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# Forage Biomass Estimated with a Pre-Calibrated Equation of a Rising Platemeter in Pastures Grown in Tropical Conditions

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**Abstract:** Accurate estimates of forage biomass allow for better adjustments of stocking rate, carrying capacity, and dry matter intake in livestock operations. Among the most common methods to estimate biomass are platemeters, for which specific calibration equations have been developed for temperate conditions. However, platemeters are not commonly used in tropical livestock operations where their goodness of fit to estimate forage biomass remains unknown. In this study, we aimed to compare three methods (the rising platemeter, Botanal®, and hand-clipping) to estimate forage biomass throughout one year on perennial ryegrass (*Lolium perenne*), Kikuyu (*Cenchrus clandestinus*), and African stargrass (*Cynodon nlemfuensis Vanderyst*) pastures in Costa Rica. Estimates of forage biomass were consistently greater with the platemeter than with the Botanal® and clippings across the three grass species evaluated. In Ryegrass pastures, the residual standard deviation (1845 kg DM ha$^{-1}$) of forage biomass estimated with the platemeter was two- and four-fold with respect to Stargrass and Kikuyu pastures (935 and 447 kg DM ha$^{-1}$), respectively. Although platemeters are straightforward methods for biomass estimation in pastures, our data suggest that their use and implementation in tropical pastures may lead to overestimating indicators such as stocking rate and carrying capacity. We suggest developing calibration equations specific for tropical conditions that consider our findings as an input to adjust the sampling procedure necessary to improve the accuracy of platemeters and foster greater adoption among livestock producers.

**Keywords:** Botanal; yield biomass; ryegrass; Kikuyu; stargrass

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## 1. Introduction

Grass-based livestock operations require accurate and timely estimates of forage biomass to allocate dry matter (DM) to cattle [1,2]. Livestock producers and technicians use estimates of the DM available in pastures as an input to make decisions on stocking rates, rest periods [3], grazing intensity [4], dry matter intake [5], supplementation, and nutritional balances [6].

Monitoring biomass in pastures must not only use a low-cost practical method [4,7] but must also be easily implemented by producers. At the farm level, the labor invested in estimating forage biomass has to offset the economic losses that a producer may incur due to the low accuracy of either method used [4].

The methods to estimate forage biomass can be grouped as destructive or direct and non-destructive or indirect [1,7]. Destructive methods include the partial or total harvest of a significant area of the paddock or plot, either by hand-clipping or with machinery [8]. Clipping and weighing forage has been the standard method used to assess biomass in pastures [4] and is also the method used to compare newer methods to estimate their efficiency [3,9,10]. Non-destructive methods extrapolate estimates taken from a small sample, from readings measured in equipment, or from a larger area by using calibrations based on direct methods that tend to use simple linear [1] or multiple regressions [11,12].

Non-destructive methods can also be grouped into visual estimation, height and density measurements, and non-vegetative attributes related to biomass yield [8]. Regardless of the indirect method, calibrations are strongly recommended before estimating forage biomass as most methods may show specificity due to the climatic conditions of where they were developed [13]. Calibrations for indirect methods have been typically developed in grass monocultures or pastures with plant compositions evenly distributed [3,4]. Thus, most of the rising platemeters available in the market use equations developed in New Zealand with green, leafy, vegetative pastures dominated by ryegrass and white clover [1].

Double sampling methods combine hand-clipped and visual samples [8], with the Botanal® method being one of the most widely used and accepted among researchers [14]. With only a few hand-clipped samples (standards), a regression equation estimates biomass (y = dependent variable) from the average of at least 50 visual samples (x = independent variable) [8].

Unfortunately, given that the standards must be dehydrated for 48 h at 60 °C as well as the labor necessary for cutting samples, many producers choose not to measure forage biomass with this method. The labor and time invested in harvesting and processing samples has, for many years, been considered a limitation for both producers [15] and researchers to make regular biomass assessments in pastures [8]. Hand-clipping makes it difficult to evaluate large areas [7], and performing assessments on a regular basis (weekly or monthly) is not a common practice among producers [4,10].

Platemeters, on the other hand, are indirect methods to estimate forage biomass that consist of pre-calibrated regression equations logged in devices that measure pasture height, density, and grass species within the pasture [1,12]. Platemeters function by placing a square or round plate that slides along a metal or plastic pole, providing an estimated height that is read directly on the pole (ruler) or on an electronic device attached to it [1,4].

Platemeters are typically described according to the direction in which the plate slides on the pole to be placed on the pasture. Thus, falling platemeters are those with the plate falling from the top of the pole [9,12], while rising platemeters slide from the bottom of the pole until the latter reaches the ground level [1,4].

Indirect methods tend to be favored due to the ease of application and the time required to take a high number of sampling points and occasions [2]. Alternative indirect methods such as rulers and sward capacitance meters have also been evaluated for forage biomass in pastures [10]. However, because platemeters provide data in situ, producers prefer them, especially with respect to direct methods [10]. Even for some indirect methods, the data collected need to be recorded into equations to obtain forage biomass [3,4], which may detract their use by producers.

The accuracy of pre-calibrated methods to predict forage biomass depends on the stage of growth [3,15], the species composition, the ratio of green leaf and dead material in the pasture, and the proportion of reproductive and vegetative growth [1]. For instance, platemeters have proven to be more reliable when estimating biomass on a dry matter basis than when estimating fresh biomass (green forage) [13]. Forage biomass estimated with platemeters may also vary in pastures with very high or very low levels of biomass, sloping ground or rough surfaces [1].

Indirect methods to estimate forage biomass with remote sensing have been recently developed for pastoral ecosystems by using vegetation indexes that provide information about forage growth on a larger scale [7]. Even though remote sensing methods look promising as they allow taking a greater number of samples in larger areas in less time [7,16,17], rising platemeters can still provide biomass estimates in a faster fashion compared to methods such as Botanal and hand-clipping.

Most studies evaluating pre-calibrated equations in rising platemeters have been developed under temperate conditions, but their accuracy and precision have not been evaluated with grass species grown in tropical conditions. In this study, we compared data on forage biomass estimated with a rising platemeter, the Botanal® method, and hand-clipping in ryegrass, Kikuyu, and African stargrass pastures in Costa Rica. Our aim was to independently compare the goodness of fit of each method with respect to the other two. We used pre-established levels of accuracy mentioned in the literature. Our hypothesis was that the goodness of fit of the rising platemeter may be greater for ryegrass with respect to Kikuyu and stargrass as the prediction equations were developed with this grass species.

