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Evaluation of the agricultural production systems simulator simulating Lucerne and annual ryegrass dry matter yield in the Argentine Pampas and south-eastern Australia

J.J. Ojeda [a,b,*], K.G. Pembleton [c,d], M.R. Islam [e], M.G. Agnusdei [f], S.C. Garcia [e]

[a] *Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Argentina*
[b] *Facultad de Ciencias Agropecuarias, Universidad Nacional de Entre Ríos, Ruta provincial 11, Km. 10.5 (3101), Oro Verde, Argentina*
[c] *Tasmanian Institute of Agriculture, University of Tasmania, Private Bag 3523, Burnie, TAS 7320, Australia*
[d] *Institute for Agriculture and the Environment, University of Southern Queensland, Toowoomba, 4350, QLD, Australia*
[e] *Dairy Science Group, Faculty of Veterinary Science, The University of Sydney, Camden 2570, NSW, Australia*
[f] *Instituto Nacional de Tecnología Agropecuaria (INTA), Estación Experimental Agropecuaria Balcarce, CC 276, 7620 Balcarce, Buenos Aires, Argentina*

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ABSTRACT

Modelling plant growth provides a tool for evaluating interactions between environment and management of forage crops for pasture-based livestock systems. Consequently, biophysical and farm systems models are becoming important tools for studying production systems that are based on forage crops. The Agricultural Production Systems Simulator (APSIM) is a model with the potential to compare the growth of annual forage crops and perennial pastures. However, information is limited about how accurately the *Lucerne* and *Weed* modules represent the growth and development of forage crops and pastures under different managements, soil types and environments in South America. This study evaluated the capacity of APSIM to simulate the growth rates and predict the dry matter (DM) yield of Lucerne (*Medicago sativa* L.) and annual ryegrass (*Lolium multiflorum* Lam.) in contrasting climatic regions of Argentina. In addition, at several Australian locations, DM yields of both crops were simulated to ensure that possible changes to the model not interfere with the robust APSIM performance that was already shown in south-eastern Australia. Initial simulations for Lucerne and ryegrass were made with original *Lucerne* and *Weed* modules of APSIM, respectively. Simulated DM yield was then compared with field data collected from the same crops grown in five locations in the Argentine Pampas and seven locations in south-eastern Australia over 5 of years. APSIM predicted DM yield of Lucerne at each harvest with reasonable accuracy [0.59, 0.77 and 0.77 for R^2, correlation coefficient and concordance correlation coefficient (CCC), respectively]. However, these statistics improved when the DM yield was analysed by annual accumulation, with values of 0.87, 0.93 and 0.92 for R^2, correlation coefficient and CCC, respectively. APSIM, generally, over-predicted DM yield of annual ryegrass at the first harvest. Nonetheless, when the *Weed* module was modified through changes in phenology and transpiration efficiency, performance improved (values of 0.89, 0.94 and 0.93 for R^2, correlation coefficient and CCC, respectively). This study showed that annual DM yield of Lucerne can be successfully modelled by the APSIM *Lucerne* module without any modifications, using a crop modelling approach. However, successfully modelling of Lucerne DM yield by harvest will require further development of the model. Moreover, modification of model parameters associated with phenology and transpiration was required to enable the *Weed* module of APSIM simulate growth and yield of annual ryegrass in a range of geographic locations within the Argentine Pampas.

1. Introduction

Over the last decade, the Argentine Pampas have experienced a process of agricultural expansion that has recently been accompanied by a demand for enhancing livestock for meat and milk. A greater demand for animal products, together with the increased pressure for land by grain crops, has resulted in an intensification of animal production systems in this region, including a shift towards annual forage crops (i.e. annual ryegrass, *Lolium multiflorum* L.) at the expense of perennial forages (e.g. Lucerne, *Medicago sativa*, also known as alfalfa).

