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Domingo M. Jariel
Louisiana State University - Eunice

Malcolm F. Vidrine
Louisiana State University - Eunice

Nicole Bordelon
Louisiana State University - Eunice

Janeel Al-Dujaili
Louisiana State University - Eunice

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by Domingo M. Jariel[1], Malcolm F. Vidrine[2], Nicole Bordelon[3] and Jameel Al-Dujaili[4]

[1]*Division of Sciences, Louisiana State University at Eunice, Eunice, LA 70535; djariel@lsue.edu*
[2]*Division of Sciences, Louisiana State University at Eunice, Eunice, LA 70535; mvidrine@lsue.edu*
[3]*Division of Sciences, Louisiana State University at Eunice, Eunice, LA 70535; nbordelon@lsue.edu*
[4]*Division of Sciences, Louisiana State University at Eunice, Eunice, LA 70535; jdujaili@lsue.edu*

Abstract

Prescribed burning every two or more years is the recommended management practice to remove unnecessary invasive plants and to enhance the regrowth of desirable plants for the development of a fire-dependent plant community native to southwestern Louisiana. A portion of Saint Augustine grass lawn at Louisiana State University at Eunice (LSUE) was converted into a Cajun Prairie restoration plot in 1989. Since 1991, the adjacent lawn has been clipped weekly, whereas the prairie has been burned every January. The objective of this study was to determine the soil chemical properties of clipped lawn and burned prairie plots. Each plot (12 m x 104 m) had four blocks (replications). Soil samples from the 0–10 cm depth were taken from each block for each plot in December 2002, March 2003, and June 2003. They were analyzed in the laboratory for soil chemical properties: pH, organic carbon (OC), electrical conductivity (EC) as a measure of soluble salts, phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), iron (Fe), zinc (Zn) and copper (Cu). Extractable soil P, Ca, Mg and Na were significantly greater in the burned prairie than in the clipped lawn. In the burned prairie from December to June, Fe increased, whereas pH, EC, P, K, Na, Cu, and Zn decreased. The results suggest that the annually burned restored Cajun Prairie provided greater nutrient deposition into the soil than the clipped Saint Augustine lawn.

Keywords: soil chemistry, prairie restoration, prescribed burning, Cajun Prairie

Introduction

Prescribed fires are used to limit encroachment of invasive species in grassland, prairie and rangeland, and to enhance the regrowth of desirable plants for the development of a fire-dependent plant community native to the area. Fire is often used to manage woody plant encroachment on rangelands (Wright and Bailey 1982). For example, in the grasslands of southwestern United States species, such as the invasive woody honey mesquite (*Prosopis glandulosa* Torr.), will sprout from stem bases following fire, which makes it necessary to apply repeated burns to reduce mesquite population (Ansley and Jacoby 1998). Prescribed burning, every year up to every six years, is commonly practiced to reduce invasive species in tallgrass prairie (Sharrow and Wright 1977).

In southwestern Louisiana, prescribed annual winter (December–February) burning is the recommended management practice (Vidrine and others 1995). The Cajun Prairie is a natural-burn ecosystem. In Louisiana, the seemingly catastrophic fire event kills the unwanted exotic herbs and the invasive woody plants, such as Chinese tallowtree (*Triadica sebifera*) and live oak (*Quercus virginina*). The fire releases nutrients in the form of ash for immediate use by plants in the early spring. As a result, fire provides for immediate greening and obvious display of early spring-blooming plants in a meadow that exemplifies the typical historical Cajun Prairie landscape in southwestern Louisiana.

After each burn, the loss or accumulation of nutrients is dependent on environmental conditions. When soils become bare following burning, they become exposed to raindrop impact, moving air or extreme ambient temperatures. The soils also become susceptible to water and wind erosion that carries away nutrients from the topsoil. Nitrogen and carbon losses can also occur through volatilization when fresh vegetation, litter, and soil-surface organic matter burn. Ammonium-N may volatilize further when ammonium is produced by microorganisms mineralize organic matter. Many scientists generally agreed that repeated annual burning may deplete soil N in some ecosystems, including tallgrass prairie (Cook 1994, Seastedt 1995, Pyne and others 1996). Accumulation of non-volatile elements after a fire may be slower in wet regions, but faster in dry or arid regions. Prescribed burning on grassland restoration in Maryland increased exchangeable calcium, magnesium, and potassium when compared to an unburned grassland (Sherman and others 2004).

