Georgia Southern University

Digital Commons@Georgia Southern

Spring 2013

Effects of Site Preparation, Seed Germination, and Harvest Maturity on Wiregrass Restoration Efforts at Fort Stewart, GA

Nickey Garrett Anderson

Follow this and additional works at: https://digitalcommons.georgiasouthern.edu/etd

Part of the Biology Commons, and the Plant Sciences Commons

EFFECTS OF SITE PREPARATION, SEED GERMINATION, AND HARVEST MATURITY

ON WIREGRASS RESTORATION EFFORTS AT FORT STEWART, GA

by

NICKEY GARRETT ANDERSON

(Under the Direction of Stephen P. Vives)

ABSTRACT

Wiregrass (*Aristida stricta* Michx.) was once the dominant ground cover species within the Atlantic Coastal Plain longleaf pine (*Pinus palustris* Mill.) ecosystem. Less than 1 million hectares of intact longleaf pine-wiregrass communities remain, due primarily to anthropogenic activities. Wiregrass is a keystone species in the longleaf pine ecosystem, as its presence facilitates the natural fire regime, a critical component in the perpetuation of these communities. Therefore, there is increased interest in wiregrass restoration in both existing longleaf pine communities and future longleaf pine restoration sites. Many restoration sites are on tracts that have been cleared of all vegetation. Removal of stumps, roots, and debris causes a high level of disturbance to the upper soil layer. Disturbed soil must first be leveled and compacted before wiregrass seed can be sown effectively. The first objective of this study was to study the effect of wiregrass seed harvest date on germination success. The second objective of this study was to compare two methods of soil compaction, bulldozer versus cultipacker, as measured by wiregrass establishment and vigor. A significant difference in germination rates was found among seed harvested on differing dates relative to seed maturation. Wiregrass seedling density and vigor were similar among compaction treatments and plots. Results of this study are discussed in the context of updating restoration protocols for wiregrass seed harvest and site preparation.

INDEX WORDS: Wiregrass, *Aristida stricta*, Site preparation, Restoration, Cultipacker, Bulldozer, Clear-cut, Stump and grub, Longleaf pine ecosystem, Atlantic Coastal Plain, After-ripening, Soil disturbance, Soil compaction, Seedbed, Wiregrass seedling establishment, Wiregrass germination

EFFECTS OF SITE PREPARATION, SEED GERMINATION, AND HARVEST MATURITY ON WIREGRASS RESTORATION EFFORTS AT FORT STEWART, GA

by

NICKEY GARRETT ANDERSON

B.S., Armstrong Atlantic State University, 2007

A Thesis Submitted to the Graduate Faculty of Georgia Southern University in Partial

Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

STATESBORO, GEORGIA

2013

EFFECTS OF SITE PREPARATION, SEED GERMINATION, AND HARVEST MATURITY

ON WIREGRASS RESTORATION EFFORTS AT FORT STEWART, GA

by

NICKEY GARRETT ANDERSON

Major Professor: Stephen P. Vives
Committee: C. Ray Chandler
                   Subhrajit K. Saha

Electronic Version Approved:
May 2013

Acknowledgements

patience, and understanding throughout my graduate career. They have kept me going through days of doubt, discouragement, and fatigue. Most of all, I thank Jesus Christ for the strength and ability He has blessed me with, without which the completion of this thesis would not have been possible (Philippians 4:3).

Table of Contents

List of Tables

List of Figures

Introduction

<u>Background</u>

Longleaf pine (*Pinus palustris* Miller) communities once dominated the southeastern United States, occupying an estimated 37 million hectares (Frost 1993, Outcalt and Sheffield 1996) from Virginia to Florida and from the eastern seaboard to Texas. The Atlantic Coastal Plain region, extending from North Carolina to Florida, contained approximately 10 million hectares of longleaf pine forest (Southern Section, Society of Range Management 1974). Presently, the range of longleaf pine ecosystems has been reduced by more than 97% (Frost 1993, Outcalt and Sheffield 1996, Aschenbach et al. 2007), due to anthropogenic activities (Outcalt et al. 1999). Of the remaining 1.2 million hectares occupied by longleaf pine in the Atlantic Coastal Plain, only an estimated 0.5-0.8 million hectares of intact understory (grasses, forbs, and shrubs) remain (Noss 1989, Outcalt et al. 1999).

Wiregrass (*Aristida stricta* Michaux., syn. *A. beyrichiana* Trinius and Ruprecht) was the dominant ground cover within the understory (grasses, forbs, and shrubs) of the Atlantic Coastal Plain longleaf pine ecosystem (Frost 2006, Shibu et al. 2006, Wells and Shunk 1931). The presence of wiregrass in the longleaf ecosystem facilitates the natural fire regime, a critical component in the perpetuation of these communities (Christensen 1993, Frost 2006, Landers 1991, Outcalt et al. 1999, Parrott 1967). The growth habit of wiregrass with outward arching leaves that overlap adjoining individuals (Outcalt et al. 1999), short-lived leaves (Parrott 1967) that remain attached after dying (Landers 1991), and slow decay of those leaves (Christensen 1993) all help to create a structural lattice-work above the forest floor. Interception of pine needles by this structural configuration results in a highly flammable matrix of fine-fuel biomass (Outcalt et al. 1999) enabling the rapid spread of natural and prescribed fire (Abrahamson and

1

Hartnett 1990, Aschenbach et al. 2007). Therefore, wiregrass is necessary for frequent, evenly burning surface fires (Outcalt et al. 1999). Surface fires regulate floristic composition by reducing the extent of invasive species that are not adapted to fire (Ahlgren 1979, Provencher et al. 2001, Reinhart and Menges 2004) while favoring native, fire-adapted species (Outcalt et al. 1999). Thus, wiregrass is a keystone species within the longleaf pine ecosystem (Clewell 1989, Noss 1989, Platt et al. 1989).

The important role of wiregrass in the perpetuation and restoration of the longleaf ecosystem has led to increased interest in its restoration in both existing longleaf pine communities where it has been eliminated and current longleaf pine restoration efforts (Outcalt et al. 1999). Once eliminated from an area, natural re-colonization of wiregrass is nearly impossible, due to its short dispersal distance (up to 596 cm) from the parent plant (Hermann 2007, Mulligan et al. 1999, Mulligan et al. 2002) and the inability of its seed (caryopses) to persist in the seed bank (McGee 1996). Therefore, reintroduction of wiregrass to longleaf pine communities is dependent upon anthropogenic restoration efforts.

Restoration of wiregrass as a ground cover in longleaf pine communities is an area of active investigation. Restoration protocols are highly variable due to the natural heterogeneity (Frost 2006) and varied historical land uses of the longleaf pine ecosystem (Frost 1993), making it nearly impossible to provide descriptions or prescriptions of restoration protocols for every situation. As such, restoration practitioners are dependent upon ecological reference models (representations of past form and functions of restoration sites, as they would have been before degradation of the ecosystem), project goals, conventional natural resource management techniques, and horticultural methods in the development and implementation of their action plans (Walker and Silletti 2006).

One type of wiregrass restoration site is a clear-cut (a contiguous geographical area in which all trees have been removed), which necessitates certain protocols before wiregrass seed can be efficiently dispersed. Once a site has been cleared of all standing trees, removal of stumps, roots, and debris should be accomplished to facilitate preparation of the seedbed and planting of the seed (Dwyer et al. 2010). This process, often called "stump and grub" or "grubbing", leaves the soil in a disturbed state that is unsuitable for successful germination of wiregrass seed (Dwyer et al. 2010, Walker 1999). Therefore, it is necessary to level and compact this disturbed soil. In order to provide a suitable seedbed for maximum germination potential of wiregrass seed, compaction of the disturbed soil should take place before or directly after sowing (Dwyer et al. 2010). Although there are no known studies supporting this method, soil compaction is a common practice among restoration practitioners (Bisset 1998, Cox et al. 2004, Disney Wilderness Preserve 2000, Hattenbach et al. 1998, Pfaff and Gonter 1996, Seamon 1998).

Wiregrass Caryopsis Production

Wiregrass (*Aristida stricta* Michx., syn. *A. berichiana* Trinius and Ruprecht) is a long-lived perennial bunchgrass. Production of wind-pollinated flowering stalks is stimulated by disturbance of the above-ground plant parts by fire or clipping (Parrott 1967) or by the release of wiregrass from competition by heavy pine thinning or hardwood control (pers. observ.) during the growing-season (mid-March to July). Wiregrass produces caryopses (seed of a grass) in late summer/early fall. Wiregrass seeds generally reach maturation in October–December (color change of spikelet from green to light brown and splaying of awns out from spikelet) (pers. observ.) and are dropped in December –January (McGee 1996). Through many years of

observation by restoration practitioners at Fort Stewart and the USDA Forest Service's Southern Research Station, evidence suggests that the date of seed production is directly related to the date of stimulatory disturbance. Therefore, the succession of dates of seed maturation among individual populations follows the same succession of dates of stimulatory disturbance for those populations (S. Osborne, pers. comm., Walker and Silletti 2006).

Three awns are attached to the lemma enclosing the fruit of the caryopses (Figure 1). The awns respond to changes in humidity levels by twisting. Twisting of these hygroscopic awns causes the seed to move after dispersal, which maximizes germination by increasing the chances of finding a microsite that meets the requirements of the regeneration niche. The barbed callus (on the tip of the lemma) anchors the seed once a suitable location has been attained. These phenotypic characteristics are considered to be adaptations to increase seedling establishment (Stamp 1989, Sindel et al. 1993).

Wiregrass Caryopsis Germination

Successful regeneration of a plant from seed is dependent upon species-specific requirements, called a regeneration niche (Grubb 1977). Regeneration involves four processes: the production of viable seed, the dispersal of the seed, germination, and establishment. Once viable seed has been dispersed, the necessary requirements for germination and establishment of a species must be met by the microclimatic conditions of the site in which the seed was sown (McGee 1996). Wiregrass seed requires certain minimum requirements to induce germination: water, oxygen, and a temperature above 10°C (McGee, 1996). By testing the effects of temperature and photoperiod in germination McGee (1996) found that there are no apparent

dormancy mechanisms in wiregrass seed. Once seed is dispersed, germination can occur as soon as appropriate conditions are met.

