

**UNIVERSIDAD DE LA REPÚBLICA  
FACULTAD DE AGRONOMÍA**

**APLICACIÓN DE SISTEMAS DE PERCEPCIÓN REMOTA PARA EL  
MONITOREO Y GESTIÓN DE RECURSOS FORRAJEROS EN SISTEMAS  
PASTORILES DE PRODUCCIÓN**

**Por**

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## RESUMEN

El objetivo del siguiente trabajo fue comparar diferentes métodos en la estimación de forraje disponible (HM) y tasa de crecimiento (GR) de pasturas en potreros individuales, así como también evaluar el impacto en la estimación de esas variables en una rotación pastoril típica en el área de plataforma de ordeño. Para HM, dos métodos fueron comparados: el pastorómetro (C-Dax) y la técnica de doble muestreo (DS); mientras que, para GR, cuatro métodos fueron utilizados: C-Dax, DS, corte con cuadrado (QC) e imágenes satelitales (SI) desde marzo 2017 a junio 2018. La biomasa estimada por C-Dax fue mayor a la estimada por DS ( $DS = 0,802 * C-Dax$ ;  $R^2=0,96$ ,  $p<0,001$ ;  $CV=19,3\%$ ,  $RMSE=353$ ) y las diferencias aumentaron a medida que había aumentos en la disponibilidad. La tasa de crecimiento estimada por C-Dax fue igual a la estimada por DS y la relación entre ambas fue ajustada por un modelo lineal ( $DS=1,0 * C-Dax$ ;  $R^2=0,53$ ,  $p<0,001$ ;  $CV=91,4\%$ ,  $RMSE=35,9$ ). La tasa de crecimiento estimada en los potreros fue mayor cuando fueron comparados SI con C-Dax ( $C-Dax=0,48 * SI$ ;  $R^2=0,67$ ,  $p<0,001$ ) y con DS ( $DS=0,63 * SI$ ;  $R^2=0,60$ ,  $p<0,001$ ). Las diferencias entre GR estimada por los métodos fueron menores cuando las mediciones se realizaron en el área de plataforma de ordeño ( $23,9 \pm 1,9$  para C-Dax ( $p<0,001$ ),  $32,7 \pm 1,9$  para DS y  $29,4 \pm 3,3$  para SI sin diferencias significativas entre estas últimas). Además, la interacción mes y método fue significativa (SI GR mayor que C-Dax y DS para el octubre (+33) pero lo opuesto ocurrió para marzo (-15);  $p<0,001$ ). Esta información es altamente valiosa para elegir el método más apropiado dependiendo de la escala espacial y temporal que los sistemas pastoriles requieren.

**Palabras clave:** área de plataforma de ordeño, biomasa de pasturas, tasa de crecimiento de pastura

## SUMMARY

### **Remote sensing application on monitoring and management of forrage resources on grazing production animal systems**

The aim of this research was to compare indirect methods for estimation of herbage mass (HM) and growth rates (GR) of individual paddocks, as well as their impact in the assessment of those variables on a typical pasture rotation in the milking platform of a dairy system. For HM, two methods were compared: pasture meter (C-Dax) and the double sample technique (DS); whilst for GR, four methods were involved: C-Dax, DS, quadrant cut (QC) and satellite image (SI) from March 2017 to June 2018. Herbage mass estimated by C-Dax was higher than DS ( $DS = 0.802 * C-Dax$ ;  $R^2 = 0.96$ ,  $p < 0.001$ ;  $CV = 19.3\%$ ,  $RMSE = 353$ ) and the difference increased with herbage mass. Growth rate estimated by C-Dax was higher than by DS and the ratio between both methods fitted in a linear model ( $DS = 1.0 * C-Dax$ ;  $R^2 = 0.53$ ,  $p < 0.001$ ;  $CV = 91.4\%$ ,  $RMSE = 35.9$ ). Paddocks' GR were overestimated by SI when compared with C-Dax ( $C-Dax = 0.48 * SI$ ;  $R^2 = 0.67$ ,  $p < 0.001$ ) and DS ( $DS = 0.63 * SI$ ;  $R^2 = 0.60$ ,  $p < 0.001$ ). Differences between GR methods were smaller at milking platform scale ( $23.9 \pm 1.9$  for C-Dax ( $p < 0.001$ ),  $32.7 \pm 1.9$  DS and  $29.4 \pm 3.3$  SI with not differences between DS and SI), yet, with a significant interaction between method and month (SI GR was higher than C-Dax and DS in October (+33) but the opposite occurred in March (-15);  $p < 0.01$ ). This information is highly valuable to choose the appropriated method dependent on the space and time scale required for grazing dairy systems.

**Keywords:** milking platform area, pasture herbage mass, pasture growth rate

## 1. INTRODUCCIÓN

### 1.1 LA RELEVANCIA PARA EL SISTEMA EN CUANTIFICAR EL FORRAJE

La finalidad de la mayoría de los sistemas pastoriles de producción animal es maximizar el beneficio económico incrementando la cantidad de forraje convertido a producto animal. Los procesos de intensificación en los sistemas lecheros se han dado mediante el aumento de la cantidad de animales por ha, que como consecuencia ha repercutido en la mejora en la utilización y la calidad del forraje (Baker y Leaver, 1986; Fales *et al.*, 1995). Sistemas con mayor proporción de pastura en la dieta, presentan mayores consumos de forraje por unidad de superficie (Holmes y Roche, 2007) que se traducen en menores costos por kg de leche producido (Dillon *et al.*, 2005, Chilibroste *et al.*, 2011). La pastura es el alimento más barato en un sistema de producción de leche pastoril si es utilizada eficientemente, por tanto, es de suma importancia, alcanzar altas producciones acompañado con altos valores de cosecha directa (Fulkerson y Doyle, 2001; Yule *et al.*, 2010). La eficiencia en la cantidad de forraje cosechado dependerá del balance entre la demanda diaria y el suministro (Holmes y Roche, 2007).

Es posible alcanzar altos valores de cosecha de forraje (Holmes y Roche 2007; Fariña *et al.*, 2011; Insua *et al.*, 2019) mediante el control y monitoreo de la tasa de crecimiento y la disponibilidad promedio de la plataforma de ordeño con el uso de métodos indirectos de estimación de forraje. Herramientas que simplifiquen las determinaciones en la pastura son un insumo para manejar la heterogeneidad espacial y temporal, de forma de reducir las fuentes de variación entre operarios (Rennie *et al.*, 2009). Si bien es reconocido por productores la importancia del monitoreo del forraje en los sistemas de producción, en países como Nueva Zelanda (netamente pastoriles e intensivos) solamente un 20% de los establecimientos realizan una rutina de seguimiento de las bases forrajeras (Clark *et al.*, 2006).



## 1.2 MÉTODOS UTILIZADOS PARA ESTIMAR BIOMASA

Muchos métodos indirectos han sido estudiados en orden de mejorar no solo la capacidad de predicción sino también, reducir el tiempo y el trabajo para lograr las determinaciones. Un ejemplo de ellos son: regla graduada (Sanderson *et al.*, 2001), doble muestreo (Haydock y Shaw, 1975; Catchpole y Wheeler, 1992; Frame, 1993) plato medidor (RPM) (Harmony *et al.*, 1997; López-Guerrero *et al.*, 2011, Hutchinson *et al.*, 2016), pasturómetros (Rennie *et al.*, 2009, King *et al.*, 2010; Yule *et al.*, 2010) y el uso de imágenes multiespectrales (Paruelo *et al.*, 2004, Piñeiro *et al.*, 2006; Insua *et al.*, 2019).

### 1.2.1 El corte de biomasa y doble muestreo

El método de mayor exactitud para determinar la biomasa de una pastura en un potrero es por medio del corte y pesado del forraje. Sin embargo, esta técnica demanda mucho esfuerzo y tiempo para lograr un número de muestras que sea realmente representativo del potrero y permita estimar con exactitud el valor de biomasa (Sanderson *et al.*, 2001). Métodos como el doble muestreo (Haydock y Shaw, 1975) realiza estimaciones de biomasa aceptando una menor precisión en comparación con la alta precisión de pocos cortes que se pueda lograr en un potrero. Pero una de las desventajas es que es sensible a la variación entre observadores y es necesaria una calibración frecuente para mantener la precisión del mismo (O'Donovan *et al.*, 2002).

### 1.2.2 Uso de la regla graduada y el plato medidor

La relación entre la altura comprimida por el plato medidor (RPM) y la biomasa ha sido reportada por varios investigadores (Michell, 1982, Schori, 2015). Sin embargo, diferencias en estimación en distintas épocas, han sido encontradas por King *et al.*, (2010) cuando no se calibra localmente el instrumento. Como ventaja, es una herramienta que reduce la variación entre operarios, permite incrementar el

número de determinaciones por potrero logrando una mejor descripción de la heterogeneidad del espacio en comparación con el corte. Pero aun presenta como limitante la dificultad de aplicarlo en unidades de producción extensas, debido al esfuerzo físico para abarcar la totalidad del área.

Otro método indirecto que relaciona altura con la biomasa disponible en un potrero es la regla graduada, método ampliamente difundido, ya que la relación entre esas variables es positiva. (Sanderson et al., 2001). Como ventaja establece un grado de independencia en la medición entre operarios, pero como desventaja mediciones altamente sensibles al error causado por factores como: estructura de la pastura, intensidad de pastoreo, composición botánica, estación del año.

### 1.2.3 Uso de pasturómetros

Métodos como los pasturómetros electrónicos (como el C-Dax) han sido recientemente incorporados al monitoreo de sistemas pastoriles con la potencialidad de suministrar información de manera rápida y precisa en tiempo real (Loaiza *et al.*, 2012). Este es un aspecto clave en unidades de producción grandes, donde se ha constatado que el uso de la herramienta disminuye hasta 1/6 el tiempo en comparación con el uso de RPM (Schori, 2015). La alta descripción del espacio, debido a su alta capacidad de registro es una bondad del instrumento que permite realizar mapeos (Yule *et al.*, 2010, Dennis *et al.*, 2015) y manejar la variabilidad en cuanto a la disponibilidad de forraje dentro y entre potreros (Hutchinson *et al.*, 2016). Como desventaja, la calibración según época y región es necesaria, debido que ha sido reportado diferencias en la estimación según región y según especie (King *et al.*, 2010).

