EXTENSION PUBLICATIONS

College of Tropical Agriculture and Human Resources
University of Hawai'i at Manoa

Best Management Practices for the Remediation of Former Sugarcane Lands for Sustainable Livestock Production in Hawaiʻi

At a Glance

The following Best Management Practices for remediating and converting former sugarcane lands into sustainable forage production systems are based on results of a three-year study on Kauaʻi and Hawaiʻi Island on the effect of various lime and nitrogen fertilization rates, along with a legume seeding, on soil fertility and forage production and quality.

Hawaii Island, Paʻauilo Mauka Block 3, showing grazed section on left and ungrazed on right.

Introduction

With the significant reduction of land in sugarcane production, there is a unique opportunity for the Hawaiʻi livestock industry to expand. Indeed, many ranchers are now leasing or purchasing former sugarcane lands on the islands of Kauaʻi, Maui and Hawaiʻi. Most of these lands, once abandoned, developed into open grasslands where Guinea grass [*Megathyrsus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs, 2003] is now the dominant species. The soils on former sugar lands tend to be strongly acidic and deficient in important plant nutrients such as nitrogen (N), phosphorous (P), potassium (K), and calcium (Ca), and thus, may limit the productivity of desirable grasses and legumes. Low fertility also encourages invasion and the competitiveness of undesirable weedy species, resulting in low forage quality, low rates of gain per animal, and generally limits the long-term sustainability of the grazing system. Thus, long-term, sustainable production from these former sugarcane lands may require soil amendments to correct potential nutrient deficiencies.

Livestock production is an efficient and low intensity agricultural production system that is suited to bringing these former sugarcane lands back to productivity. Current recommendations for remediation of these lands are based on fertilization and liming levels for crop production systems that are not feasible from a sustainable livestock production standpoint. Typically, these recommendations target cropping systems that require high inputs of lime and fertilizers to ensure high soil fertility, an approach which is costly and unnecessary for forage production systems. Consequently, there is a need to develop recommendations to remediate these lands that fit Hawaiʻi's unique livestock production requirements. These recommendations or Best Management Practices (BMPs) should

September 2022
Subject Category: Pasture and Range Management
PRM-16

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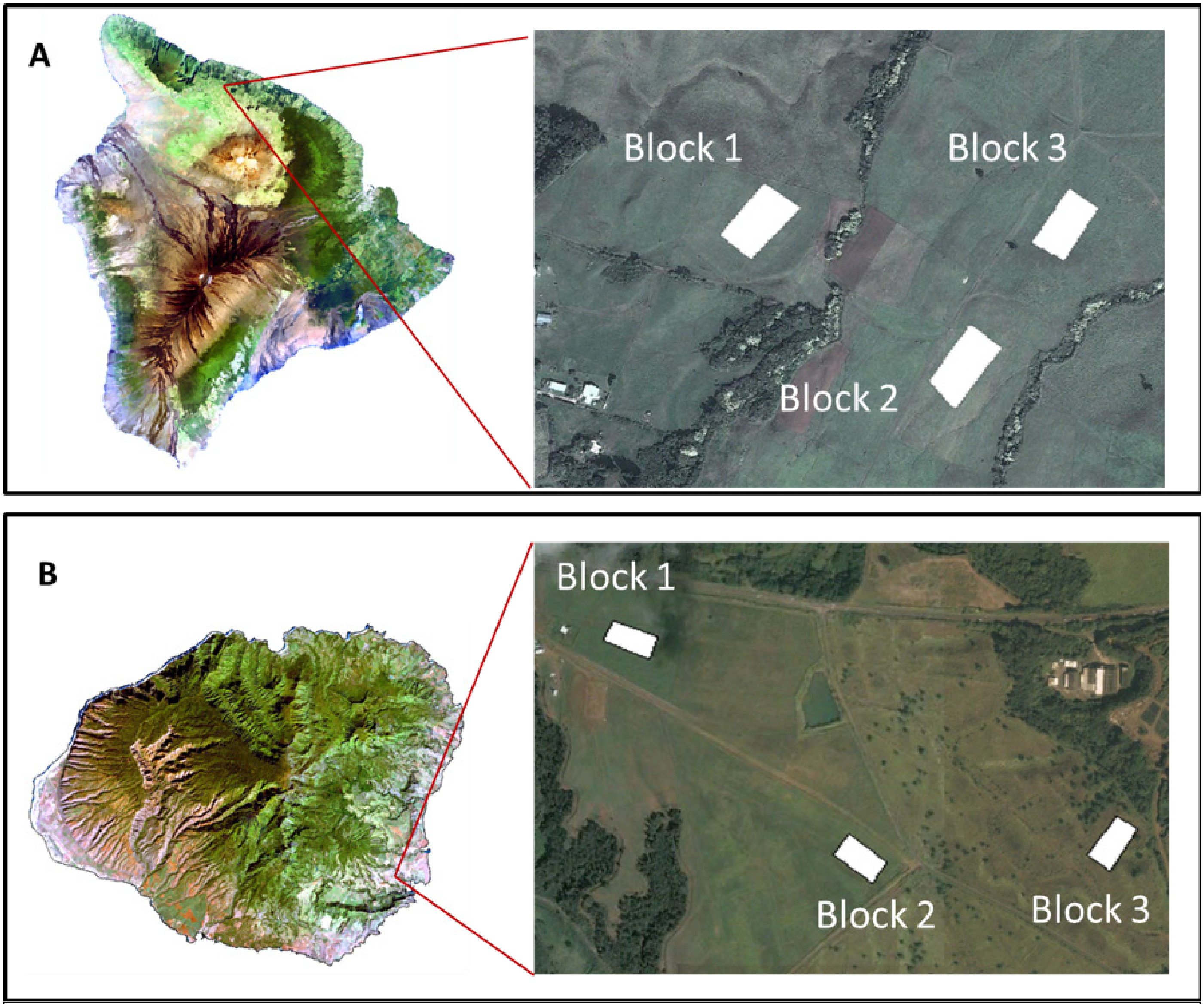

