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Forage yield, water- and solar radiation-productivities of perennial pastures and annual crops sequences in the south-eastern Pampas of Argentina

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A B S T R A C T

Livestock production systems of Argentina show an ongoing process of change in the composition of their forage base, with a gradual increase in the proportion of their area assigned to forage crop sequences (FCS) −in particular that involving successive winter and summer annual forage crops–, at the expense of the area assigned to perennial pastures (PP). However, there are several concerns regarding the efficient use of available environmental resources due to differences in the extent of the establishment periods and due to the occurrence of fallow periods in FCS, as well as regarding the species involved in these systems. Therefore, the main objective of this study was to evaluate the water (WP) and solar radiation productivity (RP) of PP [pure stands of alfalfa (*Medicago sativa* L.), fertilized and unfertilized stands of tall fescue (*Festuca arundinacea* Schreb.), and fertilized and unfertilized mixed stands of alfalfa/tall fescue] and FCS [including a summer alternative and oats (*Avena sativa* L.); the summer alternative was either maize (*Zea mays* L.) or intercropped maize/soybean (*Glycine max* L.)] through the analysis of their components, *i.e.* water (WC) and radiation capture (RC), and their water (WUE) and radiation use efficiency (RUE). Resource capture (WC and RC) was defined as the ratio between captured (evapotranspiration and intercepted solar radiation) and annual available resource (rainfall and incident solar radiation). Resource use efficiency (WUE and RUE) was computed as the dry matter (DM) yield per unit of captured resource. A field experiment was conducted during two consecutive years under rainfed conditions and under non-limiting nitrogen availability in the south-eastern Pampas of Argentina. Perennial pastures were evaluated during both their initial establishment year (Y1) and when already fully established (Y2). Annual-based forage DM yield ranged between 13.0 and 32.4 Mg ha^{-1} in Y1 and between 5.1 and 23.5 Mg ha^{-1} in Y2. Differences in resource capture between PP and FCS were directly associated with the crop establishment and fallow periods depending on the nature of the considered resource. The highest WP (2.75–3.64 g DM m^{-2} mm^{-1}) and RP (0.93–1.42 g DM MJ^{-1}) were reached by FCS, which did not differ ($P > 0.05$) from that of fully established fertilized PP. Our results demonstrate that resource productivity in FCS is not necessarily higher than for PP, once PP are fully established.

1. Introduction

Increasing world population and predicted increments in mean income per capita in developing and transition countries will steadily increase the demand for meat and milk in the coming years (Bouwman et al., 2005). This leads to a growing demand for animal feed and, consequently, a critical need to increase the forage supply in livestock systems.

The agricultural expansion recorded in Argentina in the last decades, driven mainly by the dramatic increase in soybean cropped area (Caviglia and Andrade, 2010), has been accompanied by a gradual relocation of cattle stock on marginal environments (Manuel-Navarrete

Abbreviations: A, alfalfa; AF, unfertilized alfalfa/tall fescue mixture; AF+, fertilized alfalfa/tall fescue mixture; AW, soil available water; °Cd, growing degree days; DM, dry matter; ER, Effective rainfall; ET, evapotranspiration; ET_0, reference evapotranspiration; ET_c, maximum or potential evapotranspiration; F, unfertilized tall fescue; F+, fertilized tall fescue; FCS, forage crop sequence; IPAR, intercepted photosynthetically active solar radiation; M, maize; MO, maize oats; MS, intercrop maize/soybean; MSO, intercrop maize/soybean-oats; O, oats; PAR, photosynthetically active solar radiation; PP, perennial pasture; RC, radiation capture efficiency; RP, solar radiation productivity; RUE, radiation use efficiency; S, soybean; T_{max}, maximum air temperature; T_{min}, minimum air temperature; WC, water capture efficiency; WP, water productivity; WUE, water use efficiency; Y1, year 1; Y2, year 2

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et al., 2009; Viglizzo et al., 2011; García et al., 2018). Besides, the land area allocated to forage crops has decreased significantly in the region. However, the decrease in area of perennial pastures was as much as twice that of annual forage crops (INDEC, 1988; FAOSTAT, 2016). As a result, forage systems mainly based on the use of double crops including summer crops for silage and winter grazing crops are increasingly recurrent (Arzadun et al., 2003; Abdelhadi et al., 2004; Arelovich et al., 2011). In addition, the growing need to increase livestock feed-base in Argentina is often aggravated by suboptimal forage production levels, which can be attributed to factors such as low nitrogen (N) fertilization rates and inappropriate defoliation management (Agnusdei et al., 2010).

Therefore, to meet the increasing demand, future needs should be addressed mainly through an increase of the animal feed production on current or even less cultivated land area (Evans, 1993), which would require to increase the use efficiency of available environmental resources, such as water and solar radiation. In this sense, there is a strong consensus for the need to develop crop technologies under the framework of modern eco-efficiency criteria (Keating et al., 2010) based on maximizing resource productivity, *e.g.* production of grain or total biomass, per unit of available environmental resource (Caviglia et al., 2004). Previous studies have used this approach in grain production systems, seeking an increase in resource productivity with minimal environmental impact in several regions of the Argentinian Pampas (Caviglia et al., 2004; Van Opstal et al., 2011, Andrade et al., 2015). Also, several studies evaluated the DM yield of forage crop sequences (FCS) and perennial pastures (PP) in Argentina (Ojeda et al., 2018), Uruguay (Berretta et al., 2000), Brazil (dos Santos et al., 2011; Carvalho et al., 2014), Italy (Grignani et al., 2007), Spain (Perramon et al., 2016), United States (Sulc and Tracy, 2007), New Zealand (De Ruiter et al., 2009; Rawnsley et al., 2013) and Australia (Mason et al., 1987; Chapman et al., 2006; Garcia et al., 2006, 2008; Fariña et al., 2011, 2013; Islam and Garcia, 2012; Rawnsley et al., 2013). However, the resource productivity for FCS and PP has been scarcely evaluated (Ojeda et al., 2018) in livestock production systems.

