United States Department of Agriculture

FINAL STUDY REPORT (October 2024)
Hoolehua Plant Materials Center
Hoolehua, Hawaii

Monthly Yield Potential for Tropical Forages: 'Mombasa' Guineagrass, Common Kikuyu, Common Buffelgrass, 'Marandu' Palisadegrass, and Common Signalgrass

Richard Ogoshi, David Duvauchelle, and John Colon

Abstract

Prescribed grazing is a management practice that balances available forage within a grazing system and animal consumptive demand to prevent overgrazing and consequent soil erosion. The Pacific Island Area-Prescribed Grazing Tool helps conservation planners estimate available forage and prescribes animal stocking rates, grazing periods, and forage rest periods appropriate for a grazing system. While forage yield from one grass species to another can vary widely, the tool lacks the ability to estimate forage yield for specific grass species. The EcoCrop model can provide forage yield estimates for specific species, but it requires a yield curve. There is no yield data readily accessible to fulfill this requirement. The primary objective of this study was to develop yield curves for five forage grass species, guineagrass (*Megathyrsus maximus*), kikuyu (*Pennisetum clandestinum*), buffelgrass (*Pennisetum ciliare*), palisadegrass (*Urochloa brizantha*), and signalgrass (*Urochloa decumbens*). Secondary objectives were to observe stubble yield and test a rising plate meter, hereafter referred to as a plate meter, for yield measuring capability. The five forage grass species were grown at the Hoolehua PMC over a two-year period from November 2020 to October 2022. Plots were 5 x 28 feet arranged in a randomized complete block design and yield data was collected monthly by clipping each species down to the recommended stubble height and weighing the harvested material. Irrigation was applied at 56 and 71 inches in the first and second year. Total annual fertilizer N was applied at 628 and 646 lb./acre. Repeated measures and trend analyses were used to define yield curves over a 12-month period. Additionally, plant height was measured before each harvest with a plate meter. The plate meter data from the first year was used to develop equations to estimate forage yield for each species. The equations were validated with the plate meter data from the second year. The day after the final harvest, stubble yield data was collected. Guineagrass yield displayed a moderate cubic trend ($r^2 = 0.51$). Kikuyu showed a poor quartic trend ($r^2 = 0.11$). Buffelgrass, palisadegrass, and signalgrass showed a moderate quartic trend in year 1 ($r^2 = 0.64, 0.59, 0.42$ respectively). Guineagrass, kikuyu, palisadegrass and signalgrass had stubble yield that was 66 to 68% of aboveground plant dry weight. Buffelgrass stubble yield was only 43% of aboveground plant dry weight indicating that stubble height should be increased to more than the currently recommended 3 inches. The plate meter produced forage yield estimates with adequate accuracy, but poor precision. Improved precision is needed to make this a useful tool for management decisions.

Introduction

The conservation practice Prescribed Grazing is the judicious grazing of pasture and range to promote desirable plant communities, improve forage quality and quantity, improve water quality and watershed function, and reduce soil erosion. One of the primary objectives of this practice is to prevent overgrazing. Briske et al. (2011) conducted a meta-analysis of Prescribed Grazing studies to determine the strength of association between the practice and the presumed environmental benefits. The analysis showed the practice was generally effective in achieving its environmental benefits and that site-appropriate stocking rate was the most important grazing factor. To this end, the authors recommend that land managers be encouraged to inventory and monitor forage production and develop tools to aid decision-making such as annual forage production curves.

In the Pacific Island Area (PIA), there are 18 grass species recommended for grazing. Among the recommended species, more commonly grown grasses are guineagrass (*Megathyrsus maximus*), kikuyu (*Pennisetum clandestinum*), buffelgrass (*Pennisetum ciliare*), palisadegrass (*Urochloa brizantha*), and signalgrass (*Urochloa decumbens*). Guineagrass is an erect tufted perennial native to Africa (Ripperton et al., 1933). It was introduced to Hawaii about 1870 and is a common forage found across the Pacific Islands (Whitney et al., 1939; Areghoere, 2005). Kikuyu is a perennial grass native to tropical Africa (Fukumoto and Lee, 2003). It produces stolons and develops a mat of stems and roots. Kikuyu was introduced to Hawaii in 1924 or 1925 and has become the predominant forage grass in Hawaii (Hosaka, 1958; Ripperton et al., 1933; Whitney et al., 1939; Fukumoto and Lee,2003). Buffelgrass is a perennial native to Africa and southern Mediterranean (Hosaka and Carlson, 1957). It is a spreading bunch grass that is drought tolerant and found in the dry lowland areas of Hawaii. It was introduced to Hawaii in 1935. Palisadegrass is native to sub-Saharan Africa with the earliest documented presence in Hawaii as 1939 (Gallaher et al., 2020). Palisadegrass is considered naturalized in Hawaii (Gallaher et al., 2020). Palisadegrass cv ‘Marandu’ has resistance to two-lined spittle bug (*Prosapia bicinta*), a recently introduced pest that devastated pastures on Hawaii Island (Brestovansky, 2019). Signalgrass is an erect perennial native to Africa, specifically Uganda (Ripperton et al., 1933; Fukumoto and Lee, 2002). It was introduced to Hawaii in an experimental planting in 1940 and is commonly found in the Pacific Islands (Snow, 2010; Areghoere, 2005).

Forage yield data for guineagrass, kikuyu, buffelgrass, palisadegrass, and signalgrass in Hawaii are limited. Over the past 60 years, six studies were identified that produced yield data for these grasses (Fukumoto, 2003; Fukumoto and Lee, 2002; Fukumoto and Lee 2003; Fukumoto and Yamasaki, 2000; Tamimi et al., 1968; Thorne, 2011; Whitney, 1974). Yield data was collected on the islands of Kauai, Maui, and Hawaii with harvest intervals ranging from two weeks to one year. Other forage yield data may exist, but they are not readily accessible.

The PIA Prescribed Grazing Tool (PIA-PGT) was developed to help conservation planners estimate forage production and livestock forage demand and determine the balance between the two. The tool is a spreadsheet based on Graze4 developed in Missouri (Adams et al., 2013). Graze4 served as the basis to develop similar tools in Florida, Georgia, and Tennessee (FL FOTG, 2012). The major differences between the Missouri and PIA tools are GRAZE4 accounts for seasonal growth and has separate growth curves and production values for 34 species while the PIA-PGT accounts for year-round forage growth based on site-specific average rainfall patterns, requires user entered values for total forage production (TFP) and has a single growth curve to represent all recommended grass species. Developing separate growth curves for key forage grass species in the PIA-PGT would improve the applicability of the tool in the PIA. The Natural Resources Conservation Service (NRCS) recommends forage yield be estimated from clipping data or soil properties. Clipping data is collected on-site such as a rancher's pasture (PIA FOTG, 2008). The data is entered in the spreadsheet PI-Range-1 and the yield is automatically calculated. Clippings may be performed over the course of a year to estimate annual forage yield. An alternative method to estimate forage yield is to look up forage production among the soil properties (PIA FOTG, 2008). Forage production is estimated during assessments such as soil survey (Fortiner et al., 2017), Ecological Site Description (Dobos et al., 2017), and Forage Suitability Groups (Butler, 2003). However, Ecological Site Descriptions and Forage Suitability Groups have not been completed for PIA (NRCS, 2002). Alternatively, in the absence of forage yield based on observation and expert judgement, yield may be estimated by calculation schemes (NRCS, 2019).