Wiregrass seedlings are most vulnerable immediately following emergence from seed (Maun 1981, Fenner 1987, Maze and Whalley 1992). In a natural setting, neighboring plants and small amounts of litter and debris from the pine over-story create a buffer which helps stabilize microclimatic conditions around newly emerged seedlings (Bookman 1983, Chambers et al. 1990, Potvin 1993), and acceptable seed-to-soil contact is achieved where mineral soil is exposed (Walker and Silletti 2006).

Soil disturbance, caused by logging operations or site preparation, can reduce survival of wiregrass seedlings. A loss of moisture and creation of air pockets in the soil leads to desiccation of the radicle or root of the wiregrass seedling prior to establishment (Aguilera and Laurenroth 1993). Sufficient seed bed preparation must be accomplished prior to sowing wiregrass seed in order to provide the necessary requirements for successful germination of the seed and survival of the seedling (Dwyer et al. 2010).

Objectives

The first objective of this thesis is to test the effects of differing harvest dates on wiregrass seed germination. Walker (2006) states that there may be an after-ripening effect in wiregrass seed, as higher germination rates were observed in wiregrass seed collected on later dates (van Eerden 1997, Walker and Sillettii, unpublished data, as cited in Walker and Sillettii 2006). The second objective is to compare two site preparation methods used in treating disturbed soil and maximizing soil moisture retention and seed-to-soil contact prior to planting wiregrass seed: (1) using the tracks of a bulldozer or (2) using a cultipacker (Figure 2) mounted

on a farm tractor. Bulldozers have been used by biologists at Fort Stewart in past successful wiregrass restoration efforts, although roller-compactors and cultipackers are the recommended pieces of equipment for soil preparation given by the authors of Ground Cover Restoration Implementation Guidebook (Dwyer et al. 2010). The results of wiregrass restoration efforts using a cultipacker (as opposed to a bulldozer) in restoration efforts at Fort Stewart have yet to be determined. This comparison is meant to determine which method provides ground conditions most conducive to the establishment of wiregrass seedlings and give guidance for restoration practitioners at Fort Stewart to update their soil preparation protocols.

Methods

<u>Study Area</u>

The study site was located on Fort Stewart Military Reservation, Georgia, USA (32°03' N, 81°49' W). I conducted field studies on a 13.7 hectare clear-cut tract at Fort Stewart, in Natural Resource Management Unit (NRMU) E20.3 (near the western-most boundary, in Long County) (Figure 3). The study site was a slash pine (*Pinus elliottii* Engelm. var. *elliottii*) plantation, established in 1972 by the Fort Stewart Forestry Branch, and remained in that state until the 2008 clear-cut. The site was used as an agricultural field prior to acquisition of the property by the U.S. Army in 1940. This classification is based upon a 1947 aerial photograph of the site (Figure 4) and the presence of noxious agricultural weeds, such as dog fennel (*Eupatorium capaillifolium* [Lam.] Small) and showy rattlebox (*Crotalaria spectabilis* Roth), which emerged from the seed bank after removal of stumps, roots, and debris in 2008 (pers. observ.) The study site is on Dothan series loamy sands, which are very deep, well drained,

slowly permeable soils of unconsolidated, medium to fine-textured marine sediments of the Coastal Plain. These soils are moderately to strongly acidic (National Cooperative Soil Survey 2013). The ten-year average annual rainfall is 119.9 cm (range 79.4-166.9) (Fort Stewart weather station data).

Site Preparation

The study site was clear-cut and all stumps, roots, and debris were removed in 2008. The tract was disked in January 2010, prior to preparation of the seed bed, using land-clearing harrows. Disking the tract had two purposes. First, it disturbed the soil in a fashion that mimicked the soil disturbance caused by removal of stumps, roots, and debris. Second, it turned the herbaceous ground cover into the soil and chopped pine seedlings and hardwood sprouts, reducing competition for resources, thus maximizing wiregrass seedling establishment (Walker and Roth 2007).

Seed Collection and Storage

The wiregrass seeds used in this study were harvested from one population of wiregrass, which was burned to prescription (a control burn protocol written into natural resource management plans) on 10 April 2009. The collection site is located in NRMU E12.2, approximately 6.7 km ESE of the study site. Wiregrass seed was harvested when seeds were easily stripped from spikelets as they were pulled between the thumb and index finger. Collection began on 6 November 2009 and was completed on 21 December 2009. Wiregrass seed was harvested using a Woodward Flail-Vac Seed Stripper (henceforth referred to as "seed stripper"), manufactured by Ag-Renewal Inc., which was attached to the front-end lift arms of a

farm tractor. The seed stripper uses a rotating brush to strip the seed from the stalk and deposit it into a hopper. This method of collection is non-discriminatory, meaning that in addition to wiregrass seed, dry accessory plant parts, such as chaff and stem pieces, and seeds of other species that come into contact with the brush are deposited into the hopper (Pfaff et al. 2002, Walker and Silletti 2006).

Wiregrass seed was emptied from the hopper of the seed stripper into standard woven poly feed sacs at a mean rate of 1.23±0.23 SD kg. Feed sacs were weighed, labeled and stacked in loose rows on wire shelves in a storage warehouse. The storage warehouse was heated to maintain an air temperature of about 20°C. Wiregrass seed was stored in this manner until sowing (about 4 months). Loss of viability was not a concern, as wiregrass seed stored in this manner could retain viability for 2 years (Glitzenstein et al. 2001).

Germination Test

Germination of the wiregrass seed was determined using testing protocols established and conducted at Fort Stewart Fish and Wildlife Branch in preceding years. Germination rates were tested against the date of collection (November 6 – December 21, 2009) to account for any effects in wiregrass seed germination rates that an after-ripening process may have. A random sample of wiregrass seed was taken from each feed sac. Individual seeds were chosen randomly at a rate of 25 seeds per sample. To insure viability, seeds were visually inspected for the presence of an embryo within the lemma. This is easily seen, as a lemma void of an embryo is lighter in color, thinner, and less ridged than a lemma containing an embryo (pers. observ.). Randomly selected seeds void of an embryo were discarded and another seed was randomly selected in its stead.

Each set of 25 seeds was placed on a moistened 7.5-cm diameter filter paper within a 9-cm diameter petri dish. Covered petri dishes were stored on a shelf at room temperature (about 20°C). Petri dishes were monitored weekly, at which time filter papers were re-moistened, seeds that had germinated were counted and removed, and petri dishes were rearranged to minimize microclimatic differences among samples. Germination was defined as the emergence of the radicle. The germination test was concluded at day 60 when there had been no observation of germinated seed in a seven-day period.

Study Plots

The study site was divided into 4 quadrants of similar area (Figure 5). Lines of division were established using ArcGIS software in north-south and east-west directions. . The north-western quadrant (Plot 1) is 3.60 ha, the north-eastern quadrant (Plot 2) is 3.28 ha, the south-western quadrant (Plot 3) is 3.26 ha, and the south-eastern quadrant (Plot 4) is 3.57 ha. Quadrant boundaries within the interior of the study site were marked with 1-m tall pvc pipe driven vertically into the ground. This configuration was used in an effort to reduce variability due to abiotic factors (sunlight and wind).

Seedbed Preparation

Preparation of the seed bed was accomplished using one of two methods (treatments). Disturbed soil was leveled and compacted using either a cultipacker or a bulldozer. Plots 1 and 4 received the cultipacker treatment, and Plots 2 and 3 received the bulldozer treatment. The directions of treatment passes were north-south for Plots 1 and 2, and east-west for Plots 3 and 4.

The cultipacker used for this study is a Brillion Pulverizer PPD-10 3-meter-wide cultipacker affixed to the rear lift arms of a John Deere 6400 4WD farm tractor (Figure 2). This piece of equipment uses its own weight to compact the soil and creates a ground pressure of 2.5 psi. The bulldozer used for this study is a Caterpillar D4C LPG with two 63.5-cm-wide tracks (1.27 meter overall width). This piece of equipment creates a ground pressure of 4.2 psi.

Sowing Treatment

The sowing rate established for this study was 13.6 kg of material per hectare, based on results from germination testing (16.88 % germination rate). Anecdotal evidence (sowing rates and corresponding germination rates) from previous successful restoration projects conducted by Fort Stewart Fish and Wildlife Branch were used to establish this protocol. Wiregrass restoration protocols established by Fort Stewart Fish and Wildlife Branch for their restoration program prescribe lower sowing rates than found in the literature. Sites sown in previous years at rates of 11-15 kg material per hectare have proven to yield acceptable results ($\geq$3 seedlings/m^2) (Fort Stewart Fish and Wildlife Branch unpublished data). The suggested sowing rate of wiregrass seed harvested by a seed stripper is 56 kg material per hectare to achieve a goal of 3 established wiregrass seedlings per square meter (Disney Wilderness Preserve 2000). Sowing rates used in previous studies range from 25-133 kg material per hectare for stripped seed (Disney Wilderness Preserve 2000, Seamon 1998).

Wiregrass seed was sown using a standard hay blower affixed to the rear lift arms of a farm tractor and powered by the tractor's power-take-off (PTO). Hay blowers are recommended for efficient distribution of wiregrass seed over a large area where even distribution of seed and control of seed placement is desired (Disney Wilderness Preserve 2000, Pfaff et al. 2002, Walker

and Silletti 2006). Feed sacs (containing harvested wiregrass seed) were selected in random

order while sowing to reduce variation due to differing germination rates among samples.

Sowing was conducted in an east-west direction across all quadrants without regard to plot

boundaries. Sowing took place on 23 February, 1, 4, and 5 March 2010.

Competition Control

I mowed the study site in September, 2010 using a 4.5 meter wide batwing mower

attached to a farm tractor. The mower was used at the highest setting to avoid contact with

wiregrass seedlings. The objective of mowing the study site was to inhibit an increase of the

density of competing species from seed by mowing their reproductive parts before mature seed

was produced (Dwyer et al. 2010). Prescribed fire or herbicide control methods are not

recommended during the first two years following wiregrass sowing, as the young plants are

vulnerable to destruction by either method (Dwyer et al. 2012, Walker and Sillettii 2006).

