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Article

Milk production in dairy cows grazing alfalfa (*Medicago sativa*) in the central Mexican highlands

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Abstract:

Pasture grazing and feed supplementation strategies can seriously affect milk production in dairy cows. An evaluation was done of the effects of environmental and grazing management factors on pasture productivity variables, and milk and milk solids (fat+protein+lactose) production in an alfalfa grazing system in central Mexico from 2009 to 2011. Data were collected on milk yield and composition, pre-grazing herbage mass (PHM), residual herbage mass (RHM), herbage disappearance rate (HDR), pasture growth rate (PGR), and stocking rate (SR), among other variables. Data on rainfall, temperature, and evapotranspiration at the experimental site was obtained from remote sensing databases. Grazing area increased and supplementation decreased from 2009 to 2011. Annual pasture dry matter production (t DM ha^{-1}) was 17,343 in 2009, 14,649 in 2010, and 13,497 in 2011. Annual pasture utilization rate was 75 % in 2009, 71 % in 2010 and 73 % in 2011, while SR (cows ha^{-1}) was 3.7 in 2009, 3.1 in 2010 and 2.7 in 2011. Milk production (19,290 in 2009, 13,419 in 2010, and 12,563 kg ha^{-1} in 2011) and milk solids (2,409 in 2009, 1,638 in 2010 and 1,554 kg ha^{-1} yr^{-1} in 2011) decreased over time. Based on a multiple regression, grazing interval and nighttime temperature explained PGR; daytime temperature and SR explained PHM; PGR, daytime temperature and feed energy explained milk yield; and HDR and feed energy explained milk solids yield. Feed supplement use is most needed during the 192-d window (October to April) when PGR is below average, and RHM needs to be between 400 and 500 kg DM ha^{-1} to maximize PGR in the following grazing cycle.

Key words: Milk solids production, Grazing management, Alfalfa pastures.

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Introduction

Compared to confinement systems, livestock grazing systems have economic, health and animal welfare advantages(1,2). Mixed temperate grasslands have been proposed for pasture production in the Mexican Highlands(3,4), in such pastures, clover and alfalfa and other legumes have important contributions to grasslands ecophysiology(5,6). Alfalfa is grazed in many countries under irrigated or rainfed conditions since its relatively deep roots provide an advantage over many other forage crops(7,8). In temperate climates, alfalfa is a preferred forage due to its high nutritional quality and flexible harvest for hay or silage, among other aspects. However, alfalfa cultivation has drawbacks, including occurrence of bloat when consumed fresh or grazed by livestock(9), high crude protein content, which increases the energy cost for urinary N excretion(10), the high cost of crop establishment and its need for extensive irrigation(11).

Managing alfalfa to promote its persistence in pastures requires rotational grazing to control feed selection by livestock, match the animal production system to forage availability, and balance competition between pasture plant species(9,12). Determined by ambient temperature and soil moisture, alfalfa biomass accumulation rate is seasonal[9,13]. Obtaining a biomass adequate for grazing requires adjustment of intercrop periods to ensure sufficient stem and leaf recruitment[14].

Grazing alfalfa in combination with grass fodder and concentrated feed supplementation positively affects production, offers some protection against tympanism, provides an improved nutrient balance and facilitates adjustments in grazing pressure[8]. Although supplementation offers advantages for grazing management, it also increases dependence on resources external to the grazing unit. Moreover, supplementation can lead to substitution effects, reducing forage intake in the pasture[10]. Grazing efficiency is reflected in the ability of individual cows to produce dairy solids (fat, protein and lactose) during a season or lactation; it is best expressed as yield per unit area (kg milk solids ha^{-1}). In contrast, continual housing dairy production models quantify performance based on production per herd and individual (L cow^{-1} per day or lactation), while in industrialized systems milk solids concentration is emphasized.

The combination of forage quality and quantity determines animal product quality, but in grazing systems environmental fluctuations also cause changes in production[15]. The present study objective was to evaluate what factors influence production of alfalfa for grazing and milk production by studying the relationships between the environment, pasture and animal production in a case study of dairy cows grazing pastures dominated by alfalfa but under different management regimes over a three-year period.

Material and methods

Study site

The study was carried out at the Center for Teaching, Research and Extension in Animal Production in the Highlands (Centro de Enseñanza, Investigación y Extensión en Producción Animal en el Altiplano - CEIEPAA), of the Faculty of Veterinary Medicine and Zootechny of the National Autonomous University of Mexico (UNAM), in Tequisquiapan municipality, in the state of Querétaro, Mexico. Located in the central highlands of Mexico (20°36’13.88” N; 99°55’02.91” W), the site is 1913 m asl. Local climate is temperate, with average annual rainfall of 512 mm, mostly during the rainy season (average season length = 78 days), and an average daytime temperature of 17.5 °C. Winters are relatively mild with eighteen days of frost from October to February, and warm summer[16]. Prevailing winds are northeast-southwest.

