitat Characteristics That Influence Maritime Pocket Gopher Densities

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ABSTRACT

The Maritime pocket gopher (*Geomys personatus maritimus*) is a subspecies of Texas pocket gopher endemic to the Flour Bluff area of coastal southern Texas. Little is known about the habitat and nutritional requirements of this subspecies. The amount and quality of habitat necessary to sustain Maritime pocket gophers has not been studied. Our objectives were to assess the habitat, vegetation, and nutritional parameters available to Maritime pocket gophers at four different levels of gopher mound density. We chose study sites with zero, low (25-50 mounds/ha), intermediate (75-150 mounds/ha), and high (>200 mounds/ha) gopher mound densities. Vegetation and soil samples were collected using 0.25 m^2 quadrats; vegetation was divided into above- and below-ground biomass for analysis. Maritime pocket gophers avoided areas of clay soils with high levels of calcium, magnesium, sulfur, and sodium compounds. A direct relationship existed between gopher activity within an area and vegetation biomass. However, nutritional quality of an area did not appear to be a determining factor for the presence of Maritime pocket gophers.

KEY WORDS: Population density, *Geomys personatus maritimus*, habitat selection, Maritime pocket gopher, preference

INTRODUCTION

The Maritime pocket gopher (MPG, *Geomys personatus maritimus*) is endemic to the coastal areas of Kleberg and Nueces counties of southern Texas, between Baffin Bay and Flour Bluff (Williams and Genoways 1981). Historically, this subspecies of pocket gopher was found on native prairies, but urbanization and agricultural practices have fragmented much of the coastal prairies. There is a dearth of published data on MPG, but few studies that have mentioned MPG focus on general morphology, distribution (Williams and Genoways 1981), and habitat (Williams 1982).

The MPG prefers deep sandy soils (Williams 1982) and avoids rocky, silt loam or clay soils due to the difficulty in excavation (Davis 1940; Kennerly 1958). Pocket gopher diet consists mainly of vegetation and includes grass species in the genera

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Paspalum, *Cynodon*, and *Cenchrus* and forb species in *Helianthus* (Davis and Schmidly 1994). It is thought that MPG has similar habitat preferences as the other six subspecies of the Texas pocket gopher, but no habitat preference studies with MPG have been conducted to confirm this.

Potential threats of habitat degradation, which converts native prairie into shrub land, and habitat fragmentation, which isolates populations of MPG and inhibits dispersal (Cortez 2007), place MPG in jeopardy for continued existence. Due to their restricted distribution and aforementioned threats, U.S. Fish & Wildlife Service has labeled the MPG as a species of concern (SOC) and has considered recommending it for federal listing status (Hafner 2000). Because the majority of the population of MPG occurs on Naval Air Station-Corpus Christi (NAS-CC), a U. S. Navy property, management by the Navy plays a vital role in the conservation of this subspecies. Therefore, determining the habitat characteristics that effect MPG densities will aid in creating a sound habitat management plan for this subspecies. The primary objective of this study was to determine habitat characteristics of soil, plant species composition, and vegetative nutrients that affect MPG density.

STUDY AREA

This study was conducted on NAS-CC in the Flour Bluff region, which is 16.1 kilometers southeast of Corpus Christi, in Nueces County, Texas, USA (27°41'33.47"N, 97°17'28.36"W). Flour Bluff is surrounded by Corpus Christi Bay to the north, Oso Bay to the west, and the Laguna Madre to the east, and lies in the Gulf Prairies and Marshes eco-region. Home to a U.S. Coast Guard base, an Army Depot, and a U. S. Navy base, NAS-CC is approximately 1,049 ha. The landscape of NAS-CC is urbanized with grassland and scrubland habitat fragmented by airfields, taxiways, and roadways.

Two soil types occur at NAS-CC, Galveston (Mixed, hyperthermic Typic Udipsamments) and Mustang fine (Siliceous, hyperthermic Typic Psammaquents) sand and dredge spoils (Fine-loamy, mixed, superactive, frigid Typic Haploxerolls) (Natural Resources Conservation Service (NRCS) 1960). The percentage of Galveston and Mustang fine sand and clay loam on NAS-CC is 80% and 20%, respectively.

The vegetation on NAS-CC is predominantly coastal, mid-grass prairie grasslands and scrub-dominated, mixed grassland communities. Both communities occur on Galveston and Mustang fine sand and clay loam. Grass species include sandbur (*Cenchrus spinifex*), gulf dune paspalum (*Paspalum monostachyum*), and red lovegrass (*Eragrostis secundiflora* subsp. *oxylepis*). Forbs include cardinal feather (*Acalypha radians*), frog fruit (*Phyla strigulosa*) and scarlet pea (*Indigofera miniata*). Additionally, there are three non-native grasses present: Bermuda grass (*Cynodon dactylon*), St. Augustine grass (*Stenotaphrum secundatum*), and guinea grass (*Panicum maximum* Jacq.).

MATERIALS AND METHODS

Gopher Assessment. Relative abundance of MPG was surveyed using strip line transect sampling. A strip line transect map was created using a 2004 National Agricultural Imagery Program (NAIP) aerial photograph of the study site. With ArcGIS 9.1, a 3-

hectare grid matrix was laid over the aerial photograph and each 3-ha grid then was subdivided into 1-ha strips. A random number generator in Microsoft Excel was used to choose one of the three 1-ha strips from each 3-ha grid. Maximum length of a strip line transect was 536 m and each transect was >15 m apart. The surveyor began at the designated starting point of each transect and counted every mound, within 7.5 m, right or left of the transect line while walking to the end point of each transect (Cortez et al. 2013). A Trimble (Trimble, Sunnyvale, California, USA) GPS unit (model GeoExplorer III DGPS with beacon receiver) was used to stay on the transect line and record suspected burrow system locations. The number of mounds within each suspected burrow system was recorded.

Habitat Quality Sampling. From the line transects, we located five 1-ha plots in zero gopher density (0 mounds/ha), low gopher density (25 to 50 mounds/ha), intermediate gopher density (75 to 150 mounds/ha), and high gopher density (>200 mounds/ha). A gap was intentionally left between each level so that the categories would be discrete. Once the 20 plots were determined, we created 20 random points (n = 400) within each plot for vegetation and soil sampling. The random points were created using Hawthorne's Analysis Tools 3.08 (Beyer 2004) in ArcGIS 9.1. A 0.25 m^2 quadrat was used at each point to determine plant species composition. Entire plants (above- and below-ground portions) were collected, identified by species, and placed into paper bags. In the laboratory, the plants were washed to remove soil. After washing, the plants were separated into above-ground parts and roots and dried at 40°C for 48 hours. After drying, above-ground parts and roots were weighed to the nearest 0.01 g. Plant samples were analyzed for crude protein (CP), energy, neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL). Dry matter was determined by heating 1 g of ground sample to 105°C for 24 hours. Plant samples (3.0 g) were sent to the Texas A&M University Soil, Water & Forage Testing Laboratory in College Station, Texas, to determine the crude protein. Crude protein was estimated by the Kjeldahl method, which quantifies the percent nitrogen in the sample (protein content = 6.25 x (total N)) (Maynard et al. 1979). Energy content was determined using a bomb calorimeter with benzoic acid as a standard. Samples were ashed in a muffle furnace for 16 hours at 500°C. Neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) were analyzed as described by Van Soest et al. (1991). Values of NDF, ADF, and ADL were corrected for ash content.

The plant species diversity (Simpson's Index) (Krebs 1989), species richness (number of species), and density were calculated for each quadrat of each plot. The density was calculated by dividing the sum of plant frequencies by the size of the quadrat ($0.25m^2$) and multiplying by 4, to determine density per m^2.

Soil samples (5.0 g) were taken within each quadrat after the vegetation was removed. The soil was analyzed for pH, conductivity, nitrate nitrogen ($N0_3$-N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S), and sodium (Na). The soil analysis was conducted by the Texas A&M University Soil, Water, & Forage Testing Laboratory in College Station, Texas. The samples were compared between gopher densities and between above- and below-ground plant parts. Data were analyzed by a completely randomized design with sampling error using analysis of variance (ANOVA) (SAS Institute 1989). Each pair of means was analyzed using Tukey's studentized range (HSD) test when a significant (P < 0.05) F-test was noted.

Above-ground and below-ground plant data was compared with a paired t-test. Plant frequency of occurrence was analyzed by chi-square analysis.

RESULTS

Soil Properties. Calcium, Mg, S, and Na compounds significantly differed ($F > 3.51$, $P <$ 04) between gopher densities, while soil conductivity, pH, $N0_3$-N, P, and K compounds did not differ ($P > 0.07$) between gopher densities (Table 1). Areas of zero gopher density had significantly higher concentrations of Ca, Mg, S, and Na compounds than the areas where gophers were at higher density levels (Table 1).

Plant Community Parameters. Forty-four (13 grasses, 29 forbs, two woody species) vascular plant species constituting 979 plants were identified within quadrats of the varying gopher densities (Table 2). The most predominant grass species were *Cynodon dactylon* (44%), *Cenchrus spinifex* (20%), *Urochloa maxima* (11%), and *Cenchrus ciliaris* (10%), while the predominant forbs were *Acalypha radians* (20%), *Phlya strigulosa* (12%), *Indigofera miniata* (11%), and *Rhynchosia americana* (10%). One native grass, *Cenchrus spinifex*, was found to increase in frequency as the pocket gopher density increased ($\chi^2 = 30.6$, $P < 0.001$). *Cenchrus spinifex* occurred more often than expected in high density plots, while occurred less often than expected in zero density plots. Three introduced grass species, *Cenchrus ciliaris* ($\chi^2 = 12.6$, $P < 0.01$), *Sorghum halepense* ($\chi^2 = 19.7$, $P < 0.001$), and *Stenotaphrum secundatum* ($\chi^2 = 8.3$, $P < 0.05$) occurred more often than expected in low gopher density plots. Most of the variation in *Cenchrus ciliaris* occurred between low (46%) and high (46%) gopher densities. *Urochloa maxima* ($\chi^2 = 24.2$, $P < 0.001$) occurred more often than expected when gophers were absent. The most variation occurred between zero (43%) and intermediate (55%) gopher densities. Three halophytes or salt tolerant plants, *Monanthochloe littoralis* ($\chi^2 = 14.4$, $P < 0.005$), *Salicornia virginica* ($\chi^2 = 24.0$, $\mathrm{P} < 0.001$), and *Suaeda linearis* ($\chi^2 = 9.0$, $P < 0.05$) occurred more often than expected in zero density plots. *Quercus virginiana* ($\chi^2 = 42.0$, $P < 0.001$) also occurred more often than expected in low density plots. No differences were observed ($F < 1.74$, $P > 0.20$) in plant species richness, diversity, or density among areas of various gopher mound densities (Table 1). Areas without gopher mounds had less overall vegetation biomass ($F = 4.9$, $P < 0.0001$) and below-ground biomass ($F = 8.0$, $P < 0.0001$) than plots with gophers (Table 1). Above-ground biomass was greater ($F = 6.8$, $P < 0.0001$) in areas with intermediate and high gopher mound densities than areas with low and zero mound densities (Table 1).

Plant Nutrients. No differences ($F < 1.75$, $P > 0.20$) were observed in DM, NDF, ADF, ADL, protein, or energy values between areas of various gopher mound densities (Table 1). Significant differences were found between above- and below-ground nutritional components (Table 3). Every nutrient category except dry matter and acid detergent lignin was greater in above-ground samples (t-statistic > 2.7, $P < 0.02$).

Table 1. Habitat characteristics of soil, plants, and vegetation nutritional analyses from areas of four gopher densities within Naval Air Station-Corpus Christi during summer (June – August), 2006.

	Maritime pocket gopher mound densities[1]									
	Zero		Low		Intermediate		High		ANOVA	
Habitat Parameters	x̄	SE	x̄	SE	x̄	SE	x̄	SE	*F*-Value	P-Value
Soil										
pH	7.7A[2]	0.2	7.0A	0.3	7.4A	0.2	7.2A	0.2	1.39	0.28
Conductivity	418.6A	153.4	183.0A	23.9	154.2A	28.0	223.8A	52.6	2.06	0.15
$N0_3N$	9.6A	2.5	4.4A	0.4	5.6A	0.6	5.6A	0.9	2.77	0.07
Phosphorus	59.4A	25.1	46.4A	15.4	32.4A	7.3	43.8A	7.1	0.51	0.68
Potassium	319.6A	113.8	210.2A	52.6	133.0A	31.4	142.4A	38.4	1.63	0.22
Calcium	5780.4A	726.8	2555.8B	924.0	2734.0B	455.5	1860.0B	348.5	7.08	0.003
Magnesium	339.8A	76.3	172.4AB	42.2	129.4B	35.8	106.0B	28.9	4.59	0.02
Sulfur	48.0A	9.8	18.4B	3.0	17.0B	1.3	16.0B	1.0	8.84	0.001
Sodium	266.4A	56.4	172.8A	5.3	144.6B	6.9	162.0AB	11.6	3.51	0.04
Plants										
Richness	9.4A	1.4	12.2A	1.1	13.0A	1.1	11.2A	1.0	1.74	0.20

Diversity	5.2A	0.7	6.3A	0.5	7.3A	1.2	6.8A	0.7	1.26	0.32
Density	188.0A	24.6	210.4A	11.5	218.4A	12.8	171.2A	19.2	1.46	0.26
Overall biomass	33.7A	2.2	38.3B	5.2	43.8B	2.4	55.8B	3.5	4.91	0.0001
Above-ground	26.0A	2.0	26.5A	4.4	30.9AB	1.6	39.2B	2.8	6.81	0.0001
Below-ground	7.7A	0.6	13.5B	1.8	12.9B	1.2	16.6B	1.5	7.96	0.0001
Nutritional[3]										
DM	92.2A	0.4	92.5A	0.3	91.3A	0.5	92.1A	0.2	1.75	0.20
NDF	62.3A	2.7	60.0A	3.5	60.4A	2.0	61.1A	5.1	0.08	0.97
ADF	33.3A	1.7	33.5A	3.1	33.3A	1.2	32.3A	2.2	0.07	0.98
ADL	5.7A	0.4	7.2A	1.2	5.6A	0.3	5.2A	0.5	1.59	0.23
Protein	6.8A	1.0	6.8A	0.5	7.2A	0.3	7.1A	0.4	0.12	0.95
Energy	3522.2A	109.6	3619.2A	174.9	3569.9A	116.7	3621.1A	200.2	0.09	0.96

[1]Gopher mound densities of zero = no gopher mounds, low = 25 to 50 mounds/ha, intermediate = 75 to 150 mounds/ha, and high = > 200 mounds/ha.
[2]Means with the same capital letter are not different within a row ($P > 0.05$).
[3]Nutritional components are DM = dry matter (%), NDF = neutral detergent fiber (%), ADF = acid detergent fiber (%) , ADL = acid detergent lignin (%), and protein (%). Energy is in kcal/g.

Table 2. Plant species and frequency of occurrence on four gopher densities within Naval Air Station-Corpus Christi during summer (June – August), 2006.