Monitoring and Data Collection

I stratified the plots within the study area into 0.25-hectare sub-plots by laying a grid over

a map of the study site using ArcGIS software. Monitoring points were randomly generated at a

rate of 3 per sub-plot using ArcGIS, resulting in 90 monitoring points per treatment (Figure 5). I

transferred the resulting map to a Tremble Ranger portable global positioning system (GPS). I

used ArcPad software to navigate to each monitoring point and stored data in the attributes table

for the "points" shape file.

I used a 1-m^2 inside-area quadrat constructed of pvc pipe for data collection at each point.

Data collected from within each quadrat were: number of wiregrass seedlings (establishment

frequency); wiregrass seedling leaf length and wiregrass seedling diameter (vigor). Monitoring was conducted March-April 2012, two growing seasons after wiregrass seed was sown.

I counted wiregrass seedlings only if the complete base of the seedling fell within the inside edge of the quadrat. Seedlings whose base was only partially inside the quadrat were counted as 0.5. The final number of seedlings recorded for each quadrat was rounded to the nearest whole number.

I measured wiregrass seedling leaf length using a meter stick to the nearest mm. Leaves were gathered from the base, and a measurement was taken from the longest leaf of each seedling. Mean leaf length was recorded for each quadrat.

I measured wiregrass seedling diameter using a dialMax SPi 2000 caliper to the nearest mm. Leaves were gathered from the base, and measurements were taken from the base of the seedling. Mean diameter measurements were taken for asymmetrical seedlings. Mean seedling diameter was recorded for each quadrat.

Data Analysis

I compared wiregrass seed germination rates among harvest dates with a one-way ANOVA and calculated variance components. Means and coefficients of variation (CV's) were used to describe the data collected from the plots and variance components were calculated for wiregrass seedling density, diameter, and leaf length. I tested wiregrass seedling distribution against a Poisson distribution using a Chi-square test. I generated graphs for visualization of trends in the data.

Results

Germination Test

Results of the germination test revealed a mean wiregrass seed germination rate of 16.88% (range, 0% to 50%). Harvest date (day) ($F_{11, 140}$=5.26, p<0.0001) significantly affected germination (Table 1). In this population of wiregrass, 25.7% percent of the variation in germination rates was due to among-date variation (Table 2). Mean germination rates gradually rose from early-November to mid-November (6.25% ±2.87 SE to 28.93% ±2.65 SE) and gradually declined from late-November through December (28.93% ±2.65 SE to 6.00% ±4.44 SE), with highest mean germination rate observed from seed harvested on 19 November 2009 (28.93% ±2.65 SE) (Figure 6).

Seedling Establishment

Means of wiregrass seedlings per m^2 were similar among the cultipacker treatment (mean of 7.3±0.8 SE, range 0 to 33, CV 98.4) and the bulldozer treatment (mean of 6.5±0.6 SE, range 0 to 23, CV 84.6) (Table 3, Figure 7). Means of wiregrass seedlings per m^2 were similar among plots within treatments (Table 4, Figure 8). In this site, none of the variation in seedlings per m^2 can be attributed to treatment, about 1.4% of the variation is due to within-plot effects, and about 98.6% of the variation is unexplained among-plot variation (Table 5). The distribution of wiregrass seedlings in this site does not fit a Poisson distribution (λ=6.9, χ^2=9349028070 p<0.0001), and wiregrass seedlings are clumped (CD=4.7) (Table 6, Figure 9).

<u>Seedling Vigor</u>

Means of wiregrass seedling diameter were similar among the cultipacker treatment (mean of 2.1±0.1 SE cm, range 0.2 to 5.1 cm, CV 48.8) and the bulldozer treatment (mean of 2.1±0.1 SE cm, range 0.5 to 5.2 cm, CV 52.9) (Table 3, Figure 10). Means of wiregrass seedling diameters were also similar among plots within each treatment (Table 4, Figure 11). In this site, none of the variation in seedling diameter can be attributed to treatment, about 0.1% of the variation is due to within-plot effects, and about 99.9% of the variation is unexplained among-plot variation (Table 7).

Means of wiregrass seedling leaf length were similar among the cultipacker treatment (mean of 54.5±1.1 SE cm, range 28.5 to 87.8 cm, CV 18.6) and the bulldozer treatment (mean of 52.6±0.9 SE cm, range 28.8 to 71.3 cm, CV 15.6) (Table 3, Figure 12). Means of wiregrass seedling leaf lengths were also similar among plots within each treatment (Table 4, Figure 13). In this site, about 1.1% of the variation in seedling leaf length can be attributed to treatment, none of the variation is due to within-plot effects, and about 98.9% of the variation is unexplained among-plot variation (Table 8).

Discussion

<u>Germination</u>

The germination rate of wiregrass seed used in this study (16.9%) is not typical of wiregrass germination rates observed in other studies. Most trials in Glitzenstein's (2001) study had germination rates above 30%, and in McGee's (1996) study germination rates were 30-60 %.

About 25.8% of the variation in mean wiregrass seed germination rates among samples is due to significant differences in mean germination rates among harvest dates. This suggests that there are after-ripening effects in mature wiregrass seeds that affect germination. Germination rates ranged from 13.67-28.93% on harvest days November 13 – December 1 (between the seventh and twentieth day in the harvest date range). Similar results were observed in North and South Carolina (van Eerden 1997) and other parts of Georgia (Walker and Sillettii, unpublished data, as cited in Walker and Sillettii 2006).

Delaying wiregrass seed collection for a short period of time after seed maturation could increase germination rates, as seen in Figure 6. Additionally, completing seed harvest as soon as possible could further increase germination rates. This is not always feasible or efficient due to equipment availability and the amount of time required for harvest efforts.

I would recommend a more extensive study of after-ripening effects in wiregrass seed by comparing wiregrass populations across different ecosystem types, different geographical areas, and in different years. If a more precise timeline of after-ripening could be established, restoration practitioners could adjust their action plans to take advantage of higher germination rates. Potentially, they could increase wiregrass seedling density in a restoration site or decrease the weight of stripped material distributed per hectare, thus increasing the number of hectares that could be restored.

Another factor that may have affected mean germination rates among samples was the presence of smut (*Ustilaginales* sp.), a fungus that attacks the seed during germination. I observed higher than usual amounts of smut on wiregrass seed harvested in 2009. This was likely due to the higher than normal rainfall experienced during seed production (Figure 14). Smut micorrhizae was observed on seeds and filter paper during the germination test.

Soil Preparation

Wiregrass seedling establishment frequency and vigor were similar among treatments and plots, and more than 98% of the variation is due to unexplained effects among the plots. Neither treatment can be said to be more or less effective to the establishment of wiregrass seedlings based on these data. In each of the three categories (seedling frequency, mean seedling diameter, and mean seedling leaf length), the means fall within 1 standard error of each other among treatments.

The clustered distribution of wiregrass seedlings across this site is not due to topography. I compared Figure 9 to the topography of the site and did not find any similarities. The most probable cause of the clustered distribution is variation in seed distribution. There were three people involved in seed distribution at any given time: a tractor operator, a technician feed seed into the hay blower, and a technician directing seed dispersal. I recommend a study of seed dispersal to test the effects of tractor speed, distance between passes, and beginning and end points for each bag of seed. These measurements would give a more accurate account of sow rate and spatial seed dispersal, and they would also give expected germination rate and seedling density for any given area of a restoration site.

Conclusion

I used only one restoration site in this study, which limited generalization to other sites. However, the results of this study have value to land management practices. Results of this study can be used to assess and improve current wiregrass restoration protocols by biologists at Fort Stewart, and as a consideration for restoration practitioners in the Atlantic Coastal Plain.

These results can also be used for management decisions within action plans, such as harvest dates and equipment selection.

In the area of seed bed preparation treatments, equipment may be selected according to availability, without regard to wiregrass seedling establishment frequency or vigor, as both have been shown to yield similar results, according to this study. In situations where equipment availability is not a concern, costs associated with equipment operation (fuel, time, and labor) can be easily compared in selecting the appropriate piece of equipment for seed bed preparation. Dwyer et al. (2010) and Trusty and Ober (2009) both provide cost estimates for a range of equipment usage in restoration efforts. Both treatments used in this study have proven to provide a suitable seed bed for germination and establishment of wiregrass seedlings.

It is my recommendation that restoration practitioners at Fort Stewart use the cultipacker for seed bed preparation of disturbed soils. The cultipacker covers more than twice the area per pass than the bulldozer, making it more efficient than the bulldozer. The cultipacker also requires less time per hectare (1.05 hr/ha) in seed bed preparation than the bulldozer (1.53 hr/ha), reducing the amount of time required for equipment operation. Also, the cultipacker is affixed to a farm tractor, which can be operated by any of the wildlife technicians at Fort Stewart, whereas the bulldozer can only be operated by a few trained equipment operators, meaning that there is a greater availability of operators to prepare seed beds for wiregrass restoration with the cultipacker than with the bulldozer. Finally, the cost (fuel cost/hr × operator's hourly wage × hr/ha) of using the cultipacker in this study was much less ($143.33/ha) than using the bulldozer ($381.89/ha) (Table 9). Thus, by using a cultipacker, the costs and time associated with seed bed preparation can be greatly reduced.

Literature Cited

Abrahamson WG, Hartnett DC. 1990. Pine flatwoods and dry prairies. In: Myers RL, Ewel JJ, editors. Ecosystems of Florida. Orlando, Florida: University of Central Florida Press. p 103-49.

Aguilera MO, Laurenroth WK. 1993. Seedling establishment in adult neighborhoods-interspecific constraints in the regeneration of the bunchgrass *Bouteloua gracilis*. J Ecol 81:253-61.

Ahlgren CE. 1979. Emergent seedlings on soil from burned and unburned red pine forest. Minnesota Forestry Research Notes 273. St. Paul, MN: University of Minnesota College of Forestry.

Aschenbach TA, Foster BL, Imm DW. 2007. Longleaf pine plant community restoration at the Savannah River Site: design and preliminary results. In: Proceedings of the 6th Longleaf Alliance Regional Conference; Longleaf pine: Seeing the forest through the trees. November 13-16, 2006. Tifton, GA. Longleaf Alliance Report No. 10. Andalusia, AL: The Longleaf Alliance. p 54-57.