General pasture conditions

The pasture was established in 2005 with the grasses *Dactylis glomerata* (orchard grass), *Lolium multiflorum* (Italian ryegrass), *Festuca arudinacea* (tall fescue) and *Bromus inermis* (brome grass), and the legume *Medicago sativa* (alfalfa). By 2009 alfalfa dominated the pasture. Management consisted of side roll sprinkler irrigation and grazing by dairy cows using the strip method. On average, 1.5 irrigations were applied per grazing cycle, but irrigation depth was not recorded. Cattle were controlled with a mobile electric fence. The pasture was fertilized with $Ca(H_2PO_4)_2$ at a rate of 50 kg P_2O_5 ha^{-1}, applied twice annually during spring (May-June) and early autumn (September-October). Data were collected over a three-years period from 2009 to 2011. Grazing area was 21 ha in 2009, 22 ha in 2010 and 27 ha in 2011. Only the studied dairy herd grazed the pasture during this period.

Herbage mass

Estimation of pasture herbage mass (HM) (kg DM ha-1) was done with the metal frame technique[(17)], modified to quantify alfalfa production. All vegetation (HM) inside a 0.25 m^2 metal frame was cut at a height of 10 cm to protect the alfalfa tillering. Pre-grazing HM (PHM) was estimated as pre-grazing pasture HM, and residual HM (RHM) as post-grazing HM; both were expressed in kg DM ha^{-1}. Both PHM and RHM were estimated by randomly placing the frame eight times, harvesting the HM each time and averaging the HM quantities to produce a single measurement. The herbage samples were dehydrated in a forced air oven at 95 °C for 48 h to determine dry matter (DM) content. Herbage disappearance rate (HDR) was calculated as the difference between PHM and RHM (kg DM ha^{-1}), and considered an estimate of animal consumption on the day of measurement. Grazing interval (GI) between defoliations was recorded in days (d) for each grazing period. Pasture growth rate (PGR) was calculated as PHM divided by GI. In some pastures the PHM biomass was harvested as hay, and in these cases herbage production was also quantified in terms of bales and average bale weight; this fodder was used as a supplement. Vegetation activity phenology was modeled for PGR using the TIMESAT model[(18)].

Chemical analyses

Herbage samples (200 g DM) were taken monthly and sent to the Biochemistry and Animal Nutrition Department of the FMVZ-UNAM for analyses. In vitro DM digestibility was quantified following the method of Tilley and Terry[(19)]. Herbage metabolizable energy (ME) content (MJ kg^{-1} DM) was estimated from in vitro DM digestibility values using the equations proposed by Geenty and Rattray[(20)]. Total milk solids, fat and protein contents were measured with a Milkoscan 133 (Foss Electric, Denmark).

Livestock and pasture management

The milk production model was all year-round calving and milking. The studied pastures were grazed by groups of 45 cows in 2009, 54 cows in 2010 and 61 cows in 2011; these groups included lactating and dry cows. Breeds included Holstein Friesian, Jersey and Holstein x Jersey crosses. Holstein was the predominant breed in all three years: 58 % in 2009, 54 % in 2010 and 51 % in 2011. Average cow body weight during the study period was 510 ± 66 kg. The cows were in the grazing paddocks always and supplements offered in feed bunks before milking. The supplement was commercial balanced feed and/or rolled corn grain at a rate of 1.8 kg supplement plus 1.6 kg pasture hay (dry basis) per cow per day. Average effective area devoted to grazing was 12.4 ha in 2009, 17.8 ha in 2010 and 22.2 ha in 2011. Hay was harvested during the period of highest annual DM abundance, and the area harvested annually as hay averaged 8.5 ha in 2009, 3.9 ha in 2010 and 4.5 ha in 2011. Stocking rate (SR) was 3.63 cows ha^{-1} yr^{-1} in 2009, 3.03 cows ha^{-1} yr^{-1} in 2010 and 2.75 cows ha^{-1} yr^{-1} in 2011. The animals had free access to water and mineral salts. Cows were drenched with 1 g polysiloxane cow^{-1} d^{-1} before entering the pasture during bloating season. As an additional measure, Bloat Tenz (Ecolab, Ltd., New Zealand), a mixture of ethoxylated and propoxylated alcohols used as non-ionic surfactants, was added to the drinking water at a 1:1000 ratio. The grazing control measures and application of anti-bloat medications effectively prevented mortality or clinical cases due to alfalfa-based feeding under the studied intensive grazing conditions.

