RICE (*Oryza sativa* L.) RESPONSE TO CLOMAZONE AS INFLUENCED BY RATE, SOIL TYPE, AND PLANTING DATE

A Dissertation

by

JOHN HOUSTON O'BARR

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2005

Major Subject: Agronomy

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May 2005

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ABSTRACT

Rice (*Oryza sativa* L.) Response to Clomazone as Influenced

by Rate, Soil Type, and Planting Date. (May 2005)

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Clomazone is an effective herbicide widely used for preemergence grass control in rice. However, use of clomazone on sandy textured soils of the western Texas rice belt may cause serious rice injury. When labeled for rice in 2001, sandy textured soils were excluded. Laboratory experiments were conducted to determine the effect of soil characteristics and water potential on plant-available clomazone and rice injury. A centrifugal double-tube technique was used to determine plant-available concentration in soil solution (ACSS), total amount available in soil solution (TASS), and K_d values for clomazone on four soils at four water potentials. A rice bioassay was conducted parallel to the plant-available study to correlate biological availability to ACSS, TASS, and K_d. TASS was significantly different in all soils at the 1% level of significance. The order of increasing TASS for the soils studied was Morey<Edna<Nada<Crowley which correlated well with soil characteristics. Two field experiments at three locations were conducted in 2002 and 2003 to determine the optimum rate range that maximizes weed control and minimizes crop injury across a wide variety of soil textures and planting dates. At Beaumont, Eagle Lake, and Ganado, TX, preemergence application of 0.41 to

0.56, 0.38 to 0.43, and 0.36 to 0.42 kg ha^{-1} clomazone, respectively, provided optimum weed control with minimal rice injury. Data suggests that clomazone is safe to use on rice on sandy textured soils. Injury may occur, but, rates suggested from this research will minimize injury and achieve excellent weed control. As a result, amendments to the herbicide label will allow clomazone use on sandy textured soils giving rice producers more flexibility and access to another effective herbicide.

DEDICATION

I dedicate this dissertation to all of the people in my life that have provided me with love and support over the years. To my wife, Raquel, for all of her love, support, encouragement, patience, and inspiration she has given me. I also dedicate this dissertation to my good son, Thomas, whose smile and love brightens each day.

To my parents, Gerald and Kathleen O'Barr, who taught me by word and example the importance and value of education, honesty, hard work, responsibility, and a feeling that I could do anything I put my mind to. Without their support and encouragement, none of this would be possible.

ACKNOWLEDGMENTS

I would like express my sincere appreciation to the following people who have made my dissertation research possible:

My committee chair, Dr. J.M. Chandler, for his guidance, knowledge, support and giving me an opportunity to come to Texas A&M University to pursue this degree under his direction; Dr. S.A. Senseman, for his assistance and guidance in the laboratory; Dr. G.N. McCauley, for his hard work and assistance in the field; and Dr. R.W. Bovey, for his guidance. I also express gratitude to the Rice Belt Warehouse, Texas Rice Research Foundation, Texas Agricultural Experiment Station, Texas A&M Department of Soil and Crop Sciences, FMC Corporation, and the Slick Graduate Research Fellowship Committee for their financial support and contributions.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

INTRODUCTION

Rice (*Oryza sativa* L.) is grown on approximately 1.5 million ha annually in the United States, with approximately 80,000 ha grown annually in Texas (Scherder et al. 2004). Weeds have been a problem in Texas rice production since the introduction of rice in 1846 (Craigmiles 1978). Weeds compete with rice for nutrients, and sunlight and can reduce yield. The presence of weed seeds in rice grain can reduce rice quality and grade. Weeds can also increase insect and disease severity and decrease harvesting and processing efficiency (Webster 2000).

Barnyardgrass (*Echinochloa crus-galli*) is the most common weed in rice in the US. Barnyardgrass, sprangletop (*Leptochloa* sp.) and broadleaf signalgrass *(Brachiaria platyphylla*) are three of the most troublesome grass weeds in rice production and can reduce rice grain yield by 70, 36, and 32%, respectively (Smith 1988; Webster 2000).

Herbicide use in rice production is an economical and effective way to control grassy weeds (Webster 2000). The herbicide clomazone was labeled for rice in 2001 (Command 3 ME Label, 2003), and is widely used due to its low cost and effective control. Clomazone is applied preemergence (PRE) immediately after seeding and effectively controls barnyardgrass, sprangletop, and broadleaf signalgrass. Though clomazone effectively controls weeds, it may injure rice plants by bleaching the leaves

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This dissertation follows the style and format of Weed Science.

and turning the entire plant white. The amount of injury is dependent on many variables including application rate, soil texture, and growing conditions after application. Injury, under some circumstances may result in reduced rice yield.

Injury is usually greater on light, sandy soils typical of the Texas rice growing area west of Houston, TX. When clomazone was approved for use in rice in 2001 the label excluded sandy loam, loamy sand, and sandy soils typical of this area in Texas. Research investigating differing rates of clomazone on these soils under varying environmental conditions could provide data to support the amendment of the clomazone label to include use on sandy type soils. As a result, this low cost and effective weed control option would become available for all Texas rice growers, and perhaps others in the rice belt.

LITERATURE REVIEW

Clomazone (2-[(2-chlorophenyl)methyl}-4,4-dimethyl-3-isoxazolidinone) is a selective, soil-applied herbicide from the isoxazolidinone family that was developed in the early 1980's and controls many grass and broadleaf weeds. Until 1993, clomazone was used exclusively for weed control in soybean (*Glycine max* L. Merr), pumpkin (*Cucurbita pepo* L.), pepper (*Capsicum annuum* L.), tobacco (*Nicotiana tabacum* L.), and succulent pea (*Pisum sativum* L.). Since 1993, it has additionally been used in cotton (*Gossypium hirsutum* L.), sweet potatoes (*Ipomoea Batatas* L.), winter squash

(*Cucurbita spp.*), rice (*Oryza sativa* L.), and fallow wheat (*Triticum aestivum*) (Vencill 2002).

It can be applied early preplant (EPRE), preplant-incorporated (PPI) or pre-emergence (PRE), depending on crop, geographical area, and timing. It's use in rice is more recent with full Label approval by the U.S. Environmental Protection Agency in 2001 (Command 3 ME label 2003).

Weeds susceptible to clomazone generally emerge from treated soil but are bleached white due to inhibition of chlorophyll biosynthesis. If bleaching is severe, it can lead to necrosis and eventual plant death. Clomazone is taken up by plant roots and shoots and moves primarily in the xylem to plant leaves (Duke and Paul 1986). Clomazone indirectly inhibits 1-deoxy-D-xylulose-5-phosphate synthase (DOXP) (Vencill 2002). Ultimately, biosynthesis of chlorophyll and carotenoid pigments are inhibited, causing a bleached appearance in susceptible plant species producing white, yellow or light-green plants (Duke and Paul 1986; Scott et al. 1994).

Several studies have documented crop injury in the form of bleaching from clomazone (Loux et al. 1989; Mervosh et al. 1995; Cumming et al. 2002; Kirksey et al.1996; Jordan et al. 1998). This injury is due to the unique chemical characteristics of clomazone including a relatively high water solubility (1100 mg l^{-1}) (Vencill 2002), high vapor pressure (19.2 mPa @ 25 C) (Vencill 2002), and distinctive symptomology.

Webster et al. (1999) reported 8 to 18% injury at 7 days after rice emergence with clomazone applied PRE. Up to 15% rice injury was observed with clomazone applied PRE at 0.56 kg ha^{-1} with no significant reductions in yield (Bollich et al. 2000).

Talbert et al. (1999) documented bleaching 7 days after treatment (DAT) of up to 60% when clomazone was applied PRE at 0.45 kg ha^{-1} with no significant reduction in yield. Research indicated that when clomazone is applied within label rates, rice recovers from injury caused by clomazone with no effect on yield. However, Jordan et al. (1998) observed bleaching of 35% 2 weeks after PRE treatment of clomazone at 0.56 kg ha^{-1} with maturity delay and reductions in yield observed at higher rates. Zhang et al. (2004) reported rice injury from 27 to 51% 2 weeks after 1.12 kg ha^{-1} clomazone treatment. Medium grain varieties showed the greatest injury with significant differences in yield indicating differential varietal tolerance to clomazone. It is still unclear if clomazone causes rice yield reduction. Why yield reduction in one study occurs when the same rates are applied has not been addressed. Information is lacking on the role that soil texture and environmental conditions play in severity and duration of injury and yield.

Several studies have documented clomazone adsorption to soil. However, a batch equilibrium technique using a relatively large volume of water per unit of soil was used in each case which represents a flooded field condition and not a representative soil/water environment for most agricultural situations. These studies used sorbent to solution ratios 1:10 (Loux et al. 1989), 1:5 (Mervosh et al. 1995; Cumming et al. 2002), and 1:2 (Kirksey et al. 1996). As a relative adsorption technique, these methods are acceptable, however, they do not accurately estimate the amount of herbicide available for plant uptake.

The concentration of herbicide in soil water is primarily dependent on dissolution into the liquid phase, adsorption on the soil components, leaching, and degradation

(Gaillardon et al. 1991). Determination of the herbicide concentration in soil solution is important for improving our understanding of herbicide availability to weeds, crops, soil microorganisms, and herbicide movement in soil. This has practical consequences for efficacy, selectivity, persistence, and distribution of soil-applied compounds (Gaillardon et al. 1991).

Several techniques have been developed for the extraction of soil solution for dissolved herbicide determinations (Gaillardon et al. 1991). Centrifugation (Moyer et al. 1972), suction (Green and Obien, 1969), pressure (Walker 1973; Hance and Embling 1979; Goetz et al. 1986), and displacement (Wolt et al. 1989) have been used as techniques for more accurately determining available herbicide in soil solution (Gaillardon et al. 1991; Wolt 1994). Unfortunately, most of these techniques require a relatively large amount of soil, high soil moisture, and lengthy time periods to complete (Gaillardon et al. 1991).

Another technique has been effectively used to estimate plant-available water by equating water potential to centrifugal gravity (Wolt 1994; Kobayashi et al. 1994, 1996, 1999; Lee et al. 1996). This technique employs a double-centrifuge tube apparatus where the soil is placed in an inner tube with a perforated end, then placed in an outer centrifuge tube. When the tube is placed in a centrifuge and rotated at 13,000 x g, plant-available soil water from the soil sample is dispensed in the outer tube (Kobayashi et al. 1994). Centrifuging at this force equates to a soil water potential of -1500 kPa . This soil water potential represents the permanent wilting point for plant material (Brady and

Weil 1996; Kobayashi et al. 1994). Therefore, any soil water above -1500 kPa water potential is assumed to be available for plant uptake (Kobayahi et al. 1994).

Soil moisture variations can affect herbicide availability (Dao and Lavy 1978; Green and Obien 1969; Moyer 1987). In an upland soil (non-flooded), thiobencarb concentrations in soil solution at soil moistures of 35, 45, 55, 65, and 75% were not statistically different (Lee et al. 1996). However, in lowland soils (flooded), concentrations of thenylchlor, clomeprop, and mefenacet in soil water was the most important parameter for determining phytotoxic activity (Kobayashi et al. 1994, 1996, 1999).

Several researchers have examined the relationship between rice injury caused by clomazone and soil properties and soil moisture levels. Cumming et al. (2002), using field dissipation studies with clomazone on several soils projected that estimation of phytotoxicity should not be based purely on soil concentrations. Lee et al. (1998) suggested that total available amount of herbicide in soil solution could vary due to varying water volumes potentially enhancing availability and phytotoxicity as soil moisture increases.

There are still discrepancies as to what rate(s) are the most effective for grass control while not compromising crop safety. The level of early season injury required to affect yield is not well understood. There has not been any research in rice published to evaluate the influence of environmental factors such as planting date and what impact it may have on injury or injury duration. Research is required to accurately determine the best rate(s) or combinations that are effective for grass weed control while maintaining crop safety under a wide range of soils and planting dates.

The objectives of this research were 1) to achieve a better understanding of rice response to clomazone as influenced by soil and planting date, 2) determine the rate of clomazone that maximizes weed control while minimizing rice injury, and 3) evaluate the impact of early season rice injury from clomazone on yield, and 4) determine the effect of soil characteristics and water potential on plant available clomazone and rice injury.

CHAPTER II

SOIL CHARACTERISTICS AND WATER POTENTIAL EFFECTS ON PLANT AVAILABLE CLOMAZONE IN RICE*

INTRODUCTION

Clomazone has been successfully used in rice weed control. However, rice injury is a potential problem for clomazone on light-textured soils. Clomazone is taken up by plant roots and shoots and moves primarily in the xylem to plant leaves (Duke and Paul 1986). Clomazone indirectly inhibits 1-deoxy-D-xyulose 5-phosphate synthase (DOXP) (Vencill 2002). Ultimately, biosynthesis of chlorophyll and carotenoid pigments are inhibited, causing a bleached appearance in susceptible plant species producing white, yellow or light-green plants (Duke and Paul 1986; Scott et al. 1994). Clomazone is used in row crops including soybean (*Glycine max*), tobacco (*Nicotiana tabacum, N. rustica*), peppers (*Piperaceae sp.*), pumpkin (*Cucurbita pepo*), and sugarcane (*Saccharum officinarum*) (Vencill 2002). Clomazone has recently been introduced as a rice herbicide for control of barnyardgrass (Webster et al. 1999; Jordan et al. 1998) and other grasses (Vencill 2002). However, rice injury by clomazone has been an important issue on light-textured soils (J.M. Chandler, personal communication 2004). This injury could be due to the unique chemical characteristics of clomazone

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The concentration of herbicide in soil water is primarily dependent on dissolution into the liquid phase, adsorption on the soil components, leaching, and degradation (Gaillardon et al. 1991). Determination of the herbicide concentration in soil solution is important for improving our understanding of herbicide availability to weeds, crops, soil microorganisms, and herbicide movement in soil. This has practical consequences for efficacy, selectivity, persistence and distribution of soil-applied compounds (Gaillardon et al. 1991).

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MATERIALS AND METHODS

Soil Collection and Preparation. Surface soil from a 8-cm depth was collected in September 2002 from rice fields located near Beaumont, Eagle Lake, Ganado, and Provident City, TX. Approximately, 6 kg of soil was collected at each location that had not received herbicide applications for at least two years. The soil was air dried for 30 days at 25 C and passed through a 2-mm sieve. Soil moisture for the air-dried soil was determined by oven drying subsamples at 105 C for 48 h. Soil moistures ranged from 0.5 to 3.7% depending on the soil. Soils were characterized by the Texas Agricultural Experiment Station Soil Characterization Laboratory and results are found in Table 1.

A water retention curve was constructed for each soil to accurately determine the various moisture levels needed for each moisture treatment (Romano et al. 2002). Water potentials used for constructing the water retention curves were -10, -33, -100, -250, -500, and -1500 kPa (Figure 1). Mass water content was calculated for each soil and each pressure from the following equation:

Table 1. Soil characterization of Edna (fine, smectitic, hyperthermic Aquertic Chromic Hapludalfs), Morey (fine-silty, siliceous, superactive, hyperthermic Oxyaquic Argiudolls), Nada (fine-loamy, siliceous, active, hyperthermic Albaquic Hapludalfs), Crowley (fine, smectitic, hyperthermic Typic Albaqualfs rice soils[a].

Soil series		Sand content [b]						Silt content [c]		Clay content [d]		Textural	Organic carbon	pH
Name	Location	VC	C	M	F	VF	Total	F	Total	F	Total	classification	content	(1:1) [e]
		--------------------					%			--------------------			%	
Edna	Ganado	0.5	0.4	2.5	38.0	25.1	66.5	9.0	18.9	10.2	14.6	Fine sandy loam	0.84	6.1
Morey	Beaumont	0.2	0.2	0.2	2.4	16.4	19.4	28.4	45.3	20.8	35.5	Silty clay loam	1.32	7.3
Nada	Eagle Lake	0.5	3.4	11.4	28.2	17.9	61.4	14.8	31.2	4.1	7.4	Fine sandy loam	0.75	6.1
Crowley	Provident City	0.4	2.5	10.6	35.8	17.0	66.3	13.1	25.0	4.7	8.7	Fine sandy loam	0.50	5.3

[a] Soil Characterization Laboratory, Texas Agricultural Experiment Station, TAMU, College Station, TX.
[b] VC:Very coarse sand (2.0 –1.0 mm), C:Coarse sand (1.0 – 0.5 mm), M:Medium sand (0.5 – 0.25 mm), F:Fine sand (0.25 – 0.1 mm), VF:Very fine sand (0.1 – 0.05 mm), Total sand (2.0 – 0.05 mm).
[c] F:Fine silt (0.02 – 0.002 mm), Total silt (0.05 – 0.002 mm).
[d] F:Fine clay (< 0.0002 mm), Total clay (< 0.002 mm).
[e] Soil:H_2O

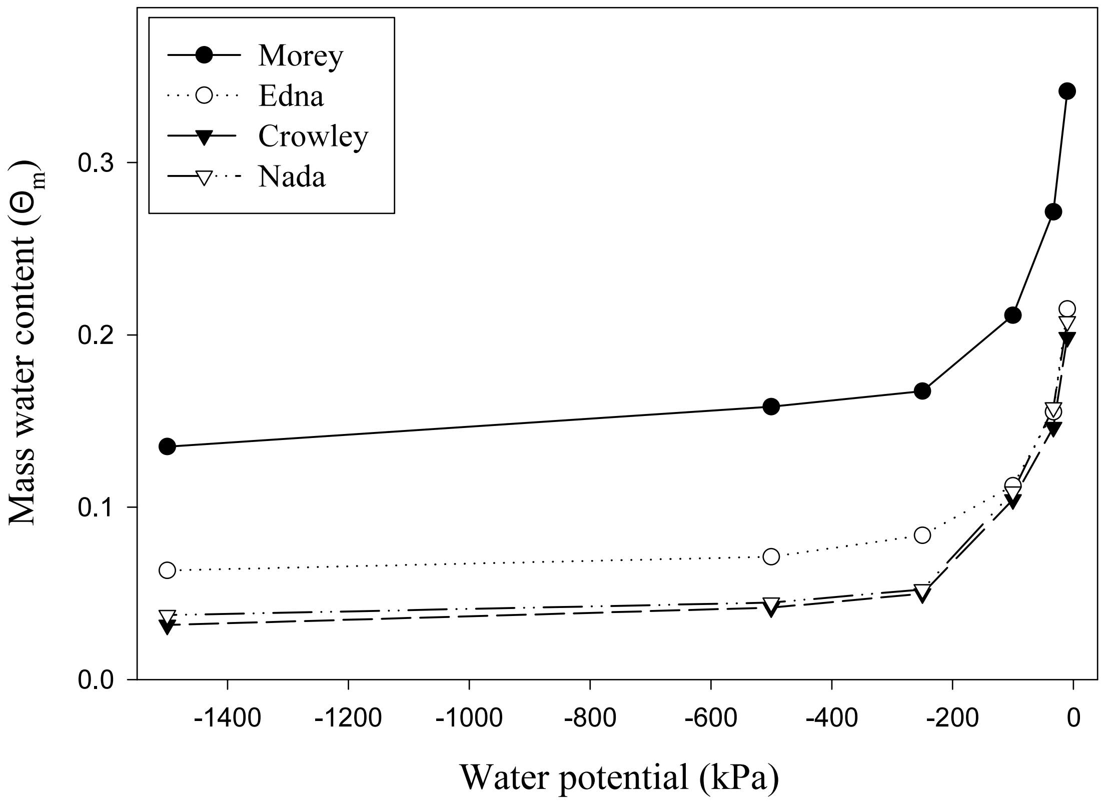

Figure 1. Relationship between mass water content (Θ_m) and water potential (kPa) of four soils. The soil moisture on a weight basis of each air-dried soil was: Morey, 3.5%; Edna, 1.2%; Nada, 0.7%, and Crowley, 0.5%.

$$Mass\ Water\ Content\ (\theta_m) = \left[\frac{(Weight\ of\ Wet\ Soil - Weight\ of\ Dry\ Soil)}{(Weight\ of\ Dry\ Soil)} \right] \quad [1]$$

Mass water content was determined for each soil in this manner and plotted versus pressure (Figure 1). Based on Figure 1, the four water potentials used in the plant-available clomazone study from soil included -90, -75, -33, and 0 kPa. The bioassay included only -75, -33, and 0 kPa due to poor rice growth at -90 kPa. These water potentials were chosen based on plant-available water estimates (Brady and Weil 1996) that would represent (1) a relatively wet soil environment that approaches a flooded condition (0 kPa), (2) field capacity and optimal conditions for plant growth (-33 kPa), 3) a relatively moderately dry soil environment capable of sustaining seed germination and plant growth (-75 kPa), and (4) a more severe dry soil environment (-90 kPa).

Determination of Plant-available Clomazone from Soil. Technical grade clomazone (98% pure) was obtained from Chem Service[1]. Ring labeled ^{14}C-clomazone (98% pure, 2.76 kBq μg^{-1} specific activity) was obtained from the FMC Corporation[2]. Prior to clomazone addition, all air-dried soils were subjected to the addition of water at a specified water potential treatment based on Figure 1. After two days of incubation at this water potential, clomazone was added to each treatment. One-hundred g of air-dried soil was treated with 3.51 kBq of ring-labeled clomazone which accounted for approximately 1% of the total clomazone concentration. Technical grade clomazone

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[1] Analytical clomazone, Chem Service, Inc. P.O. Box 599, West Chester, PA 19381-0599.
[2] Ring-labeled, radioactive clomazone, FMC Corporation, 1735 Market Street, Philadelphia, PA 19103.

was added to each treatment such that the final concentration of clomazone in the final soil sample was 1.2 μg g^{-1} of soil. This concentration represents a 2x rate of clomazone assuming a 7.5-cm furrow slice. Clomazone was added to each soil in 99.8%:0.2% water:methanol solution. Methanol was used in this mixture to aid in solubility. The soil was mixed with a laboratory spatula after clomazone addition to adequately distribute the herbicide in the sample. The incubation period began after 48 more hours to allow clomazone to equilibrate with soil.