Bissett NJ. 1998. Direct seeding wiregrass, *Aristida stricta*, and associated species. In: Proceedings of the Longleaf Pine Ecosystem Restoration Symposium. November 12-15 1997. Fort Lauderdale, Florida. The Longleaf Alliance Report No. 3. Fort Lauderdale, FL: The Longleaf Alliance. p 50-60.

Bookman PA. 1983. Microsite utilization by *Bromus tectorum* and *Poa pratensis* in a meadow steppe community. Oecologia 56:413-18.

Chambers JC, MacMahon JA, Brown RW. 1990. Alpine seeding establishment: the influence of disturbance type. Ecology 71:1323-41.

Christensen NL. 1993. The effects of fire on nutrient cycles in longleaf pine ecosystems. In: Herman SH, editor. Proceedings of the 18th Tall Timbers Fire Ecology Conference: The longleaf pine ecosystem: ecology, restoration, and management. May 30-June 2, 1991. Tallahassee, FL. Tallahassee, FL: Tall Timbers Research Station. p 205-14.

Clewell AF. 1989. Natural history of wiregrass (*Aristida stricta* Michx., Gramineae). Nat Areas J 9:223-33.

Cox AC, Gordon DR, Slapcinsky JL, Seamon GS. 2004. Understory restoration in longleaf pine sandhills. Nat Areas J 24:4-14.

Disney Wilderness Preserve. 2000. Proceedings of the Upland Restoration Workshop. Kissimmee, FL. Kissimmee, FL: The Nature Conservancy.

Dwyer N, Glass S, McCollom J, Marois K. 2010. Groundcover restoration implementation guidebook - Restoring native groundcover for FWC restoration practitioners. Florida Fish and Wildlife conservation Commission, Division of Habitat and Species Conservation, Terrestrial Habitat Conservation and Restoration Section, Groundcover Restoration Implementation strategy Team.

Fenner M. 1987. Seedlings. New Phytol 106:35-47.

Frost C. 1993. Four centuries of changing landscape patterns in the longleaf pine ecosystem. In: Hermann SH. editor. The longleaf pine ecosystem: ecology, restoration, and management. Proceedings of the 18th Tall Timbers Fire Ecology Conference; 1991 May 30-Jun 2; Tallahassee, FL. Tallahassee, FL: Tall Timbers Research Station. p 17-44.

Frost C. 2006. History and future of the longleaf pine ecosystem. In: Jose S, Jokela EJ, Miller DL, editors. The longleaf pine ecosystem: ecology, silviculture, and restoration. New York, NY: Springer. p 9-42.

Glitzenstein JS, Streng DR, Wade DD, Brubaker J. 2001. Starting new plants of longleaf pine ground-layer plants in the outer coastal plain of South Carolina, USA. Nat Areas J 21:89-110.

Grubb PJ. 1997. Maintenance of species-richness in plant communities: the importance of the regeneration niche. Biol Rev 52:107-45.

Hattenbach MJ, Gordon DR, Seamon GS, Studenmund RG. 1998. Development of direct seeding techniques to restore native groundcover in a sandhill ecosystem. In: Proceedings of the Longleaf Pine Ecosystem Restoration Symposium. November 12-15 1997. Fort Lauderdale, Florida. The Longleaf Alliance Report No. 3. Fort Lauderdale, FL: The Longleaf Alliance. p 64-70.

Hermann SM. 2007. How does longleaf pine native groundcover fit with forest management goals? In: Proceedings of the 6th Longleaf Alliance Regional Conference; Longleaf pine: Seeing the forest through the trees. November 13-16, 2006. Tifton, GA. Longleaf Alliance Report No. 10. Andalusia, AL: The Longleaf Alliance. p 28-31.

Landers JL. 1991. Disturbance influences on pine traits in the southeastern United States. In: Hermann SH, editor. Proceedings of the 17th Tall Timbers Fire Ecology Conference: High intensity fire in wildlands. May 18-21, 1989. Tallahassee, FL. Tallahassee, FL: Tall Timbers Research Station. p 61-98.

Maun MA. 1981. Seed germination and seedling establishment of *Calamovilfa* on Lake Huron sand dunes. Can J Bot 59:460-469.

Maze KM, Whalley RDB. 1992. Germination, seedling occurrence and seedling survival of *Spinifex sericeus* R.Br. (Poaceae). Aust J Ecol 17:189-194.

McGee AJ. 1996. Seed ecology of bunchgrasses of longleaf pine-wiregrass communities at Fort Stewart, Georgia. MS thesis. Statesboro, GA: Georgia Southern University.

Mulligan M, Kirkman LK, Mitchell RJ. 1999. Wiregrass (*Aristida stricta* Michx.) establishment with restoration implications. In: Kush JS (editor). Proceedings of the 2nd Longleaf Alliance Conference. November 17-19, 1998. Charleston, SC. Longleaf Alliance Report No. 4. Auburn University, AL: The Longleaf Alliance.

Mulligan MK, Kirkman LK, Mitchell RJ. 2002. *Aristida beyrichiana* (wiregrass) establishment and recruitment: Implications for restoration. Restoration Ecol 10:334-39.

National Cooperative Soil Survey, USA. [Internet]. January 2013. Dothan series. [2013 February 10]. Available from: https://soilseries.sc.egov.usda.gov/OSD_Docs/D/DOTHAN.html

Noss RF. 1989. Longleaf pine and wiregrass: Keystone components of an endangered ecosystem. Nat Areas J 9:211-213.

Outcalt KW, Sheffield RM. 1996. The longleaf pine forest: trends and current conditions. US Department of Agriculture, Forest Service Research Bulletin SRS-9. Ashville, NC: Southern Research Station.

Outcalt KW, Williams ME, Onokpise O. 1999. Restoring *Aristida stricta* to *Pinus palustris* ecosystems on the Atlantic coastal plain, USA. Restoration Ecol 7:262-70.

Parrott RT. 1967. A study of wiregrass (*Aristida stricta* Michx.) with particular reference to fire. MS thesis. Durham, NC: Duke University.

Pfaff S, Govter MA. 1996. Florida native plant collection, production, and direct seeding techniques: Interim report. Brooksville, FL: USDA, Natural Resources Conservation Service, Plant Materials Center.

Pfaff S, Gonter MA, Maura C. 2002. Florida Native Seed Production Manual. Brooksville FL: USDA, Natural Resources Conservation Service, Plant Materials Center.

Platt WJ, Glitchenstein JS, Streng DR. 1989. Evaluating pyrogenicity and its effects on vegetation in longleaf pine savannahs. In: Hermann SH, editor. Proceedings of the 17th Tall Timbers Fire Ecology Conference: High intensity fire in wildlands. May 18-21, 1989. Tallahassee, FL. Tallahassee, FL: Tall Timbers Research Station. p 143-63.

Potvin MA. 1993. Establishment of native grass seedlings along a topographic/moisture gradient in the Nebraska Sandhills. Am Midl Nat 130:248-61.

Provencher L, Herring BJ, Gordon DR, Rogers HL, Galley KEM, Tanner GW, Hardesty JL, Brennan LA. 2001. Effects of hardwood reduction techniques on longleaf pine sandhill vegetation in northwest Florida. Restoration Ecol 9:13-27.

Rhinehart KO, Menges ES. 2004. Effects of reintroducing fire to a central Florida sandhill community. Appl Veg Sci, 7:141-50.

Seamon G. 1998. A longleaf pine sandhill restoration in northwest Florida. Ecological Rest 16:46-50.

Shibu J, Jokela EJ, Miller DL. 2006. The longleaf pine ecosystem: an overview. In: Jose S, Jokela EJ, Miller DL, editors. The longleaf pine ecosystem: ecology, silviculture, and restoration. New York, NY: Springer. p 3-8.

Sindel BM, Davidson SJ, Kilby MJ, Groves RH. 1993. Germination and establishment of *Themeda triandra* (Kangaroo grass) as affected by soil and seed characteristics. Aust J Bot 41:105-17.

Southern Section, Society of Range Management. 1974. Range Resources of the South. Georgia Agriculture Experimental Station, College of Agriculture Bulletin NS 9. Athens, GA: University of Georgia.

Stamp NE. 1989. Efficacy of explosive vs. hygroscopic seed dispersal by an annual grassland species. Am J Bot 76:555-61.

Trusty JL, Ober HK. 2009. Groundcover restoration in forests of the southeastern United States. CFEOR Research Report 2009-01. Gainsville, FL: University of Florida.

van Eerden BP. 1997. Studies on the reproductive biology of wiregrass (*Aristida stricta* Michaux) in the Carolina sandhills. MS thesis. Athens, GA: University of Georgia.

Walker JL. 1999. Longleaf pine restoration on small and mid-size tracts. In: Kush JS (editor). Proceedings of the 2nd Longleaf Alliance Conference. November 17-19, 1998. Charleston, SC. Longleaf Alliance Report No. 4. Auburn University, AL: The Longleaf Alliance. p 19-22.

Walker JL, Roth L. 2007. Lessons learned about ground-layer restoration. In: Proceedings of the 6th Longleaf Alliance Regional Conference; Longleaf pine: Seeing the forest through the trees. November 13-16, 2006. Tifton, GA. Longleaf Alliance Report No. 10. Andalusia, AL: The Longleaf Alliance. p 46-48.

Walker JL, Silletti AM. 2006. Restoring the ground layer of longleaf pine ecosystems. In: Jose S, Jokela EJ, Miller DL, editors. The longleaf pine ecosystem: ecology, silviculture, and restoration. New York, NY: Springer. p 297-325.

Wells BW, Shunk IV. 1931. The vegetation and habitat factors of the coarser sands of the North Carolina coastal plain: and ecological study. Ecol Monogr 1:465-520.

Table 1: One-way ANOVA of *Aristida stricta* germination rate by harvest date (day) for seed

collected November-December 2009 and germinated December-February 2010.

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Harvest Date	11	0.570	0.052	5.264	<0.0001
Error	140	1.379	0.010		
C. Total	151	1.949			

Table 2: Variance component estimates of *Aristida stricta* seed germination rates.