	Maritime pocket gopher mound densities[1]					
Plant Species	Zero	Low	Intermediate	High	$\chi2$	P-Value
Grass						
Cyndon dactylon	55	56	50	51	0.6	0.9
Cenchrus spinifex	6	21	31	40	30.6	0.001
Cenchrus ciliaris	10	21	15	4	12.6	0.01
Urochloa maxima	25	12	0	16	24.2	0.001
Paspalum monostachyum	11	3	8	3	7.3	0.1
Sorghum halepense	0	14	3	5	19.7	0.001
Eragrostis secundiflora	1	6	0	1	11.0	0.025
Stenotaphrum secundatum	1	4	0	0	8.3	0.05
Monanthochloe littoralis	5	0	0	0	14.4	0.005
Spartina patens	0	0	4	0	12.0	0.01
Chasmanthium latifolium	0	0	0	3	9.0	0.05
Aristida purpurea	0	0	1	0	3.0	0.5
Bothriochloa laguroides.	0	0	1	0	3.0	0.5
Forb						
Acalypha radians	15	14	34	29	13.2	0.005
Phyla strigulosa	14	15	18	8	3.8	0.5
Indigofera miniata	11	13	16	12	1.1	0.9
Rhynchosia americana	15	8	18	8	6.2	0.1
Commelina elegans	4	3	18	5	19.8	0.001
Richardia brasiliensis	0	13	6	8	12.8	0.005
Mimosa strigillosa	8	7	4	2	4.3	0.25
Croton capitatus	3	6	6	3	2.0	0.75
Erigeron procumbens	2	10	4	0	14.0	0.005
Sphaeralcea lindheimeri	4	1	5	3	2.7	0.5
Astragalus nuttallianus	13	0	0	0	39.6	0.001
Zinnia acerosa	0	0	8	4	14.6	0.005
Portulaca pilosa	6	5	0	0	11.1	0.025
Salicornia virginica	8	0	0	0	24.0	0.001
Ipomoea trichocarpa	0	2	5	0	9.5	0.025
Neptunia pubescens	0	5	2	0	9.5	0.025
Philoxerus vermicularis	2	0	3	2	2.7	0.5
Lantana camara	5	0	0	0	15.0	0.005

Helianthus praecox	4	0	0	1	8.6	0.05
Thymophylla tenuiloba	0	2	2	0	4.0	0.5
Croton glandulosus	0	3	0	0	9.0	0.05
Suaeda linearis	3	0	0	0	9.0	0.05
Gaillardia pulchella	0	0	3	0	9.0	0.05
Palafoxia texana	0	2	0	0	6.0	0.25
Cooperia drummondii	1	1	0	0	2.0	0.75
Solanum elaeagnifolium	0	0	1	1	2.0	0.75
Lepidium austrinum	1	0	0	0	3.0	0.5
Phlox drummondii	0	0	1	0	3.0	0.5
Waltheria indica	1	0	0	0	3.0	0.5
Trees, shrubs & woody						
Schrankia latidens	1	2	1	8	11.2	0.02
Quercus virginiana	0	14	0	0	42.0	0.001

[1]Gopher mound densities of zero = no gopher mounds, low = 25 to 50 mounds/ha, intermediate = 75 to 150 mounds/ha, and high = > 200 mounds/ha.

Table 3. Comparison of nutritional components between above-ground vegetation and below-ground vegetation within Naval Air Station-Corpus Christi during summer (June – August), 2006.

Nutritional Component[1]	Above-ground	Below-ground	SE	t-statistic	*P*-value
DM (%)	92.0	94.1	0.3	6.14	0.001
NDF (%)	60.9	47.5	3.3	4.06	0.001
ADF (%)	33.1	27.9	1.9	2.81	0.011
ADL (%)	5.9	7.6	0.6	2.72	0.014
Protein (%)	7.0	5.3	0.3	5.10	0.001
Energy (kcal/g)	3583	2940	169	3.81	0.001

[1]Nutritional components are DM = dry matter, NDF = neutral detergent fiber, ADF = acid detergent fiber, and ADL = acid detergent lignin.

DISCUSSION

The Maritime pocket gopher is restricted to the deep sandy soils of Kleberg and Nueces counties, between Baffin Bay and Flour Bluff (Williams 1982; Williams and Genoways 1981). Williams (1982) also noted that rocky, silt loam or clay soils can create barriers to this species because of the difficulty in digging tunnels in such soil types. Only two soil types are found on NAS-CC, Galveston and Mustang fine sand and dredge spoils, the latter of which consists of clay loam sediment found on the seabed (NRCS 1960). The soil in three of the five zero mound density plots consisted mainly of dredge spoils (NRCS 1960). Therefore, the non-detection of MPG in zero density plots may be due to the soil type in these plots. In addition, dredge spoils contained shells (i.e.: oysters, snails, etc.); therefore, the large amounts of calcium, magnesium, sulfur, and sodium compounds found in the zero density plots can be attributed to the dredge spoils as well. The non-detection of gophers in these plots also could have been due to the high salt or sodium chloride content in the soil. High salt content limits the vegetation to salt-tolerant plant species. There has been no documentation of MPG utilizing salt-tolerant plants. Their diet has been reported to consist of grass species including *Paspalum, Cynodon,* and *Cenchrus* and forbs from the genus *Helianthus* (Davis and Schmidly 1994).

In addition, four of the five zero density plots were fragmented by urban development. These islands of habitat were either surrounded by wide swaths of concrete, asphalt, and buildings, or by inhospitable soils for digging (i.e. clay loam). Through personal observations, MPG were able to burrow under roads and areas with thin layers of dredge spoils, but the lack of tunnel openings in wide swaths of concrete and asphalt appeared to be a formidable barrier.

Pocket gophers are generalist herbivores (Williams and Cameron 1986). As generalists, pocket gopher densities should not be affected by plant richness or plant diversity. In other studies, gopher disturbance (i.e. gopher tunnels or mounds) did not have an effect on plant species diversity (Rezsutek and Cameron 2000) nor plant species richness (Williams and Cameron 1986), nor did they have an effect in our investigation. Although past studies focused on how pocket gophers affect plant communities, this study concentrated on whether plant community characteristics affected pocket gopher density. MPG preference for areas with high frequencies of *Cenchrus spinifex* and the fact that gopher density increased as *C. spinifex* frequency increased probably supports an overall preference by MPG for native species. In fact, the avoidance of exotic grasses by MPG further endorses this hypothesis. The avoidance of the halophytes also may be due to the inability of MPG to reach salt marsh habitat. The salt marsh is bordered by a mesquite forest and a drainage ditch, both of which can be formidable barriers for pocket gophers. Live oak avoidance is attributed to probable difficultly of digging around thick tree roots and to reduction of palatable forbs and grasses in oak habitat.

Gopher density increased as the above-ground, below-ground, and overall biomass increased, which differs from Williams and Cameron (1986) who found that frequency, cover, and biomass increased in absence of pocket gophers. Williams et al. (1986) suggested that pocket gopher mounds enhanced plant growth, which may have occurred at our study sites. Furthermore, Ward and Keith (1962) and Williams and Cameron (1986) suggested that important foods of pocket gophers were the most abundant, palatable species, which supports the study's findings that MPG densities were greater in areas with greater vegetation biomass (i.e. more available food).

The lack of variation in the nutritional composition of vegetation found among the gopher density plots may be attributed to a lack of knowing when pocket gophers arrived at a plot. Patch use of optimal foraging theory suggests that an animal will remain in its current patch until the nutritive value of the patch falls below the value of the overall habitat (Pyke et al. 1977). Pocket gophers at the high density plots may have been in the area for a period of time and already eaten the most nutritious plants before we sampled the vegetation, thus, giving the appearance of a decreased amount of nutrients within the plot. Consequently, this would decrease the amount of the variation within nutritional parameters among gopher density plots.

The differences found in the nutritional analysis of above-ground and below-ground vegetation samples may not be very indicative of gopher densities. *Geomys attwateri* consume above-ground parts of plants by pulling entire plants below ground

(Williams and Cameron 1986). The MPG has similar grazing behavior. Numerous underground caches were found that included whole plants of grass and forb species. It is unknown, however, just how much of the MPG diet consists of aboveground parts of plants. A food habits study for MPG is warranted. According to Vleck (1979), burrowing can require 360 to 3,400 times as much energy as moving the same distance across the surface. Therefore, it is likely that MPG utilize a substantial amount of the higher energy above-ground vegetation to meet its fossorial energy requirements. The lower acid detergent lignin (ADL) in the above-ground vegetation also may allow for better digestion. Lignin is totally indigestible; therefore, higher levels of lignin reduces digestibility. Conversely, the lower NDF and ADF in the below-ground vegetation may allow pocket gophers greater intake and digestibility. High NDF and ADF levels result in reduced intake and decreased digestibility. Because the greatest MPG densities occurred in areas with the greatest plant biomass and that no significance was observed in the nutritional parameters between MPG densities, our results concur with Williams and Cameron (1986) that pocket gophers are generalist herbivores and that the most important foods of pocket gophers are the most abundant palatable species, which also was reported by Ward and Keith (1962).

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Morphological Characteristics and Effects of Telazol on American Badgers in South Texas

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ABSTRACT

Five North American badgers were trapped on the Chaparral Wildlife Management Area located in Texas counties Dimmit and LaSalle Texas in 2002. Mean male badger weight was 6.29 ± 0.76 kg and weight for a female badger was 5.44 ± 0.00 kg. Weights resulted in a mean dosage of 0.75 ± 0.24 cc of Telazol® with a workable time of 7.25 minutes. We concluded that badgers can be safely immobilized under field conditions using Telazol.

KEY WORDS: badger, *Taxidea taxus*, morphological characteristics, Telazol, South Texas

INTRODUCTION

A common solitary carnivore west of the Mississippi River, the North American badger (*Taxidea taxus*) has a range extending from northern Alberta, Canada to central Mexico and eastward from the Pacific coast to a line running from east Texas to the central Great Lakes, and is represented by four subspecies (Long 1973). Badger populations have not been widely studied (Hein and Andelt 1995). Generally, badgers are associated with treeless regions, prairies, parkland, and cold desert areas (Lindzey 1982), with previous research locations in the Intermountain west and Great Plains. Badgers have many unique physical characteristics making them readily identifiable: depressed body, short, stout legs, loose skin, long, recurved front claws, and short, shovel-like hind claws (Lindzey 1982). Typically, reported morphological measurements (i.e., total length, tail length, body length, and hind foot length) are similar between sexes. Long (1973) reported total length to be 60-73 cm; tail length 10.5-13.5 cm; hind foot length 9.5-12.8 cm for both sexes respectively, while Messick (1981) found morphological

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measurements for male and female badgers were: total length 73.9 cm and 70.8 cm; body length 59.9 cm and 57.8 cm; hind foot length 10.7 cm and 10.3 cm, respectively. Adult male badgers weigh an average of 26% more than adult female badgers (Wright 1966) with average weights of 8.4 kg and 6.4 kg, respectively in South Dakota (Wright 1969) and 8.7 kg and 7.1 kg respectively in northern Utah and southern Idaho (Lindzey 1971). Ruiz-Campos et al. (2002) in Baja California, Mexico reported morphological measurements of two male badgers as: body mass 4.1 kg and 9.3 kg, total length 58.7 cm and 84.9 cm, and hind foot length 10.9 cm and 12.3 cm. Although records in the southern portion of the badger range seem to indicate a wide range of morphological measurements, little information exists about badger morphological measurements of the southernmost subspecies of the North American badger (*T. t. berlandieri*), in southern Texas.

To generate accurate in-field morphological data, rapid immobilization by intramuscular injection of anesthetic (Bigler and Hoff 1974) is necessary. Four immobilizing agents (phencyclidine hydrochloride, acepromazine maleate, chlorpromazine hydrochloride, and succinyl-choline chloride) have been used on North American badgers (Fitzgerald 1973). However, little information is available on immobilizing badgers under field conditions using Telazol® (A.H. Robins, Richmond, VA 23220) (Bailey 1971). Telazol has been used to immobilize mustelids such as American martens (*Martes americana*) (Bull et al. 1996), striped skunks (*Mephitis mephitis*) (Lariviere and Messier 1996), river otters (*Lutra canadensis*) (Serfass et al. 1993), and fishers (*Martes pennanti*) (Mitcheltree et al. 1999) under field conditions. It is a non-opid, non-barbiturate, injectable anesthetic widely used in anesthetizing wildlife (Schobert 1987; Lin et al. 1993; Lariviere and Messier 1996). Rapid induction time, good muscle relaxation, maintenance of swallowing reflex, and minimal effect on respiration (Lin et al. 1993) allow Telazol to have a wide safety margin, making it especially useful when the body mass of animals is only roughly estimated (Lariviere and Messier 1996). Telazol also provides a gradual and predictable recovery, making it safe to use with potentially dangerous species (Stirling et al. 1989). Because of these reasons, Telazol has become a useful management tool when capture and marking are required. The objectives of this research were to report and compare morphological measurements of a North American badger population in its southern range, and to evaluate the effectiveness of Telazol for immobilizing badgers under field conditions.

Study Area. The study was conducted during 2002 on the Chaparral Wildlife Management Area (CWMA), Dimmit and LaSalle Counties, which lies within the western South Texas Plains (Correl & Johnston 1979; Hatch et al. 1990) and the Tamulipan Biotic Province (Blair 1950). Climate is characterized by hot summers and mild winters with an average annual precipitation accumulation of 53 cm. The elevation ranges from 144-148 m and soils are primarily sandy. Precipitation patterns are bimodal with peaks occurring in late spring (May to June) and early fall (September to October). Typical vegetation includes mesquite (*Prosopis glandulosa*), blackbrush (*Acacia rigidula*), granjeno (*Celtis pallida*), huisache (*Acacia minuta*), and cacti (Taylor et al. 1997) which characterize the two-phase pattern of shrub clusters scattered throughout a grassland/savanna (Whittaker et al. 1979; Archer et al. 1988).

MATERIALS AND METHODS

Presumed active badger burrows were identified and had a pair of No. 3 coil spring traps (Duke Company, West Point, MS) placed at the mouth of the burrow (Collins 2004) for capture. Once captured, the weight of the individual badger was estimated to the nearest kg, then individuals were immobilized with Tiletamine/Zolazepam (Telazol®, Fort Dodge, Iowa) mixed 1:1 (250 mg of each) and reconstituted with 5 ml of sterile diluent (i.e., 100 mg/cc). Dosages (i.e., Estimated Body Weight x Dosage / Drug Concentration) were based on the estimated weights of the captured animals and adjusted accordingly. However, dosage varied because of a tendency to overestimate weight and length of time needed to process individuals. The drug was given intramuscularly with a 1-cc syringe fitted with a 16-gauge needle. Initial dosage, time of first effect, time tractable, and release time were all monitored and recorded in the field. Individuals sex and age (i.e., canine wear) were determined and morphological measurements were taken: total body mass (g), head length (cm), total body length (cm), tail length (cm), and canine length (mm) using a Macro-Line Pesola ® spring scale (20 kg capacity), measuring tape, and metric dial calipers.

RESULTS

A total of 1,430 trap-nights resulted in the capture of five badgers (two adult males, two juvenile males, and one adult female) and 12 individuals of five non-target species (Table 1).

Table 1. Location, trapping effort, and number of badgers and non-target species captured on the Chaparral Wildlife Management Area, Dimmit and LaSalle County, Texas, 2002.

		Species					
Pasture	Trap Nights	*Taxidea taxus*	*Lynx rufus*	*Procyon lotor*	*Didelphis virginiana*	*Mephitis mephitis*	*Pecari tajacu*
West Blocker	542	1	1	1	1	4	--
West Guajalote	12	--	--	--	--	--	--
Mare	30	--	--	--	--	--	--
Long	22	--	--	2	2	--	--
Mustang	73	2	--	--	--	--	--
Hogue	74	--	--	--	--	--	--
North Jay	330	1	--	--	--	--	1
South Jay	134	--	--	--	--	--	--
East Guajalote	12.5	--	--	--	--	--	--
Rosindo	88	1	--	--	--	--	--
Total	1430	5	1	3	3	4	1

Overall trap success for all captures was 1.4% and 0.03% for badgers. Mean male badger weight was 6.29 ± 0.76 kg and the lone female badger weighed 5.44 ± 0.00 kg. Total length for all badgers ranged from 70.20 cm to 77.00 cm, with a mean total length of 73.69 ± 3.03 cm. Mean head length was 12.88 ± 4.32 cm, while mean tail length was 11.77 ± 1.33 cm for both sexes respectively (Table 2).