Crop simulation models are calculation schemes designed to estimate yield. Explanatory models simulate physiological, chemical, and physical processes in fine detail (Di Paola et al., 2015). Simulations lend insight into interactions among system components. These models are complex, have many parameters and large input data requirements; however, they are not suitable to predict outcomes such as yield. In contrast, predictive models are simple, yet are suitable to make yield predictions. Typically, predictive models are based on empirical observations of related phenomena, for example regression of yield on an environmental factor. One such model successfully predicted biomass of grass growth based on minimum temperature (Andrade et al., 2015). Hybrid models have intermediate complexity between explanatory and predictive models. Explanatory grass models simulate a wider range of conditions; however, the major limitation is the availability of input data in the grasslands of the tropics (Andrade et al., 2015). Predictive grass models have much lesser input data requirements, but the predictions are more prone to error (Andrade et al., 2015). Nevertheless, predictive models are the most widely used type in the tropics.

A comparison of the number of model parameters between predictive and hybrid grass models shows the difference in their complexity. The PIA-PGT is an example of a predictive model. There is one plant-related and two weather-related input parameters required to run the model. Two other predictive models, the Hawaii Forage Production Estimator Tool (Thorne, 2013) and EcoCrop (Ramirez-Villegas et al., 2013) have 1- and 2-weather input parameters, respectively. In contrast, the hybrid model PHYGROW has 12 soil-, 35 plant-, 8 grazer animal-, and 4 weather parameters required to generate yield estimates (Stuth et al., 2003).

Because predictive models (1) generate forage yield data that is essential in a conservation plan, (2) have much fewer required input data than hybrid and explanatory models, (3) the required monthly climate input data are readily available within the PIA, and (4) parameters for 14 of the recommended grass species are readily accessible, the EcoCrop model was selected as a supplemental predictive model to improve the accuracy of the current PIA-PGT (FAO, 2000). A simple model algorithm can estimate forage yield as a function of EcoCrop suitability index and maximum forage yield, but the data that is lacking for this yield function is maximum forage yield for the Pacific Island region.

The primary objective of this study is to develop monthly and annual yield values for five forage grass species kikuyu, buffelgrass, guineagrass, palisadegrass, and signalgrass under near-optimal field conditions. Secondary objectives are 1) to determine the stubble yield of these grass species and 2) to calibrate and validate the plate meter, an indirect forage yield measurement tool. The yield results will serve as the maximum yield for the predictive model EcoCrop. This study is one of two studies being conducted concurrently by the Hoolehua Plant Materials Center to collect specific data to improve the accuracy of the PIA-PGT. The two studies will be the first of a series of studies conducted for the purpose of calibrating/validating the forage yield prediction model for five species and will serve as a template for a future study that will focus on an additional seven PIA recommended forage grass species.

Materials and Methods

The field trial was conducted at the Hoolehua Plant Materials Center (PMC), Hoolehua, Hawaii, from 2020 to 2022. The PMC is located on the leeward side of Molokai Island at 320 feet above mean sea level. Average annual air temperature was 75.0 °F, annual rainfall 20.8 inches, and average daily total global radiation 19.0 MJ / m^2 / day (Giambelluca et al., 2014). The soil was classified as Holomua series (fine, kaolinitic, isohyperthermic Typic Eutrotorrox). A composite soil sample at three depths (0-6, 6-12, and 12-18 inches) was collected on December 11, 2019. A weather station was located 2,475 feet north of the field trial. Daily air temperature, total global solar radiation and rainfall were recorded on a data logger model CR1000x (Campbell Scientific, Logan, UT).

Five grass species recommended by the NRCS were evaluated in this initial study: Guineagrass cv 'Mombasa', kikuyu, buffelgrass, palisadegrass cv 'Marandu', and signalgrass. The five grass species were planted into plots 5 x 28 feet. The experimental design was a randomized complete block with four reps. Seed were planted on April 23, 2020, with a no-till drill (Kincaid Precision Plot Seed Drill, Kincaid Equipment, Haven, KS) at the recommended seeding rates. The palisadegrass, signalgrass, buffelgrass, guineagrass, and kikuyu grass were planted at 8.0, 8.0, 5.0, 5.0, and 2.0 lb. pure live seed/acre, respectively, in rows 7.5 inches apart. Irrigation was applied with overhead impact sprinklers twice a week. Each irrigation event delivered about 0.6 inch of water. When rain fell in the preceding week, one irrigation event was skipped for each 0.5 inch of rain. Total irrigation from November 2020 to October 2021 was 56 inches, and from November 2021 to October 2022 was 71 inches. Before each harvest, plant height was measured with an EC09 plate meter (Jenquip, Feilding, New Zealand). Height was measured five times in each plot and the mean recorded.

Available forage yield, the biomass above stubble height, was collected monthly from each plot repeatedly. Available forage yield data collection started on November 17, 2020, one month after the grass in each plot were cut to appropriate stubble heights. Grass biomass above the recommended stubble heights for each species was removed with a flail chopper model 7 (International Harvester, Chicago, IL). The cutting width was 4.17 feet and harvested area for each plot was 117 $feet^2$. Stubble heights for buffelgrass, kikuyu, signalgrass, palisadegrass, and guineagrass were 3-, 4-, 6-, 6-, and 8-inches, respectively. During the second 12-months of data collection, a plot harvester (Carter Manufacturing Co., Brookston, IN) performed this task. The cutting width was 2.92 feet, and the harvested area was 81.8 $feet^2$. The total fresh biomass weight was recorded for each plot. A 150-gram sub-sample from each plot was collected and dried in a forced-draft oven at 60 °C until reaching constant weight, about 3 days. Oven-dry yield was calculated based on the total fresh biomass and the sub-sample fresh and dry weights.

Fertilizer was applied within three days after each monthly biomass harvest was completed. The total N, P_2O_5, and K_2O lb./acre applied in first 12 months was 628, 1800, and 281. The heavy application of P_2O_5 corrected for the large P-fixation capacity of iron- and aluminum-oxide in the soil (Hue et al., 2000). In the following 12 months, total applied N, P_2O_5, and K_2O lb./acre was 646, 277, and 1090. Calcium sulfate was applied at 318 lb./acre in that same 12-month period. One day after the final forage harvest on October 17, 2022, stubble from a 15 ft^2 area was cut at the soil surface from each plot. The bulk weight was recorded, and a 200-gram sub-sample dried in a forced-draft oven at 60 °C until constant weight.

Forage yield data were analyzed as repeated measures for each forage species over two years with the statistical analysis software Statistix 10 (Analytical Software, 2013). Polynomial trends on harvest month were examined by partitioning sums of squares of main and interaction effects (Howell, 2010). The highest degree polynomial examined was limited to one-third of the within-subject treatments, specifically 4^{th} degree. Analysis of variance assumptions for normal distribution and homogeneity of variance were checked with the Shapiro-Wilk and Levene's tests (Analytical Software, 2013; NIST, 2012). When normality was violated, the Box-Cox transformation was applied (Box and Cox, 1964). Sphericity assumption was routinely violated and corrected by applying the Greenhouse-Geisser epsilon to the degrees of freedom for main, interaction and error effects. Homogeneity of variance between years was violated in buffelgrass, palisadegrass, and signalgrass, so the repeated measures analyses were done separately for each year. Yield data was reported at the original scale.