Random Effect	Variance Ratio	Variance Component	Standard Error	95% Lower CL	95% Upper CL	Percent of Total
Harvest Date	0.35	0.003	0.002	-0.0002	0.007	25.68
Residual		0.01	0.001	0.008	0.01	74.32
Total		0.01	0.002	0.01	0.02	100.00

Table 3: *Aristida stricta* seedling establishment frequency (mean seedling density) and vigor (mean seedling diameter and mean seedling leaf length) among 2 treatments. CP= cultipacker, BD= bulldozer

Treatment	Mean seedling density (seedlings/m^2 ± 1 SE)/CV	Mean seedling diameter (cm ± 1 SE)/CV	Mean seedling leaf length (cm ± 1 SE)/CV
CP	7.3 (0.8)/98.4	2.1 (0.1)/48.8	54.5 (1.1)/18.6
BD	6.5 (0.6)/84.6	2.1 (0.1)/52.9	52.6 (0.9)/15.6

Table 4: Four study plots at Fort Stewart Military Reservation examined for *Aristida sticta* seedling establishment frequency (seedling density) and vigor (mean seedling diameter and mean seedling leaf length) in March 2012. CP= cultipacker, BD= bulldozer, NS= north-south direction of treatment, EW= east-west direction of treatment

Plot #	Treatment/ Direction	Seedling density (seedlings/m^2 ± 1 SE)/CV	Mean seedling diameter (cm ± 1 SE)/CV	Mean seedling leaf length (cm ± 1 SE)/CV
1	CP/NS	6.3 (1.2)/128.1	2.2 (0.2)/51.2	55.5 (1.6)/18.7
2	BD/NS	5.9 (0.9)/97.0	2.2 (0.2)/47.6	53.4 (1.3)/15.4
3	BD/EW	7.1 (0.8)/74.2	2.0 (0.2)/58.4	51.7 (1.3)/15.9
4	CP/EW	8.5 (0.9)/70.0	1.9 (0.1)/45.0	53.4 (1.6)/18.7

Table 5: Variance component estimates of *Aristida stricta* seedling density.

Random Effect	Variance Ratio	Variance Component	Standard Error	95% Lower CL	95% Upper CL	Percent of Total
Plot[Treatment]	0.01	0.57	1.48	-2.34	3.48	1.37
Treatment	-0.01	-0.39	0.86	-2.07	1.30	0.00
Residual		40.82	4.35	33.47	50.91	98.63
Total		41.39	4.50	33.82	51.84	100.00

Table 6: Poisson, Chi-square, and coefficient of distribution of *Aristida stricta* seedling density.

Source	λ	χ^2	Prob > χ^2	Coefficient of Distribution
Seedlings/m^2	6.92	9349028070	<0.0001	4.70

Table 7: Variance component estimates for *Aristida stricta* seedling diameter.

Random Effect	Variance Ratio	Variance Component	Standard Error	95% Lower CL	95% Upper CL	Percent of Total
Plot[Treatment]	0.001	0.001	0.03	-0.06	0.07	0.10
Treatment	-0.01	-0.01	0.02	-0.04	0.02	0.00
Residual		1.10	0.13	0.89	1.39	99.90
Total		1.10	0.12	0.89	1.39	100.00

Table 8: Variance component estimates for *Aristida stricta* seedling leaf length.

Random Effect	Variance Ratio	Variance Component	Standard Error	95% Lower CL	95% Upper CL	Percent of Total
Plot[Treatment]	-0.003	-0.32	1.82	-3.89	3.25	0.00
Treatment	0.01	0.93	2.78	-4.51	6.38	1.08
Residual		85.79	9.68	69.58	108.44	98.92
Total		86.72	10.08	69.92	110.43	100.00

Table 9: Cost estimates for site preparation treatments. CP=cultipacker, BD=bulldozer.

Treatment	Fuel Cost ($/hr)	Operator Wage ($/hr)	Time (hr/ha)	Total Cost ($/ha)
CP	6.50	21.00	1.05	143.33
BD	9.60	26.00	1.53	381.89

Figure 1: *Aristida stricta* caryopsis (seed of a grass) showing adaptive phenotypic characteristics (three hygroscopic awns and barbed callus) which increase chances of germination and seedling establishment.
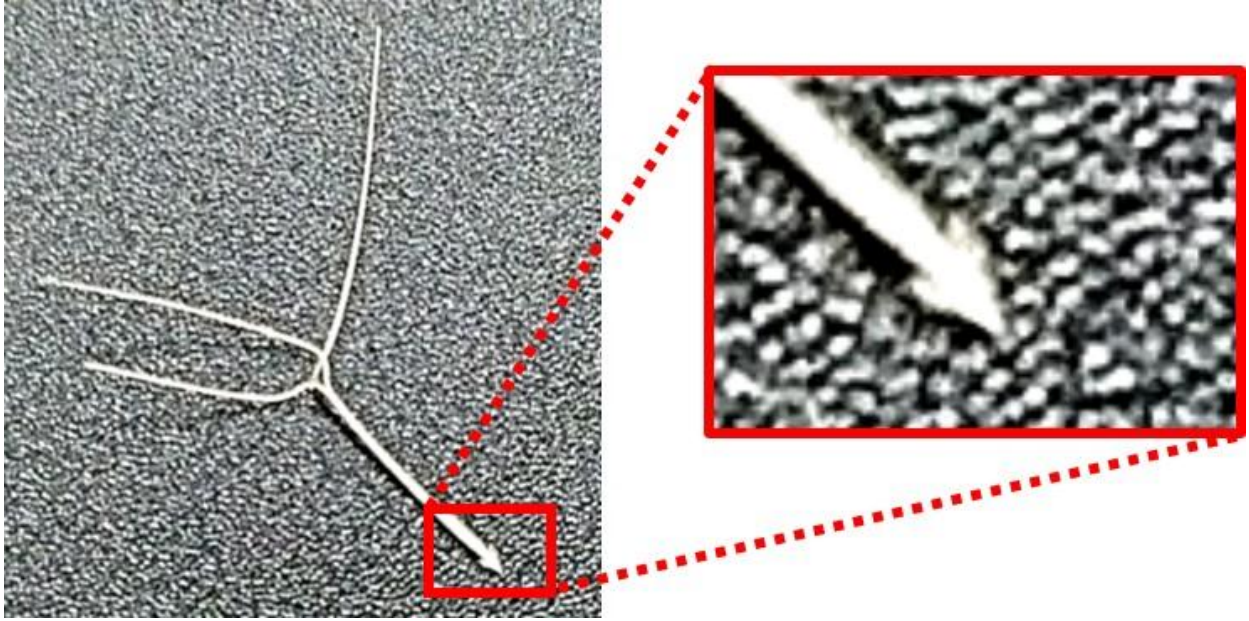
Figure 2: Brillion Pulverizer PPD-10 3-meter-wide cultipacker used in seed bed preparation.

Figure 3: 2011 aerial photograph of 13.7 hectare study site in Natural Resource Management

Unit (NRMU) E20.3, Fort Stewart Military Reservation, Georgia, USA.