Total available amount of clomazone in soil solution (TASS), available concentration in soil solution (ACSS), and K_d were determined after the 48-h clomazone equilibration period. The equilibration temperature was 10 C to minimize degradation and weed seed germination in the soil. After equilibration, 20 g of treated soil was removed from each treatment and placed in a double-tube centrifugation apparatus similar to that of Kobayashi et al. (1994) (Figure 2a). This apparatus consisted of a specially machined 20 i.d. x 75 mm stainless steel inner tube with a perforated end (Figure 2c and d). A 25-mm glass microfiber filter[3] (Figure 2f) was placed at the bottom of each tube prior to the soil being placed inside such that the soil solution would be free of particulates after centrifugation. At the opposite end of the tube, the outer diameter of the tube was 28 mm such that the tube could be placed inside a 26-mm i.d., 33-mm o.d. metal washer (Figure 2e) so as to suspend the stainless steel tube on top of a 28.6 i.d. x

[3] Millipore prefilter AP25, 25-mm, Millipore Corporation, Bedford, MA 01730.

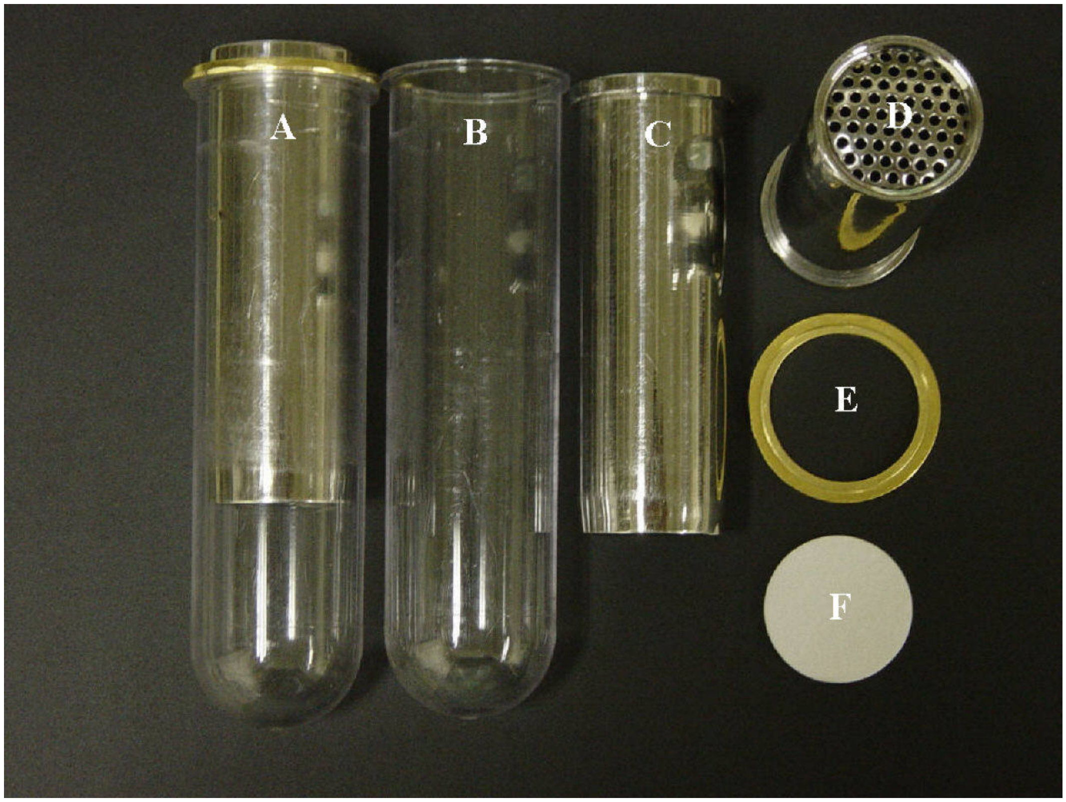

Figure 2. Centrifugation double-tube apparatus. (a) Assembled double-tube apparatus; (b) Outer Nalgene centrifuge tube; (c) side view of stainless steel inner tube; (d) end view of stainless steel inner tube showing perforated end where soil solution is dispensed; (e) metal washer that secures stainless steel inner tube when placed inside Nalgene outer centrifuge tube; (f) 25-mm glass microfiber filter that is placed at the bottom of the stainless steel inner tube to prevent soil particulate matter from getting into soil solution. Assembly of the apparatus is as follows: 1) the glass microfiber filter is placed at the bottom of the stainless steel inner tube prior to soil sample addition; 2) then the washer is placed over the stainless steel inner tube from the bottom and pushed to the top of the tube until it reaches the stop; 3) the entire apparatus is placed inside the Nalgene centrifuge tube. The assembled units are then subject to 13,000 x g by centrifuge which extracts available water for quantitation of herbicide and availability determinations.

114-mm Nalgene centrifuge tube[4] (Figure 2b) when the samples were centrifuged. The soil weight was adjusted to air-dry weight for each treatment based the soil type and the water retention results. Samples were centrifuged[5] at 13,000 x g for 30 min at a temperature of 20 C. This force was used to represent plant-available water (Kobayashi et al. 1994).

After centrifugation, extracted water at the bottom of the outer centrifuge tube was pipetted into a separate vessel and weighed to determine the volume of water extracted. Depending on the water potential, a minimum of 900 µl was removed from the extract and placed in a 7-ml scintillation vial[6] containing 5 ml of scintillation cocktail[7]. Radioactivity was quantified in each of the samples by liquid scintillation spectroscopy[8]. A concentration of radioactivity (dpms ml^{-1}) was calculated for each treatment. This information was used to calculate the total available amount of clomazone (ng g^{-1} of soil) in soil solution (TASS) from the following equation:

$$TASS = \frac{\left[(RC)(VSSE)\left[\frac{(PNR)}{(PR)}\right]\right]}{\left[(SA)(MCS)\right]} \qquad [2]$$

where RC is concentration of radioactivity (dpm ml^{-1}), VSSE is the volume of soil solution extracted from the sample (ml), PNR is percentage of non-radiolabeled clomazone added to the treatment (%), PR is the percentage of radiolabeled clomazone

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[4] Nalgene polycarbonate centrifugation tubes, Nalge Nunc International Corporation, Rochester, NY 14625-2385.
[5] IEC B-20A centrifuge, International Equipment Company, Needham Heights, MA 02194.
[6] Liquid scintillation vials, VWR Scientific Products, West Chester, PA 19380.
[7] Liquid scintillation cocktail, Ecolite ICN, Costa Mesa, CA 92626.
[8] Beckman LS 6500 multi-purpose scintillation counter, Beckman Instruments, Inc., Fullerton, CA 92634-3100.

added to the treatment (%), SA is the specific activity of clomazone (dpm of radiolabeled clomazone ng^{-1}), and MCS is the mass of soil centrifuged (g).

The available concentration of clomazone (μM) in soil solution (ACSS) was calculated by the following equation:

$$ACSS = \frac{\left[(RC)\left[\frac{(PNR)}{(PR)}\right]\right]}{[(SA)(MW)]} \qquad [3]$$

where RC is concentration of radioactivity (dpm ml^{-1}), PNR is percentage of non-radiolabeled clomazone added to the treatment (%), PR is the percentage of radiolabeled clomazone added to the treatment (%), and SA is the specific activity of clomazone (dpm of radiolabeled clomazone μg^{-1}), and MW is the molecular weight of clomazone (239.7 μg μM^{-1}).

The partitioning coefficient (K_d) was then calculated for each treatment from the following equation:

$$K_d = \frac{\left[\frac{(RA_i - RA_{ac})(SA)}{MCS}\right]}{[(ACSS)(SA)]} \qquad [4]$$

where K_d is the partitioning coefficient (ml g^{-1}), RA_i is amount of initial radioactivity (dpm), RA_{ac} is amount of radioactivity in soil solution after centrifugation (dpm), SA is specific activity (μg dpm^{-1}), MCS is the mass of soil that was centrifuged (g), and ACSS is the available concentration of clomazone in soil solution (dpm ml^{-1}).

Rice Plant Bioassay. Soil was treated with technical grade clomazone as previously described in the plant-available clomazone experiment with the exception that no ^{14}C-clomazone was added to the soil samples. One-hundred g of air-dried soil was added to a 500-ml glass jar. Fungicide (mancozeb) pretreated commercial rice seed of the 'Cocodrie' variety was pregerminated by soaking in water for 2 days at 30 C. The seed was then placed in a Petri dish with the bottom covered with wet paper towels for 24 h at 30 C. Ten pregerminated rice seed were then placed approximately 2 mm below the soil surface inside the glass jars. Jars were covered with two layers of plastic wrap and placed in a growth chamber[9] set at 26 C/20 C day/night temperatures with 12-h light and 12-h dark. Soil moisture was maintained gravimetrically. After 12 days of growth chamber incubation, 100 mg of leaf fresh weight from each treatment was removed and assayed for chlorophyll content. Untreated controls were also included to determine relative chlorophyll content when rice was grown without clomazone.

Determination of Chlorophyll Content. Chlorophyll content was determined for each set of treatments in the bioassay using the method similar to that described by Hiscox and Israelstam (1979). Leaf tissue was placed in a vial containing 7 ml of dimethyl sulfoxide[10] (DMSO) and extracted at 65 C for 1 h using a constant temperature bath[11]. The samples were vortexed 3 times at 15-min intervals during the 1-h extraction. The

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[9] Growth chamber, Controlled Environments Limited, 590 Berry Street, Winnipeg, Manitoba, Canada R3H 0R9.
[10] Dimethyl sulfoxide, Fisher Scientific, P.O. Box 1546, 9999 Veterans Memorial Drive, Houston, TX 77251-1546.
[11] Blue M constant temperature water batch, Blue M Electric Company, 304 Hart St., Watertown, WI 53094.

liquid was decanted and brought to a 10-ml volume with DMSO in a graduated test tube. Each sample was vortexed again prior to reading on the spectrophotometer. An aliquot of each sample was analyzed using a Beckman DU530 UV-visible spectrophotometer[12]. Absorbance values were read simultaneously to quantify chlorophyll a (663 nm) and chlorophyll b (645 nm) against a DMSO blank. If absorbance values were greater than 0.7, then the samples were diluted by 50% with a 90% DMSO:10% water solution. Total chlorophyll content (chlorophyll a + chlorophyll b) in ug ml^{-1} was calculated using the following equation from Arnon (1949).

$$Total\ chlorophyll_{(a+b)} = 8.02\ A_{663} + 20.20\ A_{645} \qquad [5]$$

where A_{663} is the absorbance at 663 nm for chlorophyll a and A_{645} is the absorbance at 645 nm for chlorophyll b (Arnon, 1949). These values were then converted to mg of chlorophyll g^{-1} of fresh weight.

Data Analysis. Plant-available clomazone and the bioassay were analyzed as randomized complete block designs with three replications. The experiments were repeated. The plant-available clomazone study was arranged in a 4 x 4 factorial arrangement with 4 different soils and 4 water potential levels. The bioassay experiment was also arranged in a factorial experiment with the same 4 soils and 3 water potential levels due to poor plant survival at the lowest water potential (-90 kPa). Tests for heterogeneity between runs were not significant, therefore, runs were combined. Means

[12] Beckman-Coulter DU-530 UV-Visible Spectrophotometer, Beckman Instruments, Inc., Fullerton, CA 92634-3100.

were separated by Fisher's protected least significant difference test at $\alpha = 0.01$ using SAS[13]. Comparisons were not orthogonal but chosen based on the objectives of the study.

RESULTS AND DISCUSSION

Plant-available Clomazone from Soil. The total amount available in soil solution (TASS) of clomazone showed no significant interaction between water potential and soils after the 48-h equilibration. The two-way means for TASS are reported in Table 2. TASS was significantly greater for Crowley compared to the other soils. TASS in the Crowley soil was 11, 64, and 115% > than Nada, Edna, and Morey soils, respectively. TASS was negatively correlated with % organic carbon content ($r = 0.92$). Organic carbon content was a better predictor of TASS than both % clay ($r = 0.87$) and % sand ($r = 0.72$). These data indicate that the Crowley soil has the greatest opportunity to injure rice in a field situation at equivalent clomazone rates across all soils. Since TASS has been positively correlated with herbicide injury (Lee et al. 1998), the order of decreasing potential rice injury from clomazone would be Crowley>Nada>Edna>Morey.

Averaged across all soils, TASS was positively correlated with water potential ($r = 0.95$). The order of increasing TASS was -90 kPa<-75 kPa<-33 kPa<0 kPa (Table 2). TASS values at 0 kPa were 33, 62, and 100% of the TASS at -33, -75, and -90 kPa,

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[13] SAS software, version 8.02, Statistical Analysis Systems Institute Inc., SAS Campus Drive, Cary, NC 27512.

Table 2. Total clomazone amount available in soil solution after 48-h equilibration period from four soils and four water potentials as determined by double tube centrifugation[a]. Main effects are compared since soil by moisture interactions were not significant.

Water potential[b]	Crowley	Nada	Edna	Morey	Average
kPa	-------------------------ng g^{-1} treated soil [c]----------------------				
-90	107.9	98.6	59.6	35.9	75.5
-75	132.4	115.6	80.0	43.5	92.9
-33	160.5	141.2	85.9	75.9	115.9
0	181.3	173.9	130.1	115.4	150.2
Average	145.5	132.3	88.9	67.7	11.0 [d]

[a] Centrifugation force was 13,000 x g and represented plant-available water as determined by Kobayashi et al., (1994).
[b] Water potential was determined by water retention analysis in Figure 1.
[c] Soil was treated with 1.2 µg g^{-1} clomazone to air-dried soil.
[d] LSD – Fisher's least significant difference at $\alpha = 0.01$ for main effects are $LSD_{soil\ (0.01)} = 11.0$, $LSD_{water\ potential\ (0.01)} = 11.0$.

respectively. Consequently, the higher moistures demonstrated the greatest opportunity for rice injury (Table 2).

Available clomazone concentration in soil solution (ACSS) and K_d values calculated after equilibration demonstrated an interaction between water potential and soil (Table 3). ACSS ranged from 2.7 to 7.5 µM of clomazone from the various soils and water potentials (Table 3). At the -90 kPa water potential, the order of decreasing ACSS was Crowley=Nada>Edna=Morey. A similar trend was apparent at the other water potentials of -75, -33, and 0 kPa. K_d results showed the same trend as ACSS for the soils within each water potential. K_d values ranged from 0.6 to 1.8 mls g^{-1} (Table 3). The largest value came from the Morey soil (1.8 ml g^{-1}) at the -75 kPa water potential (Table 3). These values are substantially lower than K_d values estimated by Weber et al. (2000) for clomazone that had been calculated from average K_{oc} values reported in the literature. Values obtained their work ranged from 1.62 to 4.05 assuming 0.54% and 1.35% organic carbon, respectively. It is important to note that these determinations were made using a standard batch equilibrium technique and did not account for soil moisture changes.

For the Edna soil, the decreasing order of ACSS was 0=-33<-75=-90 kPa. Therefore, as soil moisture decreased, ACSS increased. The same trend occurred for Nada and Crowley soils. Herbicide concentration has been inversely correlated with moisture content for atrazine (Green and Obien 1969). Others have reported ACSS to remain constant across varying moisture content (Lee et al. 1996; Lee et al. 1998). However, ACSS for Morey decreased as water potential increased. The decreasing

Table 3. Available clomazone concentration in soil solution and K_d values for soils collected from Edna, Morey, Nada, and Crowley after 48-h equilibration period at four water potential levels.

Water potential[a]	Soil	Available concentration in soil solution	K_d [b]
kPa		μM	ml g^{-1}
- 90	Edna	5.0	0.96
	Morey	3.0	1.68
	Nada	7.1	0.65
	Crowley	7.5	0.62
- 75	Edna	4.4	1.10
	Morey	2.7	1.81
	Nada	5.4	0.88
	Crowley	6.0	0.79
- 33	Edna	3.6	1.35
	Morey	3.1	1.59
	Nada	5.2	0.91
	Crowley	5.8	0.82
0	Edna	3.5	1.36
	Morey	4.0	1.22
	Nada	4.8	0.98
	Crowley	5.4	0.88
$LSD_{0.01}$		0.9	0.26

[a] Refer to Figure 1 for water potential equations.
[b] Partition coefficient assuming unsaturated soil conditions.

order was -90=-75<-33=0 kPa. It is unclear as to the reason why Morey ACSS values showed different trends than the other soils. Green and Obien (1969) demonstrated the influence of organic matter on atrazine availability as organic matter decreased deeper in the soil horizon. In this case, decreasing organic matter caused a decreasing trend for available atrazine as moisture increased (Green and Obien 1969). Ultimately, they concluded that only on low adsorptive soils would water content variations significantly alter herbicide concentration in soil solution (Green and Obien 1969). K_d values demonstrated essentially the same results that were determined from ACSS.

Total Chlorophyll Content from Bioassay. Results for total chlorophyll content from rice 14 d after clomazone (Table 4) addition agreed with results from plant-available clomazone estimations (Table 2). A interaction was found between water potential and soil. The total chlorophyll content as % of an untreated (TCPU) plant ranged from 6.7 to 100% for the treatments studied. The lowest TCPU value coincided with the most chlorophyll damage or bleaching and consequently, the greatest amount of clomazone injury (Table 4).

For any given soil, water potential was positively correlated with plant injury. For Edna, chlorophyll content decreased in the order of -75>-33>0 kPa. The same trend occurred for the other soils. This agreed well with earlier data for soil characteristics and plant-available clomazone estimates where higher soil moistures and lower organic carbon and clay content provided more TASS. Based on plant-available clomazone estimates from TASS, Morey would have been expected to show the least clomazone

Table 4. Total chlorophyll content of 3- to 4-leaf rice as affected by water potential 14 days after clomazone treatment represented by total chlorophyll by weight (mg g^{-1}) and chlorophyll percentage (%) of untreated.

		Total chlorophyll content [b]		
Water potential[a]	Soil	Untreated rice	Treated rice [c]	
kPa		--------mg g^{-1} fresh weight[d]--------		% of untreated[e]
- 75	Edna	1.4 ± 0.07	1.4 ± 0.17	100.0
	Morey	1.8 ± 0.07	1.4 ± 0.12	77.8
	Nada	1.8 ± 0.13	1.2 ± 0.08	66.7
	Crowley	1.8 ± 0.05	0.5 ± 0.08	27.8
- 33	Edna	1.6 ± 0.05	1.1 ± 0.08	68.8
	Morey	1.8 ± 0.07	1.0 ± 0.02	55.6
	Nada	1.6 ± 0.05	1.1 ± 0.11	68.8
	Crowley	1.9 ± 0.16	0.3 ± 0.09	15.8
0	Edna	1.4 ± 0.13	0.8 ± 0.04	57.1
	Morey	1.4 ± 0.18	0.9 ± 0.04	64.3
	Nada	1.7 ± 0.08	0.5 ± 0.04	29.4
	Crowley	1.5 ± 0.07	0.1 ± 0.04	6.7
$LSD_{0.01}$				9.3

[a] Refer to Figure 1 for water potential equations.
[b] Total chlorophyll content (Chl. a + Chl. b) = $8.02A_{663} + 20.20A_{645}$ by Arnon (1949).
[c] Clomazone treatment consisted of 1.2 ug g^{-1} clomazone in air-dried soil.
[d] Mean ± standard deviation.
[e] % of untreated – (total chlorophyll content of treated rice)/(total chlorophyll content of untreated rice) x 100.

injury, however, Edna had a substantial quantity of broadleaf signalgrass (*Brachiaria platyphylla* L.) seeds in the soil samples which germinated and absorbed substantial clomazone particularly at the -75 kPa water potential (Table 4 and Figure 3). These seedlings competed with rice for available water and ultimately available clomazone which resulted in less chlorophyll damage than expected in this treatment.

At 0 kPa water potential, Morey and Edna showed the least chlorophyll damage while Nada and Crowley had > 70% and > 93% chlorophyll loss, respectively (Table 4 and Figure 3). Perhaps these differences at the 0 kPa water potential were due to some degradation and irreversible binding of clomazone during the 14-d period. Therefore, clomazone dissipation and recovery of rice in the Morey soil probably resulted in higher chlorophyll content at 0 kPa (Table 4 and Figure 3). Higher organic carbon (r = 0.59) and clay content (r=0.40) was associated with reduced chlorophyll damage (Table 5). Similar trends of chlorophyll damage occurred at the other soil moistures.

Critical TASS and Kd Estimation Based on Total Chlorophyll Content. The relationship between ACSS and TASS for all of the soils at each water potential is shown in (Figure 4). A strong linear relationship was determined for each water potential with coefficients of determination ranging from 0.74 to 0.98. As TASS increased, ACSS was less sensitive to changes in water potential which are indicated by gentler slopes at the higher water potentials. At -90 kPa, ACSS reached a maximum and the relationship between ACSS and TASS demonstrated the steepest slope of any of the other water potentials. However, at -90 kPa the soil environment was too dry to sustain

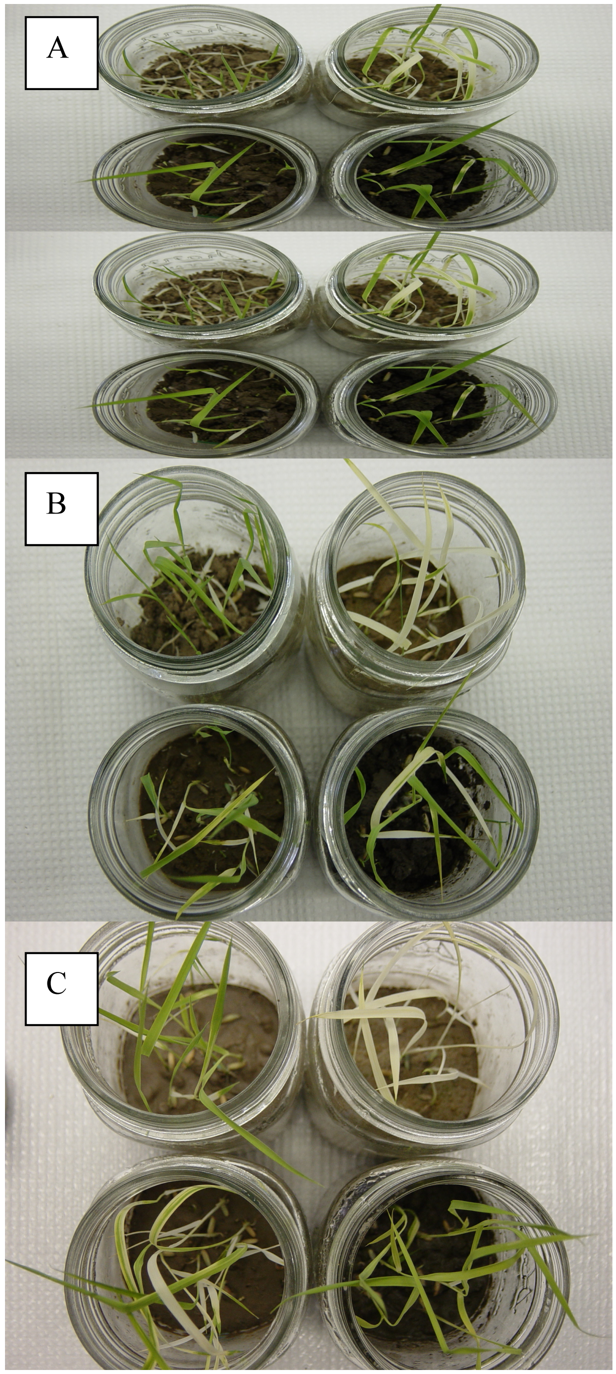


Figure 3. Bleaching patterns of rice shoots 14 d after clomazone treatment at (A) -75 kPa, (B) -33 kPa, and (C) 0 kPa. In each photo, the soil samples are ordered as follows: Above left: Edna; right: Crowley; Bottom left: Nada; Bottom right: Morey.

