TEXAS PASTURE GRASS REPELLENCY TO THE

RED IMPORTED FIRE ANT

by

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A THESIS

IN

RANGE SCIENCE

Submitted to the Graduate Faculty
of Texas Tech University in
Partial Fulfillment of
the Requirements for
the Degree of

MASTER OF SCIENCE

Approved

Chairperson of the Committee

Accepted

Dean of the Graduate School

December, 2004

ACKNOWLEDGEMENTS

I would like to thank my committee members, Dr. Gad Perry (chairperson), Dr. Carlton Britton, and Dr. Harlan Thorvilson for their ideas, expertise and guidance. It is through their direction and assistance that I was able to undertake and complete this thesis. Through this process my advisors have broadened my academic perspective and encouraged scientific research. I also thank Rafael Aldrich for his help with fieldwork, Nathan Newlon for efforts with ant identification and James Cokendolpher for his assistance with ant counting and species identification. Thanks to Joydeep Bhattacharjee and Dana Ghioca for their suggestions on preparing this thesis.

The cooperation of B.Dahl field owners and managers was essential to this project. Their willingness to let me do fieldwork on their land provided the data for this study. I hope the following results can contribute to the understanding of RIFA and B.Dahl grass.

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ABSTRACT

The Red Imported Fire Ant (RIFA) is an invasive pest that causes ecological disturbance and economic damage to habitats it invades. Since its introduction to the U.S. 75 years ago, RIFA have spread across the southeastern U.S. and are now found in California, with current research showing further territorial expansion in North America and internationally. In Texas, RIFA-related damages and expenditures are estimated to exceed $1.2 billion. Often studied, conventional RIFA control methods have not proven effective or long-lasting. New research efforts that concentrate on habitat characteristics may result in methods can repel or reduce RIFA density. This study examined different pasture grasses in Texas, focusing on WW-B.Dahl, to determine if particular grass types limit or reduce RIFA infestation compared to other grasses. Results show that WW-B.Dahl grass has significantly fewer RIFA mounds than other grasses such as Bermuda and native. However, this study failed to find a difference in ant bait cup collections in the grass types tested. Fewer mounds will improve efficiency of harvesting operations for growers and reduce vegetation loss due to RIFA mounds. Little correlation was found between ant numbers in bait cups and mound counts or mound vitality ratings, suggesting that more than one measure of ant infestation is needed to accurately determine RIFA numbers. Additionally, WW-B.Dahl grass showed some grass spread beyond its original field of planting, which increased with age of field. Due to the lack of information on the environmental conditions in which WW-B.Dahl grows, primary abiotic characteristics were compiled where B.Dahl is successfully grown in central and northern Texas.

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CHAPTER 1

LITERATURE REVIEW

Invasive Species: Introduction

Invasions by non-native species have become a major ecological problem (Alpert et al. 2000) and cause economic losses estimated at $137 billion per year in the United States (Pimentel et al. 2000). Biological invasions are a leading threat to natural ecosystems and biodiversity, cause serious and costly problems, replace native species and affect human health (Simberloff 1996). The U.S. government defines an invasive as "an alien species whose introduction does or is likely to cause economic or environmental harm" (GAO 2002). Approximately 50,000 non-native species have been introduced to the U.S. Most invasive plants and vertebrates were brought intentionally, whereas most invertebrates and microbes have entered accidentally (Pimentel et al. 2000). Although many introduced species are beneficial or harmless, the "Tens Rule" states that 1% of naturalized, non-native species are likely to become invasive (Harrington et al. 2003). The ongoing challenge presented by invasive species is preventing further damage to natural and managed ecosystems (Hall 1999).

Ant Invasiveness

Non-native ants are recognized as one of the most serious social insect pests worldwide (Moloney and Vanderwoude 2002). They can be ecologically destructive and are known to have deleterious impacts on native fauna in invaded areas (Morrison et al.

2004). The invaders often become highly abundant in their new range and can outnumber native ants, reducing their population by over 90% (Holway et al. 2002). Invasive ants have a great effect on ecologically similar native ants and may exploit food sources more efficiently and consume resources unused by indigenous ants. An example is the displacement of Dolichoderine ants (*Tapinoma sessile, Liometopum occidentale)* in parts of the U.S. by the Argentine ant (*Linepithema humile*) (Holway et al. 2002).

Red Imported Fire Ants

The red imported fire ant (Hymenoptera: Formicidae, *Solenopsis invicta* Buren, RIFA), a noxious exotic pest, is well established across the southeastern United States and in Texas (Vinson 1997). First documented in Texas in 1953, RIFA now infest over 22 million hectares in the state (Willis et al. 2001). In Texas it is found from the eastern border to Val Verde County in the southwest and Clay County in the north with additional isolated infestations further west (Taber 2000; Figure 1.1). *S. invicta* success may result from changes in colony structure during or after introduction as the ants evolved from small, territorial, family-based colonies into densely populated supercolonies covering large areas (Tsutsui and Suarez 2003).

The first introduction of the red imported fire ant (RIFA) is believed to have occurred in 1929 in Mobile, Alabama, with the ants probably arriving in soil used as ballast for ships importing agricultural products from South America (Vinson 1997). RIFA is not a problem in its original habitat where natural enemies, such as the phorid fly, suppress its numbers and limit its expansion (Taber 2000).

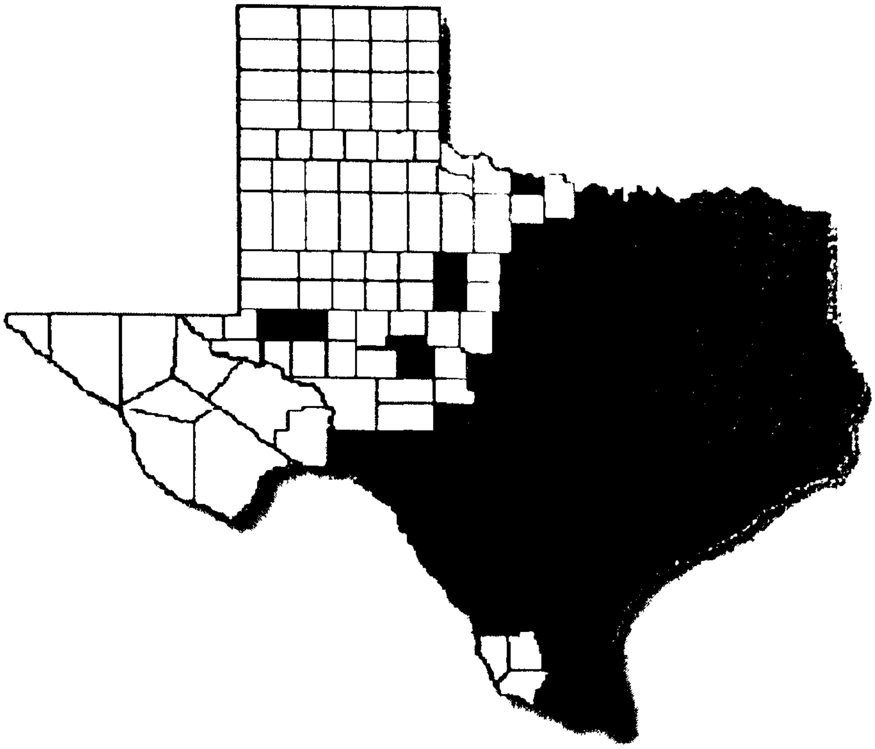

Figure 1.1 Texas Fire Ant Quarantine Map, May 2000. (Texas Department of Agriculture (from USDA Animal and Plant Health Inspection Service) 2003).

Because several species of fire ants (*Solenopsis* spp.) existed in the United States, there was little concern about an additional species until the 1950's, when it became clear that *S. invicta* was quickly expanding its range. The spread of *S. invicta* was accompanied by an increase in population density where the ant occurred (Vinson 1997). By that time the RIFA had expanded its range from Mobile through the rest of Alabama and into Georgia and Florida. A major factor in the rapid dispersal of queens and colonies in the region was their transport by the movement of nursery stock throughout the South.

In an effort to stop the spread of the RIFA, a federal quarantine was enacted in 1958. Still in place today, the quarantine restricted the movement of soils, hay, sod, potted plants, plants with soil attached, and used soil-moving equipment from affected regions to uninfested areas (Texas Agricultural Experiment Station 1992). As the RIFA spread continued, the affected public (see next section) demanded the eradication of the RIFA. Such a program was undertaken in 1957, featuring chemicals such as heptachlor and Mirex® (Allied Chemical, Claymont, Delaware). Twenty-one years and $200 million later, these chemicals were banned in the United States in 1978 because of their impact on non-target organisms and the environment, and the program was cancelled (Simberloff 1996). Today the RIFA has infested over 128,000,000 hectares across 13 southern states and Puerto Rico (Morrison et al. 2004; Core 2003). It has recently also been found in southern California (Greenberg et al. 2001) and is likely to expand further into the Mid-Atlantic, southwestern and northwestern regions (Korzukhin et al. 2001).

Aggressive, abundant and omnivorous, the weed-like properties of the RIFA include a high reproductive rate, efficient methods of dispersal and colonization, rapid colony growth, and invasiveness in disturbed habitats (Russell et al. 2001). RIFA queens can lay 5,000 eggs a day and live 7 years or longer (Vinson 1997). Developing to adults in about 30 days, the average colony contains 100,000 to 500,000 workers (Tschinkel 1993). Two kinds of RIFA colonies exist – single queen (monogyne), and multiple queen (polygyne) forms. Single queen colonies are territorial and build 100 to 375 mounds per hectare; whereas, the multiple queen colonies can build 500 to 2,000 or more mounds per hectare, spreading through colony fission and budding to form interconnected supercolonies (Moloney and Vanderwoude 2002). Common in the U.S., the high-density polygyne form of RIFA is rare in its native Brazil (Wojcik 1986; Forbes 1999).

RIFA colonies live in most soils with mound site selection based on soil type, moisture, vegetation and topography (Texas Agricultural Experiment Station 1992). Mounds reach 45 cm in height and proliferate in open, sunny areas. Entering and exiting the mound through tunnels that radiate up to 30 meters, RIFA are efficient foragers and often displace other ants at food sources (Phillips et al. 1986). *S. invicta* scavenges effectively, feeding on insects and other arthropods, which they sting and kill, animal and plant tissue, seeds, fruit, and sap flow. RIFA also forage in dung, on plants, and can climb 10 meters up trees to collect nourishment (Taber 2000). *S. invicta* is attracted to food sources because of sugars, amino acids, and certain oils containing polyunsaturated fatty acids (Vinson 1997).

An increase in RIFA genetic diversity observed after its introduction to new environments, including at the Gp-9 locus and possible gene flow from the monogyne to polygyne form via mating, may have led to changes in social structure that influence its strength as an invader (Tsutsui and Suarez 2003). Other causes of RIFA success include human modification of the landscape, community simplification, the use of pesticides and the lack of co-evolved competitors, parasites and pathogens (Holway et al. 2002). RIFA can spread up to 18 km through mating flights, with newly-mated queens landing on cars, trucks and trains, in shipments of nursery stock and soil, and as a mass of floating bodies carried downstream during flooding (Texas Agricultural Extension Service, 1998). Once they are established, eradication of RIFA infestations may be impossible (Morrison et al. 2004).

Two critical factors limiting RIFA spread are cold temperatures and a lack of moisture (Jetter et al. 2002). Lacking the ability to hibernate, RIFA infest areas with minimum temperatures above -13°C and rainfall greater than 250 mm annually (Loope 2000). In marginal areas, like Lubbock, Tx., RIFA infestation has benefited from human activities. An example is the greater insolation and resulting warmer winter soil temperatures RIFA colonies find near buildings (Thorvilson et al. 1992).

Problems associated with RIFA

An aggressive predator, RIFA reduces the populations of both pests and beneficial insects. They, therefore, eliminate many species of predatory native ants, resulting in a reduced predator component of the ecosystem and reduced species richness (Porter and Savignano 1990; Vinson 1997). For instance, succumbing to interference and competition, pre-existing fire ants (*Solenopsis xyloni* and *S. geminata)* are often displaced by invasive *S. invicta,* with *S. xyloni* now very rare to non-existent in regions occupied by *S. invicta* (Morrison 2000; Holway et al. 2002; Vinson et al. 2003). RIFA impact other animals in several ways (Norton 2003). RIFA prey on eggs and hatchlings of snakes, whiptail lizards, northern bobwhite quail, bluebirds, and snapping turtles (Taber 2000). Young birds, small mammals and reptiles can be stung; young animals can be blinded and even suffocate as a result of stings (Jetter et al. 2002). RIFA presence can lead to dehydration and starvation of domestic animals and wildlife, as ant density around food and water sources can inhibit animal access. RIFA cause the direct loss of calves in the field and indirect losses when cattle are injured but not killed (Taber 2000). In addition, RIFA compete for food resources with a variety of wildlife and reduce the biodiversity of native plants and animals (Allen et al. 1994).

An example of RIFA threat to other species is its debilitating effect on the Texas horned lizard (*Phrynosoma cornutum*). RIFA out-compete and kill harvester ants, reducing the primary food source of the lizard. Some pesticides used to kill RIFA can be deadly to the horned lizard. Additionally, ant foraging tunnel systems may prevent horned lizard eggs from incubating and individuals from hibernating successfully (Donaldson et al. 1994). As a result the horned lizard has largely been eliminated from RIFA-infested areas (Wojcik et al. 2001).

Because RIFA feed on seeds and can directly damage plants, they have a serious impact on crops and gardens. RIFA destroy seedlings and kill plants by tunneling through roots and stems, cause deformities by chewing on young growth, reduce plant quality by tunneling, damage ornamentals and citrus by girdling various parts, spread diseases, and can interfere with biological control by preying on these agents (Vinson 1997). They feed on the roots of older plants while consuming young plants entirely, damaging a wide variety of crops. Tree mortality in citrus orchards untreated for RIFA can be seven times greater than in treated orchards (Taber 2000). They can interfere with harvesting practices, mechanically disable combine operations, and cause machine damage. Inefficient harvesting can result, as combine operators adjust settings to avoid contact with RIFA mounds and damage to equipment (Vinson 1997).

Occupying the same areas where people live, work, and play, RIFA is a pest that can also directly affect humans. Their sting provokes a painful, fiery sensation, usually leading to white pustules. After attaching themselves to a victim with their mandibles, the ants arch their body and insert their stinger. Often the stinger, located at the rear of the abdomen, will be reinserted, and this process can be repeated at additional sites (McCabe and Weiner 2002). RIFA venom is comprised of approximately 90% water-insoluble 2,6-disubstituted piperdine alkaloids with an alkenyl substituent in the alkaloid's 6-position with a *trans* configuration about the ring (Forbes 1999). The reaction subsides in a matter of hours, and the pustules dissipate with time. Although most stings are medically uncomplicated, allergic reactions, including anaphylactic shock, can occur. RIFA stings are the most common cause of insect venom allergy in the southeastern United States. Approximately 14 million people living in the RIFA range are stung each year (Taber 2000). In addition, RIFA reduce park and recreational area utilization and, thus, impact tourism.

Economic Impact of RIFA

Introduced invading species can have an extensive economic impact. The cost of such species to the U.S. taxpayer is estimated to range from a few billions of dollars (Simberloff 1996) to over $120 billion annually (Hall 1999). Of this total, RIFA damage and control costs are thought to be greater than $6.5 billion per year (Core 2003). RIFA damages and expenditures to the economy of Texas are estimated to exceed $1.2 billion annually (Lard et al. 2001). The economic impact includes money spent on control and financial losses directly caused by RIFA, (e.g. destroyed crops, dead livestock). The RIFA causes annual losses to the Texas cattle industry of up to $255 million (Taber 2000), and damages to agricultural producers exceed $90 million (Lard et al 2001). In addition, households, schools, commercial businesses, golf courses, cemeteries, electrical and communications installations, airports, etc. incur great expenses for ant control and treatment, from millions to hundreds of millions of dollars annually for each sector in Texas alone. Residential households have the highest expenditures, spending $702 million annually on insecticides and "organic" treatments as well as equipment, labor and professional services. Costs to the livestock and agricultural sectors include crop and livestock losses, control efforts, equipment repair, and veterinary and medical expenses. RIFA impact is similar in other states, with associated costs of up to $989 million in California alone (Jetter et al. 2002)

RIFA can also have beneficial effects. They are reported as ecologically and economically significant predators of a variety of agricultural pests such as boll weevils, corn earworms, and ticks. Though benefits have been reported at $1.5 million annually in Texas, the numerical value remains difficult to quantify (Willis and Lard 2001). Study results suggest that RIFA benefits are inconsistent and thus difficult to calculate (Eubanks 2001).

Since the identification of RIFA as a pest, numerous efforts have been made to eradicate or control RIFA in the United States. Quarantines of infested areas are in place. Chemicals, including heptachlor, Mirex® (Allied Chemical, Claymont, Delaware), Amdro (hydramethylnon; American Cyanamid Company, Wayne, N.J.), and the insect growth regulator Logic® (fenoxycarb; Ciba-Geigy Corporation, Greensboro, N.C.), have been extensively used. Biocontrol methods, such as using phorid flies (Diptera:

Phoridae), are currently being explored. To date, safe and economical elimination of RIFA colonies on anything but the smallest scale, has proved nearly impossible (Gilbert 2001). Past failures stress the need for creative approaches to managing RIFA. The Texas Imported Fire Ant Research and Management Plan has received $2.5 million annually since 1998 (Texas Comptroller of Public Accounts 2003) to fund research into new ways to mitigate RIFA damage and infestation. One potential method of controlling the RIFA is to identify habitat characteristics, such as pasture grasses, that are antagonistic, repellent, or resistant to RIFA infiltration.

Controlling RIFA populations is a serious issue because of continued RIFA spread in the United States and increased RIFA invasions in many parts of the globe (Morrison 2004). By the 1980's RIFA had spread from Brazil to the U.S. and Puerto Rico (Callcott and Collins 1996) and has since expanded across the Caribbean (Davis et al. 2001). In 2001 RIFA incursions were discovered in both Australia and New Zealand (McCubbin and Weiner 2002; Vanderwoude 2003). This dramatic spread of fire ant infestation has led to research on the potential global range of RIFA. Using soil, precipitation, and temperature information from infested regions of the U.S., a model has been formulated to predict further RIFA expansion (Korzukhin et al. 2001). This shows much of the globe to be at risk of RIFA infestation. Susceptible areas are southern Europe, regions surrounding the Mediterranean, Black, and Caspian Seas, much of Africa and the Middle East, most of India, Southeast Asia and Australia as well as parts of Japan and Korea (Morrison et al. 2004). Recognizing the past inability to control RIFA in the U.S., ongoing and future research efforts are essential to prevent the RIFA from becoming a worldwide pest (Figure 1.2).

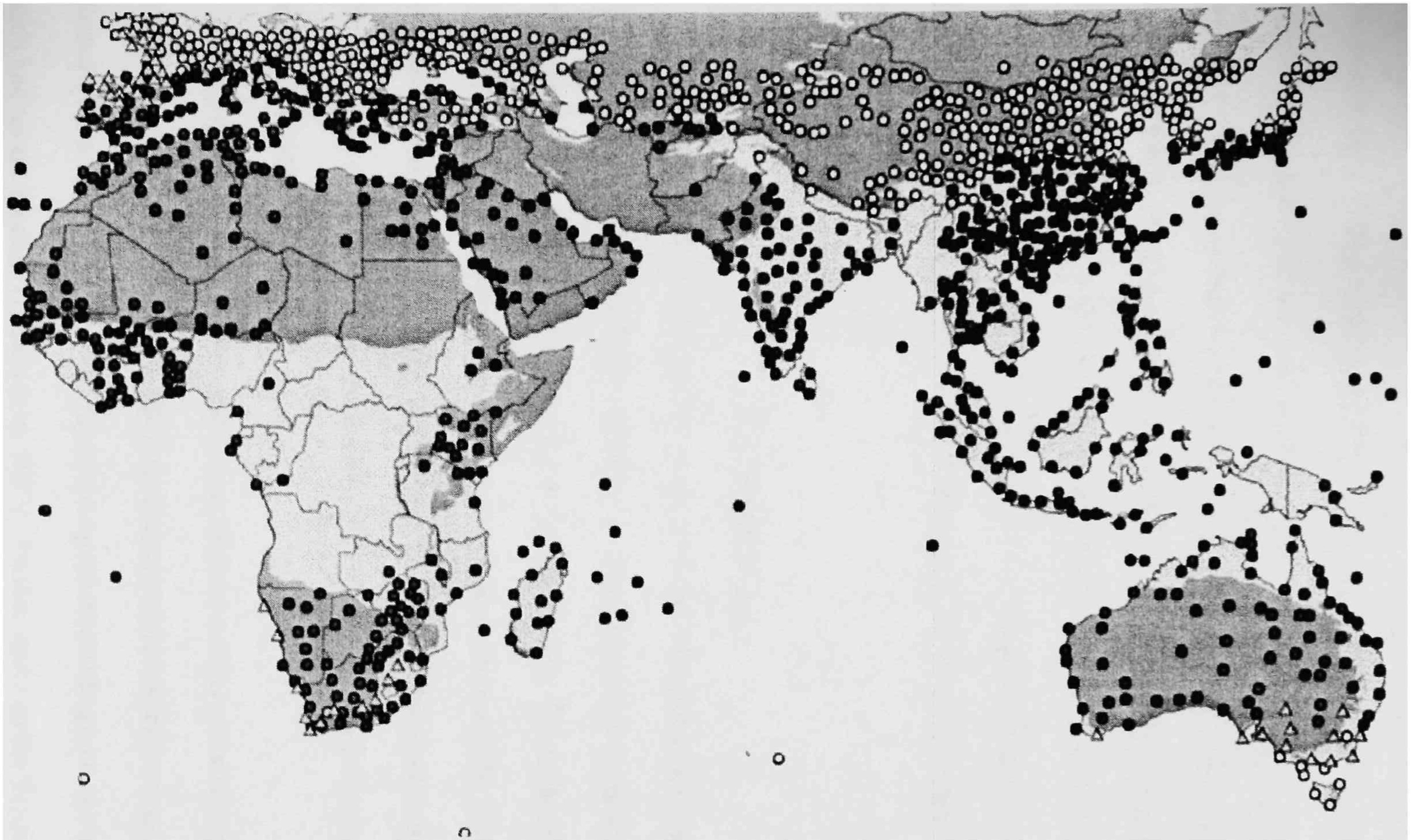

Figure 3.1. Potential global range of RIFA in the eastern hemisphere. Dark circles indicate areas of certain reproductive success; white circles indicate areas of unlikely reproductive success; triangles indicate areas of possible reproductive success, based on temperature. (Morrison et al. 2004).

Currently, RIFA are being studied in North and South America and Australia (Korzukhin et al. 2001; Porter et al. 1997; Vanderwoude 2003). Due to the long-established presence of RIFA, the ongoing concern about RIFA among the general public and the scientific community, and past availability of research funding, the overwhelming majority of RIFA research has been conducted in the United States (Vinson 1997: Congressional Record 1997). Thus continued RIFA research in the United States is essential in efforts to control RIFA infestation and damage, domestically, and to provide knowledge and technical methods to limit its potentially destructive impact on a global scale.

WW-B.Dahl Grass

WW-B.Dahl (*Bothriochloa bladhii*) grass is an Old World bluestem introduced to the U.S. from India. Prior to its release in 1994, Dr. Bill Dahl and his colleagues in the Department of Range and Wildlife at Texas Tech University did much of the research on WW-B.Dahl. The grass was given this common name in honor of Dr. Bill Dahl, professor of Range Science from 1968 to 1994 (R. Sosebee, personal communication). The grass provides strong forage production and is well suited to central and southern Texas (Dewald et al. 1995).