Stubble yield and %-stubble was analyzed as a randomized complete block. Percent stubble was calculated as the ratio of stubble yield divided by the sum of stubble yield and mean forage yield of previous two years, multiplied by 100. Normal distribution and homogeneity of variance assumptions were verified with Shapiro-Wilk and Levene's tests (Analytical Software, 2013; NIST, 2012). The %-stubble data were transformed with a Box-Cox function to satisfy the normal distribution and homogeneity of variances assumptions (Kirchner, 1995). Significant differences between stubble yield means were determined with Tukey's Honest Significant Difference all-pairwise comparison at $p < 0.05$. Yield data is reported at the original scale. Monthly plant yield and plate meter height data from the first year of growth was used to develop a linear equation to predict yield from plate meter height in the second year. Forage yield was regressed against plant height in two separate seasons, January to May and June to December, in the first year. The two linear equations were used to predict yield for the second year based on plant height. The predictions from the linear equations were evaluated with the statistics Mean Absolute Error (MAE), Root Mean Square Error-observations Standard Deviation Ratio (RSR), Percent Bias (PBIAS), and Nash-Sutcliffe Efficiency (NSE) (Moriasi et al., 2007). MAE measures the precision of the prediction in the same dimension as the original measurement. Values range from 0 to $+\infty$, where a value of 0 results from predicted values perfectly matching observed. RSR is another measure of precision. Values range from 0 to $+\infty$, where a value of 0 results from predicted values perfectly matching observed, but values < 0.7 has been suggested as satisfactory model predictions. PBIAS, a measure of accuracy, indicates the direction of deviation from observed. Values range from $-\infty$ to $+\infty$, 0 indicate predicted values perfectly match observed. Positive values indicate the observed values are generally greater than the predicted. Nash-Sutcliffe Efficiency shows the overall performance of the model. Values range from $-\infty$ to 1.0, where 1.0 result from predicted values perfectly matched observed. A model with adequate precision and accuracy would result in RSR < 0.70, PBIAS $< \pm 25\%$, and NSE > 0.50 (Moriasi et al., 2007).

Results and Discussion

The forage grasses grew well under the environmental conditions during the two-year growth period. Solar radiation peaked near the summer solstice and bottomed near the winter solstice with air temperature lagging approximately one month (figure 1). Annual air temperature in the first- and second-year were 75.1 and 75.2 °F, near the 75.0 °F long-term average (figure 1). Total rainfall in the first- and second-year were 14.3 and 13.6 inches, much lower than the long-term annual average of 20.8 inches (figure 1). Soil phosphorus content was low while soil potassium content and soil pH were adequate (Table 1). Irrigation and fertilizer were applied to supplement soil moisture and nutrients.

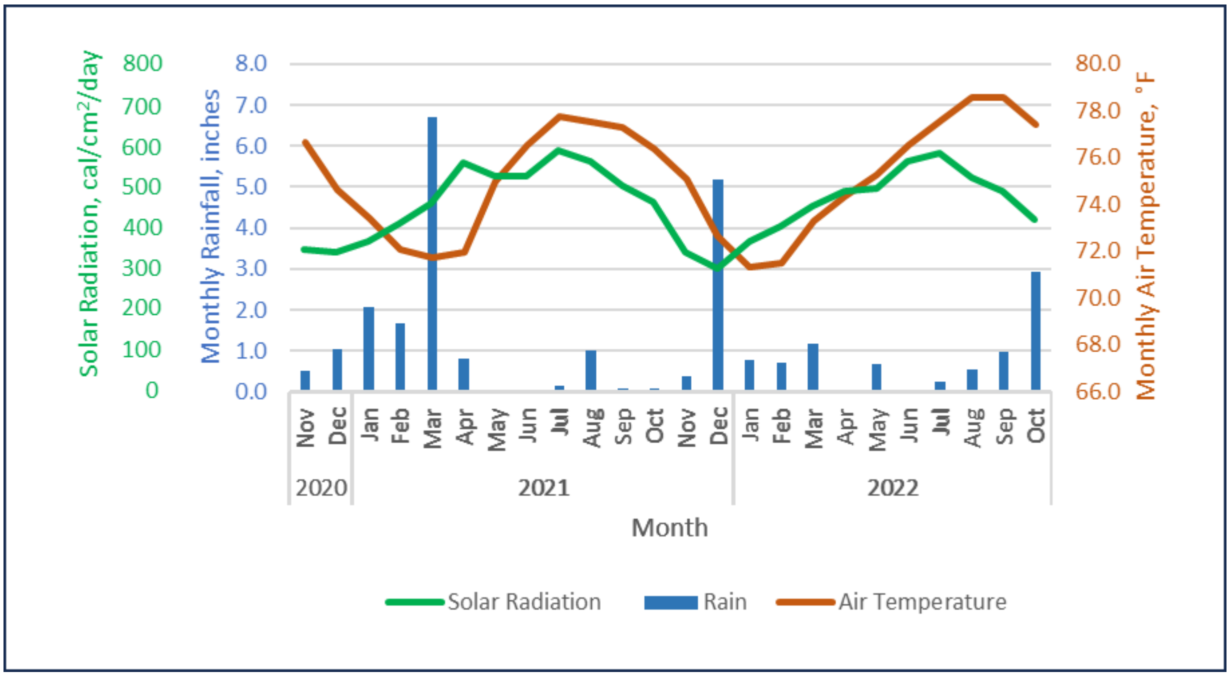

Figure 1. Monthly weather data during the forage species yield trial November 2020 to October 2022 at the Hoolehua Plant Materials Center, Hawaii.

Table 1. Soil chemical properties of a Holomua series (fine, kaolinitic, isohyperthermic Typic Eutrotorrox) at three depths collected from the Hoolehua Plant Materials Center on December 11, 2019.

	Soil Depth, inches		
Soil Properties	0 – 6	6 – 12	12 – 18
Phosphorus, mg/kg	3	3	0
Potassium, mg/kg	482	472	330
pH	6.4	6.5	6.8
Organic matter, %	2.4	2.4	1.4

Available forage yield

Yield of each grass species displayed cubic and quartic polynomial trends over time. Yield was highest in the summer months and lowest during the winter that followed solar radiation and temperature trends across months (figure 1).

Guineagrass yield showed a cubic polynomial trend that did not change between years. Yield varied from a low of 2200 oven-dry lb./acre in month-3 (January) to a high of 4339 oven-dry lb./acre in month 10 (August). The cubic effect was significant and the non-significant Year x Month(Linear), (Quadratic), (Cubic), and (Quartic) effects suggest the trend was stable across years. The significant residual partitioned from Month and Year x Month effects showed an important portion of variance that was not accounted for by trend over Months. However, the cubic trend was moderate with an r^2 of 0.51 (figure 2).

Average annual guineagrass yield was 39225 oven-dry lb./acre in the present study (data not shown). In contrast, guineagrass grown in Puerto Rico had annual yield of 26829 dry lb./acre when grown under the conditions of 56 to 102 inches annual rain, average annual temperature 76 °F, N applied at 1600 lb./acre, and harvest every 40 days (Vicente-Chandler et al., 1959).