Table 5. Correlation matrix by for total chlorophyll, water potential, clay, sand, silt, organic carbon, K_d, total available amount of clomazone (TASS), and available clomazone concentration in soil solution (ACSS) across four rice soils.

	% Total chlorophyll	Water potential	Clay	Sand	Silt	Organic carbon	K_d	TASS	ACSS
% Total chlorophyll	1.000	-0.445***	0.403***	-0.304**	0.151^{ns}	0.589***	0.466***	-0.713***	-0.508***
Water potential	-0.445***	1.000	0.000^{ns}	0.000^{ns}	0.000^{ns}	0.000^{ns}	-0.036^{ns}	0.522***	-0.075^{ns}
Clay	0.403***	0.000^{ns}	1.000	-0.949***	0.770***	0.939***	0.757***	-0.632***	-0.716***
Sand	-0.304**	0.000^{ns}	-0.949***	1.000	-0.932***	-0.913***	-0.649***	0.520***	0.590***
Silt	0.151^{ns}	0.000^{ns}	0.770***	-0.932***	1.000	0.767***	0.444***	-0.324**	-0.370***
Organic carbon	0.589***	0.000^{ns}	0.939***	-0.913***	0.767***	1.000	0.774***	-0.665***	-0.769***
Kd	0.469***	-0.036^{ns}	0.757***	-0.649***	0.444***	0.774***	1.000***	-0.758***	-0.956***
TASS	-0.713***	0.522***	-0.632***	0.520***	-0.324**	-0.665***	-0.758***	1.000	0.756***
ACSS	-0.508***	-0.075^{ns}	-0.716***	0.590***	-0.370***	-0.769***	-0.956***	0.756***	1.000

[a] ***, significant at 0.001 level.
[b] **, significant at 0.01 level.
[c] *, significant at 0.05 level.
[d] ns, not significant.

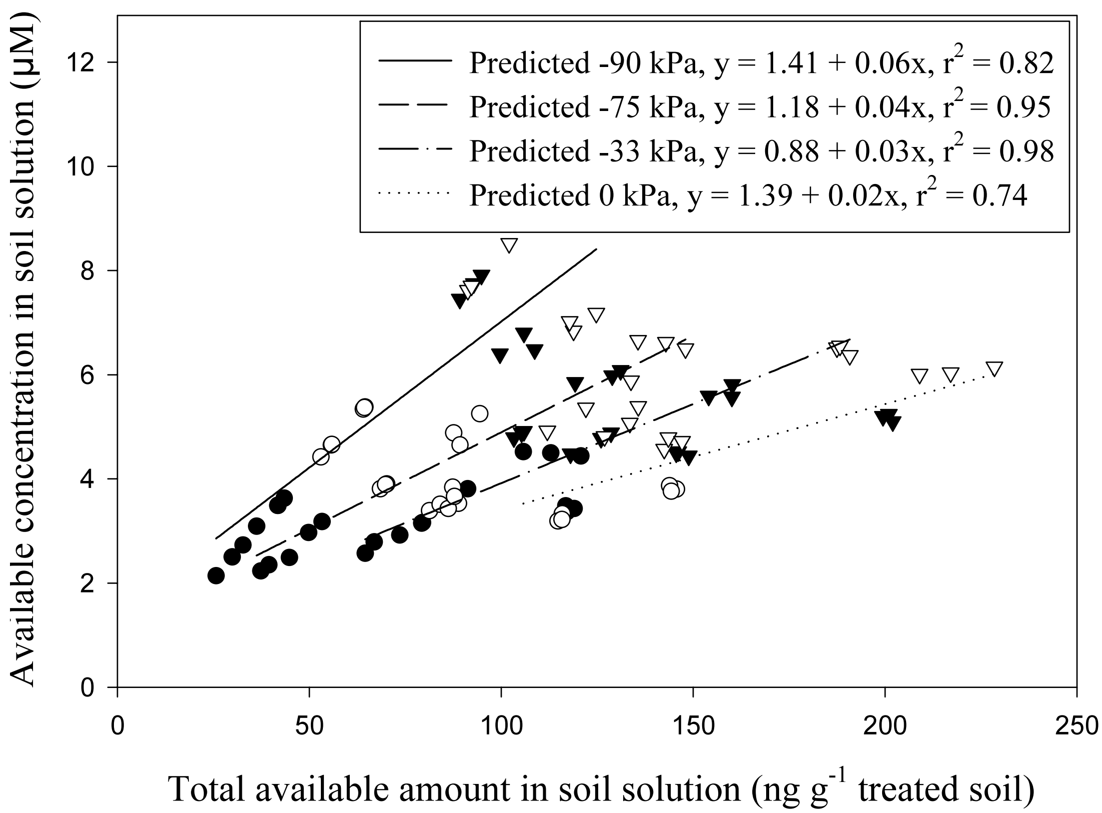


Figure 4. Relationship between available clomazone concentration in soil solution (ACSS) and total available amount of clomazone in soil solution (TASS) after 48-h equilibrium. Data were modeled by linear regression for each water potential (-90, -75, -33, and 0 kPa) and four representative rice soils (Morey (●), Edna (○), Nada (▼), and Crowley (∇)).

plant life and, therefore, may not be a particularly injurious treatment due to low plant uptake. Additionally, the maximum endpoints for ACSS decreased as water potential increased suggesting dilution of clomazone in soil solution. As water potential decreased, ACSS decreased from approximately 8 to 6 μM. However, at the same endpoints, TASS increased from approximately 125 to 240 ng g^{-1} as water potential increased. This trend of increasing TASS was consistent with increasing chlorophyll damage as water potential increased according to bioassay results (Tables 4). According to correlation statistics, TASS showed a higher correlation with chlorophyll content (r = -0.71) than ACSS with chlorophyll content (r = -0.51) (Table 5). TASS also had a stronger relationship to water potential (r = 0.52) than did ACSS (r = -0.08) (Table 5). These results are in agreement with earlier work by Lee et al. (1998) who stated that TASS was a better estimate of plant-available herbicide than ACSS.

Based on TASS being a better plant-available estimate than ACSS, it was deemed useful to describe the relationship of TASS to clomazone affinity (K_d) to soil (Figure 5). This would allow estimation of TASS for various soil types that would provide potential injury estimates across soil characteristics particularly when combined with bioassay results (Figure 6 and Table 5). TASS and K_d for each water potential were regressed using a first-order non-linear model (Figure 5). Based on residual plot analysis, a good fit was determined at each water potential. As K_d increased, TASS decreased at all water potentials. A correlation between TASS and K_d was determined (r = -0.76).

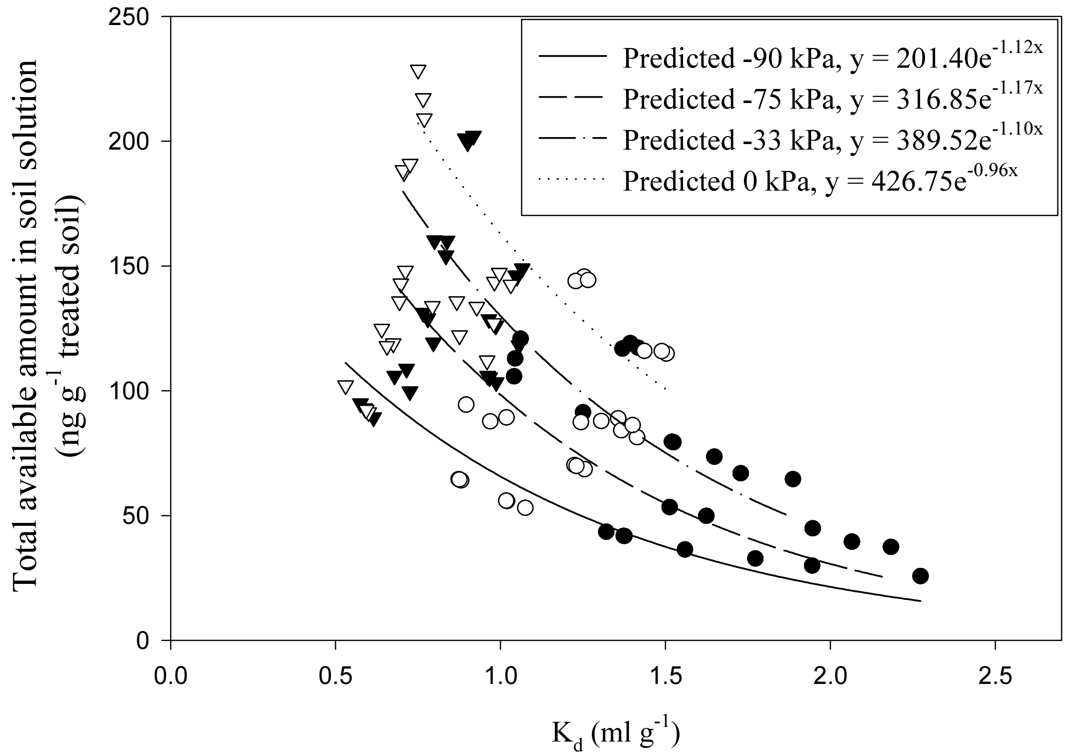
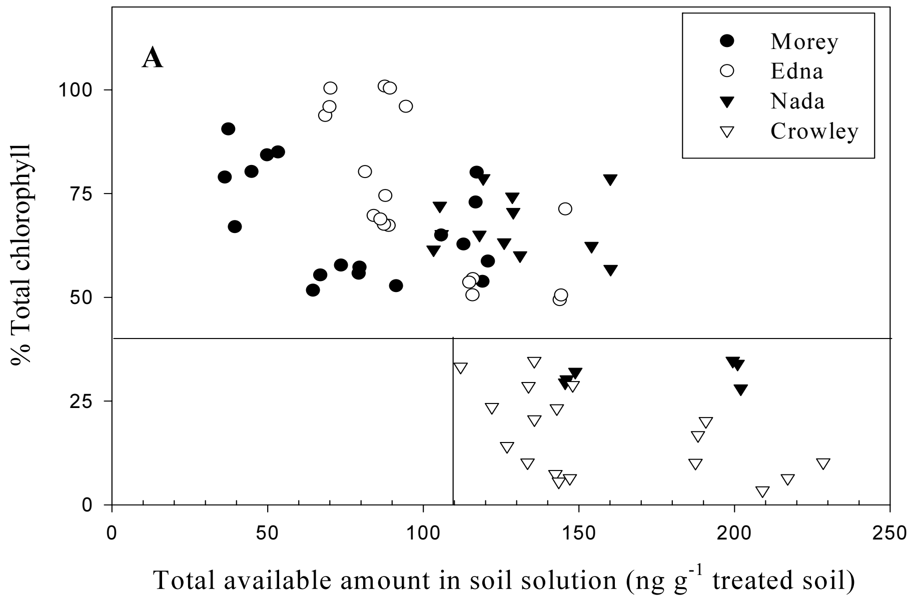


Figure 5. Relationship between total available amount of clomazone in soil solution (TASS) after 48-h equilibrium and soil affinity (K_d) of clomazone. Data were modeled using a first-order equation for each water potential (-90, -75, -33, and 0 kPa) and four representative rice soils (Morey (●), Edna (○), Nada (▼), and Crowley (∇)).



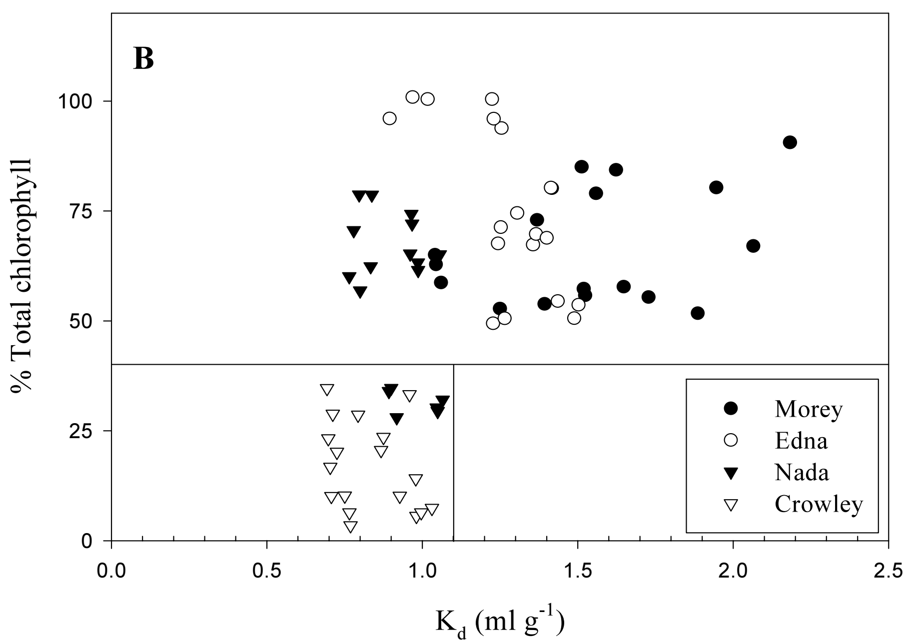


Figure 6. Relationship between % total chlorophyll (chlorophyll a + b) with (A) total available amount of clomazone in soil solution (TASS) after 48-h equilibrium and (B) K_d. Data include three water potentials (-75, -33, and 0 kPa) and four representative rice soils (Morey, Edna, Nada, and Crowley). Water potentials have not been designated with a separate symbol.

Since K_d and TASS demonstrated a strong relationship, we plotted these two variables against total chlorophyll content to determine critical ranges that would be expected to cause significant chlorophyll damage (Figure 6). In studying the relationship of TASS (Figure 6a) and K_d (Figure 6b) to total chlorophyll, soil and moisture conditions that provided TASS values of > 110 ng g^{-1} and K_d values of < 1.1 ml g^{-1} were likely to demonstrate > 60% chlorophyll damage. Rice plants with this amount of chlorophyll damage may not recover if growing conditions are not optimal soon after clomazone uptake. Total chlorophyll reduction was greater than 65% for Crowley soil at all water potentials. Data for these soils had K_d values < 1.1 ml g^{-1} and TASS > 110 ng g^{-1} within the critical range. According to these data, the clomazone rate could be reduced to allow a safer application range due to the high availability of this compound in this soil.

Nada soil at 0 kPa also showed > 70% chlorophyll damage. Therefore, depending on water potential, the rate of clomazone may need to be reduced to allow safer application on the Nada soil. Some of Edna and Morey soils at high water potentials were within the critical range of TASS and K_d but did not show as much chlorophyll damage as Crowley and Nada soils (Figures 3 and 6). Perhaps Edna and Morey soils have enough clay, organic C content, and microbial activity to reduce the quantity of available clomazone thereby reducing rice phytotoxicity within the 14-d incubation. Organic carbon (r = 0.59) and clay content (r = 0.40) were significantly correlated to total chlorophyll content (Table 5).

It is important to note that K_d values varied as much as 100% as soil moisture was altered. In other published work, researchers have used high solution:soil ratios of 2:1 (Kirksey et al. 1996), 5:1 (Mervosh et al. 1995) and 10:1 (Loux et al. 1989). Our data show that K_d was inversely correlated with water potential. Therefore, conventional batch equilibrium methods potentially underestimate plant-available herbicide. Since the double-tube technique can simulate a representative plant root/herbicide relationship by lowering solution:soil ratios <0.33:1, we propose that this method provides a more accurate estimate of plant-available herbicide. Perhaps this technique or a variation of it could be further developed such that clomazone rates could be more clearly defined particularly on lighter textured soils. It might be possible to reduce the application rate to reduce TASS to < 110 ng g^{-1} thereby providing less potential injury to rice and yet still providing adequate weed control in these types of soils.

Clomazone ACSS was inversely correlated with water potential. In earlier work by Lee et al. (1996 and 1998) ACSS stayed relatively constant across soil moistures for thiobencarb, pretilachlor, cafenstrole, benfuresate, and simetryn. These conflicting results among compounds appear to be associated with varying water solubility. The water solubility's of the previously noted compounds are 30, 50, 2.5, 190, and 400 mg l^{-1}, respectively. Clomazone's solubility is 1100 mg l^{-1} and at least 2.7 times greater than the highest water solubility of the previously mentioned moderately soluble compounds. Therefore, TASS may be a better predictor of plant-available herbicide than ACSS when evaluating highly water soluble herbicides in a non-saturated soil environment. Future studies are needed to evaluate more herbicides that encompass a wider range of pesticide properties.

As a method, the double-centrifuge technique is highly effective in quantifying differences in soil and plant available clomazone. The technique proved to be relatively simple, rapid, and reproducible. Future applications of this technique could include plant available nutrients as well as other herbicides. Also, adsorption data on agrochemicals collected using this type of technique or a variation would provide more accurate data for interpretation and modeling efforts since differences in adsorption can vary substantially with changes in soil and moisture contents.

CHAPTER III

RICE RESPONSE TO CLOMAZONE AS INFLUENCED BY RATE, SOIL TYPE, AND PLANTING DATE

INTRODUCTION

Rice (*Oryza sativa* L.) is grown annually on approximately 1.5 million ha in the United States, and on approximately 80,000 ha in Texas (Scherder et al. 2004). Weed problems have occurred in Texas rice production since its introduction from India in 1846 (Craigmiles 1978). In addition to reducing grain yield, the presence of weed seeds in rice can reduce grain quality and grade. Weeds can also increase insect and disease severity and decrease harvesting and processing efficiency (Webster 2000).

Barnyardgrass (*Echinochloa crus-galli*) (the most common rice weed) with, sprangletop (*Leptochloa* sp.) and broadleaf signalgrass *(Brachiaria platyphylla*) are three of the most troublesome grass weeds in rice production and can reduce rice grain yield by 70, 36, and 32%, respectively (Smith 1988, Webster 2000).

Herbicides are an economical and effective way to control grassy weeds in rice (Webster 2000). The herbicide clomazone was labeled for rice in 2001 (Command 3 ME Label, 2003), and is widely used due to its low cost and effective control. Clomazone is usually applied preemergence (PRE) in rice and controls barnyardgrass, sprangletop, and broadleaf signalgrass, however, it may injure rice plants by bleaching the leaves and turning the entire plant white. The amount of injury is dependent on many variables including application rate, soil characteristics, and growing conditions after application. Injury, under some circumstances may reduce rice yield.

Injury to rice plants is usually greater on sandy soils typical of the Texas rice growing area west of Houston. When clomazone was approved for use in rice the label excluded sandy loam, loamy sand and sandy soils typical of this area. Research investigating different rates of clomazone on these soils under varying environmental conditions could provide data to amend the label to include sandy soils. As a result this low cost and effective weed control option would become available for all Texas rice growers.

Clomazone (2-[(2-chlorophenyl)methyl}-4,4-dimethyl-3-isoxazolidinone) is a selective, soil-applied herbicide from the isoxazolidinone family that controls many grass and broadleaf weeds. Until 1993, clomazone was labeled exclusively for weed control in soybean (*Glycine max* L. Merr), pumpkin (*Cucurbita pepo* L.), pepper (*Capsicum annuum* L.), tobacco (*Nicotiana tabacum* L.), and succulent pea (*Pisum sativum* L.). Since 1993, it has also been labeled in cotton (*Gossypium hirsutum* L.), sweet potatoes (*Ipomoea Batatas* L.), winter squash (*Cucurbita spp.*), rice (*Oryza sativa* L.), and fallow wheat (*Triticum aestivum*) fields (Vencill 2002).

Clomazone can be applied early preplant, preplant-incorporated, pre-emergence (PRE), delayed preemergence, or early postemergence, depending on crop, geographical area, and timing. Its full label approval in rice by the U.S. Environmental Protection Agency occurred in 2001 (Command 3 ME label 2003).

Weeds susceptible to clomazone generally emerge from treated soil but are bleached white due to inhibition of chlorophyll biosynthesis. If bleaching is severe enough it can lead to plant death. Clomazone is taken up by plant roots and shoots and moves primarily in the xylem to the leaves (Duke and Paul 1986). Clomazone indirectly inhibits 1-deoxy-D-xylulose-5-phosphate synthase (DOXP) (Vencill 2002). Ultimately, biosynthesis of chlorophyll and carotenoid pigments are inhibited, causing a bleached appearance in susceptible plants causing white, yellow or light-green coloration (Duke and Paul 1986; Scott et al. 1994).

Several studies have documented rice crop injury from clomazone (Loux et al. 1989; Mervosh et al. 1995; Cumming et al. 2002; Kirksey et al.1996; and Jordan et al. 1998). Webster et al. (1999) reported 8 to 18% injury with clomazone applied PRE at 7 days after rice emergence. Up to 15% rice injury was observed with clomazone applied to rice PRE at 0.56 kg ha^{-1} with no significant reductions in yield (Bollich et al. 2000). However, Jordan et al. (1998) observed bleaching of 35% 2 weeks after treatment of clomazone applied to rice PRE at 0.56 kg ha^{-1} with maturity delay and reductions in yield observed at higher rates. Talbert et al. (1999) documented bleaching of up to 60% 7 days after treatment (DAT) when clomazone was applied PRE at 0.45 kg ha^{-1}. Zhang et al. (2004) reported rice injury from 27 to 51% 2 weeks after 1.12 kg ha^{-1} clomazone was applied PRE with medium grain varieties having greatest injury indicating differential tolerance to clomazone exists between varieties.

It is not known what rates are most effective on grasses without compromising crop safety. The amount of early season injury required to affect yield is not well understood. There has not been any research published evaluating clomazone injury with environmental factors. Research is required to accurately determine the optimum clomazone rate range for effective grass control while maintaining crop safety across a wide range of soil characteristics and planting dates.