### 1.2.4 Imágenes satelitales

El uso de imágenes satelitales ha sido utilizado en el estudio de las características funcionales de ecosistemas, como producción de biomasa a escala regional (Grigera, 2007, Baeza *et al.*, 2011). La resolución de la imagen dependerá

de la frecuencia en que la misma pasa por el mismo punto, y del tamaño del pixel (Chuvienco, 2010). Existe variadas fuentes de imágenes que según su frecuencia temporal y espacial determinan el grado de precisión en sus determinaciones. Uno de los sensores más utilizados para la estimación de la productividad forrajera es MODIS (*Moderate Resolution Imaging Spectroradiometer*), cuya resolución espacial presenta un tamaño de 5 has, lo cual establece dificultades para poder trabajar a una escala menor, por ejemplo dentro de las unidades de manejo en sistemas lecheros que son menores al tamaño de dicha resolución. De todas maneras, la alta frecuencia de registros permite poder realizar estimaciones de manera diaria y con un historial enorme de datos desde el 2000 lo que permite evaluar series históricas. Mejoras en la escala espacial se logran con el uso de imágenes Sentinel-2 (10m), sin embargo, presentan una frecuencia de registros de 5 a 10 días, lo que incrementa la probabilidad de pérdida de los mismos por interferencia de nubes. Una de las limitantes en el uso de las imágenes para la estimación de producción de forraje, es que la base teórica de estimación parte de un modelo empírico propuesto por Monteith (1972). Uno de los factores de ese modelo es la EUR<sup>1</sup>, el cual es un parámetro característico de cada especie altamente variable según la estación del año (Piñeiro *et al.*, 2006) y produce reducción en la precisión de las determinaciones en caso de no considerarlo (Nouvellon *et al.*, 2000).

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<sup>1</sup> Eficiencia de uso de la radiación.

Cuadro 1 Diferencias entre los distintos métodos de estimación para biomasa y tasa de crecimiento

| <b>Método</b>                      | <b>Doble muestreo</b>                          | <b>Corte</b>                                       | <b>C-Dax</b>   | <b>Imagen Satelital</b>                                       |
|------------------------------------|--|--|--|---|
| <b>Escala de unidad de manejo</b>  | Potrero  | Cuadrado   | Potrero sistema  | Potrero/Sistema/Región  |
| <b>Información para el sistema</b> | Biomasa<br>Tasa de crecimiento                 | Tasa de crecimiento                                | Biomasa<br>Tasa de crecimiento                               | Tasa de Crecimiento   |
| <b>Frecuencia de información</b>   | Semanal  | Mensual  | Semanal - diaria   | Variable (diarias a mensual)                                  |
| <b>Descripción espacial</b>        | Media  | Baja   | Alta   | Alta  |
| <b>Requiere calibración</b>        | SI   | NO   | SI   | SI  |
| <b>Variación entre operarios</b>   | Alta   | Baja   | Baja   | Baja  |
| <b>Entrenamiento</b>               | Alto   | Bajo   | Bajo   | Alto  |
| <b>Costo</b>                       | Bajo   | Bajo   | Alto   | -   |
| <b>Tiempo</b>                      | Insume tiempo/<br>tamaño                       | Insume tiempo                                      | Rápido<br>Fácil  | Rápido<br>caso de que esté calibrado                          |
|                                    | Haydock y Shaw 1975;<br>O'Donovan et al., 2002 | Catchpole y Wheler, 1992<br>Sanderson et al., 2001 | Rennie et al., 2009; King et al., 2010;<br>Yule et al., 2010 | Chuvieco, 2010;<br>Piñeiro et al., 2006; Paruelo et al., 2014 |

La mayoría de los métodos han sido probados en escala de potrero, y para una variada cantidad de especies. Sin embargo, no existe información del desempeño de los mismos a nivel de plataforma de ordeño. Métodos con una mejor descripción del espacio, y con capacidad de obtener alta frecuencia en la información registrada (C-Dax), permitirá mejoras en la estimación de tasa de crecimiento y biomasa, en comparación con DS. La mejora en la resolución espacial por parte de la imagen satelital (SI), permitirá poder estimar la tasa de crecimiento, a pesar de la menor frecuencia temporal en comparación con otras imágenes evaluadas (Chilibroste, 2009).

Los objetivos del siguiente trabajo fueron: comparar a nivel de potrero la biomasa (HM) estimada por el pasturómetro C-Dax y por doble muestreo (DS). El segundo objetivo fue evaluar cómo las diferencias en biomasa estimada afectan la estimación de tasa de crecimiento a nivel de potrero (GR). Tercero, evaluar cómo la tasa de crecimiento estimada por C-Dax, DS, SI y QC difieren entre sí. El cuarto objetivo es evaluar, cómo las diferencias entre métodos tanto para estimación de HM como para GR a nivel de potrero impactan en la estimación de esas variables en el área de plataforma de ordeño para una rotación pastoril de un sistema característico del Uruguay.

## **2. DETERMINATION OF PASTURE BIOMASS AND GROWING RATE AT A MILKING PLATFORM SCALE USING INDIRECT METHODS**

### 2.1. RESUMEN

El objetivo del siguiente trabajo fue comparar diferentes métodos en la estimación de forraje disponible (HM) y tasa de crecimiento (GR) de forraje en potreros individuales, así como también evaluar el impacto en la estimación de esas variables en una rotación pastoril típica en el área de plataforma de ordeño. Para HM, dos métodos fueron comparados: el pastorómetro (C-Dax) y la técnica de doble muestreo (DS); mientras que, para GR, cuatro métodos fueron utilizados: C-Dax, DS, corte con cuadrado (QC) e imágenes satelitales (SI) desde marzo 2017 a junio 2018. La biomasa estimada por C-Dax fue mayor a la estimada por DS ( $DS = 0,802 * C-Dax$ ;  $R^2 = 0,96$ ,  $p < 0,001$ ;  $CV = 19,3\%$ ,  $RMSE = 353$ ) y las diferencias aumentaron a medida que había aumentos en la disponibilidad. La tasa de crecimiento estimada por C-Dax también fue más alta que en DS y la relación entre ambas fue ajustada por un modelo lineal ( $DS = 1,0 * C-Dax$ ;  $R^2 = 0,53$ ,  $p < 0,001$ ;  $CV = 91,4\%$ ,  $RMSE = 35,9$ ). La tasa de crecimiento en los potreros fue sobreestimada cuando fueron comparados SI con C-Dax ( $C-Dax = 0,48 * SI$ ;  $R^2 = 0,67$ ,  $p < 0,001$ ) y con DS ( $DS = 0,63 * SI$ ;  $R^2 = 0,60$ ,  $p < 0,001$ ). Las diferencias entre GR estimada por los métodos fueron menores cuando las mediciones se realizaron en el área de plataforma de ordeño ( $23,9 \pm 1,9$  para C-Dax ( $p < 0,001$ ),  $32,7 \pm 1,9$  para DS y  $29,4 \pm 3,3$  para SI sin diferencias significativas entre estas últimas). Además, la interacción mes y método fue significativa (SI GR mayor que C-Dax y DS para el octubre (+33) pero lo opuesto ocurrió para marzo (-15);  $p < 0,001$ ). Esta información es altamente valiosa para elegir el método más apropiado dependiendo de la escala espacial y temporal que los sistemas pastoriles requieren.

**Palabras clave:** área de plataforma de ordeño, biomasa de pasturas, tasa de crecimiento de pastura

## 2.2 SUMMARY

The aim of this research was to compare indirect methods for estimation of herbage mass (HM) and growth rates (GR) of individual paddocks, as well as their impact in the assessment of those variables on a typical pasture rotation in the milking platform of a dairy system. For HM, two methods were compared: pasture meter (C-Dax) and the double sample technique (DS); whilst for GR, four methods were involved: C-Dax, DS, quadrant cut (QC) and satellite image (SI) from March 2017 to June 2018. Herbage mass estimated by C-Dax was higher than DS ( $DS = 0.802 * C-Dax$ ;  $R^2 = 0.96$ ,  $p < 0.001$ ;  $CV = 19.3\%$ ,  $RMSE = 353$ ) and the difference increased with herbage mass. Growth rate estimated by C-Dax was higher than by DS and the ratio between both methods fitted in a linear model ( $DS = 1.0 * C-Dax$ ;  $R^2 = 0.53$ ,  $p < 0.001$ ;  $CV = 91.4\%$ ,  $RMSE = 35.9$ ). Paddocks' GR were overestimated by SI when compared with C-Dax ( $C-Dax = 0.48 * SI$ ;  $R^2 = 0.67$ ,  $p < 0.001$ ) and DS ( $DS = 0.63 * SI$ ;  $R^2 = 0.60$ ,  $p < 0.001$ ). Differences between GR methods were smaller at milking platform scale ( $23.9 \pm 1.9$  for C-Dax ( $p < 0.001$ ),  $32.7 \pm 1.9$  DS and  $29.4 \pm 3.3$  SI with not differences between DS and SI), yet, with a significant interaction between method and month (SI GR was higher than C-Dax and DS in October (+33) but the opposite occurred in March (-15);  $p < 0.01$ ). This information is highly valuable to choose the appropriated method dependent on the space and time scale required for grazing dairy systems.

**Keywords:** milking platform, herbage mass, growing rate

## 2.3 INTRODUCTION<sup>2</sup>

The purpose of most grazing-based animal production systems is to maximize profitability by increasing the amount of homegrown forages converted into animal product. Intensification processes in dairy systems have been related to an increase in number of cows per ha, which has improved pasture utilization and quality (Baker and Leaver, 1986; Fales *et al.*, 1995). Systems with higher proportion of pasture on the diet, as a consequence of more pasture consumption per ha (Holmes & Roche, 2007), exhibited lower cost per kg of milk produced (Dillon *et al.*, 2005, Chilibroste *et al.*, 2011). Pasture is the cheapest feed available in a grazing system, therefore, it is important to achieve its high production and harvest (Fulkerson and Doyle, 2001; Yule *et al.*, 2010). The efficiency of pasture harvested on grazing systems depends on the appropriated balance between daily demand and pasture supply (Holmes & Roche, 2007).

It is possible to reach high amounts of pasture harvested on dairy milking platform areas, (Yule *et al.*, 2010; Fariña, *et al.*, 2011; Insua *et al.*, 2019) through controlling and monitoring accurately the pasture growing rate and herbage mass by using indirect estimating methods. Tools to make simpler and easier pasture determinations are relevant to manage temporal and spatial variation of growth rate (GR) on milking platforms, in order to reduce the variation by operator input (Rennie *et al.*, 2009). The necessity to have methodologies to estimate, quickly and accurately, the amount of herbage on a milking platform is recognized by workers and farmers. However, the use of pasture mass estimation technologies is limited and formal feed budgeting is used in only around 20% of New Zealand dairy farms (Clark *et al.*, 2006). Visual assessments are the most common methodologies in farms; nevertheless, the high inter-operator variations and the necessity of having a trained person, turn the results of this methodology extremely variable (Catchpole and Wheeler, 1992; Hutchinson *et al.*, 2016).

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<sup>2</sup> El artículo va a ser publicado en la revista Grass and Forage Science



Many indirect herbage estimation methods have been proposed in order to contribute towards improvements in accuracy and reducing operator's workload. An example of them are: graduated ruler (Sanderson *et al.*, 2001), double sample technique (Hutchinson *et al.* 1972; Haydock & Shaw, 1975; Frame, 1993) Rising Plate Meter (Harmony *et al.*, 1997, López-Guerrero *et al.*, 2011, Hutchinson *et al.*, 2016), C-Dax pasture meter (Rennie *et al.*, 2009; King *et al.*, 2010; Yule *et al.*, 2010) and remote sensing through multispectral images (Paruelo *et al.*, 2004, Piñeiro *et al.*, 2006; Insua *et al.*, 2019).