Kikuyu grass yield displayed significant differences between years, and trends that differed between years (Table 2). The yield trend across months showed a significant cubic effect, but there was a significant Year x Month(quartic) interaction (Table 2). This may have been caused by quartic trend being was more pronounced in the second year than the first (figure 3). The significant residual effect from the Year x Month interaction indicated that the quartic trend was weak that was confirmed by the scatter of data points in the plot of yield against months and the poor r^2 of 0.10 and 0.11 (Table 2, figure 3).

Average annual kikuyu grass yield was 18567 oven-dry lb./acre (data not shown). At Kula, Hawaii, Whitney (1974) observed kikuyu grass annual yield was 7001 lb./acre when harvested at 5-week intervals. The elevation at the Kula site was 3100 with average annual air temperature 65 °F (Ikawa et al., 1985). The cooler temperature at this site may account for the lower yield than the present study (Whitney, 1974).

Buffelgrass yield had significant quartic polynomial trends in years-1 and -2 (Table 3). The quartic trends had similar characteristics where low yields of 1445 and 1795 oven-dry lb./acre in years-1 and -2 were observed in month-3 while the high yields of 3176 and 2942 oven-dry lb./acre were seen in months-9 and -8 (figure 4). The trends had moderate r^2 of 0.64 and 0.57 in years-1 and -2 (Figure 4).

Palisadegrass yield had inconsistent trends over the two years. Year-1 had a significant quartic polynomial trend while in year-2 the significant trend was linear (Table 3). The quartic trend had low yield 1919 oven-dry lb./acre in month-3 and high yield 3401 oven-dry lb./acre in month 9 (Figure 5). The linear trend in year-2 had positive slope, however in months-1 to -5, a cubic trend can be seen (Figure 5). In month-6, the yield is very high and alternates between low and high yields to month-12. The oscillating yield was unexpected but may have been an artifact of the one-month harvest interval, cutting height and morphology of the grass. Grasses regularly cut at 4 inches above soil level at 4- to 10-week intervals had decreasing proportion of leaves, and increasing proportion of stem, as the harvest interval increased (van Man and Wiktorsson, 2003). If stem elongation required more than one-month to reach the cutting height in the present field trial, it may be possible that the high yield included stem and the low yield was due to lesser proportion of stem because stem had not elongated above the cutting height. The cause of the slower stem elongation at month-6 in year-2 is not known. The quartic polynomial trend was moderate with an r^2 of 0.59 while the linear trend was poor with r^2 of 0.12 (Figure 5).

Signalgrass yield had significant quartic polynomial trends in years 1 and 2 (Table 3). The trends had similar characteristics of low yields of 1993 and 2189 oven-dry lb./acre between months-2 and -3 and high yields of 3468 and 3540 oven-dry lb./acre in months-7 and -8 (Figure 6). The similar polynomial trends were obtained despite a yield oscillation in year-2 that started in month-6 similar to that seen in Palisadegrass. The quartic polynomial trend was moderate in year-1 with r^2 of 0.42 and poor in year-2 with an r^2 of 0.12.

Average annual yield of signalgrass was 35403 oven-dry lb./acre, or 2950 oven-dry lb./acre per month. In contrast, signal grass yield harvested at 4-week intervals at Mealani, Waiakea, and Waimanalo Research Stations on the islands of Hawaii and Oahu, Hawaii, was 669, 568, and 1363 dry lb./acre, respectively (Fukumoto et al., 2002).

Table 2. Repeated measures and polynomial trend analysis for two forage grass species harvested monthly, November 2020 – October 2022, at the Hoolehua Plant Materials Center, Hawaii.

Effect	df	guineagrass	kikuyu
Year	1	ns	*
Month	11	**	**
Linear	1	**	ns
Quadratic	1	ns	ns
Cubic	1	**	*
Quartic	1	ns	ns
Residual	7	**	**
Year x Month	11	*	**
Linear	1	ns	ns
Quadratic	1	ns	ns
Cubic	1	ns	ns
Quartic	1	ns	*
Residual	7	*	**
CV%		4.9	3.6

* Significant at the 0.05 level of probability.

** Significant at the 0.01 level of probability.

ns Not significant at the 0.05 level of probability.

CV% Coefficient of variation, %.

Table 3. Repeated measures and polynomial trend analysis for three forage grass species harvested monthly, November 2020 – October 2022, at the Hoolehua Plant Materials Center, Hawaii.

		buffelgrass		palisadegrass		signalgrass	
Effect	df	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Month	11	**	**	**	*	ns	**
Linear	1	**	ns	**	*	*	*
Quadratic	1	ns	ns	ns	ns	ns	ns
Cubic	1	**	**	**	ns	ns	*
Quartic	1	*	*	*	ns	*	**
Residual	7	*	ns	*	*	ns	**
CV%		1.3	2.1	1.9	3.9	0.4	0.3

* Significant at the 0.05 level of probability.

** Significant at the 0.01 level of probability.

ns Not significant at the 0.05 level of probability.

CV% Coefficient of variation, %.

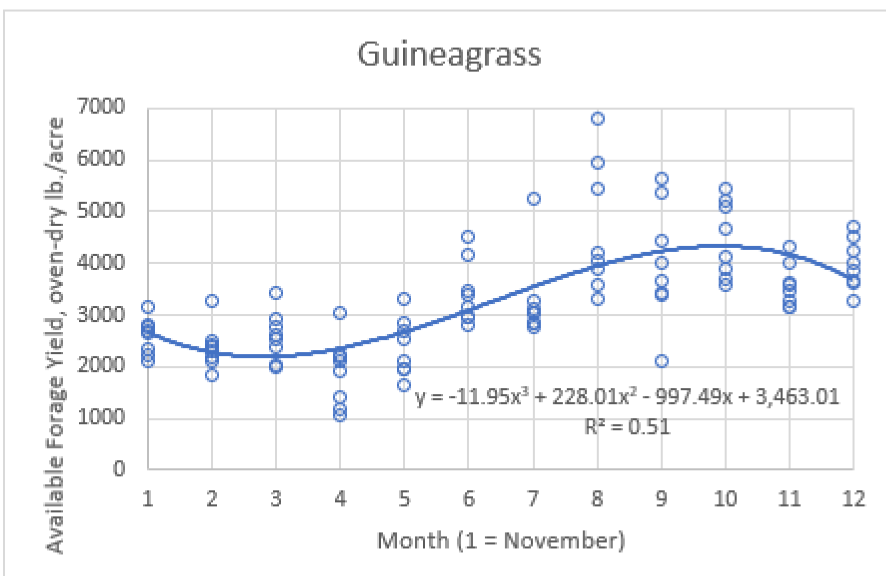

Figure 2. Polynomial trend (cubic) of monthly guineagrass yield collected at the Hoolehua PMC, Hawaii, from November 2020 to October 2022.

