Effects of feeding supplemental organic iron to late gestation and early lactation dairy cows

W. P. Weiss,^{*1} J. M. Pinos-Rodríguez,^{*2} and M. T. Socha†

^{*}Department of Animal Sciences, Ohio Agricultural Research and Development Center, The Ohio State University, Wooster 44691

†Zinpro Corp., 10400 Viking Dr., Eden Prairie, MN 55344

ABSTRACT

The objectives of this experiment were to determine the Fe status of cows in late gestation and early lactation and determine whether measures of Fe status and milk production were affected by feeding supplemental organic Fe. Starting 60 d before anticipated calving, cows and heifers were fed diets with 0 or 30 mg/kg of supplemental Fe (Availa-Fe, Zinpro Corp., Eden Prairie, MN). All animals changed to prefresh diets at 14 d before anticipated calving and then to lactation diets following calving; the Fe supplementation rates (0 or 30 mg/kg) remained constant. The experiment ended at 63 d in milk. Hematocrit, hemoglobin, serum Fe, unsaturated Fe binding capacity, and percentage Fe binding saturation were measured at the start of the experiment, 7 d before calving, 7 d after calving, and at 60 d in milk. Treatment did not affect any measure of Fe status and values did not change greatly over time. Milk production (averaged 41 kg/d), milk composition, and dry matter intake during early lactation (averaged 20.4 kg/d) were not affected by treatment. The somatic cell count of milk was reduced when cows were fed supplemental Fe (114,000 vs. 94,000 cells/mL). The limited response to supplemental Fe may have been because basal diets were adequate in Fe (ranged from 282 to 336 mg of Fe/kg of DM) even though most of the basal dietary Fe was provided by forages, which are generally considered poor sources of available Fe.

Key words: iron requirement, dairy cow, hemoglobin, iron binding capacity

INTRODUCTION

Over the past several decades, milk yield per cow has increased greatly with a concomitant increase in the

need for nutrients. Although Fe is a required nutrient for adult dairy cattle, essentially no research has been conducted evaluating its requirement in the last 50 yr. A possible reason for the lack of research in this area in dairy cows is that diets typically contain substantial concentrations of Fe. A major source of dietary Fe for dairy cows is forage. Forages, because of soil contamination, often contain more than 200 mg/kg of Fe, which presumably should be adequate to meet or exceed a cow's requirement for Fe (Underwood and Suttle, 1999). Soil Fe, however, can have very low bioavailability (Hansen and Spears, 2009). Another possible reason for the lack of research evaluating Fe requirements is the known negative effects of feeding excess Fe. Diets that contain ≥ 250 mg of supplemental Fe/kg of DM from Fe sulfate (a good source of bioavailable Fe; van Ravenswaay et al., 2001) can reduce the Cu status of cattle, increase oxidative stress, and have detrimental effects on cow health, production, intake, and fiber digestion (Boyne and Arthur, 1986; Barraza et al., 1991; Harrison et al., 1992; Campbell and Miller, 1998; McCaughey et al., 2005).

Even though new data were lacking, the National Research Council (NRC, 1989, 2001) requirements for Fe for lactating dairy cows decreased substantially from 1989 (50 mg/kg) to 2001 (approximately 20 mg/kg). The NRC (2001) Fe requirement was calculated using data from 6-wk-old calves and pregnant ewes. Because Fe absorption is strongly influenced by body iron status (Ammerman et al., 1967), nonlactating dairy cows and other species of animals may not be accurate models of a high-producing lactating dairy cow. Indirect evidence suggests that limited amounts of supplemental Fe may be beneficial to cows. Supplemental iron (< 30 mg/kg) improved in vitro cellulose digestion (Martinez and Church, 1970). An association between low hemoglobin concentrations and low milk yields has been shown in dairy goats (Atroshi et al., 1986), and hemoglobin is correlated with body iron stores of cows (Miyata and Furugouri, 1987). Based on some but not all measures, the Fe status of dairy cows may decrease during late gestation (Furugouri et al., 1982). For those measures of status that did decrease, some decreased a few weeks

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¹Corresponding author: weiss.6@osu.edu

²Current address: Instituto de Investigación de Zonas Desérticas, Universidad Autónoma de San Luis Potosí, Altair No. 200, Fracc. del Llano, 78377 San Luis Potosí, SLP, Mexico.

before parturition, but others declined throughout the dry period. Because of the life span of mammalian red cells (~120 d; Brace et al., 2000), reduced Fe status during this period may carry over several months into the lactation period.