Figure 1. Location of experimental blocks "Pa'auilo Mauka" on Hawai'i Island (A) and "Puhi" on Kaua'i (B).

provide livestock producers with efficient, economical, and ecologically sound alternatives when considering pasture improvement efforts. Ideally, these BMPs would incorporate recommendations of fertilizer and liming rates with establishment of forage legumes for long-term soil N recovery and grazing management strategies to facilitate the remediation and recovery of former sugarcane lands into sustainable grazing systems.

The purpose of this publication is to provide livestock producers, county extension agents, and federal land management personnel with a series of BMPs to efficiently remediate and convert former sugarcane lands into sustainable forage production systems. Reported here are the results and BMP recommendations derived from a three-year study investigating the effect of different lime and nitrogen fertilization rates with legume seeding on soil fertility and forage production and quality of former sugarcane lands on the islands of Kaua'i and Hawai'i.

Methods

Study Sites

A series of field experiments were conducted on former sugarcane lands grazed by livestock on Hawai'i Island and Kaua'i. On Hawai'i Island, the research site was located on a ranch about 5 miles (8km) west of Honoka'a at about 1,640 ft (500 m) elevation (Figure 1A). The soils were classified as a Kūka'iau silty clay loam, with slopes between 12 to 20% (SCS 1973a) and a pH of 5.5. Average annual precipitation is 117 in (2,980 mm) and temperatures vary on average between 77° and 66° F (25° and 18.9° C). The dominant grasses at this site include Guinea grass [*Megathyrsus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs, 2003] and California grass [*Brachiaria mutica* (Forssk.) Stapf.]. This site is representative of about 60% of the former sugarcane lands along the Hamakua Coast of Hawai'i Island.

The study site on Kaua'i was located on a ranch approximately 3.1 miles (5 km) west of Lihue at an elevation of 197 ft. (60m) (Figure 1B). The soil was classified as a Puhi silty clay loam, which occurs on slopes between 3 to 8% and have a pH of 5.3 (SCS 1973b). Temperatures average between 77° and 70° F (25° and 21.1° C) with an average annual precipitation of 41 in. (1,050 mm). This site is representative of nearly 85% of the former sugarcane lands on Kaua'i.

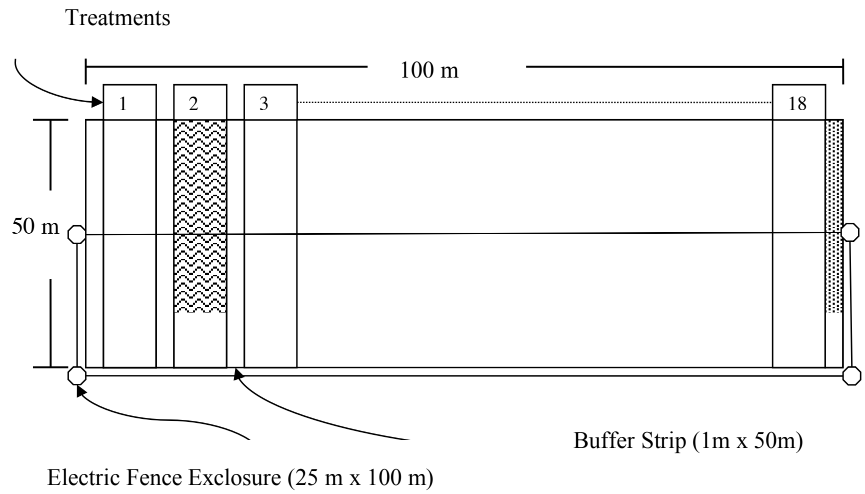

Figure 2. Diagram details layout of the research blocks. Each block was comprised of 18 (5 m x 50 m) randomly organized treatments (whole plot) separated by 1-m buffer strips. A two-strand electric fence (25 m x 100 m) allowed grazing over one half (split plot treatment) of the whole block (and excluded grazing over one half) so that the impact of grazing on the different treatments could be assessed.