Biophysical simulation models can be used as cost effective tool for the evaluation of yield capacity of a range of forage species, across the broad range of environments that make up the Argentine Pampas. Biophysical models incorporate climate, soil, crop and management interactions to

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* Corresponding author at: Facultad de Ciencias Agropecuarias, Universidad Nacional de Entre Ríos, Ruta provincial 11 Km, 10.5, Oro Verde, CP 3101, Provincia de Entre Ríos, Argentina.
E-mail addresses: ojeda.jonathan@conicet.gov.ar (J.J. Ojeda), Keith.Pembleton@usq.edu.au (K.G. Pembleton), rafiqmintu@yahoo.com (M.R. Islam), agnusdei.monica@inta.gob.ar (M.G. Agnusdei), sergio.garcia@sydney.edu.au (S.C. Garcia).

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simulate plant growth and yield processes and are becoming an accepted tool in the evaluation of pasture-based livestock production systems (Chapman et al., 2008; Cullen et al., 2009; Rawnsley et al., 2009). The agricultural production systems simulator (APSIM) framework (Keating et al., 2003) is a biophysical model with potential to simulate growth of annual forage crops and perennial pastures. However, previous studies concerning APSIM accuracy as a predictor of dry matter (DM) yield in Lucerne (Robertson et al., 2002; Dolling et al., 2005; Pembleton et al., 2011) and annual ryegrass (Deen et al., 2003; Pembleton et al., 2013) have been largely restricted to southern and Western Australia, with the exception of Chen et al. (2008) and Moot et al. (2015) who reported data from central China ?thyc=5?> and New Zealand, respectively. Although some similarities in seasonal rainfall patterns and forage cropping systems exist between Southern Australia and the Argentine Pampas, the seasonal temperatures and soil types are markedly different. Consequently, differences in the models capacity to predict DM yield between these environments is expected. As the accurate simulation of plant growth relies on an adequate description of soil hydraulic properties (Smeal et al., 1991), the model requires a thorough evaluation by region of how water and other environmental factors, such as solar radiation, interact to affect plant growth and DM yield (Smeal et al., 1991), before it can be relied on to predict growth patterns and yields of different crops.

APSIM estimates above ground growth from two calculations per day, one limited by radiant energy and the other limited by water available for transpiration (Robertson et al., 2002). The lesser of these two values gives the biomass production for the day. Radiation limits on daily aboveground biomass production are related to leaf area index, the fractions of light intercepted by the plant, radiation received and the crop's efficiency of conversion of radiation into biomass (or radiation use efficiency, RUE) (Dolling et al., 2005). Water limitations on the daily biomass production depend on soil water supply in the root zone and on the efficiency of conversion of water into biomass (or transpiration efficiency, TE), based on a transpiration efficiency coefficient (Kc) (Dolling et al., 2005). When the RUE and intercept of radiation are not limiting, the crop DM yield modelled by APSIM will depend only on soil water supply (SWS) and TE, which is the ratio of biomass produced per unit of water transpired by a crop. Transpiration efficiency is derived from the vapour pressure deficit, estimated from mean daily temperatures (Tanner and Sinclair, 1983), and a Kc that is held constant in the model. Therefore, the climate of the location where the crops are being grown has a direct influence on TE. Variations in this parameter were found in different seasons for maize, sorghum, potato, Lucerne and soybean (Tanner and Sinclair, 1983). Similarly, Kemanian et al. (2005) found TE variations in the order of 250% for barley and wheat in North America, the UK and Australia. Variations in SWS depend on the soil water balance between offer (rainfall), demand (evapotranspiration) and initial water supply at crop sowing (Sinclair et al., 1992, 2007; Caviglia et al., 2004). Also, SWS can change depending on the soils and crops types, as was studied by Meinke et al. (1993) for sunflower in five soil types and by Dardanelli et al. (2004) for several species including cotton, maize, pearl millet, grain sorghum, soybean, wheat and sunflower in thirteen types of soils. Therefore, an analysis of parameters that define the prediction capacity of DM yield in APSIM is needed in order to understand the variations that may occur when comparing forage growth rates or yields in different environments.