We hypothesized that because of fetal growth, increased maternal blood volume, and low DMI (relative to that in lactating cows), Fe status may be reduced in late gestation dairy cows and that supplementing a small quantity (30 mg Fe/kg of diet DM) of bioavailable Fe would improve measures of Fe status. Furthermore, improved Fe status in late gestation should result in increased milk production in early lactation. The objective of this experiment was to determine the effects of feeding supplemental Fe to dairy cows in late gestation through early lactation on measures of Fe status and milk production and composition.

MATERIALS AND METHODS

Cows and Diets

All procedures involving animals in this experiment were approved by the Agricultural Animal Care and Use Committee of The Ohio State University. Holstein heifers ($n = 12$) and cows ($n = 42$) were grouped by parity (heifers and cows) and anticipated calving date into 27 blocks of 2 animals. Within block, each animal was assigned randomly to the control treatment (no supplemental iron) or Fe treatment (30 mg/kg additional Fe provided by an iron-amino acid complex, Availa-Fe, Zinpro Corp., Eden Prairie, MN). Based on typical DMI and typical feedstuffs, diets with between 15 and 25 mg/kg of total Fe should meet the Fe requirement of dry, transition, and early lactation dairy cows (NRC, 2001). High supplementation rates of Fe (approximately 100 to 600 mg/kg) can be detrimental (Harrison et al., 1992) to rumen fermentation and cow health (Campbell and Miller, 1998). The supplementation rate of 30 mg/kg was chosen because nutritionists often do not consider the trace minerals supplied by the basal diet (i.e., supplemental trace minerals are added to equal NRC recommendations for total trace minerals) and it was well below rates shown to have adverse effects.

Animals started the experiment 60 d before anticipated calving and the experiment ended at 63 DIM. During the last 60 d of gestation, animals were group-housed within treatment in adjacent, similar pens (1 pen per treatment). Pen DMI was measured daily (10.8 and 10.6 kg/d for control and supplemented pens). Diets were fed as TMR once daily and were identical except for Fe supplementation (Tables 1 and 2). The amount of TMR offered was adjusted daily to maintain <2% feed

refusals (as-fed basis). At 14 d before anticipated calving, cows were moved to individual box stalls and fed a transition diet (Table 1) but remained on the same Fe supplementation treatment. Cows were fed once daily and enough was offered to provide for approximately 5% feed refusals (as-fed basis). Feed offered and feed refused was measured daily. After calving, cows were moved to tie stalls and fed a lactation diet (Table 1) but remained on the same Fe treatment to which they were first assigned. Cows were fed once daily to allow approximately 10% feed refusals (as-fed basis). During the lactation phase, cows were milked twice daily with milk weights recorded electronically. After calving, a.m. and p.m. milk samples were taken weekly (after 3 DIM) from each cow until 63 DIM and analyzed for milk fat, protein, lactose (B2000 Infrared Analyzer, Bentley Instruments, Chaska, MN) and MUN (Skalar SAN Plus segmented flow analyzer, Skalar Inc., Norcross, GA) by DHI Cooperative Inc. (Columbus, OH). Cows were weighed at the start of the experiment (60 d before anticipated calving), 14 d before anticipated calving, 3 DIM, and 63 DIM. Body condition (1 = emaciated; 5 = obese) was evaluated at 3 and 63 DIM by 2 independent scorers.