The objectives of this research were to 1) achieve a better understanding of rice response to clomazone as influenced by soil type and planting date, 2) determine the rate of clomazone that maximizes weed control while minimizing rice injury, and 3) evaluate the impact of early season rice injury from clomazone on yield.

MATERIALS AND METHODS

Logarithmic Rate Experiment. Field experiments were conducted in 2002 and 2003 at the Texas Agricultural Experiment Station (TAES) Research and Extension Center near Beaumont, TX, and at the TAES research sites near Eagle Lake and Ganado. At Beaumont, the soil was a Morey silty clay loam with a pH of 7.3 and organic matter content of 1.32%. Soil textural analysis was 19% sand, 45% silt, and 36% clay. Because of a rice-fallow rotation, experiments in 2003 were moved to another area on the station with similar soil characteristics. At Eagle Lake, research plots were located on a Nada fine sandy loam with 61% sand, 31% silt, and 8% clay with 0.75% organic matter and pH of 6.1. At Ganado, soil consisted of an Edna fine sandy loam with 67% sand, 19% silt and 14% clay with a pH of 6.1 and an organic matter content of 0.84 %. Soils at Eagle Lake and Ganado are both fine sandy loams, however, the soil at Ganado has a higher percent clay fraction than the soil at Eagle Lake.

In 2002, rice was planted April 17, 15, and 22 at Beaumont, Eagle Lake and Ganado, respectively. Mid April was selected because this time was recommended for planting in Southern Texas. In 2003, studies were planted May 13, 14, and 19 at Beaumont, Eagle Lake, and Ganado, respectively. Mid May was selected in 2003 because some of the most severe injury in the planting date experiment was observed during the May planting in 2002.

A long-grain rice variety, Cocodrie, was planted which is currently the most common variety grown in Texas. Rice was dry-seeded at 90 kg ha^{-1} with a six-row grain drill in rows 19 cm apart. Plot size was 1.1 by 15 m and herbicide application was made with a tractor-mounted logarithmic (log) sprayer (Salisbury, 1991) (Figure 7). A log sprayer can be used to observe a continuously decreasing rate within a range and give more precise rate estimates of weed control and rice crop injury.

At Beaumont, fertilization of the rice crop consisted of a pre plant incorporated (PPI) application of 45 kg ha^{-1} of P as triple super phosphate. This was followed by a 3-leaf rice application of 56 kg ha^{-1} of N as urea, which was followed by a pre-flood application of urea of 78 kg ha^{-1} of N. A fourth application of 56 kg ha^{-1} of N as urea was made at panicle differentiation. At Eagle Lake and Ganado, fertilization consisted of a PPI application of 224 kg ha^{-1} of 19-19-19. Additional nitrogen applications of 78 kg $ha^{-1}$of N as urea was made just prior to flood and 78 kg ha^{-1} of N as ammonium sulfate was applied at the rice panicle differentiation stage. Rice seed was treated with fipronil [5-amino-1(2,6-dichloro-4-(trifluoromethyl) phenyl)-4-((1,*R,S*)-(trifluoromethyl)

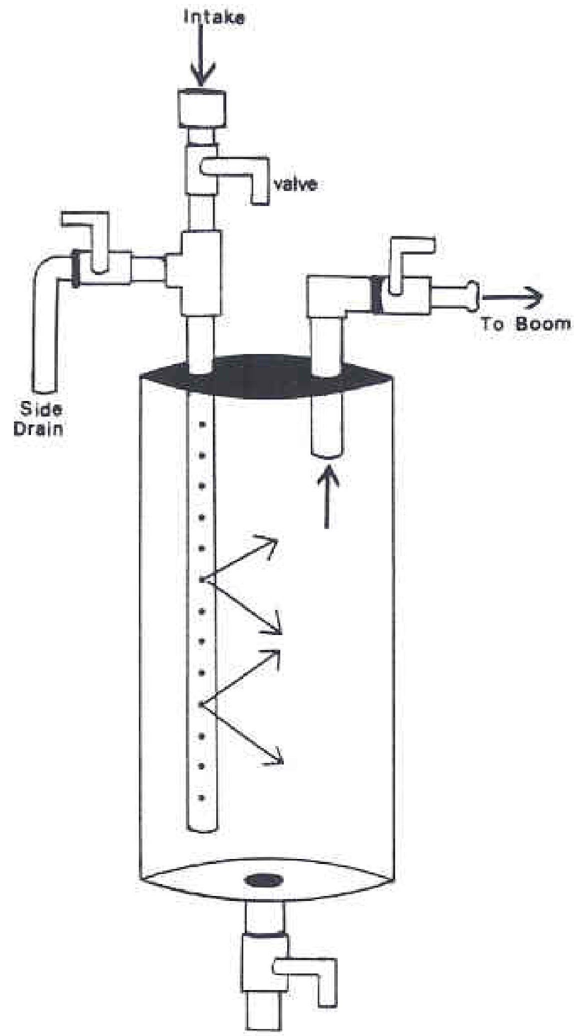


Figure 7. Diagram of tractor mounted log sprayer apparatus.

sulfinyl)-1-*H*-pyrazole-carbonitrile] insecticide prior to planting each year for rice water weevil control. Insects were monitored at all three locations, and insecticide applications were made as needed. Applications of lamda cyhalothrin [α-cyano-3-phenoxybenzyl 3-(2-chloro-3,3,3-trifluoroprop-1-enyl)-2,2-dimethylcyclopropanecarboxylate] were applied at 3-to 4-leaf stage for fall armyworm at Eagle Lake and Ganado both years. Cultural practices were the same at all three locations following the recommendations of the Texas Rice Production Guidelines (Klosterboer, 2001).

At Eagle Lake and Ganado, studies were planted to moisture, and after germination were flushed as needed until a flood was established. At Beaumont, plots were planted in dry conditions and flushed to initiate germination and flushed as needed until a flood was established. At all three locations, clomazone was applied preemergence within 24 h after seeding and rolling of the soil to a firm, flat soil surface.

The spray boom consisted of 4 flat-fan nozzles (XR8003VS) spaced 51 cm apart. The sprayer was calibrated to deliver 224 L ha^{-1} of spray solution. The treatment on each plot consisted of logarithmically decreasing clomazone rates from 0.78 kg ha^{-1} to 0.056 kg ha^{-1}. The chamber in the sprayer was loaded with 125 ml clomazone providing an initial rate of 0.78 kg ha^{-1} at the calibrated delivery rate. As the tractor mounted sprayer progressed at 4.3 km h^{-1}, water was added into the spray chamber to dilute the clomazone. Thus, a logarithmically decreased rate of clomazone was applied as the tractor moved across each plot at a constant speed. A flag was placed in the plot where the spray solution was initially deposited on the soil (start) and when the sprayer was emptied (finish). The clomazone rate at the start was the initial rate in the chamber and the distance to the half rate was calculated by:

$$x = \left[\frac{\text{tractor speed (m min}^{-1}\text{)}}{\text{sprayer output (ml min}^{-1}\text{)}} \right] \text{chamber volume (ml)} \quad [1]$$

where x is the distance (m) across the plot to reach half of the initial rate. The clomazone rate could be calculated at any distance. The treatment was replicated eight times at each location.

Data collection on each plot consisted of three visual classifications: weed control with crop injury, weed control without crop injury (optimum rate range) and no weed control or crop injury. The distance from the start was measured in each plot to note each of the three visual classifications. These distances were converted to rates and were averaged across replications. Data was not combined over years due to significant treatment by year interactions probably caused by differing planting dates.

Planting Date Experiment. Field experiments were conducted in 2002 and 2003 to evaluate weed control and crop tolerance to clomazone, at Beaumont, Eagle Lake, and Ganado. The variety and cultural practices were the same in all three locations and are identical to the previous logarithmic rate experiment.

Planting dates were in March, April, and May spaced roughly one month apart at each location (Table 6). These dates were selected so that a wide range of temperatures and variation of growing conditions could be observed on rice treated with clomazone. In March, soils are cool and air temperatures are frequently <15 C which can cause cold

Table 6. Planting dates for field studies at Beaumont, Eagle Lake and Ganado, TX in 2002 and 2003.

	Planting Dates					
	March		April		May	
Location	2002	2003	2002	2003	2002	2003
Beaumont, TX	12	25	17	14	13	13
Eagle Lake, TX	11	17	15	16	16	14
Ganado, TX	25	-[a]	22	10	29	19

[a]Rice was not planted due to wet soil conditions.

injury to the rice. April is the ideal time to plant as soils are warmer and growing conditions are more favorable. Planting delayed to May often results in reduced yields due to the shorter growing season and excessively hot temperatures.

A randomized complete block design (RCBD) with 10 treatments and 4 replications was used. Plot dimensions were 1.1 by 4.9 m at Eagle Lake and Ganado, and 1.1 by 6.1 m at Beaumont with each plot containing 6 crop rows. Treatments consisted of an untreated weedy check, clomazone applied PRE at 0.22, 0.34, 0.45, and 0.56 kg ha^{-1}; and these herbicide treatments were repeated with the addition of 28 kg ha^{-1} of N applied at the rice 3-leaf stage. A nitrogen application was added to evaluate its effect on recovery from rice plant injury.

All herbicide applications were made using a CO_2-powered backpack sprayer operated at a speed of 4.9 km h^{-1}. The spray boom consisted of 3 flat-fan nozzles (XR8003VS) spaced 51 cm apart. The sprayer was calibrated to deliver 224 L ha^{-1} of spray solution. PRE applications were made within 24 h after planting.

Data collection consisted of visual weed control and crop injury (bleaching) ratings on a scale of 0 to 100%, with 0 being no control, or no crop injury and 100% being complete weed control, or complete crop death. Rice yield data were collected from each plot. Mature grain was harvested with a mechanical plot harvester when grain moisture approached 20%. Grain from the center four rows of each plot was harvested, weighed and converted to kg ha^{-1} at 12% moisture. Data were analyzed for heterogeneous error variances between years. Crop injury, weed control and yield means were separated by Fishers LSD (0.05) (SAS Inst., 1988).

RESULTS AND DISCUSSION

Logarithmic Rate Experiment. At Beaumont in 2002, evaluations were made at 2, 4, and 6 weeks after treatment (WAT) (Figure 8). At 2 WAT, rice injury with weed control, ranged from 0.45 to 0.7 kg ha^{-1}. At 0.24 to 0.45 kg ha^{-1}, there was weed control but no crop injury. This is considered the optimum rate range. Below 0.24 kg ha^{-1}, no clomazone injury was observed but no weeds were controlled. At 4 WAT, the optimum rate range migrated to 0.33 to 0.52 kg ha^{-1} as clomazone degraded with time. By 6 WAT, this optimum rate range was 0.39 to 0.56 kg ha^{-1}. The 2003 Beaumont results were similar. The optimum rate range was 0.41 to 0.57 kg ha^{-1} at 6 WAT.

Similar trends were evident at Eagle Lake (Figure 9). However, the width of the optimum rate range was more compressed at Eagle Lake than at Beaumont for all ratings. At each successive rating, it became even more compressed and migrated to a higher rate. This indicates that the application rate is more critical when clomazone is applied on sandier soils of Eagle Lake compared to the more clayey soils of Beaumont. By 6 WAT in 2002 the optimum rate range at Eagle Lake was 0.36 to 0.43 kg ha^{-1}. In 2003, the optimum rate range was 0.38 to 0.46 kg ha^{-1}.

At Ganado in 2002, the optimum rate range was 0.36 to 0.43 kg ha^{-1} at 6 WAT (Figure 10). In 2003, it ranged from 0.34 to 0.42 kg ha^{-1}. The width of the optimum range was similar to that observed at Eagle Lake.

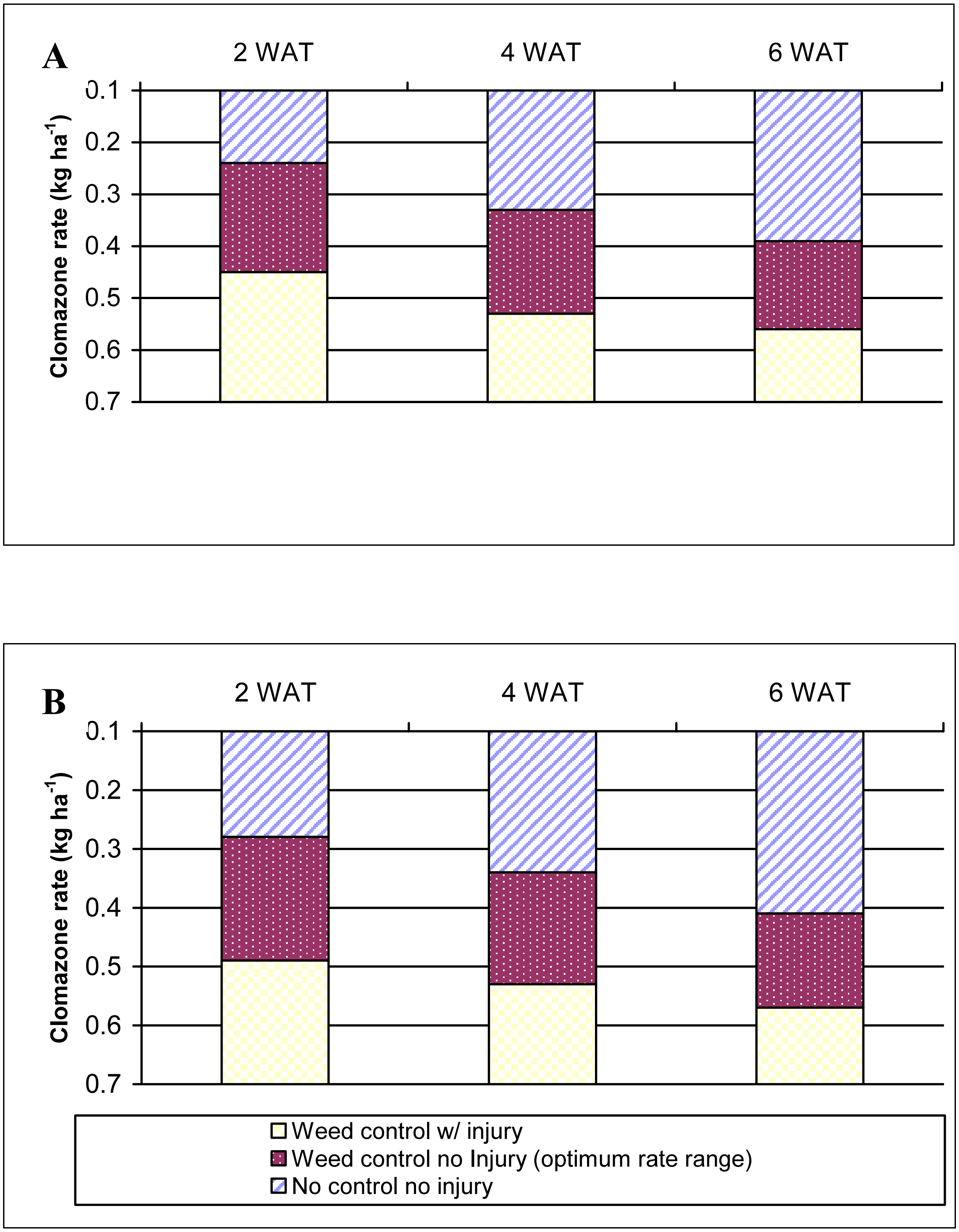


Figure 8. Logarithmic spray rate ranges for weed control and rice injury at Beaumont for 2002 (A) and 2003 (B). Ratings were collected between 3 d of target rating date.

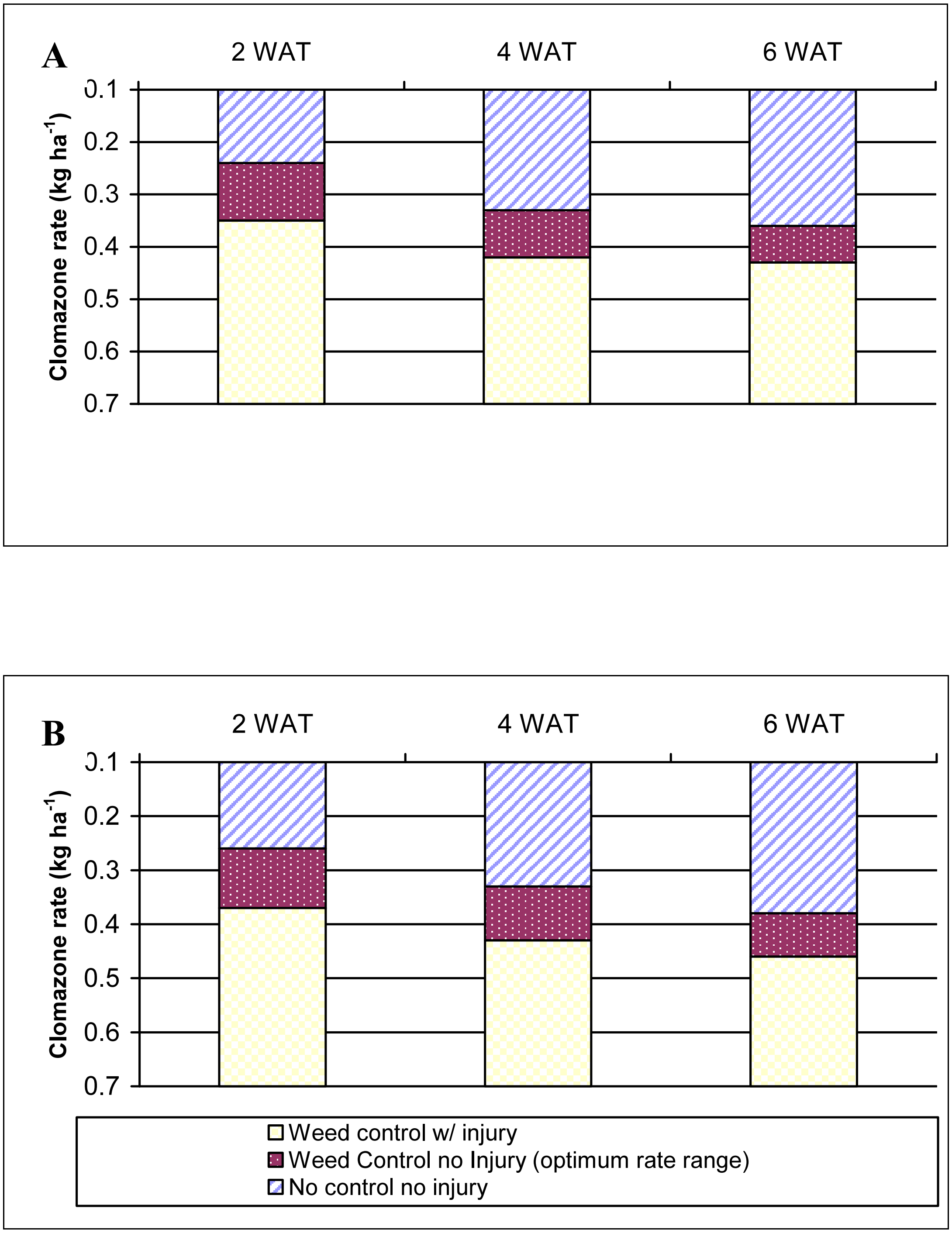


Figure 9. Logarithmic spray rate ranges for weed control and rice injury at Eagle Lake for 2002 (A) and 2003 (B). Ratings were collected between 3 d of target rating date.

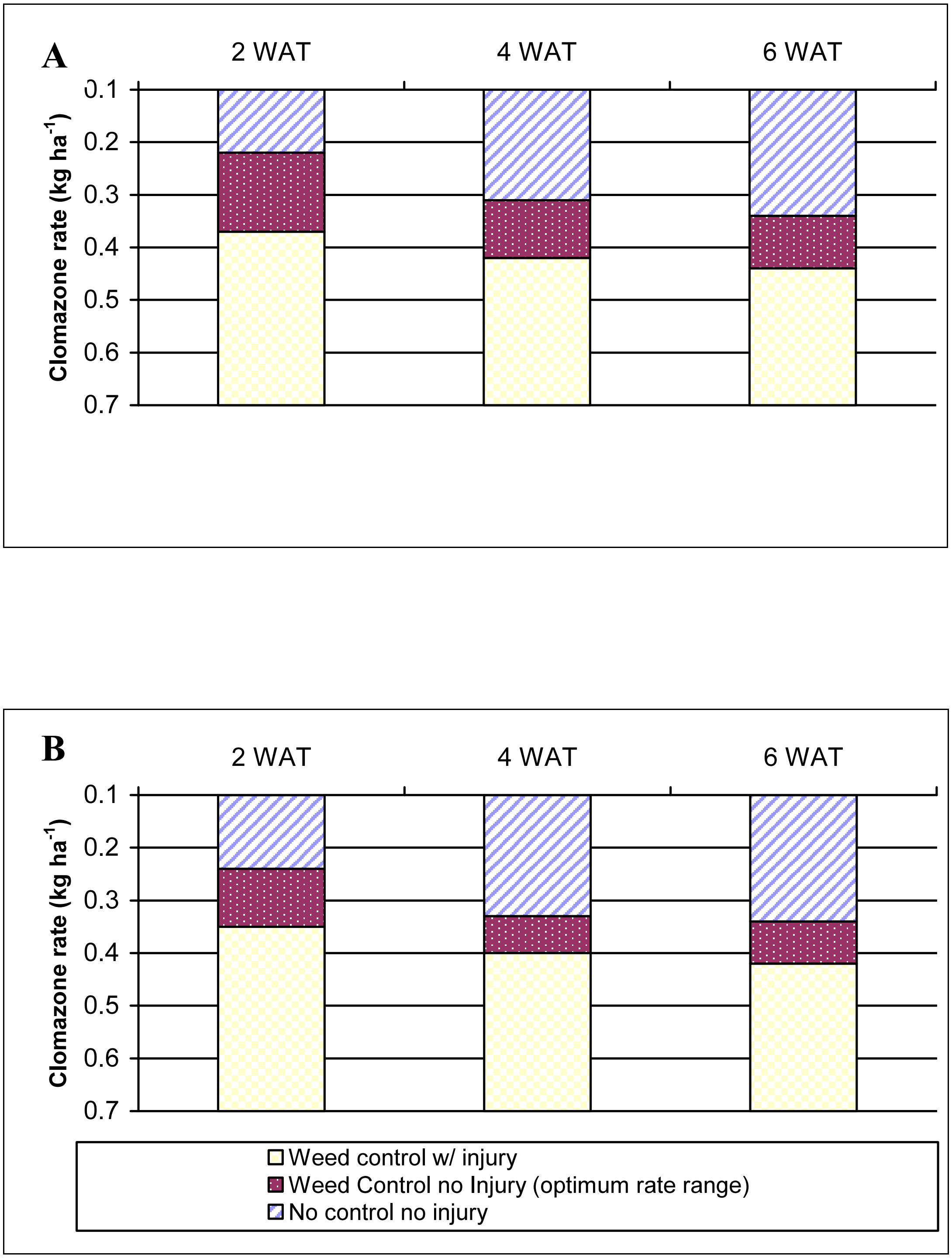


Figure 10. Logarithmic spray rate ranges for weed control and rice injury at Ganado for 2002 (A) and 2003 (B). Ratings were collected between 3 d of target rating date.

