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Opportunities and challenges for the growth of milk production from pasture: The case of farm systems in Uruguay

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ABSTRACT

Volatility of markets and climate are driving exporting dairy industries to increase milk production from pasture. However, some regions are not able to grow due to economic, social and environmental constraints. The objective of this study was to analyse at the farm system level the opportunities and challenges for the growth of pasture-based dairy production in Uruguay. A national database of 256 dairy farms was used to compare four groups of Uruguayan farms selected according to the total milk production growth rate from 2013 to 2017. Their productivity (milk production per hectare) and profit was compared by fitting mixed models. Complementarily, the International Farm Comparison Network database was used to compare biophysical and economic indicators of typical farm systems of Argentina, Australia, Ireland, Holland, New Zealand, United States and Uruguay from 2013 to 2017. The growing groups of farms (medium and high growth; > 5% per year) showed more productivity due to their higher stocking rate and achieved a higher margin over feed cost and a lower feeding cost per L of milk than the shrinking groups (medium and high decrease; < 0% per year). The growing systems showed a higher consumption per hectare of home-grown forage (pasture and conserved forage) and supplements. Margin over feed cost decreased alongside milk price over the time frame analysed, with no significant interaction between group and year. Productivity in New Zealand, Australia, United States and Holland was above 10,000 L/ha whereas in Ireland, Argentina and Uruguay it was below 7000 L/ha. Consumption of home-grown forage per hectare in the former countries more than doubled the latter, which consumed approximately half the potential forage production locally reported. Home-grown forage consumption per hectare was a more likely driver of productivity than bought-in feed or feed conversion efficiency. Uruguay achieved the lowest cost of production however current low stocking rates (0.7 cows/ha for the typical farm system) limit home-grown forage consumption and productivity growth. Inter-annual variation in economic performance was larger than the variation in biophysical performance for all countries. This study showed that pasture-based farming systems in Uruguay could make a leap in milk production without losing competitiveness by doubling their home-grown forage consumption through increased stocking rates. For such growth, some future challenges will remain around managing P accumulation and runoff in intensifying farms as well as improving farm design and infrastructure to attract labour, improve its productivity and assure animal welfare.

1. Introduction

There has been an increased interest in milk production from pasture over the past decade across many regions of the world. This was associated with the increasing volatility of both milk and grain markets and the dismantling of subsidy mechanisms in many dairy regions. However, it is unclear which countries could attain a sustainable leap in milk production from pasture-based systems in the future. The outlook for typically pasture-based industries such as Australia and New Zealand is uncertain. Over the last decade Australia has shown an annual decline of 0.9% in national milk production in contrast with a growth of 3% in New Zealand (Hemme, 2017). Nevertheless, the latter is projecting marginal growth as herd expansion will be limited by environmental regulations and land availability (ABARES, 2018; McDowell et al., 2017; Shadbolt et al., 2017). In Europe, pasture-based countries such as Ireland envisage a steady post-quota growth based on herd expansion and low cost of production strategies (McDonald et al., 2013). Other countries such as Holland will have limitations to herd growth due to environmental regulations effects (Klootwijk et al., 2016).

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Within South America, the dairy industries of Uruguay, Argentina and Chile are predominantly pasture-based, with relatively low stocking rates and intermediate levels of concentrates (Hemme, 2017). The climatic and soil characteristics of these regions could allow a large increase in forage production per hectare (Ojeda et al., 2018) to sustain further increases in herd numbers and productivity (milk production per hectare). However, it remains unclear if such a pathway for growth would compromise their competitiveness, defined as the ability of a business to provide products and services as or more effectively and efficiently than the relevant competitors. Since 70% of the milk produced in Uruguay is exported, the future of the dairy industry relies on its competitiveness. In this way, cost of production, profit and future environmental and labour challenges appear as key aspects to examine at the farm-gate level.

The objective of this study was to analyse at the farm system level the opportunities and challenges for the growth of pasture-based dairy production in Uruguay.

2. Materials and methods

The national agricultural database (DIEA, 2017) was utilized for the analysis of the evolution of the country's total number of farms, hectares for dairy production and head of dairy cattle from 1985 to 2016.

The database of a local cooperative program named “Programa de Producción Competitiva de CONAPROLE” (PPC) was utilized to analyse the effect of production growth in commercial farms on their productivity and economic performance. The PPC started in 2010 with 55 farmers and by 2017 it comprised 691 farmers voluntarily engaged, 560 million L of milk, 86,000 milking cows and 78,000 ha. This database covers a wide range of farming systems and has information to allow a thorough description and analysis of their feeding strategies and evolution over time. Farmers supply monthly reports with the number of milking and dry cows, the amount and price of supplements offered, the calvings (adult and primiparous cows), the area of the milking platform and the effective grazing area (where pasture is actively growing). This information is linked with information provided by PPC, such as the amount and composition of milk from each individual farm and the price paid per L of milk. The physical performance and margin over feed cost were calculated based on these inputs. The latter was calculated as the gross milk revenue minus total feed costs (including purchase feed, sowing and maintenance cost of home-grown forage and feeding-out costs of all feeds). To analyse dairy business evolution the database was segmented into four groups according to the mean milk production (L/year) growth rate (GR) during the period 2013–2017 as follows: high decrease (HD; $-10 < GR \leq -5\%$ per year), medium decrease (MD; $-5 < GR \leq 0\%$ per year), medium growth (MG; $0 < GR \leq 5\%$ per year) and high growth (HG; $5 < GR \leq 10\%$ per year). Annual GR was defined as the difference in total farm milk production between two successive years over the production of the first year, while GR is the mean value for the whole period. Only the dairy farms that presented information for the five years (2013–2017; $n = 256$) were considered in the analysis. A mixed model using PROC MIXED of SAS (Littell et al., 2006) was run with year as continuous variable, GR group as categorical data and their interaction (to evaluate slope heterogeneity). Farm was included in the model as random effect. An autoregressive variance of order 1 was used as a covariance structure based on IAC criteria. For all purposes, means were declared different when Tukey test resulted in $p < .05$.

The International Farm Comparison Network (Hemme, 2017) database of net exporting countries from 2013 to 2017 was utilized for the international comparison of farm systems. Main exporting regions within a country were selected where more than one region was reported. The selected countries and corresponding regions were: Argentina (Sante Fe-Córdoba Region), Australia (Gippsland region), United States (California region), Holland (national average), Ireland (national average), New Zealand (Waikato region) and Uruguay (national average). For the economic comparison the following variables were analysed: cost of production (cost of milk production only – including all expenses originated by the production of milk including labour, feed, all herd related expenses, all crop related expenses, energy, fuel, taxes and depreciation); return on investment (the revenue from operating business -excluding changes in assets value- over the total value of farm assets); operating profit margin (operating profit over operating receipts – including milk plus coupled payments in subsidized countries).

3. Results and discussion

3.1. Thirty-year evolution of dairy farm systems

Dairy production in Uruguay has grown from 597 to 2083 million L from 1985 to 2016 (DIEA, 2017) with a linear mean growth rate of 3.2% per year. During the same period the area allocated to dairy production has decreased from 1196 to 764 thousand ha (− 36%) while the number of dairy farmers declined from 7102 to 3873 (− 45%). The increase in farm and herd size as well as the reduction in the number of farmers seem to be a worldwide trend (Clark et al., 2007; Klerkx and Nettle, 2013). The growth in milk production was supported by a significant increment in productivity (3.5× baseline of 1985) due to increases in both stocking rate (1.6×) and production per cow

Fig. 1. Annual increment over baseline (100 = 1985) in productivity (L/ha; –), production per cow (L/cow; —) and stocking rate (cows/ha; ····) in dairy farm systems in Uruguay according to the national agriculture database (DIEA, 2017).

Table 1
Effect of growth rate group (GR), year (Y), and their interaction on production per cow, stocking rate, productivity, dry matter intake (DMI) of pasture, conserved forage and concentrates, feed efficiency, milk price, feed cost and margin over feed cost.