Environmental data

The National Meteorological Service database does not contain data from weather stations near the study site, therefore environmental characterization was done using remote sensing data. Precipitation data were from the Tropical Rainfall Measurement Mission (TRMM) 3B43 v.7, linked to the Global Precipitation Measurement (GPM) mission. Spanning from 1998 to the present, the TRMM is provided on a monthly basis and is derived from measurements taken at 3-h intervals with a 0.25 ° spatial resolution. Daytime and nighttime temperatures were obtained from the MOD11A2 v.5 surface temperature and emissivity product of the Medium Resolution Imaging Spectroradiometer (MODIS) on board the Terra and Aqua satellites. The MOD11A2 product provides temporary eight-day scales and a 250 m spatial scale. Estimated evapotranspiration data was obtained from the MOD16A2 product at scales of eight days and 1000 m. Both products are cloud free because they are a mosaic of daily measurements averaged only when they have the necessary quality.

Statistical analyses

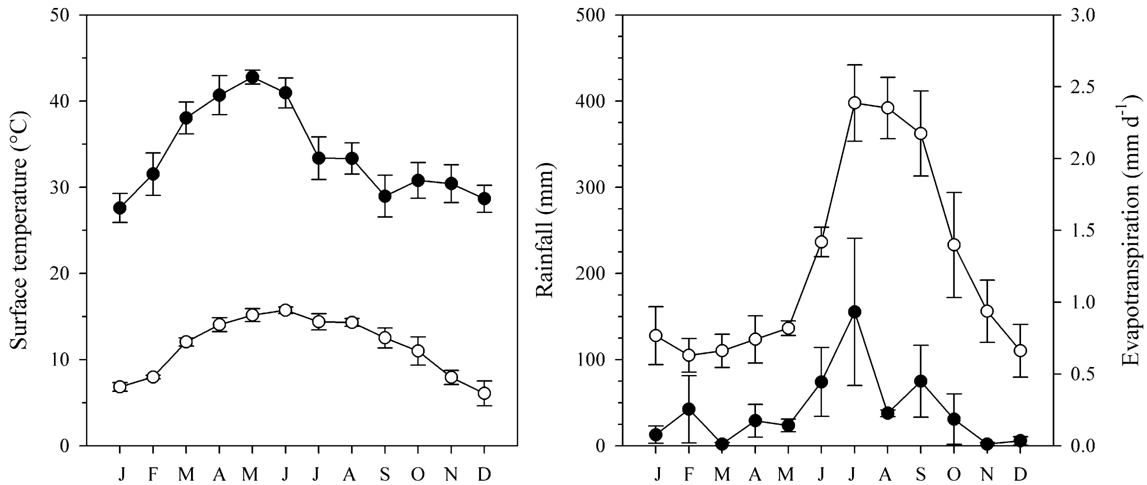
A factor analysis with repeated observations was used for the present case study, the factors being year (three levels) and month (twelve levels); this was considered a study with pseudoreplication due to the lack of randomization in the factor levels. The relationship between environmental variables and the production system was evaluated by multiple linear regression. Model variable selection was done using the variance inflation factor (VIF) with a value near 10 and elimination of reverse terms (stepwise), without considering interactions between variables. In the models, compliance was confirmed with the assumptions of normality, homogeneous variance and independence. A 5% significance level was used in the Bonferroni correction or the regression models. Analyses were run with the programs SAS University Edition (SAS Institute Inc., Cary, NC, USA) and Minitab v. 17 (Minitab Inc., State College, PA, USA).

Results and discussion

Environmental conditions

Weather during the study period coincided with the climatic description of the site, with July being the rainiest month and May the hottest (Figure 1). Daytime temperatures rose from February to June and remained stable from July to January (Figure 1A), a trend caused by cloud cover during the rainy season and the influence of polar air masses. The environment was characterized as extreme because it had a difference greater than 15 °C between the warmest (42.7 °C) and coldest (6.1 °C) months, and a broad difference between average daily daytime and nighttime temperatures in each month (Figure 1A). Average annual rainfall was 489 mm and actual evapotranspiration was 454 mm. However, these two variables’ seasonal patterns were not similar due to soil moisture content and agricultural irrigation (not measured) at the study site. The large spatial measurement scale meant these variables provided only the general environmental condition in the study region and not those of the studied alfalfa paddocks.