Changes in physiochemical properties of soils and rate of recovery of nutrients vary widely depending on fire interval, fire intensity, and season of burning (Wells and others 1979, Romanya and others 1993) and post-burn length of time

(Kutiel and others 1990, Dormaar and Schaber 1992). While many studies indicate that soil pH and calcium (Ca) increase, other elements have variable responses following fires (Scotter 1964, Wells and others 1979, McKee, Jr. 1982). Soil organic carbon (OC), total nitrogen (N), nitrate-N and phosphate-phoshorus (P) have been found to decrease, increase or not change following fires (Wells 1971, DeBano and Klopatek 1988, Almendros and others 1990, Weinhold and Klemmedson 1992). It has been observed that total manganese (Mn) concentrations increase following fires (Gonzalez Parra and others 1996), whereas extractable Mn, P, sodium (Na), iron (Fe), and soil electrical conductivity (EC) decreased significantly in a native tallgrass prairie in central Arkansas after 12 years of annual burning, which suggests that there may be possible undesirable effects of repeated fires on soil properties (Brye 2004).

Annual burning may not be the best management practice, but it is being used to maintain and restore the lost Cajun Prairie in southwestern Louisiana. However, this may be a biased paradigm developed for local habitats and not relevant to other habitats. Therefore, this study attempted to evaluate the effect of Cajun Prairie establishment on soil chemical properties in southwestern Louisiana, where efforts to restore native prairie use annual burning. Fire remains a poorly understood management technique. Much of the uncertainty regarding the role of fire in global biogeochemical cycles is a result of our limited understanding of the biogeochemical consequences of fire at the ecosystem scale, and several reviews have highlighted the need for more quantitative assessments of the role of fire in grasslands, prairies and savannas (Lavorel and others 2001, Hao and Liu 1995).

We assumed that since 1991, two adjacent plots with similar soil types developed differences in soil chemical properties because of the differences in vegetation and management. We rationalized that the soil properties of these plots should be characterized to determine how the soil chemical properties under the restored Cajun prairie (that used to be a lawn) deviate from the soil chemical properties of the adjacent, originally established lawn. Both plots belong to Crowley soil series and have similar soil properties (Murphy and others 1986) before the inclusion of restoration plot. "Did the restored Cajun prairie change the chemical properties of the soil in relation to the adjacent lawn soil?" To answer the question, 13 years after the inclusion of the Cajun Prairie this experiment was conducted to compare the soil chemical properties of the lawn with those of the restored prairie. The specific objective of this study was to determine the chemical properties of soils: pH, organic carbon, electrical conductivity as a measure of soluble salts, macroelements (P, K, Ca, Mg, Na) and microelements (Fe, Zn, Cu) in clipped lawn and burned restored prairie.

Materials and Methods

Study Site

In 1966, a lawn seeded with Saint Augustine grass (*Stenotaphrum secundatum*) was established on the campus of Louisiana State University at Eunice (LSUE) and was maintained by mowing and the cuttings left in place. In 1989 and 1990, LSUE faculty members (Charles Allen, Malcolm Vidrine and Bruno Borsari) converted a portion of the 23-year-old Saint Augustine Lawn (SAL) into a Cajun Prairie (CP) Restoration Plot. On January 21, 1989, a part of the lawn was mowed and herbicided with Roundup, burned a month later, and plowed. In March of 1989, clumps of prairie sod from Frey and Estherwood Prairie remnants were transplanted a meter apart into the prepared Cajun Prairie Restoration Plot. The winter sod was wet or damp during transplant. Since then, the growth of transplants had been dependent on rain. In the winter of 1990, seeds of different Cajun Prairie plants were broadcast by hand between transplants. The restoration plot, which now contains 100 species of warm-season perennials (Vidrine and others 1995), has been burned every January since 1991 with ash left in place (Vidrine and others 1995).

Both plots have been unfertilized, and reside on a Crowley soils series (fine, montmorillonitic, thermic Typic Albaqualfs) that is poorly drained (Murphy and others 1986) with a silt-loam surface (0–50 cm) texture and a silty clay or silty clay loam subsoil (50–150 cm). The study area receives an average of 125 cm of precipitation annually (Murphy and others 1986).

Each plot (12 m x 104 m) was divided into four blocks (replications). Each block was 12 m x 26 m.

Soil Sampling and Analysis

Five composite soil cores (0–10 cm deep, 2.5 cm diameter) were collected at random from each block per plot using an auger and placed in a plastic bag on December 21, 2002 when plants were dormant, on March 21, 2003 when plants were emerging, and on June 21, 2003 when plants were actively growing. The prairie restoration plot was burned on January 11, 2002 and on January 13, 2003.