Experimental Design

A field experiment was established at each site to evaluate the effects of lime, nitrogen fertilizer, and legume seeding rate on soil fertility and forage production and quality. At each site, three research blocks measuring 164 ft. x 328 ft. (50 m x 100 m) were established among a random sample of available pastures, with each block serving as a replicate and receiving one complete set of 36 possible treatments (Appendix A). Whole plot treatments included three application rates of lime [CaCO3 in the form of fine (200 mesh) crushed coral] at 0, 2 (4.5 Mg/ha), and 5 (11.25 Mg/ha) tons per acre applied to the soil surface without tillage; three application rates of nitrogen (N) fertilizer in the form of urea (46% available N) at 0, 163 (182 kg/ha), and 326 (365 kg/ha) lbs./ac; and two broadcast seeding rates of perennial peanut (*Arachis* species) at 0 and 12.5 (14 kg/ha) lbs./ac.

Whole plot treatments were randomly applied in 16.4 ft. (5 m) x 164 ft. (50 m) strips across each research block. Each treatment strip was separated by 3.3 ft. (1 m) buffer strips (Figure 2). The whole plot treatments were applied only once at the beginning of the project to allow for an assessment of the residual effects of the treatments on forage production and quality and soil fertility. Grazing level (ungrazed, moderately grazed) was applied as a split plot treatment and was controlled by electric fencing that excluded grazing over one-half (82 ft. x 164 ft.) of each research block (Figure 2). Grazing of the research blocks occurred as part of the normal pasture rotations.

Vegetation Measures

Forage yield (tons/acre) was estimated for all treatments at three- (Kaua'i) and six-month (Hawai'i) intervals following treatment using direct harvest methods (Bonham 1989). Harvested samples were bagged, air dried, separated among functional groups (i.e. grasses, forbs, and shrubs) and key forages species (Guinea grass, California grass, perennial peanut, etc.), and weighed accordingly. The samples were then ground in preparation for further analyses. Net primary productivity (lbs. forage/ac/day) of key forage species were estimated using the biomass estimates divided by the number of days between sample intervals (Bonham 1989). Forage quality was determined from ground harvested samples analyzed by Dairy One Forage Laboratory in Ithaca, NY.

Soil Fertility

Baseline soil fertility was assessed at each study location based on 36 soil cores (0 – 6 in); baseline determinations included: Total C and total N; available P; exchangeable cations (Ca, K, Mg, Na); and soil pH (1:5 soil:H2O) using methods described by Hue et al. (2000).

After implementation of the treatments, soil samples were collected from each experimental unit at all sites at six months (each sample consisting of three bulked cores taken at two depths: 0-2 in. and 2-6 in.) and 18 months (0-2 in.) to determine the change in soil fertility.

Results

Baseline Fertility

Data from the baseline sampling indicate that soils at both locations were infertile prior to treatment application (Table 1). The Kūka'iau soil at the Honoka'a site was acid to very acid in all three blocks. The pH values in Blocks 1 and 2 were low enough to induce aluminum (Al) toxicity; the pH in block 3 was borderline. The low pH condition of the pasture is likely a result of previous sugarcane management, which tended to acidify soils due to high ammoniacal N inputs.

Total organic C (TOC) and total N (TN) levels were relatively high in this soil, as would be expected for a volcanic ash soil along the humid Hamakua Coast. The relatively high P concentrations may be residual effects of long-term fertilization of sugarcane. Calcium and Mg levels were very low in block 2 and low in blocks 1 and 3. Potassium was very low in all three blocks. The Oxisol from the site on Kaua'i showed higher pH values and lower TOC and TN levels than the Andisol, but similarly low to very low K, Ca, and Mg concentrations. The P concentrations were very low in all three blocks.

