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ESTIMATING FORAGE MASS OF A CROP-LIVESTOCK SYSTEM (ICL) USING SATELLITE IMAGES AND CLIMATE DATA

Sandra Furlan NOGUEIRA [1]; Gustavo BAYMA [2]; Marcos ADAMI [3]; Patricia SANTOS [4]; Jose Ricardo PEZZOPANE [4]; Daniel NUÑEZ [5]; Célia GREGO [6]; Antônio Heriberto TEIXEIRA [7]; Sergii SKAKUN [8]; Isa ROLISOLA [9]

[1] Agricultural Engineer. Researcher. Embrapa Environment; [2] Geographer. Analyst. Embrapa Environment; [3] Economist. Researcher. National Institute for Space Research; [4] Agricultural Engineer. Researcher. Embrapa Southeast Livestock; [5] Biologist. Researcher. Unibras; [6] Agricultural Engineer. Researcher. Embrapa Agricultural Informatics; [7] Agricultural Engineer. Professor. Federal University of Sergipe; [8] Mathematician. Professor. University of Maryland; [9] Agricultural Engineer. Fellow. Embrapa Environment

ABSTRACT

The Simple Algorithm for Evapotranspiration Retrieving (SAFER) was used to estimate forage mass in a beef cattle production system, in São Carlos (SP), Brazil. Harmonized Landsat-8 and Sentinel-2 (HLS) surface reflectance bands were used with daily weather data from a station adjacent to the experimental area and from a INMET station (OMM: #86845). The experimental area is a crop-livestock system (iCL) with pasture managed under rotational stocking in rotation with corn for silage during pasture renewal. Monthly field campaigns in 2018 and 2019 were conducted and aimed to estimate ground-measured forage mass. A bootstrapped linear least-squares regression was employed for evaluating the results for model validation. SAFER is a feasible tool to estimate forage mass in a crop-livestock system (iCL), as around 73% of the variability in forage mass was explained through the integration of HLS surface reflectance images, ground-measured data, and cattle management, in an agrometeorological modeling approach. The methodology will assist farmers and policymakers to estimate forage availability to improve decision-making on pasture management. Future works will discriminate estimated forage mass in intensive and extensive pasture systems

Key words: digital agriculture; remote sensing; agrometeorology

INTRODUCTION

The Brazilian Gross Domestic Product (GDP) reached R$ 7.3 trillion in 2019. The agribusiness GDP reached R$ 1.5 trillion, 21% of the total Brazilian GDP, and the beef cattle GDP reached R$ 618.5 billion, 39% of the Brazilian agribusiness GDP and 8% of the total Brazilian GDP. Brazil has 213.6 million head of cattle spread over 162.5 million hectares. In 20 years, the animal stocking went from 0.71 to 1.06 heads per hectare and the productivity from 1.6 to 4.3 @ / ha / year (ABIEC, 2019). These numbers show an important role of the beef cattle sector in the Brazilian economy.

Commodities' values, food security, and environmental sustainability can be pointed as different vectors in productivity growth. In this scenario, innovation is essential to meet the demands that exist for the next decades. Precision cattle ranching is a management method that aims to improve production processes, reduce environmental impacts, obtain greater consumer satisfaction, and, thus, better economic return for rural producers (BERNARDI et al., 2014). Is a concept based on the existence of a great diversity of information and increasingly advocates the use of new technologies, such as GPS, remote identification of animals, sensors, satellites or aerial images, management software, artificial intelligence, and geographic information system (GIS) to assess and understand field variations (PIRES et al., 2014).

Satellites and unmanned aerial vehicles (UAVs) allow producers to effortlessly survey the conditions of their land, plantations, and herds. Thus, it is possible to identify wet or dry fields, identify soil erosion and other factors, which can assist in defining the most suitable types of pastures. The data can be used by the producer who will automatically adopt more favorable practices for his business (PIRES et al., 2014). Here, we examine the suitability of a remote sensing and agrometeorological modeling perspective to estimate forage mass. We aimed to address this gap using the Simple Algorithm for Evapotranspiration Retrieving (SAFER) and Monteith's light use efficiency (LUE) model to estimate forage mass in a crop-livestock system (iCL).