## 2. Materials and Methods

### *2.1. Locations and Pasture Management in the Farms*

This study was conducted from June 2016 to July 2017 at the foothills of Irazú Volcano in the province of Cartago, Costa Rica. The forage species evaluated were perennial ryegrass (*Lolium perenne*), Kikuyu (*Cenchrus clandestinus* Hochst. ex Chiov.), and African stargrass (*Cynodon nlemfuensis* Vandersyt) grown at 2800 (09°57′ N, 83°49′ W), 2400 (09°56′ N, 83°52′ W), and 1400 m of elevation (09°51′ N, 83°52′ W), respectively. These forages are three of the main species used at specialized dairy farms in Costa Rica [18,19]. Pasture management indicators of the grass species evaluated in this study are in Table 1.

**Table 1.** Pasture management indicators for perennial ryegrass, Kikuyu, and stargrass paddocks sampled at mid- and high-elevations in Costa Rica.

| Indicator | Ryegrass | Kikuyu | Stargrass |
|---|---|---|---|
| Paddock size ($m^2$) | 3044 (1933–3846) | 1677 (875–3908) | 4192 (2314–6928) |
| Stocking density ($m^2$ $cow^{-1}$ $d^{-1}$) | 68 (41–86) | 65 (27–113) | 124 (45–220) |
| Regrowth (d) | 38 | 30 | 30 |
| Phenological stage (green leaves $shoot^{-1}$) | 2.43 | 3.99 | 6.56 |
| Nitrogen fertilization (kg N $ha^{-1}$ $yr^{-1}$) | 250 | 200 | 180 |
| Slope in the pastures (%) | 15.6 ± 3.0 | 11.9 ± 3.7 | 3.3 ± 0.9 |

### *2.2. Data Collection*

The study comprised seven sampling dates during the rainy season (May–November) and three sampling dates during the dry season (December–April) of the region according to historic weather data [20]. For Ryegrass and stargrass, a total of 20 paddocks were sampled (one day before grazing), and 19 paddocks were sampled for Kikuyu grass throughout one year ($n$ = 59). At each paddock, the forage biomass was estimated using the following three methods:

(1) Platemeter

An electronic rising platemeter AgHub™ model F300 was used to estimate forage biomass on a dry matter basis with the pre-calibrated regression equation (also known as the universal equation) ('y = 140 + 500x') provided by the manufacturing company. The diameter of the F300 plate was 38 cm and its weight 315.5 g. A minimum of 30 readings (subsamples) equally spaced and evenly spread (every eight to ten steps) were taken at each paddock by walking a zigzag pattern. The procedure for the platemeter as well as the number of readings taken (30–40 depending on the size of the paddock) followed the recommendations given by the manufacturing company. In order to maintain the consistency of the number of steps walked per reading and to represent the variability within the pastures, 40 readings were only taken in two paddocks of stargrass pastures that were larger than 5000 $m^2$ (6680 and 6698 $m^2$). Once the readings were taken at each paddock, the average biomass and compressed height reported by the platemeter were manually recorded. Platemeter readings were taken prior to the other two methods to avoid any possible interference from either.

(2) Botanal®

The Botanal® method consists of the collection of real (hand-clipped standards) and visual samples [14]. Each pasture was first visually assessed for its uniformity by walking a diagonal transect. Unlike the study conducted by [14] in this study, three levels (standards) of forage biomass (1 = low, 2 = medium, and 3 = high) were assigned to each pasture by integrating both height and density. Based on previous studies [19,21], three levels have been proven to reduce the subjectivity to assign both real and visual samples. Each real sample was hand-clipped at 5 cm stubble height by using a 50 cm × 50 cm metal frame and individually packed in plastic bags for later transport in a cooler for drying in an air-forced oven at 60 °C for 48 h at the Research Centre for Animal Nutrition in the University of Costa Rica. A total of 50 visual samples were then taken at each paddock based on the three standards previously assigned, and the whole paddock was visually sampled by following a zig-zag pattern (every five to six steps). The percent dry matter estimated in the lab for each sample was incorporated into the Botanal® spreadsheet, which estimates kilograms of DM $ha^{-1}$ (y = dependent variable) by weighing the dry mass of each sample by the average level (x = independent variable) in the pasture using a simple linear regression. As mentioned above, the use of three standards implied the adjustment of the spreadsheet accordingly. As complimentary data to characterize the paddocks that were sampled, the pasture slope was collected by using a clinometer Suunto PM-5/360 PC. Along with the visual samples, species composition was assessed and estimated for all the paddocks evaluated. The species composition data were included in the Botanal spreadsheet, and, for this study, only the percent of senescent material is reported (Table 2). Further data were reported in [18].

**Table 2.** Forage biomass and agronomic traits of perennial ryegrass, Kikuyu, and stargrass pastures.

| Variable | Ryegrass * | Kikuyu | Stargrass |
|---|---|---|---|
| Platemeter biomass (kg DM $ha^{-1}$) | 4969 (3804–6534) | 4472 (3440–5260) | 6125 (5008–6870) |
| Botanal biomass (kg DM $ha^{-1}$) ** | 3124 (1546–5225) | 4042 (1927–6372) | 5190 (3150–9139) |
| Clippings biomass (kg DM $ha^{-1}$) | 3379 (1460–5376) | 4184 (1946–6605) | 5304 (3242–9077) |
| Compressed sward height (cm) | 31.8 (23.6–43.1) | 28.8 (23.9–34.0) | 40.3 (32.2–45.5) |
| Platemeter biomass by compressed height (kg DM $cm^{-1}$) | 157 (149–168) | 155 (131–185) | 153 (151–155) |
| Senescent material (%) | 2.57 (0–15.2) | 12.06 (0–44.03) | 15.39 (0–46.01) |

* $n$ = 20 paddocks per species. ** Standard error and range (min–max).

(3) Hand-clipping (clippings)

The three (real) samples collected at each pasture for Botanal were used to estimate the biomass yield by following a hand-clipping and weighing procedure [22]. The average biomass of the three subsamples (kg of green forage per square meter) was multiplied by the average dry matter content reported by laboratory to estimate the biomass (kg of dry forage per hectare) for each pasture. This procedure was previously evaluated and compared in [19] against the Botanal method with minor differences (data not published) and reducing the time spent during the sampling.

## *2.3. Data Analysis*

Descriptive statistics were used to compare the accuracy of the platemeter with respect to the Botanal method and hand-clipping. Both numerical and relative (percent) differences in biomass (in kg of DM $ha^{-1}$) were calculated with the residual standard deviation (RSD) by comparing two of the methods simultaneously. At each comparison, one method was considered the most accurate (hand-clipping > Botanal > platemeter) to represent the predictability of the indirect methods as calculated in previously studied [3].