Soils were air-dried for at least 14 days, pulverized using soil grinder and sieved through a 2-mm metal screen. Soil pH was determined using a 1:1 (weight/volume) soil-water ratio (Eckert 1988), whereas soil EC was measured using a 1:2 (weight/volume) soil-water ratio (Dahnke and Whitney 1988). Organic-carbon was determined by the chromic acid method (DeBolt 1974). Exchangeable Ca, K, Mg and Na were extracted from the soil using neutral 1 N ammonium acetate ($NH_4CH_3CO_2$) and quantified by atomic absorption spectrometry (Thomas 1982). Phosphorus was extracted using Bray # 1 (HCl-NH_4F) solution and quantified colorimetrically by developing a blue ammonium molybdenum phosphate complex (Watanabe and Olsen 1965). Available Zn, Fe and Cu were extracted using diethylene triamine pentaacetic acid (DTPA) and determined by atomic absorption spectrometry (Lindsay and Norvell 1978).

Separate soil sampling from each block per plot was conducted on July 21, 2005 for soil bulk density determination using the core method (Blake and Hartge 1986). The soil core was taken using a cylindrical sampling tube with known volume (0–10 cm deep and 7.5 cm diameter). The core was oven dried at 105°C for at least 48 hours and then weighed.

Statistical Analyses

The treatment effects on each soil variable were analyzed using a randomized complete block design with a split-plot arrangement (SAS Institute 1995). The grass management (G) was the main plot, which was split into sampling month (S) called the subplot. Using four blocks (B), the effects of grass management, sampling month, and their interactions on soil chemical properties were determined (Table 1). The B x G mainplot error term was used to test the effects of block and grass management, whereas the B x S x G subplot error term was used to test the effects of sampling month and S x G interaction. Significant differences among means were analyzed using Duncan Multiple Range Test (DMRT). Relationship of soil pH or EC with the other soil properties was determined using Pearson's correlation coefficients (SAS Institute 1995).

Results

Soil Chemical Properties

In this study, the soil under two different management practices had statistically similar bulk density (Pr > 0.05). The average soil bulk density was 1.31 g/ml in burned prairie and 1.35 g/ml in clipped lawn.

Averaged across sample dates, extractable Ca, Mg, Na and P concentrations were significantly higher in burned prairie than in clipped lawn (Figures 1 and 2). Among the properties measured, extractable Fe was the only element whose level was significantly lower in the burned prairie than in the clipped lawn (Figure 3). Soil OC, Zn, pH, EC, K, and Cu did not differ between the two management practices (Figures 4, 5 and 6). However, the timing of taking the soil sample influenced soil OC, Zn, and Ca concentrations (Table 1) as concentrations of OC, Zn and Ca decreased significantly from December to June (Figure 4). Significant interaction between sampling month and grass management (S x G) was found in pH, EC, K, Na, P, Cu, and Fe (Table 1, Figures 2, 3, 5 and 6). Generally, levels of soil pH, EC, K, and Na fluctuated in the clipped lawn, and levels decreased in the burned prairie from December to June. Iron levels also fluctuated in the clipped lawn, but increased in the burned prairie from December to June.

Correlations Among Soil Chemical Properties

Pooled over sample months, the significant correlation coefficients of soil pH with other soil properties were fewer in clipped lawn than in burned prairie (Table 2). In clipped lawn, soil pH was significantly, positively correlated with soil Mg, but negatively correlated with soil Fe and K concentrations. In burned prairie, soil pH was significantly, positively correlated with soil Mg, P, Ca, Zn, Na, OC and EC, but negatively correlated with Fe.

Similarly, the significant correlation coefficients of soil EC with other soil properties were fewer in clipped lawn than in burned prairie (Table 2). The soil EC in clipped lawn was significantly, positively correlated only with Na. On the other hand, the soil EC in burned prairie was significantly, positively correlated with soil pH, Mg, P, Ca, Zn, Na and OC, and negatively correlated with Fe concentration.

Discussion

Clipped Lawn versus Burned Prairie

Previous studies showed that soil OC decreased, increased or remained unaffected following burning (Reynolds and Bohning 1956, Almendros and others 1990, Ulery and others 1993, Jariel and others 2002). Wells and others (1979) indicated that burning has the potential to reduce soil OC levels. The soil OC concentration in this study was the same in the burned prairie and the clipped lawn (Figure 4). Similarly, the soil BD in burned prairie and in clipped lawn was statistically similar, despite of the frequent foot and mower traffic in maintaining the clipped lawn. This suggests that the fibrous root systems of Saint Augustine grass, including other soil organic matter in clipped lawn, act like a sponge that resists compaction.