Table 2. Morphological measurements of badgers captured on the Chaparral Wildlife Management Area, Dimmit and LaSalle County, Texas, 2002.

								Canine (mm)	
Capture Date	Sex	Age	ID	Total Lengt h (cm)	Head Lengt h (cm)	Tail length (cm)	Weigh t (kg)	Upper	Lower
8-Mar	Female	Adult	FB1	70.2	5.5	10.1	5.44	1.7	1.7
14-Mar	Male	Adult	MB1	70.25	10.48	10.45	5.67	1.4	1.6
30-May	Male	Juvenile	MB2	77	15.2	13.6	7.25	1.77	1.83
12-Jun	Male	Juvenile	MB3	74	16.4	12.8	6.57	1.86	1.8
25-Jul	Male	Adult	MB4	77	16.8	11.9	5.67	1.57	1.45
Mean				73.69	12.88	11.77	6.12	1.66	1.68

Five individual doses of Telazol® were administered. On average, badgers were administered 0.75 ± 0.24 cc of Telazol® and were tractable within 7.25 minutes (Table 3).

Table 3. Average dosages of Telazol® administered and time badgers were tractable after capture on the Chaparral Wildlife Management Area, Dimmit and LaSalle County, Texas, 2002.

ID	Dose (cc)	Time 1st effect (A.M.)	Time Tractable (A.M.)	Arousal Time (A.M.)	Release Time
FB1	1.50	8:34:00	8:38:52	11:45:26	12:15:00
MB1	1.00	8:48:00	8:49:20	11:06:15	11:36:00
MB2	0.50	8:19:00	8:22:52	10:11:34	10:41:00
MB3	0.35	10:00:00	10:25:42	11:42:10	12:15:00
MB4	0.40	9:09:24	9:11:06	10:36:54	11:05:00
Mean	0.75				

Typically, this dosage kept the badger tractable for approximately two hours with a standard release time of 30 minutes after the first sign of arousal. All badgers were released back into the burrow in which they were trapped to allow for further recovery. Telezol® does have some side effects such as: excessive salivation, possible chronic seizures, and an irregular respiratory rate (Schobert 1987). However, our study animals did not exhibit any visible signs of these effects.

DISCUSSION

Wright (1969) reported average weights of males and females as 8.4 kg and 6.4 kg, respectively, in South Dakota, while Lindzey (1971) found weights of males and females to be closer to 8.7 kg and 7.1 kg, respectively, in Curlew Valley, Utah and Idaho. Long (1973) reported that large males can exceed 11.5 kg. Male badger weights on our study site were less than that reported by Wright (1969) and Lindzey (1971). Badgers caught on CWMA had total body lengths and tail lengths that fell within the range reported by Long (1973) of 60-73 cm and 10.5-13.5 cm respectively, as well as the documented total body length measurements by Messick (1982) in southwestern Idaho for male (73.9 cm) and female (70.8 cm) badgers. Two male badgers documented in their southern range in northwestern Mexico were found to weigh 4.1 kg and 9.3 kg, and have total lengths of 58.7 cm and 84.9 cm (Ruiz-Campos et al. 2002). Ruiz-Campos et al. (2002) suggested this wide range in measurements is a result of sub-species variation with the larger specimen being *T. t. jeffersonii* and the smaller *T. t. berlandieri*. In our study, *T. t. berlandieri* were larger than the one reported specimen from Ruiz-Campos et al. (2002).

Telazol proved to be a reliable anesthetic agent for immobilization of badgers under field conditions and anesthesia was characterized by a rapid induction, wide safety margin, and gradual recovery. A larger sample size was needed in order to determine the best dosage an individual should receive. The first three captured individuals received a dosage that anesthetized the individuals for a period of time that was longer than required for data collection and handling and the final two individuals received a dosage that was enough for all data collection and handling. Data indicated that a mean dosage of 0.75 cc was needed to properly collect data and handle individuals. However, dosage should depend on the goals and objectives of the study. For this study, a lower dosage around 0.35-0.40 cc was needed to properly work on individuals efficiently and safely.

Studies involving badgers conclude that restraint is the number one issue when handling badgers for injection. Fitzgerald (1973) reported the defensive postures assumed by badgers made it difficult to handle and estimate weight. He suggested forcing captured individuals into a restraining cone once a neck noose was around the individual, but found it to be unsuccessful. Bailey (1971) suggested using a pole mounted syringe; however, it is easy to miss muscle mass with the injection being subcutaneous, prolonging immobilization. The badgers we captured were caught with both hind feet in a trap allowing us to place the pole noose around their head and to stretch the individual out flat, making it difficult for the badger to assume any defensive posture. We would approach the badger from the back side, minimizing movement to reduce additional stress on the badger. While capture by both hind legs was more than likely an anomaly, we would suggest being prepared with both a pole-mounted syringe and a pole noose (Ketch-all®, San Luis Obispo, California) to allow for flexibility in handling the captured animal. A pole-mounted syringe would allow for injection if the captured individual was in an awkward space or position, making approach to the animal difficult. However, this situation would increase the risk of injury to the animal as Bailey (1971) suggested. A pole noose allows for approach to captured animals no matter which leg is contained within the leg hold trap, giving the researcher the opportunity to immobilize the animal and provide an unobstructed view for injection of the selected immobilizing agent. Injection was always done in the hind quarter with a 16-gauge syringe containing the estimated dosage of Telezol. Individuals were completely anesthetized before being approached for data collection.

In conclusion, badgers in this study exhibited variation in morphology that has been previously reported in past studies across their range and were anesthetized successfully using a single intramuscular injection which provided an adequate field immobilization time for all data collection and handling procedures.

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Weed Control and Bermudagrass [*Cynodon dactylon* (L.) Pers.] Response to Nicosulfuron Plus Metsulfuron Combinations

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ABSTRACT

Research was conducted from 2007 to 2010 to evaluate nicosulfuron plus metsulfuron combinations for weed control and crop injury to Tifton 85 and Jiggs bermudagrass. Sequential applications of nicosulfuron plus metsulfuron controlled Carolina horsenettle at least 73% with the exception of nicosulfuron at 32.9 g ai/ha plus metsulfuron at 5.3 g ai/ha sequential applications, which controlled Carolina horsenettle 67%. Single applications of nicosulfuron provided 68% or less control. In one study, field sandbur control was 75 to 81% with single applications of nicosulfuron plus metsulfuron while sequential applications of nicosulfuron plus metsulfuron at the higher rates controlled sandbur at least 90%. In another study, field sandbur control was at least 94% when nicosulfuron plus metsulfuron was applied sequentially at 39.4 g ai/ha plus 10.5 g ai/ha, respectively. Johnsongrass control was 88% with nicosulfuron plus metsulfuron at 59.1 plus 13.2 g ai/ha. Although both Tifton 85 and Jiggs were stunted with nicosulfuron plus metsulfuron, stunting was greater on Jiggs. However, only Tifton 85 yield was reduced with nicosulfuron plus metsulfuron combinations.

KEY WORDS: bermudagrass, nicosulfuron, metsulfuron, weed control

INTRODUCTION

Bermudagrass occurs on approximately 12 million ha used for livestock grazing and hay production in the US (Taliaferro et al. 2004). Although ‘Coastal’ bermudagrass has been the predominant hybrid bermudagrass in the southern United States for many years, newer hybrids such as ‘Tifton 85’ have gained popularity in recent years. Tifton 85 and ‘Jiggs’ hybrid bermudagrasses offer high yield and nutritive value (Grichar et al. 2008; Matocha et al. 2010). Tifton 85 is desired by forage producers due to its large rhizomes and rapidly spreading stolons capable of growing > 7.5 cm d (Grichar et al. 2008; Matocha et al. 2010).

Field sandbur (*Cenchrus spinifex* M.A. Curtis) is an annual or short-lived perennial grassy weed commonly found in pastures throughout Texas (Gould 1975). Field sandbur is found in the southern United States from California to North Carolina and is adapted to dry, sandy soils (Holm et al. 1991). When conditions are dry, field

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sandbur is short-lived and produces few burs, while with adequate soil moisture conditions it may be long-lived, grow much larger and produce numerous burs (Holm et al. 1991). Field sandbur competes with forage grasses causing delays in establishment and reducing yield and quality (Walker et al. 1998).

Nicosulfuron plus metsulfuron (Pastora®, DuPont Crop Protection, Wilmington, DE 19898) has recently been registered for selective postemergence (POST) control of sandbur in bermudagrass pastures (Anonymous 2010b). Matocha et al. (2010) reported that field sandbur control with single or sequential applications of nicosulfuron plus metsulfruon was comparable to that previously reported with imazapic plus 2,4-D (Grichar et al. 2008). Other herbicides such as diuron have shown control of sandbur in pasture but must be applied preemergence (PRE) at establishment (Walker et al. 1998). Previous attempts at POST control of field sandbur have focused on low rates of glyphosate applied soon after forage harvest. Grichar et al. (2000) reported at least 90% control of field sandbur with glyphosate at 0.58 and 1.17 L/ha when applied within 8 d after Coastal bermudagrass harvest. Glyphosate application for sandbur control after forage harvest requires timely application (prior to bermudagrass developing new leaves), otherwise significant crop injury may result. Glyphosate applied 17 d after harvest resulted in 36 to 80% injury to Coastal bermudagrass (Grichar et al. 2000).

Grichar et al. (2008) reported that imazapic plus 2,4-D allowed grass producers to control weeds in bermudagrass pastures. However, under dry conditions where water was a limiting factor, bermudagrass stunting and a reduction in forage production was possible. Furthermore, bermudagrass varieties respond differently to imazapic plus 2,4-D with Tifton 85 being more susceptible to injury from imazapic plus 2,4-D than Coastal bermudagrass. Due to the above issues with imazapic plus 2,4-D, the pasture label was removed and imazapic plus 2,4-D is no longer available for pasture use.

Previous research has shown potential for sandbur control with nicosulfuron plus metsulfuron tank mixes (Matocha et al. 2010). Nicosulfuron is a postemergence sulfonylurea herbicide labeled for use in corn (*Zea mays* L.) and controls many difficult to control grassy weeds and some broadleaf weeds at rates of 17.5 to 70 g ai/ha (Anonymous 2009). A single application of nicosulfuron controlled over 90% of quackgrass [*Elythigia repens* (L.) Gould] five weeks after treatment (WAT) and provided greater than 80% control one year later (Bhowmik et al. 1992). When applied in corn, nicosulfuron controlled giant foxtail (*Setaria faberi* Herrm.) 98 to 100% in two years at two locations (Dobbels and Kapusta 1993). Shattercane (*Sorghum bicolor* (L.) Moench ssp. bicolor) was controlled > 90% when nicosulfuron was applied at 30 g/ha (Rosales-Robles 1993).

Metsulfuron controls several broadleaf weeds in bermudagrass (Anonymous 2010a). Kelly and Coats (2000) reported that metsulfuron alone controlled Virginia buttonweed as effectively as 2,4-D and combining the two herbicides was not advantageous if metsulfuron was applied at 32 g/ha or higher. Bradley et al. (2004) reported that metsulfuron controlled broadleaf plantain (*Plantago major* L.), buckhorn plantain (*Plantago lanceolata* L.), and wild carrot (*Daucus carota* L.) 70 to 90%. When applied alone or in combination with 2,4-D, metsulfuron reduced herbaceous broadleaf plant ground cover at several locations in Texas (Meyer and Bovey 1990). Metsulfuron applied alone is not injurious to bermudagrass (Anonymous 2010a).

Metsulfuron may be used for bahiagrass (*Paspalum* spp.) control in bermudagrass pastures, hay fields, golf courses, and sports fields (Bunnell et al. 2003). The herbicide label states that metsulfuron applied between 10.5 and 31.5 g/ha will control bahiagrass in bermudagrass (Anonymous 2010a). The label also states that the higher rate of metsulfuron is needed for control of 'Common', 'Paraguayan', and Argentine bahiagrass (*Paspalum notatum* Fluegge var. *notatum*).

Although the tolerance of hybrid bermudagrass varieties to nicosulfuron plus metsulfuron, as well as field sandbur control has been previously reported (Matocha et al. 2010), additional data using different nicosulfuron plus metsulfuron rates was necessary under the varying conditions found in south Texas. Also, weed efficacy data was needed on weeds commonly found in south Texas pastures including Carolina horsenettle (*Solanum carolinense* L.) and johnsongrass [*Sorghum halepense* (L.) Pers.]. Thus, the objective of this study was to evaluate nicosulfuron plus metsulfuron applied POST at different rates for control of field sandbur, johnsongrass, and Carolina horsenettle and bermudagrass tolerance.

METHODS AND MATERIALS

Pasture weed control studies. Field studies were conducted in 2007, 2009, and 2010 in either Dewitt County near Cuero, TX or in Lavaca County near Shiner, TX in fields with high infestations of field sandbur (10 to 15 plants/m^2), Carolina horsenettle (4 to 6 plants/m^2), or perennial johnsongrass (6 to 8 plants/m^2). The soil at the Dewitt County location was a Crockett fine sandy loam (fine, montmorillonitic, thermic Udertic Paleustalfs) with pH 7.1 and less than 1.0% organic matter, while the soil in Lavaca County was a Victoria sandy clay loam soil (Fine, smectitic, hyperthermic Udic Haplusterts) with pH 7.2 and 1.0% organic matter. Experimental design was a randomized complete block with three replications. Plot size was 2.4 m wide by 9.1 m long.

In the 2007 study near Shiner, in a pasture with a mixed stand of Carolina horsenettle and field sandbur, the herbicides included nicosulfuron at 43.6 g ai/ha plus metsulfuron at 7.0 g ai/ha, nicosulfuron at 54.8 g ai/ha plus metsulfuron at 8.8 g ai/ha, and nicosulfuron at 65.7 g ai/ha plus metsulfuron at 10.5 g ai/ha applied once when Carolina horsenettle was approximately 10 to 15 cm tall while field sandburs were approximately 4 to 6 cm tall. Nicosulfuron at 32.9 g ai/ha plus metsulfuron at 5.3 g ai/ha, nicosulfuron at 43.6 g ai/ha plus metsulfuron at 7.0 g ai/ha, and nicosulfuron at 54.8 g/ha plus metsulfruon at 8.8 g ai/ha were applied two times. Also, nicosulfuron at 43.6 g ai/ha plus metsulfuron at 7.0 g ai/ha, nicosulfuron at 54.8 g ai/ha plus metsulfuron at 8.8 g ai/ha, and nicosulfuron at 65.7 g ai/ha plus metsulfuron at 10.5 g ai/ha were applied at the initial application and followed by nicosulfuron at 32.9 g ai/ha plus metsulfuron at 5.3 g ai/ha at the second application. All herbicide treatments included Induce® [blend of alkylarylpolyoxyalkane ether, free fatty acids, and isopropyl (90%), and water and formulation acids (10%); Helena Chemical Co] at 0.5% v/v. The initial herbicide application (May 22) was made when Carolina horsenettle plants were 10 to 15 cm tall and field sandbur plants were 3 to 6 cm tall with the sequential application (June 12) when Carolina horsenettle was 15 to 18 cm tall. Seasonal rains in 2007 were approximately 51 mm for May and 87 mm for June. An untreated check was included for comparison.

In the field sandbur studies conducted in 2010 in Lavaca and Dewitt Counties, the herbicide treatments included nicosulfuron at 39.4 g ai/ha plus metsulfuron at 10.5 g ai/ha, nicosulfuron at 59.1 g ai/ha plus metsulfuron at 31.2 g ai/ha, nicosulfuron at 39.4 g ai/ha plus metsulfuron at 10.5 g ai/ha plus 32% nitrogen at 75% v/v, and glyphosate at

840 g/ha applied once while nicosulfuron at 39.4 g ai/ha plus metsulfuron at 10.5 g ai/ha was applied twice. The initial herbicide applications (May 20, Dewitt County; June 6, Lavaca County) were made when field sandburs were approximately 2.5 to 5 cm tall while the sequential applications (June 17, Dewitt County; July 6, Lavaca County) were made approximately three to four weeks later when field sandbur was 5 to 8 cm tall. All nicosulfuron plus metsulfuron combinations include Induce® at 0.25% v/v with the exception of the three-way mixture of nicosulfuron plus metsulfruon plus nitrogen which did not include a surfactant. The 2010 season can be characterized as extremely wet with 118, 95, and 201mm rainfall for May, June, and July, respectively.