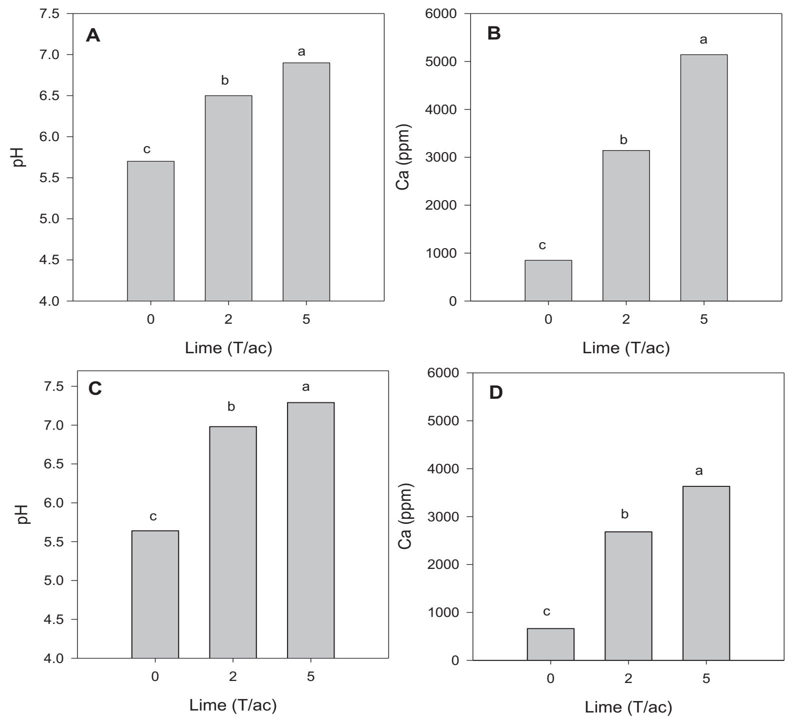

Figure 3. Liming effects on soil pH and extractable Ca in the Kūka'iau soil (A and B) and the Puhi soil (C and D). Bars represent the mean and bars with the same letters are not statistically different (P<0.05).

Table 1. Baseline soil fertility status of soils at the Hawai'i and Kaua'i locations prior to treatment implementation. Values represent the mean (N=12).

Island	Block	TOC	TN	pH	P	K	Ca	Mg
		------%------			----------ppm----------			
	1	10.4	0.62	4.59	62.7	147	518	100
Hawaii	2	9.72	0.52	4.93	82.3	74.4	227	60.4
	3	10.1	0.52	5.51	78.5	199	497	121
	1	3.78	0.11	5.64	11.2	63.9	513	200
Kauai	2	2.64	0.08	5.79	12.6	106	648	170
	3	3.18	0.07	5.18	10.2	65.9	227	95.1

Treatment Effects on Soil Fertility

Surface-applied lime significantly increased soil pH, Ca, and Mg levels in the surface soil (0-2 in) on the Kūka'iau and Puhi soils six months after application. Soil pH increased from 5.7 in the non-amended plots to 6.5 in the intermediate liming treatment and 7.0 in the high liming treatment in the Kūka'iau soil (Figure 3A), and soil Ca concentrations increased from 850 ppm in the un-limed plots to 3,141 and 5,141 ppm in the 2 and 5 t/ac plots (Figure 3B). In the Puhi soil on Kaua'i, pH increased from 5.6 in the control plots to 7.0 and 7.3 in the limed plots (Figure 3C), and soil Ca increased from 663 in the un-limed plots to 2,681 and 3,632 ppm with the lime treatments (Figure 3D). Liming increased soil P concentration from 39.2 ppm in the control to 52.8 ppm in highest lime plot in the Kūka'iau soil, and from 7.42 ppm to 16.0 ppm in the Puhi soil. Soil Mg concentrations were also increased from 218 in the un-limed treatment to 350 ppm in the Kūka'iau soil, but there was no significant effect in the Puhi soil. Liming had no effect on soil K concentrations. Surface applied lime had no significant effect on any of the measured soil fertility parameters in the underlying 2 – 6 in depth. There were no significant liming effects on TOC and TN in either soil. Nitrogen additions as urea had no significant effect on measured soil properties.

The residual effects of liming on measured soil fertility properties were variable depending on site and measured parameter (Table 2). Surface soil pH values did not change for either the 2 or 5 t/ac treatments between six and 18 months after application on the Kūka'iau soil, indicating a strong residual effect of lime. For the Puhi soil, pH decreased from month six to month 18, but maintained a desirable pH range for plant growth and higher pH values than the control plots. Soil P levels declined significantly during the 18-month sampling period at both lime levels in the Kūka'iau soil, but showed no change in the unlimed plots. Soil P did not change with time in the Puhi soil, remaining low in all treatments. At both sites, soil P was below the critical level of 85 ppm for sugarcane.