Planting Date Experiment. Statistical analyses indicated that 2002 and 2003 crop injury, weed control, and yield data had heterogeneous variances and were not combined over years (Table 7). We hypothesized that an additional application of nitrogen at the three-leaf stage would enhance recovery of injured rice. However, there were no significant differences with crop injury (bleaching), weed control, or yield when additional nitrogen was applied (Table 7). Therefore, means were averaged across nitrogen treatments.

Beaumont. Rice crop injury ranged from 0 to 39% at the March planting date (Table 8). Generally, greater injury was observed at the first rating date for each planting date. Injury was significantly higher as clomazone rate increased at all three rating dates. At each successive rating date, injury was lower than the previous rating. At the final rating evaluation, there was no visible injury at 0.22 and 0.34 kg ha^{-1}. However, up to 11% injury was still visible at 0.45 and 0.56 kg ha^{-1}. This is probably due to cooler temperatures and longer soil residual of clomazone.

Barnyardgrass (ECHCG) control at 16 DAT was 98% regardless of clomazone rate (Table 8). However, by 28 DAT the April and May planting dates had significantly lower control with clomazone at 0.22 and 0.34 kg ha^{-1}. By 45 DAT, 0.22 kg ha^{-1} clomazone provided <92% control and was significantly lower than other treatments. In 2003 the April and May plantings had significantly lower weed control with 0.34 kg ha^{-1} clomazone by 42 DAT. In 2003, greater weed pressure was observed due to weather conditions favorable for successive weed flushes.

Table 7. Analysis of variance for crop injury, weed control, and yield in 2002 to 2003 at Beaumont, Eagle Lake and Ganado.

Location	Planting date	Source	Df	Rating date 1 Crop injury	Rating date 1 Weed control	Rating date 2 Crop injury	Rating date 2 Weed control	Rating date 3 Crop injury	Rating date 3 Weed control	Yield
				----Level of significance[b]----						
Beaumont[a]	March	Year	1	*	*	*	*	*	*	NS
		Rate	3	**	NS	**	NS	*	*	NS
		Nitrogen	1	NS	NS	NS	NS	NS	NS	NS
		Year X Rate	3	*	*	*	*	*	NS	NS
		Year X Nitrogen	1	NS	*	NS	NS	*	NS	NS
		Rate X Nitrogen	3	NS	NS	NS	NS	NS	NS	NS
		CV, %		37.3	15.3	42.7	26.1	17.4	43.8	15.9
	April	Year	1	*	*	*	*	*	*	NS
		Rate	3	**	**	**	*	NS	*	NS
		Nitrogen	1	NS	NS	NS	NS	NS	NS	NS
		Year X Rate	3	*	*	*	*	NS	**	*
		Year X Nitrogen	1	NS	*	N*	NS	*	NS	NS
		Rate X Nitrogen	3	NS	NS	NS	NS	NS	NS	NS
		CV, %		19.3	17.9	19.0	34.6	22.0	38.2	24.1
	May	Year	1	*	*	*	*	*	*	NS
		Rate	3	**	*	*	*	*	*	NS
		Nitrogen	1	NS	NS	NS	NS	NS	NS	NS
		Year X Rate	3	*	NS	*	NS	*	*	*
		Year X Nitrogen	1	NS	NS	*	NS	*NS	NS	NS
		Rate X Nitrogen	3	NS	NS	NS	NS	NS	NS	NS
		CV, %		29.8	12.1	25.9	26.9	13.5	52.2	16.7

Table 7 continued.

Location	Planting date	Source	df	Rating date 1 Crop injury	Rating date 1 Weed control	Rating date 2 Crop injury	Rating date 2 Weed control	Rating date 3 Crop injury	Rating date 3 Weed control	Yield
				Level of significance[b]						
Eagle Lake[a]	March	Year	1	*	*	*	*	*	*	NS
		Rate	3	*	**	*	*	**	*	NS
		Nitrogen	1	NS	NS	NS	NS	NS	NS	NS
		Year X Rate	3	*	NS	*	NS	NS	*	NS
		Year X Nitrogen	1	NS	*	NS	NS	*	NS	NS
		Rate X Nitrogen	3	NS	NS	*	NS	NS	NS	NS
		CV, %		46.5	16.3	44.3	21.8	19.3	45.2	11.5
	April	Year	1	*	*	*	*	*	*	NS
		Rate	3	**	*	**	*	*	*	NS
		Nitrogen	1	NS	NS	NS	NS	NS	NS	NS
		Year X Rate	3	**	NS	*	NS	NS	*	NS
		Year X Nitrogen	1	NS	*	NS	*	*	NS	NS
		Rate X Nitrogen	3	NS	NS	NS	NS	NS	NS	NS
		CV, %		26.4	11.3	22.7	19.3	19.0	33.2	12.4
	May	Year	1	*	*	*	*	*	*	NS
		Rate	3	*	**	*	*	*	*	NS
		Nitrogen	1	NS	NS	NS	NS	NS	NS	NS
		Year X Rate	3	**	NS	*	*	NS	**	*
		Year X Nitrogen	1	NS	*	NS	NS	NS	NS	NS
		Rate X Nitrogen	3	NS	NS	NS	NS	NS	NS	NS
		CV, %		52.2	24.3	43.1	20.0	14.6	29.7	9.5

Table 7 Continued.

Location	Planting date	Source	df	Rating date 1		Rating date 2		Rating date 3		Yield
				Crop injury	Weed control	Crop injury	Weed control	Crop injury	Weed control	
				-----------------------------------Level of significance[b]						------------------------------
Ganado[a]	March[c]	Year	-	-	-	-	-	-	-	-
		Rate	3	**	NS	*	NS	*	NS	*
		Nitrogen	1	NS	NS	NS	NS	NS	NS	NS
		Year X Rate	-	-	-	-	-	-	-	-
		Year X Nitrogen	-	-	-	-	-	-	-	-
		Rate X Nitrogen	3	NS	NS	NS	NS	NS	NS	NS
		CV, %		29.8	14.7	37.9	15.9	21.1	38.9	14.3
	April	Year	1	*	*	*	*	*	*	NS
		Rate	3	**	*	*	*	*	*	NS
		Nitrogen	1	NS	NS	NS	NS	NS	NS	NS
		Year X Rate	3	*	NS	*	NS	NS	**	NS
		Year X Nitrogen	1	NS	*	NS	*	NS	NS	NS
		Rate X Nitrogen	3	NS	NS	NS	NS	NS	NS	NS
		CV, %		37.3	20.3	42.7	26.1	17.4	23.8	15.9
	May	Year	1	*	*	*	*	*	*	NS
		Rate	3	**	*	*	*	*	*	*
		Nitrogen	1	NS	NS	NS	NS	NS	NS	NS
		Year X Rate	3	**	NS	*	*	NS	*	*
		Year X Nitrogen	1	*	*	*	NS	NS	NS	NS
		Rate X Nitrogen	3	NS	NS	NS	NS	NS	NS	NS
		CV, %		26.5	11.3	44.3	21.8	19.3	25.2	22.3

[a]Rating date 1 ranged from 14 to 26 days after treatment; Rating date 2 ranged from 28 to 40 days after treatment; Rating date 3 ranged from 42 to 54 days after treatment.
[b]Abbreviation: NS, not significant; * Significant at 0.05 level; ** Significant at 0.01 level.
[c]March planting date at Ganado includes 2002 data only.

Table 8. Rice injury and barnyardgrass control with preemergence applications of clomazone near Beaumont, TX, for the March, April and May 2002 and 2003 planting dates[a].

		March					
		Injury[b]			Control[b]		
Year	Rate	16 DAT	28 DAT	45 DAT	16 DAT	28 DAT	45 DAT
	(kg ha^{-1})	--------------%---------------			-------------%--------------		
2002							
	0.22	6 c	0 c	0 b	98 a	98 a	91 b
	0.34	17 b	2 c	0 b	98 a	98 a	98 a
	0.45	24 a	8 b	4 b	98 a	98 a	98 a
	0.56	24 a	12 a	11 a	98 a	98 a	98 a
2003							
	0.22	9 d	10 c	0 a	98 a	97 a	92 b
	0.34	16 c	14 c	0 a	98 a	98 a	96 a
	0.45	24 b	19 b	1 a	98 a	98 a	98 a
	0.56	35 a	39 a	3 a	98 a	98 a	98 a

Table 8 Continued.

		April					
		Injury[b]			Control[b]		
Year	Rate	19 DAT	31 DAT	43 DAT	19 DAT	31 DAT	43 DAT
	(kg ha^{-1})	--------------%------------			-------------%------------		
2002							
	0.22	0 c	0 b	0 a	98 a	97 a	89 b
	0.34	3 c	1 b	0 a	98 a	98 a	96 a
	0.45	10 b	2 b	0 a	98 a	98 a	98 a
	0.56	23 a	7 a	0 a	98 a	98 a	98 a
2003							
	0.22	1 c	0 a	0 a	98 a	85 b	75 c
	0.34	4 b	0 a	0 a	98 a	97 a	93 b
	0.45	9 a	0 a	0 a	98 a	98 a	98 a
	0.56	13 a	0 a	0 a	98 a	98 a	98 a

Table 8 Continued.

		May					
		Injury[b]			Control[b]		
		22	28	42	22	28	42
Year	Rate	DAT	DAT	DAT	DAT	DAT	DAT
	(kg ha^{-1})	--------------%------------			-------------%------------		
2002							
	0.22	7 c	1 c	0 a	98 a	90 b	87 b
	0.34	23 b	4 bc	0 a	98 a	98 a	93ab
	0.45	24 b	7 b	0 a	98 a	98 a	98 a
	0.56	37 a	12 a	0 a	98 a	98 a	98 a
2003							
	0.22	6 b	0 a	0 a	98 a	86 b	72 c
	0.34	7 b	0 a	0 a	98 a	91 ab	88 b
	0.45	8 b	0 a	0 a	98 a	97 a	97 a
	0.56	14 a	0 a	0 a	98 a	98 a	98 a

[a]Abbreviations: DAT, days after preemergence treatment of clomazone.
[b]Means within a column for each year followed by the same letter are not significantly different at the 0.05 level.

Rice crop injury was greater in 2002 than in 2003, with all planting dates and rates. This may be due to more rainfall and warmer temperatures in 2003. Studies were also planted 8 to 10 days later in 2003 due to delays caused by rainfall.

Rice yield potential was generally greater in 2002 than in 2003 for all planting dates and rates (Table 9). This was probably due to lower temperatures, cloudy weather, and higher rainfall in 2003. There were no significant differences in yield except in March and April of 2003 at 0.22 kg ha^{-1} clomazone. Yield reduction was due to weed competition since crop injury was relatively low for this rate. The highest yield was observed with the April planting in both years, which is consistent with recommended planting dates for the area.

At Beaumont, application of 0.45 or 0.56 kg ha^{-1} clomazone to rice provided the best season-long weed control and did not significantly reduce yield despite some early season injury. Below 0.34 kg ha^{-1}, rice crop injury was much lower. However, weed control did not persist throughout the season and some yield reductions were observed.

Eagle Lake. At 23 DAT for the 2002 March planting, crop injury ranged from 22 to 49% and increased as clomazone rate increased (Table 10). From 0.34 to 0.45 kg ha^{-1}, there was a significant increase in injury at all ratings. The predominate grass species was broadleaf signalgrass. Broadleaf signalgrass control for the March 2002 planting was >95% regardless of clomazone rate at 23, 35, and 49 DAT (Table 10). Rates as low as 0.22 kg ha^{-1} applied to Eagle Lake soils provided adequate broadleaf signalgrass control.

Table 9. Rice yield at Beaumont, Eagle Lake and Ganado, TX for March, April and May 2002 and 2003.

Location	Clomazone Rate	Yield[a] March 2002	March 2003	April 2002	April 2003	May 2002	May 2003
	(kg ha^{-1})	---------- kg ha^{-1} ----------					
Beaumont	0.22	8524 a	4133 b	9425 a	6071 b	7122 b	6978 b
	0.34	8712 a	5688 a	9320 a	8482 a	7143 b	7174 ab
	0.45	8562 a	6041 a	8052 b	8244 a	7363 b	7954 a
	0.56	8503 a	5926 a	8775 ab	8406 a	8344 a	7669 a
Eagle Lake	0.22	9745 a	7087 a	7740 a	6177 a	4932 b	5807 a
	0.34	9395 a	7250 a	8289 a	5795 a	6045 a	5570 a
	0.45	9501 a	7447 a	7945 a	6185 a	5691 ab	5929 a
	0.56	9626 a	7183 a	7348 b	6044 a	5789 ab	6399 a
Ganado	0.22	8618 b	-[b]	9743 a	7524 a	8062 a	2617 c
	0.34	9402 a	-	10063 a	7479 a	7148 b	3889 b
	0.45	9454 a	-	9982 a	6542 a	7834 a	3804 b
	0.56	9382 a	-	10283 a	7547 a	7664 ab	4909 a

[a]Means within a column at each location followed by the same letter are not significantly different at the 0.05 level.
[b]March 2003 at Ganado not planted due to excessive rain.

Table 10. Rice injury and broadleagf signalgrass control with preemergence applications of clomazone near Eagle Lake, TX, for the March, April and May 2002 and 2003 planting dates[a].

		March					
		Injury[b]			Control[b]		
Year	Rate	23 DAT	35 DAT	49 DAT	23 DAT	35 DAT	49 DAT
	(kg ha^{-1})	--------------%---------------			-------------%--------------		
2002							
	0.22	22 b	18 b	3 b	98 a	98 a	96 a
	0.34	27 b	23 b	4 b	98 a	98 a	98 a
	0.45	46 a	41 a	10 a	98 a	98 a	98 a
	0.56	49 a	41 a	9 a	98 a	98 a	98 a
2003							
	0.22	12 d	11 b	0 b	98 a	98 a	96 a
	0.34	26 c	11 b	0 b	98 a	98 a	97 a
	0.45	38 b	15 b	1 b	98 a	98 a	98 a
	0.56	52 a	24 a	4 a	98 a	98 a	98 a

Table 10 Continued.

		April					
		Injury[b]			Control[b]		
Year	Rate	16 DAT	37 DAT	49 DAT	16 DAT	37 DAT	49 DAT
	(kg ha^{-1})	--------------%------------			-------------%------------		
2002							
	0.22	10 c	0 c	0 b	98 a	98 a	95 a
	0.34	15 b	8 c	0 b	98 a	97 a	97 a
	0.45	21 a	23 b	1 b	98 a	98 a	98 a
	0.56	27 a	47 a	13 a	98 a	98 a	98 a
2003							
	0.22	5 c	0 c	0 a	98 a	92 b	84 c
	0.34	10 bc	0 c	0 a	98 a	98 a	93 b
	0.45	15 b	6 b	0 a	98 a	98 a	97 a
	0.56	24 a	15 a	0 a	98 a	98 a	98 a

Table 10 Continued.

		May					
		Injury[b]			Control[b]		
Year	Rate	19 DAT	35 DAT	53 DAT	19 DAT	35 DAT	53 DAT
	(kg ha^{-1})	--------------%------------			-------------%------------		
2002							
	0.22	3 d	0 c	0 c	98 a	93 b	84 b
	0.34	18 c	5 c	0 c	98 a	98 a	93ab
	0.45	39 b	24 b	10 b	98 a	98 a	97 a
	0.56	60 a	47 a	15 a	98 a	98 a	98 a
2003							
	0.22	5 c	5 c	0 b	98 a	98 a	94 a
	0.34	17 b	10 b	0 b	98 a	98 a	95 a
	0.45	24 ab	14 ab	1 b	98 a	98 a	97 a
	0.56	31 a	19 a	3 a	98 a	98 a	98 a

[a]Abbreviations: DAT, days after preemergence treatment of clomazone.
[b]Means within a column for each year followed by the same letter are not significantly different at the 0.05 level.

At 23 DAT, for the 2003 March planting, rice injury ranged from 12 to 52 % with significant differences between each clomazone rate (Table 10). At 49 DAT, no injury was visible at 0.22 and 0.34 kg ha^{-1} and at 0.45 and 0.56 kg ha^{-1} clomazone injury was <4%. Broadleaf signalgrass control was >95% with no significant differences between treatments.

In the 2002 April planting, crop injury was highest at 16 DAT ranging from 10 to 27% (Table 10). At 37 DAT, significant differences in injury were observed for all treatments with no visible injury at 0.22 kg ha^{-1}. In general, injury decreased at each successive rating date. However, injury was greater at 37 DAT with 0.45 and 0.56 kg ha^{-1}clomazone compared with injury at 16 DAT. This was probably due to rainfall that enhanced herbicide uptake. At 49 DAT, <1% injury was observed at 0.22, 0.34, and 0.45 kg ha^{-1} clomazone and injury at 0.56 kg ha^{-1} was 13%. Results indicated that 0.56 kg ha^{-1} was excessive for this soil. Broadleaf signalgrass control was >95% at all ratings with no significant differences between treatments (Table 10).

At 16 DAT, for the April 2003 planting injury ranged from 5 to 24% (Table 10). By 48 DAT no treatment had any visible injury. Injury was not as severe and the rice recovered more rapidly in April 2003 than in April 2002 planting. Broadleaf signalgrass control was 98% for all treatments at 16 DAT. However by 49 DAT, broadleaf signalgrass control at the lowest clomazone rate of 0.22 kg ha^{-1} was 84% and probably would not provide season-long control. All other rates provided >93% broadleaf signalgrass control and there were no significant differences between treatments.

When planted in May 2002, injury at 19 DAT ranged from 3% at the lowest clomazone rate to 60% at the highest (Table 10). Injury ratings significantly increased as clomazone rates increased. At 35 DAT, no injury was observed at 0.22 kg ha^{-1} but injury at 0.56 kg ha^{-1} was 47%. Significant differences were observed between 0.34, 0.45 and 0.56 kg ha^{-1}. By 52 DAT, injury for all treatments was reduced with no visible injury at 0.22 and 0.34 kg ha^{-1}. Injury was significantly higher at 0.45 kg ha^{-1}clomazone for all ratings compared to the lower rates. Broadleaf signalgrass control at 19 DAT was 98% for all treatments. At 35 and 53 DAT, broadleaf signalgrass control was significantly lower at 0.22 kg ha^{-1} than the other treatments. All other rates provided >92% control with no significant differences between treatments.

When planted in May 2003, rice injury 19 DAT ranged from 5 to 31% (Table 10). By 35 DAT, injury for all treatments decreased slightly with significant differences between treatments. At 53 DAT, injury for all treatments was less <3% with no visible injury at 0.22 and 0.34 kg ha^{-1}clomazone. Injury intensity and duration were less for this planting date in 2003 than in 2002. Weed control was >93% at all rating timings with no significant differences between treatments.

Rice yield potential at Eagle Lake was lower in 2003 than in 2002 for the March and April plantings (Table 9). This was probably due to more favorable growing conditions in 2002. At Eagle Lake, March planting provided greater rice yield in both years. March is the ideal planting time for this area. A reduction in yield of approximately 1000 kg ha^{-1} was observed for each successive month delay in planting. Significantly lower yield was observed at 0.22 kg ha^{-1}clomazone due to lack of season-long weed control. To achieve good weed control and minimize crop injury at Eagle Lake, rates of 0.34 and 0.45 kg ha^{-1} clomazone gave the best results for all plantings and years.

Ganado. Rice injury at 16 DAT ranged from 9 to 49% in the March 2002 planting with 0.56 kg ha^{-1} having significantly higher injury than all other clomazone rates (Table 11). By 45 DAT, there was no visible injury at 0.22, 0.34, and 0.45 kg ha^{-1}. At 0.56 kg ha^{-1} clomazone, injury was 4%. Broadleaf signalgrass control was 98% for all ratings at 2002 March planting. This indicated that on the soil at Ganado, all clomazone rates provided >97% control. The 2003 March planting was not established due to heavy rainfall that prevented planting until April.

At 18 DAT in the 2002 April planting, injury ranged from 0 to 14% across clomazone rates (Table 11). At 38 DAT, injury was <3% for all treatments with no significant differences between treatments. At 18 DAT, broadleaf signalgrass control was 98% with no significant differences between clomazone treatments. By 58 DAT, broadleaf signalgrass control was significantly lower for clomazone at 0.22 kg ha^{-1}. This low rate of clomazone provided the least amount of crop injury but significantly lower broadleaf signalgrass control.

In 2003 April planting, injury ranged from 0 to 28% at 18 DAT significantly increasing between treatments (Table 11). By 58 DAT, no injury was visible for any treatment. At 18 DAT, broadleaf signalgrass control was 98% with no differences between treatments. At 38 and 58 DAT, 0.22 kg ha^{-1} clomazone provided significantly

Table 11. Rice injury and broadleaf signalgrass control with preemergence applications of clomazone near Ganado, TX, for the March, April and May 2002 and 2003 planting dates[a].

		March[c]					
		Injury[b]			Control[b]		
Year	Rate	16 DAT	28 DAT	45 DAT	16 DAT	28 DAT	45 DAT
	(kg ha^{-1})	--------------%---------------			-------------%--------------		
2002							
	0.22	9 c	2 b	0 b	98 a	98 a	98 a
	0.34	16 bc	2 b	0 b	98 a	98 a	98 a
	0.45	24 b	5 b	0 b	98 a	98 a	98 a
	0.56	49 a	20 a	4 a	98 a	98 a	98 a

Table 11 Continued.

		April					
		Injury[b]			Control[b]		
Year	Rate	18 DAT	38 DAT	58 DAT	18 DAT	38 DAT	58 DAT
	(kg ha^{-1})	--------------%------------			-------------%------------		
2002							
	0.22	6 c	0 a	0 a	98 a	80 c	82 b
	0.34	17 b	2 a	0 a	98 a	88 b	94 a
	0.45	21 ab	1 a	0 a	98 a	97 a	97 a
	0.56	33 a	1 a	0 a	98 a	98 a	98 a
2003							
	0.22	0 d	0 b	0 a	98 a	91 b	88 b
	0.34	7 c	4 b	0 a	98 a	98 a	94 a
	0.45	18 b	7 ab	0 a	98 a	98 a	96 a
	0.56	28 a	12 a	0 a	98 a	98 a	98 a

Table 11 Continued.