Recently, Britton et al. (2003) from Texas Tech noted that pastures planted with WW-B.Dahl grass showed much lower RIFA mound population densities than adjacent fields planted with shortgrass prairie and mixed shortgrass-bermuda grass. Several B.Dahl fields had no ant mounds (Britton et al. 2003). Further study on the Texas High Plains showed infestations of over 75 RIFA mounds per hectare in prairie and bermuda grass pastures, whereas a pure B.Dahl field nearby had no RIFA mounds. Similar incidental observations were made with red harvester ants (Hymenoptera: Formicidae) and pestiferous flies on cattle in WW-B.Dahl fields in comparison to other adjacent grasses (Britton et al. 2003). Such observations may indicate that WW-B.Dahl has general insect-repelling properties.

One potential reason for this may be that the genus *Bothriochloa*, including WW-B.Dahl, is rich in essential oils and is resistant to damage by some insect pests. A portion of the oils these plants produce, including acorenone-B, have anti-feedant properties affecting some insects (Pinder and Kerr 1980). A previous study in Texas showed that ant forage selection is influenced by repellent chemicals in plants (Waller 1986).

Invasiveness of WW-B.Dahl

Most non-native plants in the United States were introduced for food, fiber or ornamental purposes (Pimentel et al. 2000). Between 0.1% (Alpert et al. 2000) and 15% (Simberloff 1996) of introduced plant species become invaders. Invasive plants spread into habitats they have not previously occupied and can have negative effects on species already there. Annual grasses comprise the majority of invasives in various semi-desert habitats of North America (Alpert et al. 2000). Buffelgrass (*Pennisetum ciliare*), European Cheatgrass (*Bromus tectorum*) and Johnson grass (*Sorghum halepense*) are examples of introduced grasses that have become invasive in North America (GAO 2002; Pimentel et al. 2000). Invasive plants cost the U.S. economy approximately $23 billion annually, with billions more spent on environmental and public health damages caused by herbicides and pesticides used to control exotic plant species (Pimentel et al. 2000). Identification of invasive species is the first step to limiting their impact and preventing damage to natural and managed ecosystems.

Plants intentionally introduced for cultivation, selected for their ability to do well in a region, present a greater invasive threat (Harrington et al. 2003). As with most newly introduced grasses, field owners and managers plant B.Dahl based on its forage quality and suitability to livestock grazing and production (Sanderson et al. 1999). Grazing, common in B.Dahl fields, is known to increase grass distribution (Alpert et al. 2000). Little has been published regarding B.Dahl's potential invasiveness and effects on the ecosystem.

WW-B.Dahl Grass Abiotic Site Characteristics

Since its introduction to the U.S., the varied environmental conditions under which WW-B.Dahl grows well have not been thoroughly reported. Examining WW-B.Dahl grass sites for RIFA density provided an opportunity to collect additional data about locations where the grass is successful. This can establish traits of the grass, such as its ability to grow on clay soil and in erosion-prone areas, and provide producers with relevant information for future grass selection.

Research Objectives

My primary goal was to determine if RIFA population density differs in pasture grasses in Texas, focusing on WW-B.Dahl grass resistance to the red imported fire ant. In an effort to identify possible B.Dahl invasiveness, my second goal was to examine B.Dahl plots for grass spread beyond its original field of planting. Thirdly, I compiled abiotic characteristics to present a profile of environmental conditions where B.Dahl is successfully grown in regions where it interacts with the red imported fire ant.

CHAPTER II

ABIOTIC CHARACTERISTICS CONDUCIVE TO B.DAHL SUCCESS

Introduction

Since its introduction to the U.S. in 1994, WW-B.Dahl grass, an Old World bluestem, has been evaluated for issues relating to livestock forage productivity (Bell and Caudle 1994, Sanderson et al. 1999, Duch 2003). However, a literature review did not locate studies that determined the specific abiotic characteristics under which B.Dahl grows successfully. For this study I examined abiotic factors relevant to B.Dahl growth. Physical and chemical properties, such as soil texture, pH, and permeability, can affect B.Dahl suitability to a site. With 40% of Texas cropland considered highly erodible (Texas Environmental Almanac 2000), B.Dahl's potential ability to grow on soils at risk for erosion could be an important grass trait. In general, Old World bluestems perform best on loam and clay loam soils in areas receiving 38 to 89 cm of annual rainfall (Bell and Caudle 1994). Adequate precipitation and mild winter temperatures are essential for B.Dahl growth (R. Gillen, personal communication). Fertilizer, herbicide and insecticide usage may improve grass productivity.

Given the potential benefit of B.Dahl for livestock productivity, as vegetative cover to prevent erosion, and its suitability to conditions in central and northern Texas, I examined environmental conditions in which B.Dahl is currently grown. My goal was to identify basic abiotic characteristics of fields where B.Dahl is grown successfully.

Sites

The range in Texas where WW-B.Dahl grass and red imported fire ants (*Solenopsis invicta* Buren: RIFA) coexist forms a corridor from central to north-central Texas (Figure 2.1). I identified potential study sites by contacting local National Resource Conservation Service offices and County Agricultural Extension agents across the state of Texas, seed distributors, researchers working with WW-B.Dahl grass, and by conducting a literature review. Each site contained a plot of B.Dahl and an adjacent plot of a different grass species. I then obtained permission from B.Dahl field owners and managers for research visits. I established hectares planted, age of field, and the presence of RIFA in the vicinity through contact with growers. In this way I selected 25 research sites (Table 2.1) to provide a sample group distributed throughout central and northern Texas. Selected sites ranged from Runnels County in the west, Guadalupe and Wharton Counties to the south and southeast, Limestone County to the east and Grayson County to the north.

Table 2.1. Research site locations by county.

County	Number of Sites	County	Number of Sites
Brown	1	Kimble	1
Callahan	1	Lampasas	3
Comanche	1	Limestone	1
Coryell	1	McCulloch	1
Eastland	1	Milam	1
Ellis	1	Runnels	2
Fannin	1	Shackelford	2
Gillespie	1	Wharton	1
Grayson	1	Williamson	1
Guadalupe	1	Young	1
Hamilton	1		

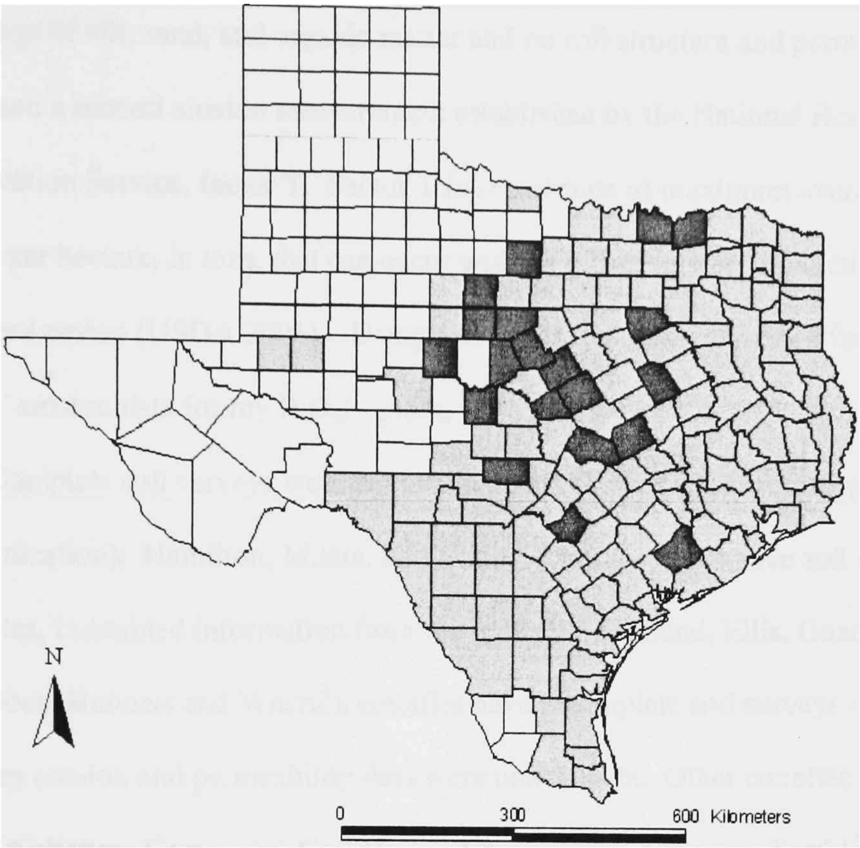

Figure 2.1. Texas counties containing RIFA infestation (gray) and research sites (dark). Texas Fire Ant Quarantine Map, May 2000 (Texas Department of Agriculture 2003).

Methods

Whenever I visited sites with B.Dahl for this study I recorded several abiotic factors. Soil properties including texture, pH, and permeability were selected to describe the physical environment in which B.Dahl grows. The Universal Soil Loss Equation tests for the erosivity of rainfall and the erodibility of the soil surface (Hugett 2003). From this equation I examined the variable most relevant to my B.Dahl plots, factor K, which measures soil susceptibility to water erosion. The estimates are based primarily on percentage of silt, sand, and organic matter and on soil structure and permeability. I also researched a second erosion measurement established by the National Resource Conservation Service, factor T. Factor T is an estimate of maximum average annual soil erosion per hectare, in tons, that can occur without affecting crop productivity over a prolonged period (USDA 2001). Using soil survey records, I obtained factor K and factor T erosion data for my B.Dahl plots.

Complete soil surveys were not available for all sites (R. Zartman, personal communication). Hamilton, Milam, and Young counties do not have soil surveys. For these sites, I obtained information from the growers. Eastland, Ellis, Guadalupe, McCulloch, Runnels and Wharton counties have incomplete soil surveys - in some instances erosion and permeability data were unavailable. Other counties including Brown, Callahan, Comanche, Coryell, Fannin, Gillespie, Grayson, Kimble, Lampasas, Limestone, Shackelford, and Willliamson had complete soil surveys (Clower 1981*a*; Clower 1981*b*; McCaleb 1985; Moore et al. 1977; Moore et al. 1977; Brooks et al. 1964; Goerdel 2002; Allison et al. 1975; Cochran 1980; Ramsey and Bade 1977; Blum 1982; Allison 2001; Griffin 1998; Wiedenfield et al. 1970; Lowther 1990; McEwen and Crout 1974; Werchan 1983).

I collected precipitation, temperature, and length of growing season data to provide a range of weather-related factors where B.Dahl grows. Information was gathered from owners and managers and through consulting additional resources including NRCS agents, County Agricultural Extension agents, USDA County Soil Surveys, and weather records. Field size and age of plots reflect current B.Dahl establishment in the region. Grower treatments on B.Dahl plots such as use of fertilizer, herbicide, insecticide, and irrigation were recorded to look at management factors undertaken with B.Dahl fields. These data produced a profile of the natural and anthropogenic conditions under which B.Dahl is currently successfully grown in Texas.

Results

Size of Field

The average B.Dahl field size was 20.4 hectares with plots ranging from 1.2 to 110 hectares. Six plots were less than 5 hectares, ten were between 6.8 and 16 hectares, six were between 20 to 26 hectares, and three were larger than 56 hectares (Table 2.2).

Age of Field

The average age of B.Dahl plots was 4.7 years (Table 2.2). Five fields were 1 or 2 years old, nine are 3 years old, five are 4 or 5 years old and five are between 7 and 9 years old. One plot was 18 years old. It was an original B.Dahl test field planted by Dr. Carlton Britton, a colleague of Dr. Bill Dahl at Texas Tech University. Long established, this plot markedly increases the average field age. Removing this field, planted before B.Dahl's public release in 1994, lowers mean field age to 4.1 years.

Table 2.2. Primary abiotic characteristics of 25 B.Dahl sites in central and northern Texas. This includes B.Dahl field size, age of plot, precipitation data (one hundred year average), July high temperature and January low temperature data (one hundred year average), and length of growing season. See text for data sources.

Site	Field Size (ha)	Age (yr)	Precipitation (cm) (annual average)	Temperature (C) July high	January low	Growing season (days)	pH range
Brown	2.4	7	69.59	35.52	0.56	242	6.1 7.8
Callahan	3.2	3	63.50	35.52	-0.56	230	7.4 - 8.4
Comanche	10	5	74.93	34.97	0.00	238	5.6 - 7.3
Coryell	10	4	81.28	36.08	0.56	244	7.4 - 8.4
Eastland	6.8	3	68.58	35.52	0.00	229	6.1 - 7.3
Ellis	24	8	91.44	35.52	1.67	245	7.5 - 8.2
Fannin	1.6	2	109.22	34.41	0.56	228	5.6 - 7.8
Gillespie	10.4	3	69.72	34.97	2.22	219	7.9 - 8.4
Grayson	22	3	93.98	35.52	-1.11	227	7.4 - 8.4
Guadalupe	14	3	83.82	35.52	5.55	275	6.6 - 7.8
Hamilton	12.4	5	75.18	35.52	1.11	239	n/a
Kimble	1.2	5	56.64	36.08	0.56	213	7.9 - 8.4
Lampasas I	24	18	76.20	35.52	-1.11	225	7.4 - 8.4
Lampasas II	80	3	76.20	35.52	-1.11	225	7.9 - 8.4
Lampasas III	4.8	9	76.20	35.52	-1.11	225	7.4 - 8.4
Limestone	20.8	2	96.52	35.52	2.78	255	7.4 - 8.4
McCulloch	56	2	63.50	35.52	-0.56	226	7.8 - 8.4
Milam	3	3	88.90	35.52	3.89	256	n/a
Runnels I	110.4	3	55.88	35.52	1.11	228	n/a
Runnels II	10.4	3	55.88	35.52	1.11	228	n/a
Shackelford I	16	9	67.56	36.08	-0.56	224	6.6 - 7.8
Shackelford II	8.4	2	67.56	36.08	-0.56	224	7.9 - 8.4
Wharton	26	1	106.68	33.86	6.66	268	6.1 7.8
Williamson	2	7	83.36	35.52	2.22	258	7.4 - 8.4
Young	8.8	4	71.12	36.63	-0.56	216	n/a
Mean	20.4	4.7	77.05	35.50	2.04	235.5	7.4 - 8.4
Standard deviation	25.73	3.56	14.66	0.54	0.93	16.2	n/a

Soil Texture

Soils at 21 of the 25 plots (84%) were classified as clay or including a large clay component (Table 2.3). At nine sites, the dominant soil texture was clay, which has a particle size less than 0.002 mm and flat shape (Allison 2001). Six sites had clay loam, soil that contains 27 to 40% clay and 20 to 45% sand (Soil Society of America 1998). Silty clay (soil that contains 40% or more clay and 40% or more silt) and silty clay loam (soil with 27 to 40% clay and <20% sand) (Soil Society of America 1998) were present at three sites each. Two sites featured sandy loam (soil that contains 7 to 20% clay, > 52% sand, and some silt) (Soil Society of America 1998). Loam (soil with 7 to 27% clay particles, 28 to 50% silt particles, <52% sand particles) (Allison 2001) and loamy sand (soil containing >50% very coarse, coarse, and medium sand and <50% fine or very fine sand) (Soil Society of America 1998) were found at one site each.

Soil Erodibility

Measured by factor K, over 70% of the fields with relevant data (11/15) showed moderate to moderately high susceptibility to erosion (Figure 2.2). Erosion factor T plot ratings ranged from 2.5 to 17.5 tons of soil loss per hectare per annum before productivity would be affected (Figure 2.3). An erosion factor T of 12.5 tons per hectare is considered the minimum rating needed to prevent productivity loss in Texas (Texas Environmental Profiles 2004). Thus the factor T findings indicate that B.Dahl can grow on soils where erosion threatens productivity.

Table 2.3. Soil texture in 25 B.Dahl fields in central and northern Texas. The texture type comes from USDA County Soil Surveys and grower information. Texture definitions come from the USDA (Allison 2001) and the Soil Society of America (1998). See text for information sources.

Site	Clay	Clay Loam	Silty Clay	Silty Clay Loam	Sandy Loam	Loam	Loamy Sand
Brown		X					
Callahan						X	
Comanche							X
Coryell			X				
Eastland					X		
Ellis	X						
Fannin					X		
Gillespie				X			
Grayson	X						
Guadalupe	X						
Hamilton	X						
Kimble				X			
Lampasas I			X				
Lampasas II				X			
Lampasas III		X					
Limestone	X						
McCulloch		X					
Milam	X						
Runnels I		X					
Runnels II		X					
Shackelford I		X					
Shackelford II			X				
Wharton	X						
Williamson	X						
Young	X						
Total	9	6	3	3	2	1	1

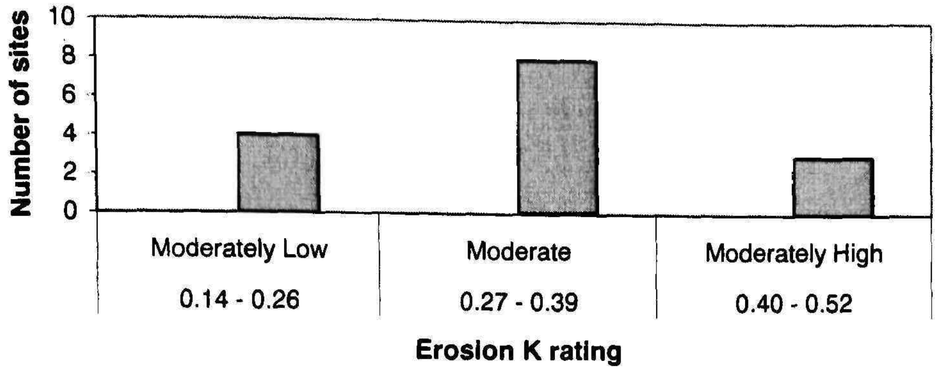

Figure 2.2. Erosion K-rating of B.Dahl plots. Erosion-K estimates soil susceptibility to water erosion. K-values range from 0.02 to 0.64 with higher values reflecting greater susceptibility to erosion.

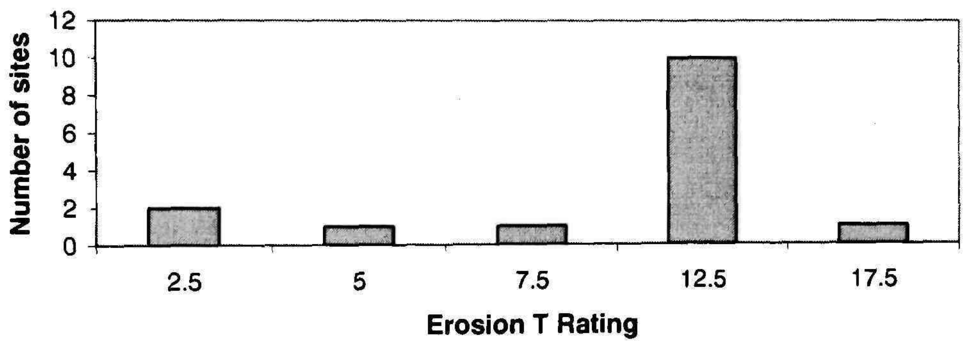

Figure 2.3. Erosion T-rating in B.Dahl plots. Erosion-T is an estimate of the amount of soil erosion caused by wind or water, in tons per hectare per year, that can occur before crop productivity is affected. A lower rating represents greater erodibility (USDA 2001).

Permeability

Reflecting the predominance of clay and clay loam soils, the permeability of 6 B.Dahl plots rated very low, 11 had moderately low permeability, 4 had moderate permeability and only one plot featured moderately rapid permeability (Figure 2.4).

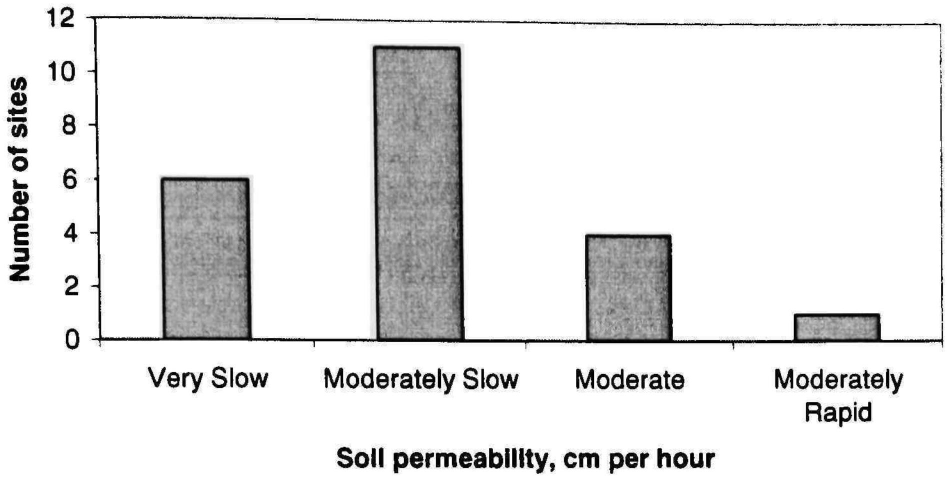

Figure 2.4. Soil permeability rates in B.Dahl plots. Values at B.Dahl plots included very slow - 0.02 cm/h, moderately slow - 0.5 - 1.5 cm/h, moderate - 1.5 - 5.0 cm/h and moderately rapid - 5.0 - 15.2 cm/h. Categories follow USDA (2001) definitions.

pH Value

The pH value, a designation of acidity and alkalinity in soil, of the B.Dahl plots varied from a low range of pH 5.6 – 7.3 to an upper range of 7.9 – 8.4, with two-thirds of the plots falling between pH 7.4 – 8.4 (Table 2.3). Values come from the USDA County Soil Survey records (see above).

Precipitation

I gathered precipitation data from published weather records (Handbook of Texas Online 2001) and compared them with grower-provided rainfall information. Only two owners kept detailed precipitation records (Kimble and Milam sites), whereas most producers made statements about rainfall without supporting documentation. Though weather data were recorded at the county seats rather than at my sites, they provide a somewhat representative rainfall measurement for each area. As stressed by producers, annual rainfall amounts varied widely, thus a one hundred year average, obtained from the Handbook of Texas Online (2001), was used. Site annual precipitation ranged from a high of 109 cm in Fannin County to a low of 56 cm annually in Runnels County (Table 2.2). A slight majority (52%) of the plots were within the middle precipitation range (25% - 75% of the precipitation range for all sites) of 86 cm to 66cm per year. Twenty-four percent of the sites featured less than 66 cm of precipitation, and 24% had more than 86 cm annually. Only two sites, Runnels I and Kimble, were irrigated to increase grass yields. The plot at Runnels I received 30 cm of irrigation annually; whereas, the owner at the Kimble site did not record the amount of irrigation.

Temperature

Temperatures (National Weather Service; Handbook of Texas Online 2001) showed little variation in average July high temperatures and some variation in January average low temperatures (Table 2.2). All 25 sites were within 1.7 degrees of the mean summer high, 35.5° C. Whereas the winter average low temperature was 0.9° C, there was an 8 degree spread among the sites, with 14 plots maintaining average temperatures above freezing throughout the winter.

Growing Season

The length of the growing season, the number of days between the last spring freeze and first winter frost, showed an average of 235 days across all sites (Handbook of Texas Online 2001) (Table 2.2). This fluctuated from 213 days in Kimble County to 275 days in Guadalupe County. The majority of plots (60%) fell below this mean, while 10 had a longer than average growing season.

Fertilizer, Herbicide and Insecticide Use

Fertilizer, herbicide and pesticide use rates varied greatly (Table 2.4). Fertilizer was commonly used, with only three sites (Callahan, Lampasas II, and Runnels II) never receiving fertilizer treatment. Nitrogen was used both by itself (3 fields), and in combination with phosphate and phosphorus (12 fields). Growers also applied general (unspecified) fertilizers. One owner used a self-made organic fertilizer, and one used chicken manure when possible. Amount of fertilizer usage varied from 18 to 135 kilograms per hectare. Of the growers that specified the amount of fertilizer used, three applied less than 45 kilograms per hectare, four used between 45 and 68 kilograms per hectare, four applied 91 kilograms, and four used 135 kilograms.

