Jul 13th, 10:50 AM - 11:10 AM

Plant trait-based assessment of the Pasture Simulation model

Anne-Isabelle Graux
PEGASE, Agrocampus Ouest, INRA

Katja Klumpp
UREP, INRA

Shaoxiu Ma
UREP, INRA, University of New South Wales, Climate Change Research Center

Raphaël Martin
UREP, INRA

Gianni Bellocchi
UREP, INRA, gianni.bellocchi@clermont.inra.fr

Graux, Anne-Isabelle; Klumpp, Katja; Ma, Shaoxiu; Martin, Raphaël; and Bellocchi, Gianni, "Plant trait-based assessment of the Pasture Simulation model" (2016). *International Congress on Environmental Modelling and Software*. 41.
https://scholarsarchive.byu.edu/iemssconference/2016/Stream-B/41

International Environmental Modelling and Software Society (iEMSs)
8th International Congress on Environmental Modelling and Software
Toulouse, France, Sabine Sauvage, José-Miguel Sánchez-Pérez, Andrea Rizzoli (Eds.)
http://www.iemss.org/society/index.php/iemss-2016-proceedings

Plant trait-based assessment of the Pasture Simulation model

Anne-Isabelle Graux[a], Katja Klumpp[b], Shaoxiu Ma[b,†], Raphaël Martin[b], Gianni Bellocchi[b]

[a] *PEGASE, Agrocampus Ouest, INRA, 35590 Saint-Gilles, France*
[b] *UREP, INRA, 63000 Clermont-Ferrand, France*
† *Currently at: University of New South Wales, Climate Change Research Center, Sydney, Australia*

Email address: gianni.bellocchi@clermont.inra.fr

Abstract: We used a functional trait-based plant classification to improve the plant module of the biogeochemical grassland model PaSim. Based on four main classes (A, B, C, D) and two derived types (b, d) covering a gradient from high to low productive/fertile grassland vegetation types, we derived new classes of model plant parameters representing an evolution of a previous parameterization obtained by calibration without considering any plant diversity. Illustrative results are presented for the French grassland site of Laqueuille, by comparing two grazing management treatments: high animal stocking rate and fertilisation “intensive” (type B) and low animal stocking rate “extensive” (type b). Model performances (reflected by root mean square error and coefficient of determination metrics) showed that accounting for plant traits may help predicting carbon-water fluxes (actual evapotranspiration, gross primary productivity, ecosystem respiration and net ecosystem exchange) and soil variables (temperature and water content). Whether the pattern of results (yet complex) generally supported the validity of the plant trait-based approach to derive model parameters, a substantiation is required by assessing model performances on a range of sites (as listed in the paper) covering a wide variety of conditions.

Keywords: Carbon and water fluxes; Grasslands; Plant traits; Pasture Simulation model; Soil variables