		May					
		Injury[b]			Control[b]		
Year	Rate	19 DAT	35 DAT	53 DAT	19 DAT	35 DAT	53 DAT
	(kg ha^{-1})	--------------%------------			-------------%------------		
2002							
	0.22	6 c	0 c	0 b	98 a	90 b	88 b
	0.34	17 b	2 c	0 b	98 a	92 b	92 ab
	0.45	24 a	8 b	4 b	98 a	94 ab	96 a
	0.56	24 a	12 a	11 a	98 a	98 a	98 a
2003							
	0.22	3 b	0 a	0 a	98 a	74 c	77 b
	0.34	6 a	0 a	0 a	98 a	92 b	92 ab
	0.45	8 a	0 a	0 a	98 a	94 ab	96 a
	0.56	9 a	0 a	0 a	98 a	98 a	98 a

[a]Abbreviations: DAT, days after preemergence treatment of clomazone.
[b]Means within a column for each year followed by the same letter are not significantly different at the 0.05 level.
[c]March 2003 at Ganado was not planted.

lower control from other treatments. Broadleaf signalgrass control was similar to 2002 results for the April planting.

At the 2002 May planting, crop injury ranged from 6 to 24% (Table 11). By 53 DAT, 0.56 kg ha^{-1} clomazone showed significantly greater injury than other treatments. At 19 DAT, broadleaf signalgrass control was 98% in all treatments. However, at 35 and 53 DAT, there was significantly lower broadleaf signalgrass control at 0.22 kg ha^{-1} clomazone compared to 0.56 kg ha^{-1}. The lowest rate of clomazone did not provide adequate season-long weed control.

Injury ranged from 3 to 9% in the 2003 May planting (Table 11). At 35 and 53 DAT, no visible injury was observed in any treatment. At 19 DAT, broadleaf signalgrass control was 98% in all treatments. However at 35 and 53 DAT, 0.22 kg ha^{-1} clomazone was significantly less than 0.45 and 0.56 kg ha^{-1}. The lowest rate of clomazone did not provide season-long control as was observed at other locations and planting dates.

Rice yield potential at Ganado was generally higher in 2002 than 2003 for all plantings as was observed at Beaumont and Eagle Lake (Table 9). Similar to Beaumont, April planting provided the highest yield. The optimum rates across all plantings to achieve weed control, minimize crop injury, and maintain yield was 0.34 and 0.45 kg ha^{-1}.

In summary, the width of the optimum rate range was more compressed at Eagle Lake and Ganado than at Beaumont for all ratings. At each successive rating, it became even more compressed and migrated to a higher rate at all locations. This indicates that the application rate is more critical when clomazone is applied on sandier soils of Eagle Lake and Ganado compared to the more clayey soils of Beaumont. The 6 WAT rating was after flood establishment and nearing canopy closure of the rice crop. The optimum rate range at this rating would be indicative of the practical crop tolerance and weed control. At 6 WAT, the optimum rate range at Beaumont, Eagle Lake, and Ganado were 0.41 to 0.57, 0.38 to 0.43, and 0.36 to 0.42 kg ha^{-1}clomazone, respectively.

In the planting date experiments, rice crop injury and weed control were greater in 2002 than in 2003 at all plantings and rates. This is due to higher rainfall differences in weather conditions since field experiments were established 8 to 10 days later in 2003 due to rainfall. At all locations, as clomazone rate increased, injury increased. However, at each sequential rating less rice injury was observed with all treatments.

To achieve good weed control, minimize crop injury, and maintain yield, clomazone at 0.34 and 0.45 kg ha^{-1} provided the best results for all planting dates and years at Eagle Lake and Ganado. At Beaumont, application of 0.45 and 0.56 kg ha^{-1} clomazone to rice provided optimum weed control and injury without yield reductions. Below 0.34 kg ha^{-1}, rice crop injury was lower, however adequate weed control did not last throughout the season. These results agreed with data from the logarithmic rate experiment. Clomazone applied at 0.22 kg ha^{-1} usually did not provide season long weed control. Also, some reductions in yield were observed due to weed competition at the lower clomazone rates. Rice injury at 0.56 kg ha^{-1} clomazone was excessive according to results in the logarithmic rate experiment. At that same rate in the planting date study, significantly higher rice injury also occurred compared to lower rates, but rice yields were not reduced.

Clomazone is safe to use on rice on sandy textured soils at adjusted rates from the current label. Injury can be expected, but, using the rates suggested from this research, injury can be minimized while achieving excellent weed control. As a result, amendments to the herbicide label are expected for use on sandy textured soils. This will give rice producers more choices and access to an inexpensive and effective herbicide.

CHAPTER IV

SUMMARY AND CONCLUSIONS

PLANT AVAILABILITY OF CLOMAZONE IN RICE

Recently, clomazone has been successfully used in rice weed control. However, rice injury is a potential problem for clomazone on light-textured soils. Experiments were conducted to determine the effect of soil characteristics and water potential on plant-available clomazone and rice injury. A centrifugal double-tube technique was used to determine plant-available concentration in soil solution (ACSS), total amount available in soil solution (TASS), and K_d values for clomazone on four soils at four water potentials. A rice bioassay was conducted parallel to the plant-available study to correlate biological availability to ACSS, TASS, and K_d. TASS was significantly different in all soils at the 1% level of significance. The order of increasing TASS for the soils studied was Morey<Edna<Nada<Crowley which correlated well with soil characteristics. The order of increasing TASS after equilibrium was -90 kPa<-75 kPa<-33 kPa<0 kPa. TASS values at 0 kPa were > 2x TASS at -90 kPa. It appears that severe rice injury from clomazone on these soils could occur if TASS >110 ng g^{-1} and K_d < 1.1 ml g^{-1}. We propose that the double-tube technique provides a more accurate estimate of available herbicide because the solution:soil ratios are <0.33:1 and would be more representative of a plant root/herbicide relationship. Perhaps this technique or some variation could be further developed such that clomazone rates could be more clearly defined particularly on lighter textured soils. TASS may be a better predictor of plant-available herbicide than ACSS when evaluating moderately to highly water soluble herbicides in a non-saturated soil environment.

LOGARITHMIC RATE EXPERIMENT

In summary, the width of the optimum rate range was more compressed at Eagle Lake and Ganado than at Beaumont for all ratings. At each successive rating, it became even more compressed and migrated to a higher rate at all locations. This indicates that the application rate is more critical when clomazone is applied on sandier soils of Eagle Lake and Ganado compared to the more clayey soils of Beaumont. The 6 WAT rating was after flood establishment and nearing canopy closure of the rice crop. The optimum rate range at this rating would be indicative of the practical crop tolerance and weed control. At 6 WAT, the optimum rate range at Beaumont, Eagle Lake, and Ganado were 0.41 to 0.57, 0.38 to 0.43, and 0.36 to 0.42 kg ha^{-1}clomazone, respectively.

PLANTING DATE EXPERIMENT

In the planting date experiments, rice crop injury and weed control were greater in 2002 than in 2003 at all plantings and rates. This is due to higher rainfall differences in weather conditions since field experiments were established 8 to 10 days later in 2003 due to rainfall. At all locations, as clomazone rate increased, injury increased. However, at each sequential rating less rice injury was observed with all treatments.

To achieve good weed control, minimize crop injury, and maintain yield, clomazone at 0.34 and 0.45 kg ha^{-1} provided the best results for all planting dates and years at Eagle Lake and Ganado. At Beaumont, application of 0.45 and 0.56 kg ha^{-1} clomazone to rice provided optimum weed control and injury without yield reductions. Below 0.34 kg ha^{-1}, rice crop injury was lower however adequate weed control did not last throughout the season. These results agreed with data from the logarithmic rate experiment. Clomazone applied at 0.22 kg ha^{-1} usually did not provide season long weed control. Also, some reductions in yield were observed due to weed competition at the lower clomazone rates. Rice injury at 0.56 kg ha^{-1} clomazone was excessive according to results in the logarithmic rate experiment. At that same rate in the planting date study, significantly higher rice injury also occurred compared to lower rates, but rice yields were not reduced.

Clomazone is safe to use on rice on sandy textured soils at adjusted rates from the current label. Injury can be expected, but, using the rates suggested from this research, injury can be minimized while achieving excellent weed control. As a result, amendments to the herbicide label are expected for use on sandy textured soils. This will give rice producers more choices and access to an inexpensive and effective herbicide.

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APPENDIX A

CLIMATIC CONDITIONS AT TEXAS AGRICULTURAL RESEARCH AND EXTENSION CENTER NEAR BEAUMONT, TX. 2002 GROWING SEASON

Date	Air Temp (˚F) Max	Air Temp (˚F) Min	2002 Precipatation (Inches)	Relative Humidity (%) Max	Relative Humidity (%) Min
3/1/2002	57	38	0.09	100	27
3/2/2002	60	54	0.36	100	89
3/3/2002	60	28	0	100	41
3/4/2002	45	23	0	43	19
3/5/2002	55	29	0	100	21
3/6/2002	62	37	0	98	25
3/7/2002	74	54	0.01	100	59
3/8/2002	77	59	0	100	55
3/9/2002	78	64	0	100	75
3/10/2002	72	43	0.02	100	14
3/11/2002	65	43	Trace	83	17
3/12/2002	68	57	0.01	100	70
3/13/2002	71	39	0	100	25
3/14/2002	73	50	0	100	42
3/15/2002	79	57	0	100	65
3/16/2002	85	61	0	100	62
3/17/2002	82	51	0.02	100	72
3/18/2002	83	70	0	100	68
3/19/2002	82	64	0	100	62
3/20/2002	76	67	0.03	95	60
3/21/2002	79	55	Trace	97	65
3/22/2002	75	41	0	83	21
3/23/2002	63	39	0	90	32
3/24/2002	69	47	0	100	43
3/25/2002	78	62	0	99	49
3/26/2002	78	46	0.28	100	67
3/27/2002	69	42	0	100	37
3/28/2002	75	48	0	100	32
3/29/2002	79	66	Trace	100	63
3/30/2002	82	65	0	100	65
3/31/2002	81	64	0.67	100	63
4/1/2002	74	52	Trace	100	58
4/2/2002	70	54	Trace	100	57
4/3/2002	80	60	0	99	53
4/4/2002	74	51	0	62	47
4/5/2002	74	54	0	67	34
4/6/2002	73	52	0	82	27
4/7/2002	73	62	0.01	90	27
4/8/2002	78	60	4.32	100	63
4/9/2002	67	64	0.59	100	92
4/10/2002	79	60	0	100	59
4/11/2002	80	62	0	100	40
4/12/2002	82	62	0	100	46
4/13/2002	83	62	0	100	50

4/14/2002	83	62	0	100	53
4/15/2002	85	64	0	96	57
4/16/2002	84	73	0	93	53
4/17/2002	81	74	0	93	65
4/18/2002	86	67	0	98	49
4/19/2002	85	72	0	100	51
4/20/2002	86	73	0	100	54
4/21/2002	85	73	0	99	50
4/22/2002	86	70	0	100	56
4/23/2002	87	64	0	93	57
4/24/2002	86	61	0	93	57
4/25/2002	87	68	0	99	54
4/26/2002	82	61	0.01	92	68
4/27/2002	86	71	0	97	51
4/28/2002	87	73	0	98	53
4/29/2002	88	70	0	100	53
4/30/2002	91	72	0	98	56
5/1/2002	88	76	0	91	53
5/2/2002	88	75	0	95	53
5/3/2002	90	76	0	97	50
5/4/2002	90	78	0	94	53
5/5/2002	90	74	0	98	62
5/6/2002	90	72	0	98	48
5/7/2002	89	77	0	96	48
5/8/2002	90	75	0	91	50
5/9/2002	90	73	0	92	53
5/10/2002	89	71	0	100	48
5/11/2002	90	74	0	99	44
5/12/2002	89	76	0	94	53
5/13/2002	90	67	0	97	54
5/14/2002	79	55	0	96	47
5/15/2002	80	57	0	90	25
5/16/2002	84	67	0	97	43
5/17/2002	90	73	0.08	100	49
5/18/2002	77	63	1.6	100	78
5/19/2002	69	50	0	100	60
5/20/2002	75	52	0	91	58
5/21/2002	78	54	0	90	27
5/22/2002	88	59	0	94	42
5/23/2002	81	63	0	87	43
5/24/2002	83	65	0	94	54
5/25/2002	85	68	0	94	43
5/26/2002	88	68	0	99	49
5/27/2002	90	67	0.02	100	42
5/28/2002	88	70	0	98	48
5/29/2002	86	67	0.06	99	50
5/30/2002	84	68	0.03	100	51
5/31/2002	86	65	0.1	100	50

6/1/2002	86	67	0.38	99	57
6/2/2002	90	68	0	98	41
6/3/2002	90	71	0	98	47
6/4/2002	90	67	0	100	52
6/5/2002	91	70	0	99	48
6/6/2002	92	72	0.07	99	47
6/7/2002	95	74	0.09	97	42
6/8/2002	91	76	0.01	98	51
6/9/2002	93	77	0	97	47
6/10/2002	93	76	0.01	96	54
6/11/2002	94	76	0	96	46
6/12/2002	91	66	0.2	99	49
6/13/2002	91	70	0	100	49
6/14/2002	93	73	0	98	40
6/15/2002	96	66	0	92	37
6/16/2002	93	75	Trace	100	39
6/17/2002	90	65	0.87	100	52
6/18/2002	87	68	0	92	50
6/19/2002	91	72	0	95	43
6/20/2002	92	75	0	94	47
6/21/2002	88	72	0.43	97	54
6/22/2002	92	69	0.15	100	47
6/23/2002	91	70	0	97	36
6/24/2002	88	70	0	100	48
6/25/2002	86	71	0.23	100	70
6/26/2002	85	72	0	100	68
6/27/2002	90	70	2.29	100	55
6/28/2002	81	73	0.71	100	85
6/29/2002	84	75	0.24	100	70
6/30/2002	84	78	0	100	79
7/1/2002	89	76	0	100	66
7/2/2002	90	77	0.09	100	66
7/3/2002	90	70	0.12	100	70
7/4/2002	91	77	0	100	62
7/5/2002	92	74	0	100	50
7/6/2002	95	74	0	100	39
7/7/2002	96	75	0	100	49
7/8/2002	95	74	0.02	85	65
7/9/2002	95	74	0	90	48
7/10/2002	90	73	0.03	100	80
7/11/2002	94	75	0	92	58
7/12/2002	97	75	0	98	57
7/13/2002	97	74	0.76	99	55
7/14/2002	82	71	0.75	100	88
7/15/2002	90	73	0.68	100	89
7/16/2002	84	71	0.68	100	93
7/17/2002	84	71	1.51	100	95
7/18/2002	92	73	0	100	64

7/19/2002	93	74	0	93	52
7/20/2002	93	73	0.03	94	71
7/21/2002	94	75	0	99	53
7/22/2002	94	72	0	95	65
7/23/2002	93	76	0	96	56
7/24/2002	97	75	0	95	62
7/25/2002	96	77	0	98	80
7/26/2002	91	77	0	99	81
7/27/2002	89	73	0.62	100	79
7/28/2002	91	77	0	100	83
7/29/2002	93	75	0	97	77
7/30/2002	94	75	0	100	70
7/31/2002	92	75	0	100	73
8/1/2002	94	73	0	99	67
8/2/2002	94	75	0	100	66
8/3/2002	97	77	0	90	50
8/4/2002	96	73	0	93	52
8/5/2002	96	71	0.01	94	56
8/6/2002	95	76	0	88	51
8/7/2002	96	76	0	89	52
8/8/2002	96	76	0.03	93	57
8/9/2002	95	78	0	95	57
8/10/2002	89	76	0.12	90	78
8/11/2002	91	73	0	92	43
8/12/2002	93	71	0.32	100	60
8/13/2002	87	69	0.47	100	92
8/14/2002	88	68	0.55	100	89
8/15/2002	84	72	2.34	100	90
8/16/2002	79	74	1.3	95	94
8/17/2002	90	76	0.43	99	74
8/18/2002	93	76	Trace	100	59
8/19/2002	92	75	0	100	63
8/20/2002	93	76	0.03	100	65
8/21/2002	92	75	0.84	99	76
8/22/2002	91	75	0.01	100	83
8/23/2002	91	75	Trace	100	82
8/24/2002	93	75	1.2	100	67
8/25/2002	90	75	0.01	100	81
8/26/2002	95	73	0	100	68
8/27/2002	95	71	0.39	100	70
8/28/2002	89	70	0.7	100	85
8/29/2002	90	70	0	100	58
8/30/2002	90	71	0	98	64
8/31/2002	91	74	0	98	87
9/1/2002	92	74	0	99	54
9/2/2002	92	75	0	99	54
9/3/2002	92	70	0	98	55
9/4/2002	86	75	0.07	99	76

9/5/2002	83	72	0.38	98	81
9/6/2002	84	76	Trace	100	75
9/7/2002	79	76	0.37	100	82
9/8/2002	84	76	0.59	100	85
9/9/2002	82	76	0.13	99	76
9/10/2002	85	72	0.09	100	70
9/11/2002	90	71	0	98	54
9/12/2002	93	71	0	94	39
9/13/2002	94	73	0	98	40
9/14/2002	95	74	0	95	37
9/15/2002	94	72	0	100	32
9/16/2002	87	72	0.17	100	55
9/17/2002	79	73	0.31	100	87
9/18/2002	87	75	0.35	100	72
9/19/2002	90	78	0.07	99	59
9/20/2002	84	72	2.83	99	80
9/21/2002	84	66	0.02	97	58
9/22/2002	87	69	0	98	42
9/23/2002	86	69	0	98	60
9/24/2002	85	66	0	97	58
9/25/2002	86	67	0	93	55
9/26/2002	82	69	0	93	62
9/27/2002	85	63	0	98	55
9/28/2002	92	65	0	98	30
9/29/2002	89	66	0	98	42
9/30/2002	89	64	0	98	41

APPENDIX B

CLIMATIC CONDITIONS AT TEXAS AGRICULTURAL RESEARCH AND EXTENSION CENTER NEAR BEAUMONT, TX. 2003 GROWING SEASON

			2003		
	Air Temp (˚F)		Precipatation	Relative Humidity (%)	
Date	Max	Min	(Inches)	Max	Min
3/1/2003	50	45	0	99	83
3/2/2003	60	48	0	96	69
3/3/2003	64	49	0	84	54
3/4/2003	64	46	0.17	95	54
3/5/2003	61	49	0.03	100	90
3/6/2003	67	45	0.07	99	79
3/7/2003	59	48	0.001	98	37
3/8/2003	73	51	0.02	98	37
3/9/2003	75	55	0	98	50
3/10/2003	81	53	0	92	31
3/11/2003	77	54	0	99	41
3/12/2003	75	57	0	90	40
3/13/2003	76	66	0	99	80
3/14/2003	70	57	2.82	100	89
3/15/2003	79	55	0.07	100	47
3/16/2003	77	60	0.03	95	47
3/17/2003	66	58	0.3	99	88
3/18/2003	79	61	0	99	47
3/19/2003	79	51	0.11	99	64
3/20/2003	78	54	0	96	24
3/21/2003	72	48	0	94	41
3/22/2003	70	48	0	96	41
3/23/2003	69	49	0.04	98	47
3/24/2003	75	49	0	100	38
3/25/2003	74	55	0	99	40
3/26/2003	79	59	0.26	96	53
3/27/2003	70	55	0	99	67
3/28/2003	75	60	0	97	55
3/29/2003	78	47	0.07	96	61
3/30/2003	60	36	0	74	31
3/31/2003	63	39	0	97	23
4/1/2003	71	53	0	93	27
4/2/2003	72	56	0	97	47
4/3/2003	75	58	0	98	49
4/4/2003	78	66	0	94	53
4/5/2003	80	67	0	98	62
4/6/2003	83	70	0	97	63
4/7/2003	76	70	0.01	90	85
4/8/2003	75	61	0.39	99	71
4/9/2003	70	39	0	75	26
4/10/2003	63	39	0	97	31
4/11/2003	75	48	0	98	20
4/12/2003	74	49	0	99	23
4/13/2003	81	52	0	100	28

4/14/2003	82	54	0	99	33
4/15/2003	81	58	0	99	27
4/16/2003	79	64	0	96	47
4/17/2003	74	67	0	97	75
4/18/2003	88	66	0	97	37
4/19/2003	83	68	0	65	48
4/20/2003	80	68	0	97	60
4/21/2003	77	64	0.48	98	72
4/22/2003	81	60	0	94	37
4/23/2003	75	61	0.14	97	46
4/24/2003	79	68	0	92	73
4/25/2003	80	71	0.04	96	70
4/26/2003	86	57	0	91	31
4/27/2003	84	58	0	96	37
4/28/2003	82	60	0	99	51
4/29/2003	82	62	0	98	49
4/30/2003	83	62	0	99	53
5/1/2003	85	67	0	97	45
5/2/2003	86	71	0	95	57
5/3/2003	89	72	0	96	49
5/4/2003	87	72	0	94	56
5/5/2003	83	75	0	92	71
5/6/2003	85	74	0	94	68
5/7/2003	85	75	0.01	96	72
5/8/2003	89	74	0	88	61
5/9/2003	88	76	0	89	58
5/10/2003	87	76	0	89	61
5/11/2003	88	77	0	88	62
5/12/2003	87	70	0	89	61
5/13/2003	81	66	0	92	45
5/14/2003	88	70	0	96	54
5/15/2003	88	72	0	96	52
5/16/2003	88	75	0	94	60
5/17/2003	89	76	0.03	93	51
5/18/2003	89	63	0	94	36
5/19/2003	90	68	0	98	36
5/20/2003	93	70	0	98	40
5/21/2003	92	71	0	93	41
5/22/2003	85	67	0	91	55
5/23/2003	85	63	0	91	44
5/24/2003	87	64	0	94	36
5/25/2003	88	69	0	92	43
5/26/2003	91	73	0	92	28
5/27/2003	91	69	0	93	40
5/28/2003	83	60	0	88	44
5/29/2003	86	63	0	86	28
5/30/2003	92	71	0	95	28
5/31/2003	94	73	0	93	32