The most precise method to measure herbage mass in a paddock is cutting and weighing the forage (QC), however, this method demands a great effort of collecting samples to increase the accuracy. Moreover, in most cases, farmers are not willing to do it frequently because of labor and time constraints (Sanderson *et al.*, 2001). In response to that, the double sampling method (DS; Haydock & Shaw, 1975) intends to estimate herbage mass with acceptable lower precision rather than taking a few samples measured precisely. However, it is possible to capture vegetation variation by operators compared to simple biomass cut. DS is a non-destructive method that allows a large numbers of yield estimates to be made in one day by one observer; therefore, it is especially valuable in large areas due to speed and low cost. Nevertheless, DS is sensible to variations among observers (O'Donovan *et al.*, 2002) and could not be accurate enough for many experimental purposes where quantitative biomass data is required (Tucker, 1980). What is more, a continuous calibration of the observer's harvest quadrant yield estimation is required in order to maintain the accuracy of the technique (O'Donovan *et al.*, 2002).

Pasture meters like C-Dax (C-Dax) have been recently introduced and are becoming more frequently in farms as they have the potential to provide fast, accurate pasture mass estimations in real-time (Loaiza *et al.*, 2012). This issue makes this tool suitable for large farms, by reducing measuring time approximately 1/6 compared to RPM (Schori, 2015). Moreover, the high record data capacity this instrument has, allows having a good description of the space (Yule *et al.*, 2010;

Dennis *et al.*, 2015) managing pasture mass variability within and between paddocks due to grazing (Hutchinson *et al.*, 2016). However, local calibrations are recommended due to temporal and regional estimation differences (King *et al.*, 2010), furthermore, this tool has been recently introduced on dairy farms without knowledge of its performance on a milking platform scale.

In order to capture spatial heterogeneity of vegetal communities, satellite images (SI) have been utilized mainly by ecologists (Paruelo *et al.*, 2014), however, remote sensing has become useful to study the functional characteristics of ecosystems, like biomass production in large areas at regional scales (Grigera, 2007; Baeza *et al.*, 2011). Image resolution would depend on the frequency the image is taken and the pixel size (Chuvieco, 2010). For MODIS satellites, the spatial resolution (5 has) makes it difficult to estimate the pasture growth in dairy farm paddocks because most of them are small. Improvements on spatial resolution like Sentinel-2 (10m), with a frequency of 10 days, established temporal limitations as the probability of having clouds increases. Other disadvantages of using remote sensing to estimate pasture production is that, using Monteith (1972), it is necessary to quantify the EUR<sup>3</sup>. This parameter is characteristic of each specie and highly dependent of seasonal variations (Piñeiro *et al.*, 2006), consequently precision may have been reduced (Nouvellon *et al.*, 2000). Recent flights with Unmanned Aerial Vehicle (UAV) have become an opportunity to handle the temporal and spatial variation of multispectral information and provided the possibility of monitoring pasture growth on a farm scale with high precision and spatial resolution (Insua *et al.*, 2019).

Most of these methods have been proved, on a paddock scale, on a widely range of pasture based dairy systems. However, there is no information on how they behave on a milking platform scale. Methods with better temporal resolution and a good description of the space (C-Dax) would allow improvements on the estimated growing rates and biomass pasture, reducing operator's workload, rather than

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<sup>3</sup> Efficiency Use of Radiation

methods with highly precision but worse spatial resolution as DS. Improvements on spatial resolution using SI, will permit accurate estimations of GR at dairy grazing paddock level, despite the lower temporal resolution.

The aims of this study were, firstly, to compare the herbage mass (HM) of individual paddock estimated by the C-Dax pasture meter (C-Dax) and the double sample technique (DS). Secondly, to assess how differences in the estimated herbage mass impact on estimated herbage GR. Thirdly, to compare GR estimated by C-Dax, DS, SI and QC. And fourthly, to assess how differences between methods on estimated GR of individual paddock impact on the estimated average GR of a typical dairy pasture rotation on milking platform scale.

## 2.4 MATERIALS AND METHODS

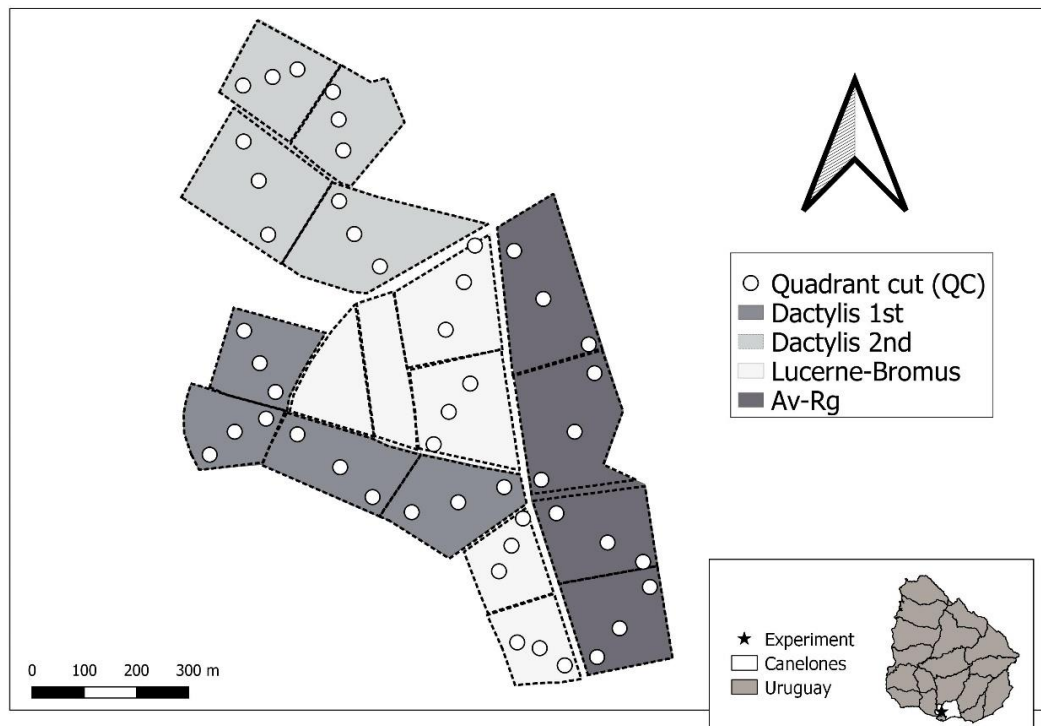
### 2.4.1 Description

The study was undertaken on the area grazed by the milking herd at the CRS (Centro Regional Sur) in the Agronomy Faculty located in Canelones, Uruguay (34° 36.810 S, 56° 13.088 W). From March 2017 to June 2018 the data was collected from 18 paddocks which represented a four-year rotation pasture based dairy system in Uruguay, which combines one year of annual grasses and three years of perennial pastures. The *Lucerne-Bromus* forage resource (*Medicago sativa* with *Bromus catharticus*) were sown on March 2015, with 15 kg ha<sup>-1</sup> and 12 kg ha<sup>-1</sup> respectively. *Dactylis glomerata* pastures sowed in May 2016 and April 2017 with 20 kg ha<sup>-1</sup> and 3 kg ha<sup>-1</sup> of *Trifolium*. Annual grasses were compound with *Lolium multiflorum* and *Avena bizantina* (Av-Rg), sowed in March with 100 and 20 kg ha<sup>-1</sup> each respectively.

Four farmlets grazed on 56 has, distributed in the 18 paddocks, with one of the four two\*two factorial arrangements of treatments: two stocking rates 1.5 or 2.0 milking cows per hectare and two pasture managements, compound with 24 cows each treatment. All paddocks received an annual application of phosphorus fertilizer

(to replace nutrient removal) and nitrogen after grazing ( $35 \text{ kg N ha}^{-1}$  application). Total amount of nutrient supplied in the period were  $200 \text{ y } 87 \text{ kg ha}^{-1}$  for nitrogen ( $\text{N}_2$ ) and phosphorous ( $\text{P}_2\text{O}_5$ ) respectively.

**Figure 1** Paddocks distribution and georeferenced points for QC estimation, and satellite image calibration.



#### 2.4.2 Double sampling (DS)

In each paddock five visual scales were defined (1-5), representing the yield scale (1- low, 2-half-low, 3-half, 4-middle-high, 5- high yield) every fifteen days. Each scale was composed with three repetitions with a total of fifteen cuts represented into a  $0.51 \text{ m X } 0.30\text{m}$  quadrant size. Biomass was removed at ground level and tagged, after that, fresh herbage was weighted and dried on a stove for 48 hours at  $60^\circ\text{C}$  to estimate dry matter. Once the samples were dry, a regression equation with dry matter yield of each scale rating was calculated. This scale was

used weekly to estimate pasture coverage (kg DM ha<sup>-1</sup>) and GR (kg DM ha day<sup>-1</sup>) in each paddock. At least twenty determinations of scale per paddock were registered weekly by a trained person walking alongside the paddock transect.

#### 2.4.3 C-Dax pasture meter

Weekly, the pasture meter (C-Dax) was driven through the same transect than DS of each paddock registering pasture height (mm) continuously. The instrument can take numerous readings (200 per second) across a paddock with speeds up to 20 km/h. The herbage mass (kg DM ha<sup>-1</sup>) at ground level was estimated using a calibrated equation for local conditions (paddock kg DM ha<sup>-1</sup> = (13.4 h C-Dax) + 826), n= 637 (Garrido *et al.*, 2018). GR was estimated accounting the differences in herbage mass between two consecutive weeks divided by the number of days between the two determinations. This result was compared with the measure reported on the DS technique.

#### 2.4.4 Herbage cuts on quadrants (QC) and sentinel calibration (SI)

In each of the eighteen paddocks, three georeferenced points (downloaded into a QGIS development team 2018) were located using a *Garmin eTrex 10* across the same transect described for DS and C-Dax. The spatial arrangement established the possibility of having twelve different sampling points per forage resource (Figure 1). Pre-grazing and post-grazing herbage mass were cut at ground level on a 0.51m X 0.3m quadrant, and dry on a stove for 48 hours at 60°C to estimate dry matter weight. The difference between post-grazing and pre-grazing, divided by the days among dates, was used to estimate GR (kg DM ha day<sup>-1</sup>) for each point.