Effects		Growth rate group (GR)				Significance			
Variable	Units	HD	MD	MG	HG	SEM	GR	Y	GR*Y
Production per cow	(kg MS[1]/cow)	431	467	497	504	8.0	NS	**	**
Stocking rate	(cows/ha)	0.95c	1.15b	1.23a	1.23ab	0.04	**	NS	***
Productivity	(kg MS/ha)	411c	539b	621a	6.27a	19.8	**	NS	***
Pasture DMI	(kg/ha/year)	3264c	3757b	3967a	4916a	103.3	**	NS	***
Conserved forage DMI	(kg/ha/year)	954c	1302b	1615a	1719a	84.7	**	NS	***
Concentrates DMI	(kg/ha/year)	1311c	1870b	2064ab	2096a	101	**	NS	***
Feed efficiency	(kg MS/t DMI)	73.7c	77.5b	79.5a	79.8a	0.69	**	***	NS
Milk Price	(US$/L)	0.356	0.359	0.360	0.361	0.055	NS	***	NS
Feeding cost	(U$S/L)	0.148a	0.151a	0.144b	0.142b	0.0018	**	***	NS
Margin over feed cost[2]	(US$/ha/d)	2.89c	3.54b	4.14a	4.16a	0.069	**	***	***

HD = high decrease; MD = medium decrease; MG = medium growth; HG = high growth; ** = P < .05; *** = P < .01; NS = non-significant.
Different letters within main effects and the same row means P < .05.
[1] Milk solids (fat + protein).
[2] Margin over feed cost is calculated as gross milk revenue minus total feed costs.

(2.6×). In 2016 the annual production per adult cow (lactating and non-lactating) was 4901 L while mean stocking rate was 0.8 adult cows/ha. The relative changes observed in productivity, stocking rate and milk production per cow are shown in Fig. 1. All the main components of productivity have grown together: stocking rate, milk production per cow (Fig. 1) and the ratio of milking/dry cows (not shown).

The continuous production growth of the dairy industry throughout decades has been a subject of research in Uruguay and elsewhere (Clark et al., 2007; Dillon et al., 2008). By keeping a low cost of production the Uruguayan dairy industry has remained competitive during its production growth over the last 30 years. However, the cost of production of Uruguay production systems has increased in the last few years, although still below its international competitors (Hemme, 2017). Such increase introduced a sign of concern and highlights the need for the analysis carried out in the following section.

3.2. Description of dairy farm systems in Uruguay

Based on the PPC database (from 2013 to 2017; n = 256) calvings occurred every month, although concentrated in autumn and winter (65% from March to September). Mean productivity was 8831 ± 266 L and 624 ± 15.2 kg of milk solids (MS; milk fat + milk crude protein) per hectare of milking platform (total area of the farm potentially grazable by the milking herd), with a stocking rate of 1.15 ± 0.03 milking cow per hectare. On an annual basis, the feeding of the dairy herds comprised pasture grazed by the milking cows (3944 ± 358 kg DM/ha), crops mechanically harvested and fed to the milking cows as roughage (1367 ± 87.4 kg DM/ha) and concentrates (1831 ± 126 kg DM/ha). It is noteworthy that over 75% of the diet was home-grown forage and only 25% of dry matter intake (DMI) was bought-in feed. Forage consumption per hectare is strongly associated with farm business profit in both Europe (Hanrahan et al., 2018) and NZ (Clark et al., 2007). Although Uruguayan dairy farm systems are pasture-based, all of them make some use of bought-in supplements due to the typical seasonality of pasture growth. The autumn and winter growth shortfalls are also deepened by the high proportion of paddocks recently sown due to the rotational sequence of annual grasses and perennial pastures which usually last 3–4 years. The annual diet of the dairy cows averaged 9.5 ± 0.6 kg DM/cow/day of pasture grazed directly plus 4.2 ± 0.64 and 3.1 ± 0.64 kg DM/cow/day of concentrate and roughage offered as supplements, respectively. The concentrates used for supplementation were a mix of grains and byproducts with a CP and NDF concentration of 140 ± 3.11 and 329 ± 9.54 g/kg DM, respectively. The roughage used as supplement was of lower quality: 95 ± 4.5 and 518 ± 13.0 g/kg DM for CP and NDF, respectively. The concentrate was fed mainly inside the milking parlor (83–85% of the dairies) while roughage was predominantly fed with feeders distributed in the field (40–45%) and in lower proportion with concrete feed pads (22–26%). Milk production efficiency in the milking platform was 1.22 L of milk/kg DM consumed and 86.7 kg MS/t of DM consumed which are in line with values reported in the international literature but below the potential of these systems (Baudracco et al., 2011; Chilibroste and Battegazzore, 2014). The margin over feeding cost was 1496 ± 386.9 (max = 1927; min = 1117) US$/cow/year and 1310 ± 338 (max = 1669; min = 972) US$/ha/year. The inter-annual changes in margin over feed cost were mainly due to changes in milk price which averaged 0.35 ± 0.06 (max = 0.41; min = 0.29) US$/L of milk. The mean feeding cost was 0.15 ± 0.01 US$/L of milk.

3.3. The impact of growth

The PPC database was segmented by farms'milk production growth rate (GR) over 5 years (2013–2017) to analyse the relationship between business performance and production growth. We hypothesize that the growing farms could have added small positive differences which, in turn, drove their higher growth. The segmentation yielded the following 4 groups: high decrease (HD, n = 26, GR = −9.4 ± 4.98% per year), medium decrease (MD, n = 85, GR = −2.0 ± 1.30% per year), medium growth (MG, n = 95, GR = +2.3 ± 1.27) and high growth (HG, n = 50, GR = +7.2 ± 1.48% per year). Variables describing productivity components, feeding components and margin over feed cost and their evolution were analysed on a yearly basis. Mean values for GR groups and main effects significance tested in the model are reported in Table 1. The growing systems (MG and HG) exhibited higher productivity than the shrinking ones (MD and HD) with productivity being mainly based on higher stocking rate (Table 1). A significant interaction between GR and year was found for stocking rate, which increased in the growing systems and decreased in the shrinking ones (Fig. 2). In line with this, the growing systems exhibited higher pasture DMI than the shrinking ones (Table 1). A significant interaction between GR and year was detected for pasture DMI with a slope along years of +159a, +84a, −77b and -277c kg pasture DMI/ha/year for HG, MG, MD and HD, respectively (p < .05). Growing dairy systems based part of their growth on their higher pasture DMI per hectare, which agrees with the higher stocking rate observed in these systems (Baudracco et al., 2010; Custodio et al., 2018; Ortega et al., 2018). The conserved forage DMI was in line with pasture DMI with a significant interaction between GR and year yielding different slopes in time:

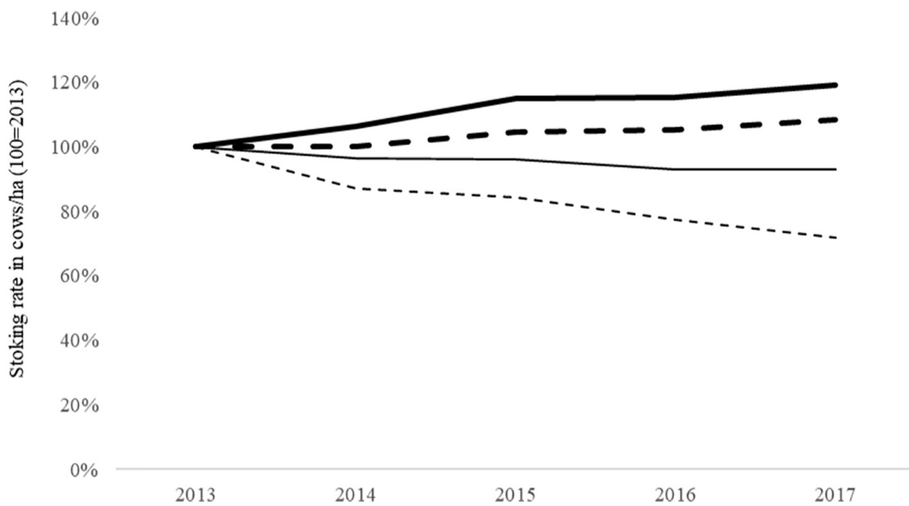

Fig. 2. Annual variation in stocking rate (cows/ha) from an initial baseline (100 = 2013) for farm systems grouped according to their total farm milk production in high growth (HG; ▬▬), medium growth (MG; ■■■) medium decrease (MD; —) or high decrease (HD; - - -).