6/1/2003	93	70	0	95	46
6/2/2003	93	74	0	94	39
6/3/2003	93	73	0.21	97	52
6/4/2003	96	70	0	96	41
6/5/2003	82	71	0.06	97	69
6/6/2003	87	73	0	98	58
6/7/2003	90	68	0	97	51
6/8/2003	91	68	0	96	34
6/9/2003	93	70	0	90	33
6/10/2003	94	75	0	96	34
6/11/2003	92	79	0	93	54
6/12/2003	92	72	0.38	95	50
6/13/2003	92	68	0.38	95	49
6/14/2003	92	70	0.21	97	54
6/15/2003	90	73	0	97	55
6/16/2003	84	70	0.8	98	59
6/17/2003	86	70	0.17	97	57
6/18/2003	88	72	0.01	97	53
6/19/2003	92	74	0	95	47
6/20/2003	92	73	0.19	97	48
6/21/2003	92	74	0.07	98	52
6/22/2003	96	76	0.46	98	47
6/23/2003	93	76	0.04	97	55
6/24/2003	94	77	0	96	54
6/25/2003	95	76	0.01	95	51
6/26/2003	91	75	0.42	96	60
6/27/2003	89	74	0.42	96	60
6/28/2003	87	71	0	97	61
6/29/2003	90	71	0	96	47
6/30/2003	91	75	0.03	97	50
7/1/2003	88	74	0.23	97	63
7/2/2003	90	74	0	97	58
7/3/2003	91	75	0.02	97	51
7/4/2003	89	73	0.76	96	61
7/5/2003	86	73	0.86	97	67
7/6/2003	87	72	0.17	79	81
7/7/2003	91	75	0	96	43
7/8/2003	90	73	0.45	98	62
7/9/2003	91	73	0.04	98	52
7/10/2003	92	75	0.02	96	51
7/11/2003	88	76	0.01	96	60
7/12/2003	88	72	0.01	97	62
7/13/2003	92	74	0	97	50
7/14/2003	92	71	0	97	50
7/15/2003	91	76	0.76	93	40
7/16/2003	85	76	0.1	95	71
7/17/2003	90	72	0	98	57
7/18/2003	95	76	0	97	41

7/19/2003	95	76	0.04	97	44
7/20/2003	92	75	0	96	54
7/21/2003	93	76	0	94	47
7/22/2003	93	75	0	96	51
7/23/2003	93	77	0	94	53
7/24/2003	89	73	0.77	96	49
7/25/2003	90	72	0.03	97	58
7/26/2003	87	73	0	97	63
7/27/2003	91	72	0	97	52
7/28/2003	92	73	0	97	48
7/29/2003	94	74	0	96	38
7/30/2003	95	74	0	96	46
7/31/2003	93	76	0	96	48
8/1/2003	95	77	0	95	49
8/2/2003	94	76	0.09	96	45
8/3/2003	96	76	0	96	34
8/4/2003	94	74	0	97	46
8/5/2003	95	76	0	95	46
8/6/2003	95	76	0	96	48
8/7/2003	97	79	0	93	43
8/8/2003	100	75	0	93	30
8/9/2003	98	78	0	93	38
8/10/2003	96	77	0	95	43
8/11/2003	97	74	0	97	36
8/12/2003	85	69	0.28	98	68
8/13/2003	88	69	0.84	98	50
8/14/2003	88	71	0	96	55
8/15/2003	91	72	0.2	95	50
8/16/2003	94	75	0	96	48
8/17/2003	95	76	0	96	43
8/18/2003	95	74	1.16	97	50
8/19/2003	95	75	0	97	47
8/20/2003	94	75	0	97	48
8/21/2003	95	75	0	97	47
8/22/2003	95	69	2.53	98	43
8/23/2003	90	74	0.01	96	57
8/24/2003	93	73	0	97	45
8/25/2003	95	73	0.55	95	46
8/26/2003	94	76	0	97	49
8/27/2003	88	74	0.3	98	70
8/28/2003	90	75	0.55	97	63
8/29/2003	92	75	0.03	97	49
8/30/2003	90	74	0	97	60
8/31/2003	82	73	4.8	97	82
9/1/2003	85	74	2.78	97	74
9/2/2003	84	74	0.18	97	75
9/3/2003	91	75	0	97	57
9/4/2003	92	74	0	96	53

APPENDIX C

CLIMATIC CONDITIONS AT TEXAS AGRICULTURAL EXPERIMENT STATION RESEARCH CENTER NEAR EAGLE LAKE, TX.

2002 GROWING SEASON

2002

Date	Air Temp (˚F) Max	Min	Precipatation (Inches)	Relative Humidity (%) Max	Min
3/1/2002	59	52	0.08	98	92
3/2/2002	55	21	0	98	40
3/3/2002	40	18	0	69	27
3/4/2002	54	25	0	85	22
3/5/2002	60	46	0	92	32
3/6/2002	75	50	0	98	35
3/7/2002	77	57	0	98	29
3/8/2002	72	65	0.03	98	29
3/9/2002	65	36	0	98	22
3/10/2002	58	44	0.01	72	23
3/11/2002	69	48	0.01	92	57
3/12/2002	69	38	0	94	27
3/13/2002	78	58	0	95	23
3/14/2002	78	66	0	90	48
3/15/2002	77	52	0	89	43
3/16/2002	77	54	0	90	42
3/17/2002	78	62	0	97	41
3/18/2002	76	63	0	97	53
3/19/2002	78	57	0.8	98	53
3/20/2002	62	48	0	98	63
3/21/2002	67	34	0	87	31
3/22/2002	56	36	0	89	34
3/23/2002	70	48	0	74	58
3/24/2002	75	58	0	92	41
3/25/2002	68	38	0.29	98	69
3/26/2002	60	39	0	87	34
3/27/2002	66	54	0	96	32
3/28/2002	80	64	0	93	43
3/29/2002	80	65	0	96	53
3/30/2002	84	53	1	93	29
3/31/2002	68	47	0	97	43
4/1/2002	74	47	0	96	40
4/2/2002	80	50	0	98	33
4/3/2002	64	52	0	58	36
4/4/2002	62	53	0	56	35
4/5/2002	69	51	0	76	66
4/6/2002	66	58	0	92	84
4/7/2002	71	56	3.79	98	62
4/8/2002	72	56	0.02	98	64
4/9/2002	72	58	0	95	42
4/10/2002	74	60	0	97	40
4/11/2002	76	62	0	97	40
4/12/2002	77	60	0	97	40
4/13/2002	80	60	0	97	40

4/14/2002	80	67	0	94	43
4/15/2002	80	68	0	94	46
4/16/2002	80	70	0	91	48
4/17/2002	82	66	0	98	40
4/18/2002	80	67	0	98	44
4/19/2002	83	66	0	96	41
4/20/2002	82	67	0	94	47
4/21/2002	85	68	0	96	39
4/22/2002	84	64	0	96	37
4/23/2002	84	66	0	96	33
4/24/2002	86	65	0	98	36
4/25/2002	85	63	0	98	36
4/26/2002	84	62	0	98	35
4/27/2002	85	63	0	98	36
4/28/2002	88	70	0	94	38
4/29/2002	90	68	0	94	36
4/30/2002	86	68	0	95	38
5/1/2002	88	70	0	89	37
5/2/2002	85	73	0	92	51
5/3/2002	84	68	0	86	49
5/4/2002	87	69	0	96	50
5/5/2002	86	70	0	93	36
5/6/2002	86	70	0	95	32
5/7/2002	85	72	0	89	41
5/8/2002	86	70	0	92	36
5/9/2002	86	71	0	95	35
5/10/2002	88	71	0	N/A	N/A
5/11/2002	88	70	0	95	30
5/12/2002	86	56	0.02	94	37
5/13/2002	64	50	0	89	29
5/14/2002	76	52	0	89	25
5/15/2002	80	65	0	96	27
5/16/2002	80	67	0.03	96	39
5/17/2002	69	58	0.21	95	60
5/18/2002	73	47	0	83	32
5/19/2002	73	48	0	83	23
5/20/2002	76	50	0	89	28
5/21/2002	80	54	0	92	29
5/22/2002	82	60	0	91	35
5/23/2002	82	62	0	91	36
5/24/2002	83	64	0	92	34
5/25/2002	88	66	0	97	29
5/26/2002	87	63	0	97	32
5/27/2002	86	61	0.22	93	28
5/28/2002	82	64	0.02	96	39
5/29/2002	76	62	0.25	97	63
5/30/2002	88	62	0	97	26
5/31/2002	83	63	0	95	32

6/1/2002	88	69	0	97	28
6/2/2002	88	69	0	95	31
6/3/2002	88	68	0	96	31
6/4/2002	88	66	0	96	37
6/5/2002	92	68	0	96	26
6/6/2002	91	69	0	88	27
6/7/2002	92	69	0	94	32
6/8/2002	92	71	0	95	30
6/9/2002	89	70	0	94	41
6/10/2002	91	70	0	95	36
6/11/2002	92	70	0	94	30
6/12/2002	92	68	0	94	33
6/13/2002	91	70	0	92	26
6/14/2002	92	68	0	92	20
6/15/2002	94	63	1.42	97	20
6/16/2002	84	66	0	96	41
6/17/2002	84	66	0	90	34
6/18/2002	88	66	0	93	27
6/19/2002	92	70	0	95	28
6/20/2002	88	68	0	95	30
6/21/2002	90	68	0.15	95	33
6/22/2002	89	65	0	87	23
6/23/2002	88	67	0	89	27
6/24/2002	88	67	0	94	29
6/25/2002	88	69	0.03	96	33
6/26/2002	89	68	0.01	95	35
6/27/2002	84	68	0	94	49
6/28/2002	81	68	0.08	96	55
6/29/2002	77	68	1.35	96	85
6/30/2002	84	70	0.1	96	34
7/1/2002	81	70	0.39	96	60
7/2/2002	84	69	1.18	96	56
7/3/2002	86	70	0	96	38
7/4/2002	86	72	0	96	40
7/5/2002	88	68	0.03	95	42
7/6/2002	90	69	0	95	28
7/7/2002	92	69	0.01	90	31
7/8/2002	90	69	0.21	93	35
7/9/2002	85	68	0	96	49
7/10/2002	85	70	0	96	40
7/11/2002	91	70	0.03	96	33
7/12/2002	91	69	0	89	35
7/13/2002	90	66	0.58	96	37
7/14/2002	86	68	0.58	95	45
7/15/2002	77	69	0.74	96	69
7/16/2002	79	67	0.22	n/a	n/a
7/17/2002	87	71	0	96	42
7/18/2002	88	70	0	95	44

7/19/2002	90	70	0	95	38
7/20/2002	90	70	0	95	38
7/21/2002	90	68	0	95	37
7/22/2002	90	71	0	95	36
7/23/2002	91	70	0	93	27
7/24/2002	92	71	0	92	28
7/25/2002	91	72	0	93	31
7/26/2002	90	70	0	95	36
7/27/2002	90	72	0	93	36
7/28/2002	90	72	0	93	37
7/29/2002	90	72	0	93	38
7/30/2002	90	69	0	94	32
7/31/2002	92	68	0	95	29
8/1/2002	93	68	0	96	28
8/2/2002	93	70	0	95	26
8/3/2002	96	68	0.16	95	24
8/4/2002	92	68	0	90	27
8/5/2002	92	71	0	90	25
8/6/2002	93	72	0	89	29
8/7/2002	92	70	0	91	30
8/8/2002	88	71	0	95	49
8/9/2002	92	70	0	95	33
8/10/2002	91	67	0	94	29
8/11/2002	92	72	0	94	29
8/12/2002	92	72	0	94	35
8/13/2002	86	69	0.6	94	46
8/14/2002	83	72	0.07	94	48
8/15/2002	80	67	1.93	95	74
8/16/2002	89	70	0.02	96	39
8/17/2002	90	72	0.01	94	34
8/18/2002	90	70	0	95	38
8/19/2002	91	72	0	94	32
8/20/2002	87	72	0.28	94	47
8/21/2002	90	72	0.19	94	36
8/22/2002	90	68	0	94	37
8/23/2002	92	68	0	95	34
8/24/2002	92	71	0	92	31
8/25/2002	92	73	0	92	30
8/26/2002	94	72	0	93	28
8/27/2002	92	69	0	93	32
8/28/2002	90	69	0	92	33
8/29/2002	88	64	0	93	26
8/30/2002	91	65	0	89	28
8/31/2002	92	70	0	90	28
9/1/2002	92	69	0	91	27
9/2/2002	92	68	0	91	27
9/3/2002	87	68	0	93	44
9/4/2002	86	70	0	93	42

9/5/2002	90	68	0	91	30
9/6/2002	83	67	2.26	98	40
9/7/2002	84	68	0.94	98	50
9/8/2002	80	72	0	94	60
9/9/2002	81	69	0.2	94	62
9/10/2002	85	68	0	94	38
9/11/2002	90	69	0	90	27
9/12/2002	92	70	0	87	23
9/13/2002	91	66	0	89	24
9/14/2002	90	68	0.01	93	24
9/15/2002	73	68	0.66	94	97
9/16/2002	74	68	0.11	95	67
9/17/2002	86	70	0.16	95	51
9/18/2002	86	75	0.26	93	38
9/19/2002	81	60	1.35	93	65
9/20/2002	75	58	0	92	65
9/21/2002	86	58	0	88	38
9/22/2002	82	63	0	86	23
9/23/2002	80	60	0	74	29
9/24/2002	81	60	0	79	32
9/25/2002	82	63	0	79	31
9/26/2002	86	58	0	79	25
9/27/2002	90	59	0	91	19
9/28/2002	86	58	0	93	28
9/29/2002	85	62	0	99	31
9/30/2002	86	68	0	94	29

APPENDIX D

CLIMATIC CONDITIONS AT TEXAS AGRICULTURAL EXPERIMENT STATION RESEARCH CENTER NEAR EAGLE LAKE, TX.

2003 GROWING SEASON

	2003				
	Air Temp (˚F)		Precipatation	Relative Humidity (%)	
Date	Max	Min	(Inches)	Max	Min
3/1/2003	53	43	0.03	94	50
3/2/2003	54	46	0.07	86	56
3/3/2003	48	44	0.91	98	75
3/4/2003	52	50	0.01	98	79
3/5/2003	55	36	0.11	98	59
3/6/2003	58	36	0	95	33
3/7/2003	72	49	0	98	23
3/8/2003	70	49	0	98	30
3/9/2003	70	48	0	93	37
3/10/2003	72	55	0	98	34
3/11/2003	70	60	0	98	43
3/12/2003	76	60	0	98	48
3/13/2003	78	56	0.25	98	36
3/14/2003	74	52	0	98	31
3/15/2003	71	56	0	98	32
3/16/2003	72	52	0	98	38
3/17/2003	73	57	0	36	98
3/18/2003	66	47	0.06	98	28
3/19/2003	75	48	0	81	18
3/20/2003	66	43	0	79	28
3/21/2003	68	45	0	79	23
3/22/2003	61	43	0.05	93	35
3/23/2003	72	48	0	98	24
3/24/2003	72	57	0	98	31
3/25/2003	68	54	0.22	94	47
3/26/2003	65	44	0.01	98	46
3/27/2003	74	58	0.01	98	24
3/28/2003	61	40	0	94	35
3/29/2003	56	30	0	n/a	n/a
3/30/2003	61	40	0	n/a	n/a
3/31/2003	70	46	0	88	20
4/1/2003	72	50	0	89	28
4/2/2003	72	56	0	91	35
4/3/2003	72	63	0	91	39
4/4/2003	80	63	0.02	94	33
4/5/2003	82	65	0.02	96	34
4/6/2003	72	65	0.06	97	79
4/7/2003	74	52	0.12	98	36
4/8/2003	60	36	0	46	24
4/9/2003	63	36	0	70	21
4/10/2003	70	45	0	74	19
4/11/2003	74	46	0	96	19
4/12/2003	80	50	0	97	19

4/13/2003	80	56	0	97	19
4/14/2003	78	62	0	97	24
4/15/2003	78	62	0.01	90	29
4/16/2003	80	66	0	93	41
4/17/2003	82	62	0	89	27
4/18/2003	81	64	0	86	33
4/19/2003	75	64	0.05	97	51
4/20/2003	68	58	0.76	97	55
4/21/2003	75	59	0	91	29
4/22/2003	68	61	0	96	46
4/23/2003	74	68	0.07	96	52
4/24/2003	84	66	0	96	31
4/25/2003	80	57	0	90	20
4/26/2003	83	54	0	97	19
4/27/2003	83	60	0	96	21
4/28/2003	80	62	0	96	29
4/29/2003	78	65	0	96	40
4/30/2003	82	65	0	95	32
5/1/2003	86	66	0.01	95	29
5/2/2003	87	67	0	92	29
5/3/2003	80	68	0	89	43
5/4/2003	82	72	0	89	41
5/5/2003	84	72	0	86	40
5/6/2003	86	72	0	89	37
5/7/2003	90	74	0	88	32
5/8/2003	88	68	0	88	32
5/9/2003	88	70	0	87	30
5/10/2003	89	70	0	81	32
5/11/2003	78	66	0	78	38
5/12/2003	80	66	0	94	34
5/13/2003	88	67	0	95	27
5/14/2003	88	67	0	95	29
5/15/2003	90	74	0	94	29
5/16/2003	91	64	0	83	21
5/17/2003	85	60	0	89	24
5/18/2003	90	68	0	94	19
5/19/2003	92	68	0	94	25
5/20/2003	88	62	0	94	28
5/21/2003	82	61	0	86	30
5/22/2003	82	60	0	83	29
5/23/2003	86	64	0	90	22
5/24/2003	89	64	0	92	20
5/25/2003	89	64	0	87	22
5/26/2003	88	68	0	85	19
5/27/2003	82	58	0	77	30
5/28/2003	84	60	0	87	18
5/29/2003	92	68	0	88	16
5/30/2003	95	64	0	86	16

5/31/2003	93	69	0	89	17
6/1/2003	92	71	0	92	19
6/2/2003	96	72	0	89	17
6/3/2003	94	68	0.05	92	21
6/4/2003	84	69	0	92	37
6/5/2003	83	64	0.69	97	41
6/6/2003	84	64	0	96	32
6/7/2003	86	65	0	92	19
6/8/2003	86	67	0	88	21
6/9/2003	92	74	0	90	23
6/10/2003	88	74	0	91	30
6/11/2003	91	68	0	90	30
6/12/2003	91	70	0	89	28
6/13/2003	91	66	0.15	92	87
6/14/2003	90	63	1.3	98	29
6/15/2003	82	65	0.01	97	33
6/16/2003	87	68	2.04	97	26
6/17/2003	84	68	0	96	29
6/18/2003	86	69	0	93	26
6/19/2003	89	71	0	93	21
6/20/2003	90	70	0	91	25
6/21/2003	90	70	0	93	28
6/22/2003	91	74	0	94	26
6/23/2003	92	74	0	93	27
6/24/2003	92	72	0	93	29
6/25/2003	93	73	0	94	25
6/26/2003	90	70	0.19	94	25
6/27/2003	86	70	0.09	91	29
6/28/2003	90	70	0	92	26
6/29/2003	90	68	0	91	20
6/30/2003	88	72	0	85	29
7/1/2003	90	67	0.07	96	27
7/2/2003	90	62	0	93	26
7/3/2003	83	70	0.04	93	44
7/4/2003	85	68	0.99	95	37
7/5/2003	84	70	0.04	95	41
7/6/2003	88	70	0.01	95	28
7/7/2003	84	68	0.66	95	42
7/8/2003	83	72	0.68	95	43
7/9/2003	81	71	0.06	96	40
7/10/2003	80	73	0	96	33
7/11/2003	90	68	0.01	92	27
7/12/2003	90	70	0	95	27
7/13/2003	90	71	0	89	26
7/14/2003	89	72	0	90	25
7/15/2003	77	72	0.46	95	68
7/16/2003	83	69	0.21	96	51
7/17/2003	89	70	0	95	26

7/18/2003	89	70	0.07	94	29
7/19/2003	89	70	0	94	29
7/20/2003	90	72	0	94	28
7/21/2003	91	73	0	93	26
7/22/2003	92	74	0	93	27
7/23/2003	82	70	0.02	95	51
7/24/2003	88	68	0.11	96	32
7/25/2003	92	68	0	96	25
7/26/2003	91	69	0.01	96	22
7/27/2003	90	68	0	94	28
7/28/2003	92	70	0	95	18
7/29/2003	90	71	0.23	96	27
7/30/2003	91	71	0	95	24
7/31/2003	94	72	0	94	17
8/1/2003	93	70	0	94	25
8/2/2003	94	70	0	92	24
8/3/2003	95	72	0	91	21
8/4/2003	95	72	0	92	19
8/5/2003	95	72	0	93	24
8/6/2003	94	74	0	93	20
8/7/2003	101	74	0	91	13
8/8/2003	102	70	0	92	14
8/9/2003	97	72	0.14	94	18
8/10/2003	92	71	0	92	25
8/11/2003	95	66	0.08	0	0
8/12/2003	84	66	0.07	0	0
8/13/2003	84	69	0.33	96	36
8/14/2003	84	70	0.07	96	36
8/15/2003	90	70	0	93	79
8/16/2003	89	70	0.25	95	35
8/17/2003	93	71	0	91	21
8/18/2003	92	72	0	93	24
8/19/2003	93	72	0	93	25
8/20/2003	96	72	0	94	19
8/21/2003	95	69	0.1	96	19
8/22/2003	85	68	0	96	33
8/23/2003	90	68	0	96	23
8/24/2003	92	72	0	96	18
8/25/2003	93	72	0	87	24
8/26/2003	93	73	0	90	18
8/27/2003	94	72	0	92	21
8/28/2003	94	72	0	94	22
8/29/2003	93	70	0	96	25
8/30/2003	91	70	0	93	26
8/31/2003	84	71	0	93	26
9/1/2003	84	70	2.03	95	49
9/2/2003	81	72	0.13	96	48
9/3/2003	78	72	0.04	96	27