In the perennial johnsongrass study conducted in Lavaca County in 2009, the herbicide treatments included nicosulfuron at 39.4 g ai/ha plus metsulfuron at 10.5 g ai/ha, nicosulfuron at 59.1 g ai/ha plus metsulfuron at 13.2 g ai/ha, nicosulfuron at 39.4 g ai/ha plus metsulfuron at 10.5 g ai/ha plus 32% nitrogen at 75% v/v, and glyphosate (Roundup Original Max®, Monsanto Company, St. Louis, MO 63167) at 840 g/ha. Johnsongrass was 15 to 20 cm tall at the time of herbicide application (May 18).

All herbicide treatments, with the exception of the three-way mixture of nicosulfuron plus metsulfuron plus nitrogen and the glyphosate treatment, included Induce® at 0.25% v/v. An untreated check was included for comparison. The growing season in 2009 was characterized as extremely dry with rainfall amounts for May, June, and July of 16, 4, and 5 mm, respectively.

Tolerance Study. A field study was conducted in 2008 in Lavaca County near Yoakum, TX on fully established ‘Tifton 85’ and ‘Jiggs’ bermudagrass fields that were weed-free and had no prior herbicide applied during that growing season. The soil in both fields was a Tremona loamy fine sand (thermic Aquic arenic Paleustalfs) with less than 1% organic matter and pH 7.0 to 7.2. The experimental design was a randomized complete block with three replications. Plot size was 2.4 m wide by 9.1 m long. Rainfall for May, June, and July were 1, 65, and 55 mm, respectively. Herbicide treatments included nicosulfuron at 39.4 g ai/ha plus metsulfuron at 10.5 g ai/ha plus Induce at 0.5 % v/v, nicosulfuron at 59.1 g ai/ha plus metsulfuron at 15.7 g ai/ha plus either Induce® at 0.5% v/v, Agridex® (blend of 83% paraffin-based petroleum oil and 17% surfactant; Helena Chemical Company, Suite 500, 6075 Poplar Avenue, Memphis, TN 38137) at 1.0% v/v. or Phase® (100% blend of methylated esters of fatty acids and organosilicone surfactant fluid; Loveland Industries, Inc., Greeley, CO 80632) at 1.0% v/v, and nicosulfuron at 59.1 g ai/ha plus metsulfuron plus either 2,4-D at 1120 g ai/ha, dicamba at 280 g ai/ha plus 2,4-D at 804 g ai/ha (Weedmaster®, BASF Corp., Research Triangle Park, NC 27709), or pendimethalin (Prowl H_20, BASF Corp.) at 2130 g ai/ha. Application timings were based on bermudagrass height with herbicides applied when bermudagrass was approximately 15 to 20 cm tall. The combinations with 2,4-D, dicamba plus 2,4-D, and pendimethalin were planned since many hay producers use these combinations to improve hay quality (author’s personal observations). Sequential nicosulfuron plus metsulfuron were planned but not applied due to extremely dry conditions.

Herbicide application, weed control, bermudagrass injury, and harvest. All herbicide applications were made with a CO_2 backpack sprayer equipped with 11002 DG flat fan nozzles (11002 DG flat fan spray tips, Teejet Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60188) calibrated to deliver 187 L/ha at 200 kPa pressure.

Weed control was estimated visually through the growing season on a scale of 0 to 100 (0 indicated no control and 100 indicated complete control), relative to the nontreated control. Very little bermudagrass was present in study areas due to heavy weed infestions; therefore, no attempt was made to rate bermudagrass response to herbicides in the weed control studies. Data were subject to ANOVA and means were separated using Duncan's MRT test at P = 0.05.

Tifton 85 and Jiggs phytotoxicity was evaluated visually at 15 and 35 d after herbicide treatment using a scale of 0 to 100 with 0 = no injury to 100 = plant death. A 1.2 m^2 area of each bermudagrass plot was hand harvested when bermudagrass was approximately 45 to 60 cm tall using hand-clippers to a height of approximately 5 cm above soil surface. Both bermudagrass varieities were harvested only once due to severe drought conditions, which developed during the 2008 growing season. After samples from each harvest were air dried, bermudagrass yields on a dry matter basis were determined. Data were subjected to ANOVA and treatment means were separated using Duncan's MRT test at P = 0.05.

RESULTS AND DISCUSSION

Field Sandbur Control. In 2007, when rated 21 days after treatment (DAT), all initial nicosulfuron plus metsulfruon combinations provided at least 80% field sandbur control (Table 1). When rated 42 DAT, all sequential applications of nicosulfuron plus metsulfuron, with the exception of nicosulfuron at 32.9 g/ha plus metsulfuron at 5.3 g ai/ha, provided at least 90% control while single applications of nicosulfuron plus metsulfuron were 75 to 81%.

In 2010, at Location 1, field sandbur control was at least 88% with all herbicide treatments (including glyphosate) when rated 27 DAT (Table 2). When rated 69 DAT, complete field sandbur control was obtained with the sequential treatment of nicosulfuron at 39.4 g ai/ha plus metsulfuron at 10.5 g ai/ha while nonsequential applications of nicosulfuron plus metsulfuron controlled field sandbur no greater than 88% and glyphosate controlled 63%. At Lavaca County, glyphosate at 840 g/ha and nicosulfuron at 59.1 g ai/ha plus metsulfuron at 13.2 g ai/ha provided at least 91% control when rated 29 DAT while at the 106 DAT rating only the sequential treatment of nicosulfuron plus metsulfuron controlled field sandbur at least 90% (Table 2). These results confirm earlier work in which Matocha et al.(2010) reported that sequential applications of nicosulfuron at 54.8 g ai/ha plus metsulfuron at 8.8 g ai/ha provided 85% field sandbur control, whereas all nonsequential treatments provided less than 63% control. Also, field sandbur control with nicosulfuron plus metsulfuron was comparable to that previously reported with imazapic plus 2,4-D (Grichar et al. 2008). Grichar et al. (2008) reported that imazapic plus 2,4-D controlled sandbur 83 to 99% in forage bermudagrass. However, bermudagrass injury from imazapic plus 2,4-D ranged between 28 to 87%. Low rates of glyphosate (280 to 540 g/ha) applied within 8 d of forage harvest has controlled field sandbur (Grichar et al. 2000) and is currently used by some hay products as a means of improving hay quality by reducing field sandbur infestations (author's personal observations).

Table 1. Field sandbur control with nicosulfuron plus metsulfuron combinations in 2007 near Shiner, TX.[a]

Treatment[b,c]	Rate	Field sandbur 21 DAT	Field sandbur 42 DAT
	(g ai/ha)	(%)	
Untreated check	-	0	0
Nicosulfuron + metsulfuron	43.6 + 7.0	83	75
Nicosulfuron + metsulfuron	54.8 + 8.8	85	81
Nicosulfuron + metsulfuron	65.7 + 10.5	87	77
Nicosulfuron + metsulfuron fb nicosulfuron + metsulfuron	32.9 + 5.3 fb 32.9 + 5.3	80	84
Nicosulfuron + metsulfuron fb nicosulfuron + metsulfuron	43.6 + 7.0 fb 43.6 + 7.0	81	90
Nicosulfuron + metsulfuron fb nicosulfuron + metsulfuron	43.6 + 7.0 fb 32.9 + 5.3	80	92
Nicosulfuron + metsulfuron fb nicosulfuron + metsulfuron	54.8 + 8.8 fb 32.9 + 5.3	83	94
Nicosulfuron + metsulfuron fb Nicosulfuron + metsufuron	65.7 + 10.5 fb 32.9 + 5.3	80	95
Nicosulfuron + metsulfuron fb nicosulfuron + metsulfuron	54.8 + 8.8 fb 54.8 + 8.8	81	90
LSD (0.05)		7	5

[a] Abbreviations: DAT, days after initial herbicide treatment; fb, followed by.
[b] Initial herbicide application made when Carolina horsenettle was 10 to 17 cm tall while field sandbur was 3 to 6 cm tall. Sequential applications made when Carolina horsenettle was 10 to 16 cm tall and field sandbur was 6 to 8 cm tall, approximately one week after initial application.
[c] All herbicide treatments included Induce at 0.5% v/v.

Johnsongrass control. When rated 22 DAT, johnsongrass control was greater than 90% with all herbicides including glyphosate; however, when rated 107 DAT, only nicosulfuron at 59.1 g ai/ha plus metsulfuron at 13.2 g ai/ha provided greater than 85% control (Table 3). Lack of rainfall after herbicide application (only 16 mm for May) may have accounted for poor johnsongrass control. The reduced performance of other postemergence herbicides such as fenoxaprop have been reported under conditions of moisture stress (Dortenzio and Norris 1980). Alleviating moisture stress with irrigation within 48 h of herbicide application improved fenoxaprop efficacy in crabgrass (*Digitaria* spp.) (Rossi et al. 1993). Rossi et al. (1993) reported that decreased spray retention and alterations in fenoxaprop metabolism contribute to reduced fenoxaprop activity observed in moisture-stressed smooth crabgrass (*Digitaria ischaemum*).

Table 2. Field sandbur control with nicosulfuron plus metsulfuron combinations[a,b].

Treatment[c,d]	Rate (g ai/ha)	Location 1 27 DAT	Location 1 69 DAT	Location 2 29 DAT	Location 2 106 DAT
		(%)			
Untreated check	-	0	0	0	0
Nicosulfuron + metsulfuron	39.4 + 10.5	94	73	87	47
Nicosulfuron + metsulfuron	59.1 + 13.2	97	88	91	83
Nicosulfuron + metsulfuron fb nicosulfuron + metsulfuron	39.4 + 10.5 fb 39.4 + 10.5	88	100	78	94
Nicosulfuron + metsulfuron + 32% nitrogen	39.4 + 10.5 + 75% v/v	92	68	84	53
Glyphosate	840 g	95	63	99	70
LSD (0.05)		10	15	10	38

[a] Location 1, Dewitt County; Location 2, Lavaca County.
[b]Abbreviations: DAT, days after initial herbicide treatment; fb, followed by.
[c] Initial herbicide application made when field sandbur was 2.5 to 5 cm tall. Sequential application made when field sandbur was 5 to 8 cm tall, approximately one month after initial application.
[d] All nicosulfuron + metsulfuron treatments with the exception of the 32% N treatment and glyphosate included Induce at 0.25% v/v.

Table 3. Johnsongrass control with nicosulfuron plus metsulfuron combinations [a b].

Treatment[c]	Rate (g ai/ha)	Lavaca County 22 DAT	Lavaca County 107 DAT
		(%)	
Untreated check	-	0	0
Nicosulfuron + metsulfuron	39.4 + 10.5	94	73
Nicosulfuron + metsulfuron	59.1 + 13.2	97	88
Nicosulfuron + metsulfuron + 32% nitrogen	39.4 + 10.5 + 75% v/v	92	68
Glyphosate	840	95	63
LSD (0.05)		10	15

[a] Abbreviations: DAT, days after initial herbicide treatment; fb, followed by.
[b] Herbicide application made when johnsongrass was 15 to 20 cm tall.
[d] All nicosulfuron + metsulfuron treatments with the exception of the 32% N treatment included Induce at 0.25% v/v.

Bermudagrass response to nicosulfuron plus metsulfuron combinations. Visual injury ratings for Tifton 85 15 DAT with nicosulfuron plus metsulfuron alone ranged from 8 to 15% while the addition of 2,4-D, dicamba plus 2,4-D, and pendimethalin to the nicosulfuron plus metsulfuron combination resulted in no greater than 4% injury (Table 4). By 35 DAT, only the nicosulfuron at 59.1 g ai/ha plus metsulfuron at 15.7 g ai/ha plus Agridex combination injured Tifton 85 10% while all other nicosulfuron plus metsulfuron combinations injured Tifton 85 4% or less. Combinations with 2,4-D, dicamba plus 2,4-D, or pendimethalin did not cause any injury.

Table 4. Bermudagrass injury with nicosulfuron plus metsulfuron combinations[a].

Treatment[b]	Rate (g ai/ha)	Tifton 85 15 DAT	Tifton 85 35 DAT	Jiggs 15 DAT	Jiggs 35 DAT
		(%)			
Untreated check	----	0	0	0	0
Nicosulfuron + metsulfuron + Induce	39.4 + 10.5 + 0.5 % v/v	13	2	17	2
Nicosulfuron + metsulfuron +Induce	59.1 + 15.7 + 0.5 % v/v	8	4	13	3
Nicosulfuron + metsulfuron +Agridex	59.1 + 15.7 + 1.0 % v/v	15	10	15	7
Nicosulfuron + metsulfuron +Phase	59.1 + 15.7 + 1.0 % v/v	12	0	18	2
Nicosulfuron + metsulfuron + 2,4-D + Induce	59.1 + 15. 7 + 1120 + 0.5 % v/v	1	0	13	0
Nicosulfuron + metsulfuron + dicamba + 2,4-D[c] + Induce	59.1 + 15.7 + 280 + 804 + 5 % v/v	1	0	10	5
Nicosulfuron + metsulfuron + pendimethalin[d] + Induce	59.1 + 15.7 + 2130 + 0.5 % v/v	4	0	10	1
LSD (0.05)		8	6	10	7

[a] Abbreviations: DAT, days after herbicide treatment.
[b] Herbicide application made when bermudagrass was 15 to 20 tall.
[c] Marketed as Weedmaster®.
[d] Marketed as Prowl H_20®.

Table 5. Bermudagrass dry matter yield with nicosulfuron plus metsulfuron combinations[a].

Treatment[b]	Rate (g ai/ha)	Bermudagrass Tifton 85 (Kg/ha)	Bermudagrass Jiggs (Kg/ha)
Untreated check	-	5770	4414
Nicosulfuron + metsulfuron + Induce	39.4 + 10.5 + 0.5 % v/v	3329	3329
Nicosulfuron + metsulfuron +Induce	59.1 + 15.7 + 0.5 % v/v	3206	3995
Nicosulfuron + metsulfuron +Agridex	59.1 + 15.7 + 1.0 % v/v	2663	4883
Nicosulfuron + metsulfuron +Phase	59.1 + 15.7 + 1.0 % v/v	2885	2441
Nicosulfuron + metsulfuron + 2,4-D + Induce	59.1 + 15. 7 + 1120 + 0.5 % v/v	4217	4883
Nicosulfuron + metsulfuron + dicamba + 2,4-D[c] + Induce	59.1 + 15.7 + 280 + 804 + 0.5 % v/v	4880	3551
Nicosulfuron + metsulfuron + pendimethalin[d] + Induce	59.1 + 15.7 + 2130 + 0.5 % v/v	5992	3995
LSD (0.05)		2213	2148

[a] Abbreviations: DAT, days after initial herbicide treatment.
[b] Herbicide application made when bermudagrass was 15 to 20 tall.
[c] Marketed as Weedmaster®.
[d] Marketed as Prowl H_20®.

Results of these studies indicate that nicosulfuron plus metsulfuron combinations are a viable option for field sandbur control and will provide partial control of johnsongrass and Carolina horsenettle which are also commonly found in bermudagrass pastures in Texas. Under low moisture conditions, some stunting and yield reduction is possible with nicosulfuron plus metsulfuron combinations.