Figure 1. Environmental conditions at study site in Tequisquiapan, Querétaro, based on remote sensing data. A) Daytime (●) and nighttime temperatures (○) according to MOD11A2 product from MODIS; B) Rainfall based on TRMM (●) and evapotranspiration (○) based on MOD16A2 product from MODIS.



Forage production

Average PGR, PHM and HDR values differed between 2009 and the following years, but were similar between 2010 and 2011 (Table 1). From year to year RHM was only similar between 2009 and 2010. Forage production was generally significantly lower in 2011, although the tendency to decrease was first observed in 2010. Values for PGR exhibited seasonal variation with greater accumulation in the summer. Dry matter (DM) accumulation during the study period was 17,343 kg ha^{-1} yr^{-1} in 2009, 14,649 kg ha^{-1} yr^{-1} in 2010, and 13,497 kg ha^{-1} yr^{-1} in 2011. Based on PGR phenology parameters the growing season was 173 d long, beginning near day 115 (April 25) and ending near day 288 (October 15) of the year. The beginning and end of growing seasons were defined based on the threshold of 50 % PGR; in other words, PGR was lower than average for 192 d which were consequently outside the growing season. It is during this period that efforts are needed to improve PGR and livestock supplementation policy and thus reduce the feed deficit. The phenology model estimated maximum PGR to be 82.7 kg DM ha^{-1} d^{-1} on day 200 of the year. Pasture utilization rate was 75 % in 2009, 71 % in 2010 and 73 % in 2011.

Table 1: Least means squares for production and management variables of a grazed alfalfa pasture

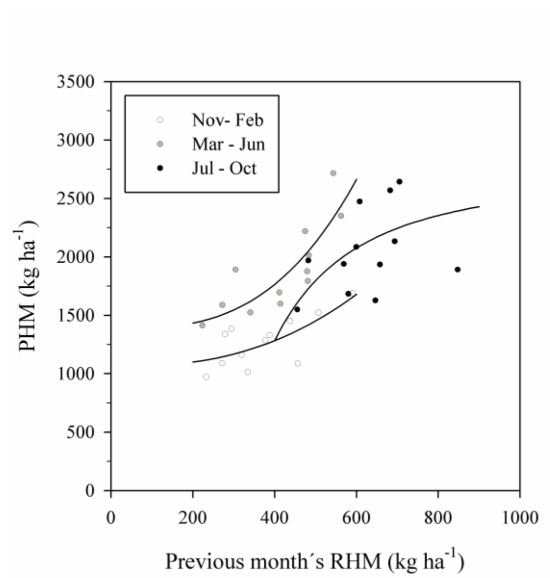
	Herbage mass						Accumulation		Rest	
	Pre-grazing		Residual (kg ha^{-1})		Disappearance Rate		Rate (kg ha^{-1} d^{-1})		Period (d)	
Year										
2009	1947	a	502	a	1445	a	58	a	36	ab
2010	1717	b	496	a	1221	b	50	b	37	a
2011	1543	b	419	b	1125	b	49	b	35	b
se	39		12		28		1.3		0.4	
Month										
Jan	1146	a	266	a	880	a	23	a	51	e
Feb	1148	a	267	a	882	a	24	a	48	d
Mar	1631	bc	412	bc	1219	bc	40	bc	41	c
Apr	1638	bc	458	bc	1180	abc	46	c	36	b
May	1861	cd	527	cd	1334	cd	60	d	31	a
Jun	2429	e	686	e	1743	e	84	e	29	a
Jul	2237	de	630	de	1607	de	78	e	29	a
Aug	2376	e	688	e	1689	e	86	e	28	a
Sep	1819	c	506	cd	1313	cd	62	d	29	a
Oct	1734	c	472	bc	1262	c	59	d	29	a
Nov	1491	abc	401	bc	1089	abc	37	bc	40	c
Dec	1324	ab	357	ab	967	ab	30	ab	44	d
se	77		25		57		2.5		0.8	

[abcde] Different letter suffixes in the same column and time category (year or month) indicate significant difference (P<0.05, Bonferroni correction).

Both PGR and PHM were highest from June to August. However, PHM values changed gradually through the months, except from August to September and from February to March (Table 1). Grazing management affected PHM behavior since it was focused on matching animal and forage production levels. Values for RHM were notably low from December to February and much higher from June to August. In response to lower PGR, which threatened winter forage production, 29-d rotations were applied in September and October. A large proportion (46%) of PHM was explained by the previous month's RHM and current month's PGR (45 %). Other sources of variation included daytime temperature, the current month's SR and GI in previous month (0.97; P<0.05). Previous month's RHM explained most (54%) of the variation in PGR, with GI explaining 30 % and nighttime temperature 2.5 % (P<0.05). The low PGR values from November to February had a proportional relationship to previous month's monthly nighttime temperature as an explanatory variable ($y= 9.70 + 2.36x$, r^2= 0.86, $F_{1,10}$= 27.4). A deficit in soil moisture can be ruled out as having had an effect in this period since evapotranspiration was similar from December to May (Figure 1B).