Sampling and Analyses

Blood samples were taken from the tail vein at 60 d before anticipated calving (before treatments were imposed), 7 d before anticipated calving, 7 DIM, and 63 DIM. One sample (approximately 7 mL) was allowed to clot and serum was harvested; one sample (7 mL) was taken into tubes containing heparin. The heparinized whole blood was analyzed the same day for hematocrit [microhematocrit tubes centrifuged at $13,000 \times g$ for 7 min in an IEC Microhematocrit Centrifuge (Thermo Fisher Scientific Inc., Waltham, MA) and read on an IEC Microcapillary Reader] and hemoglobin (Hemoglobin Reagent cat. no. 0320-650, standards cat. no. 0325-006, and tri-level controls cat. no. 0330-302; Stanbio Laboratory, Boerne, TX). The serum was assayed for serum Fe and unsaturated Fe-binding capacity using commercial kits (Iron and Total Iron Binding Capacity, cat. no. 0370-110, Stanbio Laboratory), except that all volumes were reduced by a factor of 10 and tests were performed in 96-well microplates and read on a microplate reader (Bio-Tek Instruments Inc., Winooski, VT). Total Fe binding capacity was calculated as unsaturated Fe binding capacity – serum Fe. Percentage binding saturation was calculated as (serum Fe/total Fe binding capacity) $\times 100$.

All forages were sampled weekly and composited by month. Weekly silage samples were analyzed for DM (100°C oven for 24 h) to adjust as-fed amounts. Con-

Table 1. Ingredient composition (% of DM) of control diets fed during the experiment¹

Item	Dry cow	Prefresh	Lactation
Mature grass hay	50.0	25.0	—
Mostly grass silage	22.0	—	—
Corn silage	17.0	20.3	25.0
Alfalfa silage	—	15.4	30.0
Corn grain, ground	1.25	15.90	16.7
Soybean meal, 44% CP	5.23	9.60	3.92
Soybean hulls	2.82	11.30	3.20
Treated soybean meal ²	—	—	5.85
Distillers grains with solubles	—	—	4.32
Wheat middlings	—	—	7.07
Fat supplement ³	—	—	1.76
Limestone	0.08	0.29	0.78
Mg oxide/Mg sulfate (50:50)	0.28	0.31	—
Iodized salt	0.17	0.43	0.39
Sodium bicarbonate	—	—	0.29
Organic trace mineral mix ⁴	0.09	0.09	0.07
Selenium/vitamin premix ⁵	1.08	1.38	0.65

¹Treatment diets were identical except they contained 0.003% organic Fe (10% Fe, Availa-Fe 100, Zinpro Corp., Eden Prairie, MN) in place of corn meal.

²Nonenzymatically browned soybean meal (Borregaard LignoTech, Rothschild, WI).

³Energy Booster 100 (Milk Specialties Global, Carpentersville, IL).

⁴4-Plex (Zinpro Corp.); contained 0.90% Cu from Cu lysine, 0.18% Co from Co glucoheptonate, 1.43% Mn from Mn methionine, and 2.58% zinc from Zn methionine.

⁵Provided 20 mg of biotin, 90 and 25 kIU of vitamins A and D, 500 (lactating) or 1,000 (dry/prefresh) IU of vitamin E daily, and 0.3 mg of Se/kg of diet DM (from sodium selenate).

centrates were sampled every 2 wk and composited by month. Feed refusals by lactating cows were sampled every 2 wk and analyzed for DM (100°C for 24 h) for DMI calculations. Composite feed samples were dried (55°C for 48 h) and then ground through a 1-mm screen (Wiley mill, Arthur A. Thomas, Philadelphia, PA). Ground samples were analyzed for DM (100°C oven for 24 h), NDF (Ankom²⁰⁰ Fiber Analyzer, Ankom Technology, Fairport, NY) with sodium sulfite and amylase (#FFA, Ankom Technology), CP (Kjeldahl N $\times$ 6.25),

and ash (AOAC, 2000). For specific mineral assays, ground forage samples were dry-ashed (AOAC, 2000) and concentrate feed samples were digested with perchloric acid (AOAC, 2000); inductively coupled plasma emission spectroscopy was used to quantify mineral concentrations. The drinking water for the cows was sampled monthly from 2 sites at the dairy center and analyzed for minerals (n = 10 total samples). All samples had no detectable concentrations of Fe (detection limit 0.002 mg/L).