MATERIAL AND METHODS

The study area is located at São Carlos municipality, Sao Paulo State, in Cerrado biome. According to Köppen–Geiger climate classification system, the local climate is temperate or subtropical hot summer (Cwa), with average temperature and precipitation of 19.9 °C and 250 mm, in the dry season (Apr to Sept), and with 23.0 °C and 1,100 mm in the wet season (Oct to Mar), respectively. The soil is classified as Dystrophic Red-Yellow Latosol with a medium clay texture (CALDERANO FILHO et al., 1998).

The beef cattle production system is a crop-livestock system (iCL) and was established in 2010 with Piatã palisadegrass (*Urochloa* (*syn. Brachiaria*) *brizantha* (*Hochst ex A. Rich.*) *Stapf* cv. BRS Piatã. iCL system is contiguous and composed of two replicate areas of 3 ha each. Each intensively managed pasture replicate area was divided into six paddocks (0.5 ha each). In early 2018, two paddocks from each system were grown with corn for silage, while other paddocks were grazed under rotational stocking with 9 days of occupation and 27 days of rest. Later the corn has been harvested, the paddocks were grazed under rotational stocking with 6 days of occupation and 30 days of rest.

SAFER algorithm was applied together with Monteith's Light Use Efficiency (LUE) model to estimate biomass, here forage mass. As input data, SAFER requires remote sensing and weather data. SAFER algorithm is based on the modeled ratio of actual evapotranspiration (ET) and reference evapotranspiration (ET_0) and has been developed and validated in Brazil with field data from four flux stations and Landsat image data and its equations are described in detail in Teixeira et al. (2015).

Surface reflectance time-series were extracted from the Harmonized Landsat and Sentinel-2 (HLS) project (CLAVERIE et al., 2018). HLS products combine surface reflectance data from OLI/ Landsat-8/ and MSI/ Sentinel-2 in a single data set, as both sensors have similar measurements in terms of spectral, spatial, and angular characteristics. HLS is recommended for land monitoring, including monitoring agricultural management and condition (WALDNER et al., 2016). Even though the similarity, a harmonized surface reflectance data set needed efforts to mitigate these differences, for example, grid to a common pixel resolution; atmospherically correction and cloud mask to surface reflectance using a common radiative transfer algorithm and normalize to a common nadir view geometry via Bi-directional Reflectance Distribution Function (BRDF) estimation (CLAVERIE et al., 2018).

Input weather data were global solar radiation (R_G, MJ m^{-2} dia^{-1}); air temperature (T_a, °C); and reference evapotranspiration (ET_0, mm dia^{-1}) from an agrometeorological station adjacent to the experimental area and from an INMET station (OMM: #86845). HLS bands from the visible, red-edge, NIR, and SWIR regions were used to calculate surface albedo ($\alpha 0$), the Normalized Difference Vegetation Index (NDVI), while the surface temperature (T_0) was obtained as a residue in the radiation balance (TEIXEIRA et al., 2014).

Above ground-measured forage mass was evaluated according to the protocol described by Bayma-Silva et al. (2019). Mainly, we used the double-sampling method, a traditional agronomic sampling method (Wilm et al., 1944) to measure pasture height, which was converted into kilograms of dry mass per hectare (kg DM ha^{-1}). We estimated ground-measured dry green mass (DGM) from dry mass (DM), weighing green leaves and stems.

To calculate the accumulated SAFER forage mass, the daily values estimated by the SAFER model, on the sampling dates or in a close date, were multiplied by the days according to the stage (grazing, post-grazing, growth, and pre-grazing) of the forage paddock growth. Considering the case of the grazing paddock, the value of SAFER forage mass was multiplied by the grazing days, considered negative. Each grazing day reduced 1/6 of the number of days on which growth had occurred. Linear regression between the ground-measured dry mass and the accumulated SAFER forage mass was performed using the mean values of the management stages.

Monthly accumulated SAFER forage mass was plotted with dry and green mass production to verify the relationship between them, through linear least-square regression. To assess the linear regression (equations parameters and associated error), a bootstrap procedure was performed with 1001 random repetitions (EFRON; GONG, 1983). Upper and bottom limits were estimated using a 95% confidence interval.

RESULTS AND DISCUSSIONS

Linear regression analysis for all paddocks in iCL system showed that DGM fitted better with SAFER forage mass estimation than DM, $R^2 = 0.73$ and $R^2 = 0.42$, with a root-mean-square error (RMSE) ~445 and ~637 kg of DGM and DM, respectively (Table 1 and Figure 1). We can explain this result as SAFER is an agrometeorological model based on NDVI. NDVI is calculated from the visible and near-infrared (NIR) bands from OLI/ Landsat-8 and MSI/ Sentinel-2. Nutritious vegetation reflects a large portion of the NIR and absorbs most of the visible light. Thus, a major innovation of this study lies in DGM estimation.