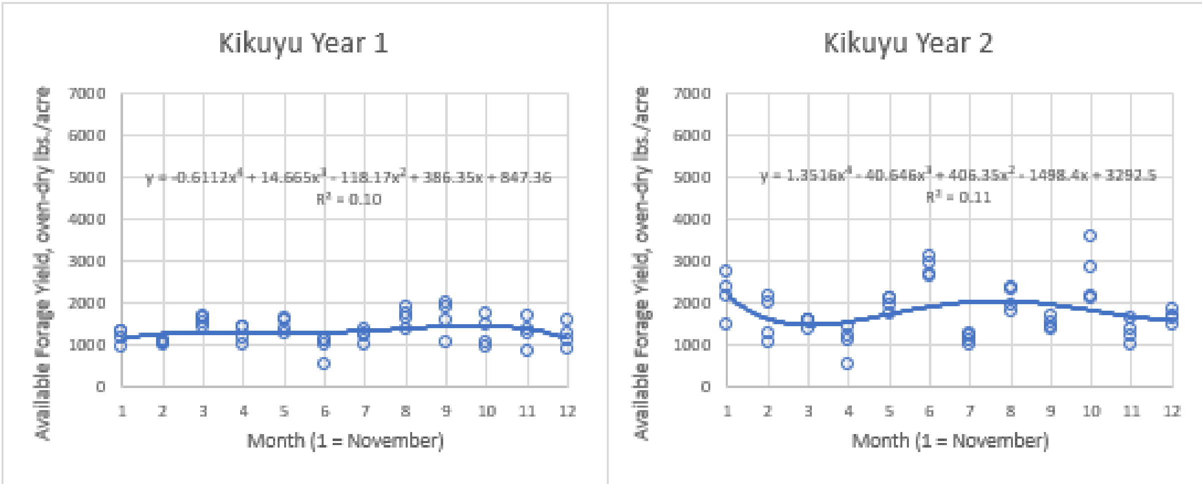

Figure 3. Polynomial trends (quartic) of monthly kikuyu grass yield for year-1 (November 2020 to October 2021) and year-2 (November 2021 to October 2022) at the Hoolehua PMC, Hawaii.

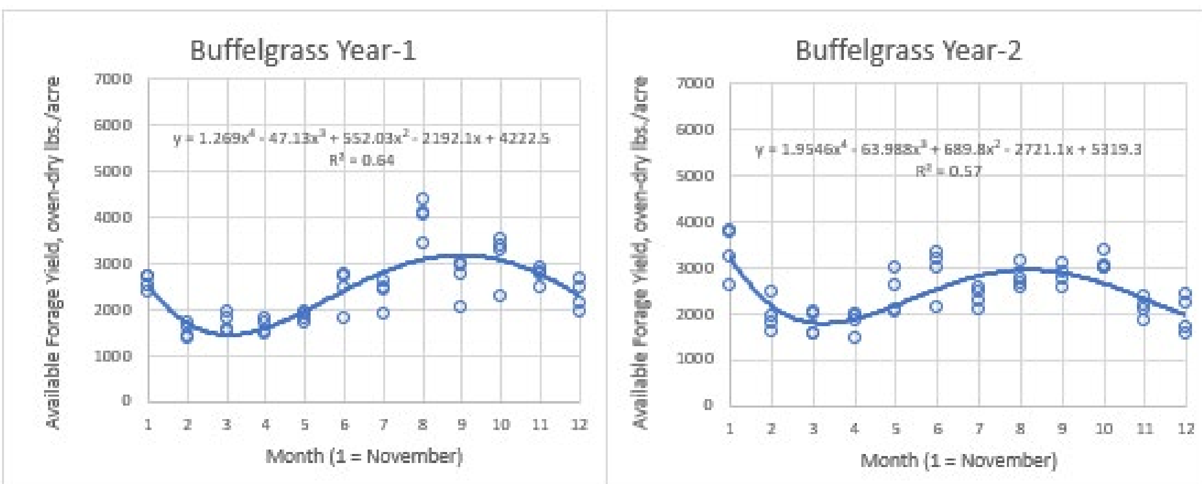

Figure 4. Polynomial trends (quartic) of monthly buffelgrass yield for year-1 (November 2020 to October 2021) and year-2 (November 2021 to October 2022) at the Hoolehua PMC, Hawaii.

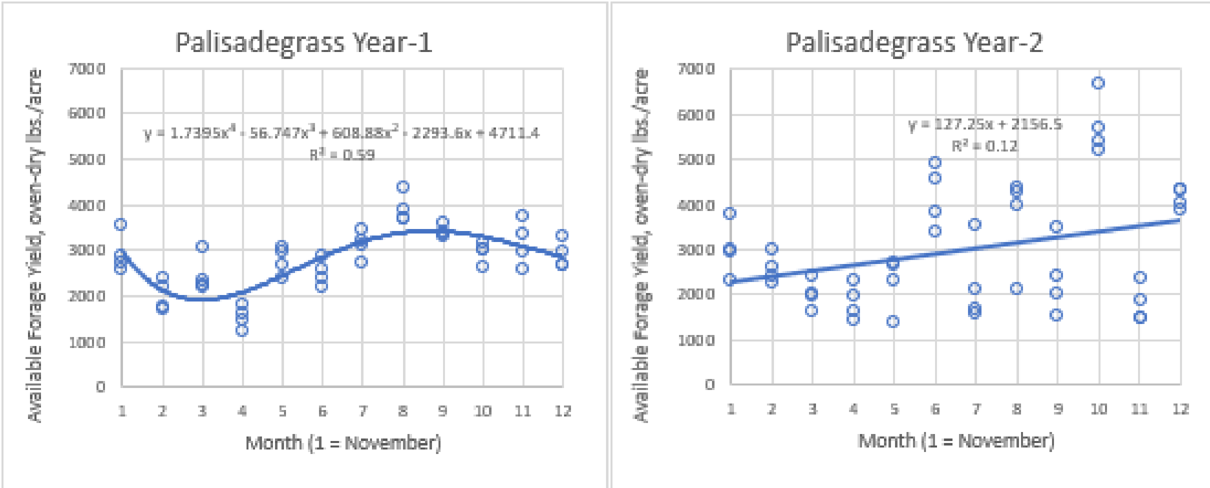

Figure 5. Polynomial trends (quartic and linear) of monthly palisadegrass yield for year-1 (November 2020 to October 2021) and year-2 (November 2021 to October 2022) at the Hoolehua PMC, Hawaii.

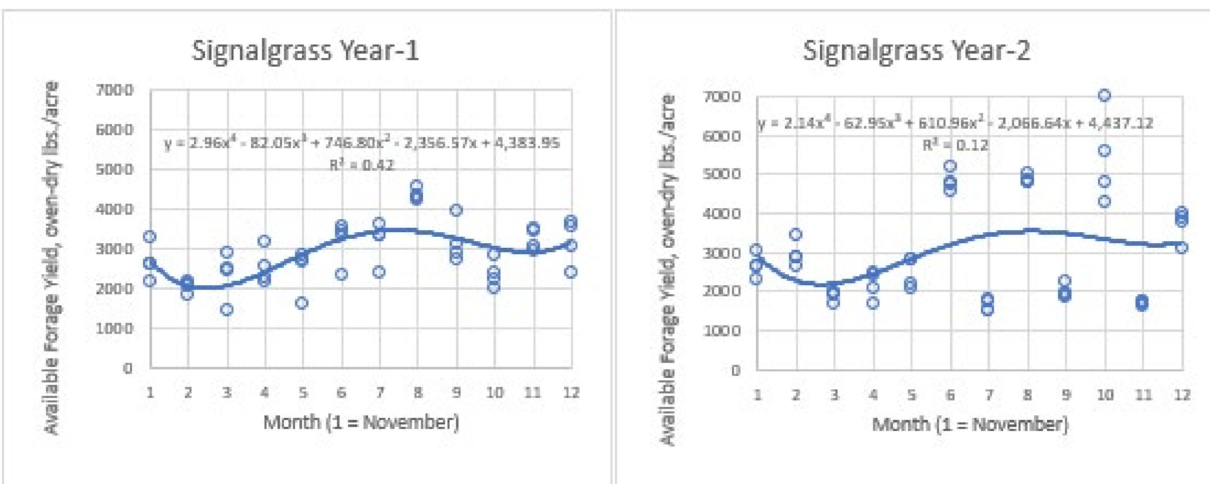

Figure 6. Polynomial (quartic) trends of monthly signalgrass yield for year-1 (November 2020 to October 2021) and year-2 (November 2021 to October 2022) at the Hoolehua PMC, Hawaii.