Just 48% of growers used an herbicide. Herbicides included Roundup® (Monsanto Company, St. Louis, MO.), Grazon® (Dow AgroSciences, Indianapolis, IN.), Cimarron® (DuPont, Wilmington, DE.) and 2,4-D (company unknown). Specified amounts applied were 1.42 liters/hectare to 2.85 liters/hectare. On only two plots, Callahan and nearby Eastland, were insecticides used on the B.Dahl plot. The Callahan grower used a fire ant bait (Extinguish®, Zoecon, Schaumburg, IL.); whereas, the Eastland owner used an insecticide Dimilin® (Uniroyal Chemical Company, Middlebury, CT.) to control grasshoppers. No insecticides were applied to the adjacent field (native grass and Bermuda, respectively). No insecticides were used on B.Dahl or other grasses at other sites.

Table 2.4. Management input in B.Dahl fields. This reflects grower management regimes at 25 B.Dahl plots in central and northern Texas. Fertilizer was the most common treatment used on B.Dahl plots.

Site	Fertilizer use	Herbicide use	Insecticide use	Irrigation	Previous field usage
Brown	yes	no	no	no	wheat
Callahan	no	no	yes	no	coastal
Comanche	yes	no	no	no	crop
Coryell	yes	yes	no	no	crop
Eastland	yes	yes	yes	no	sudan
Ellis	yes	yes	no	no	haygrazer ®
Fannin	yes	yes	no	no	native
Gillespie	yes	no	no	no	crop
Grayson	yes	yes	no	no	wheat
Guadalupe	yes	no	no	no	cotton
Hamilton	yes	no	no	no	native
Kimble	yes	no	no	yes	haygrazer ®
Lampasas I	yes	no	no	no	haygrazer ®
Lampasas II	no	yes	no	no	native
Lampasas III	yes	no	no	no	oats
Limestone	yes	yes	no	no	native
McCulloch	yes	yes	no	no	wheat
Milam	yes	yes	no	no	crop
Runnels I	yes	no	no	yes	grass
Runnels II	no	yes	no	no	crop
Shackelford I	yes	yes	no	no	n/a
Shackelford II	yes	no	no	no	wheat
Wharton	yes	yes	no	no	native
Williamson	yes	no	no	no	mixed grass
Young	yes	no	no	no	wheat
Total	22	12	2	2	----
Percentage of sites	88%	48%	8%	8%	----

Previous Field Usage

Before being planted in B.Dahl, 79% of the fields had been under cultivation and 21% were native pastures (Table 2.4). Grower reasons for switching to B.Dahl included a desire to try a new grass and to supplant an unsatisfactory crop. Recommendations from other growers and County Agricultural Agents and literature reviewed about B.Dahl were cited as motivation for planting B.Dahl. Grasses were previously planted on seven plots; crops on six plots, wheat on five plots and one had been a cotton field. Five plots were native pasture prior to B.Dahl planting. Previous field usage at one plot was unknown. Thus, in the majority of the plots, B.Dahl has replaced other introduced species.

Discussion

WW-B.Dahl grass is currently planted in central and north-central Texas and grows successfully under regional conditions. Plot size differed greatly, in part due to the desire of some producers to experiment with a small field of B.Dahl. Reflecting its newness, about three-fourths of the plots were 5 years or less in age. Examining erosion factor T data showed B.Dahl is currently grown on soil where crop productivity is affected by erosion at low soil loss rates. My plots showed crop productivity threatened at loss rates from 2.5 to 17.5 tons per hectare, much lower than the average soil loss in Texas of 35 tons per hectare per year (Texas Environmental Almanac 2000). Erosion factor K identified the majority of B.Dahl plots as being moderate to moderately high in susceptibility to erosion. These indices suggest that B.Dahl may help reduce field erosion. The grass plots tolerated a range of pH values similar to those previously described (Dewald et al. 1994). B.Dahl is predominately found on soils with high clay content or a clay component, and, therefore, low permeability rates. Though precipitation levels varied somewhat, sites showed little difference in average high and low temperature. Grower efforts on B.Dahl fields concentrated on fertilizer application and to a lesser extent on herbicides use while insecticide and irrigation efforts were minimal. In 79% of the plots B.Dahl replaced other introduced plant varieties.

The potential range of B.Dahl extends well beyond my study region. Personal contact with USDA and County Agricultural Extension agents across Texas documented that B.Dahl has been established in northwestern Texas, including in Bailey, Lubbock, Briscoe and Childress counties. Outside of the state, B.Dahl is grown in Oklahoma (Aljoe 2002), and eastern New Mexico (V. Allen, personal communication) and is considered a potential forage variety for the southeastern U.S. (Ball and Blount 2002). The Plant and Soil Science Department of Texas Tech University has distributed B.Dahl seeds to sites in Virginia and Kentucky for testing and possible introduction (V. Allen, personal communication).

The Agricultural Research Service of Woodward, OK. identifies winter tolerance and a lack of moisture as two factors limiting B.Dahl's potential northern and western range (R. Gillen, personal communication). Measured on the USDA's Plant Hardiness scale, B.Dahl is thought to be suitable for conditions in southern zone 7 and zone 8 regions (Figure 2.5) (Elstel Farm and Seeds 2002). Zone 7 has an average annual minimum temperature of –18°C to –12°C, zone 8 averages –12°C to –7°C. Further field study is needed to more accurately establish the potential range of B.Dahl grass in the U.S. B.Dahl grass is currently also being grown in the northern Mexico states of Tamaulipas, Coahuila, and Chihuahua (C. Villalobos, personal communication).

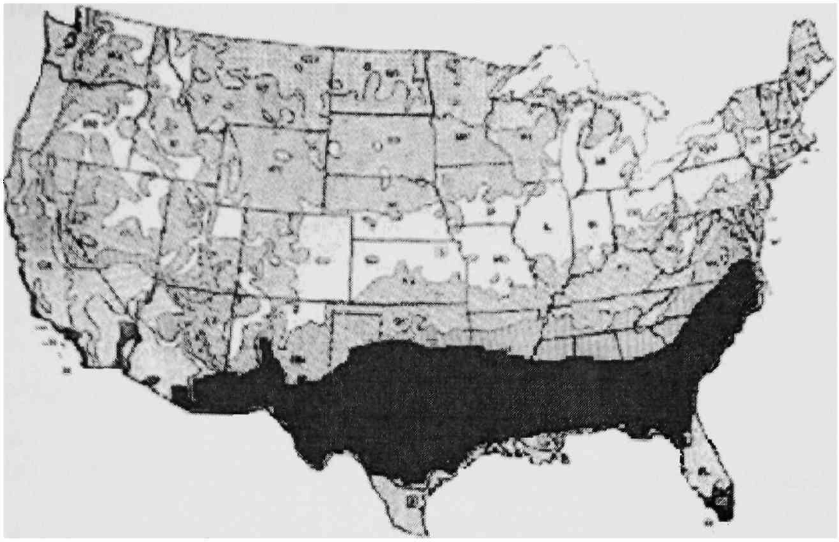

Figure 2.5. U.S. Plant Hardiness Zone Map, 1990. The map represents potential B.Dahl range (dark area) in southern Zone 7 and Zone 8 (Klingaman 1999).

Study results suggest that B.Dahl is well suited to conditions prevalent in central and north-central Texas. Currently in limited use, B.Dahl's abiotic suitability, in conjunction with its productivity in forage-livestock systems (Sanderson et al. 1999), make it a strong candidate for expanded cultivation in central and northern Texas. Previously noted strengths of WW-B.Dahl grass include its high forage yields and adaptability to diverse soil conditions and climatic conditions (Sanderson 1999). Also of importance to growers is its high seed production, later seasonal maturity that promotes livestock weight gains in the summer, and good winter hardiness in Texas and New Mexico (Duch, 2003; Dewald et al. 1995). Research in 2002 indicated B.Dahl had greater water use efficiency and dry biomass yield under irrigated conditions than other Old World bluestems (Phillips 2003). In addition, my study documents successful B.Dahl growth in central and northern Texas and suggests that B.Dahl may be useful for erosion control.

CHAPTER III

REPELLENCY OF WW-B.DAHL AND OTHER PASTURE GRASSES TO THE RED IMPORTED FIRE ANT

Introduction

RIFA population density is often highest in grass-dominated systems such as pastures, parks and conservation lands, yet much variation in different grassland sites may exist. Research has found that the presence of different grass species and cultivars can lead to differences in RIFA populations (Reinert and Perry 2003). Identifying grasses that can reduce RIFA infestation would be beneficial to land managers, ranchers, and homeowners. In an effort to identify effective grasses my study examined whether WW-B.Dahl grass plots (see Chapter I), or other adjacent pastures containing grasses, such as Bermuda, native, and Klein (*Panicum coloratum* L.), contained lower RIFA population densities.

Methods

Each of the 25 sites (see Chapter II) comprised two adjacent plots, one planted with B.Dahl and the other featuring a different grass, such as Bermuda. I examined both plots for RIFA population density at the same time. Two methods of sampling were employed, standardized bait cup (Mueller et al. 1999) and mound counts (Forbes 1999). Sampling took place between 8 a.m. and 8 p.m., when foraging activity is high (Stein 1987). All field plots were sampled with two line-transects to measure density variance within the plot. An effort was made for the line-transects to reflect the range of conditions within the plot, such as length of grass establishment, quality/density of stand, soil and slope conditions, moisture regimen, etc.

RIFA worker size is a basic aspect of colony social structure and population dynamics (Porter 1983). Size can be used to predict if RIFA colonies are monogynous (single queen) or polygynous (multiple queen). Polygyne workers are significantly smaller than workers in monogyne colonies (Greenberg et al. 1985). In an effort to identify colonies at my sites I measured ant head capsule widths using a wedge micrometer (Porter 1983; James et al. 2002). Established sample numbers (15) and headwidth parameters were used to determine monogyny (mean > 0.789 mm headwidth) and polygyny (mean < 0.74 mm headwidth) (Drees and Vinson 1987; Greenberg et al 1985).

To establish plot characteristics that may affect ant density and foraging activity, I examined several factors. Temperature parameters, most notably soil at 2 cm depth (Porter and Tschinkel 1987) and at the soil surface (Vogt et al. 2003), have been reported as significant predictors of foraging activity. Thus I recorded soil and surface temperature as well as air temperature at 1 m above the soil surface (Thorvilson, personal communication) (Appendix A.3). I measured grass height and grass density using the Daubenmire cover scale (Bonham 1989) to determine if height and density affected ant abundance (Appendix A.3). Time of day, altitude and visual estimation of shading provided additional background information (Appendix A.4). I recorded GPS coordinates to identify each transect for possible future study (Appendix A.5).

Procedure

Bait cup sampling involved placing bait cups 10 m apart along a 100 m linear transect, with the first cup placed 20 m from a field edge, for a total of 10 cups (Morrison 2002). Transect direction was determined by random direction sampling (Southwood 1978). From a sheet of 290 randomly generated numbers (Thompson 1992), I impartially selected a number. The number generated was multiplied by 360 to convert it to the corresponding compass point. The bait cup, a one-fluid ounce plastic cup (Jusino-Atrasino 1992), contained 5 g of Tender Vittles® tuna-flavored cat food (Ralston-Purina, St. Louis, MO.), moistened with water (H. Thorvilson, personal communication). I placed each cup on the ground and left for it for one hour (Russell et al. 2001). I then collected the cup and immediately placed it in a four-fluid ounce plastic specimen container (B. Dabbert, personal communication) to be frozen or chilled to reduce ant movement. I then placed the samples in 70% ethyl alcohol until the ants could be identified to species and counted in the laboratory. After counting, each transect line's specimens were stored in a separate, labeled, glass vial and deposited at the Texas Tech Imported Fire Ant Laboratory in the Agricultural Sciences Building (Jusino-Atresino 1992).

The second sampling technique was mound counts, conducted along a transect line 100 m long, 3-m wide (1.5 m on either side of the transect line and measured by a rod). Starting 20 m from the field edge, the mound count transect line was parallel to and 10 m apart from the bait cup transect line. I opened the top of each mound within this range with a shovel to determine colony activity. I rated the mounds on a scale from 0 to 25, based on the estimated number of workers per colony and whether or not worker brood was present (Thorvilson et al. 1992). Workers were rated with 1 representing < 100 ants through 5 signifying > 50,000 ants. Presence of worker brood multiplies the rating by 5, making 25 the maximum rating. The numerical ratings, with higher numbers representing greater density, established a population index for the colony and the plot area (Lofgren and Williams 1982).

Sampling took place in March, May, and June 2004 when there was sufficient warmth, between 22° C to 36° C, for maximum ant foraging activity and before heat levels led to ant sluggishness (Porter and Tschinkel 1987). Vogt et al. (2003) reported that by mid-March mean foraging activity sometimes approaches the predicted maximum for late June. As temperature is a key factor in ant foraging, I sampled warmer, more southerly sites first. Data collection at each field site took me 3 to 4 hours to complete.

Results

Mounds

The number of mounds in B.Dahl plots ranged from 0 to 4.5 mounds per transect (Table 3.1); mounds in other grasses varied from 0 to 27.5 mounds per transect. Mean mounds per transect differed greatly between B.Dahl and other grasses, the former averaging 1.48 mounds per transect with a standard deviation of 1.43, the latter averaging 5.88 mounds per transect with a standard deviation of 6.11 (Figure 3.1). Using a Student's t-test I identified significantly greater numbers ($t = -3.91$; $df = 24$, P = 0.0006) of mounds in fields containing other grasses. The significant difference in mounds per transect was further examined by comparing B.Dahl and the two main types of other grasses in this study, Bermuda and native (Table 3.2). Using t-tests, I found the number of mounds in both grasses were significantly greater than in B.Dahl plots (Bermuda, $t = 2.35$; $df = 14$, $P = 0.03$; native, $t = -2.81$; $df = 6$, $P = 0.01$).

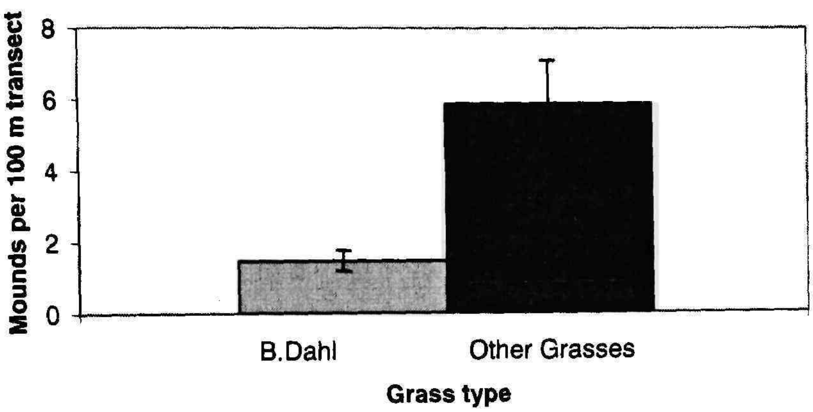

Figure 3.1. Mean mound density in B.Dahl fields vs. other grasses. This represents the mean mound density, with standard error bars, at 25 sites in central and northern Texas, 2004.

Table 3.1. Measures of RIFA and non-RIFA population density in B.Dahl and other grasses. The measurements are RIFA Numbers, number of mounds per transect, and mound vitality ratings. The table includes means per site and standard deviation for 25 sites in central and northern Texas. See Appendix Tables A.1 and A.2 for raw data.

Site	B.Dahl				Other grasses			
	RIFA (mean per cup)	Non-RIFA (mean per cup)	Mounds (mean per transect)	Mound Vitality Rating (mean)	RIFA (mean per cup)	Non-RIFA (mean per cup)	Mounds (mean per transect)	Mound Vitality Rating (mean)
Brown	28.70	0	4.50	6.67	69.70	0	11.50	5.10
Callahan	20.60	0.05	1.00	7.50	17.35	1.3	5.00	12.50
Comanche	13.30	0	0	0	3.70	0	4.50	2.20
Coryell	0.70	0	2.00	6.75	13.65	0	2.00	6.25
Eastland	102.65	0	4.50	10.67	146.40	0	8.50	11.30
Ellis	10.15	0.35	2.00	5.50	28.55	0.1	4.50	6.66
Fannin	6.40	14.3	0.50	10.00	7.55	30.2	2.00	10.00
Gillespie	105.60	0.25	3.00	8.83	13.33	0	4.00	7.75
Grayson	13.86	14.8	1.33	10.00	26.60	7.15	1.50	13.30
Guadalupe	3.05	0	0.50	10.00	5.40	0	13.50	11.50
Hamilton	33.70	0	1.00	12.50	36.70	0.05	6.50	10.15
Kimble	34.65	9.2	1.50	2.85	105.15	0	3.50	7.57
Lampasas I	34.17	3.12	0.71	8.40	49.43	1.17	6.00	7.67
Lampasas II	3.75	2.4	3.50	2.85	1.90	11.6	16.00	3.65
Lampasas III	34.70	0.15	0	0	97.80	0	7.50	6.73
Limestone	6.00	0	2.50	10.00	4.75	0	27.50	4.95
McCulloch	0	0	0	0	54.30	7.6	3.50	7.00
Milam	21.25	0	1.50	12.50	15.90	0	1.50	4.30
Runnels I	22.63	0.05	0	0	8.10	0	0	0
Runnels II	3.15	50.45	0	0	0.00	24.45	0	0
Shackelford I	152.75	1.35	0	0	44.80	0.1	0	0
Shackelford II	16.10	8.05	0	0	0.00	31.8	0	0
Wharton	0.35	0	1.00	20.00	4.00	0	5.00	13.10
Williamson	9.95	2.8	3.00	1.16	0.60	0	5.50	5.10
Young	112.90	0.7	3.00	10.00	75.85	0.45	7.00	12.28
Mean (per site)	31.64	4.32	1.48	6.24	33.26	4.64	5.88	6.76
Standard deviation	41.12	10.56	1.43	5.37	38.94	9.63	6.11	4.29

Table 3.2. Measurement of RIFA population density in other grasses by grass type. Measurements include mean RIFA numbers, mounds and mound vitality ratings in fields with other grasses. The data was collected at 25 sites in central and northern Texas in March, May and June, 2004. See Appendix Table A.1 and A.2 for raw data.

Site	Other grasses (mean RIFA per cup)	Bermuda (mean RIFA per cup)	Native (mean RIFA per cup)	Klein (mean RIFA per cup)	Wilmon lovegrass (mean RIFA per cup)	Mounds per transect (mean)	Mound Vitality Rating (mean)
Brown	69.70		69.70			11.5	5.10
Callahan	17.35		17.35			5.0	12.50
Comanche	3.70	3.70				4.5	2.20
Coryell	13.65	13.65				2.0	6.25
Eastland	146.40	146.40				8.5	11.30
Ellis	28.55	28.55				4.5	6.66
Fannin	7.55	7.55				2.0	10.00
Gillespie	13.33			13.33		4.0	7.75
Grayson	26.60	26.60				1.5	13.30
Guadalupe	5.40		5.40			13.5	11.50
Hamilton	36.70	36.70				6.5	10.15
Kimble	105.15	41.00		64.15		3.5	7.57
Lampasas I	49.43		49.43			6.0	7.67
Lampasas II	1.90	1.90				16.0	3.65
Lampasas III	97.80			97.85		7.5	6.73
Limestone	4.75	4.75				27.5	4.95
McCulloch	54.30				54.3	3.5	7.00
Milam	15.90	15.90				1.5	4.30
Runnels I	8.10	8.10				0	0
Runnels II	0		0			0	0
Shackelford 1	44.80	44.80				0	0
Shackelford 2	0		0			0	0
Wharton	4.00		4.00			5.0	13.10
Williamson	0.60	0.60				5.5	5.10
Young	75.85	75.85				7.0	12.28
Number of sites	25.0	14.5	7.0	2.5	1.0		
Mean - all sites	33.26	31.45	20.85	70.13	54.3	5.9	6.76

Ant Numbers

Ant numbers per cup varied greatly in B.Dahl plots and in fields planted in other grasses (Table 3.1). RIFA density in B.Dahl fields ranged from 0 to 152.5 ants per cup. Plots of other grasses had a RIFA density range from 0 to 146.4 ants per cup. The mean number of RIFA per cup in B.Dahl grass was 31.64 with a standard deviation of 41.12; in other grasses it was 33.26 ants per cup with a standard deviation of 38.94 (Figure 3.2). Using a t-test, I failed to find a significant difference ($t = -0.20$; $df = 24$; $P = 0.84$) in bait cup numbers in different pasture grasses.

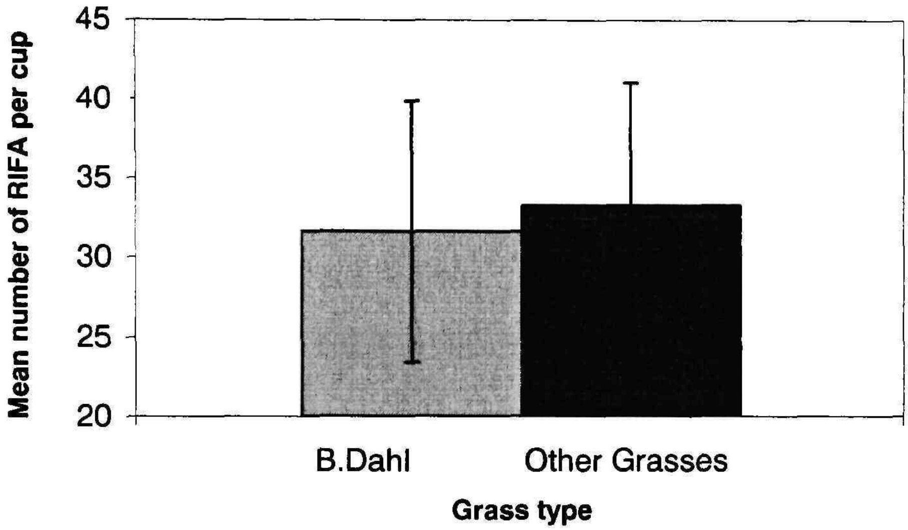

Figure 3.2. Mean RIFA abundance per cup in B.Dahl fields vs. other grasses. This represents RIFA abundance, with standard error bars, at 25 sites in central and northern Texas, 2004.

Mound Vitality Rating

In the 18 B.Dahl plots that contained mounds, the mean mound vitality ratings ranged from 1.16 to 20 (Table 3.1). The 21 fields in other grasses that had mounds averaged vitality ratings of between 2.2 and 12.28. Mean mound vitality rating in B.Dahl plots was 6.24 with a standard deviation of 5.37, whereas the mean in other grasses was 6.76 with a standard deviation of 4.29 (Figure 3.3). Using a t-test I failed to find a significant difference (t = - 0.69; df = 24, P = 0.49) between the mound vitality ratings in B.Dahl plots and fields with other grasses.

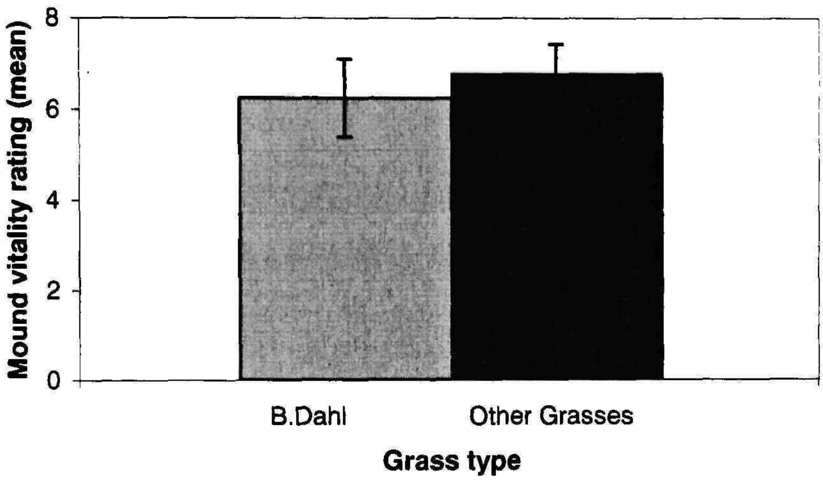

Figure 3.3. Mean mound vitality ratings in B.Dahl fields vs. other grasses. This represents mean mound vitality ratings, with standard error bars, at 25 sites in central and northern Texas, 2004.