Table 1. Bootstrap estimated parameters of dry green mass (DGM) and dry mass (DM)

	intercept DM	intercept DGM	slope DM	slope DGM	*pvalue* dm	*pvalue* DGM
Upper	3381.361	668.750	1.181	1.303	1.033e-01	5.030e-04
Median	2778.072	409.861	0.841	1.076	1.077e-03	1.035e-06
Bottom	2224.146	93.206	0.448	0.851	5.470e-07	1.328e-10
	correlation DM	correlation DGM	R^2 DM	R^2 DGM	RMSE DM	RMSE DGM
Upper	0.872	0.951	0.747	0.899	814.573	585.760
Median	0.676	0.862	0.426	0.729	636.799	444.991
Bottom	0.375	0.706	0.093	0.471	434.624	276.220

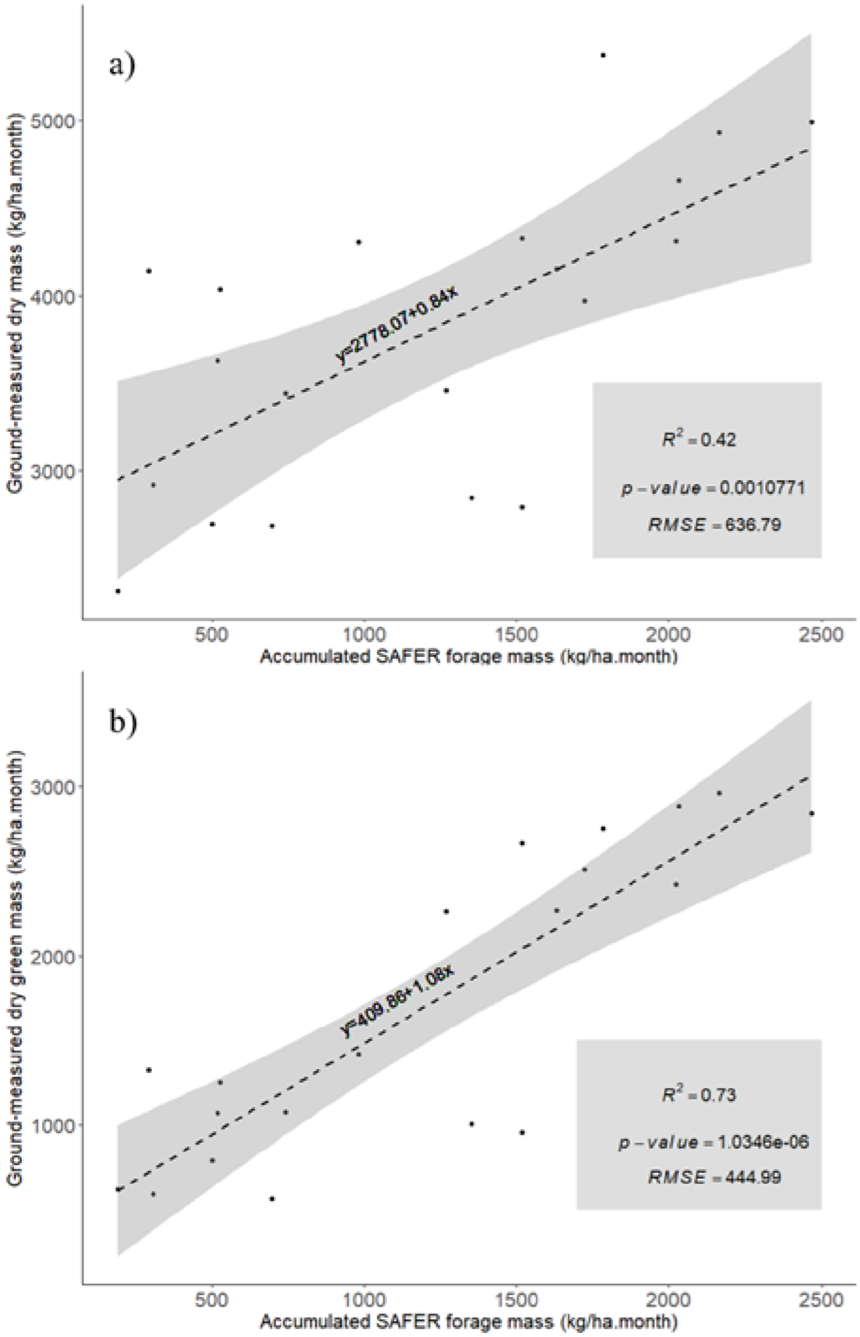

Figure 1. Relationship between the ground-measured (a) dry and (b) green mass (kg/ha.month) and accumulated SAFER forage mass (kg /ha.month). Each point represents the mean SAFER estimative for all pixels in the paddock and monthly measured forage mass.

Sibanda et al. (2015) resampled hyperspectral data to spectral resolutions of MSI/ Sentinel-2 and the OLI/Landsat-8 for comparison purposes. Using sparse partial least squares regression, the resampled data was applied in estimating above ground biomass of grasses treated with different fertilizer combinations of ammonium sulfate, ammonium nitrate, phosphorus, and lime as well as unfertilized experimental paddocks. MSI/ Sentinel-2 derived models satisfactorily performed better ($R^2 = 0.81$) than OLI/Landsat-8 ($R^2 = 0.76$). Reis et al. (2020) assessed the feasibility of using spectral and textural information derived from high spatiotemporal resolution PlanetScope imagery for estimating and monitoring aboveground biomass (AGB) and canopy height (CH) of intensively managed mixed pastures in an iCL system in the western region of São Paulo State, Brazil. The methodology was able to predict the spatiotemporal changes in pasture AGB and CH with moderate ($R^2 = 0.65$) to high ($R^2 = 0.89$) prediction accuracies, respectively, with a root mean square error (RMSE) of 26.52%.

