

Effects of Prepartum Energy and Protein Density on Productivity and
Influence of Dietary Iron on Copper Status of Holstein and Jersey Cattle

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(ABSTRACT)

In experiment 1, 24 multiparous Holsteins and 24 multiparous Jerseys were assigned at random to one of four diets containing either 1.25, 1.38, 1.50, or 1.63 Mcal NE_L/kg DM to determine the effects of prepartum energy density on productivity. Cows were assigned to diets 28 d before expected calving and received a similar diet 0 to 60 d postpartum. Prepartum DMI increased linearly as dietary energy density increased. Non-esterified fatty acids did not differ for energy density and were greater for Holsteins. Milk and 4% FCM increased linearly as dietary energy density increased, although postpartum DMI was quadratic for energy density. Fat yield increased linearly with energy density and protein yield did not differ. Increasing prepartum diet energy density increased yield of milk and 4% FCM.

In experiment 2, 26 multiparous and 18 primiparous Jerseys were assigned to one of two CP and rumen undegradable protein (RUP) concentrations 30 d before expected calving to determine the effects of CP and RUP on productivity. Cows received a similar diet 0 to 60 d postpartum. Prepartum CP concentrations were 12 and 15% and prepartum RUP (% of CP) concentrations were 30 and 45%. Dry matter intake was not affected by CP or RUP. Milk yield and 4% FCM yield did not differ for CP or RUP. In addition, milk protein concentration and yield were similar for CP and RUP. Positive calculated metabolizable protein balance for 12% CP and 30% RUP concentrations may have precluded responses to increasing prepartum CP and RUP.

In experiment 3, 12 Holstein and 12 Jersey multiparous cows were assigned at random to diets containing 0 or 500 mg FeCO₃/kg DM to investigate the effects of dietary Fe on milk production and Cu status. Hepatic Cu did not differ for breeds or Fe supplementation. For Jerseys, hepatic Fe was greater for cows receiving supplemental Fe. Hepatic Zn was similar for breed and Fe supplementation. Plasma Cu was greater for Jerseys compared to Holsteins and did not differ for Fe supplementation. Plasma Fe and Zn did not differ for breeds or Fe supplementation. Iron supplementation did not affect yield of milk or 4% FCM. Dietary Fe did not affect Cu status of Holstein and Jersey cows in this experiment.

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TABLE OF CONTENTS

ACKNOWLEDGEMENTS	III
LIST OF TABLES.....	VI
LIST OF FIGURES.....	VII
CHAPTER I: INTRODUCTION	1
CHAPTER II: LITERATURE REVIEW.....	3
PREPARTUM ENERGY AND PROTEIN.....	3
<i>Introduction</i>	3
<i>Pregnancy Energy Requirements.....</i>	3
<i>Gestational Protein Requirements.....</i>	5
<i>Effects of Prepartum Dietary Energy Density</i>	5
<i>Effects of Prepartum Grain Feeding.....</i>	7
<i>Effects of Prepartum Protein</i>	9
<i>Prepartum Dry Matter Intake.....</i>	9
COPPER METABOLISM.....	11
<i>Biological Functions.....</i>	11
<i>Absorption</i>	11
<i>Factors Influencing Absorption.....</i>	12
<i>Influence of Iron on Metabolism.....</i>	12
REFERENCES.....	14
CHAPTER III: EFFECTS OF PREPARTUM DIET ENERGY DENSITY ON PRODUCTIVITY OF HOLSTEIN AND JERSEY CATTLE	18
ABSTRACT	18
INTRODUCTION.....	18
MATERIALS AND METHODS	19
RESULTS.....	21
DISCUSSION.....	22
IMPLICATIONS.....	24
REFERENCES.....	24
CHAPTER IV: EFFECTS OF PREPARTUM CRUDE PROTEIN AND RUMEN UNDEGRADABLE PROTEIN ON PRODUCTIVITY OF JERSEY CATTLE	37
ABSTRACT	37
INTRODUCTION.....	37
MATERIALS AND METHODS	38
RESULTS.....	40
DISCUSSION.....	41
IMPLICATIONS.....	43
REFERENCES.....	43
CHAPTER V: EFFECTS OF DIETARY IRON ON COPPER METABOLISM AND MILK PRODUCTION IN HOLSTEIN AND JERSEY CATTLE	52
ABSTRACT	52
INTRODUCTION.....	52
MATERIALS AND METHODS	53
RESULTS.....	54

DISCUSSION.....	54
IMPLICATIONS.....	55
REFERENCES.....	56
CHAPTER VI: PREPARTUM DRY MATTER INTAKE PREDICTION EQUATION FOR PREGNANT NONLACTATING JERSEY COWS.....	60
ABSTRACT.....	60
INTRODUCTION.....	60
MATERIALS AND METHODS.....	60
RESULTS AND DISCUSSION.....	61
IMPLICATIONS.....	61
REFERENCES.....	61
CONCLUSIONS.....	65
VITA.....	66

LIST OF TABLES

Table 2.1. VA regression equations for determining NE_L from ADF	7
Table 3.1. Ingredient and nutrient composition of prepartum and postpartum diets.	26
Table 3.2. Nutrient content of prepartum and postpartum forages.	27
Table 3.3. Prepartum parameter least square means for energy density.	28
Table 3.4. Postpartum parameter least square means for energy density.	29
Table 3.5. Prepartum parameter least square means for Holstein by energy density.	30
Table 3.6. Prepartum parameter least square means for Jersey by energy density.	31
Table 3.7. Postpartum parameter least square means for Holstein by energy density.	32
Table 3.8. Postpartum parameter least square means for Jersey by energy density.	33
Table 3.9. Prepartum and postpartum parameter least square means for breed.	34
Table 3.10. Prepartum and postpartum parameter least square means for season.	35
Table 4.1. Nutrient composition of prepartum and postpartum forages.	45
Table 4.2. Nutrient and ingredient composition of prepartum and postpartum diets.	46
Table 4.3. Parameter least square means for crude protein and rumen undegradable protein. ...	47
Table 4.4. Parameter least square means for crude protein by undegradable protein.	48
Table 4.5. Parameter least square means for parity and season.	49
Table 4.6. Multiparous parameter least square means for crude protein and rumen undegradable protein.	50
Table 4.7. Primiparous parameter least square means for crude protein and rumen undegradable protein.	51
Table 5.1. Ingredient and nutrient composition of diets.	58
Table 5.2. Least square means of DMI, body weight, Fe intake, milk yield, milk composition, liver minerals, and plasma minerals.	59
Table 6.1. Cow distribution, body weight, and ingredient and nutrient composition of diets.	63
Table 6.2. Regression coefficients for prepartum DMI of Jersey cows.	64
Table 6.3. Asymptotic correlation matrix.	64

LIST OF FIGURES

Figure 2.1. Gestational ME requirement of 600 kg cow and calf birth weight of 40 kg.....	4
Figure 2.2. Pregnancy MP requirement of a 600 kg cow and calf birth weight of 40 kg..	6
Figure 3.1. Daily least square mean prepartum DMI by energy density... ..	36
Figure 6.1. Predicted prepartum DMI of Jersey cows.....	64

CHAPTER I: INTRODUCTION

Bovine fetal growth is exponential by age with more than half of total fetal weight being accrued during the last two months of gestation (Ferrell et al., 1976; Prior and Laster, 1979). Moe and Tyrrell (1972) summarized energy balance trials involving pregnant, nonlactating Holstein cows to determine pregnancy metabolizable energy (ME) requirements. An exponential equation was fitted to the data and ME required increased with days of gestation. A similar equation was developed by Ferrell et al. (1976). Unlike Moe and Tyrrell (1972), the National Research Council (NRC) (1989) recommendation for fetal ME required during late gestation is constant.

Current recommendation for CP in the diets of dry pregnant dairy cows is 12%, with no recommendation for RUP (NRC, 1989). However, fetal growth and therefore fetal nutrient requirements increase exponentially as gestation progresses. Bertics et al. (1992) reported a 30% reduction in dry matter intake (DMI) as parturition approached, with most of the decline occurring during the last wk of gestation. The reduction in DMI and amino acids flowing to the small intestine coincides with increasing fetal requirements.

In addition to increasing nutrient demands and declining prepartum DMI, disparity exists in predicting pregnancy ME and metabolizable protein (MP) requirements. Metabolizable energy estimates for a 600 kg cow and 40 kg calf birth weight range from 5 to 9 Mcal/d (Moe and Tyrrell; NRC, 1989; Bell et al., 1995; NRC, 1996) and MP estimates range from 200 to 350 g/d (NRC, 1989; Bell et al., 1995; NRC, 1996). Differences are due to the predicting equations and efficiencies of use of ME and MP for fetal energy and protein accretion, respectively.

Increasing prepartum dietary energy density has been shown to increase prepartum DMI (Minor et al., 1988; Kunz et al., 1985; Hernandez-Urdaneta et al., 1976), while others have reported no difference (Johnson and Combs, 1991; Coppock et al., 1972; Fronk et al., 1980). Postpartum DMI and milk yield have been unaffected by prepartum diet energy density (Boisclair et al., 1986; Johnson and Combs, 1991; Skaar et al., 1989; Hernandez-Urdaneta et al., 1976; Johnson and Otterby, 1981; Fronk et al., 1980). Prepartum nonesterified fatty acids (NEFA) concentrations have been shown to be lower with increasing energy density (Minor et al., 1988; Kunz et al., 1985), indicating less mobilization of body lipid. Lower prepartum NEFA may result in lower hepatic lipid postpartum and decreased incidence of fatty liver (Bertics et al., 1992).

In many instances, the energy density of control diets (Minor et al., 1988; Johnson and Combs, 1991; Skaar et al., 1989) were greater than recommended by the NRC (1989) or treatments began 60 to 70 d prior to parturition (Kunz et al., 1985; Boisclair et al., 1986; Johnson and Combs, 1991; Fronk et al., 1980). Generally, the prepartum transition period is considered the 2 to 3 wk prior to parturition (Grummer, 1995). Lack of response to increased energy density above NRC (1989) may be due to initiation of diets in early dry period and/or energy densities of control rations greater than NRC (1989).

Increasing CP and RUP in prepartum diets has not resulted in increased productivity. Van Saun (1993) reported increased milk protein concentration by increasing RUP, but protein yield was unaffected. Wu et al. (1997) and Putnam and Varga (1998) increased prepartum RUP and CP, respectively, with no differences in milk yield or milk composition. Lack of response may be due to positive MP balance (Garthwaite et al., 1999).

Interference by antagonist may have precluded differences in hepatic Cu previously shown between Holsteins and Jerseys (Du et al., 1996b; French et al., 1997). Jerseys have been shown to metabolize iron differently in comparison to Holsteins (Du et al., 1996a; French et al., 1997). The mode of action of iron as a copper antagonist has yet to be established. The interaction of iron and copper in ruminants may be potentiated by the formation of FeS in the rumen and presence of S^{2-} in the abomasum (Suttle et al., 1984). However, Fe has been shown to be a potent Cu antagonist in monogastrics (Bremner and Price, 1985; Yu et al., 1994). Previous studies with cattle dosed orally with ferric hydroxide (Campbell et al., 1974), calves fed ferrous carbonate (Humphries et al., 1983; Humphries et al., 1985), and lambs fed ferrous carbonate (Prabowo et al., 1988) indicate that high dietary iron can reduce copper status without a concomitant increase in dietary sulfur.

Objectives of the experiments were to determine the influence of prepartum dietary energy and protein concentrations of postpartum productivity and the effect of dietary Fe on hepatic Cu status.

CHAPTER II: LITERATURE REVIEW

PREPARTUM ENERGY AND PROTEIN

Introduction

Grummer (1995) defined the transition period as 3 wk prepartum to 3 wk postpartum. The transition period can vary ± 1 wk pre- and postpartum depending on the author. Metabolic changes that occur during the prepartum transition period are unparalleled by any other period of the lactation cycle. Plasma insulin decreases and growth hormone and thyroxine increase from late gestation to early lactation, with spikes occurring at parturition (Kunz et al., 1985). Plasma progesterone is elevated during gestation and estrogen increases during late gestation, with dramatic reduction of both hormones occurring at parturition (Chew et al., 1979).

Bauman and Currie (1980) described homeorhesis as the coordinated control in the metabolism of body tissues necessary to support a physiological state. Regulation of nutrient partitioning during pregnancy involves homeorhetic controls arising from the conceptus. Coordinated events in lipid, carbohydrate, protein, and mineral metabolism are important homeorhetic controls of nutrient partitioning that are necessary precursors for milk synthesis.

Over one-half of fetal growth occurs between 220 and 280 d of gestation (Prior and Laster, 1976), which coincides with a 60 d dry period. While nutrient demand is increasing, DMI begins to decline several wk prior to parturition with a 30% reduction commonly reported (Grummer, 1995). Current nutrient recommendations (National Research Council, 1989) may not be adequate in meeting the energy (Moe and Tyrrell, 1972) and protein (Bell, 1995) needs of the pregnant dairy cow.

Pregnancy Energy Requirements

Bovine fetal growth is exponential by age with more than half of total fetal weight being accrued during the last two months of gestation (Prior and Laster, 1979; Ferrell et al., 1976a). Jakobsen et al. (1957) estimated the amount of energy deposited as fetal tissue in Red Danish cattle as $7.24e^{0.0174t}$ kcal/d where t is day of gestation. Moe and Tyrrell (1972) summarized 97 energy balance trials involving pregnant nonlactating Holstein cows to determine pregnancy ME requirements. The amount of energy deposited as fetal tissue was estimated from the equation of Jakobsen et al. (1957). Moe and Tyrrell (1972) estimated fetal ME requirement as $0.576e^{0.0174t}$ kcal/kg body weight^{0.75}/d where t is day of gestation. Based on data of Jakobsen et al. (1957) and Moe and Tyrrell (1972), the efficiency of utilization of ME for fetal growth is 10.5%. Low efficiency is attributed to high maintenance cost of fetal tissue.

Ferrell et al. (1976a) determined the gross energy content of the gravid uterus of Herefords to be $69.73e^{(0.0323-0.0000275)t}$ kcal where t is day of gestation. Efficiency of utilization of ME was assumed to be 14% (Ferrell et al., 1976b). Metabolizable energy estimates of Ferrell et al. (1976a) and Moe and Tyrrell (1972) are similar. Likewise, gross energy estimates of Ferrell et al. (1976a) and Jakobsen et al. (1957) closely agree.

Dairy National Research Council (NRC) (1989) determined the energy required for gestation to be 30% of that required for maintenance alone for dairy cattle. Estimates were based on previous work by Moe and Tyrrell (1972). However, ME requirement as described by Moe and Tyrrell (1972) was summed over the entire dry period and averaged by d. Energy required for the last two months of gestation can be calculated as 40 kcal ME/kg of BW^{0.75}. This

recommendation results in a constant level of energy being fed during the last two months of gestation and differs markedly from Ferrell et al. (1976a) and Moe and Tyrrell (1972).

Bell et al. (1995) predicted the energy content of Holstein gravid uterus from 190 to 270 days of gestation to be $0.00159t^2 - 0.0352t - 35.4$ Mcal where t is day of gestation. Gravid uterus energy accretion between 210 and 270 d of gestation averaged 726 kcal/d. An efficiency factor of 0.14 (Ferrell et al., 1976b) yields an estimated ME requirement of 5,186 kcal/d or about 40 kcal/kg of $BW^{0.75}$, similar to NRC (1989). Fetal energy requirements estimated by Bell et al. (1995) and Ferrell et al. (1976a) are similar, but gravid uterus energy deposition estimates differ. Breed and period of gestation examined likely influence differences in energy content of the gravid uterus.

Beef cattle gestational energy requirement (NRC, 1996) was derived from Ferrell et al. (1976a). Energy content of the gravid uterus was scaled to birth weight and efficiency of ME use for accretion was assumed 13%. The following equation was used to estimate the daily ME requirement for pregnancy: $bw(0.4504 - 0.000766t)e^{(0.03233 - 0.0000275)t}$ kcal, where bw is birth weight in kg and t is day of gestation.

