Forage biomass, soil cover, stability and competition in perennial grass–legume pastures with different Paspalum species

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Abstract

The short life span, irregular forage production and susceptibility to weed colonization of cool-season grass–legume pastures are serious problems in grazing dairy systems in warm-temperate regions. The inclusion of warm-season species has the potential to mitigate these problems. In this study, we evaluated the effect of the inclusion of two warm-season grasses with different growth habits on seasonal forage biomass, soil cover and weed colonization. Three different pasture mixtures were evaluated under grazing: conventional pasture (CP) [tall fescue (Festuca arundinacea), white clover (Trifolium repens) and birdsfoot trefoil (Lotus corniculatus)], CP with Paspalum dilatatum and CP with Paspalum notatum (CP + Pn). Forage biomass and soil cover were sampled thirteen times during a 3-year trial, and sampling times were grouped by season for the analyses. The mixtures with Paspalum showed higher soil cover in the autumn, while in the winter CP had higher soil cover than CP + Pn. Competition with tall fescue was similar between mixtures with Paspalum, when considering biomass, but it was higher in CP + Pn when considering soil cover. The inclusion of P. notatum increased biomass during the autumn but decreased the mixture performance during winter by reducing tall fescue soil cover. The addition of a warm-season grass species with a moderate competing ability like P. dilatatum is likely to avoid a negative impact on the cool-season component of the pasture.

Keywords: Warm-season grass, pasture persistence, growth habit, functional diversity, Species coexistence

Introduction

In temperate and warm-temperate regions, cool-season grass–legume pastures are the basis of beef and dairy grazing production systems (e.g. North America, Europe, New Zealand, Argentina and Uruguay). One of the main limitations of these perennial pastures to achieve their potential longevity and productivity in these regions is their poor ability to survive or remain productive during the summer. The temperate origin of most of the sown species makes them susceptible to high temperatures and low water availability which is considered one of the main causes of their poor performance (Dear and Ewing, 2008). This reduces summer yield, increases differences in forage yield between seasons and enhances the probability of colonization by weeds. In fact, the productivity of perennial pastures in Uruguay and Argentina is very irregular, with periods of shortage and excess, and the life span of most pasture swards seldom exceeds 3–4 years; beyond this period, pastures become severely invaded by weeds and their forage yield decreases (Formoso, 2007). The forage shortage during the summer is exacerbated by overgrazing in the autumn when the availability of grazing land decreases, as old pastures are ending their productive life span and new pastures are being sown (Formoso, 2011). The high proportion of land sown every year is in turn a consequence of the short life span of perennial mixtures.

A potential solution for this problem is the inclusion of warm-season grasses in the pasture. When species richness is low, as in sown pastures, ecosystem function can be increased by adding new species in soils with medium-to-high fertility (Picasso et al.,...
mental plots, it has been shown that sent in the mixture (Bennett, 1941). In small experi-
ground which can be used by the other species pre-
seed recruitment, it is expected to leave available
produce throughout the year. In the Campos and Pampas
region of South America where winter frosts are
frequent, the tropical grasses widely grown worldwide
are not well adapted. For this reason, several native
Paspalum species with different degrees of domestica-
tion have long been proposed as warm-season forage
crops, although adoption by farmers has been low
(Pizarro, 2000).

Paspalum dilatatum Poir. (dallisgrass) and P. notatum
Flügge (bahiagrass) are C4 grasses, native to South
America and widely known for their high forage yield
and adaptation to grazing (Pizarro, 2000). One of the
main differences among these two species is their
growth habit, determined by the direction of the
newly developed tillers. In P. notatum, new tillers are
plagiotropous, with new axes substituting the main
ones as they turn up to flower, while the tillers of
P. dilatatum show a strong tendency to orthotrophy,
growing more or less vertically without axis substitu-
tion (Rua and Weberling, 1998). This leads to very
contrasting growth habits: P. dilatatum is cespitose and
P. notatum is rhizomatous. These species also differ in
seed recruitment. P. dilatatum has low germination
and seedling establishment (Laterra et al., 1997)
although germination and other reproductive features
differ among genotypes (Glison et al., 2015; González
Barrios et al., 2016). In contrast, P. notatum (cv.
Pensacola) has usually high germination rates and
seedling recruitment (Hodgson, 1949). These differ-
ences may lead to different interactions with other
species when sown in a mixture. Due to the above-
ground bunchy habit of P. dilatatum, and its lower
seed recruitment, it is expected to leave available
ground which can be used by the other species pre-