1. INTRODUCTION

Biodiversity experiments provided evidence of causal relationships between species number, ecosystem productivity and carbon sequestration (e.g. Tilman et al., 1997, 2006). Moreover, plant functional traits mediated by plant species composition are known to affect most key ecosystem properties, strongly depending on the relative contribution of a given species to the total plant biomass (Chapin, 2003). As such, plant traits and trait-based plant classifications provide a solid scientific basis for ecosystem service provision and management (Quétier et al., 2007). The concept of functional traits or plant functional diversity, providing a generic approach to characterize vegetation types, is attractive as a tool for inferring ecosystem processes (e.g. carbon cycling) by aggregated traits of dominant species (other than weather, soil and management factors). For that, Cruz et al. (2002) proposed a classification of perennial forage grasses (based on six functional characteristics) to discriminate among biomass production and fodder quality of species mixtures. They include plants' growth strategies (capture or conservation of resources) and phenology (early or late), which are rendered from morphological plant traits such as leaf dry matter content, specific leaf area, leaf lifespan, resistance to breakage and, for the whole plant, flowering date and maximum height. This functional composition of grasslands, based on four main types (A, B, C, D) and the identification of the dominant grass species, helps creating a classification of grasslands according to the dates of the peaks of growth and digestibility of leaves and stems. Types A and B (capture strategy species) dominate in fertile lands while the opposite is observed for types C and D (conservation strategy). Additional types have been defined by Cruz et al. (2010) to characterise late-flowering tall species in fertile (type b) or poor soils (type d). The functional diversity being correlated with species diversity (e.g. types of grasses, proportion of legumes), typologies of agricultural and environmental use can be created based on descriptors of the vegetation and the level of mineral nutrition, as well as on knowledge of farming practices and their effects (Duru et al., 2005, 2007, 2009, 2010, 2013). Upon this classification, modelling approaches (based on the knowledge of the system to diagnose) have been developed to parameterize alternative types of grasslands with the aim of predicting the dynamics of herbage biomass, structure and digestibility according to management practices and climate (Jouven et al., 2006a, b). Here, we have elaborated the concept of Cruz et al (2002) to better characterise the performances of the biogeochemical grassland model PaSim (Pasture Simulation model, https://www1.clermont.inra.fr/urep/modeles/pasim.htm), originally developed by Riedo et al. (1998), for analyses of nutrient and water cycles on managed grassland systems.

2. GRASSLAND DATASETS, PARAMETERIZATION AND SIMULATIONS

Twelve grassland sites with long-term eddy flux measurements are part of a wide research including evaluation of model performances. They cover a broad range of geographic and climatic conditions (Table 1) as well as a variety of soil types and management practices in Europe (Ma et al., 2015).

Table 1. Locations, climate and management of the study sites.

Site	Years	Geographical settings			Mean climate	
		Latitude	Longitude	Elevation (m a.s.l.)	Air temperature (°C)	Precipitation Total (mm yr^{-1})
Laqueuille, France	2004-2010	45° 38' N	02° 44' E	1040	7.8	1072
Grillenburg, Germany	2004-2008	50° 57' N	13° 30' E	375	8.5	946

Bugac Puszta, Hungary	2003-2008	46° 41’ N	19° 36 ’E	140	10.2	520
Dripsey, Ireland	2003-2005	51° 59’ N	08° 45’ W	195	9.6	1271
Amplero, Italy	2003-2007	41° 52’ N	13° 38’ E	884	9.4	781
Monte Bondone, Italy	2003-2007	46° 00’ N	11° 02’ E	1550	5.2	1003
Mitra, Portugal	2005-2007	38° 32’ N	08° 00’ W	190	14.3	627
Vall d’Alinya, Spain	2004-2008	42° 12’ N	01° 26’ W	1770	6.2	908
Oensingen, Switzerland	2002-2009	47° 17’ N	07° 44’ E	450	9.3	1197
Cabauw, The Netherlands	2004-2007	51° 57’ N	04° 54’ W	0.7	10	800
Easter Bush, United Kingdom	2002-2008	55° 52’ N	03° 02’ W	190	9.0	956

Values were attributed to a set of eco-physiological parameters in PaSim (Table 2) to characterize alternative functional types, compared to reference values as from multi-location calibration (without any plant diversity scheme) on datasets from grassland sites of Table 1.

Table 2. Summary of the PaSim parameters considered in this study.

Parameters	**Description**
Fractional C content of root structural dry matter (fcr), kg C kg^{-1} DM	These parameters multiply the root and shoot growth rates, respectively, to obtain the carbon substrate fractional variation.
Fractional C content of shoot structural dry matter (fcsh), kg C kg^{-1} DM	
Maximum plant N concentration (ntotmax), kg N kg^{-1} DM	It is the highest concentration of nitrogen in all plant tissues, which limits nitrogen absorption by plant.
Parameter of the fractional N content of new plant structural dry matter (fnref), kg N kg^{-1} DM	This parameter is used to derive the N concentration of newly produced structural dry matter.
Maximum specific leaf area (slamax), m^{2} kg^{-1}	This is the maximum value of specific leaf area, defined as the ratio of leaf area to dry weight.
Fraction of shoot growth partitioned to lamina at start of reproductive growth period (flam,a), -	These parameters represent fractions of shoot growth partitioned to the lamina during
Minimum fraction of shoot growth partitioned to lamina during vegetative growth period (flam,min), -	
Fraction of shoot growth partitioned to lamina during vegetative growth period (flam,veg), -	