Because the annual changes in carbon in most ecosystems are small relative to the mass of soil OC, changes in soil carbon storage occur slowly. It requires a long period of time

Table 1. SAS GLM analysis for soil variable responses to Grass Management (G), Sampling Month (S) and S x G interaction. **ns** not significant at P > 0.05; * significant at P < 0.05; ** significant at P < 0.01.

Source of Variation[1]	Ca	Mg	OC	Zn	pH	EC	K	Na	P	Cu	Fe
Block (B)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
G	**	**	ns	ns	ns	ns	ns	*	*	ns	*
S	*	ns	*	*	**	**	**	*	**	*	ns
S x G	ns	ns	ns	ns	**	**	**	*	*	*	**

[1] The B x G mainplot error term was used to test Block and Grass Management Treatment; the B x S x G subplot error term was used to test Sampling Month and S x G interaction.

to investigate slow changes in soil carbon. Few long-term and controlled studies have sufficient duration to observe changes in soil OC in response to different fire regimes. In a native tallgrass prairie in central Arkansas after 12 years of annual burning, organic matter and total soil carbon content increased significantly between the years of 1989 and 2001 (Brye 2004). In the North American tallgrass prairie, soil OC storage remained unchanged after 15 years of annual burning (Rice 2002). Results similar to Rice (2002) were observed in a tropical savanna in southeastern Brazil, indicating that biannual burning for 21 years had no effect on soil organic carbon storage in the upper 1 m of the profile (Roscoe and others 2000). However, an ecosystem biogeochemistry mathematical model called CENTURY predicts that annual burning of this same tallgrass prairie will result in a decline in soil organic carbon over a period of 10–20 years (Ojima and others 1990). In a sub-humid savanna in Zimbabwe, 50 years of annual burning diminished soil organic carbon storage in the upper 30 cm of the profile by 30% relative to unburned controls (Bird and others 2000).

Soil P was found to increase (Romanya and others 1993), decrease (Scotter 1964), or not change (Boyer and Miller 1994) after burning. In our study, extractable soil P concentration was greater in the burned prairie than in the clipped lawn. The discrepancy in P suggests that annual winter burning of the prairie facilitated the deposition of P from ash (Bauhus and others 1993, Knapp and Seastedt 1986).

The increase in soil pH following fire is due in part to the release of cations, such as Ca, Mg, K and Na, associated with the loss of soil organic acids and the production of hydroxides and carbonates in ash (Wells 1971, Wells and others 1979, Binkly 1986). In this study, the difference in soil pH between the burned prairie (mean = 6.50) and clipped lawn (mean = 6.36) was insignificant (Table 1, Figure 5). However, soil Ca, Mg, and Na were significantly greater in burned prairie than in clipped lawn (Table 1, Figures 1 and 2). Calcium, magnesium, and sodium were found in large amount and they were the dominant cations that could form hydroxides in soil solution to possibly be responsible for increasing the pH in burned prairie soil. In grassland restoration on the eastern shore of Maryland that received prescribed burning every three years

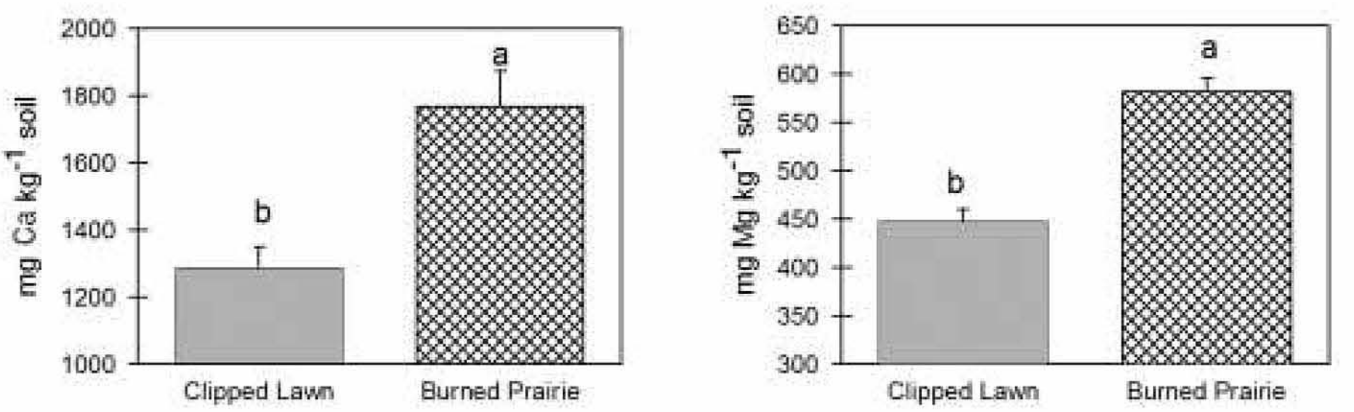

Figure 1. Exchangeable soil calcium (left) and magnesium (right) in clipped lawn and burned prairie. Bars with the same letter are not significantly different. Vertical lines on the bars are the standard errors.