Chen et al. (2021) explored the suitability of high spatio-temporal resolution MSI/ Sentinel-2 imagery and the applicability of advanced machine learning techniques for estimating aboveground biomass at the paddock level in five dairy farms across northern Tasmania, Australia. The optimal model was, therefore, able to explain about 60% of the variability existing in the pasture biomass data, with a root-mean-square error (RMSE) of ~356 kg dry mass (DM).

CONCLUSIONS

SAFER is a feasible tool to estimate forage mass in a crop-livestock system (iCL), as around 73% of the variability in forage mass (leaf +stem mass) was explained through the integration of HLS surface reflectance images, ground-measured data, and cattle management, in an agrometeorological modeling approach. The results of this study can lead farmers and farm managers to improve their productivity through better pasture management. Future work will discriminate the estimation of forage mass in intensive and extensive pasture systems.

REFERENCES

ABIEC. Associação Brasileira das Indústrias Exportadoras de Carnes. **Perfil da pecuária no Brasil**. 2019. Available at: < http://www.abiec.com.br/PublicacoesLista.aspx>. Accessed on: 06/04/2021.

BAYMA-SILVA, G; GREGO, C. R.; KOENIGKAN, L. V.; NOGUEIRA, S. F.; PEZZOPANE, J. R. M.; SANTOS, R. C.; SANTOS, P. M.; SANTOS, T. T.; TAKEMURA, C. M. **Protocolo de campo para investigação, calibração e validação de métodos para estimativa de massa de forragem baseados em sensoriamento remoto orbital e proximal.** Campinas: Embrapa Informática Agropecuária, 2019. 29 p.

BERNARDI, A. C. C.; NAIME, J. M.; RESENDE, A. V.; BASSOI, L. H.; INAMASU, R. Y. **Agricultura de precisão**: resultados de um novo olhar. Brasília: Embrapa, 2014. 596p. Available at: https://www.embrapa.br/en/busca-de-publicacoes/-/publicacao/1002959/agricultura-de-precisao-resultados-de-um-novo-olhar. Accessed on: April 2021.

CALDERANO FILHO, B.; SANTOS, H. G.; FONSECA, O. O. M.; SANTOS, R. D.; PRIMAVESI, O.; PRIMAVESI, A. C. **Os solos da Fazenda Canchim, Centro de Pesquisa de Pecuária do Sudeste, São Carlos, SP**: levantamento semidetalhado, propriedades e potenciais. Rio de Janeiro: EMBRAPA-CNPS; São Carlos, SP: EMBRAPA-CPPSE, 1998. 95 p. (EMBRAPA-CNPS. Boletim de pesquisa, 7; EMBRAPA-CPPSE. Boletim de pesquisa, 2).