	reproductive and vegetative growth periods.
Relative root dry matter in different soil layers (a), -	They calculate the proportion of roots at a given soil depth.
Parameter of the shape of the relative root dry matter distribution in different soil layers (b), -	
Maximum canopy height (hcanmax), m	It determines the canopy height to calculate the latent and sensible heat fluxes from the canopy and the soil surface.
Root turnover rate at 20 °C (kturnrt20), d^{-1}	They represent the leaf and root life-spans at a constant temperature, used to calculate the flow of plant residue.
Shoot turnover rate at 20 °C (kturnsh20), d^{-1}	
Light-saturated leaf photosynthetic rate for reproductive stage (pmrep20), $\mu mol\ m^{-2}\ s^{-1}$	They represent the influence of developmental stage (the end of ear emergence marking the transition from the reproductive to the vegetative stage) on the light-saturated leaf photosynthetic rate (defined at standard conditions of temperature, atmospheric CO_2 concentration and plant N concentration), which is a component of the rate of canopy photosynthesis.
Light-saturated leaf photosynthetic rate for vegetative stage (pmveg20), $\mu mol\ m^{-2}\ s^{-1}$	
Developmental stage at which ear emergence starts (devear), -	Developmental stage at which ear emergence starts

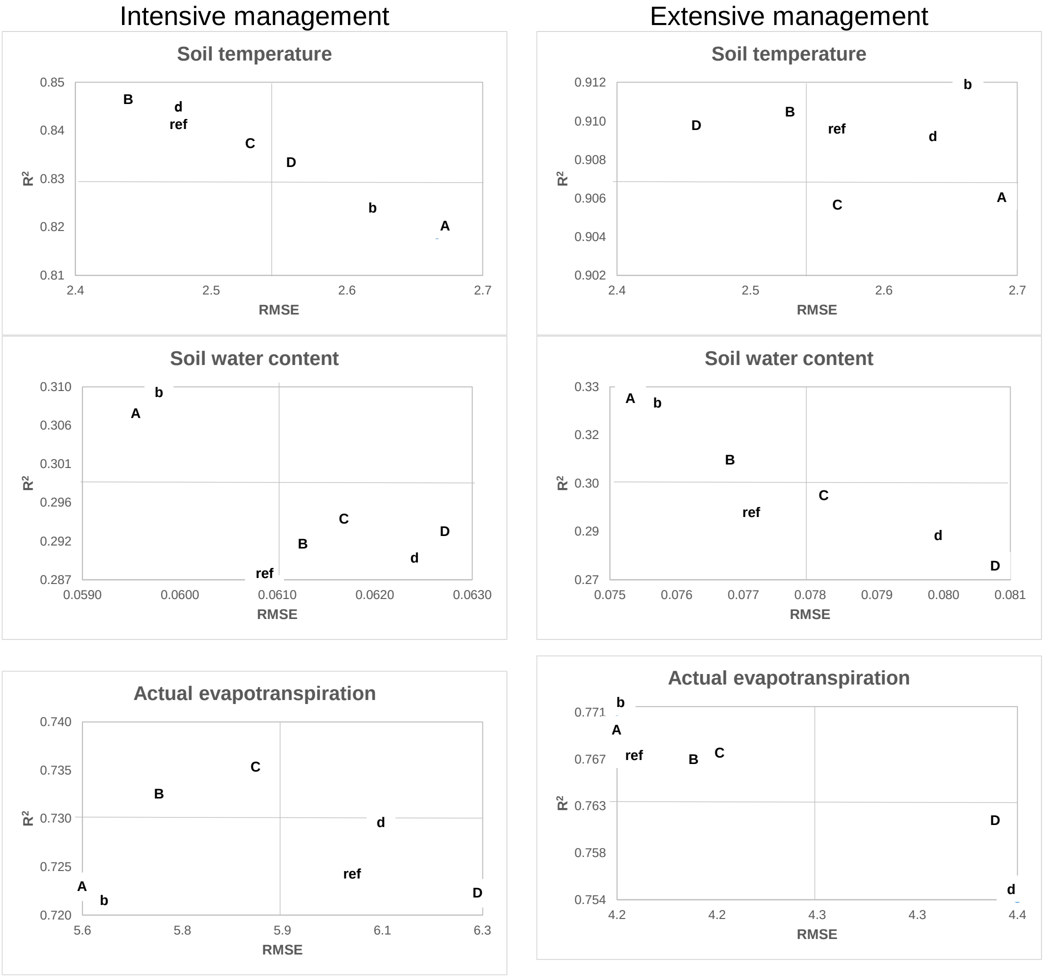
Weekly-aggregated model outputs, obtained with alternative parameter sets, including carbon fluxes (gross primary productivity, ecosystem respiration and net ecosystem exchange), a water flux (actual evapotranspiration) and two soil variables (temperature and water content at 0.1 m soil depth) were compared against observed values. Whether carbon cycle-related outputs can be considered as the most suitable for an inference from plant traits, other variables of large use were also assessed to check for any possible degradation of model performance. To assess the agreement between simulations and observations, the two most commonly used performance metrics of model evaluation (Richter et al., 2012) were calculated: root mean square error (best, $0 \leq RMSE < +\infty$, worst) and coefficient of determination (worst, $0 \leq R^2 \leq 1$, best).