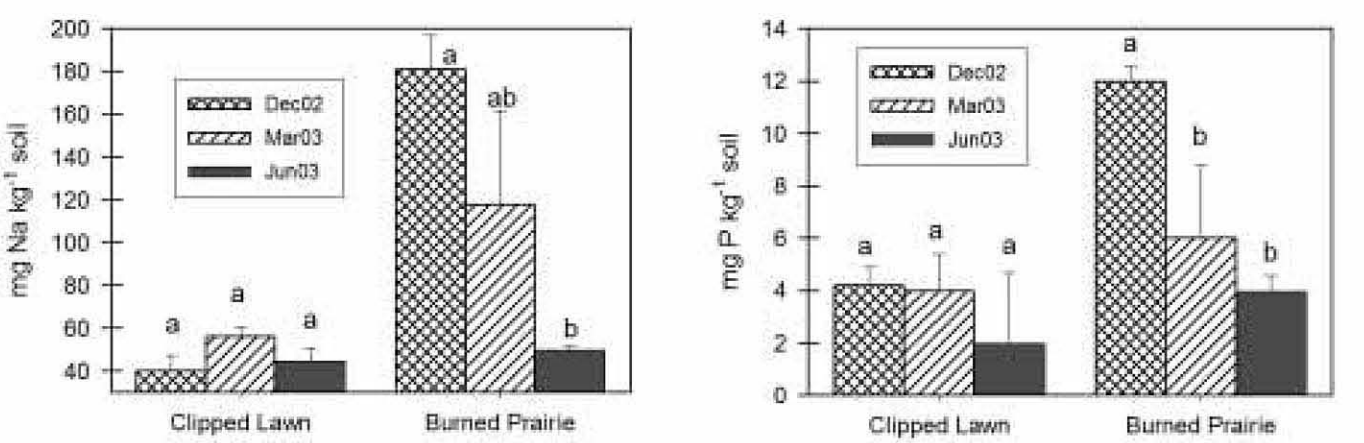

Figure 2. Exchangeable soil sodium (left) and extractable phosphorus (right) in clipped lawn and burned prairie in different sampling months. Within a group, bars with the same letter are not significantly different. Vertical lines on the bars are the standard errors.

between 1990 and 2002, the increase in soil pH was also supported by an increase in soil exchangeable Ca, Mg, and K (Sherman and others 2004).

Increasing soil pH after burning may induce fixation of microelements, such as Fe, Mn, Cu and Zn, and decrease their plant-available forms (Tisdale and others 1985, Sims 1986, Havlin and others 1998). The slight, though insignificant, increase in soil pH in burned prairie (Figure 5) was sufficient to significantly decrease DTPA-extractable Fe, which was 23% lower in the burned prairie than in the clipped lawn (Figure 3). Iron could be occluded in ash containing $CaCO_3$ compounds and could also be precipitated by hydroxides in the ash, thus decreasing Fe availability as soil pH increased. The solubility of Fe^{3+} in the soil was high at pH 3.0, and its solubility decreased as the soil pH increased from 3.0 to 7.4 (Havlin and others 1998). In one study, the availability of Fe in nutrient solution also decreased as the solution pH increased from 3.3 to 6.7 (Jariel and others 1991). In March 2003, when soil pH was 6.5 in the restored Cajun Prairie, the concentration of extractable soil Fe (44 ug/g) appeared to be adequate for plant growth as shown by the healthy emerging Cajun Prairie plants.

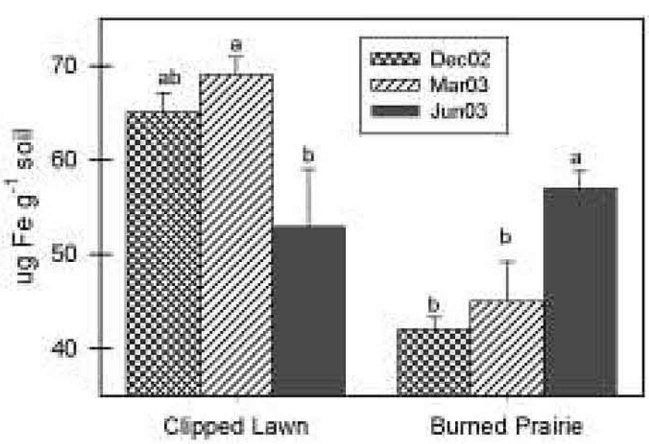

Figure 3. Extractable soil iron in clipped lawn and burned prairie in different sampling months. Within a group, bars with the same letter are not significantly different. Vertical lines on the bars are the standard errors.