Measurement	5 t Lime /ac		2 t Lime /ac		0 t Lime /ac	
	6	18	6	18	6	18
Hawaii						
pH	6.98a	6.96a	6.49a	6.39a	5.70a	5.69a
P	52.8a	25.5b	46.9a	30.4b	39.2a	33.7a
K	76.3b	202a	104b	192a	41.0b	200a
Ca	5141a	5106a	3141a	2847a	850a	626a
Mg	350a	307a	287a	257a	218a	200a
Kauai						
pH	7.29a	6.98b	6.98a	6.53b	5.66a	5.64a
P	16.0a	13.8a	12.8a	8.63b	9.66a	7.42a
K	107a	96.0a	79.5a	89.7a	105a	102a
Ca	3632a	2603b	2681a	1717b	663a	639a
Mg	288a	204b	256a	204b	268a	220b

Table 2. Lime effects on soil fertility at 6 months and 18 months after treatment application. Means followed by the same letter are not significantly different ($P<0.05$) for comparisons between sampling time within each lime application rate.

There was no time effect on soil Ca and Mg in the Kūka'iau soil, which remained high in the limed plots compared with controls. In the Puhi soil, Ca declined between six and 18 months, but remained more than twofold higher than in unlimed plots. Soil Mg levels showed significant declines between sampling periods and was below the critical level of 350 ppm in all treatments. Soil K showed significant increases with time in the Kūka'iau soil, but the reason for the rise is not clear. In the Puhi soil, there was no change in K with time, and K concentrations were low in all treatments.

Grass Production

Although we measured a significant liming effect on soil pH, Ca, and Mg, liming had no significant effect on forage production at both study sites. Forage production, however, was strongly affected by the addition of urea at both sites. On the Hawai'i Island pasture, adding urea increased total production from an average of 4.37 t/acre (dry weight, DW) in the plots not receiving urea to 7.03 t/acre with the addition of 163 lbs. urea/ac and up to 9.79 t/acre in the treatments receiving 326 lbs. urea/ac after six months of growth. Adding urea at the highest level (326 lbs./ac) increased Guinea grass production significantly, such that 70 % (w/w) of the forage was composed of Guinea grass, compared with 35% in the intermediate urea treatments (163 lbs./ac) and 20% in the treatments receiving zero urea (Figure 4).

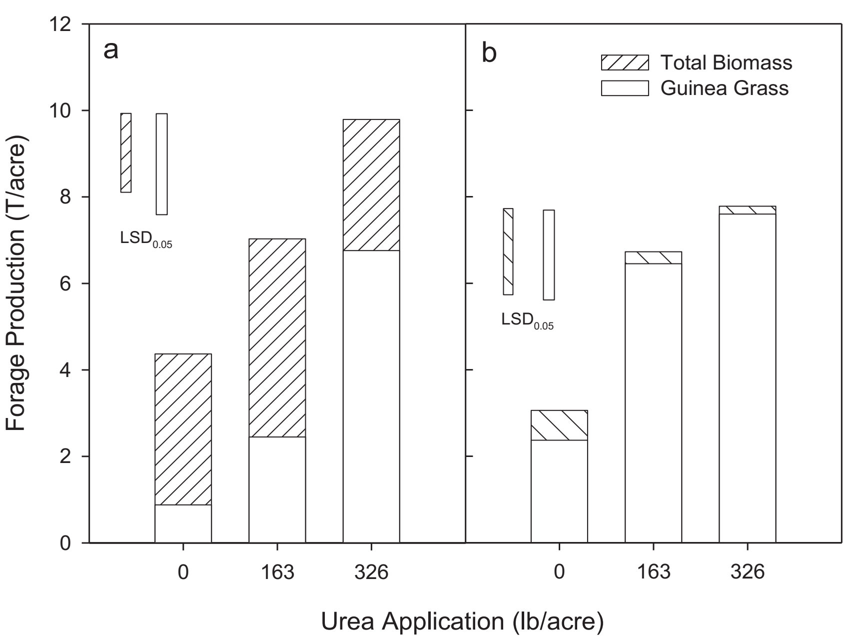

Figure 4. The effect of urea fertilization on total forage biomass (DW) and guinea grass production (DW) on Hawai'i Island (a) and Kaua'i (b). LSD0.05 represents the least significant difference ($P<0.05$) separating production means.

On Kaua'i, total biomass production was similar for the two urea additions averaging 6.76 and 7.82 t/acre for the intermediate and high urea treatments, respectively compared to 3.07 t/acre in the zero urea treatments after three months of growth. The Kaua'i pasture showed a higher proportion of Guinea grass overall (78% in the zero urea plots) compared with the Hawai'i island pasture (20%), but the same N effect on increasing Guinea grass composition observed on Hawai'i was also present on Kaua'i (Figure 4).