Materials and methods

Pasture treatments, management and measurements

The study was conducted at the Centro Regional Sur
Experimental Station of the Facultad de Agronomía,
Universidad de la República, in Canelones, Uruguay
(34°36’S 56°13’W). The trial was laid out as a com-
plete randomized block design with three replicates
and three treatments consisting of different pasture mixtures: a conventional pasture mixture (CP) [tall fescue (F. arundinacea Schreb. syn. Lolium arundinaceum (Schreb.) Darbysh.), white clover (Trifolium repens) and birdfoot trefoil (Lotus corniculatus)], CP with Paspalum dilatatum (CP + Pd) and CP with Paspalum notatum (CP + Pn). The experiment was located on a mild slope, and the area of each individual plot was 0.96 ha. The dominant soils at the experimental site are classified as Typical Vertisols (Altamirano et al., 1976). Chemical analysis prior to the experiment showed pH values of 5.9 ± 0.6, and nitrogen and phosphorus contents of 10.3 ± 2.3 and 11.1 ± 2.3 μg g⁻¹, respectively.

The experimental site had been previously planted to Avena sativa. Glyphosate [N-(phosphonomethyl)glycine] was sprayed three times before planting the pasture seed mixtures, each time with 360 g L⁻¹ of active ingredient (equivalent to 4.0 L ha⁻¹ of the commercial formulation) to eradicate volunteer oats and weeds. Frequent weeds were warm-season grasses such as Echinocloa crus-galli and Digitaria sanguinalis. Warm-season grasses were sown on 11 December 2009; seed density was 19.5 kg ha⁻¹ for P. dilatatum (Australian commercial seed) and 15 kg ha⁻¹ for P. notatum (cv. Pensacola). At this time, plots were fertilized (100 kg ha⁻¹, 7–40–0, N:P₂O₅:K₂O). The achieved density of Paspalum plants three months after sowing was 8 plants m⁻² for P. dilatatum and 114 plants m⁻² for P. notatum. The cool-season grass and the legumes were sown on 10 April 2010 at a distance between seedlines of 0.17 m; seed density was 10 kg ha⁻¹ for tall fescue (cv. Quantum), 1.5 kg ha⁻¹ for white clover (cv. Zapicán) and 12 kg ha⁻¹ for birdsfoot trefoil (cv. INIA Draco). At this time, all plots were fertilized again at the same initial dose. Initial seedling density of tall fescue was similar among different treatments (P = 0.157): 3 months after sowing, CP had 120 plants m⁻², CP + Pd had 133 plants m⁻² and CP + Pn had 101 plants m⁻². Legume seedling density was also similar among treatments (P = 0.152): CP had 160 plants m⁻², CP + Pd had 166 plants m⁻² and CP + Pn had 132 plants m⁻². Overall density of sown species was similar among treatments as well (P = 0.382): CP had 280 plants m⁻², CP + Pd had 307 plants m⁻² and CP + Pn had 347 plants m⁻².

Throughout the experimental period, dairy cattle started grazing when sward height was 0.20 m and were removed when sward height was around 0.10 m. This management resulted in 5–6 grazing periods per year. Before grazing, available forage biomass and soil cover were measured in each plot. Plots were sampled 13 times during the experimental period. Sampling times were as follows: November 2010; January, March, May and November 2011; January, March, May, August, October and November 2012; and January and February 2013. Sampling times were nested into seasons using the following criterion: summer was from December to February, autumn from March to May, winter from June to August and spring from September to November. Biomass was sampled by clipping 15 × 0.1-m² quadrats per plot. Samples were then sorted by species in the laboratory, dried at 60°C for 48 h and weighed. Total pasture biomass was calculated as the sum of the individual biomass of the sown species. The soil cover of each species was visually estimated by sampling 45 × 0.1-m² quadrats per plot. Unattached plant parts and litter were not considered as plant cover, and they were included in the bare ground category; total soil cover for each plot was calculated as the sum of the values for each sown species.