3. ILLUSTRATIVE RESULTS

For illustrative purpose, we present the case of Laqueuille (France), where the grassland area was grazed by cattle and submitted to two treatments: intensive grazing (~1 LSU ha^{-1} yr^{-1} and 200 kg N ha^{-1} yr^{-1}) and extensive grazing (~0.5 LSU ha^{-1} yr^{-1}). Based on the diagnostic tool described by Hulin (2011), the two treatments were classified as approaching functional types B (intensive) and b (extensive). The best performing parameter sets are those located in the top-left (conversely in the bottom-right) area of R^2 versus RMSE plots (Figure 1).

In the case of intensive management, type B parameterization fell into the best-performing region with all outputs but one (soil water content). For soil temperature and actual evapotranspiration, in particular, type B parameterization performed better than the calibrated model with both metrics, while type B and reference parameterization performed equally well for gross primary productivity.

In the case of extensive management, b-type fell into the best-performing region in three out of six cases. It catches up the calibrated model for actual evapotranspiration and net ecosystem exchange or even distinctly outperforms it to simulate soil water content. With soil temperature and gross primary productivity, b-type parameterization is the best fit in terms of R^2.



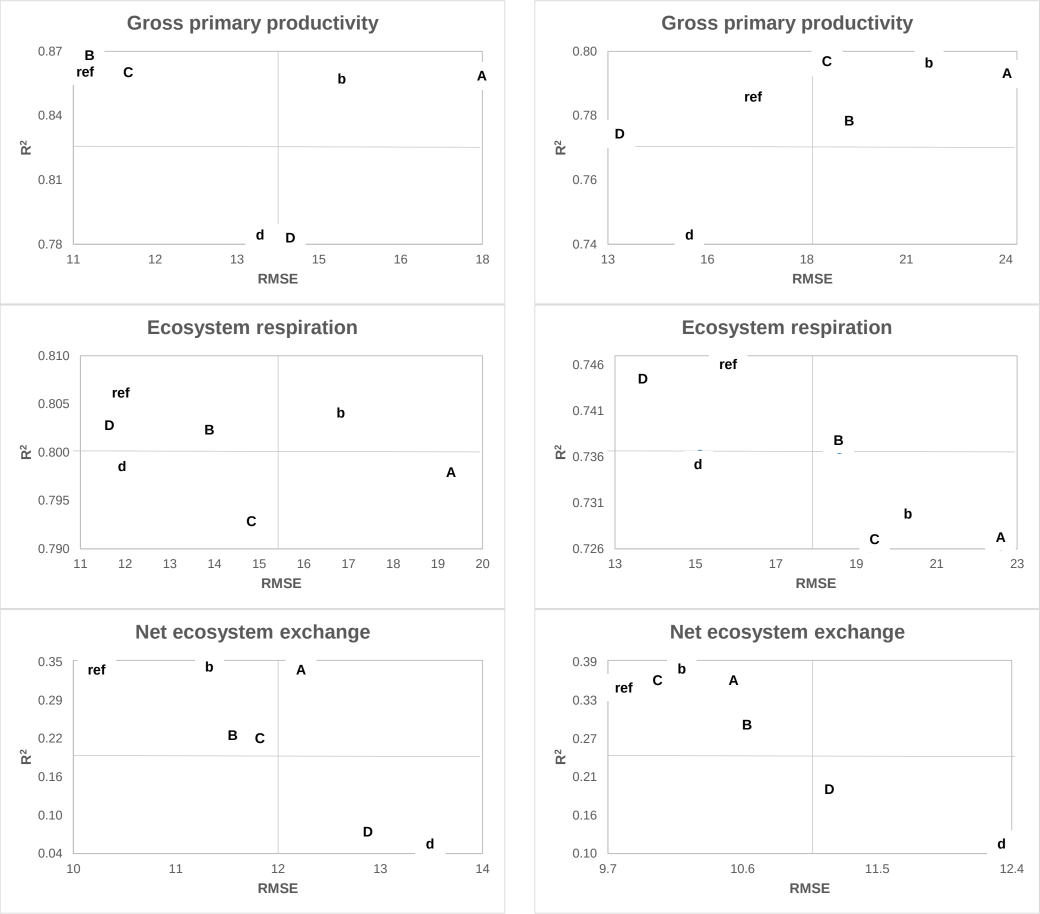


Figure 1. R^2 and RMSE of weekly values of PaSim outputs obtained with alternative sets of parameters (Table 2) at Laqueuille (France) for both intensive and extensive management.

4. CONCLUSION AND PERSPECTIVES