Climatic differences between the two study sites had a dramatic effect on forage productivity (dry weight accumulation lbs./per day). The low-elevation pastures in a warmer climate on Kaua'i showed higher productivity at the highest N level, producing on average 170 lbs. Guinea grass (DW) per day, compared with 75 lbs. DW per day at the Hawai'i island site. The higher average temperature at the Kaua'i site translates into more solar radiation and is likely the major contributor to high grass productivity.

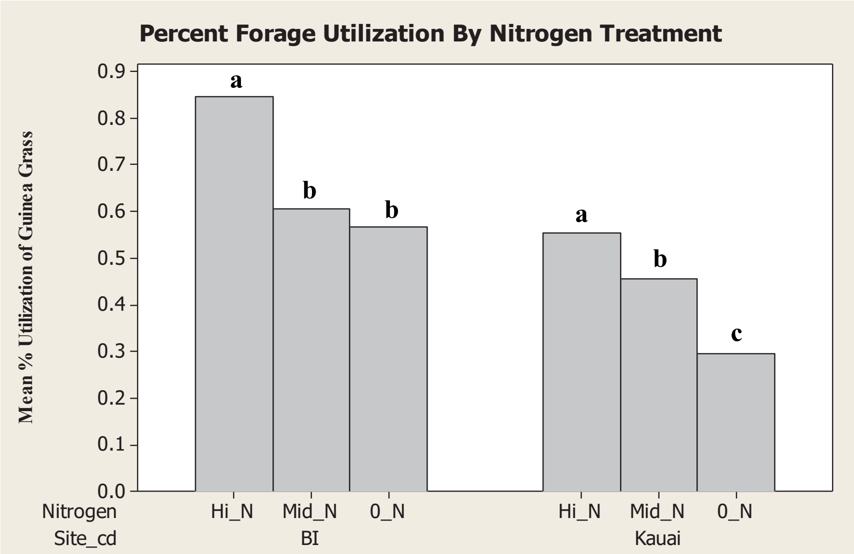

Figure 5. Average percent utilization of **Guinea grass** on the islands of Hawai'i (BI) and Kaua'i by N treatment (Hi_N, 326 #/acre; Mid_N, 163 #//acre; 0_N, 0 #/acre). Means with different letters are significantly different (P<0.05).

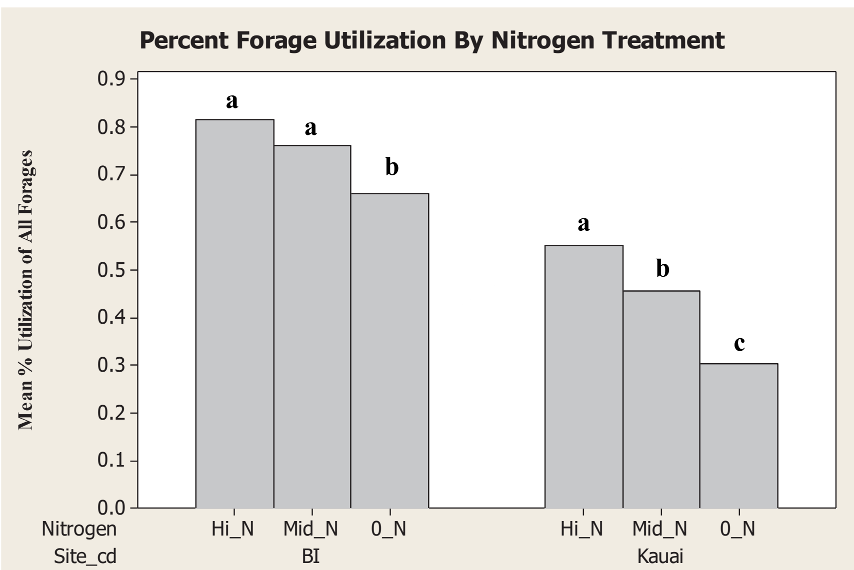

Figure 6. Average percent utilization of **all forages** on the islands of Hawai'i (BI) and Kaua'i by N treatment (Hi_N, 326 #/acre; Mid_N, 163 #//acre; 0_N, 0 #/acre). Means with different letters are significantly different (P<0.05).

Soil amendment effects on forage nutrient composition were variable and sometimes difficult to interpret. The results are summarized in Table 3. Liming at 2 t/acre significantly increased the crude protein (CP) content of forage at the Hawai'i Island site, but had no effect at the Kaua'i site. Liming had no significant effect on P, Ca, Mg, or K content of the forage at either site. Forage quality showed a variable response to urea. On Hawai'i Island, CP concentrations were highest in the 0 urea treatments, which was likely due to a dilution effect in the high urea treatments where biomass production was very high. The dilution effect was repeated for P and Ca concentrations of the forage at both sites.