Average seasonal temperature, precipitation and frost events were calculated by averaging over monthly records from the Uruguayan National Agricultural Research Institute (INIA) Agro-climatology Service (GRAS; http://www.inia.uy/investigacion-e-innovacion/unidades/GRAS/Clima/Banco-datos-agroclimatico) from the nearest location at INIA Las Brujas (Table 1). The average seasonal temperatures were similar to historical averages throughout the experimental period for all seasons. The first year (2010–2011) was very dry, except for the winter. The second year (2011–2012) was also dry.

| Table 1 | Average seasonal temperature (°C), monthly precipitation (mm month⁻¹) and meteorological frost events (per month) for the experimental period and historical record. Spring averaged September to November, summer averaged December to February, autumn averaged March to May, and winter averaged June to August. |
|---------|-------------|-------------|-------------|-------------|
| Temperature (°C) | Spring | Summer | Autumn | Winter |
| 2010–2011 | 16 | 23 | 17 | 10 |
| 2011–2012 | 16 | 22 | 17 | 10 |
| 2012–2013 | 17 | 22 | 17 | – |
| Historical (1970–2013) | 16 | 22 | 17 | 11 |
| Precipitation (mm) | Spring | Summer | Autumn | Winter |
| 2010–2011 | 36 | 39 | 58 | 127 |
| 2011–2012 | 78 | 82 | 84 | 123 |
| 2012–2013 | 132 | 136 | 114 | – |
| Historical (1970–2013) | 97 | 93 | 98 | 83 |
| Frost events | Spring | Summer | Autumn | Winter |
| 2010–2011 | 0 | 0 | 0 | 6 |
| 2011–2012 | 1 | 0 | 0 | 12 |
| 2012–2013 | 0 | 0 | 0 | – |
| Historical (1970–2013) | 0 | 0 | 0 | 1 |
although seasonal averages were closer to the historical average. During the third year (2012–2013), all seasonal precipitation records were above the historical average. Frost events were very frequent during the winters of the experimental period.

**Competition and stability over time**

A competition index was used to measure the effects of *Paspalum* species on tall fescue, calculated as the ratio between the performance of tall fescue (either soil cover or biomass) in CP + Pd or CP + Pn relative to the performance of tall fescue in CP. Index values equal to one mean that the performance of tall fescue was not affected by the presence of the warm-season grass, whereas index values lower or higher than one mean that the warm-season grass in the mixture had either detrimental or beneficial effects, respectively, on the performance of tall fescue.

Forage stability over time was calculated using the stability index (S) developed by Tilman (1999), and Lehman and Tilman (2000), defined as the mean divided by the standard deviation of a variable (\(S = \mu / \sigma\)), where higher values indicate higher stability. The index was estimated for the total biomass and total soil cover of the sown species in each treatment. Calculations were made by considering individual sampling times to compare the temporal stability of the pasture throughout the whole period and also over data pooled by season to compare the seasonal stability of each mixture.

**Statistical analysis**

Biomass and soil cover for the pasture species and weeds were analysed using a repeated measures analysis considering treatment and season as fixed effects. Sampling times were nested into seasons as described above. Seasonal means were calculated as the average of all sampling times in each season. An autoregressive variance-covariance matrix of first order was used for this analysis. Tukey-Kramer’s test was used for mean comparisons (\(P < 0.05\)). To analyse the competition index, we first tested the data for normality, and then, seasonal and overall means were tested using \(t\)-test for differences between mixtures with *Paspalum*, and the value obtained for each mixture was also tested versus one. Stability indices were analysed by a two-way ANOVA, considering treatments and blocks as fixed effects. Simple linear regressions were fitted for tall fescue, *P. dilatatum* and *P. notatum* soil cover over time for sampling times corresponding to each season in which we had more than one data point (spring, summer and autumn). For this analysis, the number of weeks after sowing the *Paspalum* species was the independent variable. When appropriate, \(P\) and \(R^2\) values were reported.