Soil electrical conductivity in the burned prairie was 44 % higher numerically than that in clipped lawn, but the difference was insignificant (Table 1, Figure 5). However, the increase could not be ignored because of the significant contributions of several ions from the soluble salts of Ca, Mg, Na and P, including the small contributions from the soluble salts of Zn, K and Cu. In this study, the small increase of EC in burned prairie relative to clipped lawn was not supported by other research studies. For example, after 12 years of annual burning from 1989 to 2001 in a tallgrass prairie of Arkansas, EC, including extractable soil P, Na, Fe and Mn decreased significantly (Brye 2004). The author of that study explained that the decline in EC with other nutrient levels indicates that annual burning for 12 years may be too frequent and that annual nutrient export (due to volatilization and losses) during burning exceeds annual nutrient imports from atmospheric deposition and organic matter mineralization.

Relationship Between pH, EC, and Soil Nutrients in Burned Prairie

In burned prairie, the availability of soil nutrients was dependent on soil pH. Positive correlation coefficients (r) of soil pH with other soil properties were in the order of EC > Zn > Ca > Na > P > OC > Mg (Table 2). The high coefficients of soil Zn (r = 0.86), Ca (r = 0.78) and Na (r = 0.76) in relation to soil pH suggest that the increasing concentrations of these elements were influenced by the increasing soil pH level.

In the burned prairie, the decreasing level of soil pH was directly related to the decreasing level of EC from December to June (Figure 5), and this relationship was supported by their significant correlation coefficient (r = 0.89) value (Table 2). Since EC was dependent on the electric current conducted by the ions of soluble salts of macroelements and microelements, decreasing level of EC was also directly related to the decreasing levels of Na, P (Figure 2), but was not directly related to the increasing levels of Fe (Table 2, Figure 3). The

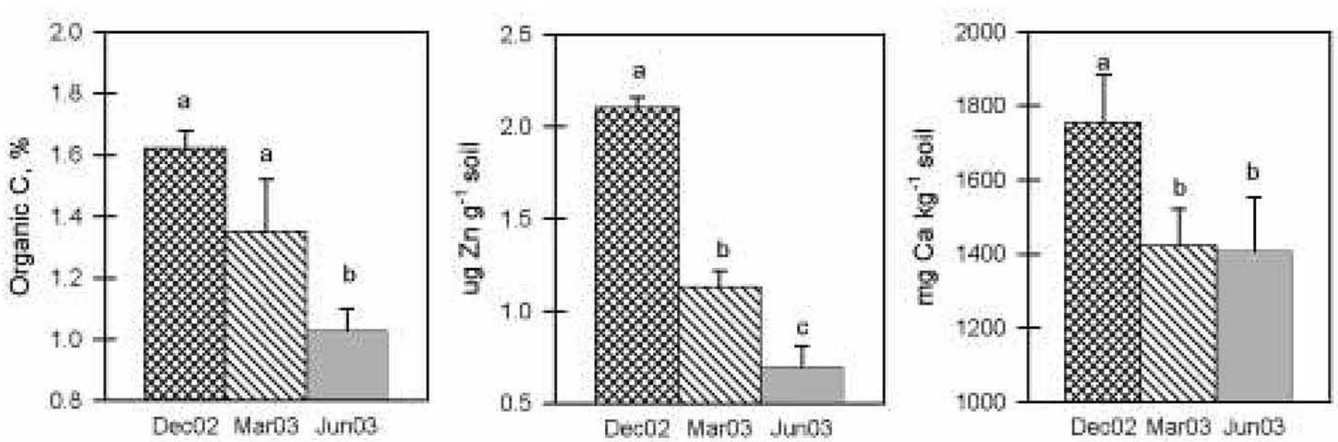

Figure 4. Soil organic carbon (left), extractable zinc (middle) and exchangeable calcium (right) in different sampling months. Within a group, bars with the same letter are not significantly different. Vertical lines on the bars are the standard errors.

decrease in Na and P from December to June could have been due to nutrient absorption by plant roots. But the increase in extractable Fe could have been due to the formation of soluble Fe as the soil pH decreased slightly from December to June (Figures 3 and 5). This inverse relationship between soil pH and Fe was supported by the significant negative correlation coefficient (r = –0.81).