+119a, +94a, −1.9b and -85 kg of conserved forage DMI/ha/year for HG, MG, MD y HD, respectively ($p < .05$). Hence it appears that the strategy of the growing systems was based on the higher DMI of home-grown forage (pasture and conserved forage) per hectare. Nevertheless, the DMI of concentrates was also higher in the growing systems (Table 1) possibly due to the higher exposure to seasonal variations in pasture growth in the increased stocking rate systems. The feed efficiency followed the same trend as productivity and was higher in HG and MG than in MD and HD, suggesting that the efficacy of animal and feeding management practices was not negatively affected by the increase in stocking rate.

Milk price received by dairy farmers was not different between GR groups and suffered a decline from 2013 to 2016 with a slight recovery in 2017. The feeding cost per L of milk was lower for the growing systems (Table 1). Margin over feed cost was higher in the growing farm systems than in the shrinking ones (Table 1), which shows that increasing productivity based on higher stocking rate and home-grown forage DMI per hectare was an effective strategy to support the better margin over feed cost of those farm systems (Baudracco et al., 2010; Ramsbottom et al., 2015). The higher demand for feeds in the growing farm systems was covered with a rather proportional increase on pasture and conserved forage (home-grown) and concentrate (bought-in) DMI per hectare, maintaining a lower feeding cost and a profitable margin over feed cost, even in a scenario of low milk prices. Ongoing research projects in Uruguay at farmlet level (Ortega et al., 2018) are conclusive in terms of the positive impact of higher stocking rate on biophysical and economic performance when milk production per cow is kept above a desired level. The decline in margin over feed cost along the years followed the same trends as milk price, without a significant interaction between GR group and year.

3.4. International comparison

To assess the competitiveness of farm systems of Uruguay, average physical and economic key performance indicators of farm systems from 2013 to 2017 were obtained and compared to those of six selected countries (Table 2). Farm systems in New Zealand, Australia, United States and Holland showed an average productivity above 10,000 L of energy corrected milk (ECM) per hectare whereas Ireland, Argentina and Uruguay reached average values below 7000 L of ECM/ha. Whilst in United States and Holland the high productivity levels were explained by a high production per cow (10,184 and 8797 kg ECM/cow/year, respectively) and high stocking rates (5.7 and 1.8 cows/ha, respectively), similar levels in New Zealand and Australia were explained mainly by high stocking rates (2.8 and 1.7 cows/ha, respectively) but intermediate production per cow (5244 and 6569 kg ECM/cow/year, respectively). The lower productivity in Ireland, Argentina and Uruguay was mainly explained by their low stocking rates, ranging from 0.7 to 1.2 cows/ha, rather than by per cow production, which was similar to the Oceania countries.

Main differences among countries in terms of milk production per hectare appear to be more likely explained by differences in the consumption of home-grown forage than by the levels of bought-in feed or by the efficiency to convert feed into milk. We refer to feed conversion efficiency (FCE) as kg of ECM per kg DM of feed, according to the definition of Beever and Doyle (2007). The three top countries in productivity (United States, Holland and New Zealand) have a fivefold higher productivity and only a 24% higher FCE than the remaining countries, hence FCE could not have been the main driver of productivity differences. Neither the use of bought-in feed appears to explain productivity differences since there was a wide range of concentrate use per cow within high productivity countries, going from zero in New Zealand to 3.5 t in United States. On the other hand, the average consumption of home-grown forage per hectare in these high productivity countries more than doubled the countries with low productivity, such as Ireland, Argentina and Uruguay, thus being a more likely driver of productivity differences. In the latter regions, home-grown forage yields could have been limited more by farm system design and management than by limitations related to climate or soil conditions. In Argentina, recent long-term studies have shown that there is potential to attain forage productions above 15 t DM/ha from both dryland and irrigated pasture and crop sequences (Ojeda et al., 2018). A similar situation can be expected for Ireland and Uruguay, where national studies monitoring commercial dairy farms have shown a pasture productivity twice the level of consumption. In Ireland a national database based on visual estimates of commercial farms has recorded annual average productions of 13 t DM/ha (Hanrahan et al., 2017). In Uruguay, a satellite image monitoring system calibrated with cuts has recently shown annual pasture productions between 12 and 15 t DM/ha (CONAPROLE, 2019) in line with the values reported by the national system of pasture evaluation (INIA-INASE, 2018).

Some general trends in terms of labour productivity (kg ECM/h) could be discussed minding the large differences amid countries in farm system infrastructure, feeding system and labour type. Confined farm systems in United States and Holland reach high labour productivity levels (396 and 274 kg ECM/h, respectively) which appear similar to those obtained on pasture-based systems in New Zealand and Australia (334 and 282 kg ECM/h, respectively). The latter countries, in turn, more than double the labour productivity of the remaining pasture-based countries analysed in this study (Ireland, Uruguay and Argentina). This contrast among pasture-based countries could be attributed to undersized farm infrastructure, particularly milking parlor

Table 2
Biophysical information of typical farm systems from United States, Holland, Ireland, New Zealand, Australia, Argentina and Uruguay: mean and s.d. from 2013 to 2017.
Source: IFCN Dairy Report 2017 (unpublished).

Variable	Units	United States		Holland		Ireland		New Zealand		Australia		Argentina		Uruguay	
		Average	s.d.	Average	s.d.	Average	s.d.	Average	s.d.	Average	s.d.	Average	s.d.	Average	s.d.
Productivity	(kg ECM/ha)	57,965.3	7553.7	15,618.8	1168.4	6638.2	259.5	14,609.3	1733.4	11,184.2	1433.3	4107.0	490.9	3971.8	253.6
Production per cow	(kg ECM/cow/ year)	10,184.1	138.5	8796.8	316.0	5407.6	153.7	5243.5	265.8	6569.3	288.9	4951.4	199.8	5842.1	280.2
Sotcking rate	(cows/ha)	5.69	0.68	1.79	0.09	1.24	0.08	2.79	0.29	1.72	0.22	0.77	0.03	0.69	0.01
Home grown forage	(kg DM/ha/ year)	14,311.2		10,679.3		4276.6		10,886.2		10,138.0		5268.4		4230.1	
Concentrate used	(t DM/cow/ year)	3.53	0.48	1.74	0.21	0.83	0.09	0.0	0.0	1.67	0.24	2.07	0.2	1.5	0.07
Feed conversion efficiency	(kg ECM/ kg DM of feed)	1.34	0.01	1.33	0.02	1.06	0.04	1.08	0.19	1.04	0.12	0.87	0.12	1.04	0.03
Labour productivity	(kg ECM/h)	395.5	2.8	274.2	11.2	109.1	14.3	333.7	15.0	282.4	28.0	96.2	1.6	98.0	3.5

and equipment which relates directly to milking duration (O'Brien et al., 2012) and reduces labour productivity. A national survey conducted in Uruguay by INALE (2014) showed that the first quintile of dairy farms according to annual growth rate had the most undersized infrastructure with a ratio of 29 cows per milking unit, more than double the recommendation for pasture-based farming (Klindworth et al., 2003). The infrastructure required by intensive and large pasture-based dairy farms has received little attention in the past (Aguerre et al., 2018; Clark et al., 2007). The lower wages paid to workers in South American countries could be another contributor, since farmers tend to compensate increases in herd size by employing more people, typically short-term workers, and prolong the milking duration instead of investing in the additional infrastructure required.