**Results**

Overall average and seasonal averages of available forage biomass of sown species did not differ between treatments (Table 2). The overall average soil cover of the sown species was also similar among treatments, but seasonal averages were different among treatments in each season except for summer (Table 3). In the autumn, both treatments with *Paspalum* had higher soil cover than the conventional pasture. In winter, the mixture with *P. notatum* had the lowest ground cover, and the conventional pasture had the highest cover. During spring, both the conventional pasture and the mixture with *P. dilatatum* showed higher soil cover than the mixture with *P. notatum*.

Tall fescue overall average biomass was significantly higher in the conventional pasture than in the mixture with *P. notatum*, and it showed intermediate values in the mixture with *P. dilatatum*. Seasonal average tall fescue biomass showed the same trend during summer, but no differences were found in the other seasons (Table 2). Tall fescue overall average soil cover was higher in CP and CP + Pd than in CP + Pn (Table 3). Tall fescue seasonal soil cover was higher in CP than in CP + Pn and showed intermediate values in CP + Pd during both summer and spring, but it was higher in CP than in both mixtures with *Paspalum* in the autumn. No differences were found for tall fescue soil cover during the winter. The soil cover percentages and biomass for both legume species were similar among treatments for each season and overall averages (Tables 2 and 3). Legumes represented 15, 13 and 17% of the total biomass and 26, 21 and 25% of the soil covered by the sown species in CP, CP + Pd and CP + Pn respectively. Both *Paspalum* species showed similar soil cover and biomass and achieved the highest value in the autumn and the lowest in the winter (Tables 2 and 3). The presence of weeds was low, and no differences were found among treatments for weed soil cover or biomass (Tables 2 and 3).

The overall competition index for tall fescue soil cover was significantly lower than one for CP + Pn and lower than one but significantly higher in CP + Pd (Table 4). Seasonal competition index for tall fescue was higher for CP + Pd than for CP + Pn during the summer and autumn both for biomass and soil cover. During winter, competition between the warm- and cool-season grasses was higher in CP + Pd for biomass, while it was higher in CP + Pd during spring for soil cover. The competition index was different from one throughout all seasons only in CP + Pn for soil cover.
Tall fescue soil cover increased linearly with time after sowing in CP when considering only spring \((Y = 19 + 0.235 \times \text{time}, R^2 = 0.645, P = 0.002)\), or autumn data \((Y = 24 + 0.271 \times \text{time}, R^2 = 0.415, P = 0.024)\), and only across spring sampling times \((Y = 16 + 0.202 \times \text{time}, R^2 = 0.631, P = 0.002)\) in CP + Pd (Figure 1). Tall fescue soil cover did not increase over time for CP + Pn across any season. This clearly supports the occurrence of competition between *Paspalum* and tall fescue, and specifically that *P. notatum* had a stronger effect on tall fescue. *Paspalum dilatatum* soil cover increased linearly with time in CP + Pd across the spring \((Y = 3 + 0.094 \times \text{time}, R^2 = 0.365, P = 0.037)\) and summer samplings times \((Y = -2 + 0.177 \times \text{time}, R^2 = 0.683, P = 0.001)\) (Figure 1). These trends are likely explained by the low initial establishment of *P. dilatatum* in this particular experiment. *P. notatum* soil cover did not change over time across seasons (Figure 1).

No significant differences were found among mixtures in either temporal or seasonal stability when calculated for biomass \((P_{\text{temporal}} = 0.39; P_{\text{seasonal}} = 0.47)\) or soil cover \((P_{\text{temporal}} = 0.49; P_{\text{seasonal}} = 0.16; \text{Table 5})\). Stability indices were very similar for the three mixtures in general, although seasonal stability for soil cover was highest for CP + Pd.

**Discussion**

In this experiment, the inclusion of warm-season grasses had no significant effect on the overall performance of the mixtures, weed colonization or stability. The three mixtures were very similar in terms of biomass, soil cover and weed biomass. The inclusion of *P. dilatatum* in mixtures had previously been reported to increase forage yield and make its availability more stable throughout the year (Santiañque and Carambula, 1981; Venuto *et al.*, 1991; Acosta *et al.*, 1994).