Each method was also compared with the other two by estimating the coefficient of determination ($r^2$), which is a basic indicator that allows to determine goodness of fit between two methods as well as their potential of prediction. $r^2$ values estimate the proportion of the variation in biomass that is explained by the regression equation with values closer to 1 being desirable [1]. Independent comparisons of two methods were used simultaneously without pooling the three methods together in the analysis.

A general regression equation was created for each grass species by taking all the intercepts (b) and slopes (m) of each pasture sampled with the Botanal method throughout the year and estimating the average for each. Each equation was then calculated with the average level (x = average from the 50 visual samples) found for all pastures sampled throughout the year for each grass species as a predictor of forage biomass. The average forage biomass estimated with Botanal for each species was compared with the biomass estimated with each general equation, and we estimated the difference between both.

## 3. Results

### 3.1. Pasture Management

The size of the paddocks varied among the three grasses evaluated (Table 1). Stargrass pastures were, on average, 37% and 150% larger than ryegrass and Kikuyu pastures, respectively. When pastures had greater areas, the number of readings taken with the platemeter were adjusted accordingly. This was the situation only in two stargrass pastures. As a result of the size of the paddocks, the stocking density was greater for stargrass pastures, indicating a less intensive grazing intensity compared to ryegrass and Kikuyu, which had almost half the grazing area per day.

The days of regrowth were similar for stargrass and Kikuyu while ryegrass typically required longer periods to regrow partly because of the elevation where it is grown. The number of leaves was greater for stargrass, followed by Kikuyu and ryegrass, and the nitrogen rates were similar among the three farms. Finally, the slope in the pastures was greater for ryegrass and Kikuyu compared to stargrass.

### 3.2. Forage Biomass

Forage biomass was greater with the platemeter than Botanal and the clippings in all three species (Table 2). Stargrass pastures consistently exhibited the greatest yields with all three methods, followed by Kikuyu and ryegrass with Botanal and clippings, respectively.

The compressed height showed similar results to the biomass yields estimated with the platemeter, with stargrass having the greatest values, followed by ryegrass and Kikuyu. Despite the differences found in biomass yields and height, the indicator of biomass by compressed height was similar among the three grass species. The senescence was greater in stargrass and Kikuyu pastures, while ryegrass had a low incidence of dead material. Both stargrass and Kikuyu had, in some cases, paddocks with more than 40% of senescent material.

The forage biomass from Botanal and clippings were similar with respect to the platemeter (Figure 1), especially for ryegrass and stargrass, while the biomass for Kikuyu pastures tended to be closer among the three methods. Ryegrass pastures had consistently greater estimates of biomass with the platemeter, whereas both Kikuyu and stargrass varied more, having paddocks where the platemeter had lower estimates than Botanal and the clippings for both species.

### 3.3. Comparison of Methods to Estimate Forage Biomass

The platemeter overestimated forage biomass compared to the Botanal method for the three species, showing that Ryegrass pastures had a residual standard deviation two- and four-fold that of the stargrass and Kikuyu pastures, respectively (Table 3). The relative differences in forage biomass (% RSD) between Botanal and the platemeter were similar for Kikuyu and stargrass, whereas for ryegrass pastures, the platemeter estimated over 70% more biomass compared to the Botanal method.

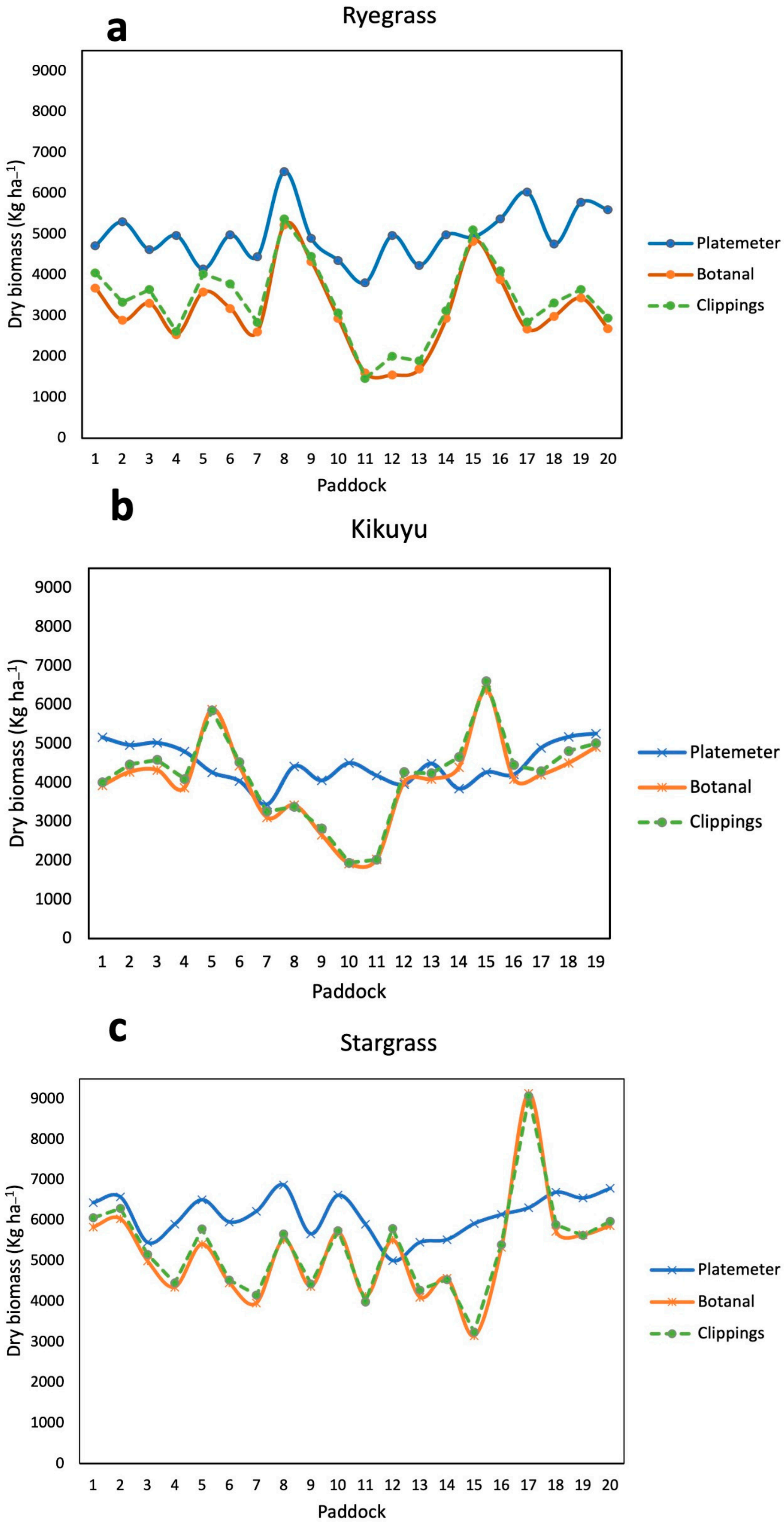


**Figure 1.** Forage biomass of ryegrass (**a**), Kikuyu (**b**) and stargrass (**c**) pastures estimated with three methods.