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Forecasting Volatility of Returns for Corn using GARCH Models

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ABSTRACT

The purpose of this paper is to model and forecast volatility of returns for corn futures prices using GARCH models. Non-linear models from the GARCH family, specifically TGARCH and EGARCH are employed to assess the role of asymmetries and to analyze the time varying volatility of corn futures prices. The results reveal that the corn return series react differently to good and bad news. The presence of leverage effect would imply that the negative news has bigger impact on volatility than positive news of the same magnitude. The estimated volatility models were compared using symmetric measures for their forecasting accuracy. It is found that the EGARCH model provides the best out of sample forecasts for corn among all the GARCH specifications.

KEY WORDS: volatility, forecasting, GARCH models, corn futures

INTRODUCTION

Financial market volatility analysis has garnered the attention of academics as well as market participants across the world for the last two decades. Volatility can be defined as fluctuations in the standard deviation of daily returns for the selected asset or commodity. Volatility analysis is important as a risk management tool for hedging effectiveness, as well as, aiding in the selection and management of asset portfolios (Jondeau and Rockinger 2003).

Commodity prices fluctuate continuously throughout the year due to changes in the underlying supply and demand variables. Analyzing the volatility behavior of an agricultural commodity, like corn, has implications for both farmers and market participants. For example, market prices of agricultural commodities typically increase before harvest and fall after harvest, thereby causing volatility swings. Any surprising USDA crop reports, whether they be the condition of current crop progress or changes in the inventory of grain stocks (either surpluses or shortages), immediately put the commodity markets into an acceleration mode. Understanding volatility helps farmers in managing their production risks and making proper marketing decisions. This also helps

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farmers in minimizing their market exposure during periods of higher volatility. Volatility analysis can also be helpful in developing an effective hedge against adverse price movements. Market investors can also benefit from these studies in properly selecting and managing their investment portfolio. Periods of excess volatility help commodity traders, especially day traders, to gain significant profits through trading strategies tailored to volatilities. Knowledge about the source of price volatility can be useful to risk managers in making decisions about the timing of their decisions (Evans et al. 1992). Price limits and contract margins imposed by commodity exchanges, also in part, depend upon the volatility of corresponding commodities. Commodity traders who write options also need to forecast the volatility of the price process over the life time of the option (Alexander 2001). Volatility also has an important effect on the macro economy of a country. For example, increased volatility, beyond a certain threshold will increase the risk of losses to investors and raise concerns regarding the stability of a particular market and the overall economy (Pan and Zhang 2006).

Previous research on volatility analysis has been mostly concentrated on the financial indices. Volatility research in the commodity markets typically focused on understanding the sources of volatility and little attention has been paid to forecasting the volatilities. The purpose of the present paper is to model and forecast volatility of returns for corn using different types of GARCH models. We are also interested in examining whether positive and negative shocks have an asymmetric effect on return volatility and thereby provide evidence for any leverage effect in corn. The paper uses three different types of Generalized Autoregressive Conditional Heteroscedasticity (GARCH) specifications: the standard GARCH, Exponential GARCH (EGARCH), and the Threshold GARCH (TGARCH) specifications to model and forecast the volatility (conditional variance). These models are known to capture the characteristics of financial time series such as time varying volatility, non-linearity dependence, and volatility clustering (See Pagan 1996; Enders 2004). The specifics of the ARCH model formulations are discussed in detail in the next section.

A quick review of recent literature shows various sources for volatility and its application in different areas. For example, Bernanke and Gertler (1999) discussed the role of volatility of financial markets and its effect on monetary policy. Crato and Ray (2000) studied the volatility of commodity markets and concluded that the volatility is more persistent for energy markets than the currency markets. Bajpai and Mohanty (2008) used EGARCH model with normal and non-normal errors to estimate the volatility of exchange rate. Their results indicate a negative relationship between exchange rate volatility and U.S. cotton exports to major countries. Brorsen and Irwin (1987) investigated if there is a significant relationship between the technical trading and increased volatility of ten different commodities. Their results show that technical trading is not a significant factor in contributing to the volatility of commodities. According to Irwin et al. (2008), recent surges in the volatility of agricultural commodities are due to structural changes in the markets and strong linkages with the energy complex. Crain and Lee (1996) suggested that the grain price volatility is influenced by changes in government programs and according to the authors, volatility typically transfers from futures markets to cash markets. With regard to the forecasting ability, Cao and Tsay (1992) point out that the TGARCH model produces better forecasts than GARCH, EGARCH, and ARMA models on the U.S. stock exchange. Balaban (2002) argues symmetric GARCH models provide relatively good forecasts of monthly exchange rate volatility in comparison with asymmetric models.

The structure of the paper is organized as follows: Section II describes the econometric methodology employed in the paper, Section III describes the data, Section IV discusses the results obtained from the analysis, and finally, the last section summarizes the paper.

METHODOLOGY

Our analysis of volatility forecasting begins with the calculation of continuously compounded daily returns for corn based on the following equation

$$r_t = [\ln(p_t / p_{t-1})] \quad (1)$$

Where r_t represents the daily log returns for corn, p_t denotes the daily settlement price for the commodity, while p_{t-1} represents the settlement prices with one lag.

Random Walk Model. The behavior of asset prices relating to its random nature has attracted the attention of researchers worldwide. Proponents of Efficient Market Hypothesis (EMH) argue that the asset prices typically behave in a random fashion and any attempt to forecast future values based on its past values is futile (Fama 1965, 1970; Cooper 1982).

The basic model for estimating the volatility of returns using OLS is the naïve random walk (RW) model and is given by:

$$r_t = \mu + \varepsilon_t \quad (2)$$

Where μ is the mean value of returns, which is expected to be insignificantly different from zero under EMH, and ε_t is the error term.

The drawback of the above model is that it can be used only to characterize the mean returns. Traditional econometric models such as ordinary least squares are built upon the assumption of constant variance. The error variances may not be constant over time. The assumption of constant variance of the error term is inconsistent with financial time series where the variance is heteroskedastic and time-varying. In order to account for the time varying volatility which cannot be captured through linear models like OLS, this study uses GARCH models.

GARCH Specifications. The Generalized Autoregressive Conditional Heteroscedasticity (GARCH), was developed independently by Bollerslev (1986) and Taylor (1986), was used in the present study to investigate the effect of volatility of corn futures prices. The appeal of the GARCH model is that it takes into consideration both mean and volatility in modeling the financial returns, and has an advantage over the traditional regression models. It also has the ability to capture volatility clustering, a characteristic of financial time series, where large returns are followed by large returns, small returns followed by small returns, leading to contiguous periods of volatility and stability (Mandelbrot 1963). Rarely, any higher order model than GARCH (1,1) is needed to capture volatility clustering (Alexander 2001; Brooks 2008).

The GARCH model is based on the assumption that forecasts of time varying variance depend upon the lagged variance of the asset. The analysis of the model involves estimation of two distinct specifications: one for the conditional mean and the other for conditional variance.

The basic GARCH (1,1) can be represented as:

$$r_t = \mu + \theta r_{t-1} + \varepsilon_t; \qquad \varepsilon_t \approx (0, h_t) \tag{3}$$

$$h_t = \omega + \alpha \varepsilon_{t-1}^2 + \beta h_{t-1} \tag{4}$$

Where $\omega \succ 0, \alpha \geq 0, \beta \geq 0$ are required to ensure that the conditional variance is never negative. The variance (h_t) is a function of an intercept (ω), a shock from the prior period (ε_{t-1}) and the variance from the last period (h_{t-1}).

The ARCH terms indicates the short run persistence of shocks whereas the GARCH term represents the contribution of shocks to long run persistence. $(\alpha + \beta)$ is a measure of persistence of volatility clustering. If $(\alpha + \beta)$ is very close to 1, it shows high persistence in volatility clustering. The GARCH (1,1) is weak stationary if $(\alpha + \beta) < 1$.

The above GARCH model assumes a symmetric volatility response to market news. According to GARCH specification, positive and negative shocks have the same effect on volatility, as the unexpected return (ε_t) always enters the conditional variance as a square. It has been suggested in the financial literature that negative shocks in the market have a larger impact on volatility than positive shocks of the same magnitude (Asteriou and Hall 2011; Brooks 2008; Zivot 2008; Bollerslev et al. 1992; Engle and Ng 1993). As a result, Asymmetric GARCH models are more appropriate.

Two Asymmetric GARCH models (TGARCH and EGARCH) have been employed in the present paper to study the possible asymmetries typically attributed to leverage effects for corn futures returns. Asymmetry can be introduced in the ARCH models by weighing ε_{t-1}^2 differently for positive and negative residuals, thus,

$$r_t = \mu + \theta r_{t-1} + \varepsilon_t; \qquad \varepsilon_t \approx (0, h_t) \tag{5}$$

$$h_t = \omega + \alpha \varepsilon_{t-1}^2 + \beta h_{t-1} + \gamma I_{t-1} \varepsilon_{t-1}^2 \tag{6}$$

This model is called TGARCH , following the works of Zakoian (1994) and Glosten et al. (1993) where α, β, and γ are constant parameters and I_t is an indicator dummy variable that takes the value of 1 if $\varepsilon_{t-1} < 0$ and zero otherwise. When ε_{t-1} is positive, the total contribution to volatility is $\alpha \varepsilon_{t-1}^2$ and when ε_{t-1} is negative, the total contribution to the volatility is $(\alpha + \gamma)\varepsilon_{t-1}^2$. The TGARCH (1,1) model is asymmetric as long as $\gamma \neq 0$.

The TGARCH models can be extended to higher order specifications by including more lagged terms. The TGARCH *(p,q)* model is defined by adding p terms to the right side of equation (6), so that

$$h_t = \omega + \sum_{i=1}^{p} (\alpha_i + \gamma_i I_{t-1}) \varepsilon_{t-i}^2 + \sum_{j=1}^{q} \beta_j h_{t-j} \tag{7}$$

The parameters in the model usually constrained by $\omega \geq 0, \alpha \geq 0, \beta \geq 0$ and $\alpha + \gamma > 0$.

The EGARCH specification of conditional volatility due to Nelson (1991) may be expressed as:

$$r_t = \mu + \theta r_{t-1} + \varepsilon_t ; \qquad \varepsilon_t \approx (0, h_t) \tag{8}$$

$$\ln(h_t) = \omega + \beta \ln(h_{t-1}) + \gamma \frac{\varepsilon_{t-1}}{\sqrt{h_{t-1}}} + \alpha \left[\frac{|\varepsilon_{t-1}|}{\sqrt{h_{t-1}}} - \sqrt{\frac{2}{\pi}} \right] \tag{9}$$

As the name indicates, EGARCH assumes conditional variance as exponential, whereas TGARCH treats conditional variance as quadratic. The above model has several advantages over the traditional GARCH specification. As h_t is modeled in log form, even if the parameters are negative, h_t becomes positive. Another advantage is allowance of asymmetries in the EGARCH model formulation. In EGARCH, γ captures the asymmetrical effect and therefore any non-zero values shows the impact of any external event being asymmetric. For detailed information on GARCH models readers may refer to Bollerslev et al. (1992, 1994).

Forecasting Methodology. The random walk and GARCH models are evaluated in terms of their ability to forecast future returns. The forecasting performance of each model is evaluated by using standard symmetric measures: the root mean square error (RMSE), the mean absolute error (MAE), the mean absolute percent error (MAPE), and the Theil inequality coefficient (TIC). The forecasting statistics are given as follows:

$$RMSE = \sqrt{\frac{1}{T} \sum_{t=1}^{T} (\hat{\sigma}_t^2 - \sigma_t^2)^2} \tag{10}$$

Where $\hat{\sigma}_t^2$ is one step ahead volatility forecast, σ_t^2 is the actual volatility and T is the number of forecasts.

$$MAE = \frac{1}{T} \sum_{t=1}^{T} \left| \hat{\sigma}_t^2 - \sigma_t^2 \right| \tag{11}$$

$$MAPE = \frac{1}{T} \sum_{t=1}^{T} \frac{\left| \hat{\sigma}_t^2 - \sigma_t^2 \right|}{\left| \sigma_t^2 \right|} \tag{12}$$

$$TIC = \frac{\sqrt{\frac{1}{T} \sum_{t=1}^{T} (\hat{\sigma}_t^2 - \sigma_t^2)^2}}{\sqrt{\frac{1}{T} \sum_{t=1}^{T} (\hat{\sigma}_t^2)^2} \sqrt{\frac{1}{T} \sum_{t=1}^{T} (\sigma_t^2)^2}} \tag{13}$$

The Theil inequality coefficient is the scaled measure that always lies between 0 and 1 where zero indicates a perfect fit. The best model for forecasting is the one with the smallest value for that measure.

The data used in the present paper is the daily settlement prices for corn, covering the period of January 3, 1995 to June 16, 2012, excluding public holidays. In order to eliminate price distortions caused by price gaps located between expiring contracts and subsequent futures contracts, this study used continuous corn futures contract developed from the settlement prices. The total sample comprises 3954 observations spanning approximately seventeen years of daily data. Corn is traded on the Chicago Board of Trade (CBOT) and is the most actively traded (liquid) contract among all the agricultural commodities. As of June 2012, the average daily volume for December 2012 corn is 137,332 contracts with an open interest of 420,282. In order to make forecasts, the full sample is divided into two parts: an in sample of 3954 observations (January 03, 1995 to September 16, 2010) and an out of sample of 439 observations (September 17, 2010 to June 16, 2012). The last 10% of observations are reserved for forecasting purposes.

RESULTS

Figure 1 represents the price index for corn (panel a) and the time series of daily returns calculated from the settlement prices (panel b) for the study period. Visual inspection of the return series shows that the mean returns are constant but the variances change over time. The commodity exhibits volatility clustering property indicating periods of high volatility (turbulence) and low volatility (tranquility). From the figure, it is evident that the volatility of corn had increased significantly during the recent times when compared to the initial periods. Periods of high volatility show large positive and negative returns when compared to the low volatility periods. The bottom part of figure 1 consists of histogram of returns (panel c) and a Gaussian QQ plot (panel d). The distribution of returns is characterized by a high peak at the center, which is considered to be a stylized fact of financial time series. For a detailed discussion of stylized facts, please see Taylor (2005) and Kovacic (2008). The QQ plot plots the quantiles of two distributions: the empirical distribution of corn returns and the hypothesized Gaussian distribution. The QQ plot clearly shows that the distribution tails for corn are heavier than the tails of the Gaussian distribution.

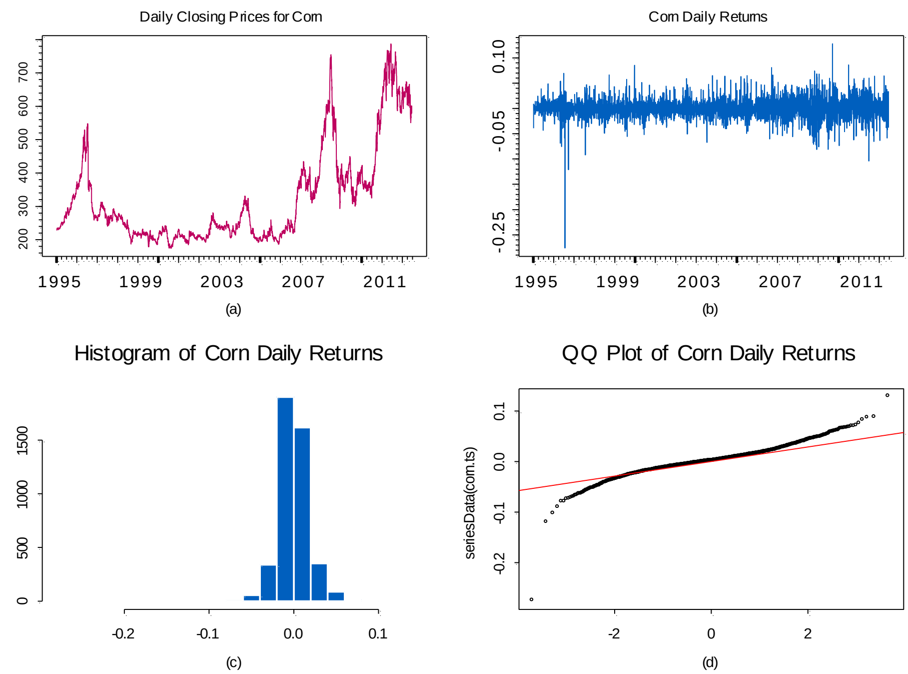

Figure 1. Corn Daily Returns and Tail Distribution.