As shown in Figure 2.1, dairy NRC (1989) recommendations result in overfeeding energy during the first month and underfeeding during the last month of the dry period compared to beef NRC (1996) and Moe and Tyrrell (1972). Recommendations by Bell et al. (1995) are similar to dairy NRC (1989) at the beginning of the dry period and exceed NRC (1989) thereafter. Gestational energy requirements are greatest for beef NRC (1996) and Moe and Tyrrell (1972) during the last three weeks of gestation, which coincides with the dry cow transition period. The apparent underfeeding of energy during the last three wk of gestation in relation to dairy NRC

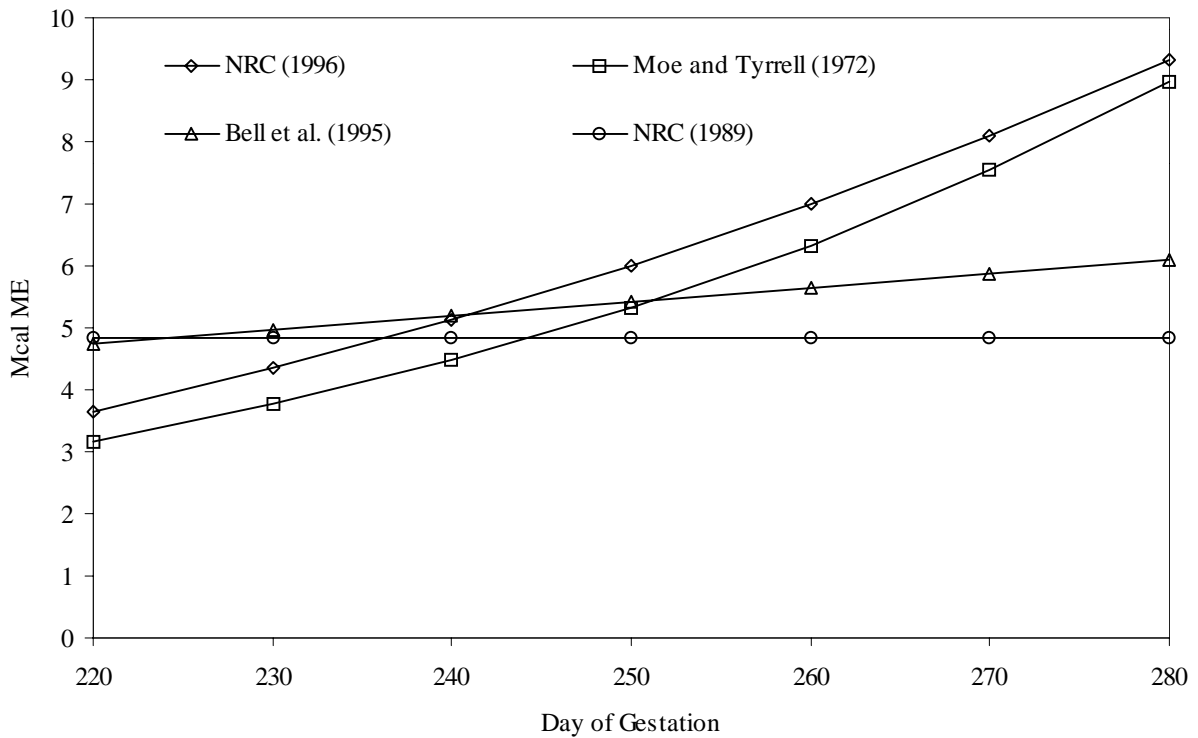


Figure 2.1. Gestational ME requirement of 600 kg cow and calf birth weight of 40 kg.

(1989) recommendations has increased sentiment toward a transition ration. A transition ration typically contains a greater concentration of nutrients. Discrepancies in ME requirement, excluding dairy NRC, arise from differences in equations used to calculate energy content of the gravid uterus, since efficiency of utilization of ME is similar for all equations. Comparisons to dairy NRC (1989) are difficult since gestational ME requirement is a function of maintenance requirement of the dam.

Gestational Protein Requirements

Prior and Laster (1979) estimated dairy beef crossbred fetal protein composition to be $0.000586e^{(0.0589t - 0.00009334t^2)}$ kg where t is day of gestation. Ferrell et al. (1976a) estimated gravid uterus nitrogen content of Herefords to be $2.312e^{(0.0278 - 0.0000176)t}$ g, where t is day of gestation. Ferrell et al. (1976a) used 70% (Agricultural Research Council, 1965) efficiency of utilization of MP for protein deposition.

Dairy NRC (1989) used the equation by Jakobsen (1957) to determine protein deposition in the gravid uterus. The daily protein accretion for 60 d prepartum was calculated as $1.136BW^{0.7}$, where BW is body weight of the dam. The efficiency of utilization of MP was assumed 50%.

Bell et al. (1995) predicted the protein content of Holstein gravid uterus from 190 to 270 days of gestation. The equation $0.345t^2 - 69.2t + 2818$ g described protein accretion where t is day of gestation. Gravid uterus protein accretion between 220 and 280 days of gestation averaged 103 g/d and ranged from 82 to 124 g/d. Efficiency of accretion of protein assumed to be 33% (Bell, 1995) would result in requirement of 290 g/d.

Beef NRC (1996) scaled the equation derived by Ferrell et al. (1976a) to birth weight. The equation to relate nitrogen content of the gravid uterus to day of gestation was $bw(0.001669 - 0.0000021t)e^{(0.0278 - 0.0000176)t}$ g, where bw is birth weight and t is day of gestation. Efficiency of protein accretion was assumed 65%.

Gestational MP requirement during the last 60 d gestation as defined by the NRC (1989) remains constant (Figure 2.2). Compared to Bell et al. (1995), beef NRC (1996) and dairy NRC (1989) recommendations are lower during the entire dry period. Beef NRC (1996) recommendation is lower than dairy NRC (1989) up to 265 d of gestation and greater thereafter. The discrepancy of gestational MP requirement is due to different equations and efficiencies of utilization of MP.

Effects of Prepartum Dietary Energy Density

Minor et al. (1988) fed 25 primiparous and 50 multiparous Holsteins either 1.34 or 1.63 Mcal net energy for lactation (NE_L)/kg DM beginning 19 d prepartum. Cows were not balanced across diets and parity balance is unclear. Actual days receiving diets were not reported. Prepartum DMI was greater for cows fed 1.63 Mcal NE_L/kg DM (12.8 vs. 10.2 kg/d). Mean prepartum DMI was 1.48 and 1.87% of BW for cows fed 1.34 and 1.63 Mcal NE_L/kg DM, respectively. Plasma nonesterified fatty acids were lower for cows consuming 1.63 Mcal NE_L/kg DM. However, only one plasma sample was obtained at 7 d prepartum based on expected parturition date. Standard error of the mean for the 7 d prepartum sample was ± 4.3 d. Plasma NEFA at 1 d postpartum was similar. Postpartum production and metabolic parameters were confounded due to varying dietary energy densities. Diets containing 1.70 and 1.61 Mcal NE_L/kg DM were fed 0 to 30 wk and 30 to 40 wk postpartum, respectively, to animals fed 1.34 Mcal NE_L/kg DM

prepartum. While 1.74 and 1.72 Mcal NEL/kg DM were fed 0 to 30 wk and 30 to 40 wk postpartum, respectively, to animals fed 1.63 Mcal NE_L/kg DM prepartum.

Kunz et al. (1985) fed cows according to requirement or *ad libitum* 70 to 5 d prepartum. Prepartum energy balance was -1.06 and 27.7 MJ NE_L/d for restricted and *ad libitum* treatments, respectively. Prepartum DMI was greater for cows consuming *ad libitum* (11.9 vs 7.3 kg/d) and plasma NEFA were lower (120 vs 210 μmol/l) compared to cows fed at requirement. Cows fed according to requirement showed no decrease in DMI at calving and DMI increased faster postpartum. In addition, cows fed at requirement experienced smaller energy deficiency in early lactation, peaked lower, persistency of lactation was greater, and free fatty acids and ketones were lower compared to cows consuming *ad libitum*. The equation used ($0.087e^{0.017t}$ MJ NE_L/d) to calculate pregnancy energy requirement results in values significantly less than those derived by Moe and Tyrrell (1972) and NRC (1989). Therefore, prepartum energy balances may have been lower than calculated. Estimated NE_L content of the requirement diet was 1.39 Mcal NE_L/kg DM and 1.48 Mcal NE_L/kg DM for *ad libitum* diet. Utilizing prepartum DMI and maintenance (NRC, 1989) and fetal (Moe and Tyrrell, 1972) energy requirement estimates, NE_L balance was estimated. Energy balance was -2.34 and 3.84 Mcal NE_L/d at 240 d of gestation and -4.08 and 2.00 Mcal NE_L/d at 270 d of gestation for cows fed at requirement and *ad libitum*, respectively. Although Kunz et al (1985) achieved energy balance differences through a combination of different prepartum DMI and diet energy densities, treatments were initiated in the early dry period.

Boisclair et al. (1986) fed cows 102, 131, or 162% of energy requirement (NRC, 1978) beginning 8 wk prepartum. Energy intake of 102 and 131% of requirement was achieved by limiting intake of a ration containing 1.45 Mcal NE_L/kg DM. Energy intake of 162% of

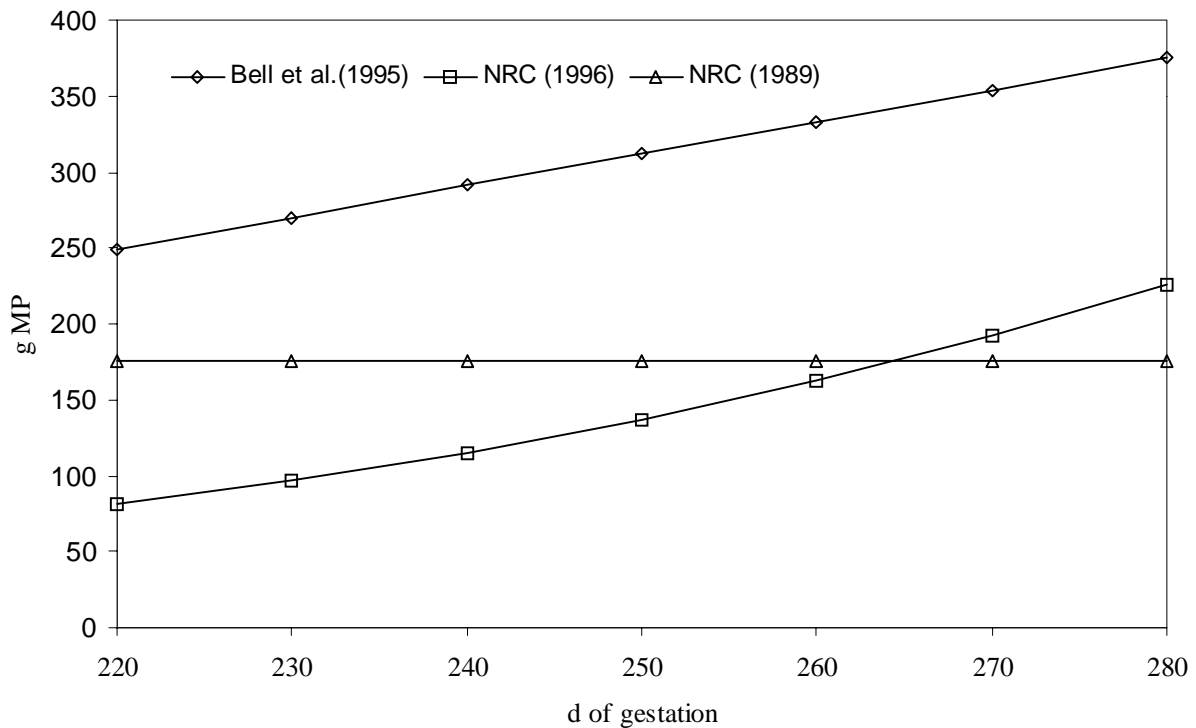


Figure 2.2. Pregnancy MP requirement of a 600 kg cow and calf birth weight of 40 kg.

requirement was achieved by *ad libitum* consumption of a ration containing 1.64 Mcal NE_L/kg DM. Energy consumption did not affect postpartum DMI and milk yield through 12 wk. Postpartum glucose and β-hydroxybutyrate levels indicated that 131 and 161% treatments were closer to a ketotic state than treatments at other times (Boisclair et al., 1987). Initiation of treatments in the early dry period and dry matter intake restriction may have precluded results.

Johnson and Combs (1991) offered six multiparous Holstein cows diets containing 1.50 or 1.68 Mcal NE_L/kg from 70 to 10 d prepartum. Cows were fed a common ration containing 1.61 Mcal NE_L/kg DM 10 d prepartum until parturition and 1.68 Mcal NEL/kg DM through 10 wk postpartum. Postpartum parameters were collected from 5 to 10 wk postpartum. Prepartum intake did not differ and was 11.1 and 12.4 kg/d for cows consuming 1.50 and 1.68 Mcal NEL/kg DM, respectively. Milk yield, fat yield, protein yield, and 3.5% fat-corrected milk tended to increase with higher energy. However, postpartum DMI did not differ between diets. Based on prepartum DMI and estimates of maintenance and fetal energy requirements at term by NRC (1989) and Moe and Tyrrell (1972), energy balances were 2.4 Mcal NEL/d for cows consuming 1.50 Mcal NEL/kg DM and 6.5 Mcal NEL/d for cows consuming 1.68 Mcal NEL/kg DM. Lack of response could be attributed to few replications, prepartum treatments ended 10 d before parturition, postpartum data collection did not begin until 5 wk, and energy balances were positive.

Skaar et al. (1989) increased energy density from 1.65 to 1.78 Mcal NEL/kg DM through addition of prilled fat. Treatments were initiated 17 d prior to expected calving date and continued through 15 wk postpartum. Pre- and postpartum DMI, milk yield, milk fat and protein concentrations, glucose, nonesterified fatty acids, and β-hydroxybutyrate did not differ. Prepartum DMI was limited to 2% of BW and forage:concentrate ratio was gradually changed from 100:0 to 50:50 from 17 to 3 d prepartum. Therefore, cows did not actually consume 1.65 and 1.78 Mcal NEL/kg DM during the entire prepartum period. In addition, postpartum diets differed in dietary energy density leading to further confounding of prepartum energy density.

Grummer et al. (1995) fed primiparous Holsteins diets containing 59.7 or 69.3% total digestible nutrients beginning 170 d prepartum. A common diet containing 1.63 Mcal NEL/kg DM was fed for 143 d postpartum. Increasing dietary energy density did not affect milk yield or composition.

Effects of Prepartum Grain Feeding

Hernandez-Urdaneta et al. (1976) offered Holstein cows one of two diets 28 d prepartum to 4 d postpartum: 95:5 or 80:20 forage to concentrate ratio. At 4 d postpartum cows were either assigned to 60:40 or 40:60 forage:concentrate and received these rations for an additional 28 d. Prepartum DMI was greater for 80:20 (10.57 kg/d, 1.80% BW) compared to 95:5 (9.31 kg/d, 1.61% BW). Although treatments differed, intakes converged by 4 d prepartum. Postpartum DMI and milk yield and composition did not differ between treatments. Utilizing Virginia

Table 2.1. VA regression equations for determining NE_L from ADF.

Forage	Mcal NE _L /kg DM
Corn Silage	1.7754 – 0.0113 × ADF
Alfalfa Hay/Silage	2.0887 – 0.0211 × ADF
Legume Hay/Silage	1.8877 – 0.0153 × ADF
Grass Hay/Silage	2.2415 – 0.0262 × ADF
Grass Legume Hay/Silage	1.0572 – 0.0172 × ADF

regression equations (Table 2.1) to determine NE_L from acid detergent fiber (ADF), 95:5 and 80:20 contained 1.31 and 1.38 Mcal NE_L /kg DM. Energy difference between the two diets may not have been great enough to elicit a response in milk production. Utilizing prepartum DMI and maintenance (NRC, 1989) and fetal (Moe and Tyrrell, 1972) energy requirement estimates, NE_L balance was estimated. Energy balance was 0.12 and 2.32 Mcal NE_L /d at 240 d of gestation and -1.53 and 0.57 Mcal NE_L /d at 270 d of gestation for cows fed 95:5 and 80:20 forage:concentrate, respectively.

Johnson and Otterby (1981) reported that DMI and milk yield was similar for Holstein cows receiving only alfalfa-grass hay or complete diets of alfalfa and corn silages with 12 or 47% of DM from grain beginning 28 d prepartum. A common ration was fed through 31 d postpartum. Prepartum DMI did not differ and was 8.3, 8.9, and 9.6 kg/d for all hay, 12% of DM from grain, and 47% of DM from grain, respectively. However, intake was greater 28 d to 13 d prepartum for cows receiving grain. All cows were consuming corn silage prior to implementation of treatments and cows receiving alfalfa-grass hay were not acclimatized, this may explain the difference seen 28 to 13 d prepartum. Postpartum DMI and milk yield were 11.8 and 20.1, 12.6 and 23.1, and 11.9 and 22.7 for all hay, 12% of DM from grain, and 47% of DM from grain, respectively. Estimated NE_L content of diets based on NRC (1989) values are 1.23, 1.52, and 1.72 Mcal/kg for all hay, 12% of DM from grain, and 47% of DM from grain, respectively. Based on diet energy density, DMI, and fetal energy estimates of Moe and Tyrrell (1972), cows consuming all hay were in negative energy balance during the experiment.

Coppock et al. (1972) offered one of four diets: 75:25; 60:40; 45:55; or 30:70 forage:concentrate to Holstein cows, 28 d before expected parturition. Dry matter intake did not differ and was 1.62, 1.36, 1.51, and 1.58% of BW for 75:25, 60:40, 45:55, and 30:70 forage:concentrate, respectively. Regression analysis of DMI on d prepartum revealed a significant depression in intake as parturition approached for 60:40, 45:55, and 30:70 forage:concentrate. Using VA regression equations to predict NE_L from ADF, diets were 1.49, 1.57, 1.65, and 1.73 Mcal/kg DM for 75:25, 60:40, 45:55, and 30:70 forage:concentrate, respectively.