Key economic performance indicators were selected according to their relevance in terms of cost competitiveness, the yield of investments and the business exposure to risk in a volatile environment (Table 3). Farm systems in United States, Oceania and South American countries attained a cost of production below 0.34 US$/ kg ECM, in contrast with Ireland and Holland, reaching 0.45 and 0.54 US$/ kg ECM, respectively. The main contrast in terms of cost structure in the European countries was around a two-fold difference in the cost of machinery and buildings (depreciation and maintenance) and labour compared to the other countries analysed. The cost of machinery and buildings was 0.14 US$/kg milk for Holland systems, 0.08 US$/kg milk for Ireland systems and 0.03 US$/kg milk for the remaining countries averaged. Labour costs averaged 0.11 US$/kg milk in Holand, 0.12 US $/kg milk in Ireland and 0.06 US$/kg milk in the remaining countries averaged. Uruguay reached the lowest average cost of production for the analysed period, suggesting that farm systems of this country can be at least as competitive as all other countries in producing a low cost product for a volatile international market. The average return on investment for the analysed period was above 5% in most countries with the exception of Holland and Ireland, reaching −0.3 and 0.07%, respectively (Table 3). Since both the latter countries belong to the European Union, their farmers could be compensating the low returns with the contribution of coupled or decoupled subsidies. Operating profit margin is a relative measure of business resiliency or exposure to risk (Shadbolt, 2012). Holland, Ireland and Argentina showed the lowest averages for this variable, with values below 15%, although a large interannual variation coefficient was present in all countries.

Interestingly, there was a considerably lower inter-annual variation for the physical indicators (Table 2) than for the economic ones (Table 3), with a coefficient of variation ranging from 0 to 24% and from 0 to 1280%, respectively. Coefficient of variation of all physical indicators was below 7%, with the exception of productivity in Argentina. Hence, this large inter-annual variation in profit found in all countries should have been explained to a larger extent by changes in terms of trade (prices of all inputs and all outputs) than by fluctuations in production efficiency due to climate or management changes. Fariña et al. (2013) also found that milk price variation had a larger impact than forage yield variation on the operating profit of intensified dairy farm systems in Australia. This is also in line with Shadbolt (2012) who found that intensifying pasture-based farms tended to increase the weight of price risk in relation to climate risk.

When increasing stocking rate leads to a higher consumption of pasture per hectare an improvement in profitability can be achieved (Baudracco et al., 2010). However, a recent modelling study in Ireland has reported reductions in profit above 2.6 cows per hectare as the farm was not capable of meeting the extra demand without purchasing additional and more expensive feed (Ruelle et al., 2018) which could, in turn, cause a decline in the level pasture harvested per hectare (Ramsbottom et al., 2015). Baudracco et al. (2011) also found in Argentina that increasing stocking rate to 2.6 cows/ha did not affect milk production per cow when supplement level per cow was maintained. Interestingly, in both these studies in Ireland and Argentina (Baudracco et al., 2011; Ruelle et al., 2018) the level of pasture production was 12 t DM/ha/year, similar to the average recorded on a farmlet study in Uruguay (Ortega et al., 2018). The current low stocking rates in Uruguay (0.72 cows/ha for IFCN typical farm and 0,8 cows/ha for national data base (DIEA, 2017) mean that there is potential to double the

Table 3
Economic information of typical farm systems from United States, Holland, Ireland, New Zealand, Australia, Argentina and Uruguay: mean and s.d. from 2013 to 2017.
Source: IFCN Dairy Report 2017.

Variable	Units	United States		Holland		Ireland		New Zealand		Australia		Argentina		Uruguay	
		Average	s.d.	Average	s.d.	Average	s.d.	Average	s.d.	Average	s.d.	Average	s.d.	Average	s.d.
Cost of production	(US$/100 kg ECM)	33.8	0.89	54.3	0.89	45.2	4.72	34.3	8.66	33.2	1.73	31.5	3.84	30.7	5.28
Return on investments	(%)	6.95%	5.1%	−0.30%	1.6%	0.07%	1.8%	5.07%	2.1%	6.99%	3.4%	6.86%	8.1%	6.54%	4.6%
Operating profit margin	(%)	23.6%	29.4%	−1.4%	19.1%	9.7%	7.7%	19.2%	9.9%	24.5%	13.3%	12.5%	23.3%	19.5%	13.6%

current stocking rate and, in turn, productivity from pasture before compromising profitability. An economic analysis of the research reported by Ortega et al. (2018) has shown the potential impact of increasing stocking rate at a national level (Pedemonte et al., unpublished). Under best management practices, rising stocking rate from 1.2 to 2.0 cows/ha increased productivity (76%) and net income (187%) reducing risk exposure to the inter-annual variation of precipitation and price of milk and concentrates.

In a recent review focusing on the next 50 years Britt et al. (2018) proposed that the greatest potential to increase milk production for export will be in countries that "have sufficient arable land to produce livestock feed, have farming areas that will be affected relatively less by climate change, have populations that will not increase in size at the rate of fastest-growing regions, and have dairy farming and processing infrastructures that can increase in scale and adopt emerging technologies comfortably". The dairy industry of Uruguay is probably well positioned to meet all the aforementioned characteristics either now or in the near future. Infrastructure in the primary sector is perhaps the limiting factor for a rapid and sustainable leap in production (Aguerre et al., 2018), particularly if this is aimed through an enlargement of the national herd. In this way, the low level of debt in the typical farm system of Uruguay may allow for future investments on additional infrastructure required if long-term loans are made available. The average debt to asset ratio from 2013 to 2017 on IFCN typical farms has been 6% in Uruguay and 49% in the remaining countries excluding Argentina (data not shown).

In the downside, the current lack of herd growth might be a factor contributing to slow down the progress of Uruguay national milk production in the near future. Herd growth has been close to zero in the last decade (DIEA, 2017) due to a poor reproductive performance of herds (Meikle et al., 2013; Pereira et al., 2017; Sotelo, 2017), high female calves mortality, averaging 18% (Schild, 2017), relatively high cow culling and mortality rates (Pereira et al., 2017) and heifers calving at 30 months of age on average (Sotelo, 2017). A contributing factor to the lack of growth could be the predominance of north American Holstein genetics in the national herd (87%; INALE, 2014) which has shown to achieve a poorer reproductive performance than other genotypes in the local environment (Pereira et al., 2010).

3.5. Future challenges

Economic performance alone will not determine the sustainability of Uruguay pasture-based dairy systems growth. Environmental and social pressures both behind and beyond the farm-gate will also shape the way farmers design and manage their production systems. Some critical aspects are discussed in this section.

3.5.1. Environmental pressures

Diffuse pollution sources, such as greenhouse gas emissions or energy and water use, might remain a matter of national interest for Uruguay since the industry will continue to focus on exports and seek an international reputation for its natural products. Although emissions may increase in association with the intensification process in Uruguay, their amount per unit of product should decline alongside (Lizarralde et al., 2014). Pasture-based intensification could have some advantages over other intensification strategies in terms of diffuse pollution as some authors have recently reported. In a modelling study in Holland (Aguirre-Villegas et al., 2017) it was found that intensified systems that include grazing for a large portion of the year have less greenhouse gas emissions or net energy intensity than total confinement. The inclusion of grazed pasture reduced emissions coming from machinery use and the off-farm emissions originated from cropping to produce bought-in feed. In Ireland O'Brien et al. (2015) found that increasing milk per hectare by prolonging the grazing season reduced both the emissions per kg of milk and increased farm profit. In contrast, achieving greater milk per hectare through more concentrate feeding both increased off-farm emissions and costs.

However, the risk of point source pollution, rather than diffuse pollution, appears as a stronger challenge for the growing dairy farm systems in Uruguay. The strong association between growth of production at the farm level and nutrient surplus has been well reported in Australia (Gourley et al., 2012; Smith et al., 2013), Holland (Nevens et al., 2006) and Ireland (Treacy et al., 2008). However, the risk of nutrient losses depends on each country's particular combination of soil, climate, topography and farming system (McDowell et al., 2017). In this way, nitrate leaching and effluents management tend to be the main environmental concern for countries with high use of N fertilizer and predominantly permeable soils (Di and Cameron, 2002; McDowell et al., 2017) such as New Zealand and Ireland. In contrast, P accumulation and runoff are the major concerns in Uruguay and Argentina where there is a lower use of N per hectare and less permeable soils (Andriulo et al., 1999; Durán and La Manna, 2009; Terra et al., 2006) whereas in Australia both nutrients are of concern (Smith et al., 2013).