The relationship between previous month’s RHM (y) and PHM (x) was directly proportional (Figure 2), although in different ways depending on the period within the year: November-February ($y = 1059.22 + 0.00007\ x^{2.5}$, $F_{1,10} = 11.23$, $r^2 = 0.52$), March to June ($y = 1386.50 + 0.0000059\ x^3$, $F_{1,10} = 24.14$, $r^2 = 0.71$) and July to October ($y = 2711.01 - 228300000 / x^2$, $F_{1,10} = 4.05$, $r^2 = 0.31$). This grouping by months was according to similarity in PGR values (Table 1). Average PHM neared 2500 kg ha^{-1} only in July. From July to October PHM was not this high despite RHM values being comparatively higher than in other months. This herbage production pattern from November to February suggests the potential to obtain higher PHM (Figure 2) if RHM were between 400-600 kg ha^{-1} (RHM averaged <400 kg ha^{-1}) (Table 1). Stocking rate (SR) decreased from 3.7 cows ha^{-1} in 2009 to 3.1 cows ha^{-1} in 2010 and 2.7 cows ha^{-1} in 2011; only 2009 differed from 2011 (P<0.05).

Figure 2: Relationship between previous month’s RHM and current PHM during three periods within the year in a grazed alfalfa pasture.



Pasture chemical composition was consistent with the availability of younger forage in the autumn and winter (Table 2). Energy concentrations were particularly high in the fall. Crude protein (CP) levels were high from the fall into the winter, with higher concentrations from November to February (22.4 %) than the rest of the year (21.9 %, P<0.05). In vitro DM digestibility changed only gradually but tended to increase in the fall, while forage DM content was higher in spring than in autumn. The only significant correlation was between PHM and CP (-0.36, P<0.05).

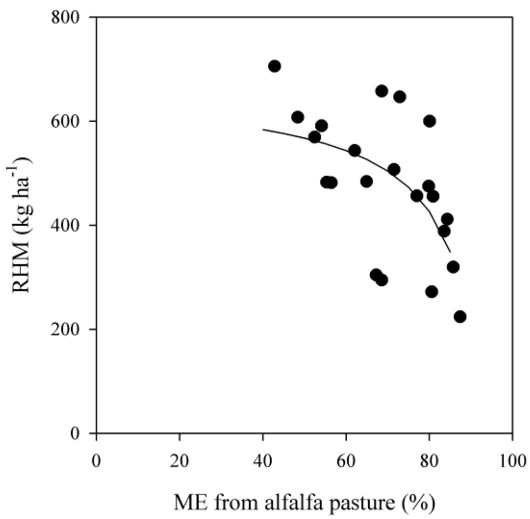
Table 2: Alfalfa pasture chemical composition

Month	Metabolizable energy Mcal kg^{-1} DM		Crude protein %		*In vitro* digestibility %		Dry matter %		Neutral detergent fiber %		Ash %	
J	11.0	ab*	22.3	ab	66.7	ab	23.3	bc	47.0	a	3.1	b
F	11.0	ab	22.3	ab	66.7	ab	23.3	bc	47.0	a	3.1	b
M	10.8	b	21.5	b	65.7	b	25.3	ba	47.7	a	3.6	a
A	11.0	b	21.8	b	66.3	ab	26.3	a	46.0	a	3.6	a
M	11.0	b	21.8	b	66.3	ab	26.3	a	46.0	a	3.6	a
J	10.8	b	21.7	b	67.0	ab	22.7	bc	45.7	a	3.1	b
J	10.8	b	21.7	b	67.0	ab	22.7	bc	45.7	a	3.1	b
A	10.8	b	21.7	b	67.0	ab	22.7	bc	45.7	a	3.1	b
S	11.3	a	22.6	a	68.0	a	22.0	c	44.3	a	3.1	b
O	11.3	a	22.6	a	68.0	a	22.0	c	44.3	a	3.1	b
N	11.3	a	22.6	a	68.0	a	22.0	c	44.3	a	3.1	b
D	11.0	ab	22.3	ab	66.7	ab	23.3	bc	47.0	a	3.1	b
se	0.1		0.16		0.46				1.0		0.9	

[abc] Different letter suffixes in the same column indicate significant difference (p<0.05, Bonferroni correction).