Figure 4: 1947 aerial photograph of 13.7 hectare study site in Natural Resource Management Unit (NRMU) E20.3, Fort Stewart Military Reservation, Georgia, USA. Plot boundaries of study site are shown.
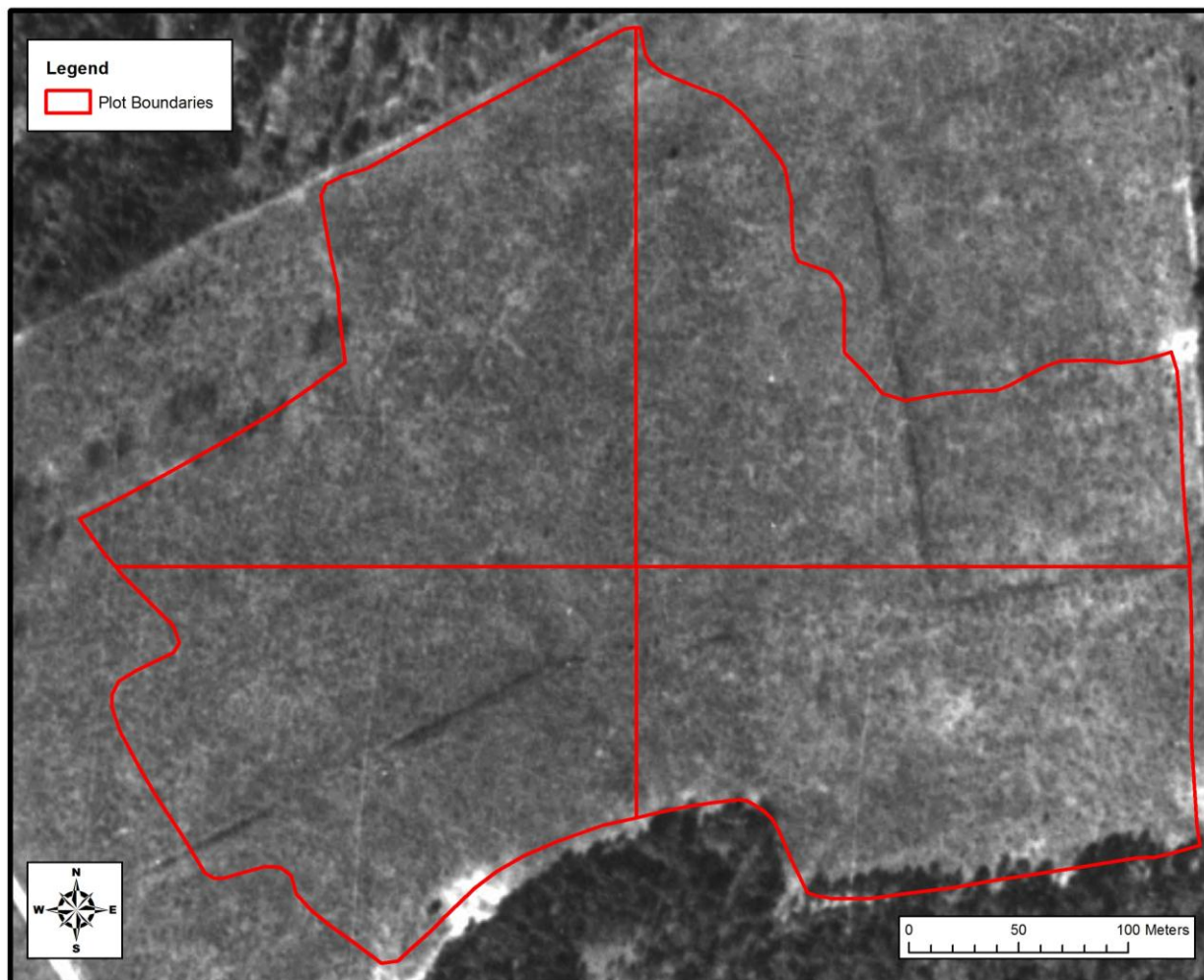
Figure 5: Digital sketch of random monitoring points in study site. Plot boundaries are outlined in red, 0.25 hectare stratifications are outlined in black, and points are blue. There are 3 random monitoring points in each subplot (created by stratification).
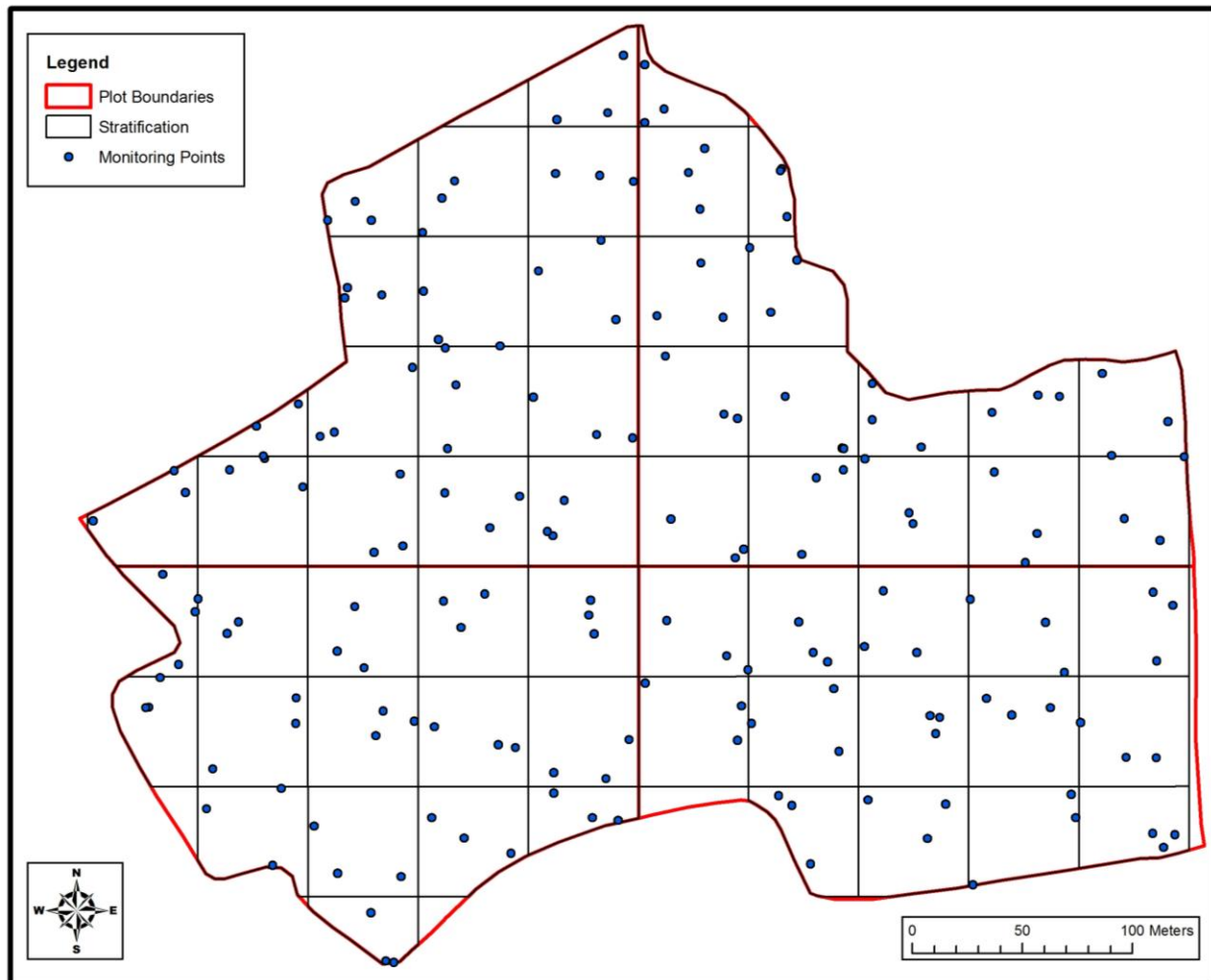
Figure 6: Mean percent germination of *Aristida stricta* seeds harvested at different dates using a Flail-Vac seed stripper, from Natural Resource Management Unit E20.3 at Fort Stewart Military Reservation, Georgia, USA. Error bars are 1 standard error from the mean.
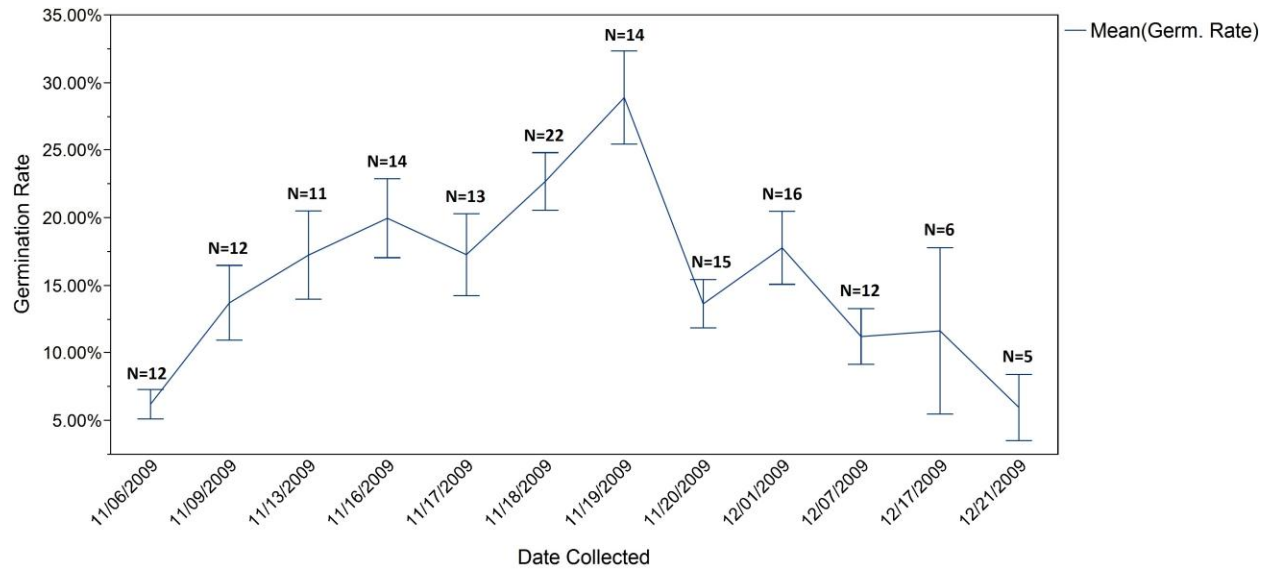
Figure 7: Mean *Aristida stricta* seedling density by cultipacker and bulldozer treatments with 2
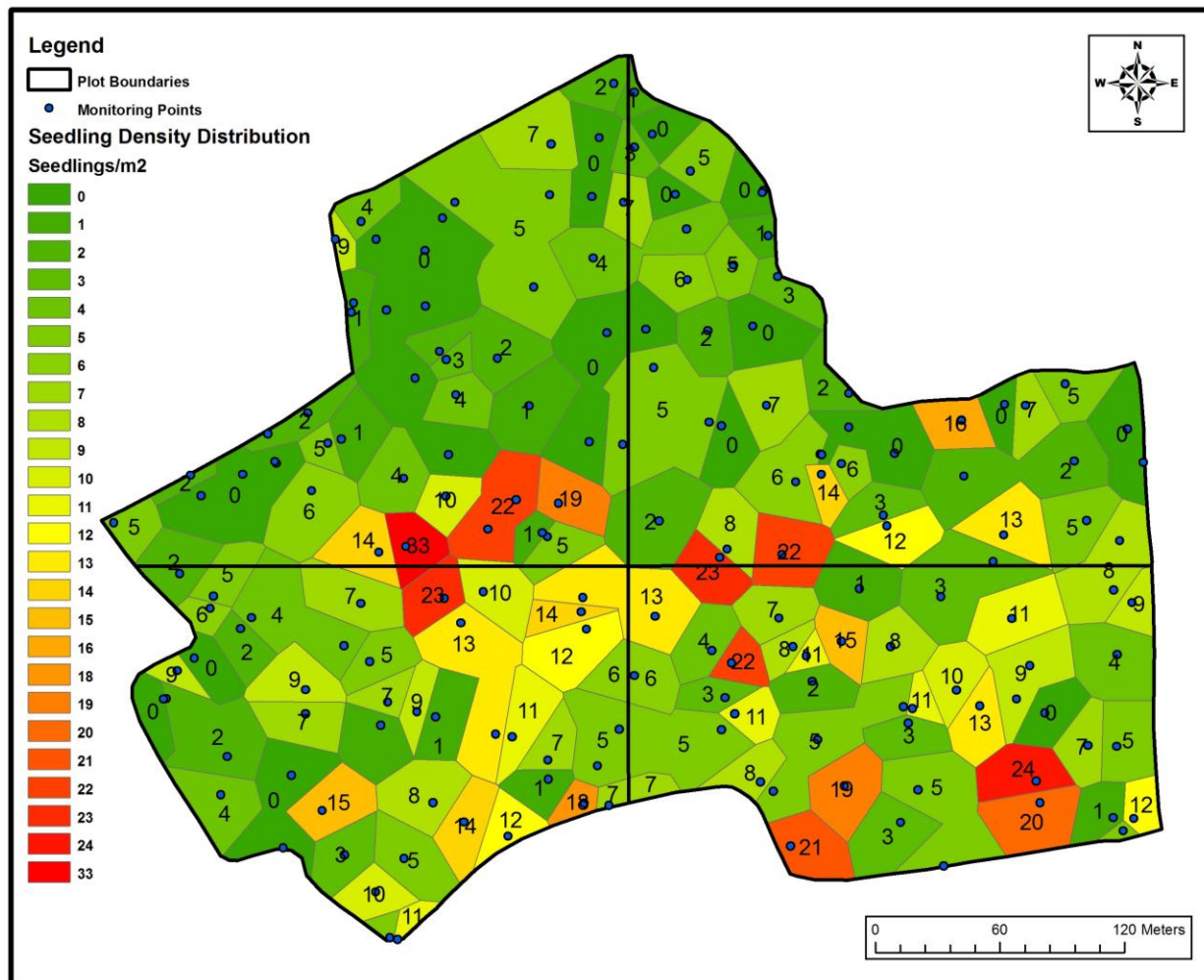
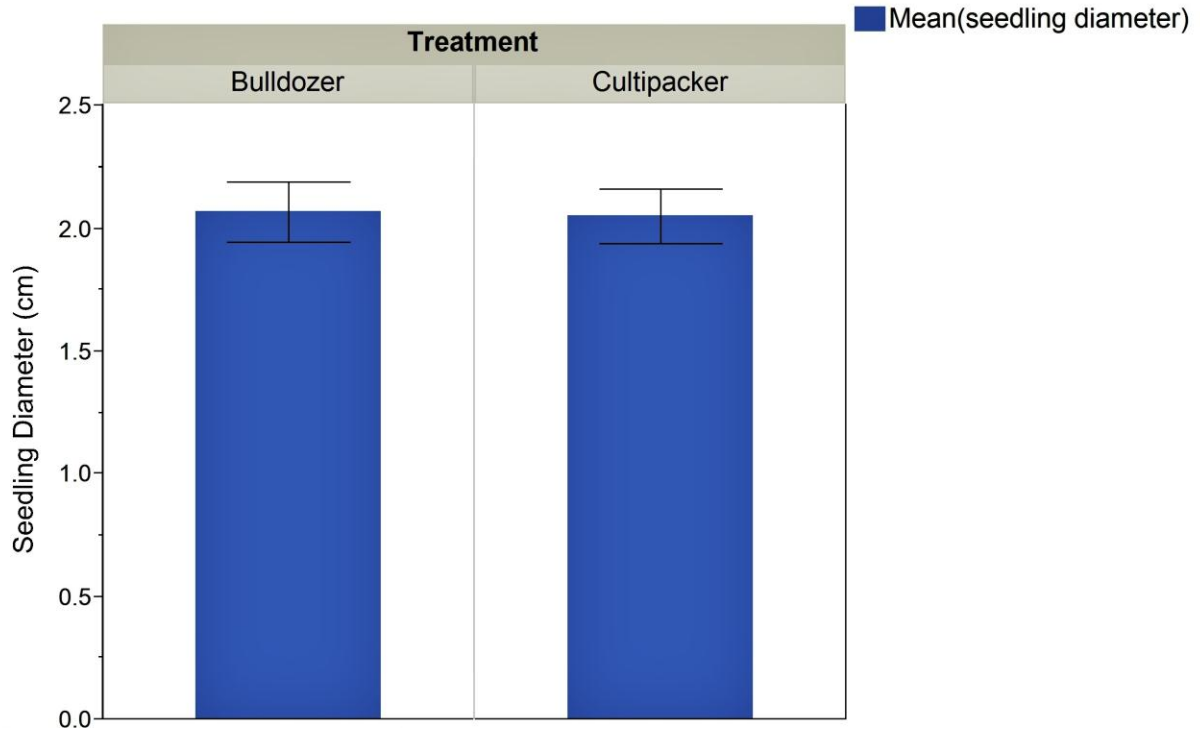replicates for each treatment. Error bars are 1 standard error from the mean.
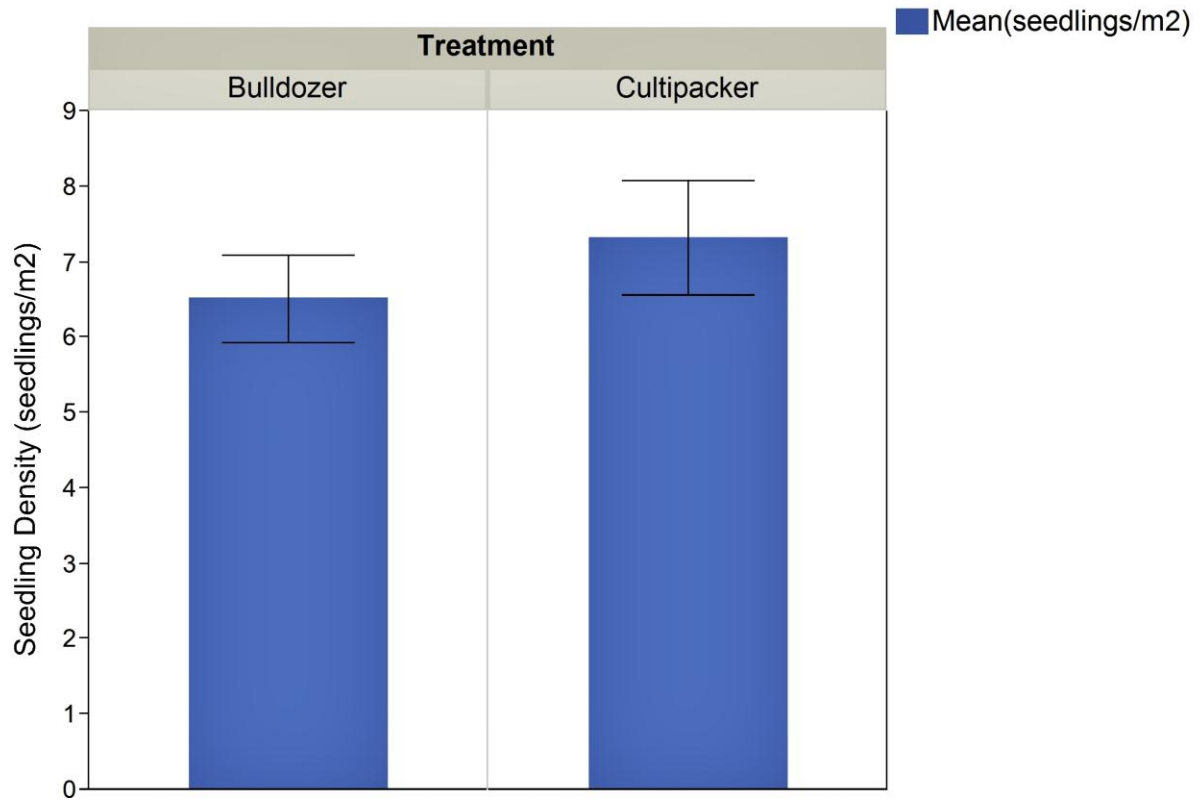
Figure 8: Mean *Aristida stricta* seedling density by cultipacker and bulldozer treatments and