Sentinel images (SI) were downloaded from U.S.G.S service (<https://earthexplorer.usgs.gov/>) for each paddock and radiometric as well as atmospheric corrections were made using a SCP complement available on QGIS version 2.18.25. As sentinel has multispectral information, through the combination

of bands 8 and 4 (Infra-Red and Red, respectively) it was possible to calculate the *Normalized Difference Green Index* (NDVI); which is a good estimator of the percentage of the radiation absorbed by vegetation (Baret and Guyot 1991; Sellers *et al.*, 1992; Paruelo *et al.*, 2004). This index integrates two spectral key features of the photosynthetic tissues: their low reflectance in the red wavelengths and their high reflectance in the infrared portion of the electromagnetic spectrum. The NDVI has been related of photosynthetically active radiation absorbed by green vegetation (Potter *et al.*, 1993; Oyarzabal *et al.*, 2011) and it is calculated by this relation:

$$(NDVI) = (IR - R) / (IR + R).$$

From the relationship between NDVI and  $fRFAA^4$ , it is possible to calculate the absorbed photosynthetically active radiation by green vegetation ( $RFAA^5$ ) from remote sensing data, by multiplying  $fRFAA$  by the incoming photosynthetically active radiation (PAR). The  $fRFAA$  was estimated by a model proposed by Potter *et al.* (1993) and adjusted by Oyarzabal *et al.* (2011) for our conditions, representing how NDVI when reach higher values the  $fRFAA$  get saturated as shown on the next equation:

$$fRFAA = \min [ 1 + NDVI / (1 - NDVI) / 10,07 - (0,15) * 0,95 ]$$

This index is directly and strongly related to net primary production (PPN)(Tucker *et al.*, 1985) and can be estimated by Monteith (1972) model as:

$$PPN = (PAR * fRFAA) * EUR$$

The value of EUR for annual and perennial pasture used was taken from Chilibroste, (2009) which value was 1 g DM/ MJ of active absorbed radiation.

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<sup>4</sup>Fraction of active absorbed radiation

<sup>5</sup> Photosintetic absorbed radiation

#### 2.4.5 Statistical analyses

Three types of analysis were carried out to compare these methods.

Simple linear regressions were fitted to compare HM (DS vs C-Dax) and GR (DS vs C-Dax; DS vs SI; C-Dax vs SI) estimations using the REG Procedure of SAS. Only the paddocks which were not under grazing at the time of determination were considered for the comparison between C-Dax and DS.

To estimate the prediction values of each method for HM and GR, the GLMMIX Procedure of SAS was used with month and forage resource as fixed effects and paddock (random) as repeated measurement. An autoregressive covariance structure was selected, based on the unbalanced distribution and time elapsed between observations.

In order to compare differences on estimations of GR at the milking platforms, mean values per paddock and per method were calculated and a mixed model with method and month as fixed effect and paddock as repeated measurement was used (GLMMIX Procedure of SAS).

### 2.5 RESULTS

#### 2.5.1 Herbage mass

Pasture biomass using DS technique was on average  $1524 \pm 72$  kg DM ha<sup>-1</sup>, with the highest estimation value in October  $2081 \pm 66$  kg DM ha<sup>-1</sup>, and the lowest on March  $977 \pm 81$  kg DM ha<sup>-1</sup> (Figure 2). Estimation of herbage mass through DS has been significantly affected by month and forage resource ( $p < 0.0001$ ) as shown in Figure 2 and 3, respectively.

For C-Dax, HM was on average  $2175 \pm 85,5$  kg DM ha<sup>-1</sup>, with maximum values reported in October  $2873 \pm 63$  kg DM ha<sup>-1</sup> and the lowest in February  $1702 \pm 93$  kg DM ha<sup>-1</sup> (Figure 2). Both factors, month and forage resource affected pasture biomass estimation ( $p < 0.001$ ; Figures 2 and 3). The difference between C-Dax and

DS in herbage mass estimation along the year was on average 651 kg DM ha<sup>-1</sup>, maximized in March and October (1002 and 792 kg DM ha<sup>-1</sup> respectively, Figure 2). For *Lucerne-Bromus* and *Av-Rg* differences among methods for HM were 771 and 884 kg DM ha<sup>-1</sup> respectively (Figure 3). Moreover, for *Dactylis 2<sup>nd</sup>* the difference between HM estimated with C-Dax compared with DS were the closest of the five forage resource (450 kg DM ha<sup>-1</sup>, Figure 3).

Figure 2 Temporal difference on average herbage mass (kg DM ha<sup>-1</sup>) estimated by C-Dax and DS, for *Dactylis*, *Lucerne-Bromus* and *Av-Rg*.

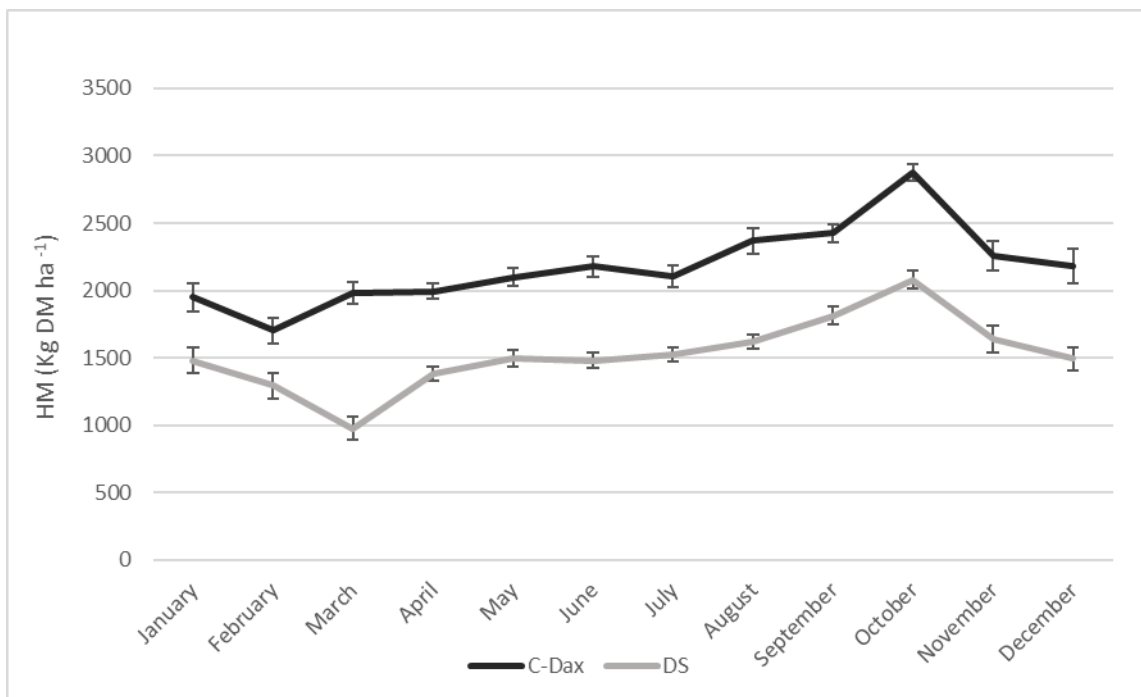
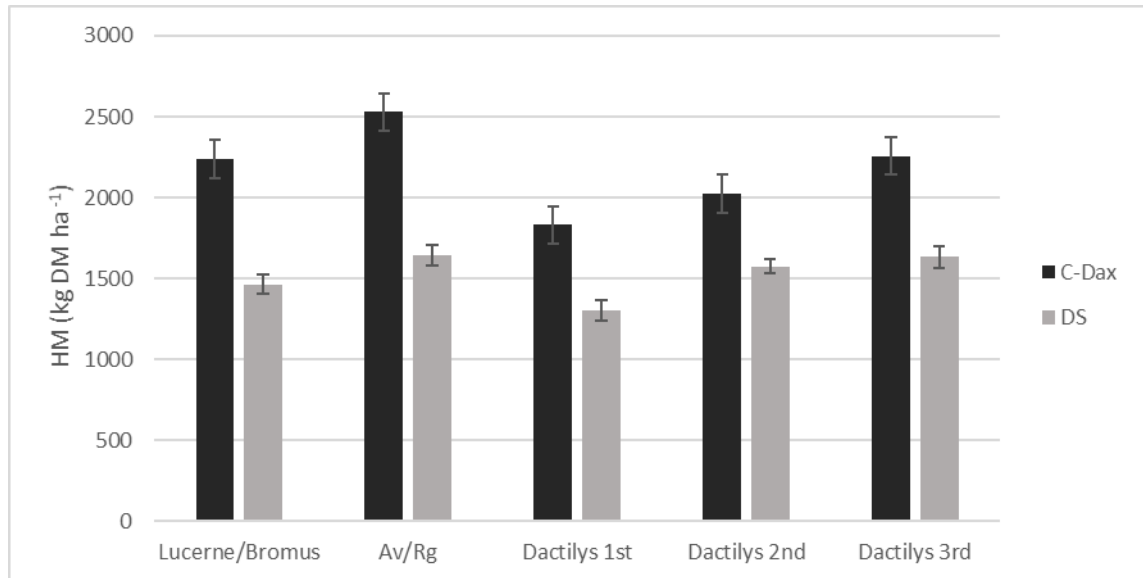


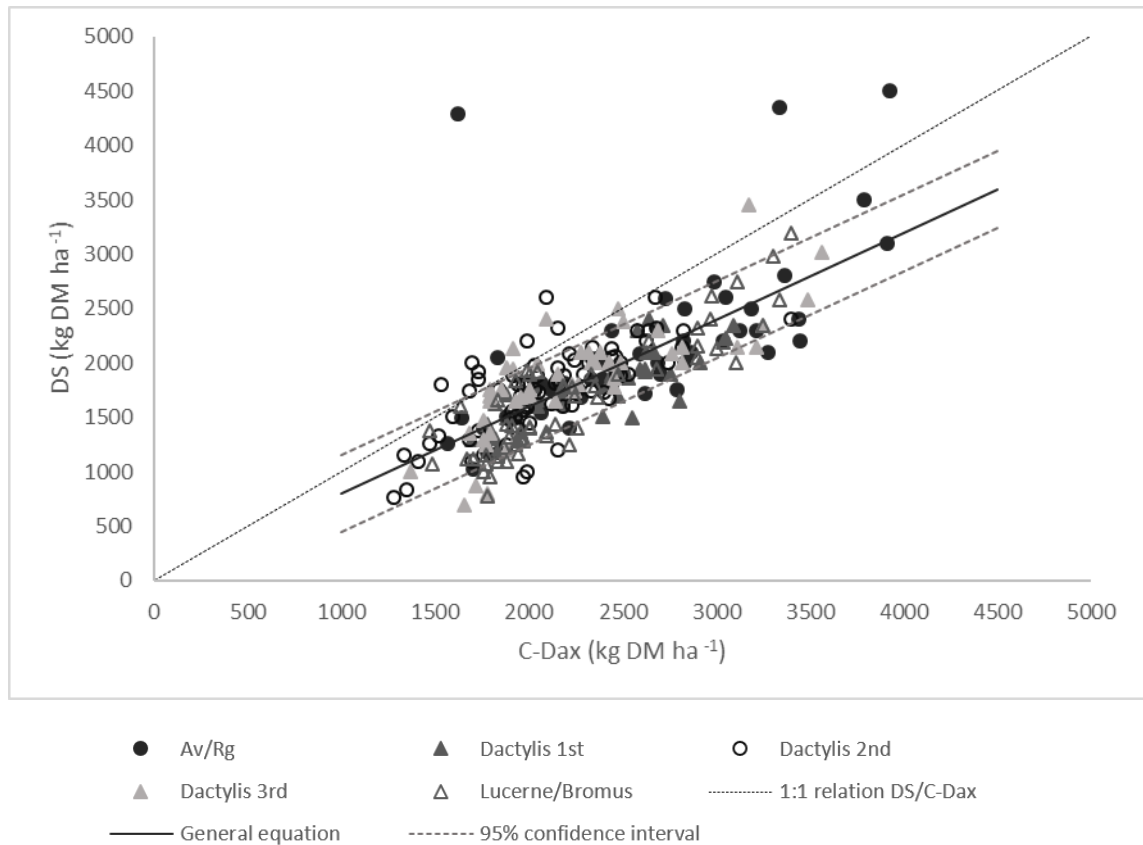


Figure 3 Herbage mass estimation (kg DM ha<sup>-1</sup>) for *Dactylis*, *Lucerne-Bromus* and *Av-Rg* trough DS and C-Dax