Water pollution associated to agricultural land use was found in the streams of the Santa Lucia river (Arocena et al., 2018; Barreto et al., 2017) which provides drinking water to two thirds of Uruguay's population. Forty percent of the dairy farms in Uruguay are near the basin of this river. Local studies have partially attributed the P enrichment found in the water of the Santa Lucia basin to runoff from soil and direct discharge of effluents from dairies (Barreto et al., 2017; Chalar et al., 2013). There has been strong public scrutiny over the dairy farming practices and a government program has been launched to support best management practices and on-farm infrastructure for effluents management (MVOTMA, 2013).

The load of P in streams of Uruguay is well below the reference values of Australia, New Zealand and the United States (Barreto et al., 2017). This is in line with the lower stocking rates utilized in Uruguay which imply a lower load of fertilisers and excreta per hectare. However, the challenge ahead for intensifying pasture-based systems appears to be how to efficiently distribute the excreted nutrients in time and space to avoid "leaks" outside the farm and comply with regulations (Klootwijk et al., 2016). The excreta deposited in a particular area of the farm is highly correlated with the time spent there (White et al., 2001). Therefore by managing spatial and time distribution of cows, "hot spots" of nutrient surpluses could be avoided in areas where they cannot be used by plants or collected for re-distribution (Gutiérrez et al., 2009; White et al., 2001). Only between 15% and 30% of the total excreta in Uruguayan pasture-based dairy systems is placed around the dairy facilities (Gutiérrez et al., 2009) since the cows spend only a few hours a day being milked or standing in the waiting yard. Managing excreta in hybrid systems (grazing plus confinement), where cows spend at least half the day in the confined areas, appears as an additional challenge for the farm intensification process (Custodio et al., 2018; Gregorini et al., 2017).

Land uses that do not alter the land-cover type could mitigate or offset the risk of biosphere integrity loss caused by the global ecosystem degradation (Steffen et al., 2015). In this way, pasture-based milk production, when is based on permanent or long-term pastures instead of annual cropping, could be a contributor to reduce the loss of biosphere integrity in regions where the original landscape was dominated by pastures. In Uruguay, Arocena et al. (2018) reported the best water quality when there was pasture cover in the watershed instead of crops. A national regulation with a P-index approach (Sharpley et al., 2003) is being applied to the main producing regions of Uruguay to keep erosion below desired levels and to reduce the effect of P losses on water quality. This regulation favors the presence of long-term pastures (3–5 years) which contribute to reduce erosion and P losses within a pasture/forage crop rotational sequence (McDowell et al., 2004).

3.5.2. Labour and lifestyle

The 30-year growth of milk production in Uruguay has involved a process of concentration, leading to fewer and larger dairy farm systems. According to a national survey (INALE, 2014) farms with the highest annual growth ended with the longest milking duration, which is a known consequence of little investment in up-grades of dairy infrastructure (O'Brien et al., 2012). These larger-fast growing farms also showed a higher proportion of employed labour than family labour (INALE, 2014). There were also large generational differences in the workplace since the average age of farm owners was 57 years old, whereas the average age of employees was 37 years old (INALE, 2014). Hence farmers and their employees belong to contrasting generations according to social classifications commonly accepted (Loughlin and Barling, 2001). The contrasting work values and priorities of these generations could be a source of potential conflicts (Gardner and Cennamo, 2008).

Future dairy farm systems should be able to attain a high level of output or number of cows per labour unit in order to be sustainable (Roche et al., 2017). Further adoption of time-saving technologies will be required in conventional dairy farms in order to save both time and effort during the milking routine and related tasks (Tarrant and Armstrong, 2012) as well as being able to make dairy farming more attractive to the technology prone new generations. The adoption of automatic milking systems have shown to have a positive impact on labour and lifestyle of farmers (Molfino et al., 2014; Tse et al., 2017) although these farm systems still require more initial investment and may not reach the same profitability as the most efficient conventional systems (Shortall et al., 2016).

The readiness of smart-farming technologies to be adopted seamlessly by farmers or staff is still a matter of discussion. Social studies conducted with dairy farmers of New Zealand (Eastwood et al., 2017) and Ireland (Regan et al., 2018) have shown how innovation activities have focused on technology development without considering wider socio-ethical implications. In Australia, Jakku et al. (2018) found that when farmers where questioned about the adoption of smart farming or big data applications they raised issues related to trust, transparency and use of their data. Eastwood et al. (2012) studied the learning process of Australian dairy farmers installing new precision technologies and highlighted the need for networks of practice among technology providers, farmers and the key role of “translators” between them. There are also divergent views among farmers, agricultural advisors, and lay citizens on the role of technology, as demonstrated by a recent qualitative study on Brazilian dairy farms (Cardoso et al., 2019). In that study both farmers and advisors referred to technology as important to improve the quality of life of farmers and workers. Lay citizens, however, not even discussed the issue of quality of life and saw technology as means to improve milk quality.

3.5.3. *Animal welfare*

Animal welfare has a social impact beyond the farm gate since consumers and local communities are increasing their awareness towards this issue. This is evident both in developed and developing countries as a recent survey in Brazil has shown (Cardoso et al., 2019). Both farmers, their advisors and citizens were concerned about animal welfare. However, whereas farmers and advisors focused on biological aspects, citizens emphasized aspects of naturalness and affective states to support their argument (Cardoso et al., 2019). In this way, many studies conducted with citizens show that access to pasture is recognized by society as very important to the welfare of dairy cows (Hötzel et al., 2017; Schuppli et al., 2014; Ventura et al., 2016). Moreover, it has been demonstrated that provision of information about zero-grazing (Hötzel et al., 2017; Schuppli et al., 2014) or a farm visit (Ventura et al., 2016) failed to increase the acceptance of such practice. In Uruguay, the predominance of pasture-based all year-round out-door grazing and small family sized farms might be seen as a comparative advantage by consumers and society in general. In contrast, research has shown that cows might prefer to stay inside when temperature is high and access a high energy density diets (von Keyserlingk and Weary, 2017). These findings highlight the opportunities for hybrid systems in Uruguay where grazing is effectively combined with a TMR diet (Mendoza et al., 2016a, 2016b) due to the frequent shortfalls in pasture growth. It appears that progress in science is required to study how animals must be taken care of whilst understanding societal values and the way citizens engage with dairy production (Boogaard et al., 2011; Miele et al., 2011; von Keyserlingk and Weary, 2017).

In the context of farm growth and concentration, current infrastructure constraints (Aguerre and Chilibroste, 2018) will remain a challenge for animal welfare. Intensification in such environment has shown to increase the risk of animal disease and metabolic problems in pasture based systems (Lean et al., 2008) leading to increased culling and mortality rates. In this context, heat stress and long walking distances are relevant issues related to animal welfare. Research on pasture-based systems in New Zealand (Kendall et al., 2007) and more recently in Uruguay (Román et al., 2019) has shown the impact of access to shade on milk production by reducing heat stress. In New Zealand, farmers are reducing environmental stress by using sprinklers at the dairy and standoff pads (Clark et al., 2007). A local study has reported the potential impact of long walking distances on milk production and composition (Fajardo et al., 2015). Long walking distances in large herds could be addressed by using once-daily milking when grazing the most distant paddocks (Clark et al., 2007) although a trade-off between labour savings and profit has been shown in New Zealand (Clark et al., 2006) and Argentina (Lazzarini et al., 2018).

4. Future direction of research

Recent efforts have been made in Uruguay towards the development of strategic research to tackle the issues highlighted in this paper. The sustainable intensification of pasture-based farm systems has been the common goal of the largest dairy research ongoing projects where university, research institutes and industry bodies are working alongside. The effect of stocking rate and contrasting pasture management strategies on biophysical, environmental and economic performance of farm systems is being investigated through an integrative approach, combining farmlet studies (Custodio et al., 2018; Ortega et al., 2018), and commercial farms monitoring (Aguerre and Chilibroste, 2018; Pereira et al., 2017). With a similar approach, a farmlet study is analysing different feeding strategies and animal genotypes to double the industry yields of home-grown forage and milk solids per hectare (Martínez et al., 2018; Stirling et al., 2018). New studies are in the pipeline to explore the sustainability of further intensification alternatives, evaluating both pasture-based systems using irrigation as well as hybrid systems that include controlled housing conditions.