plots. Error bars are 1 standard error from the mean.
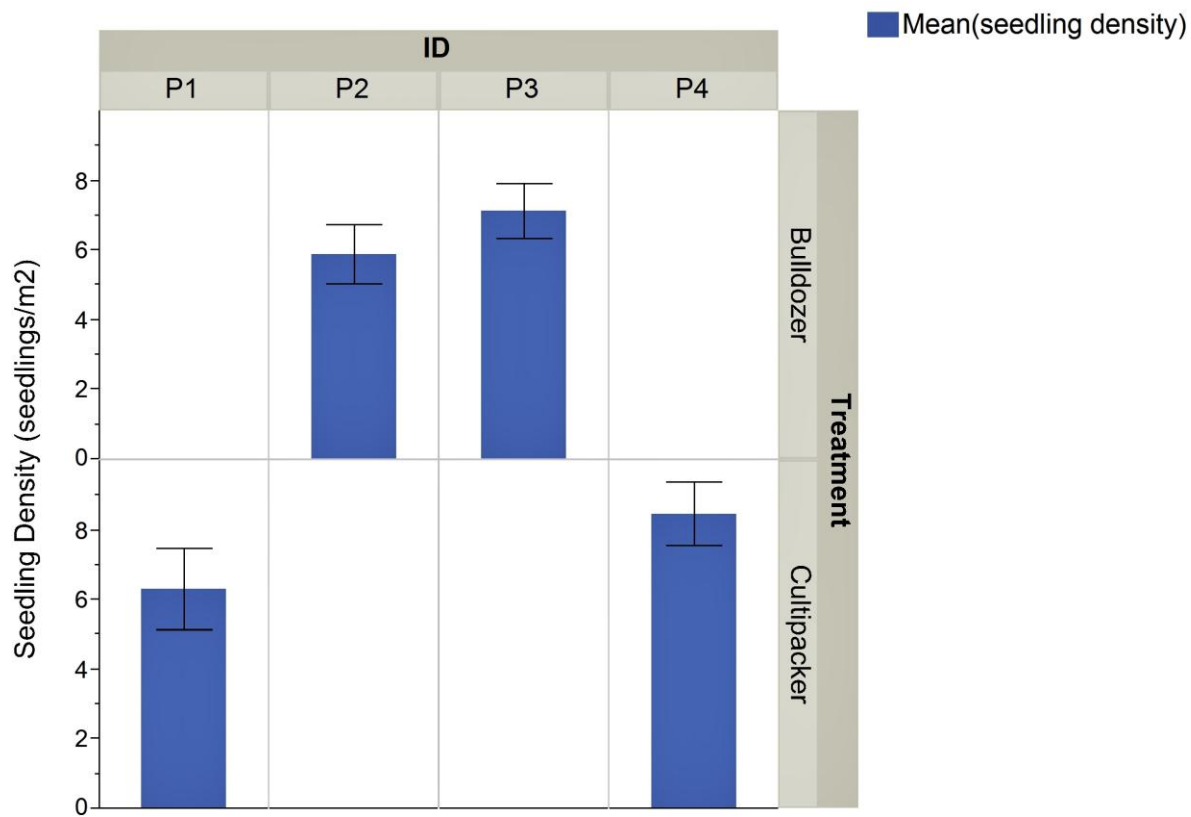
Figure 9: Spatial distribution (clumped distribution) of *Aristida stricta* seedling density (seedlings/m2) in study site. Plots are outlined in black, monitoring points are blue, and density is shown as: lowest=dark green to highest=dark red. Numbers shown on map are density.