Cattle had free choice access to all treatments across the grazed portion of each block. Results suggest they significantly preferred the N-treated plots over untreated plots (Figure 5 and 6); P<0.05). There was not a significant trend observed for the lime treatments. Guinea grass was grazed in proportion to its availability on Kaua'i, but more intensely utilized in the High N treatment on Hawai'i Island (Figure 5).

Perennial Peanut

Establishment of perennial peanut was slow in all plots. There was a slightly higher, but insignificant, density of perennial peanut plants established in the plots exposed to animal hoof action following seed broadcast than in the non-exposed plots. The methods used in this experiment to establish perennial peanut can't be recommended due to the slow and inconsistent rate of establishment observed across the different treatments.

Summary and Recommendations

Our results show that Guinea grass production responded rapidly to N fertilizer added at moderate quantities. Doubling the addition of urea more than doubled Guinea grass production in the Hawai'i Island pasture after six months of growth but resulted in only a slight increase (1.1 t/ac) in production on Kaua'i after three months of growth. The results of this study showed that N fertilization has additive affects in the remediation of former sugarcane lands beyond increased forage production. For example, N fertilization led to an increase in the relative abundance of Guinea grass to other less desirable forages and weeds, resulting in improved pasture condition. The observed increase in Guinea grass abundance was due to an increase in new tiller recruitment in the N-treated plots relative to the control. This recruitment of new tillers within the treatment plots had long-term benefits on forage production. While productivity of individual plants within the N-treated plots declined over the period of the project as soil available N returned to pre-treatment levels, overall forage production did not decline at a concomitant rate because the density of plants per unit area had increased. This effect was observed across the three years of the project, such that forage production in year Three was less than in year One following fertilization, but still higher than the control plots receiving no N.

Table 3. Lime and urea effects on nutrient composition of forage at the Hawai'i Island and Kaua'i sites. Numbers represent a mean of 18 samples, and means followed by the same level are not significantly different (P<0.05).

Treatment		Hawaii					Kauai				
		CP	P	Ca	Mg	K	CP	P	Ca	Mg	K
				%					%		
Lime	0	5.7b	0.11a	0.37a	0.30a	1.03a	7.0a	0.11a	0.44b	0.33a	1.55a
	2	6.4a	0.12a	0.47a	0.27a	1.16a	6.7a	0.12a	0.55a	0.32a	1.77a
	5	6.2ab	0.13a	0.50a	0.30a	1.03a	6.3a	0.12a	0.57a	0.31a	1.75a
Urea	0	7.0a	0.14a	0.50a	0.30a	1.02a	6.9a	0.15a	0.67a	0.31b	1.60a
	163	5.2c	0.11b	0.38b	0.27a	1.04a	5.8b	0.10b	0.45b	0.30b	1.68a
	326	6.1b	0.11b	0.46a	0.31a	1.19a	7.3a	0.10b	0.45b	0.35a	1.79a

In the short term, lime showed no effect on grass production, indicating that Guinea grass is well adapted to acid soils low in extractable Ca and P.

Although we measured no significant improvement in forage quality, cattle grazing pressure on treated plots was heavier relative to the untreated plots, indicating improved palatability. Cattle grazing occurred at greater frequency within the pastures and the grazing-exposed (grazed) plots than our clipping rates in grazing-excluded (ungrazed) plots. Thus, the forage the cattle consumed in the grazed plots was not as mature as what was clipped in our ungrazed plots and likely had a higher level of quality than what was measured in the ungrazed plots. Indeed, the recommended grazing interval for Guinea grass is between 20 and 35 days to avoid grazing over-mature plants of low quality. Our samples in the ungrazed plots were collected well outside this recommended interval.

The results of this study showed that N fertilization has additive affects in the remediation of former sugarcane lands beyond increased forage production.

Recommendations

Moderate applications of urea (163 lbs./acre) can be applied to former sugarcane lands to increase forage productivity and palatability for grazing animals. This application rate should be repeated every 2-3 years. It is not necessary to apply urea every year in most cases. Consistent applications of urea every 2-3 years should allow for a sustained increase in the annual stocking rate that will likely cover the cost of treatment.

Lime can be applied at no more than 2 t/ac to increase pH, but where Guinea grass is the dominant forage, this may not be necessary, as it did not result in an increase in productivity, though it may provide some benefit in improved crude protein content in the forage. Monitoring of soil pH over time will provide an indication on the frequency of applications. Soil pH measurements can be taken every six months, and when the values drop below an acceptable level, lime can be reapplied at the recommended rate. The pulse applications of N will help jump-start the mineral cycling in the pastoral system. Without the nutrient additions, the infertile nature of these sugarcane soils will result in poorer pasture productivity and delayed cycling of minerals required to establish and maintain a sustainable and productive grazing system.