Fronk et al. (1980) offered cows 1.8 or 6.4 to 8.2 kg grain daily, in addition to alfalfa hay and haylage beginning 64 d prepartum. A common ration was fed from parturition through 63 d postpartum. Milk yield and DMI data was collected from 65 to 7 d prepartum and 14 to 63 d postpartum. Metabolic data was collected 21 d prepartum to 63 d postpartum. Prepartum and postpartum DMI did not differ and were 13.8 and 19.2, and 14.3 and 19.6 kg/d for cows receiving 1.8 and ≥ 6.4 kg grain/d respectively. Milk yield and fat concentration did not differ. Milk protein concentration was greater for cows receiving ≥ 6.4 kg grain/d (3.39 vs 3.20%). Glucose, NEFA, and insulin were similar for treatments during pre- and postpartum. Prepartum β -Hydroxybutyrate was greater for cows receiving ≥ 6.4 kg grain/d the wk prior to parturition, but this difference diminished postpartum. Utilizing prepartum DMI and maintenance (NRC, 1989) and fetal (Moe and Tyrrell, 1972) energy requirement estimates, NE_L balance was estimated. Energy balance was -3.59 and 3.10 Mcal NE_L /d at 240 d of gestation and -3.91 and 2.83 Mcal NE_L /d at 270 d of gestation for cows fed 1.8 or 6.4 to 8.2 kg grain/d, respectively.

Nocek et al. (1986) reported no differences in postpartum DMI and milk yield between cows receiving all forage (50% corn silage:50% alfalfa silage) or forage plus grain. Grain was fed at a rate of 2 kg grain/d 3 wk prepartum and 3 kg/d 2 wk prepartum until parturition. Cows were group fed forage prepartum; therefore, individual DMI was not determined.

Effects of Prepartum Protein

Van Saun et al. (1993) increased rumen undegradable protein (RUP) as a percentage of crude protein (CP) from 27 to 39% by substitution of blood meal for soybean meal in diets of primiparous Holsteins beginning 3 wk prior to expected parturition date. However, CP increased from 12.4 to 15.3% with substitution of blood meal. Therefore, results based on RUP are confounded within CP. Prepartum DMI, milk yield, milk fat concentration, and milk fat yield did not differ for RUP. Milk protein concentration was greater for 39% RUP, although milk protein yield did not differ. Intake of CP was greater for 39% RUP and may explain the difference reported in milk protein concentration rather than the increase in RUP.

Wu et al. (1997) increased RUP from 34 to 41% by substitution of fishmeal for soybean meal in diets of multiparous Holsteins beginning 30 d prior to expected parturition date. Prepartum DMI, postpartum DMI, milk yield, milk component concentration, and milk component yield did not differ for RUP. Prepartum diets contained 14% CP, which is higher than current NRC (1989) recommendations. The authors indicate that CP may have negated response to fishmeal.

Putnam and Varga (1998) offered multiparous Holstein cows isocaloric diets that differed in CP concentration (10.6, 12.7, or 14.5% of DM) but not in CP degradability or solubility beginning 35 d prepartum. Prepartum intake was restricted to 1.5% of BW from 21 d prepartum to parturition to ensure similar caloric intake while maintaining desired differences in protein intake. Cows received a common diet postpartum. Nitrogen intake, apparent and true digestibilities, fecal and urinary concentrations, and N balance increased as the concentration of dietary CP increased. Crude protein did not influence prepartum intake, postpartum intake, or milk yield.

Santos et al. (1999a; 1999b) offered multiparous and primiparous Holsteins 12.7 or 14.7% CP beginning 30 d prior to expected calving date. Crude protein concentration did not affect milk yield, milk fat concentration, or milk protein concentration. Yields of FCM and fat were greater for primiparous cows receiving 14.7% CP. Primiparous cows may have benefited from additional CP due to the additional requirement for growth.

Garthwaite et al. (1999) calculated MP balance from data of Van Saun et al. (1993), Wu et al. (1997), Carson et al. (1998), and Putnam and Varga (1998). Metabolizable protein balance was negative only for 27% RUP fed by Van Saun et al. (1993). The primiparous cows used by Van Saun et al. (1993) may have responded due to additional requirement for growth, which may have spared maternal protein reserves. Garthwaite et al. (1999) suggests that when prepartum DMI is relatively high, additional RUP may not be needed. Indeed, DMI is the determining factor in meeting requirements, not nutrient concentration.

Prepartum Dry Matter Intake

Dry matter intake 1 to 28 d prepartum ranged from 7.3 to 13 kg/d and 1.2 to 1.8% BW, (Hernandez-Urdaneta et al., 1976; Johnson and Otterby, 1981; Nocek et al., 1986; Bertics et al., 1992; Vazquez-Anon et al., 1994). Feed intake decreased by 28% during the final 17 d prior to calving (Bertics et al., 1992). Likewise, prepartum DMI decreased 40% during the final week of gestation (Vazquez-Anon et al., 1994). Grummer (1995) suggests that a 30% reduction in prepartum DMI is typical based on available research. Current evidence suggests that postpartum intake is related to intake 1 to 5 d prepartum (Putnam et al., 1997).

Prepartum DMI determines dietary nutrient densities necessary to meet nutrient requirements of the dam and fetus. Unfortunately, little information exists pertaining to prepartum DMI relative to postpartum DMI. Hayirli et al. (1999) compiled prepartum DMI data from 661 cows involved in 15 experiments investigating 47 diets. Data were fit to a nonlinear equation to explain prepartum DMI. The equation used was $y = a + p \times e^{k \times t}$; where y is DMI as % of BW, a is asymptotic intercept at time $-\infty$, p is magnitude of depression in DMI, and $e^{k \times t}$ is the shape of the curve. Differences in prepartum DMI as % of BW were observed with different non-fiber carbohydrate (NFC) concentrations. Although statistical difference for NDF were not given, these would be expected to follow NFC concentrations due to the inverse relationship between the two. Coefficients for a, p, and k were 1.68, -0.60, 0.43, and 1.95, -0.82, 0.15, and 2.01, -0.75, and 0.18 for 21.8, 31.3, and 41.3% NFC, respectively.

COPPER METABOLISM

Biological Functions

Copper is an essential component of many enzymes and most of its biological importance is through these cuproenzymes. Most of the Cu in the circulation is bound to ceruloplasmin, where the main functions are in transport of copper, antioxidant defense, and conversion of Fe^{2+} to Fe^{3+} .

Another Cu containing enzyme is cytochrome c oxidase. Cytochrome c oxidase is the terminal enzyme of the electron transport chain and performs one of the most essential reactions in cells, the reduction of O_2 to H_2O . In conjunction with other components of the electron transport, this permits formation of ATP.

Copper/zinc superoxide dismutase protects against superoxide anions, catalyzing their dismutation to peroxide and dioxygen: $2\text{O}_2^- + 2\text{H}^+ \rightarrow \text{O}_2 + \text{H}_2\text{O}_2$. This enzyme is present in most eukaryotic cells and plays an important role in protecting intracellular components from oxidative damage.

Dopamine β -hydroxylase is responsible for synthesis of the sympathetic neurotransmitter norepinephrine and is necessary for epinephrine production. Dopamine β -hydroxylase catalyzes the reaction of hydroxyphenethylamine (dopamine) with O_2 to form norepinephrine + H_2O .

Tyrosinase, a copper-dependent enzyme located in melanocytes, is responsible for the initial formation of melanin. In mammals, melanin pigments are responsible for hair, skin, and eye color. They are also necessary for normal function of the eye.

A relationship has been shown between Cu deficiency and depressed immune function (Koller et al., 1987; Porhaska, 1991). Neutrophils collected from Cu deficient steers were shown to have decreased killing capacity of phagocytized *Staphylococcus aureus* (Xin et al., 1991). Impairment of immune function due to copper deficiency may be a result of reduced copper dependent enzymes (Linder, 1991). During infection, phagocytic cells produce large quantities of superoxide ions, which can be detoxified by superoxide dismutase. Likewise, ceruloplasmin functions as an extracellular scavenger of free radicals.

Absorption

Generally, 10 to 15% of the copper in the diet is absorbed by adult animals and young animals may absorb 15 to 30% (McDowell, 1992). Absorption ranges from 6.9 to 9.5 % in dairy cattle (Buckley et al., 1985). The extent of absorption is influenced by the chemical form of dietary copper, copper status of the animal, and interfering factors.

In ruminants, the large intestine appears to be site of significant copper absorption (Grace, 1975; Ivan and Grieve, 1976; Turner et al., 1987). There are at least two mechanisms by which copper enters the body from the intestinal lumen: combination of transport via a saturable carrier plus simple diffusion (Bronner and Yost, 1985; Wapnir and Stiel, 1987). This implies, at low copper concentrations, almost all copper is absorbed via the saturable carrier, while at higher concentrations increasing amounts appear to be absorbed by diffusion. Linder (1991) expresses that caution must be taken when making this assumption. The overall kinetic results are difficult to interpret and further work is needed in this area.

Copper first passes across the brush border, entering the mucosal cells, most probably as Cu^{2+} . The second step is transfer from the mucosal cells into the interstitial fluid and blood, across the basolateral surface. The uptake across the brush border is probably by simple

diffusion and controlled by mass action (Fisher and L'Abbe, 1985). Once in the cell cytosol, some copper becomes bound to metallothionein (Hall et al., 1979). Some copper continues on to the basolateral membrane, where it crosses to the interstitial fluid and blood by an energy-dependent, carrier-mediated, saturable process (Crampton et al., 1965; Fischer and L'Abbe, 1985). Virtually all transport at low doses may be energy dependent. At higher doses, excess copper crosses the basolateral surface by a mechanism that is not energy dependent and may involve diffusion down a chemical gradient (Linder, 1991).

Two points of copper regulation in absorption are metallothionein and the basolateral surface. Zinc induces an increased synthesis of metallothionein in the intestinal mucosa (Richards and Cousins, 1975). The affinity of metallothionein is much greater for copper than it is for zinc. Therefore, high dietary zinc intakes induce metallothionein production and copper displaces zinc once inside the mucosa and is bound so firmly that little remains to be transferred across the basolateral membrane (Linder, 1991). It is thought that most of the copper bound to metallothionein is lost due to sloughing-off of mucosal cells. In addition, copper-zinc interactions suggest regulation at the basolateral surface. Acute studies were conducted to eliminate the effects of metallothionein. Increasing the amounts of zinc in the lumen of rats, inhibited copper absorption and the reverse is also true, increasing amounts of copper in the lumen inhibited zinc absorption (Oestreicher and Cousins, 1985). Similar results were reported by Flanagan et al, (1984) in mice. The transfer of zinc across the basolateral membrane was inhibited by excess copper and two other divalent metal ions, cobalt and zinc. A specific carrier for both copper and zinc may exist, and an excess of either ion displaces the other. Alternatively, specific carriers for each ion may exist and large excesses of other of other ions may inhibit transport.

Factors Influencing Absorption

Zinc has already been implicated as an important exogenous factor involved in copper absorption. In addition to the factors discussed below, many others exist (Linder, 1991) but are too numerous to list. Both molybdenum and sulfur are very important when considering ruminants. Sulfur is implicated through the formation of copper sulfide, which is insoluble and unabsorbable. Molybdenum and copper are antagonistic to each other in the animal body (Ward, 1978). Excess molybdenum increases the requirement and the amount of copper required to cause toxicosis; increased dietary copper can reduce the deleterious effect of molybdenum. Molybdenum and sulfur together influence copper absorption. In the rumen, molybdenum and sulfur form thiomolydates that chelate copper rendering it unavailable (Mason, 1986; Price et al., 1987; Suttle, 1991).

Influence of Iron on Metabolism

The deleterious effects of feed with high levels of naturally occurring Fe concentrations have long been known in cattle (Coup and Campbell, 1964). Detrimental effects of high Fe intake are most likely to occur in ruminants consuming soil contaminated forages or soil ingestion during grazing.

Coup and Campbell (1964) decreased milk yield with increasing dose of $\text{Fe}(\text{OH})_3$. Intake and gain were reduced in steers receiving 1,600 mg $\text{FeSO}_4/\text{kg DM}$ and feed efficiency was reduced with 400 mg $\text{FeSO}_4/\text{kg DM}$ (Standish et al., 1969). Although gain decreased, intake and feed efficiency did not differ in steers supplemented with 1,000 mg $\text{FeSO}_4/\text{kg DM}$ (Standish et

al., 1971). Iron supplementation up to 1,200 mg FeCO₃/kg DM did not influence gain or intake in lambs (Prabowo et al., 1988).

Plasma Cu was depressed in steers (Standish et al., 1969) and lambs (Standish and Ammerman, 1971) receiving 1,600 mg FeSO₄/kg DM compared to controls. Standish et al. (1971) reported that plasma Cu did not differ between controls and steers receiving 1,000 mg FeSO₄/kg DM. Blood Cu decreased in heifers dosed daily with 30 mg Fe(OH)₃/kg BW (Campbell et al., 1974) compared to controls. Plasma Cu decreased three-fourths in calves receiving 800 mg FeOH₃/kg DM compared to controls (Humphries et al., 1983).

Iron content of liver was greater in steers (Standish et al., 1969) and lambs (Standish and Ammerman, 1971) fed 1,600 mg FeSO₄/kg DM compared to controls. Standish et al. (1971) increased liver Fe in steers receiving 1,000 mg FeSO₄/kg DM compared to controls.

Liver Cu was reduced in steers (Standish et al., 1969), but not in lambs (Standish and Ammerman, 1971) supplemented with 1,600 mg FeSO₄/kg DM compared to controls. Standish et al. (1971) reported that liver Cu decreased as supplemental Fe increased from 0 to 1,000 mg FeSO₄/kg DM. Campbell et al. (1974) decreased liver Cu of heifers through daily dosing of 30 mg Fe(OH)₃/kg DM. Supplementing the diet with 800 mg FeCO₃/kg was sufficient to produce Cu deficiency in calves (Humphries et al., 1983). Supplemental Fe did not reduce liver Cu concentration on pre-ruminant calves (Humphries et al., 1985). In contrast, supplemental Fe had dramatic effects on the liver Cu concentrations of the same calves after development of a functional rumen. Humphries et al. (1985) showed that 250 mg FeCl₃/kg diet is sufficient to cause depletion of liver copper. Humphries et al. (1988) decreased liver Cu of heifers through supplementation of 150 mg FeCO₃/kg DM. However, a dietary concentration of 1,200 mg FeCO₃/kg DM was needed to decrease in liver Cu of lambs (Prabowo et al., 1988). Regression of liver Cu on dietary Fe of lactating cattle showed a significant negative relationship (French et al., 1997). In addition, the slope was greater for Jersey cattle compared to Holsteins indicating that Fe was more detrimental to copper status of Jersey cattle.

As with Mo, the effect of Fe on Cu metabolism may be linked to S²⁻ metabolism in the rumen (Humphries et al., 1983). Hepatic Cu of heifers receiving diets containing 2.8 mg S/kg DM was similarly reduced by either 800 mg FeCO₃ or 5 mg (NH₄)₂MoO₄/kg DM (Humphries et al., 1983). Decreasing S from 2.8 to 1.5 mg/kg DM did not effect hepatic Cu of heifers receiving 500 or 750 mg FeCO₃/kg DM (Humphries et al., 1985). However, deleterious effects of dietary Fe have also been shown in monogastrics. Liver Cu of rats was decreased by 250 (Bremner and Price, 1985) and 389 (Yu et al., 1994) mg FeSO₄/kg DM.

The antagonistic action of Fe may act through impairment of absorption (Bremner and Young, 1981; Bremner and Price, 1985; Yu et al., 1994) and/or inhibition of Cu uptake by hepatocytes (Whitaker and McArdle, 1997). Standish et al. (1971) reported that the apparent absorption of Cu decreased from 45 to 34% with supplementation of 1,000 mg FeSO₄/kg DM. Restoration of cytochrome c oxidase activity, a measure of Cu availability during Cu repletion, in rats indicated that the availability of Cu was reduced by 50 and 85% within only 4 d by supplementation of 250 and 500 mg FeSO₄/kg DM (Bremner and Price, 1985). In addition, Yu et al. (1994) reported an inverse relationship between Fe intake and Cu absorption. Whitaker and McArdle (1997) reported that NADH oxidase activity decreased in rat hepatocytes loaded with Fe saturated transferrin. The authors suggest that Cu was binding to transporters, but the reduction of Cu⁺⁺ to Cu⁺, a condition hypothesized as necessary for transport, was not occurring.