**Table 3.** Residual standard deviation (RSD) and coefficient of determination ($r^2$) comparing three methods to estimate forage biomass in ryegrass, Kikuyu, and stargrass pastures.

| Variable | Ryegrass * | Kikuyu | Stargrass |
|---|---|---|---|
| RSD (platemeter–Botanal) * | 1845<br>(110–3420) | 447<br>(−2106–2577) | 935<br>(−2829–2768) |
| % RSD (diff./Botanal) | 73<br>(2–221) | 19<br>(−33–134) | 23<br>(−31–88) |
| RSD (platemeter–clippings) | 1590<br>(−179–3190) | 297<br>(−2339–2558) | 801<br>(−2767–2676) |
| % RSD (diff./clippings) | 59<br>(−4–161) | 16<br>(−35–131) | 62<br>(22–139) |
| RSD (Botanal–clippings) | 255<br>(−140–603) | 142<br>(−40–358) | 114<br>(−141–378) |
| % RSD (diff./clippings) | 8<br>(−10–23) | 3<br>(−1–8) | 2<br>(−4–7) |
| $r^2$ (platemeter vs. Botanal) | 0.20 | 0.04 | 0.16 |
| $r^2$ (platemeter vs. clippings) | 0.19 | 0.03 | 0.17 |
| $r^2$ (Botanal vs. clippings) | 0.97 | 0.98 | 0.98 |

* Range (min–max).

The RSD in the forage biomass found between the platemeter and the clippings decreased with respect to that of Botanal and the platemeter (Table 3) and followed the same pattern, but the relative differences were, in this case, greater for stargrass, followed by ryegrass and Kikuyu, the latter having the smallest relative difference between these two methods.

The Botanal and the clippings were the methods with the smallest differences in this study (Table 3). Both the numerical and the relative differences for all three grass species decreased for these two methods compared to the platemeter.

The coefficient of determination ($r^2$) was estimated for two of the methods simultaneously with the assumption that one has greater accuracy. The $r^2$ between the platemeter and Botanal was low for all three grasses (Figure 2), with Kikuyu pastures reporting the lowest goodness of fit. Similarly, the $r^2$ for the platemeter and clippings for the three grasses was lower than 0.20, and Kikuyu datapoints looked more scattered than ryegrass and stargrass pastures (Figure 3).

The $r^2$ estimated for the Botanal method and the clippings was greater than 0.90 for all three grasses, which indicates a greater goodness of fit between these two methods (Figure 4).

The regression equations developed in this study from the Botanal linear regressions offered, on average, similar forage biomass estimates with respect to the three species (Table 4). The ryegrass equation gave smaller differences, while the differences for the stargrass and Kikuyu pastures were, respectively, similar and greater compared to the ryegrass estimates.

**Table 4.** Forage biomass estimated with a general regression equation developed from the Botanal samples for ryegrass, Kikuyu, and stargrass pastures in Costa Rica.

| Variable | Ryegrass | Kikuyu | Stargrass |
|---|---|---|---|
| General regression equation (dry and rainy seasons) | $y = -179 + 1652x$ | $y = -340 + 2191x$ | $y = 30 + 2580x$ |
| Average for visual samples taken with Botanal (x) | 2.12 | 1.72 | 2.08 |
| Estimated biomass with general equation (kg DM $ha^{-1}$) | 3295 | 3406 | 5412 |
| Average difference (Botanal–General regression) * | 414<br>(1–1282) | 761<br>(0–1983) | 764<br>(44–2928) |

* Range (min–max).