Stubble Yield

Stubble yield ranged from 1845 to 6902 oven-dry lb./acre for the five grass species (Table 4). The percent stubble for guineagrass, signalgrass, palisadegrass and kikuyu grass were similar ranging from 66 to 68%, but buffelgrass was significantly lower at 43% (Table 4). The percent stubble for buffelgrass was below the rule-of-thumb to leave half the grass plant when grazing (NRCS, 2022). Casual observation indicated that the buffelgrass plots had more weeds than other plots. These observations showed that the recommended grazing height for buffelgrass, 3 inches, may be too low. Cutting at this height removed more than 50% of the plant and slowed re-growth to the point that weeds would have dominated the plot had there not been any weed control measures taken. The re-growth could be improved by increasing the stubble height to 4 inches. At that height, stubble percent might be 57% if stubble weight were evenly distributed along the vertical of the plant.

Table 4. Stubble yield and % stubble of five forage grass species measured at the end of a two-year growth period on October 18, 2022.

Species	Stubble Yield, dry lb./acre	% Stubble
Guinea	6902 a	68 a
Signal	6104 a	67 a
Palisade	5718 a	66 a
Kikuyu	3030 b	66 a
Buffel	1845 b	43 b

Means followed by the same letter are not significantly different at the p = 0.05 level of probability.

Estimated Available Forage Yield Based on Plate Meter Height

The available forage yield was poorly estimated from plant height obtained from the plate meter (Figure 7). The MAE as a percentage of mean observed yield ranged from 22 to 40% (Table 5). Nash-Sutcliffe Efficiency, the overall indicator of model performance, was not greater than the satisfactory threshold 0.50 for all five grass species (Table 5). Accuracy of the predicted forage yield as measured by % bias was adequate for signalgrass, palisadegrass, kikuyu, and buffelgrass, but poor for guineagrass since its value was greater than 25% (Table 5). Precision of the estimated forage yield as measured by RSR was unsatisfactory for all five grass species, as no value was below the 0.70 threshold (Table 5). High error rates in estimated forage yield were observed in other studies due to heterogeneity of pasture growth caused by year, season, sward composition, and animal interaction that included trampling (Chapa et al., 2023; Hart et al., 2020; Klootwijk et al., 2019; McSweeney et al., 2022). Better calibration of the plate meter to account for these sources of error in conjunction with optimizing number of height measurements per unit area could improve the precision to an acceptable level for management decisions (Murphy et al., 2021).

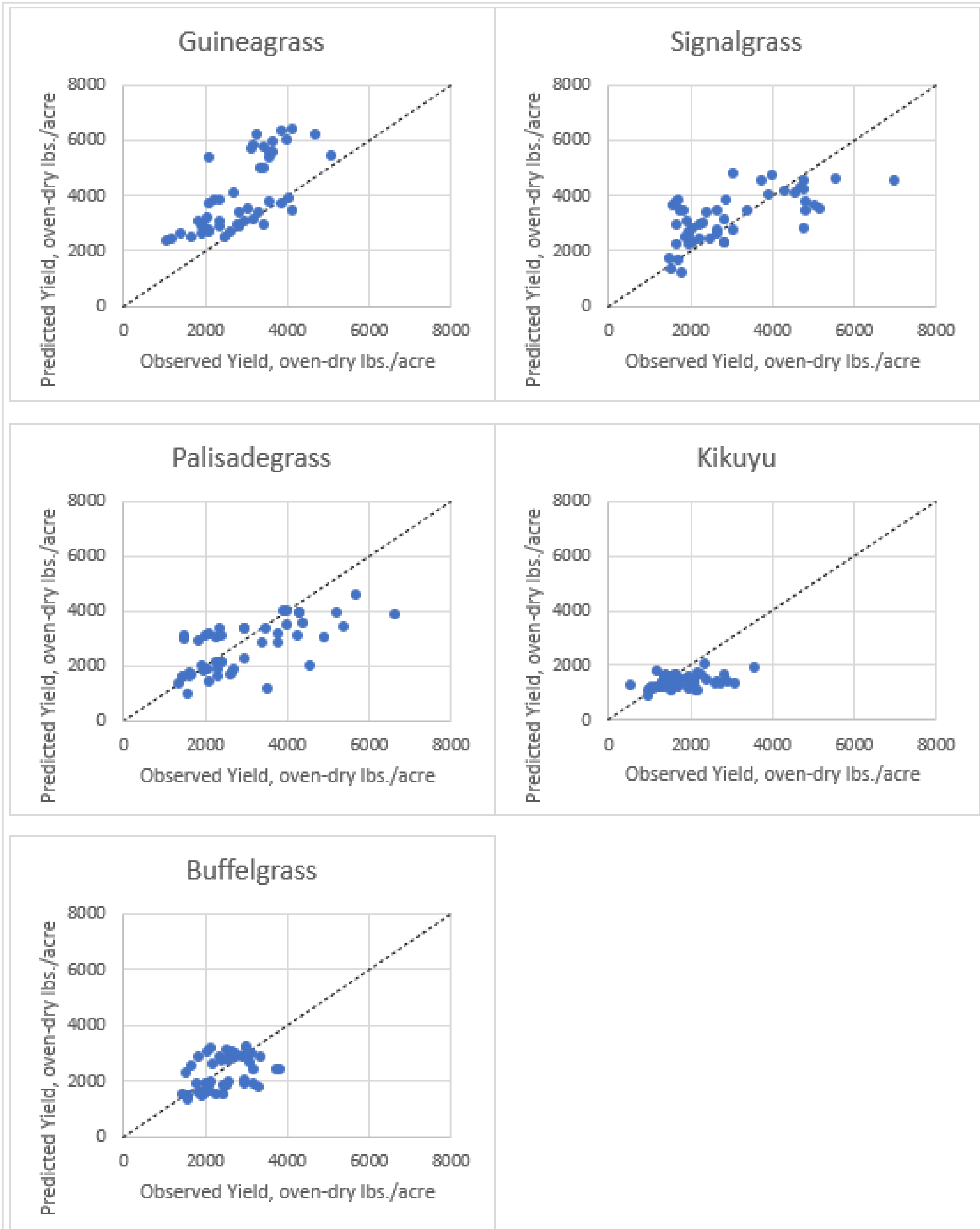

Figure 7. Plate meter validation plots comparing observed and predicted forage yields of five grass species grown in 2021-2022 at the Hoolehua PMC, Hawaii. Dotted lines are the 1:1 lines where data points would fall in cases when the predicted matches the observed.