Figure 10: Mean *Aristida stricta* seedling diameter by cultipacker and bulldozer treatments with

2 replicates for each treatment. Error bars are 1 standard error from the mean.

Figure 11: Mean *Aristida stricta* seedling diameter by cultipacker and bulldozer treatments and plots. Error bars are 1 standard error from the mean.
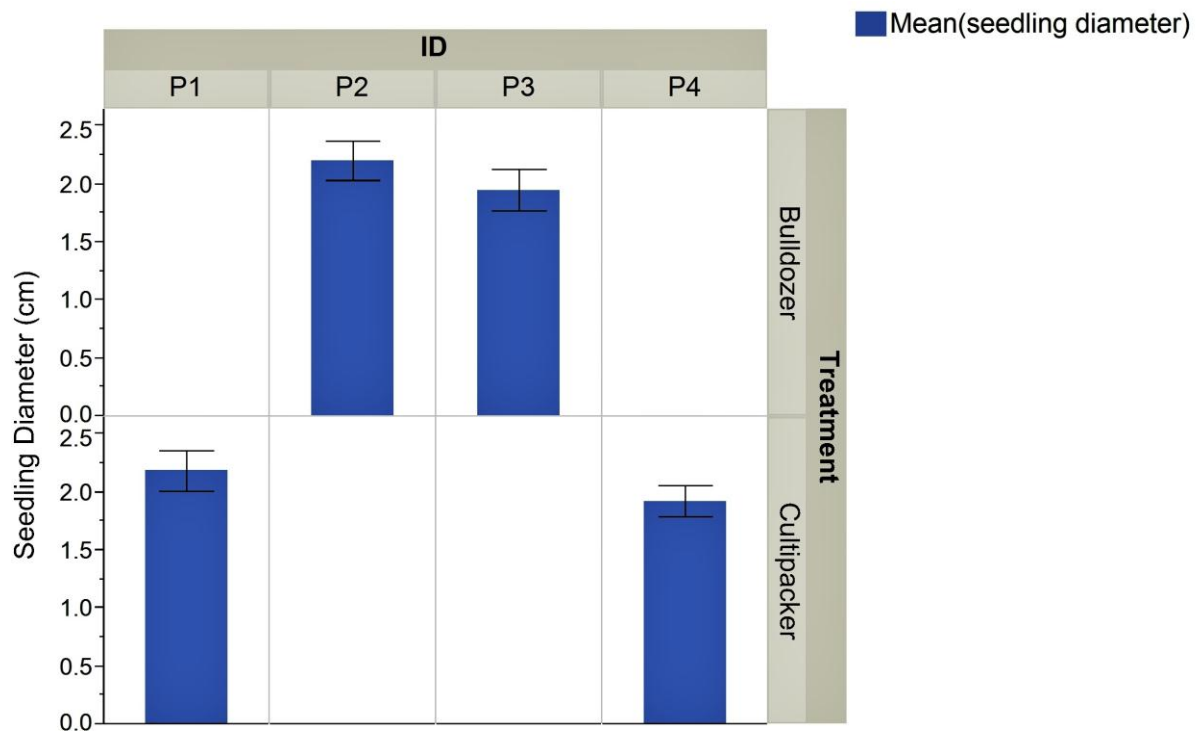
Figure 12: Mean *Aristida stricta* seedling leaf length by cultipacker and bulldozer treatments with 2 replicates for each treatment. Error bars are constructed using 1 standard error from the mean.
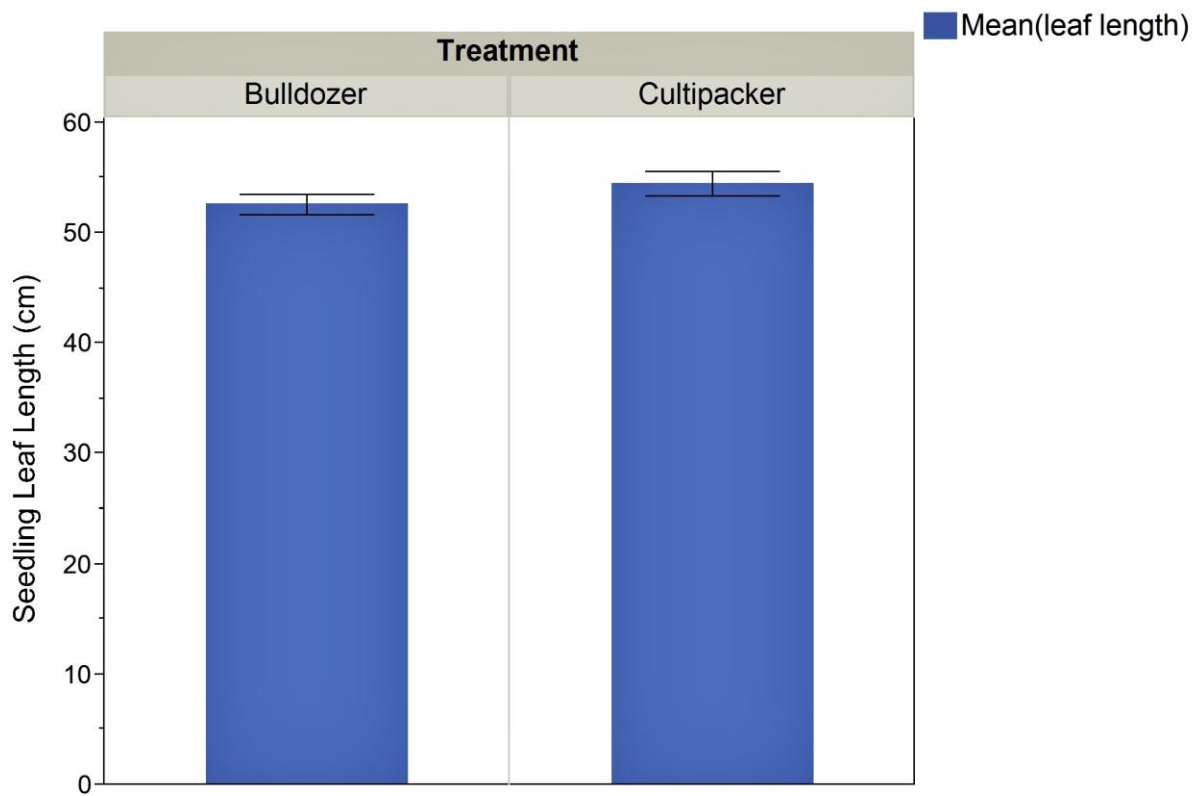
Figure 13: Distribution of *Aristida stricta* mean leaf length by cultipacker and bulldozer

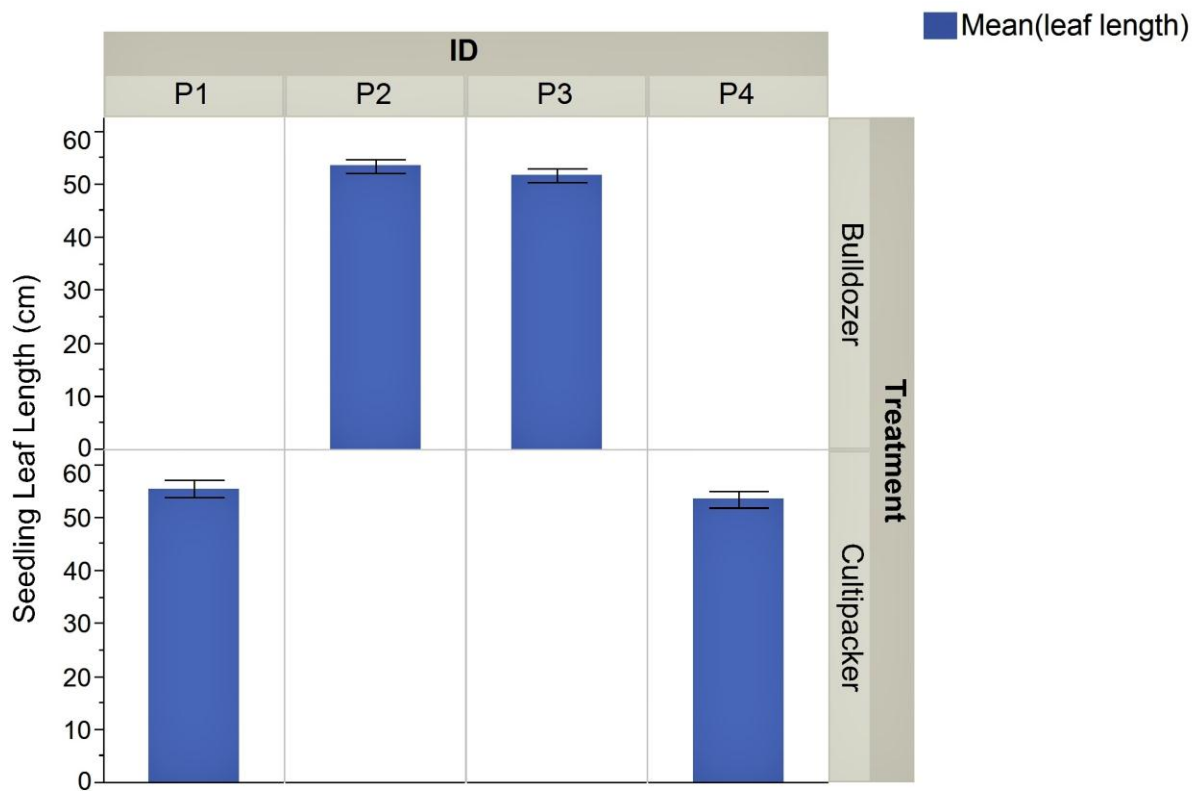treatments and plots. Error bars are 1 standard error from the mean.

Figure 14: Average monthly rainfall for past 10 years and for the year of *Aristida stricta* seed

harvest (2009). Graph created using Fort Stewart weather station data.