REFERENCES

- Agricultural Research Council. 1965. The Nutrient Requirements of Farm Livestock. No. 2. Ruminants. Agricultural Research Council, London.
- Bauman, D. E., and W. B. Currie. 1980. Partitioning of nutrients during pregnancy and lactation: a review of mechanisms involving homeostasis and homeorhesis. *J. Dairy Sci.* 63:1514-1529.
- Bell, A. W. 1995. Regulation of organic nutrient metabolism during transition from late pregnancy to early lactation. *J. Anim. Sci.* 73:2804-2819.
- Bell, A. W., R. Slepatis, and R. A. Ehrhardt. 1995. Growth and accretion of energy and protein on the gravid uterus during late pregnancy. *J. Dairy Sci.* 78:1954-1961.
- Bertics, S. J., R. R. Grummer, C. C. Cadorniga-Valino, and E. E. Stoddard. 1992. Effect of prepartum dry matter intake on liver triglyceride concentration and early lactation. *J. Dairy Sci.* 75:1914-1922.
- Boisclair, Y., D. G. Grieve, J. B. Stone, O. B. Allen, and G. K. MacLeod. 1986. Effect of prepartum energy, body condition, and sodium bicarbonate on production of cows in early lactation. *J. Dairy Sci.* 69:2636-2647.
- Bremner, I. and B. W. Young. 1981. Effect of variation in dietary iron concentration on copper metabolism in rats. *Proc. Nutr. Soc.* 40:69A.
- Bremner, I. and J. Price. 1985. Effects of dietary iron supplements on copper metabolism in rats. Pages 374-376 in *Proc. Int. Symp. Trace Elements in Man and Animals*. 5th ed. Slough, United Kingdom.
- Bronner, F. and J. H. Yost. 1985. Saturable and nonsaturable copper and calcium transport in mouse duodenum. *Am. J. Physiol.* 249:G108-G112.
- Buckley, W. T., S. N. Huckin, and G. K. Eigendorf. 1985. Stable isotope tracer methods for determining absorption of dietary copper in dairy cattle. In: *C. F. Mills, I. Bremner, and J. K. Chesters (Ed.) Trace Elements in Man and Animals (TEMA-5)*. pp. 339-341. Commonwealth Agri. Bureaux, Farnham Royal, U. K.
- Campbell, A. G., M. R. Coup, W. H. Bishop, and D. E. Wright. 1974. Effect of elevated iron intake on the copper status of grazing cattle. *N. Z. J. Agri. Res.* 17:393-399.
- Carson, V. M., N. L. Whitehouse, K. Kolinsky, B. D. Garthwaite, M. S. Piepenbrink, and C. G. Schwab. 1998. Interactions of prepartum and postpartum feeding of rumen inert amino acids on lactational performance of Holstein cows. *J. Dairy Sci.* 81(Suppl. 1):295(Abstr.)
- Chew, B. P., R. E. Erb, J. F. Fessler, C. J. Callahan, and P. V. Malven, 1979. Effects of ovariectomy during pregnancy and of prematurely induced parturition on progesterone, estrogens, and calving traits. *J. Dairy Sci.* 62:557-566.
- Coppock, C. E., C. H. Noller, S. A. Wolfe, C. J. Callahan, and J. S. Baker. 1972. Effect of forage-concentrate ratio in complete feeds fed ad libitum on feed intake prepartum and the occurrence of abomasal displacement in dairy cows. *J. Dairy Sci.* 55:783-789.
- Coup, M. R., and A. G. Campbell. 1964. The effect of excessive iron intake upon the health and production of dairy cows. *N. Z. J. Agric. Res.* 7:624-638.
- Crampton, R. F., D. M. Matthews and R. Poisner. 1965. Observations on the mechanism of absorption of copper by the small intestine. *J. Physiol.* 178:111-126.
- Du, Z., R.W. Hemken, and R. J. Harmon. 1996a. Copper metabolism of Holstein and Jersey cows and heifers fed diets high in cupric sulfate or copper proteinate. *J. Dairy Sci.* 79:1873-1880.

- Du, Z., R. W. Hemken and D. S. Trammell. 1996b. Comparison of copper tolerances between Holstein and Jersey steers. *J. Dairy Sci.* 79(Suppl. 1):231(Abstr.).
- Ferrell, C. L., W. N. Garrett, and N. Hinman. 1976a. Growth, development and composition of the udder and gravid uterus of beef heifers during pregnancy. *J. Anim. Sci.* 42:1477-1489.
- Ferrell, C. L., W. N. Garrett, N. Hinman, and G. Grichting. 1976b. Growth, development and composition of the udder and gravid uterus of beef heifers during pregnancy. *J. Anim. Sci.* 42:937-950.
- Fischer, P. W. F. and M. R. L'Abbe. 1985. Copper transport by intestinal brush border membrane vesicles from rats fed high zinc or copper deficient diets. *Nutr. Res.* 5:759-767.
- Flanagan, P. R., J. Haist, I. MacKenzie and L. S. Valberg. 1984. Intestinal absorption of zinc: Competitive interactions with iron, cobalt, and copper in mice with sex-linked anemia. *Can. J. Physiol. Pharmacol.* 62:1124-1128.
- French, P. D., D. S. Trammell, and R. W. Hemken. 1997. Copper tolerances of Holstein and Jersey cows receiving whole cottonseed. *J. Dairy Sci.* 80(Suppl. 1):271.
- Fronk, T. J., L. H. Schultz, and A. R. Hardie. 1980. Effect of dry period overconditioning on subsequent metabolic disorders and performance of dairy cows. *J. Dairy Sci.* 63:1080-1090.
- Garthwaite, B. D., C. G. Schwab, and B. K. Sloan. 1999. Low crude protein diets may work in prepartum cows. *Feedstuffs* 71:11-14.
- Grace, N. D. 1975. Studies on the flow of zinc, cobalt, copper and manganese along the digestive tract of sheep given fresh perennial ryegrass, or white or red clover. *Br. J. Nutr.* 34:73-82.
- Grummer, R. R., 1995. Impact of changes in organic nutrient metabolism on feeding the transition dairy cow. *J. Anim. Sci.* 73:2820-2833.
- Grummer, R. R., P. C. Hoffman, M. L. Luck, and S. J. Bertics. 1995. Effect of prepartum and postpartum dietary energy on growth and lactation of primiparous cows. *J. Dairy Sci.* 78:172-180.
- Hall, A. C., B. W. Young and I. Bremner. 1979. Intestinal metallothionein and the mutual antagonism between copper and zinc in the rat. *J. Inorg. Biochem.* 11:57-66.
- Hayirli, A., R. R. Grummer, E. V. Nardheim, P. M. Crump, D. K. Beede, M. J. VandeHaar, L. H. Kilmer, J. K. Drackley, D. J. Carroll, G. A. Varga, and S. S. Donkin. 1999. Prediction equations for dry matter intake of transition cows fed diets that vary in nutrient composition. *J. Dairy Sci.* 82(Suppl.):113(Abstr.)
- Hernandez-Uraneta, A., C. E. Coppock, R. E. McDowell, D. Gianola, and N. E. Smith. 1976. Changes in forage-concentrate ratio of complete feeds for dairy cows. *J. Dairy Sci.* 59:695-707.
- Humphries, W. R., M. J. Walker, P. C. Morrice, and I. Bremner. 1988. Effects of dietary molybdenum and iron on copper metabolism in calves. Pages 309-310 *in Proc. Int. Symp. Trace Elements in Man and Animals.* 6th ed. Pacific Grove, CA.
- Humphries, W. R., I. Bremner, and M. Phillippo. 1985. The influence of dietary iron on copper metabolism in the calf. Pages 371-373 *in Proc. Int. Symp. Trace Elements in Man and Animals.* 5th ed. Slough, United Kingdom.
- Humphries, W. R., M. Phillippo, B. W. Young, and I. Bremner. 1983. The influence of dietary iron and molybdenum on copper metabolism in calves. *Br. J. Nutr.* 49:77-86.
- Ivan, M., and C. M. Grieve. 1976. Effects of zinc, copper, and manganese supplementation of high-concentrate ration on gastrointestinal absorption of copper and manganese in Holstein calves. *J. Dairy Sci.* 59:1764-1768.
- Jakobsen, P. E., P. H. Sorensen, and H. Larsen. 1957. Energy investigation as related to fetus formation in cattle. *Acta. Agric. Scand.* 7:103-112.

- Johnson, D. G., and D. E. Otterby. 1981. Influence of dry period diet on early postpartum health, feed intake, milk production, and reproductive efficiency in Holstein cows. *J. Dairy Sci.* 64:290-295.
- Johnson, T. R., and D. K. Combs. 1991. Effects of prepartum diet, inert rumen bulk, and dietary polyethylene glycol on dry matter intake of lactating dairy cows. *J. Dairy Sci.* 74:933-944.
- Koller, L. D., S. A. Mulhern, N. C. Frankel, M. G. Steven and J. R. Williams. 1987. Immune dysfunction in rats fed a diet deficient in copper. *Am. J. Clin. Nutr.* 45:997-1006.
- Kunz, P. L., and J. W. Blum. 1985. Effects of different energy intakes before and after calving on food intake, performance and blood metabolites in dairy cows. *Anim. Prod.* 40:219.
- Linder, M. C. 1991. *Biochemistry of Copper*. Plenum Press, New York.
- Mason, J. 1986. Thiomolybdates: Mediators of molybdenum toxicity and enzyme inhibitors. *Toxicology.* 42:99-109.
- McDowell, L. R. 1992. Copper and Molybdenum. In: L. R. McDowell (Ed.) *Minerals in Animal and Human Nutrition.* pp. 176-204. Academic Press, Inc. San Diego.
- Minor, D. J., S. L. Trower, B. D. Strang, R. D. Shaver, and R. R. Grummer. 1998. Effects of nonfiber carbohydrate and niacin on periparturient metabolic status and lactation of dairy cows. *J. Dairy Sci.* 81:189-200.
- Moe, P. W., and H. F. Tyrrell. 1972. Metabolizable energy requirements of pregnant dairy cows. *J. Dairy Sci.* 55:480-483.
- National Research Council. 1996. *Nutrient Requirements of Beef Cattle.* 7th revised ed. Natl. Acad. Sci., Washington, DC.
- National Research Council. 1989. *Nutrient Requirements of Dairy Cattle.* 6th revised ed. Natl. Acad. Sci., Washington, DC.
- Nocek, J. E., R. L. Steele, and D. G. Braund. 1986. Prepartum grain feeding and subsequent lactation forage program effects on performance of dairy cows in early lactation. *J. Dairy Sci.* 69:734:744.
- Oestreicher, P. and R. J. Cousins. 1985. Copper and zinc absorption in the rat: Mechanism of mutual antagonism. *J. Nutr.* 115:159-166.
- Prabowo, A., J. W. Spears, and L. Goode. 1988. Effects of dietary iron on performance and mineral utilization in lambs fed a forage-based diet. *J. Anim. Sci.* 66:2028-2035.
- Price, J., A. M. Will, G. Paschaleris and J. K. Chesters. 1987. Identification of thiomolybdates in digesta and plasma from sheep after administration of 99-Mo labeled compounds in the rumen. *Br. J. Nutr.* 58:127-1378.
- Prior, R. L., and D. B. Laster. 1979. Development of the bovine fetus. *J. Anim. Sci.* 48:1546-1553.
- Prohaska, J. R. 1991. Changes in Cu, Zn-superoxide dismutase, cytochrome c oxidase, glutathione peroxidase and glutathione transferase activities in copper-deficient mice and rats. *J. Nutri.* 121:355-363.
- Putnam, D. E., and G. A. Varga. 1998. Protein density and its influence on metabolite concentration and nitrogen retention by Holstein cows in late gestation. *J. Dairy Sci.* 81:1608-1618.
- Putnam, D. E., K. J. Soder, L. A. Holden, G. A. Varga, and H. M. Dann. 1997. Periparturient traits correlate with postpartum dry matter intake and milk yield. *J. Dairy Sci.* 80(Suppl.):142(Abstr.)
- Richards, M. P. and R. J. Cousins. 1975. Mammalian zinc homeostasis: Requirements for RNA and metallothionein synthesis. *Biochem. Biophys. Res. Commun.* 64:1215-1223.

- Santos, J. E. P., E. J. DePeters, P. W. Jardon, and J. T. Huber. 1998a. Effect of prepartum crude protein level on performance of multiparous Holstein cows. *J. Dairy Sci.* 82(Suppl.):120(Abstr.)
- Santos, J. E. P., E. J. DePeters, P. W. Jardon, and J. T. Huber. 1998b. Effect of prepartum crude protein level on performance of primiparous Holstein cows. *J. Dairy Sci.* 82(Suppl.):120(Abstr.)
- Skaar, T. C., R. R. Grummer, M. R. Dentine, and R. H. Stauffacher. 1989. Seasonal effects of prepartum and postpartum fat and niacin feeding on lactation performance and lipid metabolism. *J. Dairy Sci.* 72:2028-2038.
- Standish, J. F., and C. B. Ammerman. 1971. Effect of excess dietary iron as ferrous sulfate and ferric citrate on tissue mineral composition of sheep. *J. Anim. Sci.* 33:481-484.
- Standish, J. F., C. B. Ammerman, A. Z. Palmer, and C. F. Simpson. 1971. Influence of dietary iron and phosphorus on performance, tissue mineral composition and mineral absorption in steers. *J. Anim. Sci.* 33:171-178.
- Standish, J. F., C. B. Ammerman, C. F. Simpson, and F. C. Neal. 1969. Influence of graded levels of dietary iron, as ferrous sulfate, on performance and tissue mineral composition of steers. *J. Anim. Sci.* 29:496-503.
- Suttle, N. F. 1991. The interactions between copper, molybdenum, and sulfur in ruminant nutrition. *Annu. Rev. Nutr.* 11:121-140.
- Suttle, N. F., P. Abrahams, and I. Thornton. 1984. The role of a soil x dietary sulphur interaction in the impairment of copper absorption by ingested soil in sheep. *J. Agric. Sci. (Camb.)* 103:81-86.
- Turner, J. C., V. Shanks, P. J. Osborn and S. M. Gower. 1987. Copper absorption in sheep. *Comp. Biochem. Physiol.* 86C:147-150.
- Van Saun, R. J., S. C. Idleman, and C. J. Sniffen. 1993. Effect of undegradable protein amount fed prepartum on postpartum production in first lactation Holstein cows. *J. Dairy Sci.* 76:236-244.
- Vazquez-Anon, M., S. Bertics, M. Luck, and R. R. Grummer. 1994. Peripartum liver triglyceride and plasma metabolites in dairy cows. *J. Dairy Sci.* 77:1521-1528.
- Wapnir, R. A. and L. Stiel. 1987. Intestinal absorption of copper: Effect of sodium. *Proc. Soc. Exp. Biol. Med.* 185:277-282.
- Ward, G. M. 1978. Molybdenum toxicity and hypocuprosis in ruminants: A review. *J. Anim. Sci.* 46:1078.
- Whitaker, P., and H. J. Mcardle. 1997. Iron inhibits copper uptake by rat hepatocytes by down-regulating the plasma membrane NADH oxidase. Pages 237-238 in *Proc. Int. Symp. Trace Elements in Man and Animals*. 9th ed. Alberta, Canada.
- Wu, Z., R. J. Fisher, C. E. Polan, and C. G. Schwab. 1997. Lactation performance of cows fed low or high ruminally undegradable protein prepartum and supplemental methionine and lysine postpartum. *J. Dairy Sci.* 80:722-729.
- Xin, Z. 1990. Copper status and luteinizing hormone secretion, copper distribution in tissues, neutrophil functions, superoxide dismutase activity and different copper sources for dairy cattle. Ph. D. Dissertation. University of Kentucky. Lexington, KY.
- Yu, S., C. E. West, and A. C. Beynen. 1994. Increasing intakes of iron reduce status, absorption and biliary excretion of copper in rats. *Br. J. Nutr.* 71:887-895.

CHAPTER III: EFFECTS OF PREPARTUM DIET ENERGY DENSITY ON PRODUCTIVITY OF HOLSTEIN AND JERSEY CATTLE

ABSTRACT

Twenty-four multiparous Holsteins and 24 multiparous Jerseys were assigned at random to one of four diets containing either 1.25, 1.38, 1.50, or 1.63 Mcal NE_L/kg DM in a 2 x 4 factorial plan. Cows were assigned to diets 28 d before expected calving and received a similar diet postpartum. Prepartum DMI, DMI as % BW, NE_L intake, crude protein (CP) intake, DMI change, and metabolizable energy (ME) and metabolizable protein (MP) balances increased linearly as energy density increased from 1.25 to 1.63 Mcal NE_L/kg DM. Intake of NDF, acid detergent fiber (ADF), and NDF as % of BW decreased linearly as dietary energy density increased. Prepartum DMI, DMI change, NE_L intake, ADF intake, NDF intake, CP intake, and ME balance were greater for Holsteins, while Jerseys had greater prepartum DMI and NDF intake as % of BW. Non-esterified fatty acids did not differ for energy density and were greater for Holsteins. Milk and 4% FCM increased linearly with increasing energy density, although postpartum DMI was quadratic for energy density. Milk fat concentration by energy density was cubic for Holsteins and quadratic for Jerseys. Milk protein concentration was similar for energy densities. Fat yield increased linearly with energy density and protein yield did not differ. Increasing prepartum diet energy density increased yield of milk and 4% FCM. (Key words: energy density, Holstein, Jersey, prepartum)

INTRODUCTION

Bovine fetal growth is exponential by age with more than half of total fetal weight being accrued during the last two months of gestation (Ferrell et al., 1976; Prior and Laster, 1979). Moe and Tyrrell (1972) summarized energy balance trials involving pregnant nonlactating Holstein cows to determine pregnancy metabolizable energy (ME) requirements. An exponential equation was fitted to the data and ME required increased with days of gestation. A similar equation was developed by Ferrell et al. (1976). Unlike Moe and Tyrrell (1972), the National Research Council (NRC) (1989) recommendation for fetal ME required during late gestation is constant.