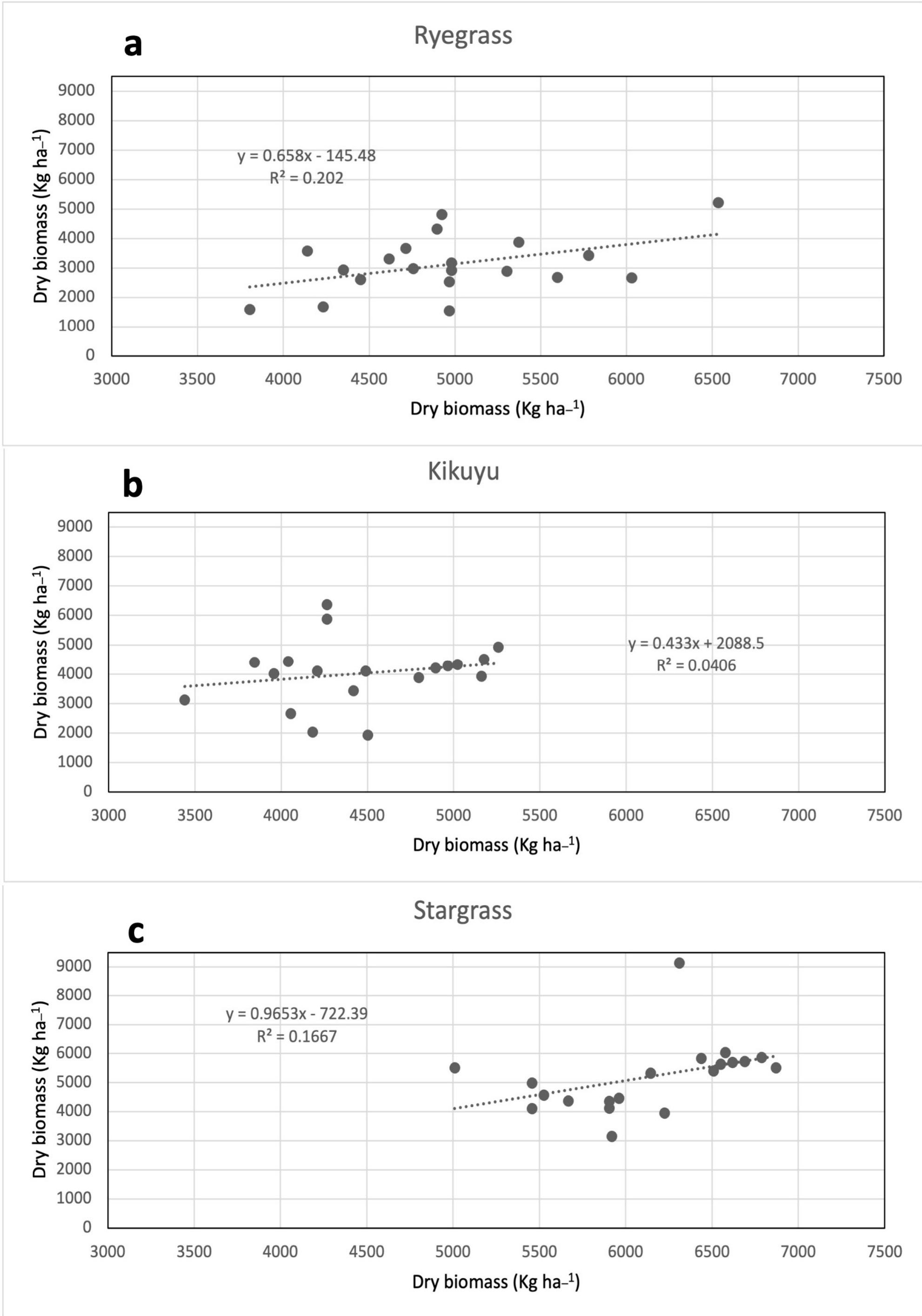


**Figure 2.** Forage biomass of ryegrass (**a**), Kikuyu (**b**), and stargrass (**c**) pastures comparing the Botanal® method (y axis) and a rising platemeter (x axis).

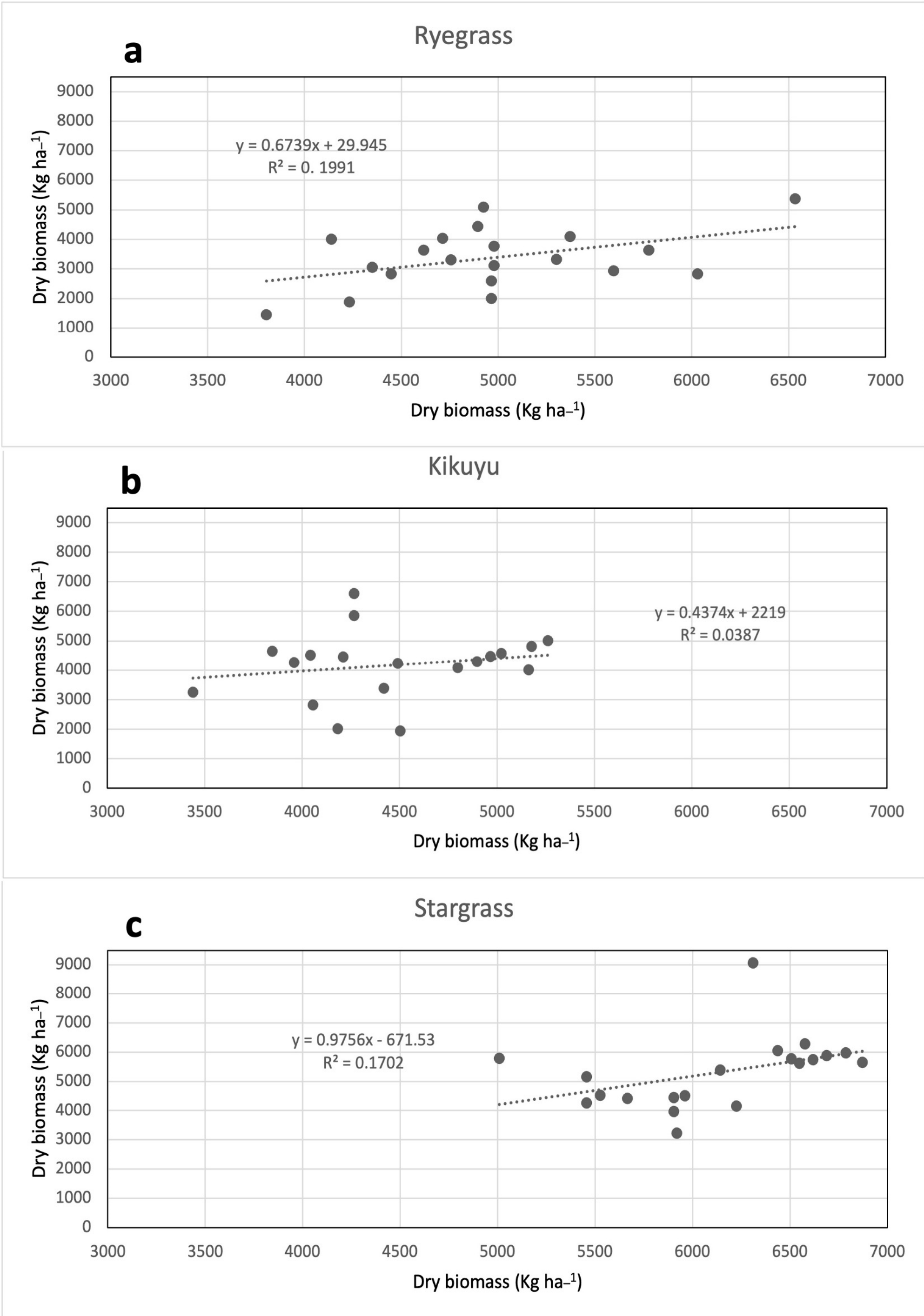


**Figure 3.** Forage biomass of ryegrass (**a**), Kikuyu (**b**), and stargrass (**c**) pastures comparing the clippings (y axis) and the rising platemeter (x axis).