The resource productivity approach uses an analysis that mechanistically accounts for the contribution of two components. In fact, resource productivity can be estimated as the product between resource capture and resource use efficiency (Caviglia et al., 2004), allowing to discriminate the contribution of each component to the forage cropping system's ability to convert available resource in biomass.

Thus, water productivity (WP) can be defined as the dry matter (DM) yield produced per unit of annual water supply, *i.e.* rainfall + irrigation (not including soil water depletion). This WP can be calculated as:

$$WP = WC * WUE \tag{1}$$

where WC is water capture efficiency calculated as the ratio between crop evapotranspiration (ET) and water supply, and WUE is water use efficiency calculated as the DM produced per unit of ET.

Analogously, the solar radiation productivity (RP), i.e. DM produced per unit of annual incident solar radiation, can be calculated as:

$$RP = RC * RUE \tag{2}$$

where RC is radiation capture efficiency calculated as the ratio between the intercepted photosynthetically active solar radiation (IPAR) and the annual incident solar radiation, and RUE is radiation use efficiency calculated as the DM produced per unit of IPAR.

Current Argentinian forage systems are increasingly based on annual crops (*e.g.* double-crops) which often have high resource use efficiencies, due to the inclusion of highly efficient species like maize (*Zea mays* L.) or sorghum (*Sorghum bicolor* [L.] Moench). However, these systems must go through, at least, two annual establishment periods, *i.e.* period between sowing to critical canopy cover, in which resource capture is limited. Therefore, livestock systems based on FCS are highly dependent on climate variability, which makes them sensitive in the face of adverse climatic conditions (Shiferaw et al., 2011). On the other hand, PP [*e.g.* alfalfa (*Medicago sativa* L.) and tall fescue (*Festuca arundinacea* Schreb.)] are often able to improve productivity under climatic constraints, given their higher capacity to capture water and solar radiation compared to annual crops (Travis and Reed, 1983; Heichel et al., 1988; Nosetto et al., 2015) due to their perennial growth habit (Fulkerson et al., 2003). Thus, a key question arises on whether the inclusion of FCS would be a mandatory requirement to maximize the resource productivity of forage-based livestock systems.

The aim of our study was to assess the water- and solar radiation-productivities and their components for FCS, pure and mixed PP under optimal and sub-optimal N conditions in the south-eastern Pampas region of Argentina. This study provides a valuable contribution for a deeper understanding of resource productivity during two different periods of the pasture cycle, *i.e.* the establishment and fully established periods. A realistic comparison between PP and FCS should necessarily include the inherent inefficiency to capture the available resources of the establishment periods in both systems as well as a period of fully established PP.

2. Materials and methods

2.1. Site and soil conditions

A field experiment was conducted at the Instituto Nacional de Tecnología Agropecuaria (INTA) Research Station located at Balcarce, Argentina (37.5° S, 58.3° W, 130 m above sea level) from 2012 to 2014 (Fig. 1) in rainfed conditions and under optimum agronomic management (pest and disease control). The experiment was carried-out on a fine, illitic, thermal and mixed (Soil Survey Staff, 2010) Balcarce Series Petrocalcic Argiudol (petrocalcic horizon at ~1 m) (Klingebiel and Montgomery, 1961) with 332 g sand kg^{-1}, 407 g silt kg^{-1} and 261 g clay kg^{-1} in the A_p horizon (0–0.23 m soil depth) and 2% of slope gradient (scarce and/or null erosion, Studdert, 2006).

Results of tests performed at the beginning of the experiment for topsoil (0.23 m depth) showed a pH of 6.2 (1:2.5 soil/water), 30 mg kg^{-1}C content (Nelson and Sommers, 1982), 61.5 mg available P kg^{-1} (Bray I) and 0.2% total N (Bremner and Mulvaney, 1982). Soil sulfur availability in the area is plenty due to organic matter (OM) mineralization (Andrade and Sadras, 2002), resulting in the lack of yield response to fertilizer addition in grain annual crops (García et al., 1998; Echeverría and García, 2005) and in temperate grass pastures (Marino, A., personal communication). Soil potassium (K) availability was above the sufficiency level (2.3 mEq K 100 g^{-1}).

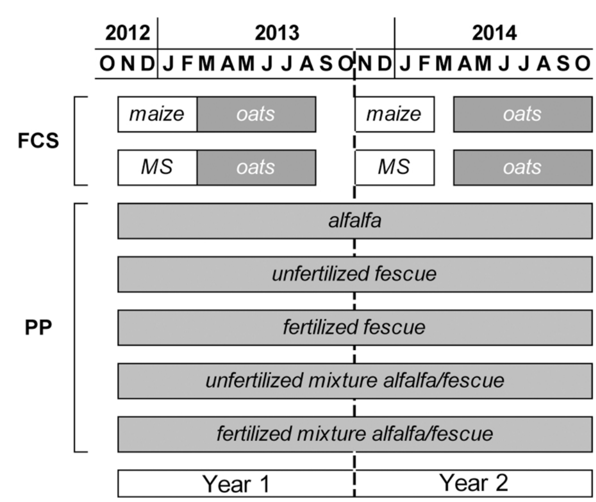

Fig. 1. Schematic representation of the treatments, forage crop sequences (FCS) and perennial pastures (PP), during the experimental period (Year 1 and Year 2). MS, intercrop maize/soybean. The dashed black line represents the separation between years.