The descriptive statistics for the time series of daily returns for corn are presented in Table 1. This table includes minimum, maximum, average daily returns, standard deviation, skewness, kurtosis, and Jarque-Bera statistics of the returns. As expected of financial time series, the mean of returns is close to zero. Positive mean returns show that the price series of corn has increased through time. The standard deviation of the daily returns is 1.847% which is equivalent to an annualized volatility of 29.32%. Corn shows high standard deviation and therefore considered to be a volatile commodity. The statistics also show a substantial difference between maximum and minimum returns for this commodity. The presence of slight negative skewness indicates that the lower tail of the distribution was thicker than the upper tail and decline in returns are more common than its increases. The kurtosis for the time series is 17, which is above the normal value of 3, and is considered as leptokurtic in nature. Generally, either a very high or very low kurtosis value indicates leptokurtic or platykurtic distribution of the sample data. The Jarque-Bera statistics indicate that the return series is non-normal and significant as evidenced by its p-value. These findings are consistent with earlier discussion related to the histogram of returns and QQ plot.

Table 1. Descriptive Statistics of Daily Returns for Corn.

Mean	0.000219	Skewness	-0.72694
Maximum	0.12757	Kurtosis	17.0095
Minimum	-0.2762	Jarque-Bera	36303.98
Std. Deviation	0.01847	Probability	0.00000

Table 2 shows the estimation results for the mean and variance equations for random walk (RW), GARCH, TGARCH, and EGARCH models of volatility for corn. The z statistics are also reported in the parentheses for each model. The results for RW model suggest that the mean of the return series is not significantly different from zero, which is consistent with the random walk hypothesis. The Ljung-Box Q statistics of the standard residuals (19.91), squared residuals (40.58) and ARCH-LM tests (5.99) are significant and show the presence of significant ARCH effects in the model. Since the OLS estimate of RW is an inadequate model to capture the financial return characteristics such as time varying volatility and volatility clustering, GARCH models were further used to understand the nature of commodity data. The model rankings also suggest that the RW model is the least preferred model among all the specifications. Columns 3, 4, and 5 in Table 2 show the mean returns and variance equation of the GARCH (1,1), TGARCH (1,1), and EGARCH (1,1) models respectively for the volatility estimation. Preliminary analysis suggests that the conditional mean equation for corn was best modeled as an autoregressive process, especially, an AR (1). The recent literature also suggests the inclusion of AR (1) is useful in order to remove any serial correlation in the returns which may be caused by non-synchronous trading (Lo and MacKinlay 1988; Campbell et al. 1997; Tsay 2002). Thus the mean equation in all the GARCH specifications includes an AR (1) term for this study. The z statistics indicate the significance of the intercept and coefficients at 5% significance level.

The mean daily returns range from 0.0387% to 0.0534% for all the GARCH specifications, whereas only GARCH (1,1) coefficient proved to be significant at 5% level. From the mean equation in the GARCH models, we also observe that the lagged value (θ) is significant for corn for all the specifications indicating that the returns of this commodity exhibit serial correlation and reflects inefficiency during the period of study. The coefficients of the conditional variance equation, α and β, are positive and significant for all the GARCH models suggesting strong support for ARCH and GARCH effects. The GARCH coefficient (β) can be used to understand the impact of past volatility on current volatility. The GARCH coefficient is significant at 5% level suggesting that the current volatility is affected by past volatility for corn. As typical of GARCH models for financial returns, the sum of the coefficients on lagged squared error (α) and lagged conditional variance (β) is very close to one implying that shocks to the conditional variance will be highly persistent for corn. A high persistence indicates that the shocks are likely to die slowly. If there is a new price shock, it will have implication on returns for a longer period. The only exception here is EGARCH model where sum of both α and β coefficients are greater than one and parameters are overestimated.

The asymmetric (leverage) coefficient γ captures the impact of negative versus positive shocks on volatility. Leverage coefficient (γ) when greater than zero under the TGARCH model, indicates that the negative shocks cause more volatility than positive shocks. Accordingly, γ is positive and significant for corn suggesting the presence of leverage effect. For this commodity, negative shocks tend to cause more volatility than positive news. Under EGARCH model, when the leverage coefficient is less than zero, then the positive shocks (good news) generate less volatility than negative shocks (bad news). Accordingly, with a negative and significant γ, the results indicate that negative news caused more volatility for corn confirming the earlier results of TGARCH model.

Table 2. Volatility Models and their Corresponding Results.

Parameter	RW	GARCH (1,1)	TGARCH (1,1)	EGARCH (1,1)
Mean Equation				
μ	0.000205 (0.71)	0.000534* (2.24)	0.000410 (1.64)	0.000387 (1.53)
θ		0.036* (2.16)	0.040* (2.38)	0.044* (2.74)
Variance Equation				
ω		3.44E-06* (9.27)	3.77E-06* (8.40)	-0.27324* (-14.68)
α		0.069* (27.26)	0.055* (12.58)	0.161* (26.42)
β		0.924* (380.87)	0.919* (358.66)	0.981* (482.37)
γ			0.038* (5.06)	-0.014* (-2.41)
LB 10	19.91* (0.03)	8.28 (0.50)	8.33 (0.50)	7.74 (0.56)
LB^2 10	40.58* (0.00)	3.25 (0.95)	3.43 (0.94)	3.25 (0.95)
ARCH-LM Test	5.99* (0.01)	0.007 (0.93)	0.0004 (0.98)	0.015 (0.90)
AIC	-5.18[4]	-5.36[3]	-5.37[2]	-5.38[1]
LL	10251.03[4]	10615.13[3]	10621.09[2]	10651.32[1]

θ is AR(1) coefficient; *denotes significance at 5% level. Numbers in parentheses below coefficient estimates are z statistics. AIC, LL are Akaike information criteria, and log likelihood respectively. LB 10 and $LB^2$10 are the Ljung-Box statistics for the standardized and squared standardized residuals using 10 lag, respectively. Numbers in parentheses below the LB statistics and arch coefficients are the p-values. Superscript denotes the rank of model.

Finally, to determine which GARCH model provides a reasonable explanation of behavior of commodity returns, some diagnostic tests are performed. The diagnostic tests results show that the GARCH models are correctly specified and there are no remaining ARCH effects in all the estimated GARCH models. The Ljung-Box Q statistics for the standard residuals and squared residuals are insignificant, suggesting that all the GARCH models are correctly specified (Table 2). Overall, using the minimum AIC, maximum log likelihood values as model selection criteria (Alagidede and Panagiotidis 2006) for the GARCH specifications, the model rankings indicate that the

EGARCH (1,1) is the preferred model for corn and captures most of the time series characteristics of the returns during the study period.

The models were also evaluated in terms of their ability to forecast volatility of future returns. The measures of forecast evaluation used in the present study include root mean square error (RMSE), mean absolute error (MAE), mean absolute percent error (MAPE) and Theil's inequality coefficient (TIC). Table 3 reports the forecast performance values and the corresponding ranking for all the GARCH models. The results indicate that the relative differences among forecasting performance measures are quite small and the largest relative difference between the best and worst performing models for out of sample data using TIC is approximately 4%. Figure 2 presents the out of sample volatility forecast and variance forecast of the corn returns. The forecasting results show that EGARCH (1,1) model is the most preferred among all the models and the naïve RW model performed worse in forecasting the volatility of returns for corn. Thus the EGARCH model was found to be the best model to study the volatility behavior and the corresponding forecasting of returns.

Table 3. Forecast Performance of the Estimated GARCH Models.

Forecast Criteria	RW	GARCH (1,1)	TGARCH (1,1)	EGARCH (1,1)
Root Mean Square Error (RMSE)	0.021796[4]	0.021609[3]	0.021606[2]	0.021412[1]
Mean Absolute Error (MAE)	0.015993[4]	0.015515[3]	0.015219[2]	0.015024[1]
Mean Absolute % Error (MAPE)	111.49[1]	143.42[4]	135.48[3]	135.03[2]
Theil Inequality Coefficient (TIC)	0.9905[4]	0.9584[3]	0.9577[2]	0.9545[1]
Overall Rank	4	3	2	1

Forecast sample: September 17, 2010 to June 16, 2012; superscript indicates the rank of the model

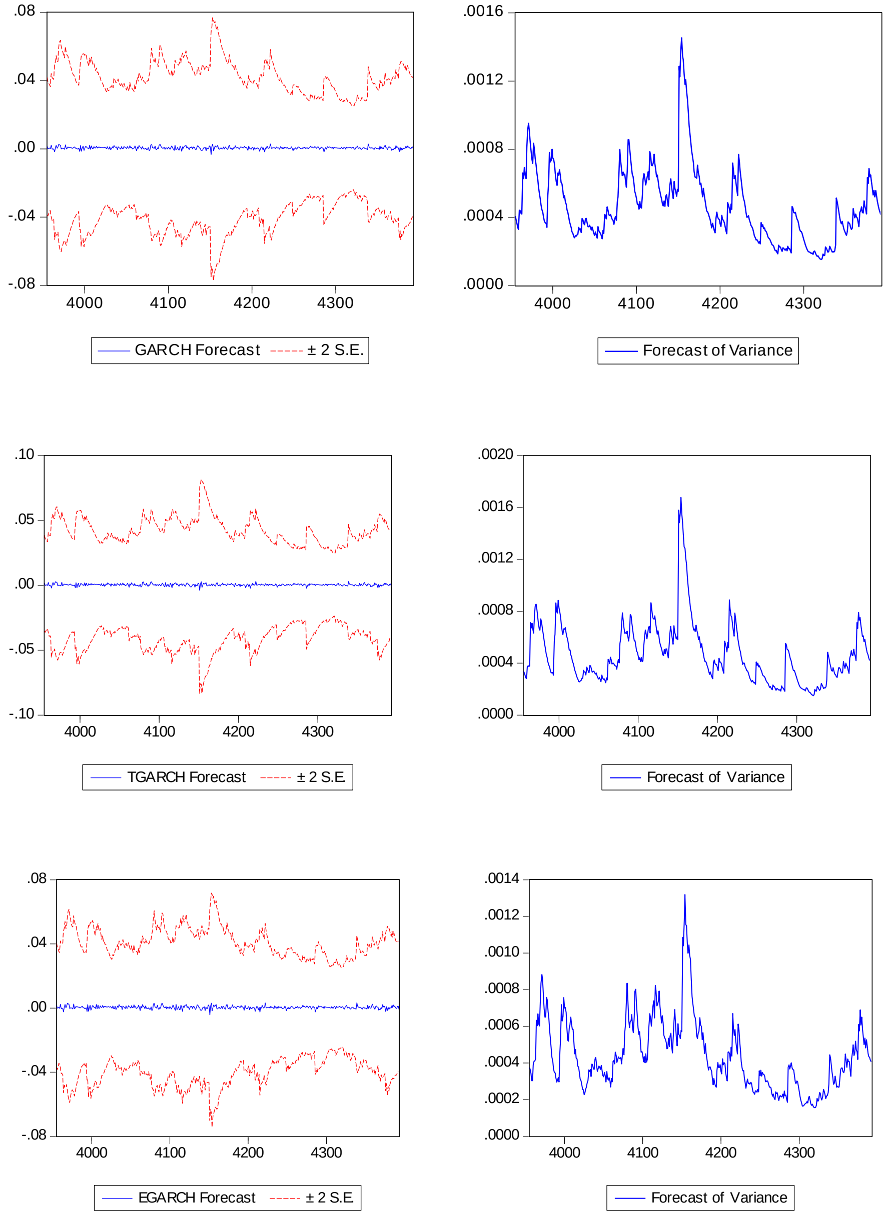

Figure 2. Volatility Forecast and Forecast of Variance Graphs.

CONCLUSIONS

This paper contributes to the existing body of literature in two aspects: first, most of the volatility studies seen in the financial literature are focused on stock exchanges and agricultural commodities were not explored in detail. By focusing on the most liquid member of agricultural commodity group, this study attempts to understand the volatility behavior for corn. Second, we analyzed alternative group of GARCH models in order to find the best model that can be used to understand and forecast the commodity returns. The significance has been tested using a traditional OLS model, a non-linear symmetric GARCH (1,1) model, and two non-linear asymmetric models, TGARCH (1,1) and EGARCH (1,1).

Under GARCH models, the results indicated that the sum of the coefficients on the lagged squared error and lagged conditional variance is close to unity for corn indicating that the shocks to the conditional variance will be highly persistent. The leverage effect term in both the TGARCH and EGARCH specifications for corn is statistically significant indicating negative shocks imply a higher next period variance than positive shocks of the same magnitude. From the overall results, it is evident that the EGARCH model performs well with the dataset and seems to capture the dynamics of the corn market including time varying volatility.

Agricultural commodities typically exhibit periods of high volatility stemming from both positive and negative shocks of new information. Market participants adjust to volatilities caused by new information as quickly as possible and try to profit from such inefficiencies. The empirical results of this paper suggest, that by properly analyzing the volatility of agricultural commodities, market participants, whether they be farmers or investors, are better prepared for shifts in market momentum and in managing their market decisions.

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How do Texas Conventional and Organic Producers Differ in their Perceptions of Barriers to Organic Production?

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ABSTRACT

In response to an increase in consumer demand for organic products, the number of organic operations has increased in the U.S. However, unlike the rest of the U.S., the number of certified organic operations in Texas has remained relatively stable. As a means to understand the perceived barriers to the adoption of organic production practices in Texas, a survey was distributed to a stratified sample of 4006 Texas producers. The difference in perception of barriers (from both market and production standpoints) to organic production between organic (or in the process) and conventional producers was assessed. In general, conventional producers perceived barriers to entry to be more severe than organic producers.

KEY WORDS: organic, Texas, perception, barriers, marketing, production

INTRODUCTION

The number of certified organic farms in the U.S. is increasing; simultaneously the number of companies involved in the processing, manufacturing, distributing, and retailing of organic products is expanding as well (Dimitri and Greene 2002; Dimitri and Oberholtzer 2009; Freundl 2009). However, organic production is not keeping pace with demand (Cantor and Strochlic 2009; Dimitri and Oberholtzer 2009), particularly in Texas (Lau et al. 2010). The objective of this research is to study the perceived barriers to organic production held by Texas producers and how perceptions differ between conventional and organic growers.

Cantor and Strochlic (2009) addressed marketing barriers facing small and mid-size organic producers in California. Volume (too much or too little) was the barrier most often cited (84%) among producers. Obtaining organic price premiums was presented as being a challenge for 66% of the producers, locating and accessing markets was a barrier for 65%, competition was cited by 55%, lack of pricing information was a concern for 47% of respondents, and difficulties meeting buyer requirements was cited by 37% of respondents.

Goldberger (2010) analyzed production and marketing barriers faced by certified organic farmers in Idaho. The most problematic production factors were

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weather-related production losses, high cost of organic inputs, high labor costs, and weed-related production losses. The most challenging market factors noted by certified organic farmers in the study were limited demand, limited distribution opportunities, and obtaining organic price premiums. Goldberger did not interview conventional farmers.

Using production type (e.g., crop, beef) as the dependent variable, Lau et al. (2010) presented an analysis of the respondents' reactions to perceived impediments to organic production. Results indicated that producers in Texas (both organic and conventional) found all market factors to be moderate barriers to organic adoption except the distance to available markets, which was considered a severe barrier to most respondents. Production factors were considered moderate barriers, with the availability of organic processing facilities considered the most severe barrier to considering organic production. This study did not delineate between conventional and organic farmers.