The relationship between HM estimated by the two methods (C-Dax and DS) was strongly related and fitted by a linear regression ( $Y_{DS} \text{ kg DM ha}^{-1} = 0.802 X_{C-Dax} \text{ kg DM ha}^{-1}$ ,  $R^2 = 0.96$ ,  $n=280$  Table 1, Figure 4). As shown by Figure 4, HM was overestimated using C-Dax; comparing with DS, this overestimation was higher as herbage mass increased.

Figure 4 Relation between herbage mass (kg DM ha<sup>-1</sup>) estimated by C-Dax and DS, for *Dactylis*, *Lucerne-Bromus* and *Av-Rg*.



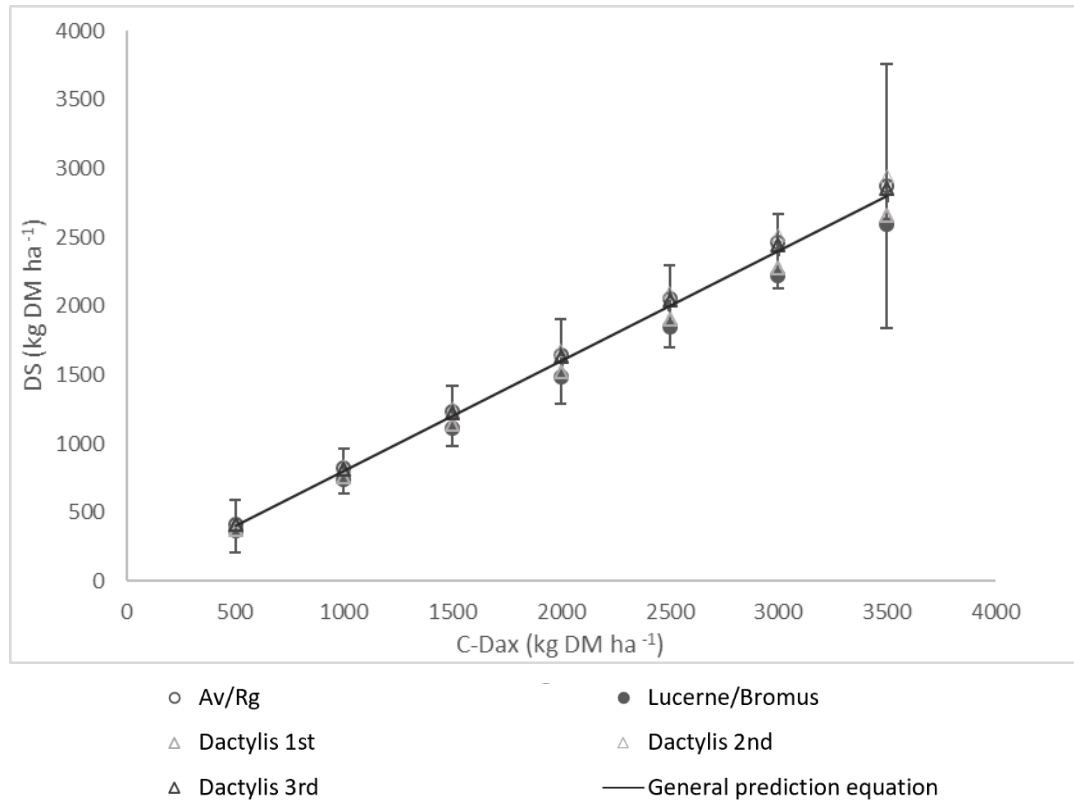
In order to know if a specific model for each forage resource improves values of herbage mass predicted by a general linear model, coefficients between HM estimations using C-Dax and DS for different forage resource are presented in Table 1. The accuracy for the comparative models of the five forage resources were high, although annual grasses (*Av-Rg*) represented the highest RMSE=580 with a coefficient of variation = 27.1. On the other hand, *Dactylis* 1<sup>st</sup> denoted the most accurate model, with less RMSE as well as less coefficient of variation.

Table 1 Predicted values of herbage mass estimation by C-Dax and DS (kg DM ha<sup>-1</sup>). Comparisons were performed for each paddock every week.

| HM (kg DM ha <sup>-1</sup> ) | Mean | SD  | N   | β1      | R2   | RMSE | CV   |
|------------------------------|------|-----|-----|---------|------|------|------|
| General model                | 1827 | 407 | 280 | 0.80245 | 0.96 | 353  | 19.3 |
| <i>Lucerne/Bromus</i>        | 1665 | 389 | 60  | 0.74913 | 0.97 | 272  | 16.3 |
| <i>Avenae + Lolium</i>       | 2138 | 504 | 49  | 0.82233 | 0.93 | 580  | 27.1 |
| <i>Dactylis</i> 1st          | 1776 | 329 | 36  | 0.76302 | 0.98 | 187  | 10.6 |
| <i>Dactylis</i> 2nd          | 1764 | 332 | 83  | 0.83977 | 0.97 | 267  | 15.1 |
| <i>Dactylis</i> 3rd          | 1857 | 415 | 52  | 0.81609 | 0.97 | 321  | 17.2 |

In Figure 5 the values predicted by an overall model and by individual forage resource predicted models (Table 1) for DS and C-Dax were compared. Mean predicted values were (1827 ± 407, 1665 ± 389; 2138 ± 505; 1776 ± 329; 1764 ± 332; 1857 ± 415 kg DM ha<sup>-1</sup> for an overall equation or a specific equation for *Lucerne-Bromus*, *Av-Rg*, *Dactylis* 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> respectively). As predicted values of herbage mass estimated by C-Dax reaches 3500 kg DM ha<sup>-1</sup> (Figure 5), the dispersion on HM estimated by DS was the highest. However, overall prediction model deviations did not differ between specific forage resource model.

Figure 5. Predicted herbage mass (kg DM ha<sup>-1</sup>) values and deviations estimated by C-Dax and DS for *Dactylis*, *Lucerne-Bromus* and *Av-Rg*.



### 2.5.2 Estimation of GR by DS, C-Dax, QC and SI

Pasture GR using DS technique was on average  $32 \pm 6.3$  kg DM ha day<sup>-1</sup>, with the highest estimation value in October  $50 \pm 3.7$  kg DM ha<sup>-1</sup>, and the lowest on June  $9 \pm 6.8$  kg DM ha day<sup>-1</sup> as seen in Figure 6. Month and forage resource have affected significantly the estimation of GR by this method ( $p < 0.001$ ) as shown in Figure 6 and 7. For C-Dax GR mean value was  $23 \pm 4.2$  kg DM ha day<sup>-1</sup>, with a maximum of  $46 \pm 4.7$  and a minimum of  $6 \pm 5.1$  kg DM ha day<sup>-1</sup> for November and March respectively. These estimations were affected by month ( $p < 0.0001$ , Figure 6) as well as by forage resource ( $p < 0.001$ ; Figure 7).

The use of QC for GR represented the highest value in November, and the lowest in April ( $62 \pm 6.7$  and  $15 \pm 11.6$  kg DM ha day<sup>-1</sup>). On average, for the period

GR was  $32 \pm 7.7$  kg DM ha day<sup>-1</sup> and the estimation was affected by month and forage resource ( $p < 0.001$  Figure 6 and 7). While remote sensing (SI) estimations reported maximum value for GR in October and minimum in March ( $79 \pm 5.1$  and  $6 \pm 5.2$  respectively kg DM ha day<sup>-1</sup>, Figure 6). On average GR was  $37 \pm 5.2$  kg DM ha day<sup>-1</sup>, and was affected significantly by month effect ( $p < 0.0001$ ). However, using SI estimated GR were not different between forage resource ( $p = 0.3895$  Figure 7).

Figure 6 Temporal GR (kg DM ha day<sup>-1</sup>) dynamic estimated by DS, C-Dax, QC and SI, for *Dactylis*, *Lucerne-Bromus* and *Av-Rg*.