We pursued in this study the question of the importance of grassland functional diversity for the prediction of biogeochemical fluxes. Based on a recognised classification of grassland types, we derived a set of parameter values for the process-based model PaSim, which was evaluated for predictions of carbon-water fluxes and soil variables. At a selected grassland site in France, plant trait-based simulations showed that *a priori* parameter values may give results comparable, or in some cases better, than the calibrated model. These first results also showed that it is difficult to relate parameter values to functional grassland types. However, they highlight the importance of knowledge-based expectation in creating sets of parameter values without the need of calibration before simulations (which may not always be feasible, either on a site-specific or regional scale). Work is ongoing on multi-location datasets in Europe to substantiate the hypothesis that plant-trait based estimates for model parameters can be derived to encompass a wide range of conditions, provided that a sufficient amount of information is available at each site for a correct attribution of the functional composition of grasslands. An automated option is also being developed in PaSim to derive plant trait-based parameter values from environmental gradients (which are site-specific model inputs). This represents an advancement in operationally exploiting modelling capabilities for the assessment of management-related changes in grassland productivity, climate regulation (e.g. through carbon sequestration), biodiversity, and nutrient contents in the canopy related to forage quality.

ACKNOWLEDGEMENTS

Contribution to the MACSUR (http://www.macsur.eu) knowledge hub of the Joint Programming Initiative for Agriculture, Climate Change, and Food Security, funded through national bodies. We thank Partner Institutions for providing grassland data. We also acknowledge technical support from the European Fluxes Database Cluster (http://www.europe-fluxdata.eu).