Increasing prepartum dietary energy density has been shown to increase prepartum DMI (Hernandez-Urdaneta et al., 1976; Kunz et al., 1985; Minor et al., 1988), while others have reported no difference (Coppock et al., 1972; Fronk et al., 1980; Johnson and Combs, 1991). Postpartum DMI and milk yield have been unaffected by prepartum diet energy density (Hernandez-Urdaneta et al., 1976; Fronk et al., 1980; Johnson and Otterby, 1981; Boisclair et al., 1986; Skaar et al., 1989; Johnson and Combs, 1991). Prepartum non-esterified fatty acids (NEFA) have been shown to be lower with increasing energy density (Kunz et al., 1985; Minor et al., 1988), indicating less mobilization of body lipid. Lower prepartum NEFA may result in lower hepatic lipid postpartum and decreased incidence of fatty liver (Bertics et al., 1992).

In many instances, the energy density of control diets (Minor et al., 1988; Skaar et al., 1989; Johnson and Combs, 1991) were greater than recommended by NRC (1989) and treatments began 60 to 70 d prior to parturition (Fronk et al., 1980; Kunz et al., 1985; Boisclair et al., 1986; Johnson and Combs, 1991). Generally, the prepartum transition period is considered

the 2 to 3 wk prior to parturition (Grummer, 1995). Lack of response to increased energy density above NRC (1989) may be due to initiation of diets in early dry period and/or energy densities of control rations greater than NRC (1989).

The objectives of the following experiment were to: 1) determine the effect of prepartum diet energy density in the late dry period on prepartum and postpartum DMI, prepartum NEFA, and milk yield and composition; and 2) determine if responses of Holstein and Jersey cattle differ.

MATERIALS AND METHODS

Twenty-four multiparous Holsteins and 24 multiparous Jerseys were assigned at random to one of four dietary energy densities 28 d before expected calving date in a 2 x 4 factorial plan. Main effects were breed and prepartum energy density. Twenty-four cows received treatments during summer-fall (warm) seasons and 24 cows received treatments during winter-spring (cool) seasons. The four prepartum energy densities were 1) 1.25 (100), 2) 1.38 (110), 3) 1.50 (120), and 4) 1.63 Mcal NE_L/kg DM (130% of NRC). The experimental period was 28 d prepartum to 60 d postpartum.

Ingredient and nutrient composition of prepartum and postpartum diets are presented in Table 3.1. Prepartum and postpartum diets were fed once daily as a TMR. Nutrient composition of prepartum and postpartum forages are shown in Table 3.2. Cows received a similar diet from 0 to 60 d postpartum. Prepartum and postpartum diets were formulated according to NRC (1989) nutrient recommendations. Prepartum diets were isonitrogenous and ADF, NDF, and non-fiber carbohydrates differed due to differing energy densities. Desired energy densities were achieved by varying dietary concentrations of corn silage, grass hay, and corn. Feed samples were taken weekly and dried at 60°C for DM determination. Crude protein (CP) and ADF were determined biweekly and CP, ADF, NDF, and minerals were determined monthly on composite ingredient samples by wet chemistry methods (VA Tech Forage Testing Laboratory, Blacksburg, VA).

Cows were group-housed prepartum in a counter-slope barn and individual daily intake was measured by the Pinpointer system (4000B, AIS Corp., Cookville, TN). Prepartum pens were 40.9 m² and limited to a maximum of five cows at any one time. Cows were moved within 4 h after calving to individual box stalls for 2 d. Prepartum cows were fed daily at 07:00 h. Cows that calved between 22:00 and 08:00 h received their respective prepartum ration until 08:00 h at which time postpartum cows were fed. All other cows were switched to the postpartum ration at calving. Cows were housed in free-stalls postpartum and individual daily intake was measured using Calan gates (American Calan, Northwood, NH).

Body weight and body condition score were determined weekly. Cows were scored on a 5-point scale (1 = thin; 5 = fat) by two independent observers and scores were averaged prior to analysis. Daily prepartum and postpartum DMI were calculated based on daily as-fed intake and weekly diet DM. Prepartum DMI change was calculated from 14 to 1 d prepartum based on average DMI from 21 to 15 d prepartum. Postpartum DMI was averaged by wk prior to analysis. Daily prepartum CP, ADF, and NDF intakes were calculated based on DMI and nutrient composition of diet ingredients. Prepartum and postpartum DMI as a % of BW were calculated based on daily DMI and an average of prepartum and postpartum BW, respectively. Prepartum NDF intake as a % of BW was calculated based on daily NDF intake and an average prepartum BW.

Prepartum metabolizable energy (ME) and metabolizable protein (MP) balances were calculated based upon ME and MP intakes and requirements. Metabolizable energy intake was calculated using daily DMI and NRC (1989) equations for converting NE_L to ME. Maintenance and fetal ME requirements were calculated using the equation by Moe and Tyrrell (1972). Equations by Bell et al. (1995) and beef NRC (1996) were used to calculate gravid uterus and dam MP requirements, respectively. The equation by Bell (1995) was scaled to calf birth weight to account for differences in breeds. Metabolizable protein supply was determined as described by Russell et al. (1992) and Sniffen et al. (1992) using daily prepartum DMI for each cow.

Milk yield was recorded daily and averaged by wk prior to analysis. Milk fat and total protein were determined (United DHIA, Blacksburg, VA) each wk on two consecutive samples and averaged prior to analysis. Fat and protein yields were calculated based on weekly average yield and milk composition.

Blood samples were taken from the jugular into heparinized tubes -21, -14, -9 and every other d until parturition and 0 and 1 d postpartum. Day 0 samples were taken within 4 h after parturition and d 1 samples 24 h later. Samples from -14, -7, -3, -1, 0, and 1 d postpartum were used in analysis. Samples were immediately centrifuged at 5,000 g for 15 min. and stored at $-18^{\circ}C$ until analysis. Plasma was analyzed for NEFA (NEFA C kit, Wako Chemicals, Richmond, VA) with modification as described by Eisemann et al. (1988).

Data were analyzed using the mixed models procedure of SAS (1996). A Jersey cow receiving 130 was eliminated from the experiment due to calving two wk early and a Holstein cow receiving 110 was removed due to lameness. Estimated relative producing ability was used as a covariate to adjust milk yield for previous lactation milk yield. Orthogonal polynomials were used to determine energy level trends and polynomials were used to determine trends over time. Results were considered different at $P < 0.05$. The statistical model used was:

$$y_{ijklm} = \mu + \beta_o(x_i - \bar{x}) + \rho_i + \alpha_j + \tau_k + \rho\alpha_{ij} + \rho\tau_{ik} + \alpha\tau_{jk} + \rho\alpha\tau_{ijk} + C_{(ijk)_l} \\ + \gamma_m + \rho\gamma_{im} + \alpha\gamma_{jm} + \tau\gamma_{km} + \rho\alpha\gamma_{ijm} + \rho\tau\gamma_{ikm} + \alpha\tau\gamma_{jkm} + \rho\alpha\tau\gamma_{ijkm} + \varepsilon_{ijklm}$$

where:

y	is the dependent variable (milk yield, intake, milk composition, NEFA, BW, BCS)
μ	is the overall mean,
$\beta_o(x_i - \bar{x})$	is the regression coefficient for estimated relative producing ability (used only for milk yield),
ρ_i	is the effect if the i th season (warm and cool),
α_j	is the effect of the j th breed (Holstein and Jersey),
τ_k	is the effect of the k th energy level (100, 110, 120, and 130),
$\rho\alpha_{ij}$	is the interaction of the i th season and the j th breed,
$\rho\tau_{ik}$	is the interaction of the i th season and the k th energy level,
$\alpha\tau_{jk}$	is the interaction of the j th breed and the k th energy level,
$\rho\alpha\tau_{ijk}$	is the interaction of the i th season, j th breed, and the k th energy level,
$C_{(ijk)_l}$	is the random error associated with the l th cow within the i th season, j th breed, and k th energy level,
γ_m	effect of the m th repeated measure (d and wk),

$\rho\gamma_{im}$	is the interaction of the <i>i</i> th season and <i>m</i> th repeated measure,
$\alpha\gamma_{jm}$	is the interaction of the <i>j</i> th breed and the <i>m</i> th repeated measure,
$\tau\gamma_{km}$	is the interaction of the <i>k</i> th energy level and the <i>m</i> th repeated measure,
$\rho\alpha\gamma_{ijm}$	is interaction of the <i>i</i> th season, <i>j</i> th breed, and <i>m</i> th repeated measure,
$\rho\tau\gamma_{ikm}$	is the interaction of the <i>i</i> th season, <i>k</i> th energy level, and <i>m</i> th repeated measure,
$\alpha\tau\gamma_{jkm}$	is the interaction of the <i>j</i> th breed, <i>k</i> th energy level, and <i>m</i> th repeated measure,
$\rho\alpha\tau\gamma_{ijkm}$	is the interaction of the <i>i</i> th season, <i>j</i> th breed, <i>k</i> th energy level, and <i>m</i> th repeated measure,
ϵ_{ijklm}	is the residual error.

RESULTS

Prepartum and postpartum results for energy density are shown in Tables 3.3 and 3.4, respectively. Days receiving prepartum diets and lactation number did not differ. Prepartum BW did not differ and prepartum BCS increased linearly as energy density increased from 1.25 to 1.63 Mcal NE_L/kg DM. Postpartum BCS by week was quadratic for 100 and decreased linearly for all other energy densities. In addition, postpartum BW by week was quadratic for 100, 120, and 130, and linear for 110. Postpartum BW and BCS losses did not differ for energy density.

Prepartum Holstein and Jersey results by energy density are shown in Tables 3.5 and 3.6, respectively, and breed results are shown in Table 3.9. Days receiving prepartum diets and lactation number did not differ. Prepartum BW was greater for Holstein and prepartum BCS did not differ for breeds. Energy density by breed interaction was significant for postpartum BW. Postpartum BW was cubic for Holstein and linear for Jersey. Postpartum BW by week was quadratic and linear for Holstein and Jersey, respectively. Postpartum BCS was greater for Jersey. Postpartum BW loss was greater for Holstein, while postpartum BCS loss did not differ. Plasma NEFA were greater for Holstein compared to Jersey.

Season results are shown in Table 3.10. Days receiving prepartum diets and lactation number did not differ. Prepartum BW and BCS were similar for seasons and postpartum BW and BCS were greater for warm season. Postpartum BW and BCS losses were greater for cool season.

Prepartum DMI increased linearly (Table 3.3 and Figure 3.1) and postpartum DMI (Table 3.4) was quadratic for energy density. Postpartum DMI increased linearly with week. Prepartum DMI as % of BW increased linearly with increasing energy density. Prepartum DMI declined linearly with energy density as parturition approached. Prepartum intake of NE_L, CP, ADF, and NDF increased linearly with energy density. Prepartum intake of ADF, CP, and NDF as % of BW by week was linear for 100 and quadratic for all other energy densities. Prepartum intake of NE_L by week was linear for 130 and quadratic for all other energy densities. Intake of NDF as % of BW decreased linearly with increasing energy density.

Prepartum and postpartum DMI were greater for Holstein (Table 3.9). Prepartum DMI as % of BW was greater for Jersey, while postpartum DMI as a % of BW differed by breed and energy density (Tables 3.7 and 3.8) with quadratic and cubic responses for Holsteins and Jerseys, respectively. There was a breed by season interaction for change in prepartum DMI. Change in

DMI as parturition approached did not differ for Holsteins between seasons, but was greater during cool season for Jerseys. Prepartum DMI did not decline until the day prior to parturition for Jerseys, while the decline began one week prior to parturition for Holsteins. In addition, the decline in prepartum DMI as parturition approached was greater for Holsteins. Prepartum intake of NE_L, CP, ADF, and NDF was greater for Holstein. Intake of NDF as a % of BW was greater for Jersey.

Prepartum DMI was greater during cool season (Table 3.10). Prepartum intake of NE_L, CP, NDF, and NDF as a percentage of BW by week was quadratic for warm and linear for cool season. Prepartum intake of ADF and intake of NDF as a % of BW was greater for cool season.

Prepartum ME requirement did not differ for energy density (Table 3.3) or season (Table 3.10) and was greater for Holstein (Table 3.9). Prepartum ME balance was positive for all energy densities, increased linearly with energy density, and was greater for Holstein and cool season. Cows remained in positive ME balance throughout the prepartum period. Prepartum MP requirement did not differ for energy density (Table 3.3) or season (Table 3.10) and was greater for Holstein (Table 3.8). Prepartum MP balance increased linearly with increasing energy density and did not differ for breed or season. Prepartum MP was positive for all energy densities until 1 d prior to parturition at which 100, 110, and 120 were negative.

Milk yield and 4% FCM yield increased linearly with increasing energy density (Table 3.4) and week. Milk protein concentrations did not differ for energy density. Fat yield by week was linear for 100, 110 and 130, and quadratic for 120. Energy density did not affect protein yield.

Milk yield and 4% FCM yield was greater for Holstein (Table 3.9). Milk fat concentration by energy density was cubic for Holsteins (Table 3.7) and quadratic for Jerseys (Table 3.8), while milk protein concentration was greater for Jersey. Protein yield was greater for Jersey and fat yield did not differ between breeds.

Yields of milk and 4% FCM were greater for cool season (Table 3.10). Milk fat was greater during cool season and milk protein concentration by wk was quadratic for warm season and linear for cool season. Fat yield was greater during cool season, while season did not affect protein yield.

Non-esterified fatty acids did not differ for energy density (Table 3.3) or season (Table 3.10) and were greater for Holstein (Table 3.9). Non-esterified fatty acids increased linearly as parturition approached with the greatest concentration observed on the day of parturition. Although NEFA concentration declined 1 d postpartum, concentration was greater than prior to parturition.

DISCUSSION

Differences in prepartum BCS for energy densities were maintained postpartum and further evidenced by similar losses in BCS. Although postpartum BW differed for energy level, BW loss was similar. Garnsworthy and Topps (1982) reported that cows in higher condition score at calving had lower DMI. Differences in BCS were approximately one-unit (Garnsworthy and Topps, 1982) compared to approximately one-half unit in the current experiment. Otto et al. (1991) estimated that a one-unit change in BCS was associated with 56 kg live weight. Average birth weight was 35 kg and assuming a 33% increase in loss (Ferrell et al., 1976) due to placenta and fetal fluids, results in a loss of 53 kg at calving. Change in BCS closely approximates change in BW adjusted for fetus, fetal fluids, and placenta.

Prepartum DMI increased as dietary energy density increased and is consistent with previous reports (Hernandez-Urdaneta et al., 1976; Kunz et al., 1985; Minor et al., 1988). Hernandez-Urdaneta et al. (1976) suggested that higher digestibility and lower bulkiness resulted in higher prepartum DMI. Physical factors were likely controlling DMI of 100 and physiological factors (NRC, 1989) controlling DMI of 130 as shown by the linear decrease in intakes of ADF, NDF, and NDF as % of BW as energy density increased. However, DMI as % of BW increased linearly with increasing energy density. Prepartum DMI of the higher energy diets exceeded previous reports (Hernandez-Urdaneta et al., 1976; Johnson and Otterby, 1981; Minor et al., 1998) where cows were confined and fed in tie-stalls. Differences in prepartum DMI between energy levels and compared to previous reports may be attributed to psychogenic regulation which involves factors in the feed or feeding environment separate from the diet's energy density or bulkiness (Mertens, 1994).

The decline in DMI two weeks prior to parturition was not as severe as reported by Bertics et al. (1992), although the greatest decline occurred the day prior to parturition and was 82, 67, 63, and 61% of average DMI between 21 to 14 d prepartum for 100, 110, 120, and 130, respectively. Coppock et al. (1972) reported that prepartum DMI depression was greater for cows consuming higher concentrate diets and is consistent with current results. Jersey prepartum DMI did not decline until the day prior to parturition, whereas Holstein DMI began declining 10 d prior to parturition. Adjusting diets for the expected decline in prepartum DMI as parturition approaches may not be necessary for Jersey cows.