In burned prairie, the levels of EC were dependent on soil pH and on the amounts of soluble salts of Na, Zn and P from December to June (Table 2, Figures 2, 4, and 5). In this study, positive correlation coefficients of soil EC with other soil properties were in the order of Na > pH > OC > P > Mg > Ca (Table 2). This suggests that soil Na concentration was the major contributing factor that influenced the level of soil EC. Despite the higher, though not significant (Table 1), EC found in burned prairie (mean = 0.20 dS/m) compared to the clipped lawn (mean = 0.14 dS/m) (Figure 5), prairie plants showed no salt toxicity symptoms. The threshold value for the soil to be considered saline is greater than 1.20 dS/m in a 1:2 soil-water ratio (Dahnke and Whitney 1988). Therefore, the contribution of soluble salts of macroelements and microelements deposited by ash into the soil was negligible. The EC of burned prairie was still low (not even close to the saline soil threshold value), and the soil was classified as non-saline after 13 years of burning.

Implication of the Study

The Crowley soil series in this study has a silty clay texture with poor internal drainage. As a result, raindrop impact on this soil produces water runoff, which could carry some of the soluble nutrients away from the site. The extensive root system of perennial prairie plants as they penetrate the subsoil could increase soil porosity and improve soil drainage. Other nutrients could leach into lower soil horizons, and most of these nutrients could be absorbed by the roots of actively growing plants. The plants that absorbed large amount of nutrients from the subsoil could deposit large amount of nutrients back into the surface soil after burning. Based on the minimal slope (0 to 1 %) of the site and the amount of rain (125 cm per year) the soil received, a separate research study should be conducted to determine the nutrient gains (due to

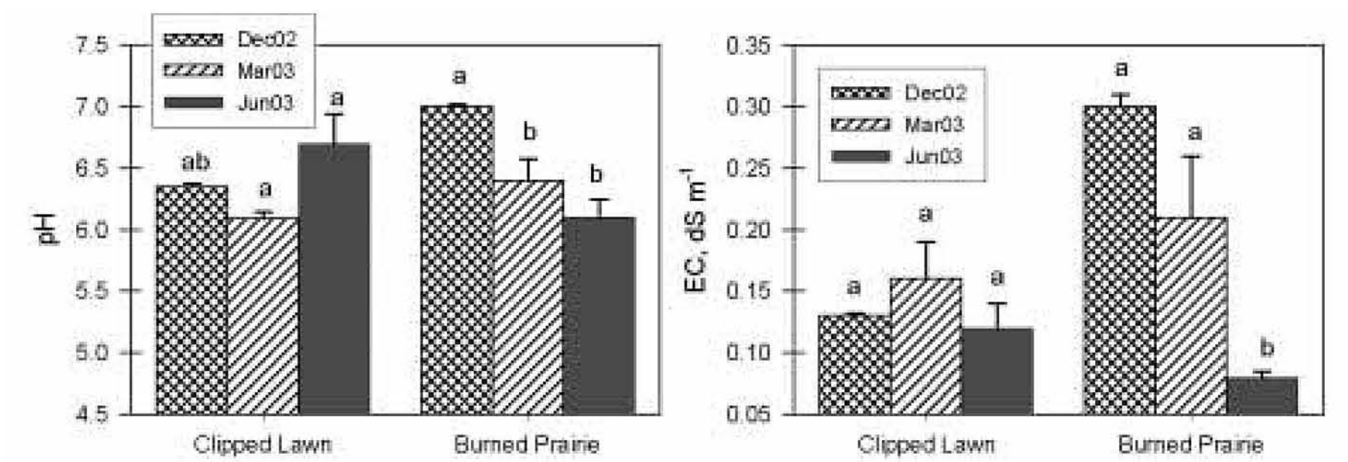

Figure 5. Soil pH (left) and electrical conductivity (right) in clipped lawn and burned prairie in different sampling months. Within a group, bars with the same letter are not significantly different. Vertical lines on the bars are the standard errors.