Statistical Analysis

Of the 54 animals that started this experiment, 3 animals (all on the Fe treatment) did not complete the experiment. One primiparous cow developed nonresponsive ketosis after calving and was culled, one multiparous cow was injured after falling and was euthanized, and one multiparous cow developed an unidentified systemic infection and was euthanized. All data from those animals were excluded from statistical analysis. Pens were not replicated; therefore, data collected during the pen feeding phase cannot be statistically analyzed. Milk SCC (cells/mL) was transformed to log₁₀ to normalize the data before statistical analysis.

The average duration of the prefresh period was 13.5 d (SD = 3.6), which corresponds to the targeted 14-d prefresh period. All cows were in box stalls for at least 7 d before actual calving; therefore, DMI data from the last 7 d of gestation were averaged within cow and analyzed statistically using PROC MIXED (SAS Institute, 2004) with a model that included block (26 df, random), treatment (1 df, fixed), and error (23 df). Average daily change in BW during late gestation (difference between 60 and 14 d before anticipated calving) and during early lactation (between 3 and 63 DIM), and change in BCS in lactation (3 to 63 DIM) were analyzed using that same model.

Table 2. Nutrient composition of diets (DM basis)

Item	Dry cow		Prefresh		Lactation	
	– Fe	+ Fe	– Fe	+ Fe	– Fe	+ Fe
DM, %	67.7	67.6	71.7	71.8	65.0	65.0
CP, %	13.0	13.0	14.6	14.7	15.9	16.3
NDF, %	52.0	51.9	42.4	42.3	35.6	35.4
Ash, %	7.6	7.6	7.3	7.2	6.6	6.5
Ca, %	0.67	0.65	0.87	0.85	0.96	0.88
P, %	0.29	0.29	0.30	0.30	0.36	0.36
Mg, %	0.29	0.28	0.32	0.31	0.21	0.22
K, %	2.03	2.04	1.61	1.62	1.41	1.41
Na, %	0.09	0.09	0.19	0.19	0.27	0.26
Cu, mg/kg	15	14	16	15	13	12
Mn, mg/kg	104	108	74	78	66	73
Zn, mg/kg	69	78	75	84	76	73

Table 3. Concentrations of iron in major diet ingredients and TMR¹

Item	Fe, mg/kg of DM	SD
Ingredient (diet)		
Grass hay (dry cows)	137	51
Grass hay (prefresh cows)	310	180
Grass silage (dry cows)	618	513
Corn silage (all cows)	429	139
Alfalfa silage (prefresh and lactating)	300	114
Dry cow control concentrate mix	432	56
Dry cow Fe concentrate mix	672	60
Lactating cow control concentrate mix	189	11
Lactating cow Fe concentrate mix	241	19
Calculated concentrations of total diets		
Dry cow, control	313	—
Dry cow, Fe treatment	340	—
Prefresh, control	336	—
Prefresh, Fe treatment	362	—
Lactating cow, control	282	—
Lactating cow, Fe treatment	306	—

¹Prefresh cows (last 14 d of gestation) did not have a separate concentrate mix. They were fed a mixture of dry and lactating cow concentrate mixes.

Milk and DMI data (3 to 63 DIM) were averaged into six 10-d periods within cow and analyzed using PROC MIXED with block (26 df, random), treatment (1 df, fixed), period (5 df, repeated, fixed), treatment by period interaction (5 df, fixed) and error. Milk composition data were analyzed with the same model except that samples were taken weekly resulting in 8 periods rather than 6. Blood data were analyzed within each day using the same model as used for prefresh DMI and also across all days (−7, 7, and 63 DIM) using the repeated measures model described above except that period had only 2 df.