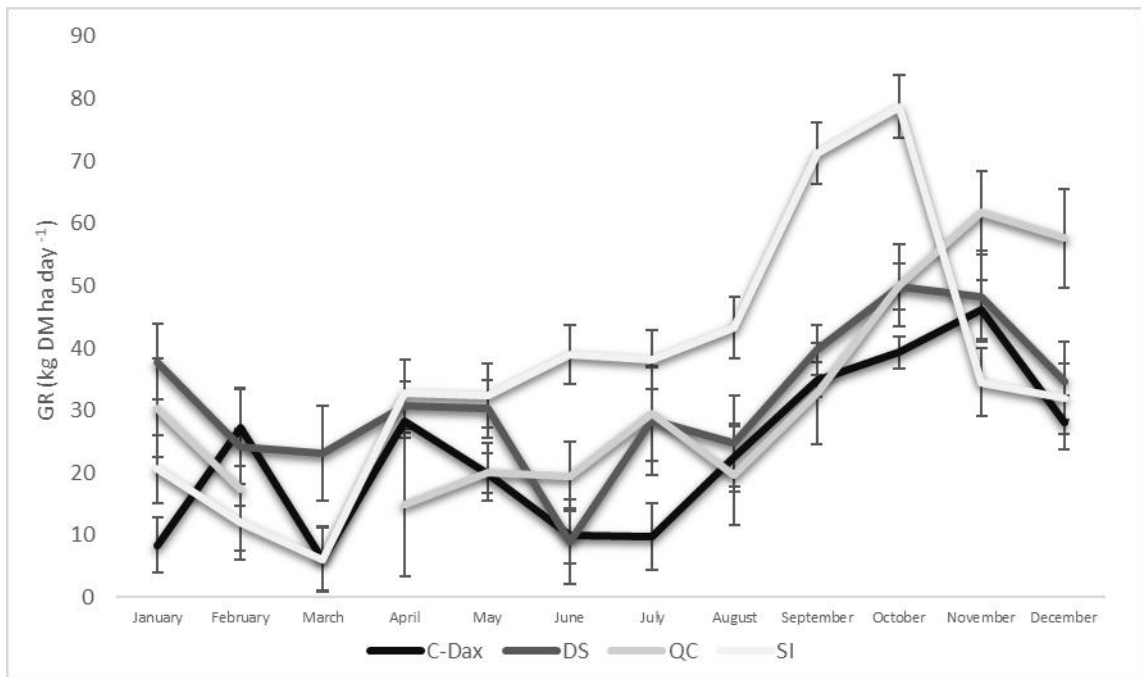
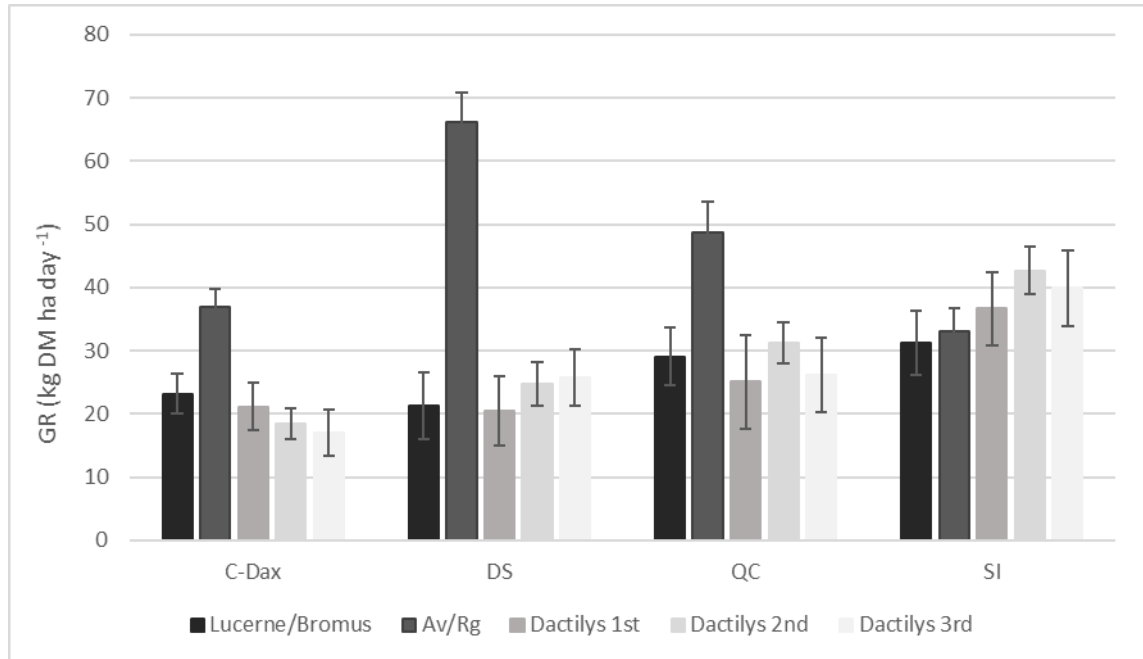


Figure 7 GR estimation (kg DM ha day<sup>-1</sup>) with DS, C-Dax, QC, and SI for *Dactylis*, *Lucerne/Bromus* and *Av-Rg*.

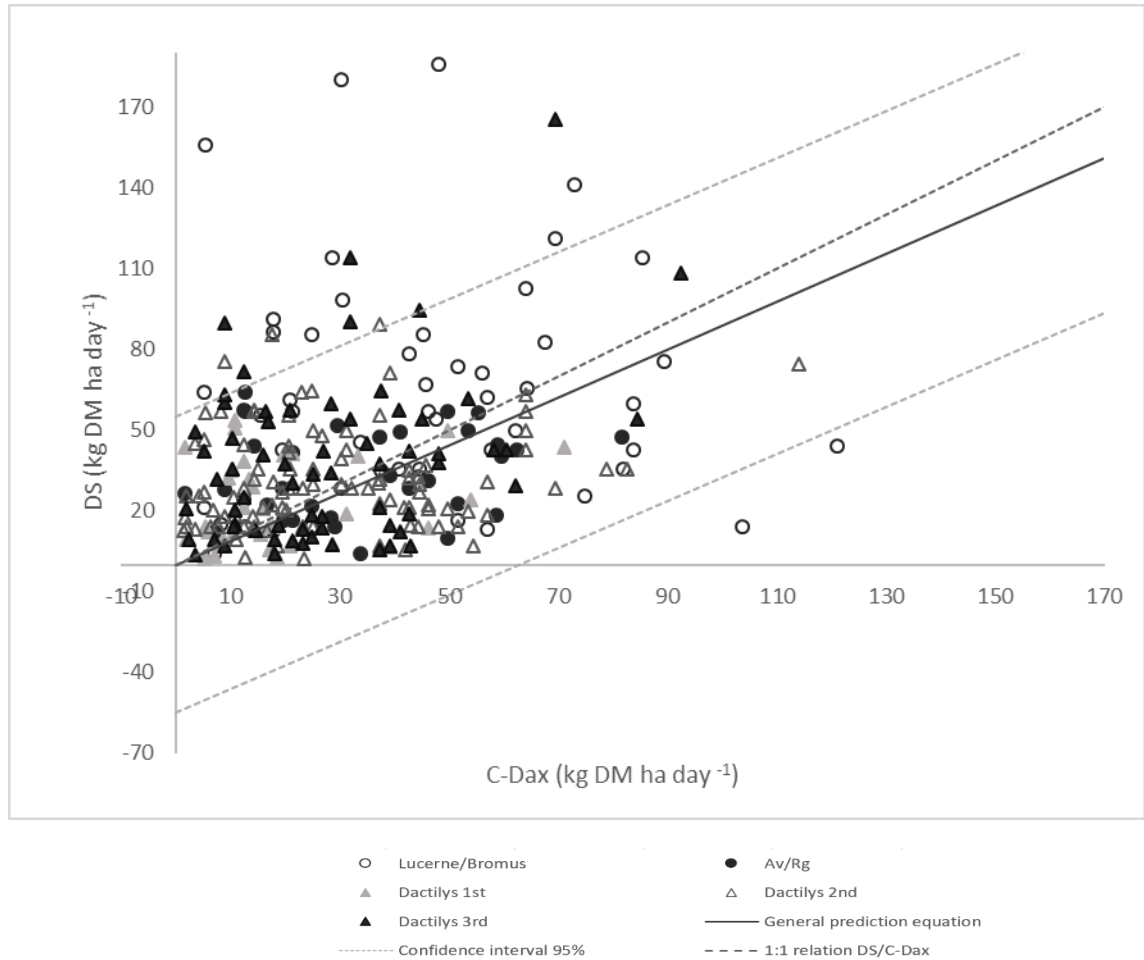


Estimations of GR made by C-Dax, DS and QC showed differences for Av-Rg compared with the other forage resources. Furthermore, estimations values for Av-Rg were three times bigger, compared with *Dactylis* and *Lucerne-Bromus* assessed by DS. However, for SI GR estimation forage resources did not differ (Figure 7).

### 2.5.3 Comparison of GR estimated by C-Dax and DS

The relation between C-Dax and DS on GR estimation was represented by a linear regression model ( $Y_{DS} \text{ kg DM ha day}^{-1} = 1.0C_{-Dax} \text{ kg DM ha day}^{-1}$ ,  $R^2 = 0.53$ ,  $n=282$  Figure 8). The highly dispersed GR values were reflected on the value of  $R^2$ , furthermore, paddock GR overestimations by C-Dax occurs at higher values of GR compared with DS.

Figure 8 Relation between pasture GR (kg DM ha day<sup>-1</sup>) estimated by C-Dax and DS, for *Dactylis*, *Lucerne-Bromus* and *Av-Rg*.



#### 2.5.4 Comparison of GR estimated by DS vs SI and C-Dax vs SI

In order to compare GR estimations by DS and C-Dax with SI a simple linear regressions were fitted ( $Y_{DS} \text{ kg DM ha day}^{-1} = 0.63 \text{ SI kg DM ha day}^{-1}$ ,  $R^2 = 0.60$ ,  $RMSE=24.6$   $CV=72$   $n=76$  Figure 9;  $Y_{C-Dax} \text{ kg DM ha day}^{-1} = 0.48 \text{ SI kg DM ha day}^{-1}$ ,  $R^2 = 0.67$ ,  $RMSE=16.7$ ,  $CV 67$ ,  $n=76$  Figure 10). SI overestimate paddock GR for DS and C-Dax; moreover, this overestimation was higher for C-Dax rather than DS (Figure 9 and 10).

Figure 9 Relation between pasture GR (kg DM ha day<sup>-1</sup>) estimated by SI compared with DS for *Dactylis*, *Lucerne-Bromus* and *Av-Rg*.

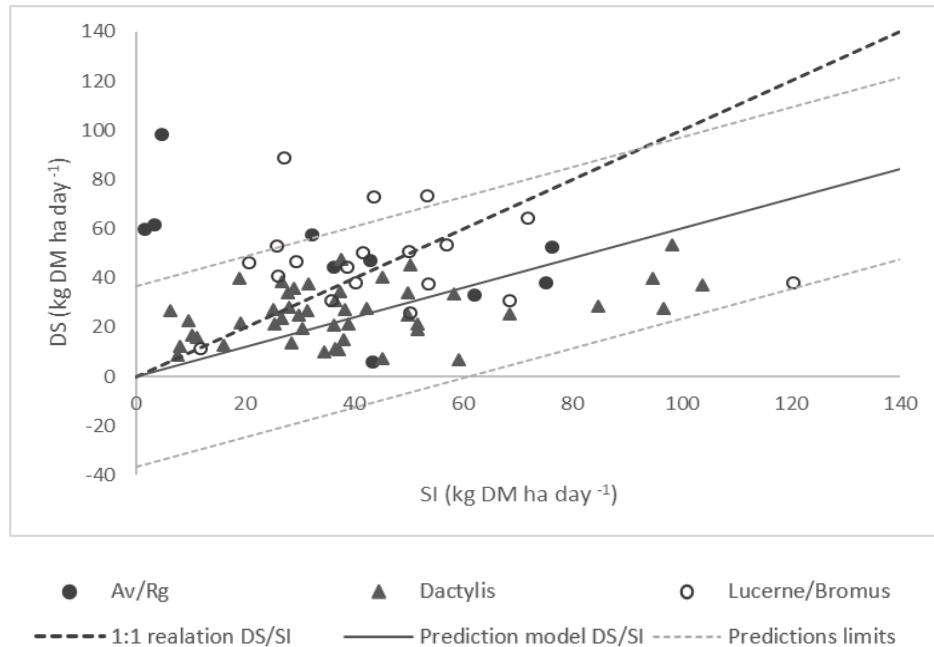
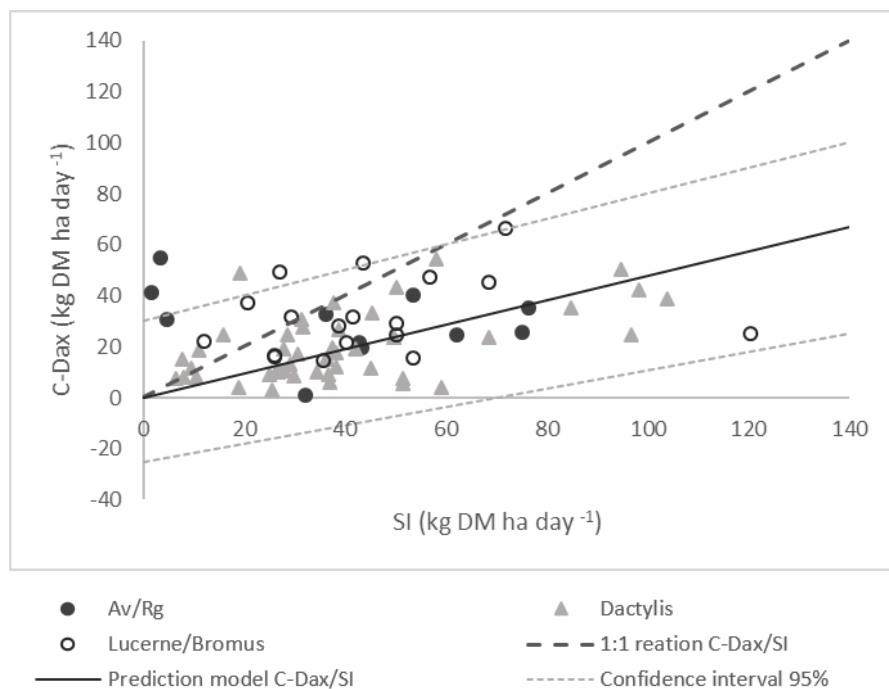