Mixtures did not differ during summer probably because of the low rainfall recorded (Table 1), but mixtures with *Paspalum* performed better than the
Table 3  Seasonal and overall average soil cover before grazing (± s.e.) for individual and total sown species and weeds for each pasture.

<table>
<thead>
<tr>
<th></th>
<th>Summer</th>
<th>Autumn</th>
<th>Winter</th>
<th>Spring</th>
<th>Overall*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of sampling times</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>Tall fescue</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CP</td>
<td>40 ± 3 a†</td>
<td>50 ± 3 a</td>
<td>54 ± 6</td>
<td>46 ± 4 a</td>
<td>48 ± 5 a</td>
</tr>
<tr>
<td>CP + Pd</td>
<td>32 ± 3 ab</td>
<td>36 ± 3 b</td>
<td>49 ± 6</td>
<td>40 ± 4 ab</td>
<td>39 ± 2 a</td>
</tr>
<tr>
<td>CP + Pn</td>
<td>26 ± 3 b</td>
<td>28 ± 3 b</td>
<td>29 ± 6</td>
<td>28 ± 4 b</td>
<td>28 ± 1 b</td>
</tr>
<tr>
<td>White clover</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CP</td>
<td>6 ± 2</td>
<td>4 ± 1</td>
<td>5 ± 1</td>
<td>13 ± 3</td>
<td>7 ± 4</td>
</tr>
<tr>
<td>CP + Pd</td>
<td>5 ± 2</td>
<td>4 ± 1</td>
<td>2 ± 1</td>
<td>11 ± 3</td>
<td>6 ± 3</td>
</tr>
<tr>
<td>CP + Pn</td>
<td>6 ± 2</td>
<td>3 ± 1</td>
<td>2 ± 1</td>
<td>11 ± 3</td>
<td>6 ± 4</td>
</tr>
<tr>
<td>Lotus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CP</td>
<td>10 ± 1</td>
<td>11 ± 1</td>
<td>5 ± 2</td>
<td>13 ± 2</td>
<td>10 ± 3</td>
</tr>
<tr>
<td>CP + Pd</td>
<td>10 ± 1</td>
<td>9 ± 1</td>
<td>3 ± 2</td>
<td>11 ± 2</td>
<td>8 ± 3</td>
</tr>
<tr>
<td>CP + Pn</td>
<td>11 ± 1</td>
<td>9 ± 1</td>
<td>5 ± 2</td>
<td>12 ± 2</td>
<td>9 ± 3</td>
</tr>
<tr>
<td>Paspalum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CP + Pd</td>
<td>17 ± 2</td>
<td>19 ± 1 b</td>
<td>3 ± 0</td>
<td>10 ± 1 b</td>
<td>12 ± 6</td>
</tr>
<tr>
<td>CP + Pn</td>
<td>20 ± 2</td>
<td>30 ± 1 a</td>
<td>3 ± 0</td>
<td>15 ± 1 a</td>
<td>17 ± 10</td>
</tr>
<tr>
<td>Weeds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CP</td>
<td>3 ± 2</td>
<td>6 ± 1</td>
<td>3 ± 1</td>
<td>5 ± 1</td>
<td>4 ± 1</td>
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<td>CP + Pd</td>
<td>3 ± 2</td>
<td>4 ± 1</td>
<td>2 ± 1</td>
<td>7 ± 1</td>
<td>4 ± 2</td>
</tr>
<tr>
<td>CP + Pn</td>
<td>6 ± 2</td>
<td>3 ± 1</td>
<td>5 ± 1</td>
<td>8 ± 1</td>
<td>6 ± 2</td>
</tr>
<tr>
<td>Total sown</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CP</td>
<td>57 ± 2</td>
<td>65 ± 1 b</td>
<td>65 ± 4 a</td>
<td>72 ± 1 a</td>
<td>65 ± 5</td>
</tr>
<tr>
<td>CP + Pd</td>
<td>63 ± 2</td>
<td>68 ± 1 a</td>
<td>57 ± 4 ab</td>
<td>72 ± 1 a</td>
<td>65 ± 6</td>
</tr>
<tr>
<td>CP + Pn</td>
<td>63 ± 2</td>
<td>71 ± 1 a</td>
<td>39 ± 4 b</td>
<td>66 ± 1 b</td>
<td>60 ± 12</td>
</tr>
</tbody>
</table>