APPENDIX E

CLIMATIC CONDITIONS FOR JACKSON COUNTY, TX NEAR PLOTS AT GANADO

2002 GROWING SEASON

	2002			
	Air Temperature (˚F)		Precipatation	Relative Humidity (%)
Date	Max	Min	(Inches)	Average
3/1/2002	68.8	55.3	0.3	100
3/2/2002	63.7	32	0	90.8
3/3/2002	46.8	27.6	0	50.8
3/4/2002	58.6	19.8	0	55
3/5/2002	59.7	28.6	0	85.4
3/6/2002	74.5	53.4	0	94.9
3/7/2002	77.3	60.1	0	91.4
3/8/2002	74.9	64.4	0.02	100
3/9/2002	70.4	51.3	0	60.3
3/10/2002	62.6	42.8	0.01	54.3
3/11/2002	72.4	52.2	0.01	95.9
3/12/2002	76.1	51.1	0	69.4
3/13/2002	77.1	42.1	0	85.5
3/14/2002	76.4	63.1	0	99.8
3/15/2002	75	63.6	0	99
3/16/2002	75.9	60.4	0	82.9
3/17/2002	79.5	62.8	0.04	99.1
3/18/2002	78.5	69.8	0	99.2
3/19/2002	80.4	67.9	0	99.2
3/20/2002	71.9	56.8	0.13	95.7
3/21/2002	75	52.2	0	73.5
3/22/2002	62.9	40.8	0	70.8
3/23/2002	70.2	42.5	0	88.7
3/24/2002	75	56.7	0	96.4
3/25/2002	74.4	49	0.07	100
3/26/2002	68.1	44.7	0	80.5
3/27/2002	71.3	45.4	0	87.5
3/28/2002	80.2	54.2	0	97.4
3/29/2002	82.8	69.9	0	98.2
3/30/2002	85.9	66	0.05	92.2
3/31/2002	76.5	57.2	0.01	88.6
4/1/2002	77.5	49.6	0	92.2
4/2/2002	80	61.6	0	92.8
4/3/2002	72.2	58.2	0	77.8
4/4/2002	65	56.4	0	71.9
4/5/2002	72.3	58.1	0	73.1
4/6/2002	69.9	56.1	0.23	94.6
4/7/2002	75.1	65.9	0.01	99.9
4/8/2002	78.3	60.4	2.66	99.8
4/9/2002	76.8	63.4	0	96
4/10/2002	78.4	61.3	0	98.1
4/11/2002	78.9	60.1	0	97.2
4/12/2002	80.1	64.3	0	95.7

4/13/2002	79.6	61.1	0	94.9
4/14/2002	79.8	63.8	0	98.2
4/15/2002	80.4	70.1	0	98.4
4/16/2002	80.8	73.2	0.01	99.7
4/17/2002	82	72.8	0	97.8
4/18/2002	81.7	72.2	0	97.2
4/19/2002	82.6	71.9	0	97.2
4/20/2002	81.7	72.6	0	97.8
4/21/2002	83.1	71.8	0	96.8
4/22/2002	85.7	70.7	0	96.1
4/23/2002	84.5	67.9	0	95.6
4/24/2002	84.7	70.9	0	96.5
4/25/2002	85.7	70.4	0	94.4
4/26/2002	82.3	68.7	0	96.4
4/27/2002	84.4	73	0	97.4
4/28/2002	86	73.5	0	97.2
4/29/2002	87.4	74.7	0	97
4/30/2002	85.4	71.4	0	96.6
5/1/2002	85.8	74.9	0	97.4
5/2/2002	85.2	75.6	0	99.2
5/3/2002	87.4	76.5	0	97.3
5/4/2002	87.9	74.1	0	94.6
5/5/2002	86.1	76.7	0	95.2
5/6/2002	85.4	74.5	0	94.2
5/7/2002	85.8	77.5	0	96
5/8/2002	85.9	78.5	0	96.3
5/9/2002	86.5	75	0	94.5
5/10/2002	87	72.9	0	92.5
5/11/2002	85.8	77	0	94.4
5/12/2002	87	76.9	0	94.8
5/13/2002	77.8	61.3	0.14	93.4
5/14/2002	80.5	56.3	0	79.1
5/15/2002	83.7	56.5	0	88.7
5/16/2002	86.2	72.7	0	96.9
5/17/2002	79.4	65.3	2.23	100
5/18/2002	74	60.7	0	92.7
5/19/2002	74.8	54.6	0	80.3
5/20/2002	78.5	55.2	0	84.1
5/21/2002	80.6	56.5	0	87.3
5/22/2002	81.5	60.9	0	93.9
5/23/2002	82.6	68.5	0	92
5/24/2002	81.6	65.7	0	91.8
5/25/2002	86.9	65.1	0	91.5
5/26/2002	85.4	69.2	0	91.6
5/27/2002	85.3	66.1	0	92.5
5/28/2002	86.2	70.2	0.03	90.3
5/29/2002	83.7	66.2	1.08	99
5/30/2002	93.3	63.3	0	89.4

5/31/2002	85.1	65.5	0	91.5
6/1/2002	86.8	67.9	0	92.1
6/2/2002	86.9	67.2	0	94.2
6/3/2002	87.4	70.9	0	92.9
6/4/2002	88.1	72.7	0	93.8
6/5/2002	91.6	70.6	0	89.2
6/6/2002	92.3	72	0	91.6
6/7/2002	90.4	72.6	0	92.7
6/8/2002	90.1	71.7	0	92.7
6/9/2002	89	76.1	0	95.8
6/10/2002	90.7	76.9	0	92.5
6/11/2002	91.5	74.7	0	93
6/12/2002	89.4	73.4	0.08	96.1
6/13/2002	90	70.7	0	90.6
6/14/2002	96.8	71.1	0	85.9
6/15/2002	92.5	73.6	0	86.9
6/16/2002	90.8	68.6	0.06	90.3
6/17/2002	89.3	67.9	0	83.4
6/18/2002	92.3	66.7	0	86
6/19/2002	92.6	68.7	0	89.2
6/20/2002	92.9	75.3	0	87.8
6/21/2002	91.6	71.7	0	88.3
6/22/2002	92.7	70.4	0	79.2
6/23/2002	90.9	67.8	0	82.8
6/24/2002	92.9	68.7	0.32	89.1
6/25/2002	89.8	71.3	0.61	97
6/26/2002	89.1	71.7	0	95.8
6/27/2002	86.8	69.9	0.11	96.1
6/28/2002	82.9	71.6	0	99.5
6/29/2002	80.2	71.4	2.63	100
6/30/2002	86.9	75	0.01	98.1
7/1/2002	84.9	75.6	0.12	99.8
7/2/2002	88.9	70.5	0.53	97.6
7/3/2002	88.5	75.7	0	94.4
7/4/2002	89.1	78.1	0	94.3
7/5/2002	90.4	76	0	94.2
7/6/2002	94.1	72.5	0	91.3
7/7/2002	92.5	74.3	0.26	95.1
7/8/2002	92.1	74.3	0	93.6
7/9/2002	86.7	74.5	0	99.3
7/10/2002	88.5	73.2	0.07	98
7/11/2002	94	72.5	0.32	89.7
7/12/2002	93.2	74	0.2	89.1
7/13/2002	93.4	72.6	0	91.3
7/14/2002	92.4	71.3	0.06	96.4
7/15/2002	78.2	71	2.92	100
7/16/2002	85.1	71.5	1.45	99.5
7/17/2002	89.2	71.6	0.01	96.3

7/18/2002	89.8	74.8	0	96.6
7/19/2002	90.4	75	0	93.7
7/20/2002	90.8	73.1	0	92.8
7/21/2002	91.1	75.5	0	94.2
7/22/2002	92	73.6	0	91.2
7/23/2002	92.9	72.3	0	92.8
7/24/2002	94.1	71.7	0	90.3
7/25/2002	92.6	71.5	0	89.7
7/26/2002	91.4	74.8	0	94.1
7/27/2002	91.4	76.4	0	93.5
7/28/2002	91.7	79.8	0	93.1
7/29/2002	92.1	79.2	0	92.6
7/30/2002	93.1	78	0	91.8
7/31/2002	92	73.2	0	92.1
8/1/2002	93.2	71	0	90.1
8/2/2002	96.4	70.7	0	87.5
8/3/2002	94.7	70.7	0.24	93.6
8/4/2002	92.8	70.6	0.05	91.2
8/5/2002	93.5	70.8	0.01	92.3
8/6/2002	95.8	72.3	0	89.3
8/7/2002	96	75.5	0	85.8
8/8/2002	87.4	75.5	0.03	99.5
8/9/2002	91.4	74.8	0	95.2
8/10/2002	90.8	71	0.01	94
8/11/2002	90.9	69.4	0	96.8
8/12/2002	91.4	74.6	0.01	93.5
8/13/2002	90.6	76.3	0.01	96.1
8/14/2002	85.7	75	0	99.9
8/15/2002	90.6	72.6	0	97.8
8/16/2002	90.3	75	0.32	96.4
8/17/2002	91.1	76.6	0.01	94
8/18/2002	91.4	76.6	0	95
8/19/2002	92.1	74.7	0	92.3
8/20/2002	91.6	76.6	0.09	95.1
8/21/2002	92.7	74.6	0	92.6
8/22/2002	93	74.5	0	95.4
8/23/2002	93.6	72.1	0.01	92.3
8/24/2002	93.4	75.3	0	92.9
8/25/2002	96.3	74.2	0	87.4
8/26/2002	97	73.8	0	87.9
8/27/2002	95.9	74.3	0	90.4
8/28/2002	95.6	73.4	0	91
8/29/2002	92	72.4	0	81.2
8/30/2002	93.4	69.1	0	84
8/31/2002	92.3	71.1	0	89.9
9/1/2002	89.7	74.1	0	98.1
9/2/2002	93.5	72.5	0.02	94.4
9/3/2002	88.6	72	0	96

9/4/2002	87.3	75.4	0.01	98.1
9/5/2002	87.6	74.1	0	92
9/6/2002	85.1	73	0	95.5
9/7/2002	86.3	71.8	0.05	97.1
9/8/2002	80.9	73	0.43	100
9/9/2002	83	73.4	0.44	100
9/10/2002	87.4	73.5	0.36	98.9
9/11/2002	90.5	72.6	0.16	91.4
9/12/2002	94.8	71.7	0.16	85.6
9/13/2002	92.5	71	0	85.4
9/14/2002	91.8	68.8	0	87.1
9/15/2002	75.9	71.6	0.09	100
9/16/2002	81.6	71.6	0.02	100
9/17/2002	87.4	74.1	0.02	99.4
9/18/2002	87.8	77.3	0.01	99.2
9/19/2002	85.9	76.3	0.01	100
9/20/2002	83.2	64.9	0	90.5
9/21/2002	85.6	62.5	0	84.6
9/22/2002	85.8	62.3	0	93.3
9/23/2002	85.1	68	0	89.6
9/24/2002	84.9	64.6	0	83.1
9/25/2002	86.8	68	0	88.2
9/26/2002	89	66	0	82.8
9/27/2002	92.2	61.4	0	80.2
9/28/2002	87.7	65.1	0	88.4
9/29/2002	87.5	66.7	0	90.8
9/30/2002	88.1	65.9	0	91.9

APPENDIX F

CLIMATIC CONDITIONS FOR JACKSON COUNTY, TX NEAR PLOTS AT GANADO

2003 GROWING SEASON

	2003			
	Air Temperature (˚F)		Precipatation	Relative Humidity (%)
Date	Max	Min	(Inches)	Average
3/1/2003	59.2	50.1	0	100
3/2/2003	63.5	55.2	0	97.9
3/3/2003	56.5	47.4	0.21	100
3/4/2003	59.9	49.2	0.01	100
3/5/2003	62.5	46.3	0.08	100
3/6/2003	59.9	43.7	0	95.4
3/7/2003	76.8	40.3	0	91.3
3/8/2003	73.2	53.8	0	97.6
3/9/2003	78	58.3	0	93.5
3/10/2003	76.3	54.4	0	94.6
3/11/2003	72.3	59.8	0	99.9
3/12/2003	77.6	65.3	0	100
3/13/2003	81.6	63.5	0.31	98.6
3/14/2003	78.2	59.9	0	98.2
3/15/2003	69.4	56.8	0.33	100
3/16/2003	76.4	62.2	0.01	97.9
3/17/2003	75.4	56.5	0	99
3/18/2003	73.2	57.6	0.12	97.9
3/19/2003	80.2	55.5	0	72.3
3/20/2003	73.7	53.5	0	78.4
3/21/2003	73.6	48.6	0	82.5
3/22/2003	64	50.6	0.03	98.8
3/23/2003	74.7	47.4	0	89.1
3/24/2003	74	49.9	0	95.5
3/25/2003	76.8	59.3	0.09	99.1
3/26/2003	69.1	54.9	0.39	99.7
3/27/2003	75.1	48.6	0.01	93.3
3/28/2003	71.9	53.1	0	93.9
3/29/2003	62.4	42	0	64
3/30/2003	66.1	36.2	0	65.8
3/31/2003	71.1	43.5	0	79.7
4/1/2003	73.8	52.9	0	88.5
4/2/2003	75.6	61.3	0	95.4
4/3/2003	76.3	65.6	0	98.8
4/4/2003	82.8	67.8	0	96.5
4/5/2003	80.8	67.8	0	98.9
4/6/2003	73.7	70.9	0.05	100
4/7/2003	73.7	70.9	0.05	100
4/8/2003	73	66.7	0.17	100
4/9/2003	67.7	49.5	0	72.2
4/10/2003	73	40.1	0	68.6
4/11/2003	73.5	55.3	0	90.3
4/12/2003	78.9	50.4	0	83.7

4/13/2003	80.1	51.9	0	85.2
4/14/2003	79.9	57.6	0	92.6
4/15/2003	78.4	65.3	0	96.1
4/16/2003	77.2	66.9	0.04	100
4/17/2003	89	64.3	0	85.4
4/18/2003	80.3	67.7	0	97.6
4/19/2003	76.9	70.2	0	99.9
4/20/2003	77	65.8	0	100
4/21/2003	78.8	63.4	0	94.2
4/22/2003	81.7	63.8	0	98.3
4/23/2003	77.8	70.6	0	99.8
4/24/2003	84.5	71.5	0	98.9
4/25/2003	85.7	68.2	0	77.3
4/26/2003	87.6	55.6	0	78.7
4/27/2003	85	55.9	0	87.6
4/28/2003	81.6	64.1	0	92.7
4/29/2003	84.5	68.8	0	97
4/30/2003	83.6	68.1	0	97.9
5/1/2003	86.8	72	0	94.5
5/2/2003	86.5	72.5	0	96.2
5/3/2003	84.4	71.9	0	97.1
5/4/2003	85.4	74.1	0	99.3
5/5/2003	86.3	75.3	0	99.1
5/6/2003	86.1	75.9	0	99.1
5/7/2003	89.1	76.6	0	96.6
5/8/2003	87.2	77.2	0	97.1
5/9/2003	88	74.4	0	97.2
5/10/2003	87.8	76.9	0	97.5
5/11/2003	87.8	75.6	0	97.7
5/12/2003	87	72.9	0	94.2
5/13/2003	87	71.9	0	94.9
5/14/2003	87.1	75.4	0	94.9
5/15/2003	87.6	73.8	0	96.3
5/16/2003	88.3	77.2	0	94.2
5/17/2003	91.8	71.9	0	78.2
5/18/2003	91.8	65.1	0	86.5
5/19/2003	91.7	69.3	0	93.1
5/20/2003	91.5	69	0	88.3
5/21/2003	87.4	65.9	0	89.4
5/22/2003	87.5	68.2	0	87.9
5/23/2003	89.9	67.2	0	87.1
5/24/2003	87.3	66	0	85.9
5/25/2003	89.4	65.5	0	88.5
5/26/2003	88.5	66.3	0	86.1
5/27/2003	85.4	71.5	0	96.7
5/28/2003	88.5	65.7	0	77.7
5/29/2003	94.4	63.5	0	81.9
5/30/2003	92.3	70.8	0	83

5/31/2003	90	68.1	0	86.9
6/1/2003	88.7	69	0	92.9
6/2/2003	91	76.9	0	93.9
6/3/2003	91.6	74.8	0	95.3
6/4/2003	87.7	71	0	95.3
6/5/2003	89.7	69.4	1.53	98.3
6/6/2003	89.3	70.7	0.01	93.2
6/7/2003	89.4	66.7	0	84.6
6/8/2003	90.8	68.1	0	88.3
6/9/2003	89.1	70.5	0	95.4
6/10/2003	85.6	73.2	0.4	99.5
6/11/2003	88	78.7	0	99.4
6/12/2003	88.2	79.9	0	97.2
6/13/2003	88.5	69.4	0.69	97.2
6/14/2003	86.9	69.1	0.05	97.8
6/15/2003	83.9	71.4	0.07	96.2
6/16/2003	88	71.2	0	96.7
6/17/2003	89.7	69.5	0	91.1
6/18/2003	90.8	72.2	0	89.2
6/19/2003	93.3	72.7	0	88.8
6/20/2003	93.3	73	0	90.1
6/21/2003	92.5	74	0	92.6
6/22/2003	91.6	74.2	0	94.3
6/23/2003	91.7	76.1	0	96.4
6/24/2003	90	77	0.24	97.2
6/25/2003	91.6	76.4	0	95.3
6/26/2003	91.1	74.2	0.78	97.2
6/27/2003	88.5	71.7	2.28	99.1
6/28/2003	90.9	74.1	0	96
6/29/2003	90.5	74	0	91.6
6/30/2003	91.7	72.6	0.38	94.4
7/1/2003	89.6	73.2	0.01	98.5
7/2/2003	91.3	72.5	0	95.4
7/3/2003	84.3	75.8	0	99.7
7/4/2003	86.2	74.8	0.17	99.9
7/5/2003	86.5	70.2	1.9	99.5
7/6/2003	88	75.6	0.08	96.4
7/7/2003	86	72.2	0.44	100
7/8/2003	84.5	74	0.13	99.9
7/9/2003	88.3	75.1	0	98.5
7/10/2003	88.5	75.6	0	99.6
7/11/2003	90.8	72.9	0.07	97
7/12/2003	91.5	71	0	95.3
7/13/2003	91.5	73.4	0	94.3
7/14/2003	90.2	73.9	0	92.2
7/15/2003	78.6	72.8	2.23	98.6
7/16/2003	85.7	74.7	0	99.9
7/17/2003	90.7	76.1	0.01	98

7/18/2003	91.9	72.6	0	94.7
7/19/2003	90.3	73.9	0	93.9
7/20/2003	89.9	75	0	96
7/21/2003	91.4	74.1	0	95
7/22/2003	90.7	74.6	0.58	97.7
7/23/2003	86.8	72.2	1.18	99.9
7/24/2003	90.9	75.6	0	98.4
7/25/2003	90	73.8	0.01	96.7
7/26/2003	89.9	74.1	0	95.1
7/27/2003	89.1	74.5	0	98.1
7/28/2003	84.4	73	0.05	100
7/29/2003	90.5	73.6	0	97
7/30/2003	91.6	73.8	0	94.6
7/31/2003	91.8	73.6	0	92.2
8/1/2003	90.8	74.6	0	94.8
8/2/2003	91.1	74.8	0	94.1
8/3/2003	90.6	75.5	0	95.1
8/4/2003	90.9	74	0	94.1
8/5/2003	91.7	75.6	0	94.1
8/6/2003	93.9	74.4	0	92
8/7/2003	99	74.8	0	89.2
8/8/2003	99.7	76.1	0	89.5
8/9/2003	94.6	77.3	0	90.5
8/10/2003	92	75.8	0	96.3
8/11/2003	95.4	69.7	0.72	91.9
8/12/2003	87.6	68.8	0	90.7
8/13/2003	86.1	68.9	0	96.5
8/14/2003	85	71.3	1.29	99.1
8/15/2003	92.9	73.2	0	88.3
8/16/2003	89.5	75.5	0.48	99.6
8/17/2003	93.7	73	0	92.6
8/18/2003	92.4	74.3	0	91.3
8/19/2003	91.4	74	0	94.6
8/20/2003	92.2	73.7	0.02	94.2
8/21/2003	91.8	74	0	94.5
8/22/2003	88.4	72.1	0	95.3
8/23/2003	92.2	71.4	0	89.7
8/24/2003	95.6	70.6	0	87.4
8/25/2003	95.4	72.1	0	88.7
8/26/2003	95.9	73.4	0	89.6
8/27/2003	95.2	74.6	0	89.5
8/28/2003	94	74	0	90.2
8/29/2003	92.7	73.9	0	94.9
8/30/2003	94.3	74.5	0	92.6
8/31/2003	90.8	75.3	0	94.7
9/1/2003	88.4	74.9	0.09	99.3
9/2/2003	87.6	74.3	0.29	99.2
9/3/2003	89	74.3	0.06	98.5

9/4/2003	85.4	74.8	0.14	100
9/5/2003	89.7	74.2	0	92.1
9/6/2003	88.1	66.8	0	81.9
9/7/2003	88.7	66.1	0	84.3
9/8/2003	89.2	65.8	0	87.3
9/9/2003	90.7	68.7	0	95.1
9/10/2003	89	74.1	0	98.9
9/11/2003	89.9	73.3	0.57	99
9/12/2003	82.9	66.7	1.45	97.4
9/13/2003	88.2	69.5	0	96.5
9/14/2003	87.3	69.3	0.29	99.4
9/15/2003	86.8	68.4	0.01	96.6
9/16/2003	85.5	71	0.01	97.8
9/17/2003	87	69	0	95.7
9/18/2003	76.2	69.4	1.54	100
9/19/2003	85.1	68.5	0	96.9
9/20/2003	77.2	72.4	0.13	100
9/21/2003	76.8	70.4	1.22	100
9/22/2003	82.7	68.5	0.01	98.6
9/23/2003	85.6	66.1	0	95.5
9/24/2003	85.5	66.2	0	94.9
9/25/2003	86.9	67.8	0	94
9/26/2003	86.3	70.8	0.04	92
9/27/2003	86.7	69.6	0	93.2
9/28/2003	84.4	64.7	0	79.3
9/29/2003	80.2	60.1	0	79.9
9/30/2003	78.7	56.2	0	81.6

VITA

John Houston O'Barr was born in La Jolla, California on December 29, 1974 to Gerald and Kathleen O'Barr. John attended public schools in San Diego, and graduated from University City High School in June of 1993. He then attended Brigham Young University his freshman year before departing to Spain where he voluntarily served his church for two years and became fluent in Castilian Spanish. John returned to Brigham Young University where he received a Bachelor of Science degree in agronomy in April of 1999. John then went to North Dakota State University and obtained a Master of Science degree in plant sciences specializing in weed science. He received his Master's degree in August 2001. In June of 2001, he came to Texas A&M University to pursue a Doctor of Philosophy degree in agronomy specializing in weed management systems in rice. John received his Ph.D. in Agronomy from Texas A&M in May, 2005. John is currently a field biologist for BASF Corporation covering the Pacific Northwest and lives in Pasco, WA with his wife, Raquel and son, Thomas.

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