RESULTS AND DISCUSSION

Dietary Fe Concentrations

The targeted supplementation rate for Fe was 30 mg/kg; based on assayed values (Table 3), the supplemented diets had 27, 26, and 24 mg/kg more Fe than control diets during the dry period, prefresh period, and lactation period, respectively. Calculated dietary concentrations of Fe (based on assayed values of ingredients) ranged from 282 to 362 mg/kg, values that are more than 10 times higher than the NRC (2001) requirement for Fe. The supplemental Fe contributed approximately 8% of the total dietary Fe across all phases of this experiment. During the gestation phase, forage provided 65 and 60% of the total dietary Fe for the control and supplemented groups; during the lactation phase, forages provided 70 and 64% of the dietary Fe (Table 3). Most of the forages had more than 300 mg/kg of Fe and concentrations were highly variable (CV for forages ranged from 37 to 84%). The Fe concentrations in

the concentrates were much less variable (CV ranged from 6 to 13%). Coefficients of variation for forages often exceed 100% [feed composition databases from Dairyland Laboratories Inc. (www.dairylandlabs.com) and Dairy One Cooperative Inc. (www.dairyone.com)]. The primary reason silage and hays often have high and variable concentrations of Fe is soil contamination. The Fe in soil is considered to have poor bioavailability because of the presence of chelating agents (Hansen and Spears, 2009) and because the Fe is mostly in the ferric form, which is generally much less bioavailable, at least in nonruminants, than ferrous or heme iron (Miret et al., 2003). The availability of soil Fe, however, might be increased by silage fermentation. Using various in vitro and chemical measurements that may be related to bioavailability, Hansen and Spears (2009) reported that soil Fe added to corn plants and then fermented for 90 d was 3 to 12 times more bioaccessible than soil Fe added to corn silage and assayed immediately. Nevertheless, even following fermentation, soil Fe was <2% bioaccessible based on dialyzable Fe concentrations. The diets in this study contained substantial concentrations of Fe, but because much of it was provided by forage (and likely soil contamination) bioavailability may have been limited.

Blood Measures

We hypothesized that the most likely response to supplemental Fe would occur during late gestation and early lactation; therefore, this type of cow was the experimental unit. Supply of dietary Fe is relatively low during this period because of low DMI (relative to a high-producing dairy cow) but the need for Fe is high

Figure 1. Effect of feeding diets with 0 or 30 mg/kg of supplemental Fe to late gestation and early lactation dairy cows on hematocrit and hemoglobin concentrations. Treatment did not affect these measures, but time ($P < 0.05$) and the treatment $\times$ time interaction ($P < 0.05$) affected both measurements ($P < 0.05$). When error bars are not visible, the SE is smaller than the size of the symbol. Color version available in the online PDF.

because of fetus and conceptus growth and increased maternal blood volume. During the last 80 d of gestation, the accretion rate of Fe in the conceptus (fetus, fluids, fetal membranes, and uterine tissue) was 18 mg/d for Holstein cows (House and Bell, 1993). In addition to fetal accretion, maternal blood volume increases during gestation (Reynolds, 1953), which may require as much as 10 mg/d of Fe for maternal hematopoiesis (assumed Fe concentration of erythrocytes = 20 mM). The total Fe needed by cows in late gestation (approximately 28 mg/d) is equivalent to the daily Fe secreted in milk by a cow producing 28 kg of milk/d, but the lactating cow would be expected to consume 8 to 10 kg more DM/d than a late gestation cow.

Based on several indicators of Fe status (Figures 1, 2, 3, and 4), there was no evidence to suggest reduced status from 60 d prepartum through 60 d postpartum, and values were within normal reference ranges (Underwood and Suttle, 1999). Time (samples collected at -60, -7, 7, and 60 DIM) did not affect ($P > 0.3$) Fe binding capacity measurements but did affect ($P < 0.05$) serum Fe, hemoglobin, and hematocrit. Differences, however, were minor across time points (Figures 1 and 2) and are likely not biologically important. Supplemental Fe did not affect hematocrit, hemoglobin, serum Fe, Fe binding capacity saturation, and percentage saturation ($P > 0.4$ for all measurements), probably because no indication of reduced status was observed in control cows. Interactions between time and treatment were observed ($P < 0.05$) for hematocrit and hemoglobin as illustrated by the crossing lines in Figure 1 that occur between -7 and 7 DIM. However, the numerical changes that occurred were very small and probably not biologically important.

Figure 2. Effect of feeding diets with 0 or 30 mg/kg of supplemental Fe to late gestation and early lactation dairy cows on serum Fe concentrations. No treatment or treatment by time interactions were observed ($P > 0.2$), but values were affected by time ($P < 0.05$). Color version available in the online PDF.