Figure 10 Relation between pasture GR (kg DM ha day<sup>-1</sup>) estimated by SI compared with C-Dax, for *Dactylis*, *Lucerne-Bromus* and *Av-Rg* in contrast with SI.





### 2.5.5 Estimation of GR for the milking platform using DS, C-DAX and SI

Temporal resolution of each method is shown on Table 2. For C-Dax and DS, frequency of measures were similar ( $9.7 \pm 3.4$ ;  $7 \pm 0$  days, respectively). However, the frequency for SI measures was  $22.8 \pm 10$  days and, as consequence, has the lowest number of determinations  $n=342$ .

Table 2 Number of observations per month and frequency between measurements for C-Dax, DS and SI.

| Month     | C-Dax |           | DS |           | SI |           |
|-----------|-------|-----------|----|-----------|----|-----------|
|           | N     | Frequency | N  | Frequency | n  | Frequency |
| January   | 27    | 6.9       | 27 | 7         | 36 | 20.0      |
| February  | 10    | 7.0       | 10 | 7         | 36 | 12.5      |
| March     | 16    | 8.7       | 16 | 7         | 54 | 10.3      |
| April     | 65    | 7.5       | 65 | 7         | 18 | 20.0      |
| May       | 41    | 8.5       | 41 | 7         | 36 | 20.0      |
| June      | 21    | 11.5      | 21 | 7         | 18 | 25        |
| July      | 13    | 16.7      | 13 | 7         | 18 | .         |
| August    | 16    | 10.9      | 16 | 7         | 18 | 33.0      |
| September | 57    | 16.1      | 57 | 7         | 18 | 45.0      |
| October   | 70    | 7.1       | 70 | 7         | 18 | 35.0      |
| November  | 18    | 8.2       | 18 | 7         | 36 | 12.6      |
| December  | 24    | 7.2       | 24 | 7         | 36 | 17.8      |

Estimation of GR on the grazing platform was different between methods ( $p<0.001$ ; Table 3). C-Dax was significantly the lowest GR estimation at milking platform ( $23.9 \pm 1.9$  kg DM ha day<sup>-1</sup>) compared with DS and SI with no differences between them ( $32.7 \pm 1.9$  and  $29.4 \pm 3.3$  respectively). Furthermore, month effect for GR values was significant ( $p<0.001$ ; Table 3), as well as the interaction between month and method for GR ( $p= 0.0042$ , Table 4).

Table 3 GR (kg DM ha day<sup>-1</sup>) means on milking platform estimated by C-Dax, DS, and SI

| <b>Method</b> | <b>Weekly</b> |
|---------------|---------------|
| C-Dax         | 23.9 ± 1.9 a  |
| DS            | 32.7 ± 1.9 b  |
| SI            | 29.4 ± 3.3 b  |
|               |               |
| Method Pr>F   | 0.0030        |
| Method*Month  | 0.0042        |

Different letter established differences between treatments for same month p<0.001

Table 4 Month differences between GR (kg DM ha day<sup>-1</sup>) estimated on milking platform area by C-Dax, DS, and SI, with data grouped weekly

| <b>Month</b> | <b>C-Dax</b> | <b>DS</b> | <b>SI</b> |
|--------------|--------------|-----------|-----------|
| January      | 10 b         | 29 a      | 17 ab     |
| February     | 30 a         | 19 ab     | 7.0 b     |
| March        | 9 ab         | 16 a      | 0.8 bc    |
| April        | 31 a         | 39 a      | 26 a      |
| May          | 22 a         | 31 a      | 24 a      |
| June         | 16 a         | 29 a      | 29 a      |
| July         | 26 b         | 46 a      | 29 ab     |
| August       | 17 a         | 24 a      | 33 a      |
| September    | 40 a         | 49 a      | 59 a      |
| October      | 36 b         | 43 b      | 75 a      |
| November     | 32 a         | 39 a      | 28 a      |
| December     | 19 a         | 23 a      | 25 a      |

Different letters established differences between treatments for same month p<0.001.

## 2.6 DISCUSSION

### 2.6.1 Herbage mass

Pasture biomass estimations with C-Dax were different compared with DS. Same results were reported by López-Guerrero *et al.*, (2011), who found that indirect methods overestimate mass cover compared with visual assessments. Furthermore, the difference between pasture biomass estimated by C-Dax and DS was on average 651 Kg DM ha<sup>-1</sup> year, while King *et al.*, (2010), reported that during summer the pasture meter can overestimate pasture mass by more than 1000 kg DM ha<sup>-1</sup>. This overestimation turns higher when herbage mass increased (Figure 4), this sward height is common due to a high proportion of the mass being concentrated in the lower layers (Frame, 1993), moreover, it is not possible for the pasture meter to distinguish stem or seed head height from the leaf height.

Other reason for the necessity of regional calibrations is the lack of adjustments between methods for seasonal differences (King *et al.*, 2010). For DS, biweekly calibrations were made in agreement with O'Donovan *et al.*, (2002). Although the C-Dax calibration equation was generated in the same experimental setup, the forage resource may have affected estimations due to differences in structure and pasture height, as was shown on figure 6 for Lucerne-Bromus and Av-Rg. Moreover, Rennie *et al.*, (2009); and Yule *et al.*, (2010) supported the importance of generating local equations. This issue was reported by other methods which work with height and pasture yield relation, as RPM and graduated ruler (Michell,1982, Frame, 1993).

Seasonal difference between C-Dax and DS for pasture biomass was not significant ( $521 \pm 148$ ;  $739 \pm 228$ ;  $674 \pm 186$ ;  $672 \pm 103$  kg DM ha<sup>-1</sup>; for summer, autumn, winter and spring respectively Figure 2). This is remarkable because the experiment took place on a milking platform area with specific grazing judgments, under continuous measurements, guaranteeing a highly heterogenous environment

but controlling entrance and residual pasture conditions. This represented a difference with other experiments which compare methods, where determinations are associated to specific paddocks on pre-grazing period (O'Donovan et al, 2002), such as monthly sampling (Rennie *et al.*, 2009) or short-term determinations (Loaiza *et al.*, 2012) where temporal effects are limited to a short period of time. The high frequency of C-Dax on registering data could have captured the heterogeneity due to grazing better than DS. Likewise, C-Dax operator input is minimal and, therefore, low operator error and variation would also be expected on milking platform area. For that reason, the use of pasture meter in that area could be showing better accuracy in the estimation of pasture biomass than DS (King *et al.*, 2010).

#### 2.6.2 Paddock and milking platform GR estimations

The high heterogeneity may affect the estimation of GR between methods. The QC could not be suitable for heterogeneous paddock conditions, because estimation's precision obtained from clipping decreases as the spatial variation of the vegetation increases due to patchy or large discrete weight (Catchpole and Wheeler, 1992). March is the only month where GR could not be estimated for QC as a consequence of drought (Figure 6). This clearly reflect the limitations of the methodology, because for SI, C-Dax and DS estimations were possible to be made.

Comparatively with herbage mass, GR predictions values showed higher variation between season, month, and method. Predictions between C-Dax and DS had temporal differences expressed in January, March and July (Figure 6). When GR was low, C-Dax and DS estimations were closer to each other, however, July overestimation by DS could be explained by biweekly calibrations of DS, where Av-Rg sward residual height could have increased and high proportion of herbage is concentrated in low layers of the sward, product of higher amounts of tillers (Frame, 1993). As DS calibration has a subjective component, aforementioned factors make difficult the construction of the scales (Catchpole and Wheler, 1992), affecting the overestimation made with DS compared to C-Dax.

From June to November, estimations for SI were the highest of the four methods (Figure 7), this difference may be explained by the estimation made through Monteith (1972), where the EUR assumed was the same for all forage resource as reported Chilibroste (2009). This could have affected estimations of PPN, as reported by Piñeiro *et al.*, (2006) on how environment conditions affect the value of EUR. Nevertheless, temporal resolution of SI (each 22.8 days Table 4) is the method with most detailed description of the paddocks compared with C-Dax, DS and QC; however, differences in seasons with lower growing rates are quite similar (January to May, Figure 6).

Remote sensing estimations were higher for September and October, and lower from November to March. The explanation in this case was that SI discriminated dead from green plant material by increasing red light reflectance and by decreasing NDVI values (and pasture cover estimations); whereas estimations by C-Dax, DS and QC methods did not discriminate between dead and green plant tissue. The increase on dry matter percentage of the forage (related to season), in addition to the less spatial resolution, may have affected the overestimation in November and December for QC as well as for DS from January to April, season where a high hydric deficit was established.