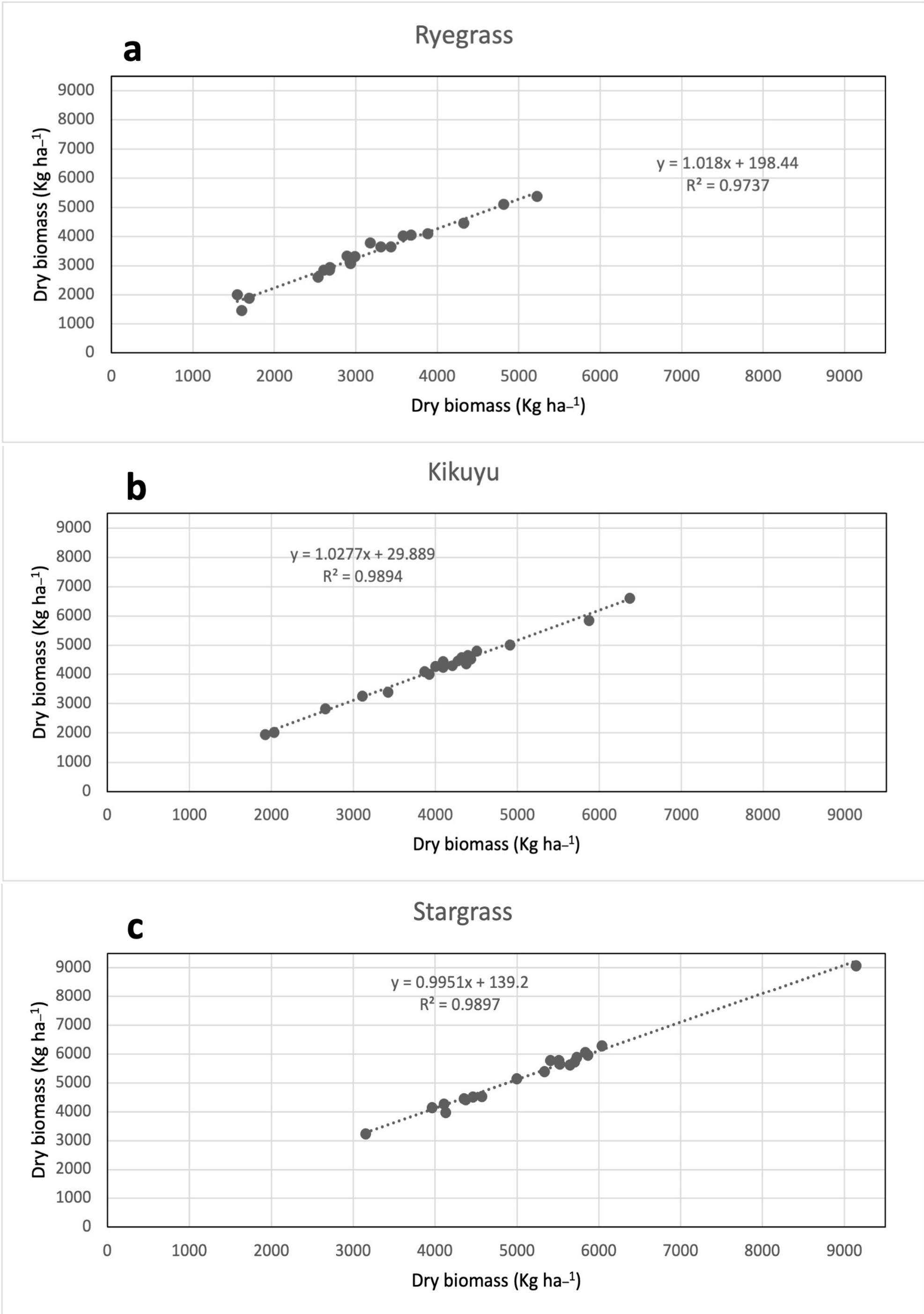


**Figure 4.** Forage biomass of ryegrass (**a**), Kikuyu (**b**), and stargrass (**c**) pastures comparing the Botanal® method (x axis) and the clippings (y axis).

## 4. Discussion

### *4.1. Pasture Management*

Ryegrass and Kikuyu paddocks were steeper than those of Stargrass (Table 1), and swards were taller in the latter. The indicators of pasture management are similar to those reported by previous studies under rotational grazing systems in specialized dairy farms [19].

### 4.2. Forage Biomass

The forage biomass was within the estimates given in previous evaluations using the Botanal method in ryegrass and Kikuyu pastures (3360 and 3517 kg DM $ha^{-1}$, respectively) but was greater than the estimates given in previous evaluations of stargrass (3185 kg DM $ha^{-1}$) [19]. In our study, we used the same stubble height of 5 cm (ground level), which is recommended in order to achieve more precise estimates with respect to using a specific aboveground cutting height [13].

### 4.3. Comparison of Methods to Estimate Biomass Yield

Because platemeters have been used extensively in cool-season pastures, a greater goodness of fit was expected in data collected in Ryegrass pastures with respect to Kikuyu and stargrass in this study. Although previous studies have evaluated pre-calibrated equations in platemeters, no data were found of comparisons like ours under tropical conditions. Among the various equations provided by the manufacturing company of the rising platemeter, we decided to use the factory default (also known as the universal equation) in the pastures evaluated as it is a general equation that comprises six months of pasture growth (April–September) throughout the year, thus encompassing more potential variability in the assessments. The other equations are suggested for specific months or seasons under the temperate conditions of New Zealand, which added some extra difficulty in choosing the calibration equation, as also indicated by [1].

The differences found between the platemeter and the Botanal method were greater in ryegrass compared to Kikuyu and stargrass. Here, we found a minimum difference of 16% between estimates in all species, while other studies have suggested that 10% is a maximum acceptable difference relative to Botanal or other hand-clipping methods [4].

Our study found that the rising platemeter overestimated biomass with respect to the Botanal and hand-clipping methods, which coincides with other studies comparing indirect methods with direct sampling [3,9,13].

Previous studies have obtained indicators with different criteria for their suitability. For [1], indirect methods are considered acceptable when the RSD is close to 400 kg DM $ha^{-1}$ and $r^2$ 0.80–0.85. Ref [13] found an RSD ranging from 258 to 525 and from 636 to 918 kg DM $ha^{-1}$ in spring and summer, respectively, with $r^2$ values greater than 0.9. In tall fescue, [9] compared a falling platemeter with hand-clipped samples and obtained an RSD of 885–1456 kg DM $ha^{-1}$ with an $r^2$ = 0.72, which indicates that both indicators are complementary to ensure accuracy in indirect methods.

Ref [3] evaluated four methods to estimate biomass in mixed pastures (warm- and cool-season grasses and legumes) and found an $r^2$ that ranged from 0.36 to 0.85 with an average of 0.59 for all observations for a rising platemeter with respect to hand-clipping samples. Ref [16] compared a laser sensor with a pasture ruler and a rising platemeter and obtained $r^2$ values greater than 0.75, and Ref [17] found an $r^2$ between 0.12–0.25 for platemeter models that were compared with hand-clipped samples in pastures of bermudagrass, alfalfa, and mixtures of both. Ref [12] compared hand-clipped samples with a falling platemeter across four different sites with mixed cool-season pastures and obtained an $r^2$ between 0.29–0.88. These authors attributed such variation to pasture species composition and the growth habit of the dominant species in the pastures.

Similarly to our study, other researchers have compared rising platemeters with hand-clipped samples using equations that were developed in New Zealand with ryegrass–white clover pastures and provided by the manufacturing companies. Ref [4] obtained $r^2$ values of 0.16 and 0.31 for hand-clipped samples compared with a rising platemeter and a pasture ruler, respectively. In Scotland, Ref [23] reported a low relationship between the forage biomass estimated with a rising platemeter and clipped samples. Ref [8] indicated that indirect methods such as platemeters and sward sticks are very useful on short pastures and should be avoided in very tall or lodged grass due to the loss of accuracy when stemmy material is accumulated.