This is the first experiment to show a linear increase in milk and 4% FCM yield as dietary energy density increases and differs from previous reports (Hernandez-Urdaneta et al., 1976; Fronk et al., 1980; Johnson and Otterby, 1981; Boisclair et al., 1986; Skaar et al., 1989; Johnson and Combs, 1991). The difference in milk yield cannot be explained by the difference in postpartum DMI, which responded in a quadratic trend to energy density. Likewise, mobilization of lipid stores to support additional milk yield was not evident based on change in BW. Johnson and Combs (1991) reported a tendency for increased 3.5% FCM without an increase in DMI. Putnam et al. (1997) reported a positive correlation between prepartum DMI and milk yield.

Bell (1995) reported that only 32% of amino acid nitrogen taken up by the near term fetus is deposited in tissue protein and catabolism of amino acids accounts for over half of the daily energy supply. Labile protein contribution is critical during the first two wk of lactation when the cow is in negative nitrogen balance (Bauman and Elliot, 1983). Based on estimates by Bell (1995), considerable amounts of endogenous amino acids are used for gluconeogenesis during the first wk of lactation. Differences in milk yield between energy densities were greater during the first wk of lactation. If the estimated MP balance is accurate, endogenous amino acids could have contributed to the increase in milk yield as energy density increased. Estimated MP balance increased linearly with energy level. Due to increased prepartum DMI as energy density increased, protein reserves may have been spared during late gestation and/or replenished from the previous lactation.

Plasma NEFA did not differ for energy density, which may indicate that 100 was adequate in meeting energy needs, and differs from previous reports (Kunz et al., 1985; Minor et al., 1988). In addition, ME balances indicate that all energy densities were in positive balance which may further explain similar NEFA. The gradual increase in plasma NEFA as parturition approaches as reported by Vazques-Anon et al. (1994) did not occur. Plasma NEFA did not increase until the day of parturition. Bertics et al. (1992) suggested that the depression in DMI

might account for increased plasma NEFA. Although DMI depression differed for energy levels, plasma NEFA was similar. In addition, the magnitude of increase in NEFA was not as great as reported by Bertics (1992) and Vazquez-Anon et al. (1994) and may be due to less depression in prepartum DMI. However, the difference in breed NEFA might be explained by the hypothesis of Bertics et al. (1992). Jersey prepartum DMI did not decline to the extent of Holsteins. Although breed by day interaction did not exist for NEFA, the difference in breed NEFA likely occurred 0 and 1 d postpartum.

IMPLICATIONS

Increasing prepartum diet energy density resulted in a linear increase in milk and 4% FCM yield. It is hypothesized that increases in nutrient intake due to a linear increase in prepartum DMI contributed to increased yield, since postpartum DMI did not respond to prepartum energy density in a similar manner. The decline in Jersey prepartum intake did not occur to the extent as in Holsteins and may have lead to lower NEFA. Therefore, increasing nutrient density in anticipation of DMI decline prior to parturition may not be warranted in Jersey cattle.

REFERENCES

- Bauman, D. E., and J. M. Elliot. 1983. Control of nutrient partitioning in lactating ruminants. In: T. B. Mepham (Ed.) *Biochemistry of Lactation*. p 437. Elsevier, Amsterdam, The Netherlands.
- Bell, A. W. 1995. Regulation of organic nutrient metabolism during transition from late pregnancy to early lactation. *J. Anim. Sci.* 73:2804-2819.
- Bell, A. W., R. Slepatis, and R. A. Ehrhardt. 1995. Growth and accretion of energy and protein on the gravid uterus during late pregnancy. *J. Dairy Sci.* 78:1954-1961.
- Bertics, S. J., R. R. Grummer, C. C. Cadorniga-Valino, and E. E. Stoddard. 1992. Effect of prepartum dry matter intake on liver triglyceride concentration and early lactation. *J. Dairy Sci.* 75:1914-1922.
- Boisclair, Y., D. G. Grieve, J. B. Stone, O. B. Allen, and G. K. MacLeod. 1986. Effect of prepartum energy, body condition, and sodium bicarbonate on production of cows in early lactation. *J. Dairy Sci.* 69:2636-2647.
- Coppock, C. E., C. H. Noller, S. A. Wolfe, C. J. Callahan, and J. S. Baker. 1972. Effect of forage-concentrate ratio in complete feeds fed ad libitum on feed intake prepartum and the occurrence of abomasal displacement in dairy cows. *J. Dairy Sci.* 55:783-789.
- Eisemann, J. H., G. B. Huntington, and C. L. Ferrell. 1988. Effects of dietary clenbuterol on metabolism of the hindquarter in steers. *J. Anim. Sci.* 66:342-353.
- Ferrell, C. L., W. N. Garrett, and N. Hinman. 1976. Growth, development and composition of the udder and gravid uterus of beef heifers during pregnancy. *J. Anim. Sci.* 42:1477-1489.
- Fronk, T. J., L. H. Schultz, and A. R. Hardie. 1980. Effect of dry period overconditioning on subsequent metabolic disorders and performance of dairy cows. *J. Dairy Sci.* 63:1080-1090.
- Garnsworthy, P. C., and J. H. Topps. 1982. The effect of body condition of dairy cows at calving on their food intake and performance when given complete diets. *Anim. Prod.* 35: 113-119.
- Grummer, R. R., 1995. Impact of changes in organic nutrient metabolism on feeding the transition dairy cow. *J. Anim. Sci.* 73:2820-2833.

- Hernandez-Uraneta, A., C. E. Coppock, R. E. McDowell, D. Gianola, and N. E. Smith. 1976. Changes in forage-concentrate ratio of complete feeds for dairy cows. *J. Dairy Sci.* 59:695-707.
- Johnson, D. G., and D. E. Otterby. 1981. Influence of dry period diet on early postpartum health, feed intake, milk production, and reproductive efficiency in Holstein cows. *J. Dairy Sci.* 64:290-295.
- Johnson, T. R., and D. K. Combs. 1991. Effects of prepartum diet, inert rumen bulk, and dietary polyethylene glycol on dry matter intake of lactating dairy cows. *J. Dairy Sci.* 74:933-944.
- Kunz, P. L., and J. W. Blum. 1985. Effects of different energy intakes before and after calving on food intake, performance and blood metabolites in dairy cows. *Anim. Prod.* 40:219.
- Mertens, D. R. 1994. Regulation of forage intake. In: G. C. Fahey, Jr. (Ed.) *Forage Quality, Evaluation, and Utilization*. American Society of Agronomy, Madison, WI.
- Minor, D. J., S. L. Trower, B. D. Strang, R. D. Shaver, and R. R. Grummer. 1998. Effects of nonfiber carbohydrate and niacin on periparturient metabolic status and lactation of dairy cows. *J. Dairy Sci.* 81:189-200.
- Moe, P. W., and H. F. Tyrrell. 1972. Metabolizable energy requirements of pregnant dairy cows. *J. Dairy Sci.* 55:480-483.
- National Research Council. 1989. *Nutrient Requirements of Dairy Cattle*. 6th revised ed. Natl. Acad. Sci., Washington, DC.
- National Research Council. 1996. *Nutrient Requirements of Beef Cattle*. 7th revised ed. Natl. Acad. Sci., Washington, DC.
- Otto, K. L., J. D. Ferguson, D. G. Fox, and C. J. Sniffen. 1991. Relationship between body condition score and composition of ninth to eleventh rib tissue in Holstein dairy cows. *J. Dairy Sci.* 74:852-.
- Prior, R. L., and D. B. Laster. 1979. Development of the bovine fetus. *J. Anim. Sci.* 48:1546-1553.
- Putnam, D. E., K. J. Soder, L. A. Holden, G. A. Varga, and H. M. Dann. 1997. Periparturient traits correlate with postpartum dry matter intake and milk yield. *J. Dairy Sci.* 80(Suppl.):142(Abstr.)
- Russell, J. B., J. D. O'Conner, D. G. Fox, P. J. Van Soest, and C. J. Sniffen. 1992. A net carbohydrate and protein system for evaluating cattle diets: I. Ruminant fermentation. *J. Anim. Sci.* 70:3551-3561.
- SAS® System for Mixed Models. 1996. R. C. Littell, G. A. Milliken, W. W. Stroup, and R. D. Wolfinger, ed. SAS Inst., Inc., Cary, NC.
- Skaar, T. C., R. R. Grummer, M. R. Dentine, and R. H. Stauffacher. 1989. Seasonal effects of prepartum and postpartum fat and niacin feeding on lactation performance and lipid metabolism. *J. Dairy Sci.* 72:2028-2038.
- Sniffen, C. J., J. D. O'Connor, P. J. Van Soest, D. G. Fox, and J. B. Russell. 1992. A Net carbohydrate and protein system for evaluating cattle diets: II. Carbohydrate and protein availability. *J. Anim. Sci.* 70:3562:3577.
- Vazquez-Anon, M., S. Bertics, M. Luck, and R. R. Grummer. 1994. Peripartum liver triglyceride and plasma metabolites in dairy cows. *J. Dairy Sci.* 77:1521-1528.

Table 3.1. Ingredient and nutrient composition of prepartum and postpartum diets.

Ingredient	Prepartum				Postpartum
	100	110	120	130	
	-----% of DM-----				
Corn silage	23.0	46.7	62.8	46.1	24.0
Grass hay	63.8	37.6	15.2	7.4	
Dry corn	7.7	9.1	14.8	38.4	
Soybean meal	6.9	7.4	7.8	7.3	8.6
Molasses	0.4	0.4	0.4	0.4	
Mineral-vitamin mix ^{1,2}	0.4	0.4	0.4	0.4	1.2
Alfalfa Silage					23.6
Whole cottonseed					11.4
High moisture corn					26.0
Animal-marine protein					3.8
Limestone					0.6
Sodium bicarbonate					0.6
Nutrient					
DM, % as-fed basis	65.4	52.6	46.4	52.9	56.7
CP, % of DM	12.1	12.1	12.1	12.1	18.7
ADF	34.9	28.9	22.8	17.0	18.7
NDF	55.9	47.0	37.9	28.0	27.6
NFC ³	17.0	27.7	38.6	50.0	38.4
Ca	0.30	0.29	0.28	0.23	0.97
K	1.79	1.56	1.32	1.06	1.32
Mg	0.20	0.19	0.18	0.18	0.27
Na	0.09	0.08	0.08	0.08	0.32
P	0.28	0.28	0.29	0.31	0.46
S	0.17	0.15	0.14	0.15	0.27
Cu, mg/kg DM	8.7	8.6	8.6	8.8	11.2
Fe	84.8	104.9	117.6	110.3	186.0
Mn	78.4	60.7	44.6	38.1	35.7
Zn	37.9	40.3	42.1	42.6	43.3
NE _L , Mcal/kg of DM ⁴	1.25	1.38	1.50	1.63	1.67

¹Prepartum mineral-vitamin mix contained 15% Ca, 8.5% Cl, 2% Mg, 5.5% Na, 9% P, 0.0026 % Co, 0.0690 % Cu, 0.1300 % Fe, 0.2600 % Mn, 0.0052 % Se, 0.4500 % Zn, 273 KIU A/kg DM, 55 KIU D/kg DM, and 682 IU E/kg DM.

²Postpartum mineral-vitamin mix contained 16% Ca, 5.8% Cl, 3.5% K, 2.2% Mg, 6.5% Na, 6.5% P, 3.2% S, 0.0003 % Co, 0.0132 % Cu, 0.0265 % Fe, 0.1100 % Mn, 0.0005 % Se, 0.1325 % Zn, 14 KIU A/kg DM, 9 KIU D/kg DM, and 114 IU E/kg DM.

³Calculated non-fiber carbohydrates

⁴NRC (6) values were used for concentrates.

Table 3.2. Nutrient content of prepartum and postpartum forages.

Nutrient	Prepartum		Postpartum	
	Corn Silage	Grass Hay	Corn Silage	Alfalfa Silage
DM, % as-fed basis	36.7	88.8	35.2	52.0
CP, % of DM	8.7	9.6	8.0	18.6
ADF	23.5	46.0	22.4	30.0
NDF	43.1	78.1	39.4	40.6
Ca	0.24	0.26	0.25	1.41
K	1.25	2.12	1.08	2.52
Mg	0.16	0.19	0.18	0.33
Na	0.06	0.08	0.06	0.14
P	0.21	0.20	0.21	0.22
S	0.10	0.17	0.11	0.28
Cu, mg/kg DM	4.4	5	10.0	10.7
Fe	138.4	53.4	260.0	186.4
Mn	25.3	94.0	30.0	30.3
Zn	24.0	14.9	21.0	24.8
NE _L , Mcal/kg of DM ¹	1.50	1.03	1.50	1.41

¹Equations were used to calculate the NE_L (Mcal/kg of DM) content of corn silage (0.807 – 0.0051ADF), grass hay (2.2415 – 0.0262ADF), and alfalfa silage (0.949 – 0.00957ADF).

Table 3.3. Prepartum parameter least square means for energy density.

Item	Energy Density (Mcal NE _L /kg DM)								Contrast*			
	1.25		1.38		1.50		1.63		L	Q	C	
	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE	----- P < -----			
n	12		11		12		11					
Lactation #	3.1	0.3	2.9	0.4	3.1	0.3	3.0	0.4	0.92			
d on Diets	30.6	0.9	28.4	0.9	28.9	0.9	30.1	0.9	0.28			
BW, kg	569	16	586	15	624	15	578	16	0.09			
BCS	3.05	0.10	3.36	0.11	3.55	0.11	3.40	0.10	0.01	0.01	0.03	0.59
DMI, kg/d	9.1	0.3	10.4	0.3	11.8	0.3	14.2	0.3	0.01	0.01	0.07	0.54
DMI, % of BW	1.62	0.06	1.83	0.06	1.94	0.06	2.48	0.06	0.01	0.01	0.01	0.06
DMI Change, %	105	2.5	91	2.5	96	2.5	93	2.5	0.01	0.02	0.04	0.03
ME Requirement, Mcal/d	18.1	0.4	18.2	0.4	19.7	0.4	18.8	0.4	0.20			
ME Balance, Mcal/d	8.6	1.3	14.7	1.4	19.6	1.4	29.2	1.4	0.01	0.01	0.21	0.38
MP Requirement, g/d	699	23	700	26	744	25	711	24	0.51			
MP Balance, g/d	25	39	172	41	406	40	771	40	0.01	0.01	0.02	0.81
NE _L Intake, Mcal/d	11.4	0.4	14.1	0.4	17.7	0.4	23.1	0.3	0.01	0.01	0.03	0.64
CP Intake, kg/d	1.13	0.04	1.28	0.04	1.46	0.04	1.75	0.04	0.01	0.01	0.08	0.66
ADF Intake, kg/d	3.15	0.07	2.94	0.07	2.56	0.07	2.43	0.07	0.01	0.01	0.59	0.22
NDF Intake, kg/d	5.41	0.12	5.11	0.12	4.74	0.12	4.26	0.12	0.01	0.01	0.44	0.95
NDF Intake, % of BW	0.97	0.02	0.91	0.03	0.78	0.03	0.75	0.02	0.01	0.01	0.73	0.14
NEFA, μ mol/l	258	22	254	21	269	21	248	25	0.93			

*L = linear, Q = quadratic, C = cubic

Table 3.4. Postpartum parameter least square means for energy density.

	Energy Density (Mcal NE _L /kg DM)								Contrast*			
	1.25		1.38		1.50		1.63		L	Q	C	
	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE	----- P < -----			
n	12		11		12		11					
BW, kg	493	9	477	10	531	9	509	9	0.01	0.02	0.79	0.01
BW Loss, kg	76	6	88	6	93	6	77	6	0.14			
BCS	2.49	0.07	2.65	0.08	2.84	0.07	2.83	0.07	0.01	0.01	0.27	0.49
BCS Loss	0.55	0.09	0.73	0.09	0.71	0.09	0.61	0.09	0.13			
DMI, kg/d	23.4	0.07	21.1	0.07	23.0	0.07	24.1	0.07	0.05	0.15	0.01	0.09
DMI, % of BW	4.88	0.11	4.86	0.11	4.50	0.11	4.74	0.11	0.04	0.44	0.01	0.61
Milk Yield, kg/d	35.1	0.9	35.5	1.0	38.3	1.0	37.9	0.9	0.05	0.05	0.70	0.19
4% FCM, kg/d	34.8	1.1	34.2	1.2	39.1	1.2	38.5	1.1	0.01	0.01	0.99	0.06
Milk fat, %	4.05	0.09	3.96	0.10	4.25	0.10	4.19	0.09	0.17			
Fat Yield, kg/d	1.38	0.05	1.32	0.06	1.58	0.06	1.58	0.05	0.05	0.01	0.65	0.05
Milk Protein, %	3.38	0.05	3.19	0.05	3.31	0.05	3.27	0.05	0.06			
Protein Yield, kg/d	1.15	0.04	1.09	0.04	1.22	0.04	1.23	0.04	0.06			

*L = linear, Q = quadratic, C = cubic

Table 3.5. Prepartum parameter least square means for Holstein by energy density.