Guinea grass pastures are best managed for grazing using short-duration, high density, multi-pasture rotations (Thorne et al. 2007). The recommended grazing interval for Guinea grass is between 20 and 35 days to avoid grazing over-mature plants of low quality. The grazing return interval can vary between 20 days when growth is fast (late-spring to summer) and 35 days when it is dry and/or cold (typically late summer and fall, and winter).

Guinea grass begins to mature and become sexually reproductive (elongate culm and form seed head) when it reaches the 5-6 leaf stage or roughly 36 inches in height. Once the culm elongates and forms the flag leaf, forage quality declines precipitously. Therefore, we recommend that animals graze Guinea grass pastures before it reaches 36 inches high (hip height) to no less than 8 inches of stubble height. It is important to leave at least 8 inches of stubble height to prevent grazing new forming tillers and other meristematic tissue that the plant needs to initiate new growth. So long as an 8-inch stubble height remains post grazing, Guinea grass will tolerate a 20-day return interval. Stocking rates should be determined and adjusted over time, following procedures outlined in Thorne and Stevenson 2007.

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Acknowledgements

The authors thank Dr. Harold Keyser, Dr. Linda Cox, Lincoln Ching, John Powely, and Matthew Stevenson for their contributions to this project. Funding for this project

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was provided by USDA-NIFA through the Tropical-Subtropical Agriculture Research program as project No. HAW00215-05G.

Appendix A. Each treatment block (50m x 100m) served as a replicate and received one complete set of 36 treatments. Whole plot treatments included 3 application rates of lime [CaCO3 in the form of fine (200 mesh) crushed coral] at 0, 4.5 and 11.2 (0, 2, and 5 t/acre) metric tons/ha (Mg/ha), 3 application rates

Treatment Number	Lime ($CaCO_3$)	Nitrogen (Urea; 46% N)	Perennial Peanut (*Arachis spp.*)	Grazed (G)/Ungrazed (UG)
1	0 Mg/ha	0 kg/ha	0 kg/ha	UG
2	0 Mg/ha	0 kg/ha	0 kg/ha	G
3	0 Mg/ha	0 kg/ha	14 kg/ha	UG
4	0 Mg/ha	0 kg/ha	14 kg/ha	G
5	0 MG/ha	182 kg/ha	0 kg/ha	UG
6	0 Mg /ha	182 kg/ha	0 kg/ha	G
7	0 Mg /ha	182 kg/ha	14 kg/ha	UG
8	0 Mg/ha	182 kg/ha	14 kg/ha	G
9	0 Mg/ha	365 kg/ha	0 kg/ha	UG
10	0 Mg/ha	365 kg/ha	0 kg/ha	G
11	0 Mg/ha	365 kg/ha	14 kg/ha	UG
12	0 Mg/ha	365 kg/ha	14 kg/ha	G
13	4.5 Mg/ha	0 kg/ha	0 kg/ha	UG
14	4.5 Mg/ha	0 kg/ha	0 kg/ha	G
15	4.5 Mg/ha	0 kg/ha	14 kg/ha	UG
16	4.5 Mg/ha	0 kg/ha	14 kg/ha	G
17	4.5 Mg/ha	182 kg/ha	0 kg/ha	UG
18	4.5 Mg/ha	182 kg/ha	0 kg/ha	G
19	4.5 Mg/ha	182 kg/ha	14 kg/ha	UG
20	4.5 Mg/ha	182 kg/ha	14 kg/ha	G
21	4.5 Mg/ha	365 kg/ha	0 kg/ha	UG
22	4.5Mg/ha	365 kg/ha	0 kg/ha	G
23	4.5 Mg/ha	365 kg/ha	14 kg/ha	UG
24	4.5 Mg/ha	365 kg/ha	14 kg/ha	G
25	11.2 Mg/ha	0 kg/ha	0 kg/ha	UG
26	11.2 Mg/ha	0 kg/ha	0 kg/ha	G
27	11.2 Mg/ha	0 kg/ha	14 kg/ha	UG
28	11.2 Mg/ha	0 kg/ha	14 kg/ha	G
29	11.2 Mg/ha	182 kg/ha	0 kg/ha	UG
30	11.2 Mg/ha	182 kg/ha	0 kg/ha	G
31	11.2 Mg/ha	182 kg/ha	14 kg/ha	UG
32	11.2 Mg/ha	182 kg/ha	14 kg/ha	G
33	11.2 Mg/ha	365 kg/ha	0 kg/ha	UG
34	11.2 Mg/ha	365 kg/ha	0 kg/ha	G
35	11.2 Mg/ha	365 kg/ha	14 kg/ha	UG
36	11.2 Mg/ha	365 kg/ha	14 kg/ha	G