REFERENCES

Chapin, F.S., 2003. Effects of plant traits on ecosystem and regional processes: a conceptual framework for predicting the consequences of global change. Ann. Bot.-London 91, 455-463.

Cruz, P., Duru, M., Therond, O., Theau, J.P., Ducourtieux, C., Jouany, C., Al Haj Khaled R., Ansquer, P., 2002. Une nouvelle approche pour caractériser les prairies naturelles et leur valeur d'usage. Fourrages 172, 335-354. (in French)

Cruz, P., Theau, J.P., Lecloux, E., Jouany, C., Duru, M., 2010. Typologie fonctionnelle de graminées fourragères pérennes : une classification multitraits. Fourrages, 201, 11-17. (in French)

Duru, M., Adam, M., Cruz, P., Martin, G., Ansquer, P., Ducourtieux, C., Jouany, C., Theau, J.P., Viegas, J., 2009. Modelling above-ground herbage mass for a wide range of grassland community types. Ecol. Model. 220, 209-225.

Duru, M., Cruz, P., Theau, J.P., 2010. A simplified method for characterising agronomic services provided by species-rich grasslands. Crop and Pasture Science 61, 420-433.

Duru, M., Cruz, P., Theau, J.-P., Jouany, C., Ansquer, P., Al Haj Khaled, R., Therond, O., 2007. Typologies de prairies riches en espèces en vue d'évaluer leur valeur d'usage : bases agro-écologiques et exemples d'application. Fouurages 192, 453-475. (in French)

Duru, M., Jouany, C., Le Roux, X., Navas, M.L., Cruz, P., 2013. From a conceptual framework to an operational approach for managing grassland functional diversity to obtain targeted ecosystem services: Case studies from French mountains. Renew. Agr. Food Syst. 29, 239-254.

Duru, M., Tallowin, J., Cruz, P., 2005. Functional diversity in low-input grassland farming systems: characterisation, effect and management. Agronomy Research 3, 125-138.

Hulin, S., 2011. Diagnostic prairial en zones fromagères AOP du Massif central – Outil 1 : Typologie multifonctionnelle des prairies. Pôle fromager AOP Massif central, Aurillac, France, 451 p. (in French)

Jouven, M., Carrère, P., Baumont, R., 2006a. Model predicting dynamics of biomass, structure and digestibility of herbage in managed permanent pastures. 1. Model description. Grass Forage Sci. 61, 112-124.

Jouven, M., Carrère, P., Baumont, R., 2006b. Model predicting dynamics of biomass, structure and digestibility of herbage in managed permanent pastures. 2. Model evaluation. Grass Forage Sci. 61, 125-133.

Ma, S., Lardy, R., Graux, A.-I., Ben Touhami, H., Klumpp, K., Martin, R., Bellocchi, G., 2015. Regional-scale analysis of carbon and water cycles on managed grassland systems. Environ. Modell. Softw. 72, 356-371.

Quétier, F., Lavorel, S., Thuiller, W., Davies, I., 2007. Plant-trait-based modeling assessment of ecosystem-service sensitivity to land-use change. Ecol. Appl. 17, 2377-2386.

Richter, K., Atzberger, C., Hank, T.B., Mauser, W., 2012. Derivation of biophysical variables from Earth observation data: validation and statistical measures. J. Appl. Remote Sens. 6, 063557.

Riedo, M., Grub, A., Rosset, M., Fuhrer, J., 1998. A pasture simulation model for dry matter production, and fluxes of carbon, nitrogen, water and energy. Ecol. Model. 105, 141-183.

Tilman, D., Knops, J., Wedin, D., Reich, P., Ritchie, M., Siemann, E., 1997. The influence of functional diversity and composition on ecosystem processes. Science 277, 1300-1302.

Tilman, D., Reich, P.B., Knops, J.M.H., 2006 Biodiversity and ecosystem stability in a decade-long grassland experiment. Nature 441, 629-632.