When methods were used to estimate GR on/at the milking platform, annual differences between C-Dax and DS GR was of 8.8 kg DM ha day<sup>-1</sup>, which translates on 3212 kg DM ha<sup>-1</sup> per year. This amount of herbage is almost what an individual cow could eat in one year in this system (Ortega *et al.*, 2018), so it would be possible to increase the stocking rate or save it as haylage. However, as shown on Table 2, methods have temporal differences, and if we translate the importance of monitoring and controlling GR (Holmes & Roche, 2007), a year is a huge scale on a dairy milking platform area. The differences of 32 kg DM ha day<sup>-1</sup> between SI with C-Dax and DS (October, Table 4) represent, in a high stocking rate system (Ortega *et al.*, 2018), the possibility of making haylage on the 42% of the area. Using SI in October instead C-Dax or DS, will produce inconvenience on herbage allowance (Holmes &

Roche, 2007), probably affecting the farm target sward mass residual and, as a consequence, the whole GR system (Dillon *et al.*, 2005). That issue is relevant on platform herbage management because it regulates the rotation speed (pasture regrowth days, Chapman, 2016) and supplementation (Bargo *et al.*, 2002). Controlling stock and growing rate frequently and accurately (Insua *et al.*, 2019) helps keeping the system competitive and sustainable. Changes in temporal resolution could represent differences of 4 – 5 kg DM ha day<sup>-1</sup> between methods; depending on the season this variation would mean more supplements, more herbage per cow (or to increase haylage area).

## 2.7 CONCLUSIONS

There was a difference in HM estimation by C-Dax compared with DS, which is magnified at higher values of mass cover. Moreover, herbage mass estimation was different in all forage resource comparing C-Dax and DS. Estimation of paddock GR for Av-Rg was different from Lucerne-Bromus and Dactylis, for C-Dax, QC and DS, but not when SI was used. Overestimations in paddock GR were found between methods which combines a good description of the space (SI with C-Dax) as well as suitable temporal resolution (SI compared with C-Dax and DS). Even though overestimation in GR were reported between methods with similar temporal resolution (DS and C-Dax) differences were not as big as found comparing these methods with SI. Furthermore, when estimations took place in milking platform area, differences between methods for GR were reduced, especially in the months where lowest GR was registered. The interaction between month and method, enable to identify the dispersion of predicted values of different methods depending on the months, to choose the appropriated method dependent on the space and time scale required for grazing dairy systems.

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### **3. RESULTADOS Y DISCUSIÓN**

#### **3.1 RESULTADOS PARA HM Y GR A NIVEL DE POTRERO**

Las estimaciones de pastura realizadas con C-Dax fueron diferentes en comparación con las realizadas por DS. Mismos resultados fueron reportados por López-Guerrero *et al.* (2011) quien encontró que la utilización de métodos indirectos sobreestimaba en comparación con estimaciones visuales. Diferencias entre HM estimada por C-Dax y DS fueron de 651 kg DM ha<sup>-1</sup> en este trabajo, mientras que King *et al.* (2010), reportó que durante el verano el uso del C-Dax puede sobreestimar en más de 1000 kg DM ha<sup>-1</sup>. Esta sobreestimación para las condiciones de nuestro trabajo se vuelve mayor, a medida que el valor de HM incrementa (Figura 4). A valores altos del forraje es común que ocurra que la mayor proporción del forraje está concentrada en las zonas más bajas (Frame, 1993), además, no es posible por el pasturómetro distinguir porciones florales de zonas de láminas.

La necesidad de contar con calibraciones estacionales y por recurso para C-Dax (King *et al.*, 2010) pudo haber influenciado en los mayores valores de HM estimados en comparación con DS. Para DS las calibraciones por recursos eran de manera quincenal (O'Donovan *et al.*, 2002), sin embargo, para C-Dax la ecuación calibrada si bien no era la de origen, se utilizó la misma sin discriminar por recurso. Este aspecto pudo haber afectado la estimación debido a diferencias de estructura, altura de la pastura como se muestra en la figura 6 para Lucerne-Bromus y Av-Rg. Además, Rennie *et al.* (2009) y Yule *et al.* (2010) han remarcado la importancia de generar ecuaciones de calibración locales y por especie para el uso de C-Dax en distintas zonas de Nueva Zelanda.

Las diferencias entre la HM estimada por C-Dax y DS se mantuvo a lo largo de las estaciones (521 ± 148; 739 ± 228; 674 ± 186; 672 ± 103 kg DM ha<sup>-1</sup>; para verano, otoño, invierno y primavera respectivamente. Esto es un hecho remarcable debido que el experimento tomó lugar en una plataforma de ordeño con criterios de

pastoreos estrictos de entrada y salida a la pastura con medidas continuas que garantizaron un ambiente heterogéneo. Un aspecto a resaltar en comparación con otros trabajos en lo que se evaluaron métodos para la estimación de HM, y las determinaciones fueron o en momentos específicos ya sea entrada y salida de pastoreo (O'Donovan *et al.*, 2002) asociados a muestreos mensuales (Rennie *et al.*, 2009), o a determinaciones en corto período de tiempo (Loaiza *et al.*, 2012) donde visualizar los efectos temporales es limitado.

Para la estimación de GR se utilizaron los métodos C-Dax, DS, QC e imágenes satelitales. La alta heterogeneidad del potrero pudo haber afectado la diferencia entre métodos sea el caso del QC, donde las limitantes del método se ven relegadas ya que la precisión disminuye a medida que la variación de la vegetación aumenta a causa de parches, ya sea por efecto del bosteo, pisoteo y pastoreo (Catchpole y Wheeler, 1992). En marzo fue el mes donde GR no pudo ser estimada por consecuencia de la falta de precipitaciones en esos meses, esto refleja una limitante en la metodología debido que en los otros tres métodos las estimaciones pudieron ser realizadas.

Comparativamente con HM, las predicciones de tasa de crecimiento mostraron mayor variación entre estaciones, meses y método. Las predicciones entre C-Dax y DS, tuvieron diferencia temporal para los meses de enero, febrero y julio (Figura 6). Cuando la GR fue baja, las estimaciones entre C-Dax y DS estuvieron cercanas entre sí. Sin embargo, en julio la sobreestimación por parte de DS, pudo estar asociado a la subjetividad que presenta el método, ya que la heterogeneidad pudo haber dificultado la construcción de escalas que se tradujeron en mayores volúmenes de forraje estimados (Catchpole y Wheeler, 1992).

Desde junio a noviembre estimaciones para SI fueron las más altas de los cuatro métodos evaluados (Figura 7), esta diferencia estuvo explicada por el uso del modelo de Monteith (1972), donde el uso para el parámetro EUR fue el mismo para todos los recursos tomado de Chilibroste, (2009). Esto afectó el valor de las

estimaciones de PPN, según fuera reportado por Piñeiro *et al.* (2006) en como las condiciones del ambiente afectan el valor de EUR. A pesar, que la resolución temporal de SI fue de una imagen cada 22,8 días, fue posible lograr una estimación por mes, además de ser el método que mejor descripción del espacio presenta en comparación con C-Dax, DS y QC. Sin embargo, las diferencias en estimación para las estaciones con menor crecimiento (comprendidas desde enero a mayo) fueron similares entre métodos (Figura 6).

Las estimaciones con SI fueron mayores en setiembre y octubre y menores desde noviembre a marzo. La explicación para este caso es que, SI discrimina el material muerto por senescencia del material verde que está en activo crecimiento y aumenta el porcentaje de luz roja absorbida, y por tal motivo incrementa el NDVI. Mientras que estimaciones con C-Dax, DS y QC, no logran discriminar entre el material muerto y verde. El aumento en el contenido de materia seca del forraje (en distintas estaciones del año) sumado a la menor resolución espacial pudo haber afectado la sobreestimación en los meses de noviembre y diciembre en la utilización del QC, así como también en los meses de enero a abril, épocas donde el déficit hídrico fue muy marcado.

### 3.2 ESTIMACIONES A NIVEL DE PLATAFORMA DE ORDEÑO

Cuando los métodos se utilizan para estimar GR en el área de plataforma de ordeño, ocurren diferencias entre ellos. La diferencia en estimación entre C-Dax ( $23,9 \pm 1,9$ ) y DS ( $32,7 \pm 1,9$ ) es significativa ( $p < 0,001$ ) en una magnitud de 8,8. Sin embargo, las medias para DS y SI ( $29,4 \pm 3,3$ ) no fueron diferentes entre sí. El diferencial estimado entre los métodos C-Dax y DS representa un volumen de forraje de 3212 kg DM ha en un año. Esta cantidad de forraje sería suficiente para alimentar a una vaca en pastoreo en un sistema de alta carga animal (Ortega *et al.*, 2018). Sin embargo, interacciones entre el método y el mes fueron reportadas, por lo que trabajar en una escala anual para visualizar la diferencia entre los métodos es demasiado grande para la importancia que tiene el control y el monitoreo de GR en



un sistema pastoril (Holmes y Roche, 2007). En octubre la diferencia entre C-Dax y DS fue de 32 kg DM ha day<sup>-1</sup>, donde en un sistema pastoril de alta carga la posibilidad de obtener área de reserva podría ser del 42% de la superficie (Ortega *et al.*, 2018). Este es un factor relevante a escala predial ya que errores en la estimación, estarán afectando los factores mencionados anteriormente, pero además afectará aspectos relacionados al residuo en la pastura (Dillon *et al.*, 2005) la velocidad de rotación del pastoreo, el estado fenológico adecuado para las plantas para tolerar el pastoreo (Chapman, 2016) y la suplementación (Bargo *et al.*, 2002).

Cambios en la resolución temporal entre los métodos puede representar diferencias entre métodos de 4 a 5 Kg DM ha day<sup>-1</sup> dependiendo de la época esta variación repercutirá en, mayor valor de suplemento ofrecido, mas forraje por vaca (o incrementar el área con destino a reserva forrajera).

#### **4. CONCLUSIONES**

Existieron diferencias en el uso de C-Dax y DS para la estimación de HM, donde a valores mayores de biomasa la sobreestimación de C-Dax en comparación con DS se magnificó. Estimaciones de GR a nivel de potrero para Av-Rg se diferenciaron de Lucerne-Bromus y Dactylis, para los métodos C-Dax, DS y QC, pero utilizando como método SI. Sobreestimaciones en la GR fueron encontradas cuando se compararon métodos que combinan buena descripción del espacio (SI con C-Dax) conjuntamente con métodos que presentan adecuada resolución temporal (SI con C-Dax y DS). Sin embargo, si bien existieron sobreestimaciones en la GR entre métodos que presentan una escala temporal similar comparados entre sí (DS con C-Dax) estas fueron de menor magnitud a las encontradas entre estos métodos en contraste con SI.

Además, cuando las estimaciones tomaron lugar en la plataforma de pastoreo, las diferencias entre métodos se vieron reducidas, especialmente en los meses del año donde la GR es menor. La interacción detectada entre mes y método permite conocer la dispersión en la predicción de GR según el momento del año, de forma de tener insumos para seleccionar el método más apropiado según la escala espacial y temporal requerida en un sistema de pastoreo intensivo. Además de la precisión de en la estimación de los métodos es determinante la frecuencia con que se obtienen las medidas debido que métodos más frecuentes, permiten corrección en la toma de decisión en un período de tiempo menor y por ende un mejor control del forraje en el área de plataforma de pastoreo.

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## 6. ANEXOS

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