CP, conventional pasture (Festuca arundinacea, Trifolium repens and Lotus corniculatus); CP + Pd, conventional pasture with P. dilatatum; CP + Pn, conventional pasture with P. notatum.
*Overall average across seasons.
†Means followed by different letters are significantly different (P < 0.05).

Table 4  Competition index for tall fescue biomass and soil cover (± s.e.) for each season and average over all seasons in mixtures with two different Paspalum species.

<table>
<thead>
<tr>
<th></th>
<th>Summer</th>
<th>Autumn</th>
<th>Winter</th>
<th>Spring</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>Tall fescue biomass</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CP + Pd</td>
<td>0.86 ± 0.15 a†</td>
<td>0.75 ± 0.16 a</td>
<td>0.99 ± 0.03 a</td>
<td>0.98 ± 0.16</td>
<td>0.89 ± 0.11 a</td>
</tr>
<tr>
<td>CP + Pn</td>
<td>0.62 ± 0.15† b</td>
<td>0.57 ± 0.20† b</td>
<td>0.83 ± 0.29 b</td>
<td>0.87 ± 0.19</td>
<td>0.72 ± 0.15† a</td>
</tr>
<tr>
<td>Tall fescue soil cover</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CP + Pd</td>
<td>0.81 ± 0.16 a†</td>
<td>0.74 ± 0.16 a</td>
<td>0.93 ± 0.24</td>
<td>0.87 ± 0.18 a</td>
<td>0.84 ± 0.080† a</td>
</tr>
<tr>
<td>CP + Pn</td>
<td>0.67 ± 0.24† b</td>
<td>0.57 ± 0.20† b</td>
<td>0.53 ± 0.24† b</td>
<td>0.64 ± 0.23† b</td>
<td>0.60 ± 0.063† b</td>
</tr>
</tbody>
</table>

CP, conventional pasture (Festuca arundinacea, Trifolium repens and Lotus corniculatus); CP + Pd, conventional pasture with P. dilatatum; CP + Pn, conventional pasture with P. notatum.
*Means followed by different letters are significantly different (P < 0.05).
†Competition index significantly different from 1.

Conventional mixture in the autumn. When weather conditions are less severe, the inclusion of warm-season grasses may help overcome the dry period because C₄ grasses are more tolerant to dry conditions and high temperatures (Hatch, 1992). Consequently, they are expected to recover their active growth more readily as soon as conditions become less limiting, increasing the performance of mixtures in that period.
productive mixture of *P. dilatatum* experiments (Jacobo et al., 2009) been previously documented in the region in pot compatibility between *P. dilatatum* cover, similar to that of the conventional pasture. This mixture with *P. dilatatum* showed similar biomass and soil cover during the win-

resistant to frost than that of *P. dilatatum* of soil cover of each treatment over time (*P* values and *R*^2^ shown for these significant regressions). Dashed lines represent the non-significant linear trends. *Paspalum* species were sown in December 2009, and tall fescue and legumes were sown in April 2010.

Table 5 Stability indices of the three pasture mixtures (±s.e.) across individual sampling times (Temporal) and seasons (Seasonal) for total biomass and soil cover (higher values mean higher stability). No significant differences were found (*P* values in text).

<table>
<thead>
<tr>
<th>Stability index</th>
<th>Temporal</th>
<th>Seasonal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil cover</td>
<td>Biomass</td>
<td>Soil cover</td>
</tr>
<tr>
<td>CP</td>
<td>4.5 ± 0.5</td>
<td>2.7 ± 0.5</td>
</tr>
<tr>
<td>CP + Pd</td>
<td>5.0 ± 0.7</td>
<td>2.2 ± 0.4</td>
</tr>
<tr>
<td>CP + Pn</td>
<td>5.0 ± 1.1</td>
<td>2.2 ± 0.6</td>
</tr>
</tbody>
</table>

CP, conventional pasture (*Festuca arundinacea, Trifolium repens* and *Lotus corniculatus*); CP + Pd, conventional pasture with *P. dilatatum*; CP + Pn, conventional pasture with *P. notatum*.