To explore options facing the labour and lifestyle challenges related to dairy intensification, the first pasture-based voluntary milking system is already operating in Uruguay and will serve as a research platform to study its potential adaptation to local conditions and profitability. Besides this, further research focused on conventional dairying is being explored involving researchers from social disciplines. Research and co-innovation to tackle the on-farm lack of growth in the national dairy herd is still lacking and will require additional efforts in the future.

5. Conclusions

There is a clear opportunity for production growth in dairy farm systems in Uruguay without losing their international competitiveness. Lifting production and utilisation of home-grown forage through a two-fold increase in stocking rate from the current industry average appears as the most sustainable pathway. In this way, a particular focus on permanent pastures might bring both environmental and social advantages. It appears that current restrictions related to infrastructure, herd dynamics and animal welfare are still a challenge but could be overcome in the mid-term. Future changes in labour and lifestyle choices will probably remain a challenge in the long term.

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References

ABARES, 2018. Agricultural Commodities: March Quarter 2018. Canberra, Australian Capital Territory, Australia.
Aguerre, M., Chilibroste, P., 2018. Análisis nutricional y manejo de la alimentación en predios lecheros: ¿Hay oportunidades de mejoras? In: XLVI Jornadas Uruguayas de Buiatría, pp. 137–147 Paysandú, Uruguay.
Aguerre, M., Méndez, M.N., Torterolo, S., Chilibroste, P., 2018. Pasture base dairy farm intensification: the role of growth strategy (stocking rate vs. individual milk production) and availability of infrastructure. J. Dairy Sci. 101, 255–256.
Aguirre-Villegas, H.A., Passos-Fonseca, T.H., Reinemann, D.J., Larson, R., 2017. Grazing intensity affects the environmental impact of dairy systems. J. Dairy Sci. 100, 6804–6821. https://doi.org/10.3168/jds.2016-12325.
Andriulo, A., Guérif, J., Mary, B., 1999. Evolution of soil carbon with various cropping sequences on the rolling pampas. Determination of carbon origin using variations in natural 13C abundance. Agronomie 19, 349–364. https://doi.org/10.1051/agro:19990503.
Arocena, R., Chalar, G., Pacheco, J.P., 2018. Agriculture and elevation are the main factors for Pampasic stream habitat and water quality. Environ. Monit. Assess. 190, 254. https://doi.org/10.1007/s10661-018-6622-6.
Barreto, P., Dogliotti, S., Perdomo, C., 2017. Surface water quality of intensive farming areas within the Santa Lucia River basin of Uruguay. Air Soil Water Res. 10, 1–8. https://doi.org/10.1177/1178622117715446.
Baudracco, J., Lopez-Villalobos, N., Holmes, C.W., Macdonald, K.A., 2010. Effects of stocking rate, supplementation, genotype and their interactions on grazing dairy systems: a review. New Zeal. J. Agric. Res. 53, 109–133. https://doi.org/10.1080/00288231003777665.
Baudracco, J., Lopez-Villalobos, N., Romero, L.A., Scandolo, D., Maciel, M., Comeron, E.A., Holmes, C.W., Barry, T.N., 2011. Effects of stocking rate on pasture production, milk production and reproduction of supplemented crossbred Holstein-Jersey dairy cows grazing lucerne pasture. Anim. Feed Sci. Technol. 168, 131–143. https://doi.org/10.1016/j.anifeedsci.2011.03.017.
Beever, D.E., Doyle, P.T., 2007. Feed conversion efficiency as a key determinant of dairy herd performance: a review. Aust. J. Exp. Agric. 47, 645–657.
Boogaard, B.K., Bock, B.B., Oosting, S.J., Wiskerke, J.S.C., van der Zijpp, A.J., 2011. Social acceptance of dairy farming: the ambivalence between the two faces of modernity. J. Agric. Environ. Ethics 24, 259–282. https://doi.org/10.1007/s10806-010-9256-4.
Britt, J.H., Cushman, R.A., Dechow, C.D., Dobson, H., Humblot, P., Hutjens, M.F., Jones, G.A., Ruegg, P.S., Sheldon, I.M., Stevenson, J.S., 2018. Invited review: learning from the future—a vision for dairy farms and cows in 2067. J. Dairy Sci. 1–20. https://doi.org/10.3168/jds.2017-14025.
Cardoso, C.S., von Keyserlingk, M.G., Hötzel, M.J., 2019. Views of dairy farmers, agricultural advisors, and lay citizens on the ideal dairy farm. J. Dairy Sci. 102, 1811–1821. https://doi.org/10.3168/jds.2018-14688.
Chalar, G., Delbene, L., González-Bergonzoni, I., Arocena, R., 2013. Fish assemblage changes along a trophic gradient induced by agricultural activities (Santa Lucía, Uruguay). Ecol. Indic. 24, 582–588. https://doi.org/10.1016/j.ecolind.2012.08.010.
Chilibroste, P., Battegazzore, G., 2014. Proyecto Producción Competitiva, 1st ed. Conaprole, Montevideo, Uruguay.
Clark, D.A., Phyn, C.V.C., Tong, M.J., Collis, S.J., Dalley, D.E., 2006. A systems comparison of once- versus twice-daily milking of pastured dairy cows. J. Dairy Sci. 89, 1854–1862. https://doi.org/10.3168/jds.S0022-0302(06)72254-8.
Clark, D.A., Caradus, J.R., Monaghan, R.M., Sharp, P., Thorrold, B.S., 2007. Issues and options for future dairy farming in New Zealand. New Zeal. J. Agric. Res. 50, 203–221. https://doi.org/10.1080/00288230709510291.
CONAPROLE, 2019. Seguimiento Forrajero Satelital [WWW Document]. Portal Prod. Leche. http://www.eleche.com.uy/cooperarios/productores-seguimiento-forrajero-satelital?es.
Custodio, D., Ortega, G., López, Y., Nuñez, T., Mello, R., Chilibroste, P., 2018. Effect of stocking rate on feeding strategies and individual milk production of autumn calving grazing dairy cows. In: Abstracts of the 2018 American Dairy Science Association Annual Meeting. American Dairy Science Association, Knoxville, Tennessee, pp. 291.
Di, H.J., Cameron, K.C., 2002. Nitrate leaching in temperate agroecosystems: sources, factors and mitigating strategies. Nutr. Cycl. Agroecosyst. 64, 237–256. https://doi.org/10.1023/A:1021471531188.
DIEA, 2017. Anuario estadístico agropecuario. (Montevideo, Uruguay).
Dillon, P., Hennessy, T., Shalloo, L., Thorne, F., Horan, B., 2008. Future outlook for the Irish dairy industry: a study of international competitiveness, influence of international trade reform and requirement for change. Int. J. Dairy Technol. 61, 16–29. https://doi.org/10.1111/j.1471-0307.2008.00374.x.
Durán, H., La Manna, A., 2009. Implicancias productivas, económicas y ambientales de la intensificación de la producción de leche pastoril en Uruguay, in: Simposio Efectos de La Agricultura, La Lechería y La Ganadería En El Recurso Natural Suelo: Impactos y Propuestas (Montevideo, Uruguay). pp. 81–84.
Eastwood, C.R., Chapman, D.F., Paine, M.S., 2012. Networks of practice for co-construction of agricultural decision support systems: case studies of precision dairy farms in Australia. Agric. Syst. 108, 10–18. https://doi.org/10.1016/j.agsy.2011.12.005.
Eastwood, C., Klerkx, L., Ayre, M., Dela Rue, B., 2017. Managing socio-ethical challenges in the development of smart farming: from a fragmented to a comprehensive approach for responsible research and innovation. J. Agric. Environ. Ethics 1–28. https://doi.org/10.1007/s10806-017-9704-5.
Fajardo, M., Mattiauda, D.A., Motta, G., Genro, T.C., Meikle, A., Carriquiry, M., Chilibroste, P., 2015. Use of mixed rations with different access time to pastureland on productive responses of early lactation Holstein cows. Livest. Sci. 181, 51–57. https://doi.org/10.1016/j.livsci.2015.09.023.
Fariña, S.R., Alford, A., Garcia, S.C., Fulkerson, W.J., 2013. An integrated assessment of business risk for pasture-based dairy farm systems intensification. Agric. Syst. 115, 10–20. https://doi.org/10.1016/j.agsy.2012.10.003.
Gardner, D., Cennamo, L., 2008. Generational differences in work values, outcomes and person-organisation values fit. J. Manag. Psychol. 23, 891–906. https://doi.org/10.1108/02683940810904385.
Gourley, C.J.P., Dougherty, W.J., Weaver, D.M., Aarons, S.R., Awty, I.M., Gibson, D.M., Hannah, M.C., Smith, A.P., Peverill, K.I., 2012. Farm-scale nitrogen, phosphorus, potassium and sulfur balances and use efficiencies on Australian dairy farms. Anim. Prod. Sci. 52, 929–944. https://doi.org/10.1071/AN11337.
Gregorini, P., Villalba, J.J., Chilibroste, P., Provenza, F.D., 2017. Grazing management: setting the table, designing the menu and influencing the diner. Anim. Prod. Sci. 57, 1248–1268.
Gutiérrez, S., Cabrera, N., Benítez, A., Melani, E., 2009. Reducing variability in estimating wastewater composition in dairy farms during milking operations. Biosyst. Eng. 103, 497–503. https://doi.org/10.1016/j.biosystemseng.2009.06.004.
Hanrahan, L., Geoghegan, A., O'Donovan, M., Griffith, V., Ruelle, E., Wallace, M., Shalloo, L., 2017. PastureBase Ireland: a grassland decision support system and national database. Comput. Electron. Agric. 136, 193–201. https://doi.org/10.1016/j.compag.2017.01.029.
Hanrahan, L., McHugh, N., Hennessy, T., Moran, B., Kearney, R., Wallace, M., Shalloo, L., 2018. Factors associated with profitability in pasture-based systems of milk production. J. Dairy Sci. 101, 5474–5485. https://doi.org/10.3168/jds.2017-13223.
Hemme, T., 2017. IFCN Dairy Report 2017. (Kiel, Germany).
Hötzel, M.J., Cardoso, C.S., Roslindo, A., von Keyserlingk, M.A.G., 2017. Citizens' views on the practices of zero-grazing and cow-calf separation in the dairy industry: does providing information increase acceptability? J. Dairy Sci. 100, 4150–4160. https://doi.org/10.3168/jds.2016-11933.
INALE, 2014. Encuesta lechera INALE 2014 - Resultados preliminares. (Montevideo, Uruguay).
INIA-INASE, 2018. Evaluación Nacional de Cultivares Uruguay [WWW Document]. URL. http://www.cultivares.uy/forrajeras_byp.html, Accessed date: 14 November 2018.
Jakku, E., Taylor, B., Fleming, A., Mason, C., Fielke, S., Sounness, C., Thorburn, P., 2018. "If they don't tell us what they do with it, why would we trust them?" Trust, transparency and benefit-sharing in smart farming. NJAS - Wageningen J. Life Sci. https://doi.org/10.1016/j.njas.2018.11.002.
Kendall, P.E., Verkerk, G.A., Webster, J.R., Tucker, C.B., 2007. Sprinklers and shade cool cows and reduce insect-avoidance behavior in pasture-based dairy systems. J. Dairy Sci. 90, 3671–3680. https://doi.org/10.3168/jds.2006-766.
Klerkx, L., Nettle, R., 2013. Achievements and challenges of innovation co-production support initiatives in the Australian and Dutch dairy sectors: a comparative study. Food Policy 40, 74–89. https://doi.org/10.1016/j.foodpol.2013.02.004.
Klindworth, D., Robert, G., Campbell, J. (Eds.), 2003. CowTime Guidelines for Milk Harvesting. Dairy Research and Development Corporation, Melbourne, VIC, Australia.
Klootwijk, C.W., Van Middelaar, C.E., Berentsen, P.B.M., de Boer, I.J.M., 2016. Dutch dairy farms after milk quota abolition: economic and environmental consequences of a new manure policy. J. Dairy Sci. 99, 8384–8396. https://doi.org/10.3168/jds.2015-10781.
Lazzarini, B., Lopez-Villalobos, N., Lyons, N., Hendrikse, L., Baudracco, J., 2018. Productive, economic and risk assessment of grazing dairy systems with supplemented cows milked once a day. Animal 12, 1077–1083. https://doi.org/10.1017/S1751731117002853.
Lean, I.J., Westwood, C.T., Playford, M.C., 2008. Livestock disease threats associated with intensification of pastoral dairy farming. N. Z. Vet. J. 56, 261–269. https://doi.org/10.1080/00480169.2008.36845.
Littell, R.C., Milliken, G.A., Stroup, W.W., Wolfinger, R.D., Schabenberger, O., 2006. SAS for Mixed Models, 2nd ed. SAS Institute, Inc, Cary, NC, USA.
Lizarralde, C., Picasso, V., Rotz, C.A., Cadenazzi, M., Astigarraga, L., 2014. Practices to reduce Milk carbon footprint on grazing dairy farms in southern Uruguay: case studies. Sustain. Agric. Res. 03.
Loughlin, C., Barling, J., 2001. Young workers' work values, attitudes, and behaviours. J. Occup. Organ. Psychol. 74, 543–558. https://doi.org/10.1348/096317901167514.
Martínez, R., Stirling, S., Pla, M., Waller, A., Mendoza, A., Morales, J., Fariña, S., 2018. Sistemas de alta producción con estrategias de alimentación y genotipos animales contrastantes: performance animal. VI Congreso AUPA (Tacuarembó, Uruguay).
McDonald, R., Shalloo, L., Pierce, K.M., Horan, B., 2013. Evaluating expansion strategies for startup European Union dairy farm businesses. J. Dairy Sci. 96, 4059–4069. https://doi.org/10.3168/jds.2012-6365.
McDowell, R.W., Biggs, B.J.F., Sharpley, A.N., Nguyen, L., 2004. Connecting phosphorus loss from agricultural landscapes to surface water quality. Chem. Ecol. https://doi.org/10.1080/02757540310001626092.
McDowell, R.W., Monaghan, R.M., Dougherty, W., Gourley, C.J.P., Vibart, R., Shepherd, M., 2017. Balancing water-quality threats from nutrients and production in Australian and New Zealand dairy farms under low profit margins. Anim. Prod. Sci. 57, 1419–1430.
Meikle, A., Cavestany, D., Carriquiry, M., Adrien, M. de L., Artegoitia, V., Pereira, I., Ruprechter, G., Pessina, P., Rama, G., Fernández, A., Breijo, M., Laborde, D., Pritsch,