Before APSIM can be adopted as a possible predictor of forage production of Lucerne and annual ryegrass in the Argentine Pampas, an evaluation of its accuracy under each environment is needed. Hence, we used experimental field data collected in several locations of Argentina to evaluate the ability of APSIM to simulate the growth patterns of Lucerne and ryegrass, and to predict DM yields in this region. In addition, Lucerne and annual ryegrass DM yields at several Australian locations were simulated to ensure that possible changes into the model not ruin the well APSIM performance that was already shown in these environments.

2. Materials and methods

2.1. Experimental locations

2.1.1. Argentine Pampas

The Argentine Pampas are situated between 28 and 40°S and 68 and 57°W (Caviglia and Andrade, 2010); they occupy a vast area of ca. 52 million ha of land, suitable for agricultural and livestock production (Hall et al., 1992). The Pampas have a warm temperate climate. Mean annual rainfall increases from 400 mm in the SW to more than 1200 mm in the NE, whereas the rainfall regime shifts from monsoonal in the NW to more evenly distributed in the SE (Hall et al., 1992). The north and south potential evapotranspiration values are between 850 and 750 mm yr.^{-1}, respectively. Mean annual temperature increases from around 13.5 in the south to 18.5 °C in the north of the region (Hall et al., 1992). Soils of the Argentine Pampas belong, predominantly, to the order of Mollisols, being Argiudols and Haplustols the most representative great groups of soils (INTA-SAGyP, 1990).

Data relating to forage crop DM yield were collected from five locations of the Argentine Pampas: Rafaela, Pergamino, General Villegas, Trenque Lauquen and Balcarce (Fig. 1a). Experimental sites were within research stations of the National Institute of Agriculture Technology (INTA). The location, climate and soil characteristics of each site are provided in Table 1. This information was used in the APSIM calibration. Daily meteorological data (maximum and minimum air temperatures, rainfall and incident radiation) for each location were sourced from the corresponding meteorological station of each INTA research station. Any missing data of maximum and minimum temperatures and/or incident radiation were sourced from an international meteorological database (http://power.larc.nasa.gov/cgi-bin/cgiwrap/solar/agro.cgi?email=agroclim@larc.nasa.gov).

2.1.2. South-eastern Australia

Three locations in Victoria, Terang, Flynn and Yarram and four locations in Tasmania, Elliot, Cambridge, Cranbrook and Forth were used as experimental locations. A summary of these data from each location is given in Table 1. Daily meteorological data (maximum and minimum temperatures, rainfall, solar radiation) at Terang, Flynn and Yarram were sourced from the SILO meteorological database (www.longpaddock.qld.gov.au/silo) as patched point datasets (Jeffrey et al., 2001). Climate data from Elliot and Forth were collected from weather stations of the Australian Bureau of Meteorology, at the locations. Climate data for Cranbrook were generated as a patched-point dataset (Jeffrey et al., 2001). Meteorological data at Cambridge were collected at 10 minute intervals with a HOBO weather station and data logger (Onset Computer Corporation, Bourne, MA, USA). In consultation with agronomists and scientists working in each location, soil parameters as drained upper limit (DUL) and the lower limit (LL), used to calculate the maximum plant-available water capacity (PAWC) were chosen from the available Tasmanian and Victorian soils in APSIM, that best reflected the soil types at each location (Table 1). Initial soil water values were set, based on observations made in the field (Table 2). The Australian soil information provided by agronomists/scientists was, initially, classified by Isbell (2002). This nomenclature was converted to that of Soil Survey Staff (2010) of the United States Department of Agriculture, as noted by Morand (2013).

2.2. Climatic and soil conditions

Data used for testing the model were from experiments conducted under rainfed and irrigated conditions in the Argentine Pampas and south-eastern Australia. Long-term mean maximum air temperature ranged from 13.6 to 24.6 °C and the mean minimum air temperature between 3.9 to 12.1 °C (Table 1). The mean annual rainfall varied from 500 to 1200 mm for Cambridge and Elliot, respectively. Similarly, the plant