Furugouri et al. (1982), in a limited study (10 Holstein cows), reported that serum Fe and Fe binding measurements decreased during the peripartum period, reaching their nadir at or shortly after parturition. Hematocrit and hemoglobin concentrations also decreased during this period but reached their nadir 2 to 3 wk after parturition. Diets and milk production were not reported in that paper. Miltenburg et al. (1991) also reported that serum Fe and some Fe binding measures decreased at calving in crossbred Friesian cattle (diets and milk yields not reported). The reasons why measures of Fe status in this study did not change over late gestation and early lactation when earlier studies found decreased status around calving cannot be elucidated

Figure 3. Effect of feeding diets with 0 or 30 mg/kg of supplemental Fe to late gestation and early lactation dairy cows on serum unsaturated Fe binding capacity. No treatment, time, or treatment $\times$ time interaction effects were observed ($P > 0.2$). Color version available in the online PDF.

but differences in diet composition and DMI might be involved.

Studies examining the effects of supplemental Fe on measures of Fe status in adult cattle are lacking. In calves that are deficient in Fe, supplemental Fe can increase hemoglobin, hematocrit, and serum Fe (Reece et al., 1985; Kume and Tanabe, 1994); in Fe-deficient pigs, supplemental Fe reduces unsaturated Fe binding capacity by increasing the percentage saturation (Furugouri, 1972). However, in calves that were Fe adequate, feeding additional Fe (even very high amounts of Fe) did not affect these measures (McGuire et al., 1985). The lack of substantial treatment effects on blood measures of Fe status suggests that cows in this study were adequate in Fe and additional Fe was unnecessary.

Production Data

Body weights during the experiment were not affected by treatment (Table 4). On average, BW increased during the late gestation period (0.25 kg/d; SE = 0.14; $P > 0.9$, data not shown) and decreased during early lactation (−0.71 kg/d; SE = 0.16; $P > 0.5$). Body condition score during early lactation was not affected by treatment ($P > 0.4$). The BCS averaged 3.3 at 3 DIM and 2.9 at 60 DIM (SE for both time points = 0.1).

Intake during the 7 d before calving, milk production, milk composition, and DMI by cows in early lactation was not affected by feeding supplemental Fe (Table 4, Figure 5). If supplemental Fe had increased milk production, the most likely mode of action would be increased oxygen carrying capacity of the blood or improved health (e.g., less mastitis) via reduced oxidative stress because of enhanced antioxidant status. Published data with lactating dairy cows is lacking but anemic dairy calves grow slower than healthy calves,

Figure 4. Effect of feeding diets with 0 or 30 mg/kg of supplemental Fe to late gestation and early lactation dairy cows on percentage of Fe binding capacity that is saturated. No treatment, time, or treatment × time interaction effects were observed ($P > 0.2$). Color version available in the online PDF.

and supplemental dietary Fe can increase growth rate when given to Fe-deficient calves (Thomas et al., 1954). The lack of treatment responses for hemoglobin and hematocrit suggests that the oxygen-carrying capacity of the blood was not altered by treatment and was not limiting in the control cows. Other dietary situations including lower basal concentrations of Fe and the presence of Fe antagonists might influence Fe status and might change the response to supplemental Fe. For example, in a recent study with beef cattle, supplementation with 10 mg/kg of Cu (basal diet was 7 mg/kg of Cu) significantly reduced Fe concentrations in plasma and liver (Hansen et al., 2009) although concentrations were still in the normal range.