Pasture energy contribution differed from 60 % in 2009 to 95 % in 2010 to 84 % in 2011(P<0.05) as supplementation progressively decreased. The lower SR can be attributed to the lower pasture production and lower supplementation level. Greater supplementation in 2009 allowed for higher SR. Higher supplementation levels also led to lower RHM (Figure 3), even though effective grazing area increased over time (12.4 ha in 2009, 17.8 ha in 2010 and 22.2 ha in 2011). The supplementation strategy and pasture management were apparently not clearly linked.

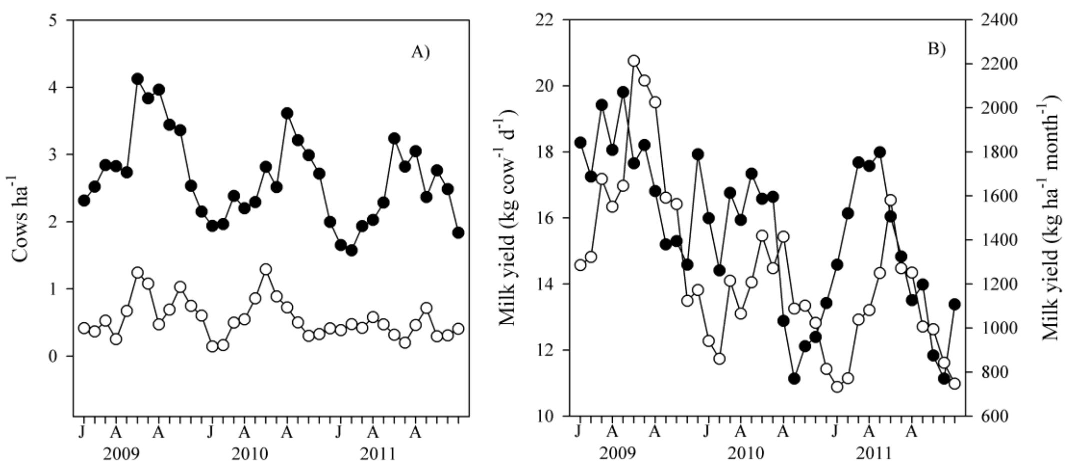
Figure 3: The relationship between metabolizable energy (ME, %) from the alfalfa pasture and RHM in months with more than 10% energy supplementation.



Milk production

The potential profitability of grazing systems depends on multiple factors. Prominent among these are high forage production per hectare per year, high forage use levels by the grazing dairy herd, and the cows' genetic potential for milk production exclusively from grazed pasture. Milk production can be modified by adding concentrated feed, hay or silage in the diet to supplement (or complement) nutrient supply. In the present case study, different nutritional regimes were established in the form of supplementation supporting animal productivity in 2009, and the almost total absence of supplements in 2010 and 2011. Moreover, the supplementation strategy was not focused on compensating for the seasonal nutrient deficit, and the productive model's seasonal pattern consequently exhibited a mismatch between peak pasture forage production from June to August (Table 1) and peak milk production from March to May, especially in 2009 (Figure 4). Monthly milk production (kg milk ha^{-1} mo^{-1}) was explained linearly by SR in the range of 2.0 to 5.5 cows ha^{-1} (y= 2.0 + 392.7 x, corrected r^2= 0.74, P<0.0001). Changes in SR and increasing the grazing area were the main strategy used to compensate for the feed deficit. Average milk production was higher in 2009 than the other two years (which did not differ), be it by animal unit (17.4 kg cow^{-1} d^{-1} in 2009, 14.6 kg in 2010 and 14.9 kg in 2011; P<0.05) or unit area (1,607.5 kg ha^{-1} mo^{-1} in 2009, 1,118.3 kg in 2010 and 1,047.0 kg in 2011; P<0.05).

Figure 4: Stocking rate (A): lactating (●) and dry (○) cows, and milk yield (B): per cow (●) and area unit (○) for Holstein and Jersey dairy herd grazing an alfalfa pasture.