Table 5. Plate meter validation statistics of predicted forage grass yield based on plant height against observed yield of five grass species grown in 2021-2022 at the Hoolehua Plant Materials Center, Hawaii.

Species	MOY	MAE	NSE	% Bias	RSR
guineagrass	3646	1151	-1.49	-37.4	1.58
signalgrass	2878	810	-0.40	-5.5	0.77
palisadegrass	2814	803	0.32	11.4	0.82
kikuyu	1301	518	-0.30	24.1	1.14
buffelgrass	2401	519	-0.21	7.8	1.10

MOY Mean observed yield.

MAE Mean absolute error.

NSE Nash-Sutcliffe Efficiency.

% Bias Percent bias.

RSR Root Mean Square Error-observations Standard Deviation Ratio.

Conclusions

This study was able to define monthly yield curves for each of the five grass species tested. The monthly yields showed significant cubic and quartic trends over time which coincided with air temperature and solar radiation. The annual yields of kikuyu, guineagrass, and signalgrass were higher than other yield data from Hawaii and Puerto Rico obtained under similar management conditions indicated that the yields during the present study may have been near-optimal for the Pacific region. These yield trends will be incorporated into the EcoCrop model to supplement the Prescribed Grazing Tool model that estimates the forage yield portion of the livestock-forage balance in the PIA.

The stubble yield showed that 66 to 68% of aboveground plant weight was left after harvesting the herbage mass of guineagrass, signalgrass, palisadegrass, and kikuyu. However, when cut to the recommended grazing height of 3 inches, buffelgrass stubble yield was only 43% of the aboveground plant weight. This indicated that stubble height recommendation should be raised to 4 inches which would leave a minimum of 50% of plant weight after grazing to promote quick regrowth and soil cover. This hypothesis will be tested in a future study.

The plate meter is a tool that could make estimating forage yield quicker than the standard clipping method. The accuracy of the plate meter to estimate forage yield was adequate for signalgrass, palisadegrass, kikuyu and buffelgrass. However, the precision of the yield estimates was poor for all grass species. Other researchers attributed poor precision to insufficient number of measurements and environmental factors such as soil moisture or air temperature. Improving precision by considering these factors or developing site-specific calibration equations would be necessary before using this tool to make management decisions.

Acknowledgement

The authors extend their appreciation to Dr. Steve Smith, University of Arizona, for his assistance with the statistical analysis in this study.

Literature Cited

Adams, P. and Cape Girardeau Staff. 2013. Graze4, version 3.3. https://www.nrcs.usda.gov/wps/portal/nrcs/mo/technical/nrcs144p2_012547/ . Accessed January 22, 2020.

Analytical Software. 2013. Statistix 10, user's manual. Analytical Software, Tallahassee, FL.

Andrade, A.S., P.M. Santos, J.R.M. Pezzopane, L.C. de Araujo, B.C. Pedreira, C.G.S. Pedreira, F.R. Marin, and M.A.S. Lara. 2015. Simulating tropical forage growth and biomass accumulation: an overview of model development and application. Grass and Forage Science 71:54-65. Doi: 10.1111/gfs.12177.

Aregheore, E.M. 2005. Feeds and forages in Pacific Island farming systems. Department of Animal Science, University of the South Pacific, Alafua, Samoa.

Box, G.E.P., and D.R. Cox. 1964. An analysis of transformations (with discussion). Journal of Royal Statistical Society, Ser. B, 26:211-252.

Briske, D.D., J.D. Derner, D.G. Milchunas, and K.W. Tate. 2011. An evidence-based assessment of prescribed grazing practices. P. 22-74 In D.D. Briske (ed.) Conseration Benefits of Rangeland Practices: Assessment, Recommendations, and Knowledge Gaps. Allen Press, Lawrence, KS.

Brestovansky, M. 2019. Farmers have few options for fighting two-lined spittle bug. Hawaii Tribune Herald. https://www.hawaiitribune-herald.com/2019/12/10/hawaii-news/farmers-have-few-options-for-fighting-two-lined-spittle-bug/. Accessed February 24, 2020.

Butler, L.D. 2003. National Range and Pasture Handbook, revision 1. Grazing Lands Technical Institute, Natural Resources Conservation Service, U.S. Department of Agriculture.

Chapa, J.M., B. Pichlbauer, M. Bobal, C. Guse, M. Drillich, and M. Iwersen. 2023. Field evaluation of a rising plate meter to estimate herbage mass in Austrian pastures. Sensors 23:7477. Doi: 10.3390/s23177477.

Di Paola, A., R. Valentini, and M. Santini. 2015. An overview of available crop growth and yield models for studies and assessments in agriculture. Journal of the Science of Food and Agriculture 96:709-714. Doi: 10.1002/jsfa.7359.

Dobos, R., C. Seybold, J. Chiaretti, S. Southard, M. Levin, and Soil Science Division Staff. Interpretations: The impact of soil properties on land use, Chapter 8. In C. Ditzler, K. Scheffe, and H.C. Monger (eds) Soil Survey Manual, USDA Handbook 18. Government Printing Office, Washington, D.C. https://www.nrcs.usda.gov/sites/default/files/2022-09/SSM-ch8.pdf. Accessed April 12, 2024.

FL FOTG. 2012. Florida Graze Tool. https://efotg.sc.egov.usda.gov/references/public/FL/Florida_Graze_Tool.xlsb.xlsm. Accessed January 22, 2020.

FAO. 2000. The EcoCrop Database. Food and Agriculture Organization, Rome, Italy.

Fortiner, J. and Soil Science Division Staff. Soil survey data collection, management, and dissemination, Chapter 7. In https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcs142p2_054257 . Accessed January 17, 2020.

Fukumoto, G. 2003. Forages website. College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa, Honolulu, HI. https://www.ctahr.hawaii.edu/forages/nutrients/Yield.html. Accessed June 21, 2024.

Fukumoto, G.K., and C.N. Lee. 2002. Signalgrass for forage. Livestock Management LM-3, College of Tropical Agriculture and Human Resources, University of Hawaii, Honolulu, Hawaii.

Fukumoto, G.K., and C.N. Lee. 2003. Kikuyugrass for forage. Livestock Management LM-5, College of Tropical Agriculture and Human Resources, University of Hawaii, Honolulu, Hawaii.

Fukumoto, G.K., and M. Yamasaki. 2000. Evaluation of various fertilizer formulation on pasture yield. College of Tropical Agriculture and Human Resources, University of Hawaii, Honolulu, Hawaii.

Gallaher, T.J., K. Brock, B.H. Kennedy, C.T. Imada, and N. Walvoord. 2020. Plants of Hawaii. http://www.plantsofhawaii.org. Accessed June 24, 2024.

Giambelluca, T.W., X. Shuai, M.L. Barnes, R.J. Alliss, R.J. Longman, T. Miura, Q. Chen, A.G. Frazier, R.G. Mudd, L. Cuo, and A.D. Businger. 2014. Evapotranspiration of Hawaii. Final report submitted to the U.S. Army Corps of Engineers – Honolulu District, and the Commission on Water Resource Management, State of Hawaii.