Pre-calibrated prediction equations were not useful for predicting forage biomass in previous studies because of variations in growth characteristics, spatial variability [17], management, and climate [24]. The low $r^2$ values found in our study may have been affected by differences in grazing management among the three farms. Pastures with levels of utilization less than 40% have been reported for most dairy farms in Costa Rica [19], which impacts the level of residual biomass that becomes senescent material in subsequent rotations.

Although the three grass species were grown in the same region (<10 km distance between stargrass and Kikuyu pastures and <6 km between Kikuyu and ryegrass pastures), the elevation gradient between stargrass pastures (1400 m) with respect to Kikuyu (2400 m) and ryegrass pastures (2800 m) may have created microclimates that influenced the days of regrowth used in the three farms. Kikuyu pastures had, for instance, regrowth periods that were twice those reported in subtropical conditions [16], making the pastures prone to conditions such as vegetation lodging, which is a factor that lowers the relationship between direct and indirect methods [4].

A visual assessment together with the difficulty to find spots to conduct platemeter readings indicated that pasture management was interfering with the adequate functioning of the platemeter. This coincides with [13] who found a poor relationship in the biomass estimates of a rising platemeter in tall pastures.

Although recent research has suggested that forage biomass estimated with rising platemeters is mostly a result of height measurements [16], more studies agree that these devices actually integrate pasture height, pasture density, and the species present into each measurement [1,4,8,12]. In our study, the standards harvested for the Botanal method and the readings taken with the platemeter confirmed that the compressed height reported was influenced by both density and species composition.

Earlier research has already noted how senescence that accumulates from previous rotations in pastures interferes with adequate measurements of biomass with platemeters [13,15]. In this study, the percent of senescent material found in some of the pastures interfered with the readings of the platemeter. Even though the readings taken with the platemeter could have been selected differently (not randomly), the condition itself of a pasture with accumulated biomass reduced the goodness of fit for this method, implying more time spent to find adequate readings. Other reasons mentioned for poor regression relationships are the topography within the pasture, trampling, lodging, the heterogeneity of species, tillage, and observer bias [4,11].

When the number of readings was increased in the larger pastures, the methods showed the same pattern of overestimating biomass with the platemeter. Similarly, Ref [4] found that increasing the number of measurements with indirect methods only increased the precision of the estimates but not the accuracy because of the lack of appropriate calibration equations.

Rising platemeters evaluated under different environments and with grass species with different growth habits have shown varied results in terms of their goodness of fit. Warm-season and cool-season grasses have shown $r^2$ values that vary in their goodness of fit (0.36–0.85), which was attributed to differences in morphological traits and growth habits [3]. Specific equations for annual grasses such as wheat and rye have also shown variations with $r^2$ values of 0.56–0.85 and 0.26–0.76, respectively [11]. These authors found a greater $r^2$ in wheat pastures tilled during non-winter months, while rye pastures had a greater goodness of fit during winter with no tilling, which not only indicates the need for specific equations but also that alternative methods might be a better fit for some forage species.

Ref [9] compared a falling platemeter and a capacitance meter with hand-clipped samples in tall fescue and obtained a greater $r^2$ for the first method (0.72 vs. 0.54–0.70, respectively). These authors indicate that indirect methods such as platemeters are preferred to estimate biomass with respect to visual assessments that are highly subjective [9].

Similarly, another study reported lesser subjective effects when using platemeters with respect to ruler height measurements [10].

The morphology of the forage species may also influence the fitness of the method used to estimate biomass. The jointing nature of some grass species interferes with estimates of biomass [3,12]. Cool-season grasses, for example, with long-shoot jointing aftermath growth habits have a tendency to increase biomass as their height increases, while short-shoot non-jointing species have greater forage density in the lower canopy [12]. The growth habits of Kikuyu grass and ryegrass are considered more comparable to that of Stargrass. The latter had greater proportions of senescence in our study, with platemeter readings for biomass greater than the biomass estimated with hand-clipped samples, indicating the interference of senescent material in the accurate estimation of forage biomass with a rising platemeter. Additionally, in the other two grasses, senescence accumulated from previous rotations interfered with the readings taken with the platemeter as the maximum height of the pole was not always reached in areas with excessive biomass. This is a finding similar to the results from [15], who indicated that disk meters may not turn out to be functional in pastures with excessive accumulation of plant residues due to undergrazing or trampling. Regardless of how biomass is estimated, but especially for indirect methods, recalibration has proven to be necessary in order to obtain values closer to direct methods that can account for pasture species and differences in species composition [4].

The results achieved with the Botanal and hand-clipping methods are comparable [14] but these were different to those achieved with the platemeter, which partly explains the $r^2$ greater than 0.90 found in our study. Because we used the same real samples for both Botanal and hand-clipping methods, high $r^2$ values were expected due to the high correlation between the samples. One additional finding from this research is that the hand-clipping method may be used to estimate biomass when well-trained operators oversee sample collection, thus reducing the time spent per pasture sampled with respect to Botanal. Producers and technicians lacking experience in grass sampling techniques may be encouraged to use the hand-clipping method with a greater number of subsamples taken per pasture. This method has shown to be more intuitive and less intimidating with respect to not only Botanal but other methods too.

The equations developed in this study may work as a guide for the potential forage biomass that each species may yield under the specific climatic conditions where the three grass species are grown. However, those equations should not be used as a reference for indirect methods due to the different independent variables used by the Botanal method (average of the standards) and the platemeter (compressed height).

## 5. Conclusions

The rising platemeter evaluated in this study was inaccurate in predicting forage biomass when compared to the Botanal and hand-clipping methods, showing an RSD greater than that reported to be acceptable in previous studies.

The pre-calibrated equation provided by the manufacturing company that was evaluated in this study overestimated the forage biomass with respect to the Botanal and hand-clipping methods in the environmental conditions considered.

The senescent material accumulated in the pastures evaluated in this study interfered with the accuracy of the platemeter to a greater extent than the Botanal and the hand-clipping methods.

The regression equations developed in this study should not be uploaded to rising platemeters in other studies. We suggest instead to develop calibration equations by species and by season.

The rising platemeter will require the development of specific calibration equations for the climatic conditions of this study. This is strongly recommended before producers and researchers start monitoring forage biomass in pastures and use the data to allocate forage with inaccurate stocking rates and carrying capacities in livestock operations.

Our findings suggest that, with specific calibration equations, the rising platemeter could still be beneficial for producers to estimate forage biomass in tropical conditions, providing various benefits such as less labor (one person can take the readings), time (20–30 min for an average size paddock), and materials (bags, clippers, oven, and scale) compared to the Botanal and hand-clipping methods.

Although the hand-clipping method may be used as an alternative to estimate forage biomass with less complexity than the Botanal method, a more robust estimate could be achieved when using a greater number of subsamples.