I also examined the population index using the mound vitality ratings. This was done by multiplying the number of mounds in each category by the numerical rating (Lofgren and Williams 1982). Using a t-test I failed to find a significant difference between B.Dahl plots and other grasses (t = - 1.85; df = 8; P = 0.10).

Non-RIFA

In addition to RIFA, other ants were collected at 17 sites. There was little variation in the number of non-RIFA collected in B.Dahl and other adjacent grasses. B.Dahl plots averaged 4.32 non-RIFA per cup per site (Table 3.1). Other grasses had a mean of 4.64 non-RIFA per cup per site. A t-test failed to find a significant difference ($t = -0.18$; $df = 16$, $P = 0.85$) in the number of non-RIFA collected in B.Dahl and in other grasses.

Head Capsule Width

Head capsule width measurements showed differences between B.Dahl plots and other grass fields (Table 3.3). In B.Dahl plots RIFA in 36% (17/44) of the transects were monogynous, 21% (10/44) were undetermined (mean headwidth between monogyne and polygyne), and 43% (20/44) were polygynous. In other grasses 23% (10/44) of RIFA transects were monogynous, 14% (6/44) were undetermined, and 63% (28/44) were polygynous. Some transects lacked sufficient ant numbers (<15) to determine colony type (n/a). Within the 23 study sites where determinations were made, RIFA colonies in B.Dahl and other grasses were identified as of the same type in 11 transects, and in 9 of these transects colonies were polygynous. At two sites colony types were the same in B.Dahl plots and other grasses.

Table 3.3. RIFA colony type from ant head capsule width (mm). Headwidth was measured to determine if colonies were monogynous (> 0.789 mm headwidth), undetermined (0.74 to 0.789 mm headwidth), or polygynous (< 0.74 mm headwidth). N/A signifies fewer than 15 ants were available to determine colony type (Greenberg et al. 1985; Drees and Vinson 1987). SD = standard deviation. Results are for 25 sites in central and northern Texas where RIFA were collected in March, May, and June 2004.

Site/	B.Dahl			Other grasses			
Transect	Mean per transect	SD	Colony type	Mean per transect	SD	Colony type	Grass type
Brown							
1	0.798	0.065	monogyne	0.735	0.149	polygyne	native
2	0.832	0.152	monogyne	0.708	0.074	polygyne	native
Callahan							
1	0.944	0.152	monogyne	0.078	0.109	undetermined	native
2	0.708	0.083	polygyne	0.744	0.051	undetermined	native
Comanche							
1	0.725	0.106	polygyne	n/a	n/a	n/a	bermuda
2	n/a	n/a	n/a	0.692	0.053	polygyne	bermuda
Coryell							
1	n/a	n/a	n/a	0.794	0.181	monogyne	bermuda
2	n/a	n/a	n/a	0.740	0.057	polygyne	bermuda
Eastland							
1	0.777	0.169	undetermined	0.682	0.047	polygyne	bermuda
2	0.788	0.134	undetermined	0.698	0.123	polygyne	bermuda
Ellis							
1	0.907	0.254	monogyne	0.910	0.199	monogyne	bermuda
2	0.823	0.077	monogyne	0.790	0.096	monogyne	bermuda
Fannin							
1	0.883	0.151	monogyne	0.705	0.045	polygyne	bermuda
2	0.835	0.134	monogyne	0.682	0.123	polygyne	bermuda
Gillespie							
1	0.732	0.176	polygyne	0.655	0.107	polygyne	klein
2	0.793	0.102	monogyne	0.647	0.073	polygyne	klein
3	0.967	0.202	monogyne	0.693	0.074	polygyne	klein
4	0.939	0.248	monogyne	0.695	0.161	polygyne	klein
Grayson							
1	0.732	0.176	polygyne	0.588	0.046	polygyne	bermuda
2	0.859	0.207	monogyne	0.577	0.056	polygyne	bermuda
3	0.835	0.187	monogyne	—	—	—	—
Guadalupe							
1	n/a	n/a	n/a	0.816	0.187	monogyne	native
2	0.789	0.133	undetermined	0.798	0.092	monogyne	native
Hamilton							
1	0.767	0.19	undetermined	0.711	0.063	polygyne	bermuda
2	0.836	0.12	monogyne	0.605	0.092	polygyne	bermuda
Kimble							
1	0.897	0.108	monogyne	0.697	0.084	polygyne	klein
2	n/a	n/a	n/a	0.820	0.153	monogyne	bermuda

Table 3.3. Continued.

Site/ Transect	B.Dahl Mean per transect	SD	Colony type	Other grasses Mean per transect	SD	Colony type	Grass type
Lampasas I							
1	0.762	0.239	undetermined	n/a	n/a	n/a	native
2	0.733	0.168	polygyne	0.617	0.079	polygyne	native
3	0.627	0.079	polygyne	n/a	n/a	n/a	native
4	n/a	n/a	n/a	n/a	n/a	n/a	native
5	n/a	n/a	n/a	0.708	0.095	polygyne	native
6	0.719	0.104	polygyne	0.618	0.113	polygyne	native
7	0.679	0.13	polygyne	0.752	0.146	undetermined	native
Lampasas II							
1	0.681	0.103	polygyne	0.729	0.125	polygyne	bermuda
2	0.656	0.089	polygyne	n/a	n/a	n/a	bermuda
Lampasas III							
1	0.654	0.097	polygyne	0.705	0.119	polygyne	klein
2	0.681	0.076	polygyne	0.729	0.128	polygyne	klein
Limestone							
1	0.679	0.110	polygyne	0.638	0.078	polygyne	bermuda
2	0.699	0.160	polygyne	n/a	n/a	n/a	bermuda
McCulloch							
1	n/a	n/a	n/a	0.665	0.113	polygyne	lovegrass
2	n/a	n/a	n/a	0.806	0.123	monogyne	lovegrass
3	n/a	n/a	n/a	—	—	—	—
4	n/a	n/a	n/a	—	—	—	—
Milam							
1	0.671	0.081	polygyne	0.695	0.176	polygyne	bermuda
2	0.755	0.12	undetermined	0.762	0.182	undetermined	bermuda
Runnels I							
1	0.761	0.045	undetermined	0.860	0.079	monogyne	bermuda
2	0.834	0.131	monogyne	n/a	n/a	n/a	bermuda
3	0.812	0.060	monogyne	—	—	—	—
4	n/a	n/a	n/a	—	—	—	—
Runnels II							
1	0.860	0.136	monogyne	n/a	n/a	n/a	native
2	n/a	n/a	n/a	n/a	n/a	n/a	native
Shackelford I							
1	0.669	0.118	polygyne	0.751	0.054	undetermined	bermuda
2	0.724	0.158	polygyne	0.837	0.175	monogyne	bermuda
Shackelford II							
1	n/a	n/a	undetermined	n/a	n/a	n/a	native
2	0.721	0.093	polygyne	n/a	n/a	n/a	native
Wharton							
1	n/a	n/a	n/a	0.781	0.051	undetermined	native
2	n/a	n/a	n/a	0.734	0.064	polygyne	native
Williamson							
1	0.744	0.075	undetermined	n/a	n/a	n/a	bermuda
2	0.692	0.06	polygyne	—	—	—	—
Young							
1	0.731	0.129	polygyne	0.812	0.119	monogyne	bermuda
2	0.761	0.175	undetermined	0.718	0.082	polygyne	bermuda

Correlation

Interestingly, data indicated little correlation between RIFA numbers in bait cups and the number of mounds per transect or the mound vitality rating. Results were similar in B.Dahl plots and in other grasses. The number of RIFA per cup and the number of mounds in B.Dahl plots had a correlation of $R^2 = 0.057$; $P = 0.247$ (Figure 3.4); in other grass plots the correlation was $R^2 = 0.001$; $P = 0.881$ (Figure 3.5). Mound vitality ratings and ant numbers in bait cups also showed slight interaction. B.Dahl plots had a correlation of $R^2 = 0.00001$; $P = 0.998$ (Figure 3.6); other grass plots had a correlation of $R^2 = 0.0826$; $P = 0.163$ (Figure 3.7).

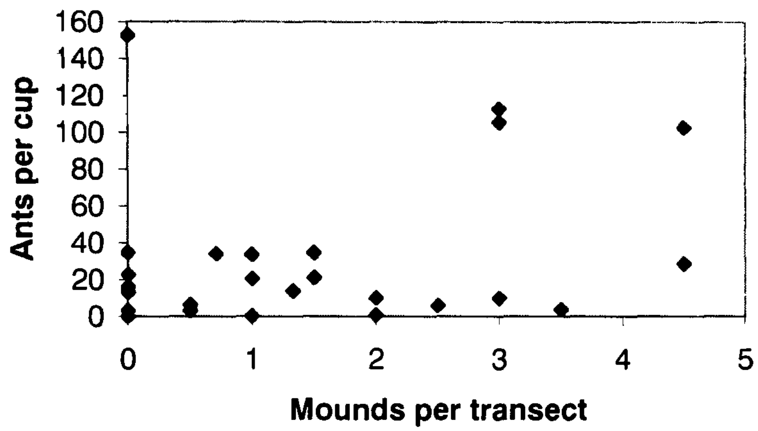

Figure 3.4. Relationship between ants per cup and mound density in B.Dahl plots. This is based on 25 B.Dahl plots in central and northern Texas.

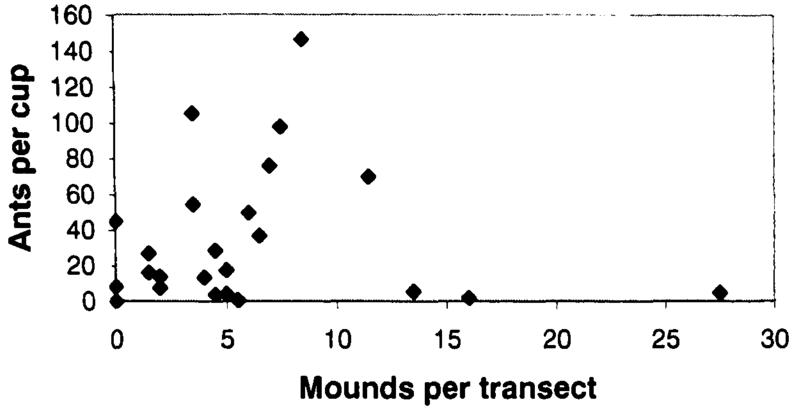

Figure 3.5. Relationship between ants per cup and mound density in other grass fields. This is based on 25 plots containing other grasses in central and northern Texas.

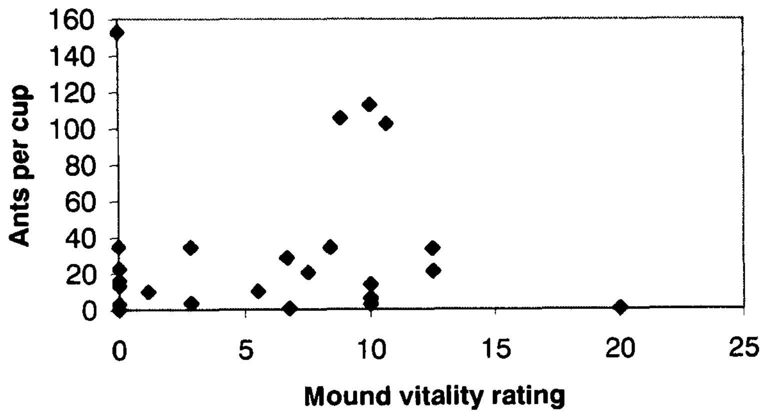

Figure 3.6 Relationship between ants per cup and mound vitality rating in 25 B.Dahl plots in central and northern Texas.

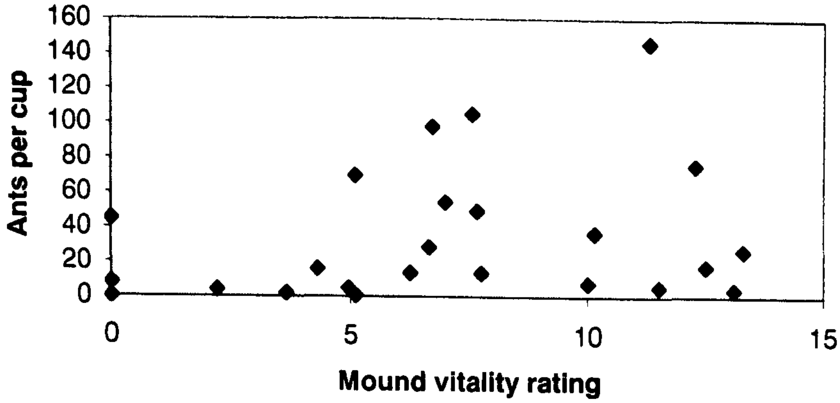

Figure 3.7. Relationship between ants per cup and mound vitality rating in other grasses. This is based on 25 plots containing other grasses in central and north Texas.

Plot Characteristics

To determine if plot characteristics were related to ant abundance, I examined several factors. B.Dahl coverage, as measured by the Daubenmire cover scale, had a weak relationship to ant bait cup numbers ($y = -34.259x + 5.647x^2 + 59.314$; $R^2 = 0.1756$; $P = 0.120$) (Figure 3.8). Coverage of other grasses, on the Daubenmire scale, also showed a limited relationship ($y = -37.718x + 5.7974x^2 + 74.157$; $R^2 = 0.1583$; $P = 0.1502$) (Figure 3.9). Grass height had a slight relationship to ant bait cup numbers in both B.Dahl plots ($y = 0.3433x + 19.413$; $R^2 = 0.0139$; $P = 0.575$) (Figure 3.10) and other grasses ($y = 0.8884x + 7.6749$; $R^2 = 0.1702$; $P = 0.04$) (Figure 3.11). I found soil, surface and air temperature, age and altitude had little relationship to ant bait cup numbers across the study fields (Table 3.4) (Figures 3.12 - 3.19).

Table 3.4. Regression equations, R^2, and P values associated with different plot characteristics and ant bait cup numbers at 25 B.Dahl study sites in central and northern Texas.

Soil temperature - B.Dahl	$y = -2.127x + 87.957$	$R^2 = 0.0436$	$P = 0.31$
Soil temperature - other grasses	$y = -1.0823x + 62.943$	$R^2 = 0.0105$	$P = 0.62$
Surface temperature - B.Dahl	$y = -2.5407x + 106.55$	$R^2 = 0.0624$	$P = 0.29$
Surface temperature - other grasses	$y = 1.0411x + 2.0314$	$R^2 = 0.0113$	$P = 0.61$
Air temperature - B.Dahl	$y = 3.0533x + 118.16$	$R^2 = 0.0527$	$P = 0.27$
Air temperature - other grasses	$y = 0.9498x + 6.0997$	$R^2 = 0.0063$	$P = 0.70$
Age of B.Dahl plots	$y = 2.4925x + 19.977$	$R^2 = 0.0467$	$P = 0.29$
Altitude of B.Dahl plots	$y = 0.0826x + 3.4743$	$R^2 = 0.0999$	$P = 0.12$

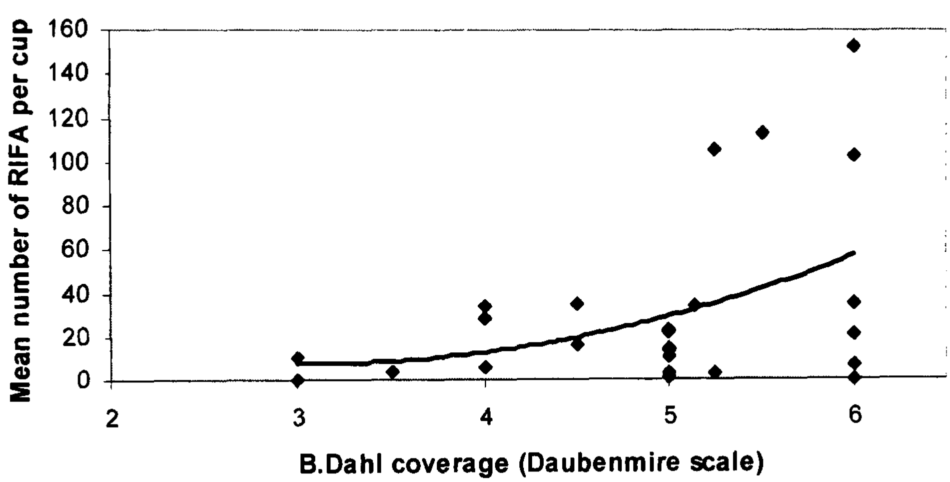

Figure 3.8. Relationship between B.Dahl coverage (Daubenmire scale) and ant bait cup numbers.

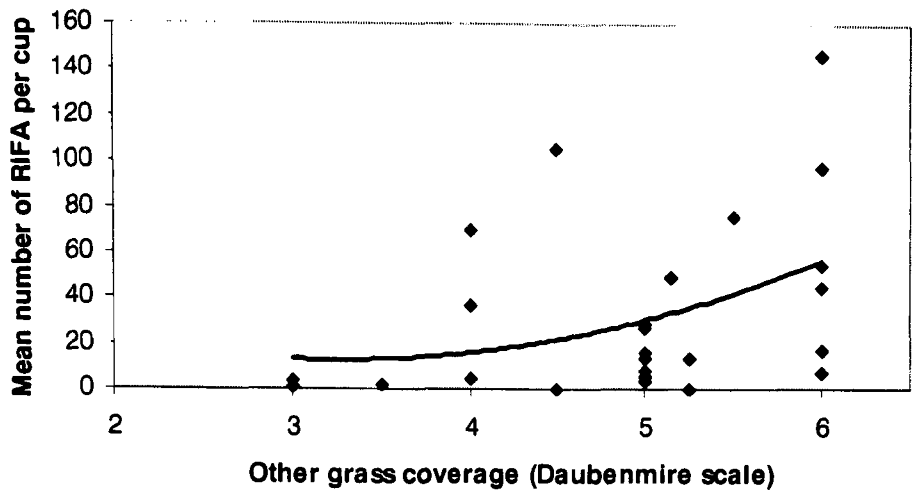

Figure 3.9. Relationship between other grass coverage (Daubenmire scale) and ant bait cup numbers.

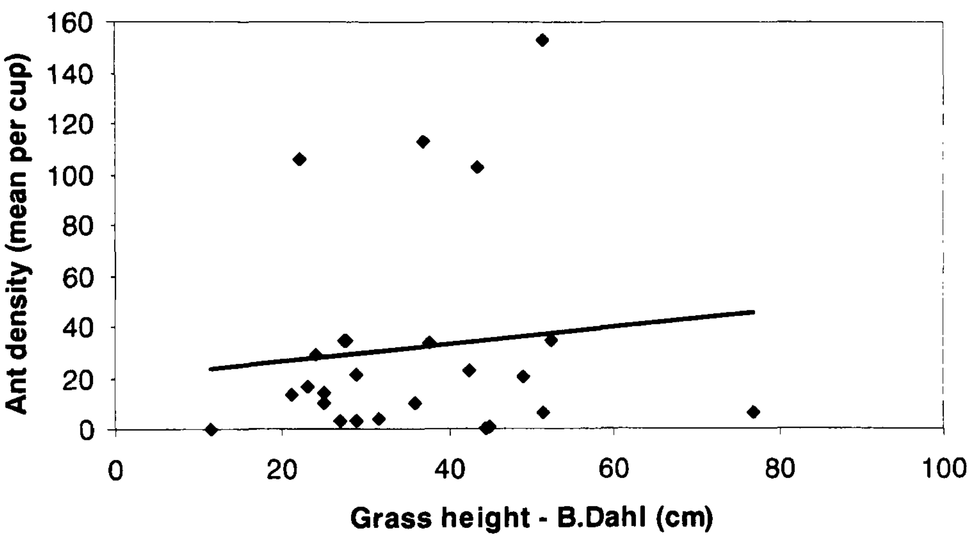

Figure 3.10. Relationship between grass height (cm) and ant bait cup numbers in B.Dahl plots.

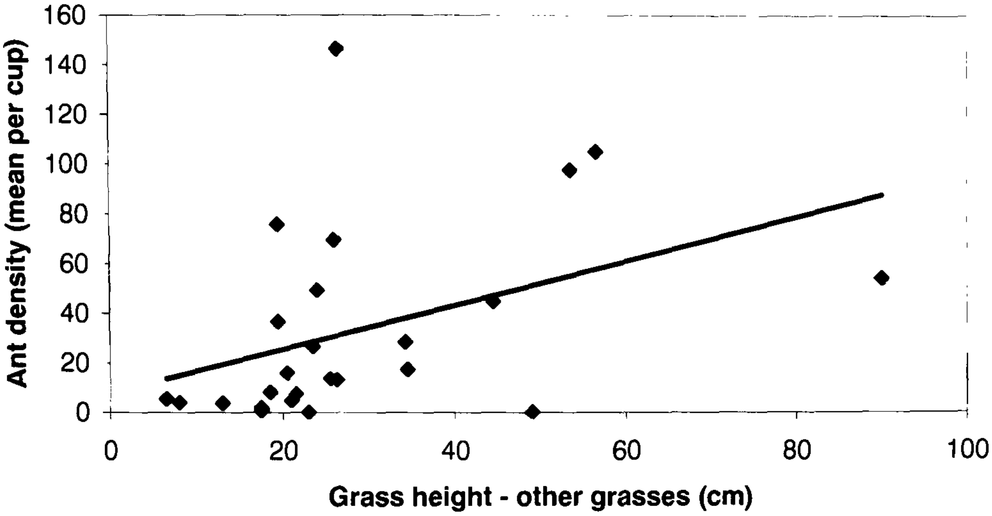

Figure 3.11. Relationship between grass height (cm) and ant bait cup numbers in other grasses ($y = 0.8884x + 7.6749$; $R^2 = 0.1702$; $P = 0.040$)

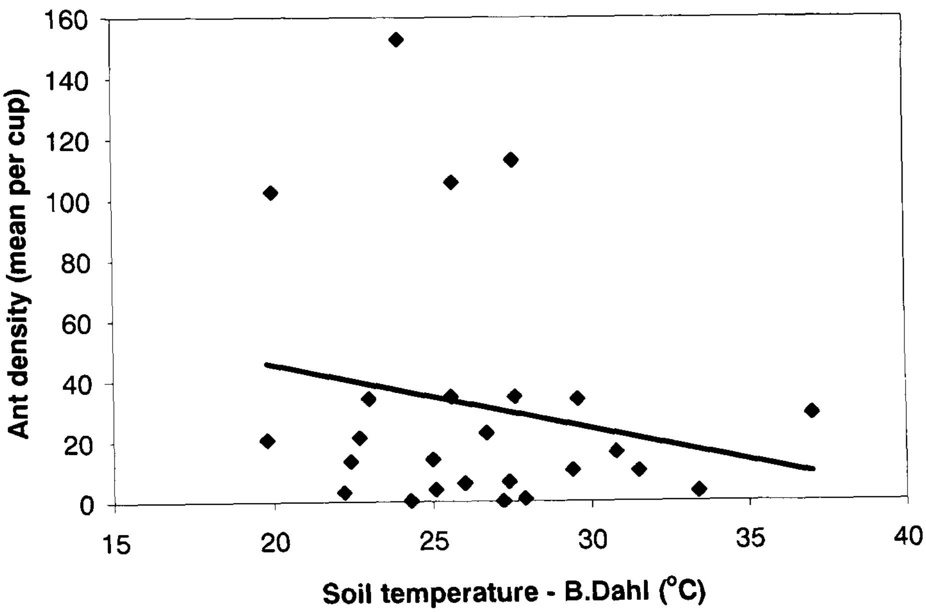

Figure 3.12. Relationship between soil temperature (°C) and ant bait cup numbers in B.Dahl plots.