Even though the foliage of *P. dilatatum* is more resistant to frost than that of *P. notatum*, both species showed similar biomass and soil cover during the winter. However, the higher tall fescue soil cover in the mixture with *P. dilatatum* maintained a high mixture cover, similar to that of the conventional pasture. This compatibility between *P. dilatatum* and tall fescue had been previously documented in the region in pot experiments (Jacobo et al., 2009) suggesting that a productive mixture of *P. dilatatum* and tall fescue can be obtained when sowing both species together in the autumn. The lower mixture soil cover of CP + Pn can be explained by the low tall fescue cover. This is a clear example that when considering the benefits of including new functional groups in pastures, the relative abundance of each component is very relevant. In a community dominated by one species, the community would only be as resistant to extreme conditions as the dominant species is.

We expected that the inclusion of warm-season grasses would increase pasture biomass and stability, but instead, the performance of the three mixtures was similar. Although the high standard errors found in our study may have reduced the precision of our analysis, competition between grasses may also explain the absence of differences among treatments. The warm-season grass competed with the other grass component in the mixture, reducing tall fescue biomass and soil cover in mixtures with *Paspalum*. The inclusion of *P. notatum* had a greater impact on the performance of tall fescue as competition calculated for biomass was only significant in CP + Pn. Moreover, the regression analysis showed that the presence of *Paspalum* prevented tall fescue from increasing its soil cover across springs and autumns over 3 years. Moreover, the fact that tall fescue soil cover in the mixture with *P. notatum* did not increase across years for any season suggests that *P. notatum* is a stronger competitor for tall fescue.

**Table 5** Stability indices of the three pasture mixtures (±s.e.) across individual sampling times (Temporal) and seasons (Seasonal) for total biomass and soil cover (higher values mean higher stability). No significant differences were found (*P* values in text).
different growth habits of the two *Paspalum* species, their dynamics over time and the effect of these on other species probably underlie the different performance of the mixtures throughout the length of the experiment. The caespitose growth habit of *P. dilatatum* and its lower plant establishment at the beginning of the experiment may have left available resources which were effectively used by tall fescue. However, at the same time, the low establishment of *P. dilatatum* plants may explain why its inclusion did not increase average biomass or soil cover. Soil cover by *P. dilatatum* was only around 13% by the first summer and may not have been enough to contribute a significant increase in biomass. On the other hand, soil cover by *P. notatum* reached around 25% during the first summer and remained constant through the studied period. In spite of this, the inclusion of *P. notatum* did not result in an increase in the total sown biomass or soil cover. Its negative impact on the performance of tall fescue suggests that the contribution of a given species may be counteracted by the magnitude of its competitive effects and overcome the expected benefits of increasing diversity.

The temporal response of different mixtures to specific climatic events is of great economic interest because it determines not only the long-term resilience of the mixture, but also its productive performance during specific climatic conditions. The general trends observed in this experiment may hold true for a variety of environments such as warm-temperate regions in which the seasonal relative advantages of different functional groups are moderate. However, further observations will be necessary to clearly describe the effect of the inclusion of *Paspalum* in pastures in terms of soil cover and biomass production in the face of the irregular precipitation and temperature regime which is usual in Uruguay.

**Conclusion**

The different growth habits of *P. notatum* and *P. dilatatum* had different effects on the performance of the mixtures. When testing these effects across seasons, the inclusion of *P. notatum* increased the productivity of the mixture during summer but decreased its performance during the cold season by negatively affecting tall fescue. The addition of a warm-season grass species with a moderate competitive ability such as *P. dilatatum* is desirable to avoid a negative impact on the cool-season component of the pasture, improve forage availability and reduce variability of over time.

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