Iron supplementation can affect immune function and oxidative balance in animals. Beef cattle fed diets with high concentrations of supplemental Fe (500 mg/

Table 4. Production data for 3 to 63 d in milk for cows fed diets with 0 or 30 mg/kg of supplemental Fe¹

Item	Control	Fe	SEM	$P <$
BW at dry-off, kg	710	690	15.0	0.76
BW at 14 d before calving, kg	722	703	14.7	0.36
BW at 3 DIM, kg	669	647	12.7	0.24
BW at 60 DIM, kg	624	611	12.0	0.45
Prepartum DMI, ² kg/d	11.8	11.3	0.39	0.19
Postpartum DMI, kg/d	20.7	20.1	0.51	0.24
Milk, kg/d	41.7	42.0	1.25	0.84
Milk/DMI	2.04	2.11	0.039	0.19
Milk fat, %	4.80	4.60	0.12	0.19
Milk protein, %	2.83	2.82	0.037	0.8
Milk fat, kg/d	2.01	1.95	0.07	0.5
Milk protein, kg/d	1.18	1.19	0.03	0.7
MUN, mg/dL	9.19	8.95	0.24	0.35
SCC, log ₁₀ (cells/mL)	4.62	4.37	0.11	0.04

¹The time (six 10-d periods) by treatment interaction was not significant ($P > 0.3$) for any postpartum measurement (time was not included in statistical analysis for BW).

²DMI during the last 7 d of gestation.

Figure 5. Effect of feeding diets with 0 or 30 mg/kg of supplemental Fe to late gestation and early lactation dairy cows on milk production and DMI. Period 1 started at 3 DIM. No treatment or treatment $\times$ time interactions were observed ($P > 0.2$). Color version available in the online PDF.

kg from Fe sulfate) had reduced neutrophil function (phagocytosis and killing ability), which was ascribed to reduced Cu status (Boyne and Arthur, 1986). Other studies have shown no negative effects of high dietary Fe (Niederman et al., 1994; Gengelbach et al., 1997). Interestingly, in one study (Gengelbach et al., 1997), neutrophil kill was substantially higher (although not statistically higher) when cattle were fed 600 mg/kg of supplemental Fe (from Fe sulfate) compared with cattle not fed supplemental Fe. Iron-deficient rats had evidence of increased oxidative damage compared with rats fed Fe-adequate diets (Rao and Jagadeesan, 1996). One presumed mode of action for that response is via catalase, an Fe-containing enzyme that catalyzes the reaction that converts hydrogen peroxide to water. However, in the Rao and Jagadeesan (1996) study, hepatic catalase activity was not different between Fe-deficient and Fe-adequate rats although several measures confirmed increased oxidative stress with Fe deficiency. Based on measures of Fe status in our study, control and supplemented cows were probably in similar Fe status suggesting that oxidative stress did not differ between groups. However, cows fed supplemental Fe had lower $\log_{10}$ SCC ($P < 0.05$) than control cows, and increased mastitis is related to oxidative stress and antioxidant status (Weiss and Spears, 2005). The treatment effect on SCC, however, must be considered carefully. Arithmetic mean SCC was 114,000 and 94,000 cells/mL for control and treatment, respectively, and the biological and economic significance of this difference is probably limited. Additional research (preferably with cows with higher SCC) is needed to verify this finding.

This experiment ended at 63 DIM and the voluntary waiting period before breeding for our herd is 60 d. Therefore, this study was not designed to evaluate the effects of Fe on reproduction measures. After the experiment concluded, cows on this protocol may have been culled for various reasons or would have been assigned to other experiments. Retrospective analysis of reproductive records were available on 19 (control) and 18 (Fe-supplemented) animals. Average days open were 87 and 90, and services per conception were 1.68 and 1.78 for control and Fe treatment. The data are inadequate to reach a valid conclusion on the effects of Fe on reproduction, but there is also no indication that it had any effect.

CONCLUSIONS

Adding 30 mg/kg of supplemental Fe from a Fe-amino acid complex to diets fed to dry cows, transition cows, and early lactation cows did not affect measures of Fe status and did not affect milk production and milk composition. Iron status did not change appreciably during the dry period and peripartum period and control cows appeared to be in adequate Fe status. Control diets contained between 282 (lactation) and 336 mg/kg of Fe (prefresh), which greatly exceeded NRC recommendations for Fe (approximately 20 mg/kg of diet DM). However, much of the dietary Fe was provided from forages that were likely contaminated with soil. Supplemental Fe reduced SCC but whether the difference was economically or biologically important is unclear. Overall, control cows appeared adequate in Fe and cows generally did not respond to additional Fe.

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