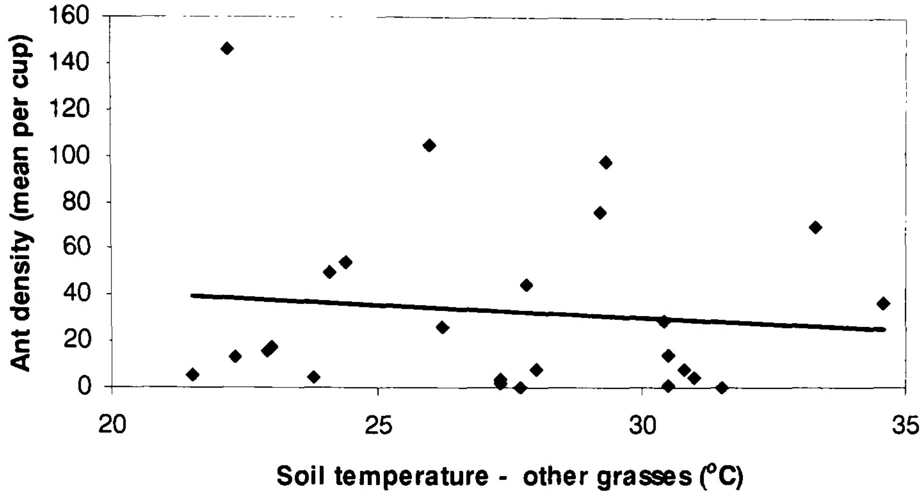

Figure 3.13. Relationship between soil temperature (°C) and ant bait cup numbers in other grasses.

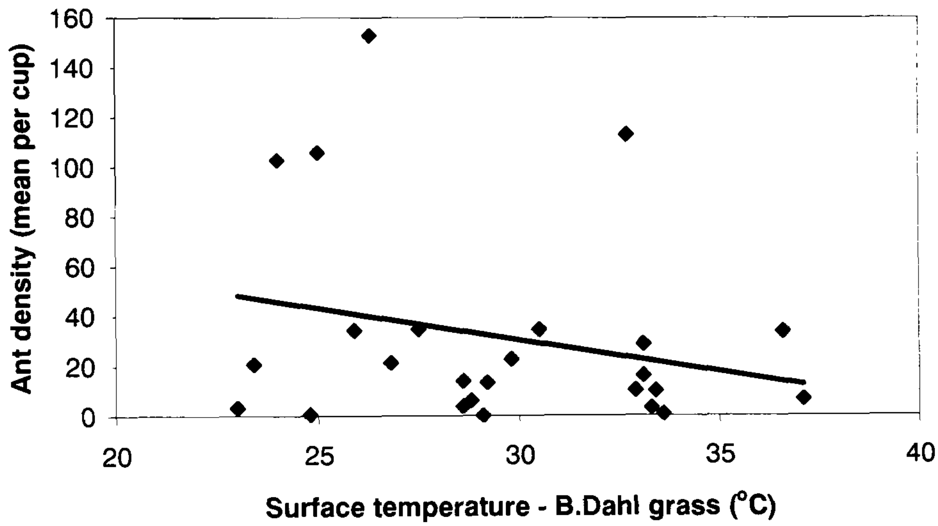

Figure 3.14. Relationship between surface temperature (°C) and ant bait cup numbers in B.Dahl plots.

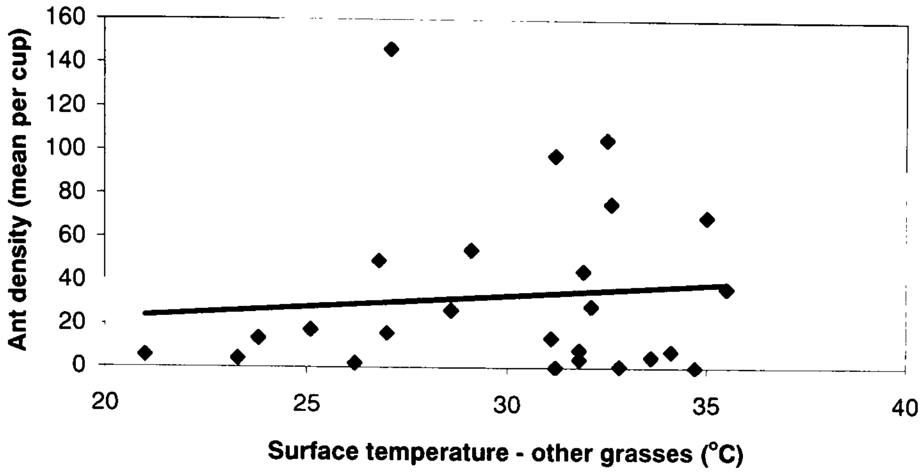

Figure 3.15. Relationship between surface temperature (°C) and ant bait cup numbers in other grasses.

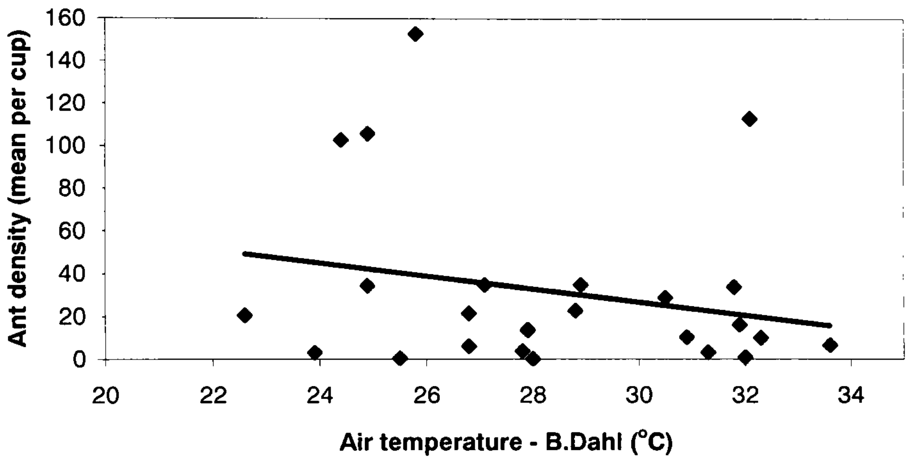

Figure 3.16. Relationship between air temperature (°C) and ant bait cup numbers in B.Dahl plots.

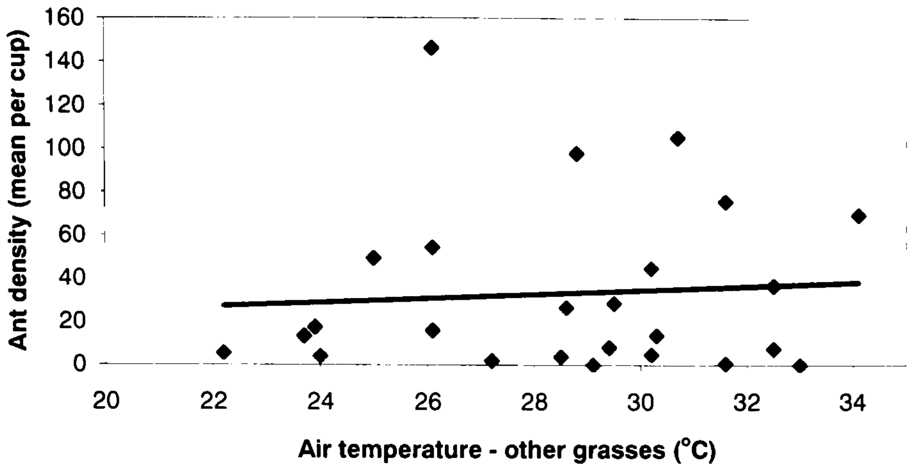

Figure 3.17. Relationship between air temperature (°C) and ant bait cup numbers in other grasses.

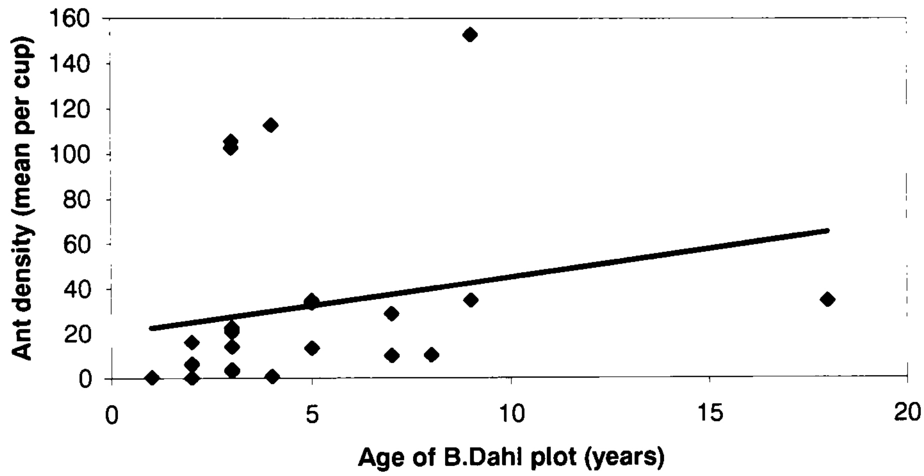

Figure 3.18. Relationship between age of B.Dahl plots (years) and ant bait cup numbers.

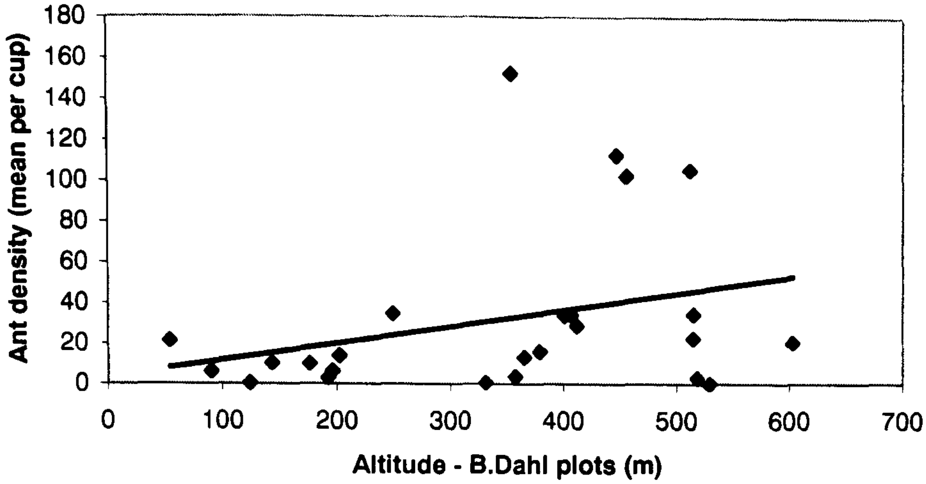

Figure 3.19. Relationship between altitude of B.Dahl plots (m) and ant bait cup numbers.

Another factor common in B.Dahl plots was cattle grazing. Nineteen plots reported intermittent grazing, four plots were not grazed, and grazing information was unknown at two plots (Appendix A.4). The grazed plots averaged 36.94 ants per cup. Mean number of ants per cup in the ungrazed plots was 15.82. These data, obtained through grower interviews and personal observation, are incomplete and were not a part of the study. They present a factor that may affect RIFA activity and abundance in B.Dahl pastures.

Discussion

RIFA infest the central to north-central Texas corridor where B.Dahl grass is grown. RIFA infestations were found at all 25 sites examined. The number of ants collected in bait cups, the number of mounds per transect, and the mound vitality ratings were highly variable. I found significantly fewer mounds in B.Dahl plots than in other grass fields. This important finding suggests that B.Dahl limits the number of RIFA mounds in a field more effectively than did other grasses studied. RIFA infestation, as measured by bait cups, was similar in B.Dahl plots and the other grasses that comprised this study, Bermuda, native, Klein grass and Wilman Lovegrass. Failing to find a significant difference in bait cup abundance between B.Dahl and other grasses was unexpected, given the significant difference in mound counts. Mound vitality ratings varied little among grass types. Polygyny was the dominant RIFA colony type at my sites yet B.Dahl fields contained a higher proportion of monogyne colonies and a lower percentage of polygyne mounds than other grass fields.

Fewer mounds in B.Dahl plots can be beneficial to producers. Operators of hay harvesting equipment are forced to raise cutting levels because of RIFA mounds in infested fields to avoid equipment damage. Significantly lower mound density will lessen crop loss due to inefficient harvesting (Taber 2000). A decrease in mounds also means less cultivatable land is lost to RIFA mounds. Landowners benefit from decreased mound density as high RIFA mound infestation reduces land values (Texas Agricultural Experiment Station 1992).

A striking result was that mound counts did not correlate with RIFA bait cup collections. Higher ant abundance in bait cups would imply a greater number of mounds or more active mounds in the vicinity of the bait cup to contribute foraging ants to the bait cup. Mean number of ants per cup and mound vitality ratings were similar in B.Dahl plots and other grass fields, yet the number of mounds per transect were significantly lower in B.Dahl plots than in other grass fields. This suggests that RIFA foraging activity, measured by bait cups, and mound density were not well correlated in this study. This calls into question the effectiveness of sampling techniques, such as bait cups, that have traditionally been used to estimate ant populations.

Scientists have sought an effective, reproducible technique for sampling fire ants, because a precise technique would provide reliable estimates of ant population density in a field. Sampling accuracy has been a concern for decades (Fillman et al. 1983). Current ant sampling techniques include passive methods such as pitfall traps, bait cups, and quadrant sampling. Active methods are colony counts, direct, and intensive sampling. Available techniques may be appropriate in different habitats or depend on research goals (Bestelmeyer et al. 2000). Each existing ant sampling method has advantages and disadvantages in terms of accuracy, repeatability, and convenience (Wang et al. 2001).

A single sampling method is unlikely to capture all ants present in a study plot. Therefore a combination of sampling procedures can attempt to overcome this problem (Delabie et al. 2000; Martelli et al. 2003). The difference in my study between two sampling techniques, bait cups and mound counts, points to inadequacy in each of the sampling methods. A potential explanation is that bait cup counts of foraging ants are not a reliable indicator of mound density (Merchant 2000; Bestelmeyer 1996). This issue would need further study to verify a lack of equivalency between bait cup counts and mound density in B.Dahl plots.

An example of the difficulty in standardizing ant sampling is reflected in the use of bait cups and pitfall traps as sampling techniques in Texas and the southeastern US

(Mueller et al. 1999; Norton 2003; Vogt 2003; Wang et al. 2001; Lubertazzi and Tschinkel 2003). Comparison of these two most commonly employed methods (Bestelmeyer 1996) leads to contradictory results that do not establish a standard sampling method that can obtain unbiased results. Wang et al. (2001) reported that pitfall traps are superior to bait traps for ant studies. In a different location and conditions Morrison (2002) found baits and pitfall traps obtained similar results. Though sampling methods for estimating ant density have been studied (Fillman et al. 1983; Martelli et al. 2003), the ant researcher remains without a definitive sampling technique.

RIFA are efficient foragers covering large territories – bait in infested areas is usually discovered within ten minutes (Taber 2000). RIFA have large foraging territories which could mean mounds not on the transect line may have contributed foragers to the bait cups (Reagan 1986). In fact, the farther the food source is from the mound, the greater the recruitment rate to it (Taber 2000). Territory size and varying recruitment rates may in part explain why a significantly lower mound density in B.Dahl plots did not have a corresponding low ant density.

Another possibility is that the similar RIFA bait cup collections average in the grasses reflect a sufficient number of ants needed to secure a food source. Additional ants may be more productive foraging elsewhere. Such a negative feedback process is found in honeybees when workers are unable to forage efficiently because too many workers are already present (Ramel 2004). An existing adequate supply of ants finding and retrieving the available food may limit the number of ants per cup. Thus additional mounds might not lead to an increase in bait cup density in this study.

Fewer RIFA mounds in B.Dahl plots may affect RIFA impact on the surrounding ecological community. However, one can not conclude that native species, such as the horned lizard, are less threatened by RIFA in B.Dahl plots because ant abundance appears to remain similar in different fields.

Continued research on methods of RIFA control is important because of its known invasiveness and role as one of the most serious insect pests worldwide (Moloney and Vanderwoude 2002). Each study undertaken, such as my project as part of the Texas Red Imported Fire Ant Management Plan, adds to the scientific community's knowledge of *S. invicta* and may lead to future control of this invasive species. As RIFA have the potential to expand in the U.S. and colonize numerous other regions (Morrison 2004), further research on the fire ant is vital to control the infestation and damage caused by RIFA.

CHAPTER IV

INVASIVENESS OF WW-B.DAHL GRASS

Introduction

For centuries the introduction of non-native plants has been a common practice around the world. Reasons for deliberate plant dispersion include their ability to provide food, medicine, shelter, and aesthetic value. Non-native plants play an integral role in the economies and cultures of all regions (Ewel et al. 1999). To the people and ecosystems in a new environment, human action as global plant dispersers can be beneficial, neutral, or detrimental. Essential to agriculture, establishing plants beyond their native ranges has most often been beneficial. Even though the consequences of plant dispersal have often been positive or neutral, some introduced species can cause environmental and economic damage (Mack and Lonsdale 2001). According to McNeely (1996), alien species whose establishment and spread threaten ecosystems, habitats, or species with economic or environmental harm are considered "invasive." As the invaders can greatly alter ecosystem structure and form (Vitousek et al. 1987), invasion by introduced plants constitutes one of the most serious threats to biodiversity. Early identification of invasiveness is important because well-established invaders are almost impossible to eradicate (Ewel et al. 1999). Preventing damage to natural and managed ecosystems by invasive species remains a challenge (Pimental et al. 2000).

Many grasses are invasive. In the southern U.S., 60 grass species are on the Federal Noxious Weed List, state laws, and exotic pest plant lists (University of Georgia 2004). Annual grasses constitute the majority of invasives in the semi-deserts of North

America (Alpert et al. 2000). It is therefore important to evaluate new non-indigenous grass species, however beneficial, for invasiveness. Introduced in 1994, the invasiveness of WW-B.Dahl has yet to be evaluated. Factors known to contribute to plant spread, including invasives' ability to establish themselves in disturbed environments, nutrient and water availability for plant growth, and the effect of grazing, may encourage B.Dahl spread (Alpert et al. 2000). In this study I examined the invasiveness of B.Dahl in its new habitat in Texas.

Methods

Twenty-five plots were examined for WW-B.Dahl invasiveness, measured by the grass' spread beyond the area of its original planting. Random direction sampling - randomly generating a number and converting it to the corresponding compass point (Southwood 1978) - was employed to select a direction to search for grass dispersion. Potential natural obstacles to dispersal, such as hills and waterways, were avoided. When grass spread was noted in one direction only, sampling took place in that direction. Thus, reported values are along a 100 meter, line-transect representing typical or greater-than-average dispersal chances. The first 10 meters, where I expected greater grass spread, were sampled every 1 meter, with the remaining line-transect sampled every 10 meters. At each demarcation, a 20 cm x 50 cm plot was examined to determine WW-B.Dahl grass density using the Daubenmire cover scale (Bonham 1989). When B.Dahl coverage was low, a larger area, such as 1m x 1m or 2m x 2m, was examined. Area covered by B.Dahl was rated from 1 to 6, with 6 reflecting highest density. B.Dahl coverage ratings on the Daubenmire scale were as follows: 1 = 0-5%, 2 = 5-25%, 3 = 25-50%, 4 = 50-75%, 5 = 75-95%, and 6 = 95-100%. Two indicators of grass invasiveness were examined: distance from the original field of planting and the age of the B.Dahl plot.

Results

The 25 B.Dahl sites showed some grass spread in the immediate proximity of 20 of the B.Dahl fields, whereas 5 had no grass dispersion. B.Dahl grass was recorded at each measurement distance in at least one field. Greatest spread was noted closest to the original field of planting (Figure 4.1, Figure 4.2). The two highest density plots documented B.Dahl at 13 and 10 of the 19 measurement points. Ten fields showed B.Dahl at 4 to 6 measurement points. Eight plots evidenced B.Dahl spread at one or two measurement points. Rather than a gradual decrease with distance from the planted field, results varied at measurement points. Lower densities were found 7, 8, 70, 90 and 100 meters, with higher densities at 20, 30, 40 and 60 meters. Higher coverage ratings reflected increased B.Dahl spread at a few fields that markedly increase the group average.

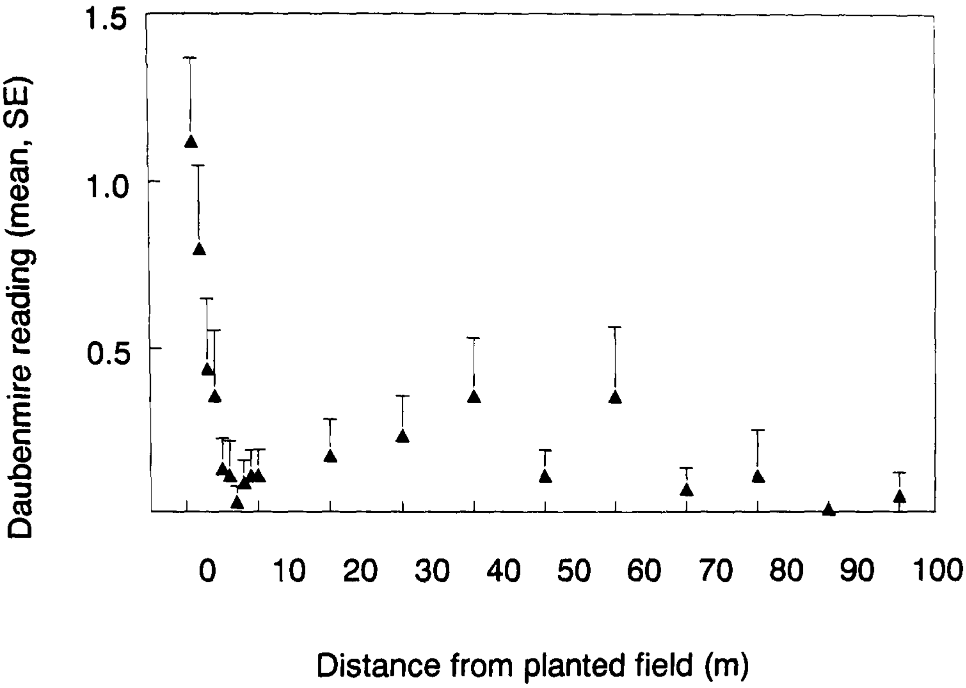

Figure 4.1. B.Dahl invasiveness by distance from original field. This represents the mean coverage (Daubenmire scale) per measurement point, with standard error bars, at 25 sites in central and northern Texas. The first 10 meters were measured each meter; whereas, 10 to 100 meters were measured every 10 meters.

I found distance to be a highly significant determinant of grass spread independent of plot age (analysis of covariance, $F = 5.52$; $df = 18$; $P = <0.001$). The distance of the measurement point was negatively correlated with B.Dahl coverage (Pearson $r = 0.158$; $P = 0.001$, $N = 25$).