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## References

1. Hodgson, J.; Matthews, P.N.P.; Matthew, C.; Lucas, R.J. Pasture Measurement. In *New Zealand Pasture and Crop Science*; James, W., John, H., Eds.; Oxford University Press: Victoria, Australia, 1999; pp. 59–65.
2. Correll, O.; Isselstein, J.; Pavlu, V. Studying spatial and temporal dynamics of sward structure at low stocking densities: The use of an extended rising-plate-meter method. *Grass Forage Sci.* **2003**, *58*, 450–454. [CrossRef]
3. Harmoney, K.R.; Moore, K.J.; George, J.R.; Brummer, E.C.; Russell, J.R. Determination of pasture biomass using four indirect methods. *Agron. J.* **1997**, *89*, 665–672. [CrossRef]
4. Sanderson, M.A.; Rotz, C.A.; Fultz, S.W.; Rayburn, E.B. Estimating Forage Mass with a Commercial Capacitance Meter, Rising Plate Meter, and Pasture Ruler. *Agron. J.* **2001**, *93*, 1281–1286. [CrossRef]
5. Decruyenaere, V.; Buldgen, A.; Stilmant, D. Factors affecting intake by grazing ruminants and related quantification methods: A review. *Base* **2009**, *13*, 559–573.
6. Tozer, P.R.; Bargo, F.; Muller, L.D. The effect of pasture allowance and supplementation on feed efficiency and profitability of dairy systems. *J. Dairy Sci.* **2004**, *87*, 2902–2911. [CrossRef] [PubMed]
7. Matos, F.S.; Da Silva, W.P.; Ferraz, R.L.; Rêgo, A.M.; Sobral, L.T.; Bigatello, C.S.; Coelho, T.; De Morais, L.; Cavalcante, A.C.; Aquino, D.; et al. Remote Sensing Applied to Grassland Ecosystems in Regions with Climatic Vulnerability. *Open Sci. Res. VII* **2022**, *7*, 150–165.
8. 't Mannetje, L. Measuring Biomass of Grassland Vegetation. In *Field and Laboratory Methods for Grassland and Animal Production Research*; 't Mannetje, L., Jones, R.M., Eds.; CABI Publishing: Cambridge, UK, 2000; pp. 151–177.
9. López-Guerrero, I.; Fontenot, J.P.; García-Peniche, T.B. Comparaciones entre cuatro métodos de estimación de biomasa en praderas de festuca alta. *Rev. Mex. Ciencias Pecu.* **2011**, *2*, 209–220.
10. Rayburn, E.B.; Lozier, J.D.; Sanderson, M.A.; Smith, B.D.; Shockey, W.L.; Seymore, D.A.; Fultz, S.W. Alternative Methods of Estimating Forage Height and Sward Capacitance in Pastures Can Be Cross Calibrated. *Forage Grazinglands* **2007**, *5*, 1–6. [CrossRef]
11. Cho, W.; Brorsen, B.W.; Biermacher, J.T.; Rogers, J.K. Rising Plate Meter Calibrations for Forage Mass of Wheat and Rye. *Agric. Environ. Lett.* **2019**, *4*, 180057. [CrossRef]
12. Rayburn, E.B.; Shockey, W.L.; Seymour, D.A.; Smith, B.D.; Basden, T.J. Calibration of Pasture Forage Mass to Plate Meter Compressed Height Is a Second-Order Response with a Zero Intercept. *Crop. Forage Turfgrass Manag.* **2017**, *3*, 1–3. [CrossRef]
13. Michell, P.; Large, R.V. The estimation of herbage mass of perennial ryegrass swards: A comparative evaluation of a rising-plate meter and a single-probe capacitance meter calibrated at and above ground level. *Grass Forage Sci.* **1983**, *38*, 295–299. [CrossRef]

14. Tothill, J.C.; Hargreaves, J.N.G.; Jones, R.M.; McDonald, C.K. BOTANAL—A comprehensive sampling and computing procedure for estimating pasture yield and composition. 1. Field sampling. *Trop. Agron. Tech. Memo.* **1992**, *78*, 1–23.
15. Vartha, E.W.; Matches, A.G. Use of a Weighted-disk Measure as an Aid in Sampling the Herbage Yield on Tall Fescue Pastures Grazed by Cattle 1. *Agron. J.* **1977**, *69*, 888–890. [CrossRef]
16. Benvenutti, M.A.; Barber, D.G.; Mayer, D.G.; Ison, K.; Colman, M.V.; Findsen, C. Comparison between a laser sensor and mechanical tools to estimate pasture mass in strata of kikuyu (*Pennisetum clandestinum*) pastures. *Anim. Feed Sci. Technol.* **2019**, *249*, 31–36. [CrossRef]
17. Pittman, J.J.; Arnall, D.B.; Interrante, S.M.; Moffet, C.A.; Butler, T.J. Estimation of biomass and canopy height in bermudagrass, alfalfa, and wheat using ultrasonic, laser, and spectral sensors. *Sensors* **2015**, *15*, 2920–2943. [CrossRef] [PubMed]
18. Villalobos, L.; WingChing-Jones, R. Los pastos estrella africana, kikuyo y 'rye grass' en Cartago, Costa Rica: Biomasa, composición botánica y nutrientes. *UNED Res. J.* **2020**, *12*, 65–74. [CrossRef]
19. Villalobos-Villalobos, L.A.; Arce, J.; WingChing-Jones, R. Producción de biomasa y costos de producción de pastos Estrella Africana (*Cynodon nlemfuensis*), Kikuyo (*Kikuyuocloa clandestina*) y Ryegrass Perenne (*Lolium perenne*) en lecherías de Costa Rica. *Agron. Costarric.* **2013**, *37*, 91–103. [CrossRef]
20. Retana, J. Climatología de la región del distrito de San Juan de Chicuá y el Volcán Irazú. *Inf. Anu. del Inst. Meteorológico Nac.* **2006**, *1*, 1–4.
21. Villalobos, L.; Arce, J. Evaluación agronómica y nutricional del pasto estrella africana (*Cynodon nlemfuensis*) en la zona de Monteverde, Puntarenas, Costa Rica. I. Disponibilidad de biomasa y fenología. *Agron. Costarric.* **2013**, *37*, 91–101. [CrossRef]
22. McCutcheon, J. *Using Pasture Measurement to Improve Your Management*; The Ohio State University Extension: Columbus, OH, USA, 2011.
23. Dowdeswell, A. Grass 99 monitor farms project. *DRC Dairylink* **1998**.
24. Frame, J. Herbage mass. In *Sward Measurement Handbook*, 2nd ed.; Davies, A., Baker, R.D., Grant, S., Laidlaw, A.S., Eds.; British Grassland Society: Reading, UK, 1993; pp. 39–67.