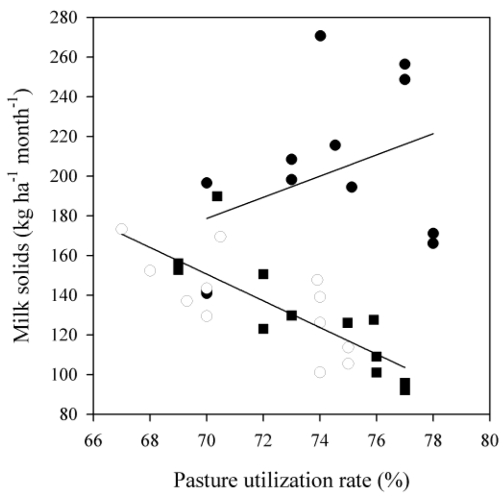


Lactating cows were incorporated seasonally, using more in June to August and fewer from December to January (Figure 4A). Milk yield per hectare was linked to the number of lactating cows. In all three years of the study period milk yield per cow was lower in the three months of September to November (13.1 kg cow^{-1} d^{-1}) than during the rest of the year (16.5 kg cow^{-1} d^{-1}) (P<0.05). One strategy tested was to increase the number of cows in an effort to match forage availability to nutrient demand. However, it was not very effective at resolving the feed deficit of the autumn and winter months and led to a drop in milk production most evident in individual productivity (kg cow milk^{-1} d^{-1}, Figure 4B).

There was a strong correlation between different yields (milk, solids or fat) and the variables of CP concentration (-0.41 in 2009, -0.39 in 2010 and -0.37 in 2011), NDF (0.48 in 2009, 0.49 in 2010 and 0.41 in 2011) and monthly energy intake from pasture (-0.41 in 2009, -0.45 in 2010 and -0.39 in 2011). Analysis of milk yield with progressive elimination multiple regression models and candidate explanatory variables related to the environment, the pasture and feed intake showed daytime temperature, monthly energy intake from the pasture and monthly energy intake from concentrate to be the common explanatory variables in the models for milk, total solids and fat yields; these models' corrected r^2 was greater than 0.9 (P<0.05). When feed composition was the only candidate variable the yields (milk, total solids or fat) were explained mainly by monthly energy intake from the pasture or concentrate, although CP and NDF concentration also had some effect; these models' corrected r^2 was less than 0.84 (P<0.05). In the presence of environmental variables, pasture CP and NDF concentrations had no significant effect.

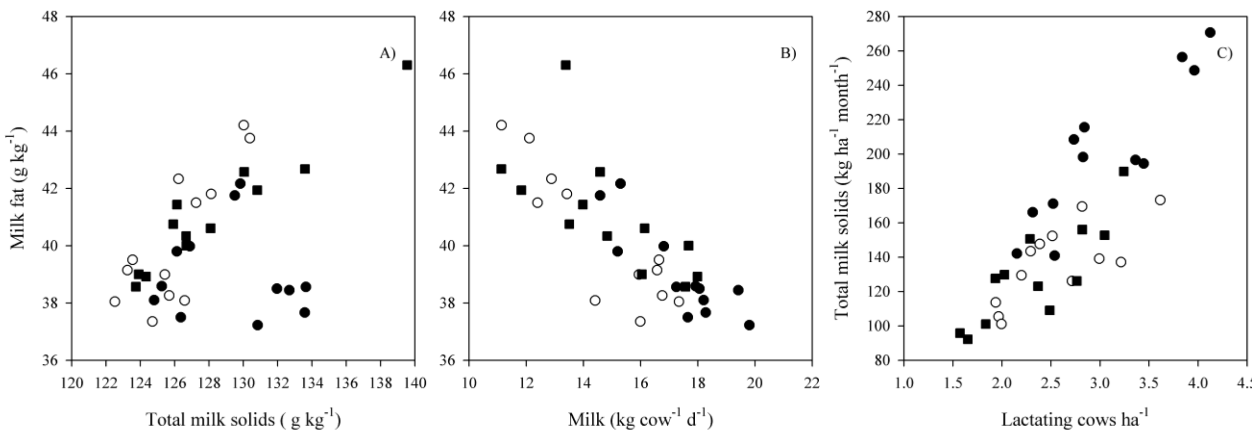
Pasture use level and total milk solids production were closely related (Figure 5). In 2009 pasture use level had no effect on solids production due to the good availability of concentrated feed. A lack of concentrates in 2010 and 2011 resulted in heavier pasture use, with a consequently negative effect on milk solids production. Increasing PHM to levels above 2000 kg ha^{-1} and RHM to at least 600 kg ha^{-1} kg would result in a use level (70%) approximating a balance between animal and pasture production.

Figure 5: Relationship between pasture utilization rate and milk solids per hectare in 2009 (●), 2010 (○) and 2011 (■). During 2010 and 2011 supplementation was low.