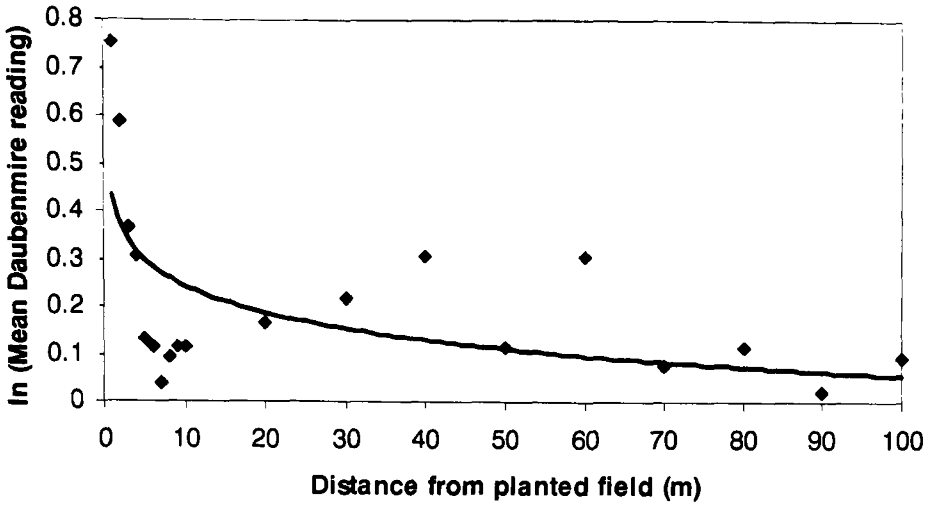

Figure 4.2. B.Dahl invasiveness investigated by correlation between grass coverage (natural logarithm of mean Daubenmire readings for each field) and distance from planted field (m). A logarithmic regression function was fitted ($\ln(y) = 0.432 - 0.08 \ln(x)$; $R^2 = 0.3720$; $P = 0.006$) to describe this relationship at 25 sites in central and northern Texas. The first 10 meters were measured each meter whereas 10 to 100 meters were measured every 10 meters.

With field age ranging from 1 to 18 years it was necessary to look at grass spread by age, because I expected younger fields to show less spread than older ones (Figure 4.3). Five B.Dahl sites had been established between 1 and 2 years. These showed spread in the first 4 meters with little additional spread (Table 4.1). Fourteen sites were between 3 and 5 years old. This group showed greater dispersal than the previous group with grass recorded at each measurement point up to and including 70 meters. Five fields were between 7 and 9 years old. This group showed limited spread with 8 measurement points recording no grass spread. The single 18 year-old site, which was measured for invasiveness at two locations, had much greater grass spread than the other age groups.

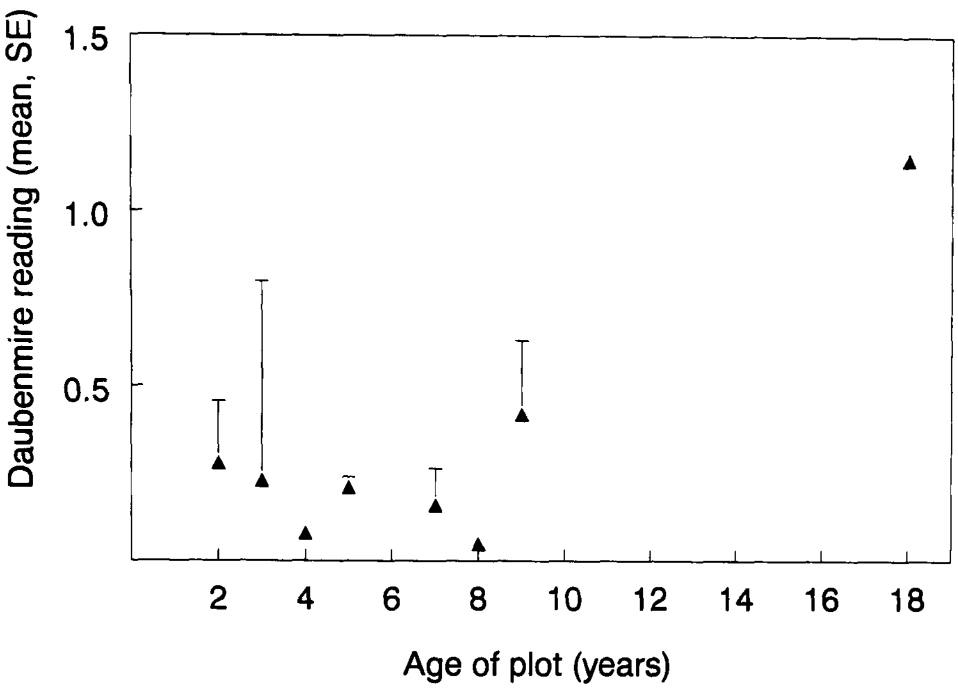

Figure 4.3. B.Dahl invasiveness by age of plot. This represents the mean coverage (Daubenmire scale) per measurement point, with standard error bars, at 25 sites in central and northern Texas. The first 10 meters were measured each meter whereas 10 to 100 meters were measured every 10 meters.

Table 4.1. Mean B.Dahl spread by age group at 25 sites in central and northern Texas. Coverage was determined by the Daubenmire cover scale (1 = 0-5%, 2 = 5-25%, 3 = 25-50%, 4 = 50-75%, 5 = 75-95%, and 6 = 95-100%). The first 10 meters were measured each meter whereas 10 to 100 meters were measured every 10 meters. See Table 3.1 for site location and age.

Age of plots (years)	Number of plots	Distance from planted field - meters																		
		1	2	3	4	5	6	7	8	9	10	20	30	40	50	60	70	80	90	100
1 to 2	5	1	1	1	0.6	0	0	0	0	0	0.2	0	0	0.2	0	0	0	0	0	0.2
3 to 5	14	1.1	0.7	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.3	0.1	0.1	0.1	0.1	0	0	0
7 to 9	5	1	0.6	0	0.2	0	0	0	0.2	0	0.2	0.2	0.2	0.6	0.2	1.4	0	0	0	0.2
18	1	2.5	2	3	2.5	1.5	1	0	0	1	0	0	1	3	1	0	0	3	0.5	0.5

An analysis of covariance identified that age of plot was a highly significant factor in grass spread ($F = 35.4$; $df = 1$; $P = <0.001$), independently of distance. I found that grass spread was positively correlated with age (Pearson $r = 0.245$; $P < 0.001$; $N = 25$).

Discussion

This study showed that B.Dahl grass can establish itself outside its original field, most notably in the first 4 meters beyond where it was planted. Data indicated some dispersion, yet its ability, density, and rate of invasion varied at different sites. Age and distance from the planted field were both highly significant predictors of the extent of grass invasion. The pattern was not completely "even," thus higher density at a measurement point in one plot influenced the overall results. For example, one plot recorded B.Dahl coverage of over 60% at 60 meters, increasing the average B.Dahl density at this point. This suggested elevated spread at 60 meters for all sites when more accurately the mean represented a high rating at one point along the transect at one field.

Though age and distance from the planted field were both highly significant factors, grass spread showed a non-linear decrease, and greater grass invasion did not always increase with age of field. For example, four of the five 7 to 9 year-old fields showed less invasion than two of the youngest fields and less than eight of the 3 to 5 year-old fields. Other considerations, such as site characteristics and grower management efforts in B.Dahl and adjacent plots, may affect the rate of B.Dahl invasion.

The threat of invasive plants has been well reported (see above), yet a way to measure or track the initial stages of this process is elusive. Also lacking are comparisons of introduced plants as they become invasive. Attempts to model plant invasiveness based on biological attributes - life form, stem height and flowering period - could not predict invasiveness (Goodwin et al. 1999). As a result, we monitor the distribution of Federal noxious weeds after they have become established (USDA 2002) and study specific infestations, such as cheatgrass and buffelgrass (Asher 1998). Yet grass invasion can be documented. In a recent paper on genetically engineered creeping bentgrass (for use on golf courses) the Environmental Protection Agency reported the grass pollinated test plants 13 miles from an experimental farm, showing faster and further spread than expected (Pollack 2004). Factors that contributed to this finding were a larger study area, concern about the bioengineered grass' probable use in a suburban setting, and interest and funding generated as part of the producer's application for governmental approval of the bioengineered seed (Callimachi 2004). This suggests similar research efforts on non-native grasses might lead to notable results.

Without standardized guidelines to determine plant invasiveness, introduced species such as B.Dahl cannot be easily categorized as to their degree of invasiveness. The knowledge I have gained from field observation suggests that B.Dahl has the potential for limited invasion into new territory. The oldest field had sufficient grass invasion for concern, thus I would use age as the key factor when examining B.Dahl fields for invasion. Further study will be integral to documenting B.Dahl's ability and rate of spread beyond its field of planting. This is important, as swift and accurate classification of introduced species is key to predicting and identifying invasive plants (Mack and Lonsdale 2001).

LITERATURE CITED

Aljoe, H. 2002. Looking for the "Silver Bullet" in our Forage Arsenal. Noble Foundation Ag News and Views. April.

Allen, C., Demarais, S, Lutz, R. 1994. Red Imported Fire Ant Impact on Wildlife: an Overview. Texas Journal of Science 46:51-59.

Allen, V. September, 2004. Personal Communication, Texas Tech University, Lubbock, Texas.

Allison, J., Dittmar, G., Hensell, J. 1975. Soil Survey for Gillespie County, Texas. United States Department of Agriculture, Soil Conservation Service. U.S. Government Printing Office.

Allison, J. 2001. Soil Survey for Lampasas County, Texas. United States Department of Agriculture, Natural Resource Conservation Service. U.S. Government Printing Office.

Alpert, P., Bone, E., Hozapfel, C. 2000. Invasiveness, Invasibility and the Role of Environmental Stress in the Spread of Non-native Plants. Perspectives in Plant Ecology, Evolution and Systematics 3:52-66.

Asher, J. 1998. The Spread of Invasive Weeds in Western Wildlands: A State of Biological Emergency. Proceedings from the Governor's Idaho Weed Summit. Boise, Idaho. pp. 1-11.

Ball, D., Blount, A. 2002. New (2000 – 2003) Forage Varieties for the Southeast. North Florida Research and Education Center, Research and Extension Updates. 4:4-6.

Bell, J., Caudle, D. 1994. Management of Old World Bluestems. USDA Soil Conservation Service. Temple, Texas.

Bestelmeyer, B. 1996. Field Techniques: An Overview and Description of Collecting Techniques. Draft Version. American Museum of Natural History, Department of Entomology. www.research.amnh.org/entomology/social_insects/ms2_1.

Bestelmeyer, B., Agosti, D., Alonso, L., Brandao, C., Brown, W., Delabie, J., Silvestre, R. "Field Techniques for the Study of Ground-Dwelling Ants" in Agosti, D., Majer, J., Alonso, L., and Schultz, T. (eds.), Ants – Standard Methods for Measuring and Monitoring Biodiversity. Smithsonian Institution Press. Washington. pp. 122-144.

Blum, E. 1982. Soil Survey for Kimble County, Texas. United States Department of Agriculture, Soil Conservation Service. U.S. Government Printing Office.

Bonham, C. 1989. Measurements for Terrestrial Vegetation. John Wiley & Sons, New York.

Britton, C., Perry, G., Villalobos, C., Kellison, R., Craig, C., Thorvilson, H., Allen, V., Racher, B. 2003. Red Imported Fire Ants and WW-B.Dahl: Preliminary Observations. Research Highlights, Range, Wildlife and Fisheries Management, 2002, vol.32, p. 22. Texas Tech University College of Agricultural Sciences and Natural Resources, Lubbock, Texas.

Brooks, C., Huntsinger, J., Mayberry, J., McSpadden, J., Mitchell, J., Rogers, C. 1964. Soil Survey for Ellis County, Texas. United States Department of Agriculture, Soil Conservation Service. U.S. Government Printing Office.

Callamachi, R. 2004. World's Most Controversial Grass. CBS News. www.cbsnews.com/stories/2004/04/12/tech.

Callcott, M., Collins, H. 1996. Invasion and Range Expansion of Imported Fire Ants (Hymenoptera: Formicidae) in North America from 1918 - 1995. Florida Entomologist 79(2):240-251.

Clower, D. 1981*a*. Soil Survey for Brown and Mills Counties, Texas. United States Department of Agriculture, Soil Conservation Service. U.S. Government Printing Office.

Clower, D. 1981*b*. Soil Survey for Callahan County, Texas. United States Department of Agriculture, Soil Conservation Service. U.S. Government Printing Office.

Congressional Record. 17 June 1997:S.932.

Cochran, R. 1980. Soil Survey for Grayson County, Texas. United States Department of Agriculture, Soil Conservation Service. U.S. Government Printing Office.

Core, J. 2003. Update: Hot on the Trail of Fire Ants. USDA Agricultural Research Service. 51(2):20-23.

Dabbert, B. January, 2004. Personal Communication, Texas Tech University, Lubbock, Texas.

Davis, L., Vander Meer, R., Porter, S. Red Imported Fire Ants Expand Their Range Across the West Indies. Florida Entomologist 84(4):735-736.

Delabie, J., Fisher, B., Majer, J., Wright, I. "Sampling Effort and Choice of Methods" in Agosti, D., Majer, J., Alonso, L., and Schultz, T. (eds.), Ants – Standard Methods for Measuring and Monitoring Biodiversity. Smithsonian Institution Press. Washington. pp. 145-154.

Drees, B., Vinson, S. 1987. Are Multiple Queen Mounds of the Red Imported Fire Ant More Difficult to Control than Single Queen Mounds? TA22928. fireant.tamu.edu/ Research/arr/Category/Ecological/86-87Pg10/86-87Pg10.htm.

Dewald, C., Sims, P., Berg, W. 1995. Registration of 'WW-B.Dahl' Old World Bluestems. USDA – Southern Plains Research Station.

Donaldson, W., Price, A., Morse, J. 1994. The Current Status and Future Prospects of the Texas Horned Lizard. Texas Journal of Science 46:97-113.

Duch, T. 2003. Sustainable Crop/Livestock Systems in the Texas High Plains. Sustainable Agriculture Research and Education – Southern Regional Program. http://www.orgs.ttu.edu/forageresearch/teresa.htm.

Elstel Farm & Seeds. 2002. Our Products.www.crabgrass.hypermart.net/ products. html.

Eubanks, M. 2001. Estimates of the Direct and Indirect Effects of Red Imported Fire Ants on Biological Control in Field Crops. Biological Control 21: 35-43.

Ewel, J., O'Dowd, D., Bergelson, J., Daehler, C., D'Antonio, C., Gomez, L., Gordon, D., Hobbs, R., Holt, A., Hopper, K., Hughes, M., Leakey, R., Lee, W., Loope, L., Lorence, D., Louda, S., Lugo, A., McEvoy, P., Richardson, D., Vitousek, P. 1999. Bioscience 49:619-630.

Fillman, D., Sterling, W., Dean, D. 1983. Precision of Several Sampling Techniques for Foraging Red Imported Fire Ant (Hymenoptera: Formicidae) Workers in Cotton Fields. Journal of Economic Entomology. 76:748-751.

Forbes, A. 1999. Effects of Bobwhite Habitat Management on Red Imported Fire Ant Populations. Masters Thesis. Texas Tech University, Lubbock, Texas.

Gilbert, L. 2001. Fire Ants, Armadillos, and Phorid Flies – Answers to Frequently Asked Questions. Brackenridge Field Laboratory, University of Texas at Austin.

Gillen, R. September, 2004. Personal Communication, Agricultural Research Service, Woodward, OK.

Greenberg, L., Fletcher, D., Vinson, S. 1985. Differences in Worker Size and Mound Distribution in Monogynous and Polygynous colonies of the Fire Ant *Solenopsis invicta* Buren. Journal of the Kansas Entomological Society. 58(1):9-18.

Greenberg, L., Klotz, J., Kabashima, J. 2002. Pest Notes: Red Imported Fire Ant. University of California Pest Management Guidelines Publication 7487.

Goerdel, A. 2002. Soil Survey for Fannin County, Texas. United States Department of Agriculture, Natural Resource Conservation Service. U.S. Government Printing Office.

Goodwin, B., McAllister, A., Fahrig, L. 1999. Predicting Invasiveness of Plant Species Based on Biological Information. Conservation Biology 13(2):422-426.

Griffin, E. 1998. Soil Survey for Limestone County, Texas. . United States Department of Agriculture, Natural Resource Conservation Service. U.S. Government Printing Office.

Hall, A. 1999. Costly Interlopers. Scientific American. www.sciam.com/print_version.

Handbook of Texas Online. 2001. "Texas Counties." The General Libraries of the University of Texas. www.tsha.utexas.edu/handbook/online/articles/ view/CC/ hcc3.html.

Harrington, R., Kujawaski, R., Ryan, D. 2003. Invasive Plants and the Green Industry. Journal of Arboriculture 29:42-48.

Holway, D., Lach, L., Suarez, A., Tsutsui, N., Case, T. 2002. The Causes and Consequences of Ant Invasions. Annual Review of Ecological Systems 33:181-233.

Huggett, R. 2003. Fundamentals of Geomorphology. Routledge. London.

James, S., Pereira, R., Vail, K., Ownley, B. 2002. Survival of Imported Fire Ant (Hymenoptera: Formicidae) Species Subjected to Freezing and Near-Freezing Temperatures. Environmental Entomology. 31(1):127-133.

Jetter, K., Hamilton, J., Klotz, J. Red Imported Fire Ants Threaten Agriculture, Wildlife and Homes. 2002. California Agriculture 56:26-34.

Jusino-Atresino, R. 1992. Alteration of Foraging Patterns of Native Ant Species in Central Texas by the Red Imported Fire Ant, Solenopsis invicta, Buren. Masters Thesis. Texas Tech University, Lubbock, Texas.

Klingaman, G. 1999. Arkansas and U.S. Plant Hardiness Zone Maps. Timely Tips Series. University of Arkansas Division of Agriculture, Cooperative Extension Service. FSA 2097-2M-6-99R.

Korzukhin, M., Porter, S., Thompson, L., Wiley, S. 2001. Modeling Temperature Range Limits for the Fire Ant *Solenopsis invicta* (Hymenoptera: Formicidae) in the United States. Environmental Entomology 30(4):645-655.

Lard, C., Salin, V., Willis, D., Robison, S., Hadley, J., Schroeder, K. 2001. The Statewide Economic Impact of Red Imported Fire Ants in Texas: A Part of the Texas Fire Ant Initiative 1999-2001. Fire Ant Economic Research Report #01-08.

Lofgren, C., Williams, D. 1982. Avermectin B_1a: Highly Potent Inhibitor of Reproduction by Queens of the Red Imported Fire Ant. Journal of Economic Entomology. 75:798-803.

Loope, L. 2000. *Solenopsis invicta.* Meeting Report, Coordinating Group on Alien Pest Species. www.bishopmuseum.org/ants/solenopsis/Solinv.html.

Lowther, A. 1990. Soil Survey for Shackelford County, Texas. United States Department of Agriculture, Soil Conservation Service. U.S. Government Printing Office.

Lubertazzi, D., Tschinkel, W. 2003. Ant Community Change Across a Ground Vegetation Gradient in North Florida's Longleaf Pine Flatwoods. Journal of Insect Science. 3:21-38.

Mack, R., Lonsdale, W., 2001. Humans as Global Plant Dispersers: Getting More Than We Bargained For. BioScience 51:95-102.

Martelli, M., Ward, M., Fraser, A. 2003. Ant diversity Sampling on the Southern Cumberland Plateau: A Comparison of Litter Sifting and Pitfall Trapping. Southeastern Naturalist. 3:113-126.

McCaleb, N. 1985. Soil Survey for Coryell County, Texas. United States Department of Agriculture, Soil Conservation Service. U.S. Government Printing Office.

McCubbin, K., Weiner, J. 2002. Fire Ants in Australia: a New Medical and Ecological Hazard. The Medical Journal of Australia 176(11): 518-519.

McEwen, H., Crout, J. 1974. Soil Survey for Wharton County, Texas. United States Department of Agriculture, Soil Conservation Service. U.S. Government Printing Office.

McNeely, J. 1996. "Human Dimensions of Invasive Alien Species: How Global Perspectives are Relevant to China" in Peter, Wang and Xie (eds.) Conserving China's Biodiversity (II), pp169-181. China Environmental Science Press. Beijing.

Merchant, M. 2000. Fire Ant Management on Pop-up Target Firing Ranges. Report on Contract No. TX98-E23-04 401-9-5504. www. Fireant.tamu.edu/research/arr/ Category/site/97-01pg91/97-01pg91htm.

Moloney, S., Vanderwoude, C. 2002. Red Imported Fire Ants: A Threat to Eastern Australia's Wildlife? Ecological Management & Restoration 3 (3): 167-175.

Moore, J., Coburn, W., Harris, E. 1977 Soil Survey for Eastland County, Texas. United States Department of Agriculture, Soil Conservation Service. U.S. Government Printing Office.

Moore, J., Kendrick, B., Wagner, B., Harris, E. 1977. Soil Survey for Comanche County, Texas. United States Department of Agriculture, Soil Conservation Service. U.S. Government Printing Office.

Morrison, L. 2000. Mechanisms of Interspecific Competition among an Invasive and Fire Ants. Oikos 90:238-252.

Morrison, L. 2002. Long-Term Impact of an Arthropod-Community Invasion by the Imported Fire Ant, *Solenopsis invicta*. Ecology 83:2337-2345.

Morrison, L., Porter, S., Daniels, E., Korzukhin, M. 2004. Potential Global Range Expansion of the Invasive Fire Ant, *Solenopsis invicta*. Biological Invasions 6:183-191.

Mueller, J., Dabbert, C., Demarais, S., Forbes, A. 1999. Northern Bobwhite chick Mortality caused by Red Imported Fire Ants. Journal of Wildlife Management. 63(4):1291-1298.

National Weather Service. www.srh.weather.gov.

Norton, A. 2003. Integrating Prescribed Burning and Insecticide to Reduce Fire Ant Impacts on Bobwhite Chicks. Masters Thesis. Texas Tech University, Lubbock, Texas.

Phillips, D. 2003. Research Summary 2001/2002. Department of Plant and Soil Sciences, Texas Tech University, Lubbock, Texas.

Phillips, S., Jones, S., Claborn, D. 1986. "Temporal Foraging Patterns of *Solenopsis invicta* and Native Ants of Central Texas" in Lofgren, N. and Vander Meer, R. (eds.), Fire Ants and Leaf-Cutting Ants: Biology and Management. Westview Press, Boulder. Pp.114-122.

Pimentel, D., Lach, L., Zuniga, R, Morrison, D. 2000. Environmental and Economic Costs of Non-indigenous Species in the United States. BioScience 50:53-65.

Pinder, A., Kerr, S. 1980. The Volatile Essential Oils of Five *Bothriochloa* Species. Phytochemistry 19:1871-1873.

Pollack, A. Genes from Engineered Grass Spread for Miles, Study Finds. New York Times 21 September 2004, internet edition.

Porter, S. 1983. Fast, Accurate Method of Measuring Ant Head Widths. Annals of the Entomology Society of America. 76:866-867.

Porter, S., Savignano, D. 1990. Invasion of Polygyne Fire Ants Decimates Native Ants and Disrupts Arthropod Community. Ecology 71:2095-2106.

Porter, S., Tschinkel, W. 1987. Foraging in *Solenopsis invicta*: Effects of Weather and Season. Environmental Entomology 16:802-808.

Porter, S., Williams, D., Patterson, R., Fowler, H. 1997. Intercontinental Differences in the Abundance of *Solenopsis* Fire Ants (Hymenoptera: Formicidae): Escape from Natural Enemies? Environmental Entomology 26(2):373-384.

Ramel, G. 2004. The Social Bees = Apidae. www.earthlife.net/insects/socbees.html.

Ramsey, R., Bade, N. 1977. Soil Survey for Guadalupe County, Texas. United States Department of Agriculture, Soil Conservation Service. U.S. Government Printing Office.

Reagan, T. 1986. "Beneficial Aspects of the Imported Fire Ant: A Field Ecology Approach" in Lofgren, N. and Vander Meer, R. (eds.), Fire Ants and Leaf-Cutting Ants: Biology and Management. Westview Press, Boulder. pp.58-71.

Reinert, J., Perry, G. 2003. Identification and Development of Grasses to Repel or Significantly Reduce Red Imported Fire Ant Density in Pastures, Conservation Lands, Urban Lawns, and Recreational Areas. Proposal for 2004-2005 competitive grants program, Texas Imported Fire Ant Research and Management Plan.

Russell, S., Thorvilson, H., Phillips Jr., S. 2001. Red Imported Fire Ant (Hymenoptera: Formicidae) Populations in Texas Highways Rights-of-Way and Adjacent Pastures. Environmental Entomology:30:267-273.