O., Ramos, J.M., De Torres, E., Nicolini, P., Mendoza, A., Dutour, J., Fajardo, M., Ana, L., Olazábal, L., Mattiauda, D., Chilibroste, P., 2013. Advances in knowledge of the dairy cow during the transition period in Uruguay: a multidisciplinary approach. Agrociencia Uruguay 17, 141–152.

Mendoza, A., Cajarville, C., Repetto, J.L., 2016a. Digestive response of dairy cows fed diets combining fresh forage with a total mixed ration. J. Dairy Sci. 99, 8779–8789. https://doi.org/10.3168/jds.2016-11023.

Mendoza, A., Cajarville, C., Repetto, J.L., 2016b. Short communication: intake, milk production, and milk fatty acid profile of dairy cows fed diets combining fresh forage with a total mixed ration. J. Dairy Sci. 99, 1938–1944. https://doi.org/10.3168/jds.2015-10257.

Miele, M., Veissier, I., Evans, A., Botreau, R., 2011. Animal welfare: establishing a dialogue between science and society. Anim. Welf. 20, 103.

Molfino, J., Kerrisk, K., García, S.C., 2014. Investigation into the labour and lifestyle impacts of automatic milking systems (AMS) on commercial farms in Australia. In: Proc. 5th Australian Dairy Sci. Symp. Melbourne, Australia, pp. 339–342.