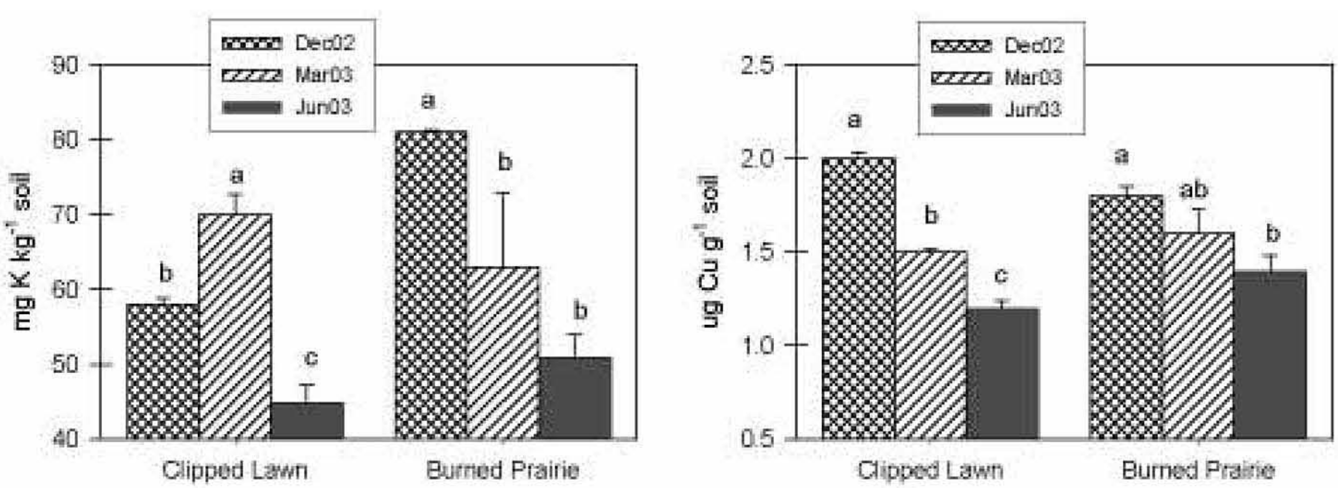

Figure 6. Exchangeable soil potassium (left) and extractable copper (right) in clipped lawn and burned prairie in different sampling months. Within a group, bars with the same letter are not significantly different. Vertical lines on the bars are the standard errors.

Table 2. Pearson's correlation coefficients (r)[1] of soil pH or electrical conductivity (EC) against soil chemical properties (pooled over sample months) under clipped Saint Augustine Lawn and burned Cajun Prairie.

	Clipped St. Augustine Lawn		Burned Cajun Prairie	
Soil Property	soil pH	EC	soil pH	EC
PH	1.00 **	0.02 ns	1.00 **	0.89 **
Mg	0.78 **	–0.09 ns	0.56 *	0.59 *
Fe	–0.75 **	–0.01 ns	–0.81 **	–0.81 **
K	–0.72 **	0.35 ns	0.55 ns	0.52 ns
P	–0.45 ns	0.31 ns	0.62 *	0.60 *
Ca	–0.34 ns	0.02 ns	0.78 **	0.57 *
Zn	–0.32 ns	–0.02 ns	0.86 **	0.83 **
Cu	–0.28 ns	–0.06 ns	0.55 ns	0.55 ns
Na	0.19 ns	0.57 *	0.76 **	0.91 **
OC	–0.08 ns	–0.05 ns	0.61 *	0.81 **
EC	0.03 ns	1.00 **	0.89 **	1.00 **

[1]The correlation coefficient (r) between two soil properties is not significant (ns) at Pr > 0.05, significant (*) at Pr ≤ 0.05, and highly significant (**) at Pr ≤ 0.01.

root absorption and ash deposition) and nutrient losses (due to runoff) in this area.

In this study, it was important to compare the soil chemical properties of two similar types of soil with different vegetation under different management practices: burned restored prairie and clipped lawn. For one reason, this comparative procedure can be applied in many Cajun Prairie restoration projects that are being conducted in southwestern Louisiana. It is a common practice to establish a small-scale Cajun Prairie restoration plot in a large existing ecosystem (a forested wetland or grassland). Knowing that a certain ecosystem contains similar soil types and properties before the inclusion of the prairie restoration plot, we can also compare the soil chemical properties of two differently managed ecosystems: restored Cajun prairie and forested wetland or restored Cajun prairie and grassland. Between the burned restored prairie and clipped lawn in this study, we were able to determine that annually burned, restored Cajun prairie modified the soil chemical properties of the originally established clipped lawn. Also, the baseline data provided are needed for further study.

Conclusion

The conversion of Saint Augustine lawn to Cajun prairie, which was maintained by winter annual burning for 13 years, modified some nutrient levels of the soil relative to the clipped lawn. The burned restored prairie provided greater nutrient deposition into the soil than the clipped lawn. Burning the prairie increased the levels of some nutrients in the soil. However, the levels are insufficient to damage the plants or to make the soil saline. In the burned prairie, soil nutrients, such as Ca, K, Na, P, Zn and Cu, decreased from December to June as they were removed from the soils by root absorption and possibly by other environmental factors. Additional study is necessary to determine the amount of nutrients present in plants to help explain the role of plants in nutrient cycling and nutrient deposition from ash in annually burned prairie.

Acknowledgments

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