Sanderson, M., Voigt, P., Jones, R. 1999. Yield and Quality of Warm-Season Grasses in Central Texas. Journal of Range Management. Volume 52:145:150.

Simberloff, D. 1996. Impacts of Introduced Species in the United States. Consequences 2:13-23.

Soil Science Society of America. 1998. Soil Science Glossary. www.soils.org.

Sosebee, R. October, 2004. Personal communication, Texas Tech University, Lubbock, Texas.

Southwood, T. 1978. Ecological Methods. Chapman and Hall, London.

Stein, M. 1987. Red Imported Fire Ant, Solenopsis Invicta, Buren, Recruitment and Bait Preference, with Observations on Sympatric Ant Species, in Southeastern Texas. Masters Thesis, Texas Tech University, Lubbock, Texas.

Taber, S. 2000. Fire Ants. Texas A&M University Press, College Station.

Texas Agricultural Experiment Station. 1992. Identification, Distribution and Biology of Fire Ants in Texas. Texas Code of Federal Regulations, Subpart – Imported Fire Ant (301.81).

Texas Agricultural Extension Service. 1998. Managing Red Imported Fire Ants in Agriculture. B-6076.

Texas Comptroller of Public Accounts. 2003. GG 42 Eliminate Duplicative Funding for the Texas Imported Fire Ant Research and Management Plan. www.window. state.tx.us / specialrpt/etxaddnl/gg42.html.

Texas Department of Agriculture. 2003. Fire Ant Quarantine Information (from USDA Animal and Plant Health Inspection Service). http://www.agr.state.tx.us/producer_ info/regulatory/reg_fire_ant.html

Texas Environmental Almanac. 2000. University of Texas Press. Austin.

Texas Environmental Profiles. 2004. www.texasep.org/html/lnd/lnd_2agr_serstat.

Thompson, S. 1992. Sampling. John Wiley & Sons, New York.

Thorvilson, H. February, 2004. Personal Communication, Texas Tech University, Lubbock, Texas.

Thorvilson, H., Cokendolpher, J., Phillips Jr., S. 1992. Survival of the Red Imported Fire Ant (Hymenoptera: Formicidae) on the Texas High Plains. Environmental Entomology. Vol. 21 No. 5 pp. 964-968.

Tschinkel, W. 1993. "The fire ant (*Solenopsis invicta*): Still Unvanquished" in McKnight (ed.), Biological Pollution: The Control and Impact of Invasive Exotic Species. Indiana Academy of Science, Indianapolis.

Tsutsui, N., Suarez, A. 2003. The Colony Structure and Population Biology of Invasive Ants. Conservation Biology 17:48-58.

United States General Accounting Office. 2002. Invasive Species: Clearer Focus and Greater Commitment Needed to Effectively Manage the Problem. GAO-03-01.

University of Georgia – College of Agriculture and Environmental Science. 2004. Invasive Plants of the Thirteen Southern States. www.invasive.org/seweeds.cfm.

USDA Cooperative Agricultural Pest Survey. 2002. Detecting Plant Pests and Weeds Through a National Survey Program. Program Aid No. 1710.

Vanderwoude, C. 2003. Inquiry into the Regulation, Control and Management of Invasive Species and the Environment. Senate Standing Committee on Environment, Communications, Information Technology and the Arts, Australian Parliament. www.aph.gov.au/Senate/committee/ecita_ctte/invasion.

Vinson, S.B. 1997. Invasion of the Red Imported Fire Ant (Hymenoptera: Formicidae):Spread, Biology, and Impact. American Entomologist 43:23-39.

Vinson, S., O'Keefe, S., Cook, J. 2003. The Common Ant Genera of Texas. Texas A&M University System Extension Publication B-6138.

Villalobos, C. September, 2004. Personal Communication, Texas Tech University, Lubbock, Texas.

Vitousek, P., Loope, L., Stone, C. 1987. Introduced Species in Hawaii: Biological Effects and Opportunities for Ecological Research. Trends in Ecology and Evolution 2:224-227.

Vogt, J. 2003. Attractiveness and Effectiveness of an Artificial Diet Fed to Hybrid Imported Fire Ants, *Solenopsis invicta x Richteri* (Hymenoptera: Formicidae). Florida Entomologist 86:456-459.

Waller, D. 1986. "The Foraging Ecology of *Atta texana* in Texas" in Lofgren, N. and Vander Meer, R. (eds.), Fire Ants and Leaf-Cutting Ants: Biology and Management. Westview Press, Boulder. Pp.146-158.

Wang, C., Strazanac, J., Butler, L. A Comparison of Pitfall Traps for Studying Leaf Litter Ant Communities. Journal of Economic Entomology. 94:761-765.

Werchan, L., Coker, J. 1983. Soil Survey for Williamson County, Texas. United States Department of Agriculture, Soil Conservation Service. U.S. Government Printing Office.

Wiedenfield, C., Barnhill, L., Novosad, C. 1970. Soil Survey for Runnels County, Texas. United States Department of Agriculture, Soil Conservation Service. U.S. Government Printing Office.

Willis, D., Salin, S., Lard, C., Robison, S. 2001. An Economic Assessment of Red Imported Fire Ant Impacts on Texas Production Agriculture. Texas Journal of Agriculture and Natural Resources 14:68-79.

Willis, D., Lard, C. 2001. A County Level Analysis of the Cost and Benefit of Implementing a RIFA Control Program to Agricultural Crop Producer and Electric Utilities in Texas. 2001. Texas Imported fire Ant Research and Management Project – Final Progress Report.

Wojcik, D. 1986. "Observation on the Biology and Ecology of Fire Ants in Brazil" In Lofgren and Vander Meer (eds.), Fire Ants and Leaf-cutting Ants: Biology and Management, pp 88-103. Westview Press, Boulder.

Wojcik, D., Allen, C., Brenner, R., Forys, E., Jouvenaz, D., Lutz, R. 2001. Red Imported fire Ants: Impact on Biodiversity. American Entomologist 47:16-23.

Zartman, R. August, 2004. Personal Communication, Texas Tech University, Lubbock, Texas.

APPENDIX A

DATA TABLES

Table A.1. Mean RIFA numbers per bait cup by transect with standard deviations. Data is from 25 sites with B.Dahl and other grasses in central and northern Texas in March, June, and July 2004.

Site/Transect	B.Dahl Mean RIFA per bait cup	Standard deviation	Other grasses Mean RIFA per bait cup	Standard deviation	Grass type
Brown					native
1	19.7	54.38	71.9	66.21	
2	38.8	49.22	67.5	66.81	
Callahan					native
1	13.3	22.45	27.1	24.84	
2	27.9	57.44	7.6	10.91	
Comanche					bermuda
1	26.6	15.98	6.7	8.80	
2	0.0	0	0.7	1.25	
Coryell					bermuda
1	0.4	0.96	1.7	1.7	
2	0.3	0.94	25.6	61.07	
Eastland					bermuda
1	117.9	70.24	174.7	76.95	
2	87.4	40.75	118.1	95.44	
Ellis					bermuda
1	13.4	18.63	33	31.76	
2	6.9	11.07	24.1	20.84	
Fannin					bermuda
1	8.2	14.08	10.8	29.34	
2	4.6	8.36	3.2	6.93	
Gillespie					klein
1	7.8	7.1	5.4	5.3	
2	4.5	4.1	4	5.4	
3	247.4	148.7	5.8	10.4	
4	163.1	89.7	38.4	86.4	
Grayson					bermuda
1	24.6	24.1	12.8	14.5	
2	10.2	31.9	40.9	50.6	
3	6.8	7.9	–	–	
Guadalupe					native
1	0.3	0.49	5.4	8.8	
2	5.8	6.2	5.4	7.9	
Hamilton					bermuda
1	39.8	24.8	53.1	46.8	
2	27.6	30.5	22.3	36.6	

Table A.1. Continued.

Site/Transect	B.Dahl Mean RIFA per bait cup	Standard deviation	Other grasses Mean RIFA per bait cup	Standard deviation	Grass type
Kimble					
1	69.1	76.6	128.6	112.1	klein
2	0.2	0.4	81.8	69.9	bermuda
Lampasas I					
1	1.9	2.9	0.7	1.3	native
2	29.7	39.8	15.1	27.7	
3	2.9	2.3	0	0	
4	0	0	0	0	
5	0	0	86.7	99.4	
6	112.9	50.1	200.7	114.9	
7	91.8	60.2	42.8	61.6	
Lampasas II					
1	7.5	8.1	2.7	3.2	bermuda
2	0	0	1.1	2.8	
Lampasas III					
1	41.7	44.6	111.9	57.3	klein
2	27.7	51.8	83.8	60.5	
Limestone					
1	4.5	9.2	8.1	20.8	
2	7.5	13.1	1.4	2.5	
McCulloch					
1	0	0	49	61.4	wilman
2	0	0	59.6	77.8	lovegrass
3	0	0	–	–	
4	0	0	–	–	
Milam					bermuda
1	19.2	22.9	23.5	42	
2	25.2	17	6.4	7.6	
Runnels I					
1	43.9	39.4	16.2	30.6	bermuda
2	38.3	20	0	0	
3	7.9	11.6	–	–	
4	0.4	1.3	–	–	
Runnels II					bermuda
1	6.3	19.9	0	0	
2	0	0	0	0	
Shackelford I					bermuda
1	106.1	77	72.9	57.9	
2	199.4	76.4	16.4	23	
Shackelford II					native
1	0	0	0	0	
2	32.2	31	0	0	

Table A.1. Continued.

Site/Transect	B.Dahl Mean RIFA per bait cup	Standard deviation	Other grasses Mean RIFA per bait cup	Standard deviation	Grass type
Wharton					
1	0.6	1.6	3.8	5	
2	0.1	0.3	4.2	6.5	
Williamson					
1	14.5	19	n/a	n/a	bermuda
2	5.4	4.8	0.7	0.8	
Young					
1	141.3	29.3	105.2	45.4	bermuda
2	84.5	68.3	46.3	47.6	

Table A.2. Mound numbers and mound vitality ratings. Data was collected at 25 sites in central and northern Texas in March, May and June, 2004.

Site/Transect	B.Dahl			Other grass			
	Mounds			Mounds			
	number	vitality rating	mean site vitality rating	number	vitality rating	mean site vitality rating	grass type
Brown							
1	2	1		4	1		native
	3	10		5	2		
	1	15		4	10		
2	1	1		1	1		
	1	2		4	2		
	1	10		4	10		
	–	–		1	15		
site total	9	60	6.66	23	0	5.13	
Callahan							
1	1	10		5	10		native
	1	5		2	15		
	–	–		1	20		
2	–	–		1	15		
site total	2	15	7.5	9	0	12.77	
Comanche							
1	0	0		2	1		bermuda
2	0	0		4	1		
	–	–		2	2		
	–	–		1	10		
site total	0	0	0	9	20	2.22	
Coryell							
1	1	2		1	2		bermuda
	1	5		1	3		
	1	10		1	10		
2	1	10		1	1		
	–	–		5	2		
	–	–		5	10		
site total	4	27	6.75	14	76	5.43	

Table A.2. Continued.

Site/Transect	B.Dahl Mounds number	vitality rating	mean site vitality rating	Other grass Mounds number	vitality rating	mean site vitality rating	grass type
Eastland							
1	1	1		1	5		bermuda
	3	10		6	10		
	2	15		1	15		
	–	–		1	20		
2	2	10		1	2		
	1	15		4	10		
	–	–		2	15		
	–	–		1	20		
site total	9	96	10.66	17	192	11.29	
Ellis							
1	1	1		2	10		bermuda
	2	10		–	–		
2	1	1		1	1		
	–	–		2	2		
	–	–		2	5		
	–	–		1	10		
	–	–		1	15		
site total	4	22	5.5	9	60	6.66	
Fannin							
1	1	10		3	10		bermuda
	0	0		1	10		
site total	1	10	10	4	40	10	
Gillespie							
1	1	1		1	1		klein
	2	2		1	2		
	2	15	35	2	10		
	–	–		2	15	53	
2	1	2		1	1		
	1	4		1	2		
	2	15	36	1	3		
	–	–		1	4		
	–	–		1	10	20	
3	1	10		0	0		
	1	15		–	–		
4	1	10	35	2	10		
	–	–		2	15	50	
site total	12	106	8.83	15	123	8.2	

Table A.2. Continued.

Site/Transect	B.Dahl Mounds number	vitality rating	mean site vitality rating	Other grass Mounds number	vitality rating	mean site vitality rating	grass type
Grayson							
1	2	10		1	15		bermuda
2	0	0		1	10		
	–	–		1	15		
site total	2	20	10	3	40	13.33	
Guadalupe							
1	1	10		4	10		native
	–	–		5	15		
	–	–		1	25		
2	0	0		2	5		
	–	–		13	10		
	–	–		2	15		
site total	1	10	10	27	310	11.48	
Hamilton							
1	1	10		1	1		bermuda
	1	15		2	3		
	–	–		5	10		
	–	–		5	15		
2	0	0		0	0		
site total	2	25	12.5	13	132	10.15	
Kimble							
1	1	2		1	10		bermuda
	1	3		–	–		
	1	15		–	–		
2	0	0		1	1		klein
	–	–		1	2		
	–	–		4	10		
site total	3	20	6.67	7	53	7.57	

Table A.2. Continued.

Site/Transect	B.Dahl Mounds number	B.Dahl Mounds vitality rating	B.Dahl mean site vitality rating	Other grass Mounds number	Other grass Mounds vitality rating	Other grass mean site vitality rating	grass type
Lampasas I							
1	0	0		1	2		native
	–	–		2	10		
	–	–		2	20		
2	1	15		6	1		
	–	–		6	2		
	–	–		1	5		
	–	–		1	10		
	–	–		1	15		
3	1	2		0	0		
	1	15		–	–		
4	0	0		0	0		
5	0	0		1	2		
	–	–		3	10		
	–	–		1	15		
6	1	10		1	1		
	–	–		2	2		
	–	–		1	5		
	–	–		8	10		
	–	–		5	15		
7	1	5		0	0		
	1	10					
site total	6	57	9.5	42	322	7.67	
Lampasas II							
1	2	1		10	1		bermuda
	1	2		4	2		
	1	4		1	3		
	1	10		2	5		
	–	–		1	10		
	–	–		3	15		
2	2	1		6	1		
	–	–		3	2		
	–	–		1	10		
	–	–		1	15		
site total	7	20	2.86	32	123	3.84	

Table A.2. Continued.

Site/Transect	B.Dahl Mounds number	B.Dahl Mounds vitality rating	B.Dahl mean site vitality rating	Other grass Mounds number	Other grass Mounds vitality rating	Other grass mean site vitality rating	grass type
Lampasas III							
1	0	0		1	2		klein
	–	–		2	5		
	–	–		4	10	52	
2	0	0		2	1		
	–	–		1	2		
	–	–		1	5		
	–	–		4	10		
site total	0	0		15	101	6.73	
Limestone							
1	1	5		7	1		bermuda
	2	10		3	2		
	–	–		2	5		
	–	–		12	10		
2	1	10		13	1		
	1	15		8	2		
	–	–		10	10		
site total	5	50	10	55	272	4.95	
McCulloch							
1	0	0		1	1		wilman lovegrass
	–	–		1	10		
2	0	0		1	1		
	–	–		1	2		
	–	–		2	10		
	–	–		1	15		
3	0	0		–	–		
4	0	0		–	–		
site total	0	0	0	7	49	7	
Milam							
1	2	10		1	1		bermuda
	1	15		1	2		
2	1	15		1	10		
site total	4	40	10	3	13	4.33	

Table A.2. Continued.

Site/Transect	B.Dahl Mounds number	vitality rating	mean site vitality rating	Other grass Mounds number	vitality rating	mean site vitality rating	grass type
Runnels I							
1	0	0		0	0		bermuda
2	0	0		0	0		
3	0	0		0	0		
4	0	0		0	0		
site total	0	0	0	0	0	0	
Runnels II							
1	0	0		0	0		native
2	0	0		0	0		
site total	0	0	0	0	0	0	
Shackelford I							
1	0	0		0	0		bermuda
2	0	0		0	0		
site total	0	0	0	0	0	0	
Shackelford II							
1	0	0		0	0		native
2	0	0		0	0		
site total	0	0	0	0	0	0	
Wharton							
1	1	20		4	15		native
2	1	20		1	1		
	–	–		2	10		
	–	–		2	15		
	–	–		1	20		
site total	2	40	20	10	131	13.1	
Williamson							
1	4	1		1	1		bermuda
	–	–		1	2		
	–	–		1	10		
	–	–		1	15		
2	1	1		2	1		
	1	2		3	2		
	–	–		2	10		
site total	6	7	1.17	11	56	5.1	

Table A.2. Continued.

Site/Transect	B.Dahl Mounds number	vitality rating	mean site vitality rating	Other grass Mounds number	vitality rating	mean site vitality rating	grass type
Young							
1	4	10		1	2		bermuda
	–	–		5	10		
	–	–		4	15		
2	2	10		1	10		
	–	–		2	15		
	–	–		1	20		
site total	6	20	6.67	14	152	10.86	

Table A.3. Primary B.Dahl plot characteristics. Data was collected at 25 sites in central and northern Texas in March, May, and June.

Site/Transect	Coverage density (Daubenmire scale)	Grass height (cm)	Soil temperature (°C)	Surface temperature (°C)	Air temperature (°C)
Brown					
B.Dahl 1	4	23	37.6	33.5	31.5
B.Dahl 2	4	25	37.2	32.7	29.9
Native 1	5	16	33.5	34.3	33.7
Native 2	5	35	31.0	36.6	34.5
Callahan					
B.Dahl 1	6	45	19.7	23.4	22.6
B.Dahl 2	6	53	19.9	23.3	22.6
Native 1	4	38	23.7	25.0	23.6
Native 2	5	31	22.3	25.1	24.2
Comanche					
B.Dahl 1	5	20	20.3	29.1	28.0
B.Dahl 2	5	22	24.5	29.3	27.8
Bermuda 1	5	12	27.7	33.4	29.8
Bermuda 2	5	14	26.8	30.3	27.2
Coryell					
B.Dahl 1	5	45	28.8	35.6	33.1
B.Dahl 2	5	45	27.0	31.6	30.9
Bermuda 1	5	27	30.1	31.6	30.3
Bermuda 2	4	24	30.8	30.7	30.3
Eastland					
B.Dahl 1	6	45	20.0	24.0	24.2
B.Dahl 2	6	42	20.0	23.9	24.6
Bermuda 1	6	23	23.0	27.0	26.3
Bermuda 2	5	30	21.4	27.1	25.8
Ellis					
B.Dahl 1	5	27	29.4	33.0	31.1
B.Dahl 2	5	45	29.4	32.7	30.7
Bermuda 1	5	41	29.8	32.1	29.6
Bermuda 2	5	27.4	31.0	32.1	29.4
Fannin					
B.Dahl 1	6	81	26.7	37.9	34.5
B.Dahl 2	6	22	28.1	36.3	32.7
Bermuda 1	5	23	27.3	33.5	32.5
Bermuda 2	5	20	28.6	34.7	32.5

Table A.3. Continued.

Site/Transect	Coverage density (Daubenmire scale)	Grass height (cm)	Soil temperature (°C)	Surface temperature (°C)	Air temperature (°C)
Gillespie					
B.Dahl 1	4	19	26.8	25.0	27.9
B.Dahl 2	5	25	24.5	29.1	27.3
B.Dahl 3	6	48	20.2	22.7	22.3
B.Dahl 4		40	20.4	23.1	22.1
Klein 1	4	9	23.3	22.5	26.1
Klein 2	3	14	23.0	25.9	23.6
Klein 3	5	46	22.0	23.3	22.2
Klein 4	4	36	21.0	23.3	22.8
Grayson					
B.Dahl 1	5	24	23.1	26.6	26.3
B.Dahl 2	5	26	23.4	27.9	27.0
B.Dahl 3	5	23	28.6	31.3	30.3
Bermuda 1	4	23	26.1	29.7	28.8
Bermuda 2	4	24	26.2	27.5	28.4
Guadalupe					
B.Dahl 1	5	30	23.5	22.3	24.6
B.Dahl 2	5	28	20.9	23.6	23.1
Bermuda 1	5	8	23.3	20.2	22.2
Bermuda 2	4	5	1908.0	21.8	22.1
Hamilton					
B.Dahl 1	4	38	29.0	36.1	31.3
B.Dahl 2	4	37	30.2	37.2	32.3
Bermuda 1	4	13	34.8	35.2	33.0
Bermuda 2	5	26	34.6	35.7	31.9
Kimble					
B.Dahl 1	6	35	26.1	29.2	28.4
B.Dahl 2	3	20	29.0	31.8	29.4
Bermuda 1	6	41	24.0	30.9	29.1
Klein 1	5	72	28.0	34.0	32.3

Table A.3. Continued.

Site/Transect	Coverage density (Daubenmire scale)	Grass height (cm)	Soil temperature (°C)	Surface temperature (°C)	Air temperature (°C)
Lampasas I					
B.Dahl 1	5	50	23.0	22.1	23.4
B.Dahl 2	6	40	27.0	30.4	29.3
B.Dahl 3	4	16	19.5	23.2	23.2
B.Dahl 4	5	14	16.0	22.1	21.4
B.Dahl 5	5	13	21.0	24.0	21.7
B.Dahl 6	6	33	26.8	29.5	27.4
B.Dahl 7	5	27	27.8	30.3	27.9
Native 1	6	28	19.0	26.4	22.7
Native 2	3	12	21.0	22.9	21.3
Native 3	4	14	19.0	22.6	22.1
Native 4	3	15	23.0	22.6	22.8
Native 5	4	33	28.0	29.9	28.1
Native 6	4	33	31.0	31.9	29.1
Native 7	5	33	27.8	31.0	29.0
Lampasas II					
B.Dahl 1	4	40	25.0	31.1	30.0
B.Dahl 2	3	23	25.2	26.1	25.6
Bermuda 1	2	20	29.9	25.0	27.8
Bermuda 2	5	15	24.8	27.4	26.5
Lampasas III					
B.Dahl 1	6	48	27.1	28.5	27.7
B.Dahl 2	6	57	24.0	26.4	26.4
Klein 1	5	55	29.8	30.9	28.9
Klein 2	6	52	28.8	31.4	28.6
Limestone					
B.Dahl 1	4	80	26.0	28.0	27.4
B.Dahl 2	4	74	26.0	27.5	26.1
Bermuda 1	5	21	30.6	32.5	30.0
Bermuda 2	5	21	31.3	34.6	30.3
McCulloch					
B.Dahl 1	6	43	23.4	26.7	26.8
B.Dahl 2	6	46	24.5	29.3	27.1
B.Dahl 3	6	43	31.8	30.8	27.8
B.Dahl 4	6	50	29.1	29.9	30.4
Wilman lovegrass	6	88	27.0	29.1	26.1
Wilman lovegrass	6	92	21.7	29.0	26.1

Table A.3. Continued.

Site/Transect	Coverage density (Daubenmire scale)	Grass height (cm)	Soil temperature (°C)	Surface temperature (°C)	Air temperature (°C)
Milam					
B.Dahl 1	5	26	22.6	26.5	27.0
B.Dahl 2	6	32	22.8	27.0	26.6
Bermuda 1	5	21	22.8	26.6	26.6
Bermuda 2	5	20	23.0	27.3	25.5
Runnels I					
B.Dahl 1	5	35	28.0	26.7	27.6
B.Dahl 2	6	48	21.3	31.3	29.8
B.Dahl 3	5	29	30.7	30.6	29.8
B.Dahl 4	5	26	28.7	30.7	27.8
Bermuda 1	4	13	31.7	32.2	29.2
Bermuda 2	5	24	30.0	31.4	29.5
Runnels II					
B.Dahl 1	5	31	30.7	32.0	30.2
B.Dahl 2	5	23	36.0	34.5	32.3
Native 1	6	25	28.2	29.9	28.8
Native 2	4	21	34.8	32.4	29.4
Shackelford 1					
B.Dahl 1	6	51	24.0	26.8	25.8
B.Dahl 2	6	52	24.0	25.7	25.7
Bermuda 1	4	44	27.5	31.2	30.1
Bermuda 2	5	45	28.0	32.6	30.2
Shackelford 2					
B.Dahl 1	5	27	31.2	32.4	30.8
B.Dahl 2	4	20	305.0	33.9	33.0
Native 1	6	54	28.0	34.4	32.2
Native 2	5	44	27.3	34.9	33.8
Wharton					
B.Dahl 1	3	11	24.7	24.0	25.7
B.Dahl 2	3	12	24.0	25.8	25.3
Native 1	5	8	24.6	22.2	24.1
Native 2	5	8	23.0	24.4	23.9

Table A.3. Continued.