MVOTMA, 2013. Plan de acción para la protección del agua en la cuenca del Santa Lucía [WWW Document]. URL. http://www.mvotma.gub.uy/ambiente/prevencion-y-control-para-el-cuidado-del-ambiente/estado-del-ambiente/plan-santa-lucia (accessed 3.7.19).

Nevens, F., Verbruggen, I., Reheul, D., Hofman, G., 2006. Farm gate nitrogen surpluses and nitrogen use efficiency of specialized dairy farms in Flanders: evolution and future goals. Agric. Syst. 88, 142–155. https://doi.org/10.1016/j.agsy.2005.03.005.

O'Brien, B., Jago, J., Edwards, J.P., Lopez-Villalobos, N., McCoy, F., 2012. Milking parlour size, pre-milking routine and stage of lactation affect efficiency of milking in single-operator herringbone parlours. J. Dairy Res. 79, 216–223. https://doi.org/10.1017/S0022029912000088.

O'Brien, D., Hennessy, T., Moran, B., Shalloo, L., 2015. Relating the carbon footprint of milk from Irish dairy farms to economic performance. J. Dairy Sci. 98, 7394–7407. https://doi.org/10.3168/jds.2014-9222.

Ojeda, J.J., Caviglia, O.P., Agnusdei, M.G., Errecart, P.M., 2018. Forage yield, water- and solar radiation-productivities of perennial pastures and annual crops sequences in the south-eastern Pampas of Argentina. F. Crop. Res. 221, 19–31. https://doi.org/10.1016/j.fcr.2018.02.010.

Ortega, G., Nuñez, T., Custodio, D., Mello, R., López, Y., Chilibroste, P., 2018. Effect of stocking rate on pasture production and utilisation on a grazing dairy system during winter and spring. In: Abstracts of the 2018 American Dairy Science Association Annual Meeting. American Dairy Science Association, Knoxville, Tennessee, pp. 257.

Pereira, I., Laborde, D., Carriquiry, M., Lopez-Villalobos, N., Meikle, A., 2010. Productive and reproductive performance of Uruguayan Holstein and Uruguayan Holstein x New Zealand Holstein Friesian cows in a predominantly pasture-based system. In: Proceedings of the New Zealand Society of Animal Production, pp. 306–310.

Pereira, I., Cruz, I., Ruprechter, G., Meikle, A., 2017. Salud y eficiencia reproductiva de vacas lecheras en sistemas de base pastoril de Florida: resultados preliminares del monitoreo. In: XLV Jornadas Uruguayas de Buiatría, pp. 127–139 (Pysandú, Uruguay).

Ramsbottom, G., Horan, B., Berry, D.P., Roche, J.R., 2015. Factors associated with the financial performance of spring-calving, pasture-based dairy farms. J. Dairy Sci. 98, 3526–3540. https://doi.org/10.3168/jds.2014-8516.

Regan, A., Green, S., Maher, P., 2018. Smart Farming in Ireland: Anticipating positive and negative impacts through a qualitative study of risk and benefit perceptions amongst expert actors in the Irish agri-food sector. In: Proceedings of the 13th European IFSA Symposium. Chania, Greece.

Roche, J.R., Berry, D.P., Bryant, A.M., Burke, C.R., Butler, S.T., Dillon, P.G., Donaghy, D.J., Horan, B., Macdonald, K.A., Macmillan, K.L., 2017. A 100-year review: a century of change in temperate grazing dairy systems. J. Dairy Sci. 100, 10189–10233. https://doi.org/10.3168/JDS.2017-13182.

Román, L., Saravia, C., Astigarraga, L., Bentancur, O., La Manna, A., 2019. Shade access in combination with sprinkling and ventilation effects performance of Holstein cows in early and late lactation. Anim. Prod. Sci. 59, 347–358.

Ruelle, E., Delaby, L., Wallace, M., Shalloo, L., 2018. Using models to establish the financially optimum strategy for Irish dairy farms. J. Dairy Sci. 101, 614–623. https://doi.org/10.3168/jds.2017-12948.

Schild, C., 2017. Estimación de la tasa de mortalidad anual de terneros y caracterización de los sistemas de crianza en establecimientos lecheros de Uruguay. Universidad de la República.

Schuppli, C.A., von Keyserlingk, M.A.G., Weary, D.M., 2014. Access to pasture for dairy cows: responses from an online engagement. J. Anim. Sci. 92, 5185–5192. https://doi.org/10.2527/jas.2014-7725.

Shadbolt, N.M., 2012. Competitive strategy analysis of NZ pastoral dairy farming system. Int. J. Agric. Manag. 1, 19–27.

Shadbolt, N., Apparao, D., Hunter, S., Bicknell, K., Dooley, A., 2017. Scenario analysis to determine possible, plausible futures for the New Zealand dairy industry. New Zeal. J. Agric. Res. 60, 349–361. https://doi.org/10.1080/00288233.2017.1351377.

Sharpley, A.N., Weld, J.L., Beegle, D.B., Kleinman, P.J.A., Gburek, W.J., Moore, P.A., Mullins, G., 2003. Development of phosphorus indices for nutrient management planning strategies in the United States. J. Soil Water Conserv. 58, 137–152.

Shortall, J., Shalloo, L., Foley, C., Sleator, R.D., O'Brien, B., 2016. Investment appraisal of automatic milking and conventional milking technologies in a pasture-based dairy system. J. Dairy Sci. 99, 7700–7713. https://doi.org/10.3168/jds.2016-11256.

Smith, A.P., Western, A.W., Hannah, M.C., 2013. Linking water quality trends with land use intensification in dairy farming catchments. J. Hydrol. 476, 1–12. https://doi.org/10.1016/j.jhydrol.2012.08.057.

Sotelo, F., 2017. Indicadores Reproductivos: Análisis de registros y su distribución histórica. (Montevideo, Uruguay).

Steffen, W., Richardson, K., Rockström, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., de Vries, W., de Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B., Sörlin, S., 2015. Planetary boundaries: guiding human development on a changing planet. Science 347 (80-.).

Stirling, S., Martínez, R., Pla, M., Waller, A., Mendoza, A., Fariña, S., 2018. Sistemas lecheros de alta producción con estrategias de alimentación y genotipos animales contrastantes: cosecha de pasto por hectárea. In: VI Congreso AUPA, (Tacuarembó, Uruguay).

Tarrant, K.A., Armstrong, D.P., 2012. An Economic Evaluation of Automatic Cluster Removers as a Labour Saving Device for Dairy Farm Businesses. AFBM J, pp. 1449–5937.

Terra, J.A., García Préchac, F., Salvo, L., Hernández, J., 2006. Soil use intensity impacts on total and particulate soil organic matter in no-till crop-pasture rotations under direct grazing. Adv. Geoecol. 38, 233–241.

Treacy, M., Humphreys, J., Namara, K.M., Browne, R., Watson, C.J., 2008. Farm-gate nitrogen balances on intensive dairy farms in the south west of Ireland. Irish J. Agric. Food Res. 47, 105–117.

Tse, C., Barkema, H.W., DeVries, T.J., Rushen, J., Pajor, E.A., 2017. Effect of transitioning to automatic milking systems on producers' perceptions of farm management and cow health in the Canadian dairy industry. J. Dairy Sci. 100, 2404–2414. https://doi.org/10.3168/jds.2016-11521.

Ventura, B.A., Von Keyserlingk, M.A.G., Wittman, H., Weary, D.M., 2016. What difference does a visit make? Changes in animal welfare perceptions after interested citizens tour a dairy farm. PLoS One 11. https://doi.org/10.1371/journal.pone.0154733.

von Keyserlingk, M.A.G., Weary, D.M., 2017. A 100-year review: animal welfare in the journal of dairy science—the first 100 years. J. Dairy Sci. 100, 10432–10444. https://doi.org/10.3168/jds.2017-13298.

White, S.L., Sheffield, R.E., Washburn, S.P., King, L.D., Green, J.T., 2001. Spatial and time distribution of dairy cattle excreta in an intensive pasture system. J. Environ. Qual. 30, 2180–2187. https://doi.org/10.2134/jeq2001.2180.