	Energy Density (Mcal NE _L /kg DM)								Breed x Energy Density ----- P < -----
	1.25		1.38		1.50		1.63		
	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE	
n	6		5		6		6		
d on Diets	30.7	1.2	28.8	1.4	29.8	1.2	30.5	1.2	0.90
Lactation #	3.0	0.3	2.3	0.4	3.2	0.3	3.0	0.4	0.69
BW, kg	681	22	684	22	764	22	664	19	0.11
BCS	2.90	0.15	3.34	0.16	3.74	0.16	3.33	0.13	0.11
DMI, kg/d	10.1	0.4	11.9	0.4	13.3	0.4	15.4	0.4	0.59
DMI, % of BW	1.49	0.08	1.84	0.09	1.76	0.08	2.29	0.07	0.07
DMI Change, %	99	3.5	87	3.5	93	3.5	90	3.3	0.90
ME Requirement, Mcal/d	20.9	0.5	20.0	0.6	22.0	0.5	20.8	0.5	0.60
ME Balance, Mcal/d	10.8	1.9	17.3	2.1	21.3	2.1	31.6	1.8	0.27
MP Requirement, g/d	837	32	799	39	866	38	822	31	0.71
MP Balance, g/d	-33	55	196	62	403	62	789	52	0.47
NE _L Intake, Mcal/d	12.7	0.6	16.0	0.7	20.0	0.6	25.1	0.6	0.40
CP Intake, g/d	1.27	0.05	1.46	0.06	1.66	0.05	1.91	0.05	0.84
ADF Intake, g/d	3.54	0.10	3.33	0.10	2.78	0.10	2.67	0.09	0.19
NDF Intake, g/d	6.09	0.16	5.77	0.18	5.36	0.16	4.78	0.15	0.43
NDF Intake, % of BW	0.90	0.03	0.91	0.04	0.71	0.03	0.69	0.03	0.25
NEFA, μ mol/l	250	33	277	31	308	29	309	26	0.22

Table 3.6. Prepartum parameter least square means for Jersey by energy density.

	Energy Density (Mcal NE _L /kg DM)								Breed x
	1.25		1.38		1.50		1.63		Energy Density
	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE	----- P < -----
n	6		6		6		5		
d on Diets	30.5	1.2	28.7	1.2	28.0	1.2	29.8	1.4	0.90
Lactation #	2.8	0.5	3.2	0.5	3.0	0.5	3.3	0.5	0.69
BW, kg	457	22	486	22	483	22	481	25	0.11
BCS	3.20	14	3.38	15	3.37	14	3.47	16	0.11
DMI, kg/d	8.0	0.4	8.8	0.4	10.3	0.4	12.9	0.4	0.59
DMI, % of BW	1.76	0.08	1.82	0.08	2.13	0.08	2.67	0.09	0.07
DMI Decline, %	111	3	95	3	100	3	97	4	0.90
ME Requirement, Mcal/d	15.3	0.5	16.4	0.5	17.3	0.5	16.9	0.6	0.60
ME Balance, Mcal/d	2.4	1.9	5.6	1.9	11.3	1.8	20.4	2.1	0.27
MP Requirement, g/d	560	33	600	34	623	32	599	37	0.71
MP Balance, g/d	83	55	148	55	409	62	753	52	0.47
NE _L Intake, Mcal/d	10.1	0.6	12.2	0.6	15.4	0.6	21.1	0.7	0.40
CP Intake, kg/d	0.99	0.05	1.10	0.05	1.27	0.05	1.56	0.06	0.84
ADF Intake, kg/d	2.75	0.10	2.54	0.10	2.34	0.10	2.18	0.11	0.19
NDF Intake, kg/d	4.72	0.17	4.45	0.17	4.12	0.16	3.83	0.18	0.43
NDF Intake, % of BW	1.03	0.03	0.92	0.03	0.86	0.03	0.80	0.04	0.25
NEFA, μ mol/l	265	29	231	30	229	30	188	42	0.22

Table 3.7. Postpartum parameter least square means for Holstein by energy density.

	Energy Density (Mcal NE _L /kg DM)								Breed x Energy Density ----- P < -----
	100		110		120		130		
	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE	
n	6		5		6		6		
BW, kg	585	13	539	15	639	13	568	12	0.01
BW Change, kg	97	8	103	9	125	8	96	7	0.23
BCS	2.37	0.10	2.63	0.12	2.80	0.10	2.61	0.09	0.26
BCS Change	0.50	0.12	0.72	0.14	0.94	0.12	0.61	0.11	0.14
DMI, kg/d	24.5	0.9	22.2	1.0	23.9	0.9	25.4	0.9	0.99
DMI, % of BW	4.19	0.15	4.11	0.17	3.77	0.15	4.39	0.14	0.03
Milk Yield, kg/d	39.7	1.3	40.6	1.4	42.8	1.3	43.8	1.4	0.68
4% FCM, kg/d	36.9	1.6	35.6	1.6	41.8	1.8	42.4	1.5	0.54
Milk fat, %	3.68	0.13	3.27	0.15	3.92	0.13	3.86	0.12	0.04
Fat Yield, kg/d	1.39	0.08	1.28	0.09	1.63	0.08	1.68	0.07	0.33
Milk Protein, %	3.12	0.06	2.84	0.07	2.99	0.06	2.84	0.06	0.32
Protein Yield, kg/d	1.22	0.05	1.14	0.06	1.24	0.05	1.17	0.05	0.81

Table 3.8. Postpartum parameter least square means for Jersey by energy density.

	Energy Density (Mcal NE _L /kg DM)								Breed x Energy Density ----- P < -----
	100		110		120		130		
	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE	
n	6		6		6		5		
BW, kg	400	13	413	13	423	13	450	15	0.01
BW Change, kg	56	8	73	8	61	8	58	9	0.23
BCS	2.62	0.10	2.67	0.10	2.88	0.10	3.03	0.12	0.26
BCS Change	0.60	0.12	0.73	0.12	0.50	0.12	0.49	0.14	0.14
DMI, kg/d	22.3	0.9	20.0	0.9	22.1	0.9	22.9	1.0	0.99
DMI, % of BW	5.66	0.15	4.82	0.15	5.23	0.15	5.09	0.17	0.03
Milk Yield, kg/d	30.6	1.3	30.2	1.3	33.8	1.3	32.0	1.5	0.68
4% FCM, kg/d	32.6	1.6	32.8	1.6	36.4	1.6	34.6	1.8	0.54
Milk fat, %	4.43	0.13	4.66	0.13	4.58	0.13	4.51	0.15	0.04
Fat Yield, kg/d	1.36	0.08	1.37	0.08	1.52	0.08	1.48	0.09	0.33
Milk Protein, %	3.61	0.06	3.54	0.06	3.60	0.06	3.60	0.07	0.32
Protein Yield, kg/d	1.09	0.05	1.05	0.05	1.20	0.05	1.17	0.06	0.81

Table 3.9. Prepartum and postpartum parameter least square means for breed.

	Holstein		Jersey		--- P < ---
	\bar{X}	SE	\bar{X}	SE	
n	23		23		
Prepartum					
d on Diets	29.9	0.6	29.2	0.6	0.43
Lactation #	2.8	0.2	3.1	0.2	0.50
BW, kg	698	11	470	11	0.01
BCS	3.32	0.07	3.35	0.07	0.76
DMI, kg/d	12.7	0.2	10.1	0.2	0.01
DMI, % of BW	1.85	0.04	2.09	0.04	0.01
DMI Change, %	92	2	101	2	0.01
ME Requirement, Mcal/d	20.9	0.3	16.4	0.3	0.01
ME Balance, Mcal/d	11.9	1.0	9.9	1.0	0.03
MP Requirement, g/d	831	18	596	17	0.01
MP Balance, g/d	339	29	348	28	0.81
NE _L Intake, Mcal/d	18.4	0.3	14.7	0.3	0.01
CP Intake, kg/d	1.58	0.03	1.24	0.03	0.01
ADF Intake, kg/d	3.08	0.05	2.45	0.05	0.01
NDF Intake, kg/d	5.48	0.08	4.28	0.08	0.01
NDF Intake, % of BW	0.80	0.02	0.90	0.02	0.01
NEFA, μ mol/l	286	15	228	17	0.01
Postpartum					
BW, kg	583	7	422	7	0.01
BW Loss, kg	105	4	62	4	0.01
BCS	2.60	0.05	2.80	0.05	0.01
BCS Loss	0.72	0.06	0.58	0.06	0.11
DMI, kg/d	24	0.5	21.8	0.5	0.01
DMI, % of BW	4.11	0.08	5.18	0.08	0.01
Milk Yield, kg/d	41.7	0.7	31.7	0.7	0.01
4% FCM, kg/d	39.2	0.8	34.1	0.8	0.01
Milk fat, %	3.68	0.07	4.54	0.07	0.01
Fat Yield, kg/d	1.50	0.04	1.43	0.04	0.25
Milk Protein, %	2.97	0.03	3.60	0.03	0.01
Protein Yield, kg/d	1.22	0.03	1.13	0.03	0.02

Table 3.10. Prepartum and postpartum parameter least square means for season.

Item	Warm Season		Cool Season		--- P < ---
	\bar{X}	SE	\bar{X}	SE	
N	23		23		
Prepartum					
d on Diets	28.9	0.6	30.3	0.6	0.14
Lactation #	3.0	0.2	2.8	0.2	0.57
BW, kg	589	11	589	11	0.98
BCS	3.31	0.07	3.37	0.07	0.52
DMI, kg/d	11.0	0.2	11.7	0.2	0.05
DMI, % of BW	1.94	0.04	2.00	0.04	0.29
DMI Change, %	100	2	93	2	0.01
ME Requirement, Mcal/d	18.6	0.3	18.5	0.3	0.56
ME Balance, Mcal/d	9.7	1.0	12.1	1.0	0.01
MP Requirement, g/d	716	18	711	17	0.80
MP Balance, g/d	314	29	373	28	0.16
NE _L Intake, Mcal/d	16.0	0.3	17.1	0.3	0.04
CP Intake, kg/d	1.40	0.03	1.41	0.03	0.84
ADF Intake, kg/d	2.57	0.05	2.97	0.05	0.01
NDF Intake, kg/d	4.65	0.08	5.11	0.08	0.01
NDF Intake, % of BW	0.82	0.02	0.88	0.02	0.02
NEFA, μ mol/l	277	15	237	17	0.09
Postpartum					
BW, kg	518	7	487	7	0.01
BW Loss, kg	66	4	101	4	0.01
BCS	2.80	0.05	2.60	0.05	0.01
BCS Loss	0.51	0.06	0.79	0.06	0.01
DMI, kg/d	22.9	0.5	22.8	0.5	0.94
DMI, % of BW	4.11	0.08	5.18	0.08	0.03
Milk Yield, kg/d	37.2	0.7	36.2	0.7	0.30
4% FCM, kg/d	34.8	0.8	38.5	0.8	0.01
Milk fat, %	3.83	0.07	4.39	0.07	0.01
Fat Yield, kg/d	1.37	0.04	1.56	0.04	0.01
Milk Protein, %	3.21	0.03	3.36	0.03	0.01
Protein Yield, kg/d	1.15	0.03	1.20	0.03	0.21

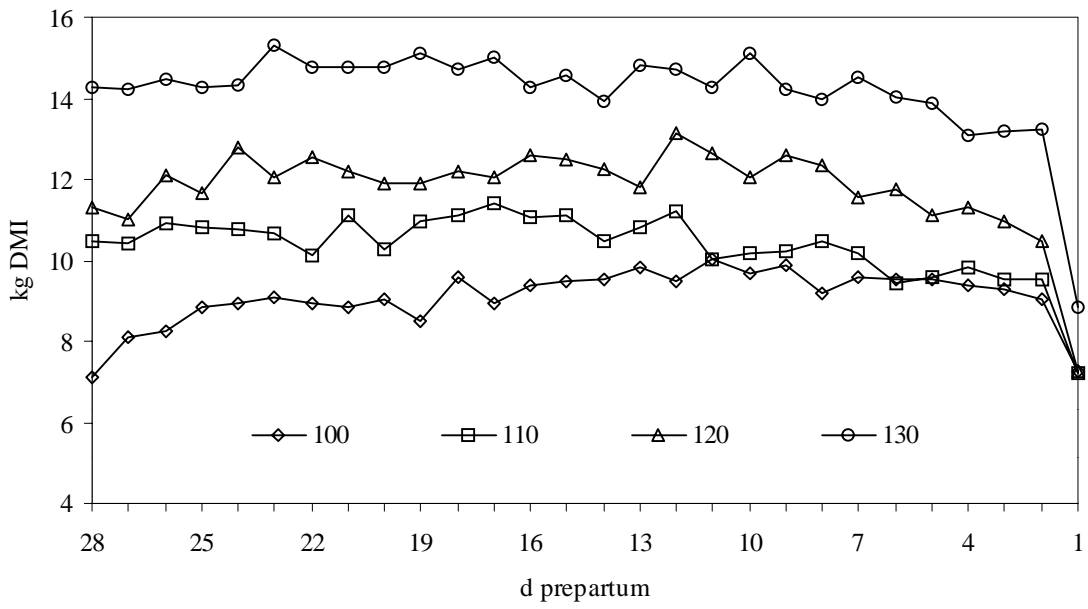


Figure 3.1. Daily least square mean prepartum DMI by energy density.

CHAPTER IV: EFFECTS OF PREPARTUM CRUDE PROTEIN AND RUMEN UNDEGRADABLE PROTEIN ON PRODUCTIVITY OF JERSEY CATTLE

ABSTRACT

An experiment was conducted to evaluate the influence of crude protein (CP) and RUP on performance of Jersey cattle. Twenty-six multiparous and 18 primiparous Jerseys were assigned at random to one of two CP and RUP concentrations 30 d before expected calving date in a 2 x 2 factorial plan. The experiment was conducted over two seasons and the main effects were CP and RUP concentrations. Prepartum CP concentrations were 12 and 15% and prepartum RUP (% of CP) concentrations were 30 and 45%. Soybean meal and an animal-marine protein blend were varied in prepartum diets to give desired CP and RUP concentrations. Prepartum diets were isocaloric (1.50 Mcal NE_L/kg DM) and contained corn silage, grass hay, and corn in addition to protein supplements. Cows received a similar ration 0 to 60 d postpartum. Neither season nor parity affected response of intake or production parameters to CP or RUP. Dry matter intake and DMI as % of BW were not affected by CP or RUP. Crude protein intake was greater for 15% CP compared to 12% CP. Calculated MP supply was greater for 45% RUP compared to 30% RUP, however all cows were in positive calculated MP balance during the prepartum period. Milk yield and 4% FCM yield did not differ for CP or RUP. In addition, milk protein concentration and yield were similar for CP and RUP. Positive MP balance for 12% CP and 30% RUP concentrations may have precluded responses to increasing prepartum CP and RUP. (Key words: crude protein, rumen undegradable protein, Jersey cattle)

INTRODUCTION

Current recommendation for CP in the diets of dry pregnant dairy cows is 12%, with no recommendation for RUP (NRC, 1989). However, fetal growth and therefore fetal nutrient requirements increase exponentially as gestation progresses. Bertics et al. (1992) reported a 30% reduction in DMI as parturition approached, with most of the decline occurring during the last wk of gestation. The reduction in DMI and AA flowing to the small intestine coincides with increasing fetal requirements.

In addition to increasing nutrient demands and declining prepartum DMI, disparity exists in predicting pregnancy MP requirement. Estimates for a 600 kg cow range from 200 to 350 g MP/d (NRC, 1989; Bell et al., 1995; NRC, 1996). Differences are due to the prediction equations and efficiencies used in conversion of MP to net protein, which range from 0.33 to 0.65 (NRC, 1989; Bell et al., 1995; NRC, 1996). Bell (1995) reported that only 32% of amino acid nitrogen taken up by the near term fetus is deposited in tissue protein and catabolism of amino acids accounts for over half of the daily energy supply. Based on estimates by Bell (1995), considerable amounts of endogenous amino acids are used for gluconeogenesis during the first week of lactation when contribution of mobilized protein is critical (Bauman and Elliot, 1983).

Increasing CP and RUP in prepartum diets has not resulted in increased productivity. Van Saun (1993) reported increased milk protein concentration by increasing RUP, but protein yield was unaffected. Wu et al. (1997) and Putnam and Varga (1998) increased prepartum RUP

and CP, respectively, with no differences in milk yield or milk composition. Garthwaite et al. (1999) calculated MP balance from data of Van Saun et al. (1993), Wu et al. (1997), Carson et al. (1998), and Putnam and Varga (1998). Metabolizable protein balance was negative only for cows receiving the 27% RUP fed by Van Saun et al. (1993). The primiparous cows used by Van Saun et al. (1993) may have responded due to additional requirement for growth, which may have spared maternal protein reserves. Garthwaite et al. (1999) suggests that when prepartum DMI is adequate, additional RUP may not be needed. Putnam and Varga (1998) reported that N balance was positive for cows receiving CP ranging from 10.6 to 14.5%.