Hart, L., J. Werner, E. Velasco, S. Perdana-Decker, J. Weber, U. Dickhoefer, and C. Umstaetter. 2020. Reliable biomass estimates of mulstispecies grassland using the rising plate meter, pp. 641-643. In P. Virkajarvi, K. Hakala, M. Hakojarvi, J. Helin, I. Herzon, V. Jokela, S. Peltonen, M. Rinne, M. Seppanen, and J. Uusi-Kamppa (eds.) Meeting the future demands for grassland production, Proceedings of the 28th general meeting of the European Grassland Federation, October 19-22, 2020 Helsinki, Finland.

Hue, N.V., H. Ikawa, and X. Huang. 2000. Predicting soil phosphorus requirements. In J.A. Silva and R. Uchida (eds.) Plant nutrient management in Hawaii’s soils, approaches for tropical and subtropical agriculture. College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa, Honolulu, HI.

Hosaka, E.Y. 1958. Kikuyu grass in Hawaii. Circular 389, Agricultural Extension Service, University of Hawaii, Honolulu, Hawaii.

Hosaka, E.Y., and N.K. Carlson. 1957. Buffelgrass for Hawaiian ranges. Extension Circular 380, Agricultural Extension Service, University of Hawaii, Honolulu, Hawaii.

Howell, D.C. 2010. Statistical methods for psychology. Cengage Wadsworth, Belmont, CA.

Hue, N.V., H. Ikawa, and X. Huang. 2000. Predicting soil phosphorus requirements. In J.A. Silva and R. Uchida (eds.) Plant nutrient management in Hawaii's soils, Approaches for tropical and subtropical agriculture. College of Tropical Agriculture and Human Resources, University of Hawaii, Honolulu, Hawaii.

Ikawa, H., H.H. Sato, A.K.S. Chang, S. Nakamura, E. Robello, Jr., and S.P. Periaswamy. 1985. Soils of the Hawaii Agricultural Experiment Station, University of Hawaii: Soil survey, laboratory data, and soil descriptions. Research Extension Series 022, College of Tropical Agriculture and Human Resources, University of Hawaii, Honolulu, HI.

Kirchner, J. 1995. Tools for transforming data, Toolkit 3. Data Analysis Tookits, Earth and Planetary Science, University of California, Berkley, CA. http://seismo.berkeley.edu/~kirchner/eps_120/EPSToolkits.htm. Accessed April 12, 2024.

Klootwijk, C.W., G. Holshof, A. van den Pol-van Dasselaar, K.L.M. van Helvoort, B. Engel, I.J.M. de Boer, and C.E. van Middelaar. 2019. The effect of intensive grazing systems on the rising plate meter for perennial ryegrass pastures. Journal of Dairy Science 102:10439-10450. Doi: 10.3168/jds.2018-16118.

McSweeney, D., L. Delaby, B. O'Brien, A. Ferard, N. Byrne, J. McDonagh, S. Ivanov, and N.E. Coughlan. 2022. Dynamic algorithm conversion of compressed sward height to dry matter yield by a rising plate meter. Computer and Electronics in Agriculture 196:106919. Doi: 10.1016/j.compag.2022.106919.

Moriasi, D.N., J.G. Arnold, M.W. Van Liew, R.L. Bingner, R.D. Harmel, and T.L. Veith. 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the ASABE 50:885-900.

Murphy, D.J., B. O'Brien, D. Hennessy, M. Hurley, and M.D. Murphy. 2021. Evaluation of the precision of the rising plate meter for measuring compressed sward height on heterogenous grassland swards. Precision Agriculture 22:922-946. Doi: 10.1007/s11119-020-90765-9.

NIST. 2012. NIST/SEMATECH e-Handbook of Statistical Methods. http://www.itl.nist.gov/div898/handbook. Accessed April 12, 2024.

NRCS (Natural Resources Conservation Service). 2002. Section II-E-1. Forage suitability groups. Field Office Technical Guide, Section II, NRCS, U.S. Dept. of Agriculture. https://efotg.sc.egov.usda.gov/references/public/HI/Section_II_E_Forage.pdf. Accessed January 20, 2020.

NRCS. 2019. National soil survey handbook, title 430-VI. http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcs142p2_054242. Accessed January 20, 2020.

NRCS. 2022. Prescribed grazing (528) conservation practice specification. Pacific Island Area, Natural Resources Conservation Service, U.S. Department of Agriculture. https://efotg.sc.egov.usda.gov/#/state/HI/documents/section=4&folder=-186. Accessed June 10, 2024.

PIA FOTG. 2008. Archived – 528 Worksheets – PI Aug. 2008 – 150211. https://efotg.sc.egov.usda.gov/#/details. Accessed January 22, 2020.

Ramirez-Villegas, J., A. Jarvis, and P. Laderach. 2013. Empirical approaches for assessing impacts of climate change on agriculture: The EcoCrop model and a case study with grain sorghum. Agricultural and Forest Meteorology 170:67-78. doi:10.1016/j.agrformet.2011.09.005

Ripperton, J.C., R.A. Goff, D.W. Edwards, and W.C. Davis. 1933. Range grasses of Hawaii. Bulletin no. 65, Hawaii Agricultural Experiment Station, University of Hawaii, Honolulu, Hawaii.

Snow, N. 2010. Notes on grasses (Poaceae) in Hawaii: 2. Records of the Hawaii Biological Survey for 2008. N.L. Evenhuis and LG. Eldredge (eds) Bishop Museum Occasional Papers 107:46-60.

Stuth, J., D. Schmitt, R.C. Rowan, J. Angerer, and K. Zander. 2003. PHYGROW (Phytomass Growth Simulator) User's Guide Technical Documentation. Ranching Systems Group, Department of Rangeland Ecology and Management, Texas A&M University, College Station, TX.

Tamimi, Y.N., L.B. Sherrod, S.M. Ishizaki, and T. Izuno. 1968. The effect of levels of nitrogen, phosphorus, and potassium fertilization upon beef production on kikuyugrass. Technical Bulletin No. 76, Hawaii Agricultural Experiment Station, University of Hawaii, Honolulu, Hawaii.

Thorne, M.S. 2011. Hawaii Rainfall and Forage Production Index Project – Final Performance Report. A Final Report submitted to the Natural Resources Conservation Service in fulfillment of Conservation Innovation Grant, Cooperative Agreement No. 69-9251-7-778.

Thorne, M.S., and J.P. Hewlett. 2013. Hawaii Forage Production Estimator Tool. https://globalrangelands.org/state/hawaii/hawaii-forage-production-estimator-tool. Accessed January 22, 2020.

Van Man, N., and H. Wiktorsson. 2003. Forage yield, nutritive value, feed intake and digestibility of three grass species as affected by harvest frequency. Tropical Grasslands 37:101-110.

Vicente-Chandler, J., S. Silva, and J. Figarella. 1959. The effect of nitrogen fertilization and frequency of cutting on the yield and composition of three tropical grasses. Agronomy Journal 51:202-206. Doi: 10.2134/agronj1959.00021962005100040006x.

Whitney, A.S. 1974. Growth of kikuyugrass (Pennisetum clandestinum) under clipping. I. Effects of nitrogen fertilization, cutting interval, and season on yield and forage characteristics. Agronomy Journal 66:281-287.

Whitney, L.D., E.Y. Hosaka, and J.C. Ripperton. 1939. Grasses of the Hawaiian ranges. Bulletin no. 82, Hawaii Agricultural Experiment Station, University of Hawaii, Honolulu, Hawaii.