MATERIALS AND METHODS

Several studies have considered the barriers organic producers face as they engage in organic production. However, this study is the first one to focus specifically on the differences in perceived barriers to organic production between conventional and organic producers.

The data source used in this analysis is the same as that used by Lau et al. (2010). Using a database of producers acquired from the USDA National Agricultural Statistics Service (NASS), Texas farmers with farm sales above $25,000 were grouped by what self-reported primary commodity they produced. Subsequently, a stratified sample of about 6% of the total population was drawn based on the commodities identified. The survey was distributed in the Spring 2007 via mail to 4006 randomly selected producers. Second and third mailings were used to increase the response rate. The total number of surveys returned was 1178 (29.4%) with 961 (24.0%) of these surveys usable.

The primary research hypothesis was that the perceived barriers to engaging in organic production differed between farmers who had, were, or planned to engage in organic agricultural production compared to farmers using conventional methods. Therefore, respondents were asked the question presented in Figure 1.

2. Which of the following statements are most accurate regarding your CURRENT agricultural operation? (Mark all that apply.)

☐ Conventional ☐ Certified organic
☐ Previously certified organic but no longer certified ☐ Non-certified organic
☐ Conventional but in the process of becoming certified organic

Figure 1. Survey question regarding respondents' type(s) of agricultural operation.

After reviewing survey respondents' replies, the data were organized into two groups as follows:

- Conventional - respondents checking only the "conventional" box (n = 851),
- Organic (n = 111) - respondents checking:
  - "Previously certified organic but no longer certified" (n = 2),
  - "Conventional but in the process of becoming certified organic" (n = 19),
  - "Certified organic" (n = 5),

- "Non-certified organic" (n = 85) - self-reported based on personal definition.

Taking the total number of usable surveys, farmers identifying themselves as conventional growers (88.6%) and those who consider themselves organic growers (11.4%) were compared based on their perceptions of barriers to organic production. The data was analyzed using IBM SPSS Statistics 20. Descriptive statistics and cross tabulation statistics were generated, and Analysis of Variance (ANOVA) was conducted. Significant differences in this study are expressed by: * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$.

RESULTS AND DISCUSSION

Farm Characteristics. The farm characteristics of the conventional growers and organic group were analyzed. Respondents were asked to indicate the production category(ies) that best described their business. Figure 2 presents respondents' answers organized by category. There is a significantly larger percentage of organic respondents engaged in vegetable/fruit/nut ($p = 0.000$), greenhouse/floriculture/sod ($p = 0.002$), and poultry/egg production ($p = 0.008$) compared to the conventional growers. Conversely, a significantly larger percentage of conventional respondents are engaged in row crop production ($p = 0.000$). Figure 3 compares the two groups by years engaged in agricultural operations. Those farming for less than 10 years are using organic practices at a significantly higher rate: < 5 years ($p = 0.010$) and 5-10 years ($p = 0.025$) compared to those farming more than 20 years where conventional methods are more commonly used ($p = 0.006$). The data indicates that the transition period began 10 to 20 years ago where there is no significant difference expressed between the two methods of agricultural production. Figure 4 shows that almost 70% of organic growers generate sales of less than $50,000 ($p = 0.000$) likely implying small operations. Finally, Figure 5 indicates some differences in terms of how conventional and organic operations see the future of their farming operation. A significantly larger percentage of organic farmers envision their operation becoming more diverse ($p = 0.001$) over the next three years while conventional respondents are more likely to expect no changes ($p = 0.066$).

Please indicate the type of producer category that best describes your business. (Select all that apply.)

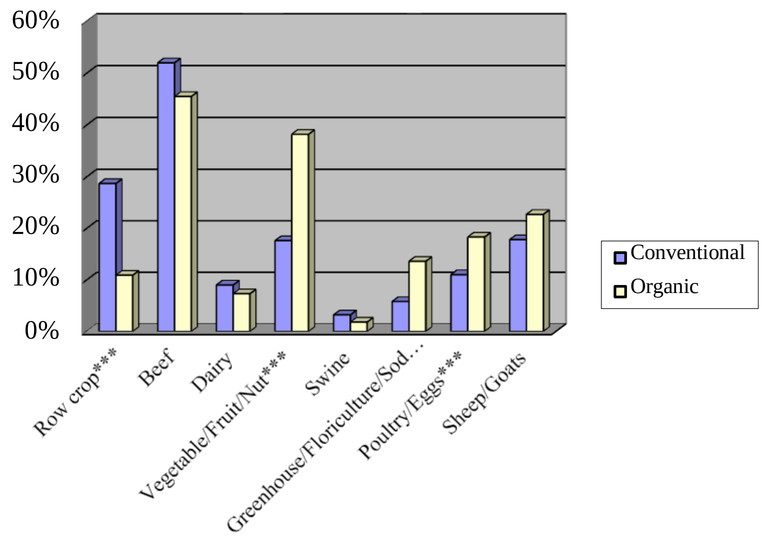

Figure 2. Types of production activities reported by survey respondents (* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$).

Please indicate your years in agricultural operation (including conventional and organic).

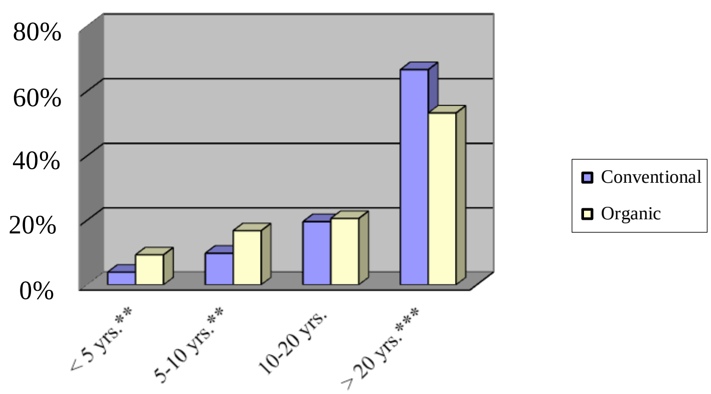

Figure 3. The number of years survey respondents have been involved in agricultural operations (* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$).

Please identify the size of your operation by selecting the category that best describes your annual gross sales.

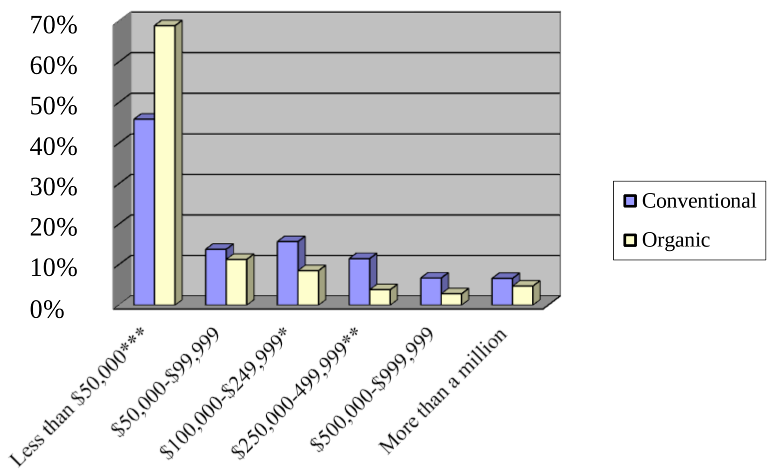

Figure 4. Respondents' annual gross sales. * p < 0.10, ** p < 0.05, *** p < 0.01.

How do you see your operation CHANGING in the next three years? (Select all that apply.)

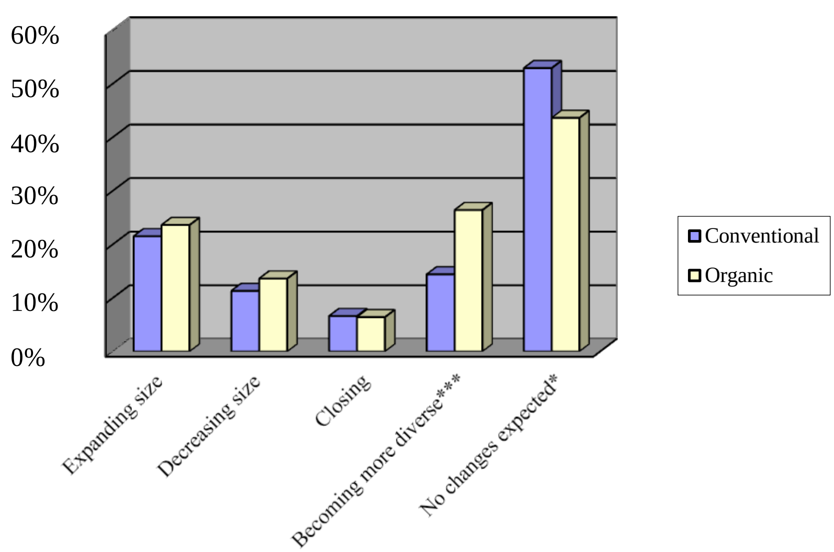

Figure 5. Respondents' perception of the future of their operation.
* p < 0.10, ** p < 0.05, *** p < 0.01.

Perception of Barriers. Various questions regarding the marketing and production barriers to organic production are summarized below. These questions were presented in the survey using a three-point Likert-type scale. The results are first summarized for the overall sample and then broken down to compare rankings across conventional and organic producer categories.

Producers were asked to determine the main adoption barriers to organic production via two separate questions: one pertaining to marketing conditions and the other to production conditions. The producers were given the following ranking choices: 1 - "Not a barrier" = no issue to entering organic markets; 2 - "Moderate barrier" = some level of barrier for entry to organic markets; 3 - "Severe barrier" = a definite barrier to entry.

Conventional and organic producers' perceptions of barriers to market conditions are significantly different (Table 1). Conventional producers identify the following as greater barriers to entering the organic market compared to the organic group: finding reliable buyers/market for organic products ($p = 0.008$), the difficulty in obtaining organic price information ($p = 0.003$), the uncertainty in obtaining organic price premiums ($p = 0.022$), the unstable organic market and/or prices ($p = 0.010$), the distance to available organic markets ($p = 0.076$), and the lack of organic marketing networks ($p = 0.041$). Conventional producers also perceive significant differences among production factors (Table 2). Conventional producers are more prone to consider production factors as being a severe barrier, while organic producers consistently found these same barriers to be moderate. Availability of organic processing facilities ($p = 0.000$) was the barrier considered to be the most significant production barrier to the adoption of organic farming practices by conventional producers. It was followed by pest-related production losses ($p = 0.000$), high input costs ($p = 0.000$), weed-related production losses ($p = 0.000$), disease-related production losses ($p = 0.000$), availability of organic inputs ($p = 0.024$), lack of understanding regarding organic production methods ($p = 0.001$), weather-related production losses ($p = 0.015$), and finally, fertility-related production losses ($p = 0.000$).

Producers were asked, "Would an increase in revenue facilitate your adoption of organic production?" Over 43% of the conventional farming respondents indicated that "No, no amount of additional revenue would prompt a change in their operation." Fifty percent of the conventional farming respondents indicated that, "Yes, additional revenue might encourage a change to organic production." The remaining 7% of the conventional growers selected the choice, "An increase in revenue is not necessary for me to adopt organic production." One might surmise that those farmers who selected that, "No, no increase in revenue would interest them in switching to organic production," also perceived the barriers to adoption as moderate to severe. However, a cross-tab analysis of the production and marketing barriers identified by this subset of respondents actually showed that they are more prone to consider marketing and production factors as either not being a barrier or as being a severe barrier (i.e., bimodal distribution) with a larger percentage considering the factors as not being a barrier. In other words, they may simply not be interested in organic production.

Table 1. Differences in perception of marketing barriers between conventional and organic producers.

Market Conditions		Not	Moderate	Severe	Pearson chi-square[a]
Finding reliable buyers/market for my organic products	Conventional	30.5	32.6	36.9	9.574***[b]
	Organic	43.2	34.7	22.1	
Difficulty obtaining organic price information	Conventional	26.1	40.1	33.8	11.620***
	Organic	43.0	32.3	24.7	
Uncertainty in obtaining organic price premiums	Conventional	23.3	36.2	40.5	7.632**
	Organic	33.0	40.7	26.4	
Unstable organic market	Conventional	25.7	36.7	37.7	9.180**
	Organic	39.8	35.2	25.0	
Distance to available organic markets	Conventional	25.9	30.2	44.0	5.166*
	Organic	37.0	27.2	35.9	
Competition with "non-organic" products	Conventional	28.5	30.9	40.6	1.749
	Organic	32.2	34.4	33.3	
Lack of organic marketing networks	Conventional	24.7	32.9	42.4	6.402**
	Organic	31.9	39.6	28.6	

[a] These numbers represent the Pearson chi-square statistic of the chi-square test of cross tabulation.
[b] * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 2. Differences in perception of production barriers between conventional and organic producers.

Production conditions (%)		Not	Moderate	Severe	Pearson chi-square[a]
Weather-related production losses	Conventional	24.8	34.7	40.5	8.335**[b]
	Organic	34.1	40.7	25.3	
Pest-related production losses	Conventional	22.1	29.9	48.0	18.000***
	Organic	33.3	42.2	24.4	
Disease-related production losses	Conventional	22.1	32.5	45.4	25.649***
	Organic	38.2	43.8	18.0	
Weed-related production losses	Conventional	24.3	29.0	46.8	20.292***
	Organic	40.4	37.1	22.5	
Fertility-related production losses	Conventional	28.4	34.4	37.2	28.144***
	Organic	55.7	26.1	18.2	
High input costs	Conventional	20.5	31.8	47.7	16.327***
	Organic	36.5	36.5	27.1	
Availability of organic inputs (feed, fertilizer, etc.)	Conventional	20.6	34.6	44.8	7.496**
	Organic	28.9	41.1	30.0	
Availability of organic processing facilities	Conventional	20.4	27.0	52.6	19.206***
	Organic	29.8	42.9	27.4	
Lack of understanding regarding organic production methods	Conventional	24.0	34.9	41.1	13.568***
	Organic	40.0	35.6	24.4	

[a] These numbers represent the Pearson chi-square statistic of the chi-square test of cross tabulation.
[b] * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Usefulness of Information and Services. The final section of the survey focused on organic and conventional growers' perceptions of information and/or services related to organic production. Not surprisingly, organic producers found most information and services described in the survey to be significantly more useful than the conventional producers (Table 3). Assuming that a response of 2 is neutral or average, conventional producers consistently ranked information and services below average; the only exception was organic processing facilities at 2.06. Conversely, organic respondents' consistently ranked information and services well above the mid-point of 2, except for organic export programs/market development and crop insurance for organically grown products, where no significant difference existed between organic and conventional growers. Based on ordinal ranking, the organic group seems most interested in directories of organic product buyers, local or regional organic market development, and consumer education programs about organic options.

Table 3. Means of responses to the question "Please rate the usefulness of the following information and/or services for marketing your products organically."

Information and/or Services	Means (1 = not useful, 3 = very useful)		t-statistic for difference in means
	Conventional	Organic	
Directories of organic product buyers	1.97	2.28	3.570***
Local/regional organic market development	1.97	2.26	3.311***
Consumer education programs about organics	1.94	2.25	3.465***
Organic marketing workshops/seminars	1.91	2.21	3.462***
Organic-specific research and extension services	1.95	2.20	2.854***
Development of organic marketing co-ops/ associations	1.89	2.20	3.470***
Organic price reporting services	1.91	2.14	2.557**
Organic processing facilities	2.06	2.13	0.455
Representation on organics-related public policy issues	1.80	2.02	2.607***
Organic export programs/market development	1.83	1.99	1.845*
Crop insurance for organically grown products	1.90	1.84	-0.635

[a] These numbers represent the t-statistic of the test for difference of means (two-tailed).
[b] * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Respondents were also asked to select the organic production topic they would like to learn more about (Table 4). Topics listed, except for post-harvest handling, appropriate equipment/machinery, health regulations, rotational grazing, recordkeeping, crop rotations, exporting organics, labeling, and irrigation, were found to be significantly more useful to organic producers than conventional growers. Insect control seems to be a particularly important topic to organic producers, as noted in the ordinal ranking.