Site/Transect	Coverage density (Daubenmire scale)	Grass height (cm)	Soil temperature (°C)	Surface temperature (°C)	Air temperature (°C)
Williamson					
B.Dahl 1	3	33	30.0	35.5	31.7
B.Dahl 2	3	17	33.0	31.3	32.8
Bermuda 1	5	16	31.0	33.5	31.0
Bermuda 2	5	19	30.0	32.1	32.4
Young					
B.Dahl 1	5	34	26.8	32.8	32.0
B.Dahl 2	6	40	28.5	32.5	32.1
Bermuda 1	5	20	29.9	31.8	31.7
Bermuda 2	5	19	28.4	33.6	31.4

Table A.4. Secondary B.Dahl plot characteristics. Data was collected at 25 sites in central and northern Texas in March, May, and June.

Site/Transect	Shade (0 = none)	Altitude (m)	Grazing	Date	Time of day (Central daylight time)
Brown				5/20/2004	
B.Dahl 1	0	412	yes		2:30
B.Dahl 2	0	413	yes		2:50
Native 1	0	420	no		4:45
Native 2	0	407	no		4:40
Callahan				6/10/2004	
B.Dahl 1	overcast	599	yes		2:58
B.Dahl 2	overcast	607	yes		3:15
Native 1	overcast	604	yes		4:10
Native 2	overcast	592	yes		4:31
Comanche				5/20/2004	
B.Dahl 1	0	342	yes		11:05
B.Dahl 2	0	388	yes		11:20
Bermuda 1	0	311	yes		11:40
Bermuda 2	0	342	yes		11:50
Coryell				5/17/2004	
B.Dahl 1	0	332	yes		4:00
B.Dahl 2	0	330	yes		3:45
Bermuda 1	0	328	yes		5:01
Bermuda 2	0	325	yes		5:16
Eastland				6/10/2004	
B.Dahl 1	overcast	456	yes		8:55
B.Dahl 2	overcast	456	yes		9:25
Bermuda 1	overcast	460	yes		10:20
Bermuda 2	overcast	463	yes		10:46
Ellis				5/18/2004	
B.Dahl 1	0	158	yes		3:38
B.Dahl 2	0	128	yes		3:12
Bermuda 1	0	160	yes		4:40
Bermuda 2	0	148	yes		5:10
Fannin				6/11/2004	
B.Dahl 1	0	194	yes		2:43
B.Dahl 2	0	198	yes		3:11
Bermuda 1	0	279	yes		4:51
Bermuda 2	0	279	yes		4:33

Table A.4. Continued.

Site/Transect	Shade (0 = none)	Altitude (m)	Grazing	Date	Time of day (Central daylight time)
Gillespie					
B.Dahl 1	0	520	yes	3/18/2004	12:55
B.Dahl 2	0	519	yes		1:12
B.Dahl 3	overcast	504	yes	5/24/2004	8:51
B.Dahl 4	overcast	503	yes		9:27
Klein 1	0	518	yes	3/18/2004	10:50
Klein 2	0	518	yes		11:07
Klein 3	overcast	488	yes	5/24/2004	10:31
Klein 4	overcast	484	yes		10:55
Grayson				6/11/2004	
B.Dahl 1	0	183	yes		9:21
B.Dahl 2	0	205	yes		9:06
B.Dahl 3	0	218	yes		10:44
Bermuda 1	0	202	yes		10:26
Bermuda 2	0	224	yes		
Guadalupe					
B.Dahl 1	overcast	188	yes	3/18/2004	5:20
B.Dahl 2	overcast	196	yes		5:40
Bermuda 1	overcast	193	yes	3/19/2004	10:02
Bermuda 2	overcast	190	yes		9:42
Hamilton				6/14/2004	
B.Dahl 1	0	377	yes		11:31
B.Dahl 2	0	425	yes		11:57
Bermuda 1	0	393	yes		1:36
Bermuda 2	0	387	yes		2:00
Kimble				5/24/2004	
B.Dahl 1	0	505	no		2:53
B.Dahl 2	0	525	no		3:21
Bermuda 1	0	517	no		4:01
Klein 1	0	512	no		4:46

Table A.4. Continued.

Site/Transect	Shade (0 = none)	Altitude (m)	Grazing	Date	Time of day (Central daylight time)
Lampasas I					
B.Dahl 1	0	399	no	3/16/2004	11:30
B.Dahl 2	0	419	no	5/23/2004	5:02
B.Dahl 3	0	399	no	3/16/2004	4:30
B.Dahl 4	0	420	no	3/17/2004	9:16
B.Dahl 5	0	421	no		9:30
B.Dahl 6	0	387	no	5/23/2004	1:48
B.Dahl 7	0	404	no		2:24
Native 1	0	383	no	3/16/2004	2:30
Native 2	0	401	no		5:20
Native 3	0	428	no	3/17/2004	9:38
Native 4	0	428	no		9:42
Native 5	0	411	no	5/23/2004	3:30
Native 6	0	414	no		3:10
Native 7	0	418	no		4:30
Lampasas II					
B.Dahl 1	0	351	yes	3/17/2004	4:06
B.Dahl 2	0	363	yes	3/20/2004	3:59
Bermuda 1	0	345	yes	3/17/2004	4:34
Bermuda 2	0	366	yes	3/20/2004	4:40
Lampasas III				5/17/2004	
B.Dahl 1	0	270	yes		10:23
B.Dahl 2	0	228	yes		10:20
Klein 1	0	270	yes		12:15
Klein 2	0	266	yes		12:05
Limestone				5/18/2004	
B.Dahl 1	0	105	no		9:42
B.Dahl 2	0	75	no		10:11
Bermuda 1	0	130	no		11:40
Bermuda 2	0	104	no		12:10
McCulloch				5/22/2004	
B.Dahl 1	0	514	yes		11:13
B.Dahl 2	0	525	yes		11:36
B.Dahl 3	0	524	yes		1:53
B.Dahl 4	0	551	yes		2:18
Wilman lovegrass	0	547	yes		12:22
Wilman lovegrass	0	540	yes		12:30

Table A.4. Continued.

Site/Transect	Shade (0 = none)	Altitude (m)	Grazing	Date	Time of day (Central daylight time)
Milam				5/19/2004	
B.Dahl 1	0	40	yes		9:48
B.Dahl 2	0	67	yes		10:00
Bermuda 1	0	64	yes		10:15
Bermuda 2	0	47	yes		10:30
Runnels I				5/21/2004	
B.Dahl 1	0	505	unknown		12:15
B.Dahl 2	0	519	unknown		12:30
B.Dahl 3	0	515	unknown		1:40
B.Dahl 4	0	521	unknown		2:00
Bermuda 1	0	516	unknown		12:40
Bermuda 2	0	511	unknown		12:53
Runnels II				5/21/2004	
B.Dahl 1	0	489	unknown		4:15
B.Dahl 2	0	546	unknown		4:38
Native 1	0	504	unknown		3:40
Native 2	0	512	unknown		4:47
Shackelford 1				6/15/2004	
B.Dahl 1	0	350	no		9:40
B.Dahl 2	0	358	no		9:27
Bermuda 1	0	364	no		11:30
Bermuda 2	0	378	no		11:01
Shackelford 2				6/15/2004	
B.Dahl 1	0	372	yes		2:30
B.Dahl 2	0	385	yes		2:08
Native 1	0	378	no		3:38
Native 2	0	394	no		4:05
Wharton				3/19/2004	
B.Dahl 1	overcast	124	yes		2:00
B.Dahl 2	overcast	124	yes		2:25
Native 1	overcast	125	yes		4:00
Native 2	overcast	125	yes		4:30
Williamson				5/19/2004	
B.Dahl 1	0	176	yes		4:20
B.Dahl 2	0	176	yes		4:50
Bermuda 1	0	136	yes		5:00
Bermuda 2	0	176	yes		5:21

Table A.4. Continued.

Site/Transect	Shade (0 = none)	Altitude (m)	Grazing	Date	Time of day (Central daylight time)
Young				6/10/2004	
B.Dahl 1	0	443	yes		4:20
B.Dahl 2	0	451	yes		4:38
Bermuda 1	0	381	yes		2:40
Bermuda 2	0	365	yes		3:05

Table A.5. B.Dahl invasiveness. Invasion is measured by grass spread from the original field of planting (Daubenmire scale 1 = 0-5%, 2 = 5-25%, 3 = 25-50%, 4 = 50-75%, 5 = 75-95%, and 6 = 95-100%). The first 10 meters were measured each meter; whereas. 10 to 100 meters were measured every 10 meters. No readings were taken at points noted (xx).

Site	Distance from planted field (m)								Grass type	Age of field (yrs)
Brown									native	7
	1	—	6	—	20	—	70	—		
	2	—	7	—	30	—	80	—		
	3	—	8	—	40	2	90	—		
	4	—	9	—	50	—	100	—		
	5	—	10	—	60	2				
Callahan									native	3
	1	2	6	—	20	—	70	—		
	2	1	7	xx	30	—	80	—		
	3	1	8	xx	40	—	90	—		
	4	—	9	—	50	—	100	—		
	5	—	10	—	60	—				
Comanche									klein	5
	1	2	6	—	20	—	70	—		
	2	1	7	1	30	—	80	—		
	3	—	8	—	40	—	90	—		
	4	—	9	2	50	—	100	—		
	5	—	10	—	60	—				
Coryell									unknown	4
	1	1	6	—	20	—	70	—		
	2	—	7	—	30	—	80	—		
	3	—	8	—	40	—	90	—		
	4	—	9	—	50	—	100	—		
	5	—	10	—	60	—				
Eastland										
	1	—	6	—	20	—	70	—	native	3
	2	—	7	—	30	—	80	—		
	3	—	8	—	40	—	90	—		
	4	—	9	—	50	—	100	—		
	5	—	10	—	60	—				
Ellis									bermuda	8
	1	1	6	—	20	—	70	—		
	2	—	7	—	30	—	80	—		
	3	—	8	—	40	—	90	—		
	4	—	9	—	50	—	100	—		
	5	—	10	—	60	—				

Table A.5. Continued.

Site	Distance from planted field (m)								Grass type	Age of field (yrs)
Fannin									native	2
	1	3	6	—	20	—	70	—		
	2	3	7	—	30	—	80	—		
	3	3	8	—	40	1	90	—		
	4	3	9	—	50	—	100	—		
	5	—	10	1	60	—				
Gillespie									native	3
	1	2	6	—	20	—	70	1		
	2	—	7	—	30	1	80	—		
	3	1	8	—	40	—	90	xx		
	4	—	9	—	50	—	100	xx		
	5	—	10	—	60	1				
Grayson										
	1	—	6	—	20	2	70	1	bermuda	3
	2	—	7	—	30	2	80	—		
	3	—	8	—	40	1	90	—		
	4	—	9	—	50	1	100	—		
	5	—	10	—	60	1				
Guadalupe									native	3
	1	2	6	—	20	—	70	—		
	2	2	7	—	30	1	80	—		
	3	—	8	1	40	1	90	—		
	4	2	9	—	50	—	100	—		
	5	—	10	—	60	—				
Hamilton										5
	1	—	6	—	20	—	70	—		
	2	3	7	—	30	—	80	—		
	3	—	8	—	40	—	90	—		
	4	—	9	—	50	—	100	—		
	5	—	10	—	60	1				
Kimble									bermuda	5
	1	—	6	2	20	—	70	—		
	2	—	7	—	30	—	80	—		
	3	—	8	—	40	—	90	—		
	4	—	9	1	50	—	100	—		
	5	—	10	1	60	—				
Lampasas I									native	18
	1	2.5	6	1	20	—	70	—		
	2	2	7	—	30	1	80	3		
	3	3	8	—	40	3	90	0.5		
	4	2.5	9	1	50	1	100	0.5		
	5	1.5	10	—	60	—				

Table A.5. Continued.

Site	Distance from planted field (m)								Grass type	Age of field (yrs)
Lampasas II									native	3
	1	2.5	6	—	20	0.5	70	—		
	2	1	7	—	30	—	80	—		
	3	—	8	0.5	40	—	90	—		
	4	0.5	9	—	50	—	100	—		
	5	1	10	—	60	—				
Lampasas III									klein	9
	1	2	6	—	20	1	70	—		
	2	—	7	—	30	1	80	—		
	3	1	8	1	40	1	90	—		
	4	—	9	—	50	1	100	1		
	5	—	10	1	60	2				
Limestone									oats	2
	1	2	6	—	20	—	70	—		
	2	2	7	—	30	—	80	—		
	3	2	8	—	40	—	90	1		
	4	—	9	—	50	—	100	—		
	5	—	10	—	60	—				
McCulloch									native	2
	1	—	6	—	20	—	70	—		
	2	—	7	—	30	—	80	—		
	3	—	8	—	40	—	90	—		
	4	—	9	—	50	—	100	—		
	5	—	10	—	60	—				
Milam									bermuda	3
	1	—	6	—	20	—	70	—		
	2	—	7	—	30	—	80	—		
	3	—	8	—	40	—	90	—		
	4	—	9	—	50	—	100	—		
	5	—	10	—	60	—				
Runnels I									bermuda	3
	1	—	6	—	20	—	70	—		
	2	—	7	—	30	—	80	—		
	3	—	8	—	40	—	90	—		
	4	—	9	—	50	—	100	—		
	5	—	10	—	60	—				
Runnels II									native	3
	1	2	6	—	20	1	70	—		
	2	—	7	—	30	—	80	—		
	3	1	8	—	40	—	90	—		
	4	—	9	—	50	—	100	—		
	5	1	10	—	60	—				

Table A.5. Continued.

Site	Distance from planted field (m)								Grass type	Age of field (yrs)
Shackelford I									bermuda	9
	1	—	6	—	20	—	70	—		
	2	3	7	—	30	—	80	—		
	3	—	8	—	40	—	90	—		
	4	—	9	—	50	—	100	—		
	5	—	10	—	60	1				
Shackelford II									native	2
	1	—	6	—	20	—	70	—		
	2	—	7	—	30	—	80	—		
	3	—	8	—	40	—	90	—		
	4	—	9	—	50	—	100	—		
	5	—	10	—	60	—				
Wharton									native	1
	1	—	6	—	20	—	70	—		
	2	—	7	—	30	—	80	—		
	3	—	8	—	40	—	90	—		
	4	—	9	—	50	—	100	—		
	5	—	10	—	60	—				
Williamson									mixed grass	7
	1	2	6	—	20	—	70	—		
	2	—	7	—	30	—	80	—		
	3	—	8	—	40	—	90	—		
	4	—	9	—	50	—	100	—		
	5	—	10	—	60	—				
Young									native	4
	1	—	6	—	20	—	70	—		
	2	1	7	—	30	—	80	—		
	3	1	8	—	40	—	90	—		
	4	—	9	—	50	—	100	—		
	5	—	10	—	60	—				

Table A.6. Global positioning system (latitude/longitude) location of each bait cup transect line. The degrees/minutes/seconds coordinate system was used. Data is for 25 sites in central and northern Texas.

Site/Transect	North	West
Brown		
B.Dahl 1	31.54' 20.739	99.06' 57.153
B.Dahl 2	31.54' 20.343	99.06' 46.469
Native 1	31.54' 19.741	99.07' 00.363
Native 2	31.54' 17.594	99.07' 01.020
Callahan		
B.Dahl 1	32.14' 27.300	99.16' 58.596
B.Dahl 2	32.14' 31.676	99.17' 01.533
Native 1	32.14' 26.246	99.16' 57.365
Native 2	32.14' 22.426	99.16' 59.147
Comanche		
B.Dahl 1	31.58' 56.351	98.47' 67.362
B.Dahl 2	31.58' 53.075	98.47' 41.907
Bermuda 1	31.59' 00.678	98.47' 38.917
Bermuda 2	31.59' 00.783	98.47' 27.981
Coryell		
B.Dahl 1	31.17' 03.684	98.02' 01.286
B.Dahl 2	31.17' 04.817	98.01' 53.950
Bermuda 1	31.16' 52.653	98.01' 42.218
Bermuda 2	31.16' 55.970	98.01' 40.026
Eastland		
B.Dahl 1	32.14' 16.209	98.47' 23.944
B.Dahl 2	32.14' 11.133	98.47' 24.879
Bermuda 1	32.14' 22.720	98.47' 23.777
Bermuda 2	32.14' 26.682	98.47' 30.424
Ellis		
B.Dahl 1	32.06' 19.723	96.56' 06.370
B.Dahl 2	32.06' 28.510	96.56' 07.133
Bermuda 1	32.06' 09.447	96.56' 03.018
Bermuda 2	32.06' 15.856	96.56' 02.986

Table A.6. Continued.

Site/Transect	North	West
Fannin		
B.Dahl 1	33.39' 59.620	96.22' 44.561
B.Dahl 2	33.40' 03.738	96.22' 52.300
Bermuda 1	33.39' 54.315	96.22' 31.544
Bermuda 2	33.59' 53.315	96.22' 50.944
Gillespie		
B.Dahl 1	30.10' 47.220	98.56' 14.400
B.Dahl 2	30.10' 48.900	98.56' 23.700
B.Dahl 3	30.10' 52.847	98.56' 15.347
B.Dahl 4	30.10' 52.831	98.56' 24.754
Klein 1	30.11' 11.940	98.56' 24.540
Klein 2	30.11' 11.940	98.56' 24.540
Klein 3	30.11' 13.152	98.56' 26.813
Klein 4	30.11' 12.981	98.56' 25.465
Grayson		
B.Dahl 1	33.29' 08.309	96.29' 24.801
B.Dahl 2	33.28' 58.020	96.29' 18.681
B.Dahl 3	33.29' 20.439	96.29' 16.421
Bermuda 1	33.29' 10.968	96.29' 21.230
Bermuda 2	33.29' 16.391	96.29' 21.249
Guadalupe		
B.Dahl 1	29.41' 51.900	97.52' 41.340
B.Dahl 2	29.41' 49.200	97.52' 44.880
Bermuda 1	29.41' 52.140	97.52' 43.260
Bermuda 2	29.41' 49.440	97.52' 48.000
Hamilton		
B.Dahl 1	31.40' 56.236	98.12' 42.242
B.Dahl 2	31.40' 59.058	989.12' 40.157
Bermuda 1	31.41' 35.197	98.12' 26.961
Bermuda 2	31.41' 30.013	98.12' 21.605
Kimble		
B.Dahl 1	30.40' 34.900	99.35' 45.712
B.Dahl 2	30.40' 31.539	99.35' 45.327
Bermuda 1	30.40' 35.408	99.35' 48.296
Klein 1	31.40' 32.212	99.35' 40.092

Table A.6. Continued.

Site/Transect	North	West
Lampasas I		
B.Dahl 1	31.14' 01.800	98.29' 07.980
B.Dahl 2	31.13' 46.237	98.29' 10.555
B.Dahl 3	31.13.51.360	98.29' 04.380
B.Dahl 4	31.14' 35.640	98.28' 40.860
B.Dahl 5	31.14' 39.360	98.28' 43.080
B.Dahl 6	31.14' 02.727	98.92' 01.160
B.Dahl 7	31.14' 04.554	98.28' 54.772
Native 1	31.12' 59.520	98.29' 10.920
Native 2	31.13' 54.180	98.29' 17.400
Native 3	31.14' 39.000	98.28' 35.160
Native 4	31.14' 39.000	98.28' 30.360
Native 5	31.13' 59.545	98.28' 56.999
Native 6	31.14' 10.874	98.28' 54.434
Native 7	31.13' 47.926	98.29' 12.090
Lampasas II		
B.Dahl 1	31.14' 10.620	98.13' 05.880
B.Dahl 2	31.14' 10.500	98.13' 15.240
Bermuda 1	31.14' 03.240	98.12' 56.940
Bermuda 2	31.13' 57.120	98.12' 46.740
Lampasas III		
B.Dahl 1	31.08' 52.547	98.08' 38.017
B.Dahl 2	31.08' 46.670	98.08' 34.191
Klein 1	31.08' 49.495	98.08' 44.670
Klein 2	31.08' 46.105	98.08' 42.428
Limestone		
B.Dahl 1	31.45' 10.212	96.40' 56.767
B.Dahl 2	31.45' 08.023	96.40' 52.856
Bermuda 1	31.40' 01.596	96.41' 24.686
Bermuda 2	31.45' 10.042	96.41' 34.716
McCulloch		
B.Dahl 1	31.10' 46.430	99.30' 32.498
B.Dahl 2	31.10' 53.066	99.30' 27.287
B.Dahl 3	31.11' 55.481	99.32' 36.667
B.Dahl 4	31.11' 48.490	99.32' 35.568
Wilman lovegrass	31.10' 45.847	99.31' 11.178
Wilman lovegrass	31.10' 40.047	99.31' 07.563

Table A.6. Continued.

Site/Transect	North	West
Milam		
B.Dahl 1	30.49' 49.139	97.08' 02.818
B.Dahl 2	30.49' 48.088	97.07' 58.457
Bermuda 1	30.49' 47.142	97.07' 56.215
Bermuda 2	30.49' 50.361	97.07' 53.961
Runnels I		
B.Dahl 1	31.56' 57.005	99.55' 35.921
B.Dahl 2	31.56' 56.095	99.55' 36.757
B.Dahl 3	31.56' 10.925	99.55' 29.814
B.Dahl 4	31.56' 18.165	99.55' 30.883
Bermuda 1	31.56' 56.431	99.55' 08.633
Bermuda 2	31.56' 53.428	99.55' 00.677
Runnels II		
B.Dahl 1	31.52' 47.667	99.58' 54.646
B.Dahl 2	31.52' 40.045	99.58' 23.140
Native 1	31.52' 44.965	99.58' 55.479
Native 2	31.52' 45.806	99.58' 47.281
Shackelford 1		
B.Dahl 1	32.39' 23.954	99.09' 02.886
B.Dahl 2	32.39' 23.551	99.09' 11.151
Bermuda 1	32.39' 23.952	99.09' 02.886
Bermuda 2	32.39' 28.493	99.09' 08.379
Shackelford 2		
B.Dahl 1	32.44' 11.023	99.14' 02.853
B.Dahl 2	32.44' 15.615	99.14' 01.425
Native 1	32.44' 15.146	99.14' 03.754
Native 2	32.44' 16.195	99.14' 03.800
Wharton		
B.Dahl 1	29.05' 03.780	96.04' 54.180
B.Dahl 2	29.04' 54.900	96.04' 48.720
Native 1	29.04' 57.900	96.05' 12.900
Native 2	29.04' 54.84	96.05' 18.540
Williamson		
B.Dahl 1	30.42' 09.179	97.16' 26.791
B.Dahl 2	30.42' 09.059	97.16' 20.74
Bermuda 1	30.42' 20.141	97.16' 26.050
Bermuda 2	30.42' 19.491	97.16' 26.651

Table A.6. Continued.

Site/Transect	North	West
Young		
B.Dahl 1	33.13' 29.478	98.29' 43.352
B.Dahl 2	33.13' 27.910	98.29' 42.855
Bermuda 1	33.13' 26.721	98.29' 03.520
Bermuda 2	33.13' 23.714	98.28' 57.782

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