CLAVERIE, M.; JU, J.; MASEK, J. G.; DUNGAN, J. L.; VERMOTE, E. F; ROGER, J. C.; SKAKUN, S. V.; JUSTICE, C. The Harmonized Landsat and Sentinel-2 surface reflectance data set. **Remote Sensing of Environment**, v. 219, 2018, p.145-161, 2018. DOI: 10.1016/j.rse.2018.09.002

CHEN; Y. GUERSCHMAN, J.; SHENDRYK, Y.; HENRY, D.; HARRISON, M. T. Estimating Pasture Biomass Using Sentinel-2 Imagery and Machine Learning. **Remote Sensing**, v. 13, p. 603, 2021. DOI: 10.3390/rs13040603

EFRON, B.; GONG, G. A leisurely look at the bootstrap, the jackknife, and cross validation. **American Statistician**, v.37, p.36-48, 1983.

PIRES, P. P.; SANTOS NETO, Q. I.; COSTA JUNIOR, J. B. G. Histórico e desafios futuros da pesquisa em pecuária de precisão na Embrapa Gado de Corte. In: SIMPÓSIO BRASILEIRO DE

PECUÁRIA DE PRECISÃO APLICADA À BOVINOCUTURA DE CORTE, 1., 2014, Campo Grande. **Anais...** Campo Grande: Embrapa Gado de Corte, 2014. 6 p.

REIS, A. A.; WERNER, J. P. S.; SILVA, B. C.; FIGUEIREDO, G. K. D. A.; ANTUNES, J. F. G.; ESQUERDO, J. C. D. M.; COUTINHO, A. C.; LAMPARELLI, R. A. C.; ROCHA, J. V.; MAGALHÃES, P. S. G. Monitoring Pasture Aboveground Biomass and Canopy Height in an Integrated Crop–Livestock System Using Textural Information from PlanetScope Imagery. **Remote Sens**. v. 12, 2534, 2020. DOI: 10.3390/rs12162534.

SIBANDA, M.; MUTANGA, O.; ROUGET, M. Examining the potential of Sentinel-2 MSI spectral resolution in quantifying above ground biomass across different fertilizer treatments. **ISPRS Journal of Photogrammetry and Remote Sensing.**, v. 110, pp. 55-65, 2015. DOI: 10.1016/j.isprsjprs.2015.10.005

TEIXEIRA, A. H. C.; HERNANDEZ, F. B. T.; ANDRADE, R. G.; LEIVAS, J. F.; VICTORIA, D. C.; BOLFE, E. L. Irrigation Performance Assessments for Corn Crop with Landsat Images in the São Paulo State, Brazil. **Proceedings…** II Inovagri International Meeting - 2014, [s. l.], n. I, p. 739–748, 2014. Available at: <http://www.bibliotekevirtual.org/index.php/2013-02-07-03-02-35/simposios/221-ii-inovagri-2014/1414-ii-inovagri-2014-a099.html>. Accessed on: June 2015.

TEIXEIRA, A.H.C.; HERNANDEZ, F. B. T.; SCHERER-WARREN, M. M., ANDRADE, R. G.; LEIVAS, J. F.; VICTORIA, D. C.; BOLFE, E. L.; THENKABAIL, P. S. AND FRANCO, R. A. M. Water productivity studies from earth observation data: Characterization, modeling, and mapping water use and water productivity. In: PRASAD, S. T. (Ed.). **Remote Sensing of Water Resources, Disasters, and Urban Studies**. 1st Ed. Boca Raton: CRC Group, Taylor and Francis, 2015.

WALDNER, F.; ABELLEYRA, D.; VERON, S. R.; ZHANG, M.; WU, B. F.; PLOTNIKOV, D.; BARTALEV, S.; LAVRENIUK, M.; SKAKUN, S.; KUSSUL, N.; LE MAIRE, G.; DUPUY, S.; JARVIS, I.; DEFOURNY, P. Towards a set of agrosystem-specific cropland mapping methods to address the global cropland diversity. **International Journal of Remote Sensing**., v. 37, p. 3196-3231, 2016. DOI: 10.1080/01431161.2016.1194545

WILM, H. G.; COSTELLO, D. F.; KLIPPLE, G. E. Estimating forage yield by the double-sampling method. **Journal of the American Society of Agronomy**, v.36, p.194–203, 1944.