Finally, respondents were presented with several statements regarding organic production and asked to indicate whether they agreed, disagreed, or did not know about the statement. The percentage of respondents disagreeing with each statement is listed in Table 5. For all statements, except "I understand the process of organic certification," there are significant differences between the conventional growers and the organic group.

Table 5 also shows that a high percentage of respondents disagreed with the statements, "My lenders support the idea of organic production" and "I understand the process of organic certification," suggesting there is room for improvement in these two areas.

Table 4. Responses to the question "Please indicate which of the following topics will help you learn more about organic production. (Select all that apply.)."

Topics	% of respondents selecting the topics		Pearson chi-square[a]
	Conventional	Organic	
Insect control	39.5	57.3	12.696***
Weed control	40.8	51.8	4.830**
Disease control	36.7	51.8	9.400***
Fertilizing techniques	36.9	50.9	8.076***
Marketing of organic products	32.2	47.3	9.876***
Soil amendments	23.5	44.5	22.470***
Best management practices	30.0	39.1	3.792*
Organic certification	25.0	36.7	6.778**
Cover crops	16.8	31.8	14.551***
Consumer education on organics	18.3	31.2	10.068***
Value-added products	18.1	28.4	6.579**
Composting	16.1	28.2	9.859***
Rotational grazing	19.8	26.4	2.600
Recordkeeping	19.5	26.4	2.832
Health regulations	20.4	25.5	1.472
Cooperative input/supply buying	17.5	25.5	4.093**
Season extension techniques	13.3	22.7	7.072**
Crop rotations	17.7	21.8	1.129
Irrigation	15.6	21.8	2.730
Labeling	13.6	19.1	2.359
Appropriate equipment/machinery	18.3	18.2	0.001
Post-harvest handling	14.1	17.3	0.783
Exporting organics	12.5	15.5	0.768

[a] These numbers represent the Pearson chi-square statistic of the chi-square test of cross tabulation.
[b] * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 5. Miscellaneous questions regarding respondents' perceptions and attitudes about organic farming.

Statements	% of respondents selecting "disagree"		Pearson chi-square[a]
	Conventional	Organic	
Organic farming is attractive because I have experienced problems with my conventional system.	86.3	66.7	15.472***
My lenders support the idea of organic production.	93.9	64.7	29.067***
I understand the process of organic certification.	72.2	60.8	2.783
I am concerned about the economic risks of transitioning to organic methods.	26.2	56.9	23.448***
Organic production is compatible with my high production system of farming.	86.0	50.0	42.364***
I feel the necessary informational support for organic farming is available.	63.3	42.9	8.421***
I am interested in organic production, but not organic certification.	68.4	41.3	17.402***
I have the right equipment for organic production.	70.1	38.5	20.566***
Organic farming is financially viable for me.	81.6	31.6	65.773***
Organic markets are reliable to me.	69.1	28.8	32.107***
I am satisfied with my present farming system.	14.3	28.4	11.447***
Organic farming has proven to be profitable.	72.2	26.3	46.793***
Organic farming is a feasible long-term production method for me.	80.3	26.2	77.202***
I can successfully farm without the use of synthetic chemicals.	70.5	21.9	56.223***
Organic farming is technically viable for me.	71.7	20.3	67.763***
I support the philosophy of organic farming.	36.6	8.5	25.202***

[a] These numbers represent the Pearson chi-square statistic of the chi-square test of cross tabulation.
[b] * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

CONCLUSION AND DISCUSSION

The differences in respondents' perceptions of marketing and production barriers to the adoption of organic farming practices were analyzed. The two groups sampled and compared were conventional agricultural producers and organic producers in Texas. The two groups do differ in their perceptions.

Statistically significant differences are evident between the two groups in their perceptions regarding marketing and production barriers. A substantial proportion of conventional producers perceive the barriers to adopting organic production as being more severe than organic producers. This can explain the lack of adoption of organic production. Providing networking opportunities for conventional producers to meet with organic producers in Texas and discuss their perceptions about barriers to adoption could provide an incentive to some conventional producers to switch at least part of their production to organic to meet rising domestic demand. However, the survey showed that 43% of the conventional producers would not move to organic production regardless of the increase in additional revenue that such a conversion could possibly generate.

The analysis also indicates that producers perceive a lack of support for organic production from lending institutions and a lack of informational support about the process of organic certification. In short, conventional producers perceive that marketing and production barriers are high, which appears to be stifling the adoption of organic production practices in Texas.

Note that 77% of the organic group was composed of those growers identifying themselves as "non-certified organic" producers. The survey as designed did not ask additional questions to verify the types of organic production practices employed by this group. Table 5 reveals that 60.8% of the organic sample does not understand the process of organic certification. This may imply that those producers identifying themselves as "non-certified organic" growers may be selectively choosing the parts of the certification process that work best for them or possibly have different definitions as to what constitutes organic.

As indicated, this analysis is limited to Texas. A similar analysis could be conducted across the rest of the United States to see if results are similar in other states with specific attention to states where organic production is more significant (e.g., California). In addition, this analysis is based on a small number of organic respondents, both certified and non-certified, from the overall stratified sample. A similar survey could be conducted in an effort to capture responses from a larger number of organic producers in Texas.

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Use of Composted Dairy Cow Manure as a Peat Moss Substitute in a Greenhouse Growing Substrate

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ABSTRACT

Dairies and other confined animal feeding operations (CAFOs) produce large amounts of manure that, when not disposed of properly, can lead to contaminated runoff into creeks and rivers or leach into ground water. Geenhouse experiments were conducted to determine if composted dairy cow manure can replace peat moss in greenhouse substrates. Bedding plants were grown in four substrate mixes: 1) 100% peat; 2) 50% peat, 25% perlite, 25% vermiculite; 3) 25% peat, 25% compost, 25% perlite, 25% vermiculite; and 4) 50% compost, 25% perlite, 25% vermiculite. The plants were grown to marketable size then dried, weighed, and analyzed for nitrogen content. Plants grown in mixes including compost had weights and nutrient levels that were equal to or higher than those grown in peat moss. This study suggests that dairy manure compost may be a suitable substitute for peat moss for greenhouse bedding plant production.

KEY WORDS: compost, peat moss, dairy cow manure, greenhouse production

INTRODUCTION

Dairies and other confined animal feeding operations (CAFOs) produce large amounts of manure that, when not disposed of properly, can lead to contaminated runoff into creeks and rivers or leach into ground water (Leatham et al. 1992; Hutson et al. 1998). Nutrients from manure, especially N and P, have been shown to encourage eutrophication in freshwater systems (Osei et al. 2003). Excess nutrients introduced into surface water may also increase the growth of algae and rooted aquatic plants. Oxygen is consumed when these plants die and decay and can lead to fish kills (Sharpley and Withers 1994). Some blue-green algal blooms produce carcinogens resulting in a direct health risk to humans and animals if consumed. These toxins also contribute to the unpalatability of drinking water derived from these bodies of water (Sharpley and Withers 1994).

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To reduce the amount of nutrients flowing from animal feeding operations into waterways, the Environmental Protection Agency (EPA 2007) requires CAFOs, including any dairy with more than 199 mature dairy cows, to apply for permits. These permits describe what measures must be taken to ensure the protection of the surrounding waterways from dairy waste effluent contamination. Some of the strategies for preventing the release of dairy waste into surface and ground waters include the construction of containment lagoons (Leatham et al. 1992), the application of wastes on crop production areas (Osei et al. 2003), turfgrass fields, and composting of waste material (Munster et al. 2004).

Another possible use for this material is as a substitute for peat moss (peat) in greenhouse growing substrate (Boodley and Sheldrake 2005; Chen et al. 1988; Inbar et al. 1993; Nelson 1991). The demand for peat as a component of growing substrate is rising while the supply is falling (Lohr et al. 1984). More than half of the peat used in the United States is imported, primarily from Canada. About 80% of U.S. peat production occurs in Florida, Michigan, and Minnesota. Domestic development of and the expansion of peat bogs has been reduced because of Federal and State wetland regulations.

Rawe and Cawthon (accessed 2005) replaced the peat constituent of a greenhouse mix with untreated raw dairy cow manure. They found that mixes containing untreated raw dairy manure had lower salinity levels than commercially-prepared potting mixes. These mixes also had low N levels and produced plants with lower dry weight and reduced height when compared to a commercial mix that contained no manure. When similar mixes were prepared using composted dairy manures prepared with an in-vessel composting system, the resulting plants were superior to those grown in mixes with raw manure and were comparable to those grown in the standard peat-lite substrate (Rawe and Cawthon, accessed 2005). Peat-based substrate can become contaminated during use and root, and crown rot diseases can become a problem in the greenhouse. Paviv et al. (2004) have shown that dairy cow manure-based composts can suppress at least some of the organisms that can cause these diseases. They also have demonstrated that these composts suppress some species of nematodes.

METHODS AND MATERIALS

Composted dairy cow manure (compost), sphagnum peat, horticultural vermiculite, and perlite were used to prepare four growing mixes (v/v). The substrates tested were: 1) 100% peat; 2) 50% peat, 25% perlite, 25% vermiculite; 3) 25% peat, 25% compost, 25% perlite, 25% vermiculite; and 4) 50% compost, 25% perlite, 25% vermiculite. The components of each mix were placed in a concrete mixer which was then operated for 10 minutes.

Three 200-cell plug trays filled with 50% peat, 25% perlite, and 25% vermiculite were used to germinate the seeds to produce plants for this research. One tray each was seeded with French marigold, *Tagetes patula* 'Durango Bolero', Salvia, *Salvia splendens* 'Vista Red,' and periwinkle, *Catharanthus roseus.* The plug trays were placed in a Pro-grow PC-46 germination cabinet at 22º C.

Twenty-seven 4-inch nursery containers were filled with each of the four substrate mixes for a total of 108 containers. Seedlings of marigold, salvia, and periwinkle were transplanted into the prepared containers. The containers were arranged in three plots on benches within a metal and glass greenhouse. The plots contained one row each of marigold, salvia, and periwinkle. Within each row, one seedling was placed into a container with one of the four substrate treatments for a total of 12 pots per row, and arranged randomly at 23 cm on center.

To simulate typical greenhouse procedures and to minimize differences in nutrient levels within the mixes, containers were watered daily and 20-20-20 fertilizer, at 200 ppm N, was applied at each irrigation (Nelson 1991).

After 45 days, three plants from each plot were removed from the growing media and roots cleaned of any foreign material. The plants were placed in paper bags and dried at 60º C for 48 hrs at the Texas Agrilife Experiment Station in Stephenville, Texas. The dried samples were ground to pass a 1 mm screen, weighed, and total dry weight for each plant was determined.

Nitrogen levels were measured using an Elementar vario Macro C:N analyzer (Elementar Americas, Inc., Mt. Laurel, NJ, USA). The experiment was a complete block design and the data were analyzed using Proc GLM (SAS Institute, Cary, NC). Means were separated using ($p < 0.05$) mixed model ANOVA.

RESULTS

There was no significant difference ($P > 0.05$) in total plant weight of periwinkles or marigolds grown in the different substrates (Fig. 1). Salvia grown in compost-amended media were larger ($P < 0.05$) than those grown in either peat-based substrate.

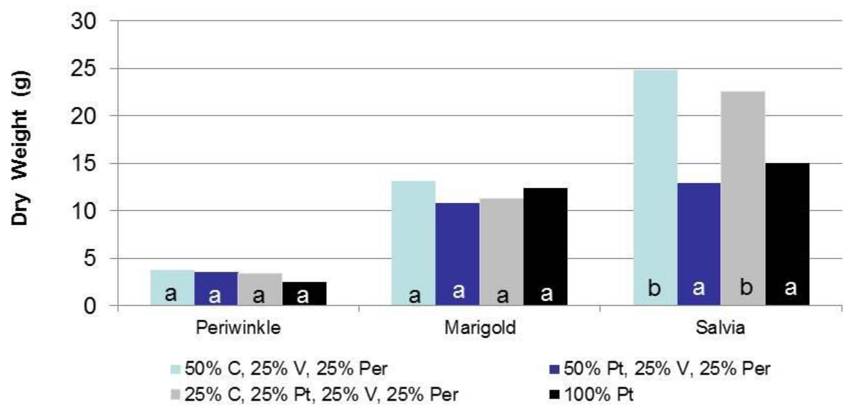

Figure 1. Mean plant weight +SE of periwinkle, marigold, and salvia grown in four media mixes. Bars with different letters differ ($P < 0.05$; LSD SAS Institute) by mixed model ANOVA.

Total nitrogen in periwinkle plants grown in 50% peat did not differ significantly from those grown in any of the other mixes (Fig. 2). Periwinkles grown in 50% compost and 25% compost, 25% peat had the highest nitrogen levels and did not differ significantly from each other, but were significantly higher than those grown in 100% peat. Total nitrogen in marigolds grown in 25% compost, 25% peat, and 100% peat did not differ from each other or from those grown in any of the other mixes. Those grown in 50% peat had the lowest levels of nitrogen and did not differ significantly from those grown in 25% compost, 25% peat, and 100% peat but did differ significantly from those grown in 50% compost which had the highest levels. Total nitrogen levels in salvia plants did not differ significantly among treatments.

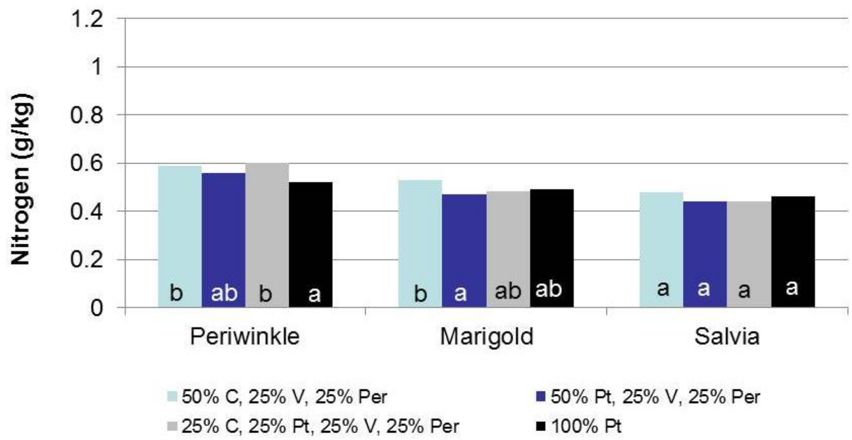

Figure 2. Mean nitrogen content ±SE of periwinkle, marigold, and salvia plants grown in four media mixes. Bars with different letters differ ($P < 0.05$; LSD SAS Institute) by mixed model ANOVA.

DISCUSSION

Salvia plants had significantly greater mass when grown in either of the mixes that contained compost than in the two mixes without compost. All other roots, shoots, and plants of any species grown in 50% compost had masses that were greater than or not significantly different from those grown in the other mixes.

In all species, the shoots and total nitrogen levels were higher than or not significantly different than those in plants that were grown in the mixes with compost compared to those grown in mixes without compost.

Although there were some differences in plant responses among some of the treatments the mixes that contained compost produced weights and nitrogen levels that were equal to or greater than the standard peat-lite mix. Composted dairy cow manure was a suitable substitute for peat in a peat-lite greenhouse substrate. Salvias in particular responded to it as a complete replacement for peat or as a replacement for 50% of the peat.

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