In 2010 and 2011 total milk solids increased in response to milk fat, but in 2009 milk fat did not exceed 43 g kg^{-1} regardless of the higher total solids levels in this year (Figure 6A). The highest total solids and fat values were in the months of November and December 2011, when milk yield was the lowest at any point during the study period (Figure 4B). Milk fat generally decreased as milk production increased (Figure 6B), but without clear differences between years, possibly due to the seasonal effects of other variables. However, total milk solids produced per hectare was proportional to the number of cows per hectare and the highest yield levels were in 2009, mainly due to higher supplementation levels (Figure 6B). This higher supplementation also resulted in higher milk solids yield per hectare although with a lower fat proportion. In 2010 and 2011 total milk solids yield did not exceed 200 kg ha^{-1} month^{-1} in most months. These discrepancies in milk solids yield highlight the need to assess the economic costs of supplementation (Figure 5).

Figure 6: Relationship between milk characteristics in 2009 (●), 2010 (○) and 2011 (■). (A) Milk fat and total solids; (B) milk fat and milk yield; and (C) monthly milk solids yield and lactating cows per hectare.



During the study period total milk solids (fat, protein and lactose) yield (2,409 kg ha^{-1} yr^{-1} in 2009, 1,638 kg in 2010 and 1,554 kg in 2011) was near the 1,580 kg ha^{-1} reported for the highly productive grasslands of the Waikato area of New Zealand(21), although the current definition of total solids in New Zealand does not include lactose(22). Milk fat yields (727 kg ha^{-1} yr^{-1} in 2009, 523 kg in 2010 and 496 kg in 2011) were also near the 600 kg ha^{-1} reported in the same study. Annual milk yield (19,290 kg ha^{-1} in 2009, 13,419 kg ha^{-1} in 2010 and 12,563 kg ha^{-1} in 2011) was within levels reported for alfalfa-based grazing production with strategic supplementation (10,000 L ha^{-1} year^{-1}), lactations ranging from 7,000 at 7,500 L, and a two-cow ha^{-1} stocking rate(23).

Improving the production system used in the present study would depend on matching forage production and feed demand, and strategic use of feed supplements to compensate for pasture PHM deficit. Alfalfa growth in the present case was seasonal whereas milk production was constant year-round, lacking a planned period without production during which all cows were simultaneously dry, as is commonly done in seasonal grazing systems(24). According to the phenology model, PGR was higher than average for 173 d, meaning there were 192 d during which forage production could be improved by addressing the limiting factors of temperature, water and nutrients. Climate change is predicted to bring milder winters and warmer nights to the study region(25,26), suggesting that alfalfa may perform better based on the temperature results of the regression model. Levels for PGR were lowest from November to February, meaning strategic application of nitrogen fertilizer(27) and adequate irrigation management to compensate for evaporation could improve yield during this season. Additional soil moisture and mineralizable nitrogen data are needed to better support these decisions. However, during this period alfalfa CP concentration was high compared to nutrient requirements, highlighting the need to balance the diet through supplements or promote grass growth in the pasture.

Fluctuations in milk yield suggest there is an opportunity for improvement since yield per hectare did not precisely follow individual yield, particularly in the November to February period. One strategy would be to focus on supplementation and better pasture management during this period.

Conclusions and implications

The present work showed the importance of representing the performance of pasture production in terms of harvested area per unit of time. Minimum cut height to assess grazing management was 10 cm in order to maintain a safety margin against overgrazing and decrease defoliation of alfalfa regrowth. When pasture residual herbage mass was lower so were the herbage mass available for grazing and accumulation rate in the following month. Pasture metabolizable energy also decreased when post-grazing residual mass was lower, which required feed supplements. Based on the present results a minimum threshold for management of residual mass would be from 400 to 500 kg DM ha^{-1} depending on the period of the year, but especially from November to February. Total milk solids production per hectare declined at higher pasture utilization rate and lower feed supplementation levels; clearly, supplementation had a compensatory effect. Nighttime temperature had a positive effect on herbage accumulation rate, while daytime temperature had a positive effect on milk or total solids yield. Mismatches in pasture production and milk yield peaks were notable, indicating a need to better synchronize the annual phases in this grazing system. The mismatch between the year-round milk production model, the seasonal yield of alfalfa pasture and the inefficiencies of grazing management could be addressed particularly during the 192-d period of phenology when pasture accumulation rate was 50 % below maximum. Feed supplementation is clearly needed in cattle grazing alfalfa and must be applied strategically during certain periods of the year and considering the targeted total milk solids yield. Finally, deeper study is needed of microclimate interactions in a grazing milk production model based on alfalfa, especially given rainfall deficits during drought and the alternative use of irrigation in other production options.

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