The objectives of the following experiment were to examine the affects of CP and RUP on prepartum and postpartum DMI, and milk yield and composition in Jersey cattle, a breed known to have greater milk protein concentration compared to previous experiments utilizing Holsteins to investigate the affects of CP and RUP.

MATERIALS AND METHODS

Twenty-six multiparous and 18 primiparous Jerseys were assigned at random to one of two RUP and CP concentrations 30 d before expected calving date in a 2 x 2 factorial plan. Main effects were CP and RUP concentrations. Twenty-one cows received treatments during summer-fall (warm) and 23 received treatments during winter-spring (cool) seasons.

Prepartum CP concentrations were 12 and 15% and prepartum RUP (% of CP) concentrations were approximately 30 and 45%. The four prepartum treatments will be referred to as LL (12% CP:30% RUP), LH (12% CP:45% RUP), HL (15% CP:30% RUP), and HH (15% CP:45% RUP). Crude protein and ADF were determined biweekly and CP, ADF, NDF, and minerals (Table 4.1) were determined monthly on composite samples by wet chemistry methods (VA Tech Forage Testing Laboratory, Blacksburg, VA). Prepartum and postpartum forage analyses are shown in Table 4.1. Prepartum and postpartum diets were fed once daily as a TMR. Prepartum diets (Table 4.2) contained approximately equal proportions of corn silage and grass hay and differed only in corn, soybean meal, and Prolak (H. J. Baker and Bro., Inc., New York). Soybean meal, Prolak, and corn grain were varied to achieve desired CP and calculated RUP concentrations. Calculated RUP for LL, LH, HL, and HH were 31, 46, 29, and 43%. Cows received a similar diet (Table 4.2) from 0 to 60 d postpartum.

Cows were group-housed prepartum in a counter-slope barn and individual daily intake was measured by the Pinpointer system (4000B, AIS Corp., Cookville, TN). Pens were 40.2 m² and limited to a maximum of five cows at any one time. Cows were moved within 4 h after calving to individual box stalls for 2 d. Intake was not measured 0 and 1 d postpartum. Cows were housed in free-stalls postpartum and individual daily intake was measured by Calan gates (American Calan, Northwood, NH).

Body weight and body condition score were determined each wk. Body condition was determined based on a 5-point scale (1 = thin, 5 = fat) by two independent observers and scores were averaged prior to analysis. Daily prepartum and postpartum DMI were calculated based on daily as-fed intake and weekly diet DM. Prepartum DMI decline was calculated from 14 to 1 d prepartum based on average DMI from 21 to 15 d prepartum. Postpartum DMI was averaged by wk prior to analysis. Daily prepartum CP intake was calculated based on DMI and CP concentration of diets. Prepartum DMI as % of BW was calculated based on daily DMI and average prepartum BW.

Prepartum MP balance was calculated based upon MP intake and requirement. Equations by Bell et al (1995) and NRC (1996) were used to calculate gravid uterus and dam MP requirements, respectively. The equation by Bell et al. (1995) was scaled to calf birth weight to account for differences in breeds. Metabolizable protein supply was determined as described by Russell et al. (1992) and Sniffen et al. (1992) using daily prepartum DMI for each cow.

Milk yield was recorded daily and averaged by wk prior to analysis. Milk fat and total protein were determined (United DHIA, Blacksburg, VA) each wk on two consecutive samples and averaged prior analysis. Fat and protein yield were calculated based on weekly average milk yield and milk composition.

Data were analyzed using the mixed models procedure of SAS (1998). Results were considered different at $P < 0.05$. Two multiparous cows receiving LH were removed from analyses, one due to early calving and the other to mammary injury. The statistical model used was:

$$y_{ijklm} = \mu + \rho_i + \tau_j + \alpha_k + \beta_l + \alpha\tau_{ij} + \rho\alpha_{ik} + \rho\beta_{il} + \tau\alpha_{jk} + \tau\beta_{jl} + \alpha\beta_{kl} \\ + \rho\tau\alpha_{ijk} + \rho\tau\beta_{ijl} + \tau\alpha\beta_{jkl} + c_{(ijkl)_m} + \gamma_m + \rho\gamma_{im} + \tau\gamma_{jm} + \alpha\gamma_{kn} + \beta\gamma_{ln} \\ + \rho\tau\gamma_{ijn} + \rho\alpha\gamma_{ijn} + \rho\beta\gamma_{iln} + \tau\alpha\gamma_{jkn} + \tau\beta\gamma_{jln} + \alpha\beta\gamma_{kln} + \rho\tau\alpha\gamma_{ijkn} + \rho\tau\beta\gamma_{ijkln} + \tau\alpha\beta\gamma_{jklm} + \varepsilon_{ijklm}$$

where:

- y is the dependent variable (intake, milk yield, etc)
- μ is the overall mean,
- ρ_i is the effect if the i th season (warm or cool),
- τ_j is the effect of the j th parity (primiparous or multiparous),
- α_k is the effect of the k th CP concentration (12 or 15%),
- β_l is the effect of the k th RUP concentration (30 or 45%),
- $\rho\tau_{ij}$ is the interaction of the i th season and the j th parity,
- $\rho\alpha_{ik}$ is the interaction of the i th season and the k th CP concentration,
- $\rho\beta_{il}$ is the interaction of the i th season and the l th RUP concentration,
- $\tau\alpha_{jk}$ is the interaction of the j th parity and the k th CP concentration,
- $\tau\beta_{jl}$ is the interaction of the j th parity and the k th RUP concentration,
- $\alpha\beta_{kl}$ is the interaction of the k th CP concentration and the l th RUP concentration,
- $\rho\tau\alpha_{ijk}$ is the interaction of the i th season, j th parity, and k th CP concentration,
- $\rho\tau\beta_{ijl}$ is the interaction of the i th season, j th parity, and l th RUP concentration,
- $\tau\alpha\beta_{jkl}$ is the interaction of the j th parity, k th CP concentration, and k th RUP concentration,
- $c_{(ijkl)_m}$ is the random error associated with the m th cow within the i th season, j th parity, k th CP concentration, and l th RUP concentration,
- γ_m effect of the m th repeated measure (d and wk),
- $\rho\gamma_{im}$ is the interaction of the i th season and m th repeated measure,
- $\tau\gamma_{jm}$ is the interaction of the j th parity and m th repeated measure,

$\alpha\gamma_{km}$	is the interaction of the jth CP concentration and mth repeated measure,
$\beta\gamma_{lm}$	is the interaction of the kth RUP concentration and mth repeated measure,
$\rho\tau\gamma_{ijm}$	is the interaction of the ith season, jth parity, and mth repeated measure,
$\rho\alpha\gamma_{ikm}$	is the interaction of the ith season, kth CP concentration, and mth repeated measure,
$\rho\beta\gamma_{ilm}$	is the interaction of the ith season, lth RUP concentration, and mth repeated measure,
$\tau\alpha\gamma_{jkm}$	is the interaction of the jth parity, kth CP concentration, and mth repeated measure,
$\tau\beta\gamma_{jlm}$	is the interaction of the jth parity, lth RUP concentration, and mth repeated measure,
$\alpha\beta\gamma_{klm}$	is the interaction of the kth CP concentration, lth RUP concentration, and mth repeated measure,
$\rho\tau\alpha\gamma_{ijkm}$	is the interaction of the ith season, jth parity, kth CP concentration, and mth repeated measure,
$\rho\tau\beta\gamma_{ijlm}$	is the interaction of the ith season, jth parity, kth CP concentration, and mth repeated measure,
$\tau\alpha\beta\gamma_{jklm}$	is the interaction of the jth parity, kth CP concentration, lth RUP concentration, and mth repeated measure,
$\rho\tau\alpha\beta\gamma_{ijklm}$	is the interaction of the ith season, jth parity, kth CP concentration, lth RUP concentration, and mth repeated measure,
ϵ_{ijklm}	is the residual error.

RESULTS

Results from effects of CP and RUP are shown in Table 4.3 and CP by RUP interactions in Table 4.4. Days receiving prepartum diets and lactation number did not differ for CP or RUP. Prepartum DMI and DMI as % of BW did not differ for CP or RUP. There was a significant CP by RUP interaction for DMI decline. Decline in DMI was greater for cows receiving HH compared to HL with no differences for CP. As expected, prepartum CP intake was greater for cows receiving 15% CP and similar for RUP. Metabolizable protein requirement and balance did not differ for CP. Metabolizable protein supply and MP from RUP were similar for CP and MP from bacteria was greater for 12% CP. Postpartum BW and BCS were greater for 12% CP. Postpartum DMI, milk and 4% FCM yields, milk protein concentration, and fat and protein yields did not differ for CP.

Results from effects of RUP are shown in Table 4.3 and CP by RUP interactions in Table 4.4. Days receiving prepartum diets and lactation number did not differ for RUP. Prepartum DMI, DMI as % of BW, and intake of CP was similar for RUP. Metabolizable protein requirement did not differ for RUP, but MP balance was greater for 45% RUP. Although MP from bacteria was similar for RUP, MP from RUP was greater for 45% RUP resulting in greater MP supply. Postpartum DMI, milk and 4% FCM yields, milk fat and protein concentrations, and fat and protein yields were similar for RUP.

Results from effects of parity are shown in Table 4.5. Multiparous and primiparous interactions are shown in Tables 4.6 and 4.7, respectively. Days receiving prepartum diet and DMI decline did not differ for parity. Interactions for parity prepartum BW and BCS by CP and RUP were significant. Body weight of primiparous cows receiving 12% CP was greater than 15% CP and 45% RUP was greater than 30% RUP. Multiparous BCS was greater for 12% CP compared to 15% CP, while primiparous BCS was greater for 15% CP compared to 12% CP. Interactions for parity postpartum BW and BCS by RUP were significant. There was a difference in the direction of response of postpartum BW. Multiparous BW declined and primiparous increased for cows receiving 30% RUP compared to 45% RUP. Postpartum primiparous BCS was greater for 45% RUP compared to 30% RUP. As expected, prepartum DMI, DMI as % of BW, CP intake, MP supply and balance, milk and 4% FCM yields, and fat and protein yields were greater for multiparous cows. There was a difference in the direction of response of milk fat concentration. Multiparous milk fat increased and primiparous decreased for cows receiving 15% CP compared to 12% CP.

Results from effects of season are shown in Table 4.5. Prepartum DMI, DMI as a percentage of BW, MP balance and supply, and postpartum BW were greater for warm season. Prepartum BW, fat and protein concentrations, and protein yield were greater for cool season. Lactation number, d receiving prepartum diets, prepartum and postpartum BCS, DMI decline, MP requirement, postpartum DMI, and milk and 4% FCM yields were similar for seasons.

DISCUSSION

As expected, multiparous cows consumed more DM prepartum, resulting in greater CP intake and therefore greater MP supply and balance. Likewise, postpartum DMI and milk yield were greater resulting in greater yields of milk fat and protein. Excluding parity interactions for prepartum BW and BCS by CP and RUP, and postpartum BW and BCS by RUP, primiparous and multiparous cows responded similarly to CP and RUP.

Cows calving during warm season consumed more DM prepartum, resulting in greater intake of CP, and MP supply and balance. In addition, Prepartum BW was less for cows calving during warm season leading to greater DMI as a percentage of BW. Postpartum DMI and milk yield were similar for seasons, while fat yield and milk protein concentration and yield were greater for cool season. Differences in season are attributed to changes in environment and diet ingredient chemical composition between seasons. Although differences existed between season, cows responded similarly to CP and RUP in warm and cool seasons.

Although parity by CP and parity by RUP interactions were significant for prepartum BW and BCS, prepartum BW and BCS did not change, indicating that differences existed at assignment of treatments and were not due to CP or RUP. Mean differences of parity by RUP interactions for postpartum BW and BCS were small and therefore there is little biological significance of these differences. Wu et al. (1997) and Putnam and Varga (1998) reported no influence of prepartum RUP or CP, respectively, on BW or BCS for multiparous Holstein cows. Van Saun et al. (1993) reported that BCS at 21 d prepartum did not differ for primiparous Holsteins receiving 27 or 39% RUP as a percentage of CP, but BCS score at calving was greater for 39% RUP. The authors did not explain the loss in BCS of 27% RUP. Results of Van Saun et al. (1993) are confounded with CP since 27 and 39% RUP contained 12.4 and 15.3% CP, respectively.

As with previous reports (Van Saun et al., 1993; Wu et al., 1997), increasing RUP did not affect prepartum DMI. Likewise, increasing prepartum CP concentration did not influence prepartum DMI (Putnam and Varga, 1998). Apparently, increasing prepartum CP and RUP concentrations did not alter rumen fermentation enough to influence DMI. Assuming physical factors, such as diet bulkiness, influence DMI, prepartum DMI of the current experiment would not be expected to differ since diets contained similar NDF. Wu et al. (1997) reported an increase in prepartum DMI as a percentage of BW with higher RUP, but differences were not observed in the current study. Similar to previous reports, RUP (Van Saun et al., 1993; Wu et al., 1997) and CP (Putnam and Varga, 1998) did not influence postpartum DMI.

The decline in DMI the two wk prior to parturition was not as severe as reported by Bertics et al. (1992), although the greatest decline occurred the d prior to parturition and was 84, 88, 95, and 78% of average DMI between 21 to 14 d prepartum for LL, LH, HL, and HH, respectively. Explanation for the greater decline of HH is not evident. Van Saun et al. (1993) reported that RUP did not influence DMI decline and a 38% reduction in DMI as primiparous Holsteins cows approached parturition, while primiparous Jersey cows in the current experiment experienced a 16% reduction in DMI. Although data were not reported, Wu et al. (1997) suggested that DMI did not decline as parturition approached. Prepartum housing used in the current experiment was similar to the prepartum housing used by Wu et al. (1997). Cows were group housed and fed in a counter-slope facility. Animal behavior in the counter-slope facility may differ from tie-stall facilities, which were used by Bertics et al. (1992) and Van Saun et al. (1993).

Differences in CP intake for cows receiving 12% CP compared to 15% CP was achieved. In addition, CP intake of cows receiving 30 and 45% RUP was similar. Similar BW for CP and RUP, and 20% growth allowance for primiparous cows resulted in similar MP requirements. Although predicted MP from bacteria was greater for 15% CP, MP supply and balance did not differ due to a nonsignificant increase in MP from RUP. Metabolizable protein supply and balance were greater for 45% RUP due to MP from RUP.

Bell (1995) reported that only 32% of amino acid nitrogen taken up by the near term fetus is deposited in tissue protein and catabolism of amino acids accounts for over half of the daily energy supply. Based on estimates by Bell (1995), considerable amounts of endogenous amino acids are used for gluconeogenesis during the first wk of lactation. Differences in milk yield would not be expected since MP balance was positive for CP and RUP concentrations. Other researchers have observed no influence of prepartum CP (Putnam and Varga, 1998; Santos et al., 1998a) or RUP (Van Saun et al., 1993; Wu et al., 1997) on milk yield.

Garthwaite et al. (1999) calculated MP balance from RUP several experiments (Van Saun et al., 1993; Wu et al., 1997; Carson et al. 1998; Putnam and Varga, 1998). Metabolizable protein balance was negative only in one experiment (Van Saun et al., 1993). Only Van Saun et al. (1993) reported a production response, greater milk protein concentration with increasing RUP. Garthwaite et al. (1999) suggested that when prepartum DMI is relatively high, additional RUP may not be needed. In addition, Putnam and Varga (1998) reported that N balance was positive and did not differ for 10.6, 12.7, or 14.5% CP in multiparous Holstein cows restricted to 1.5% DMI as a percentage of BW.

Milk protein concentration did not differ for CP or RUP and is similar to previous observations (Putman and Varga, 1998; Santos et al., 1999a; Santos et al., 1999b; Wu et al., 1997). Van Saun et al. (1993) observed an increase in milk protein concentration with an increase in prepartum RUP, but milk protein yield did not differ and is similar to the current

experiment. Van Saun (1993) suggested that increasing prepartum RUP might spare maternal protein reserves. Milk protein concentration would not be expected to differ in the current experiment based on MP balance. Milk fat concentration for parity by CP differed. However, the biological influence of CP acting differently on parity is unexplainable. Crude protein (Putnam and Varga, 1998; Santos et al., 1999a; Santos et al., 1999b) and RUP (Van Saun et al., 1993; Wu et al., 1997) have not been shown to influence milk fat concentration. Although parity milk fat concentration differed for CP, RUP did not influence milk fat concentration or yield.

IMPLICATIONS

Most experiments, including the current experiment, generally evaluate NRC (1989) nutrient concentrations rather than absolute requirements. Nutrient intake depends not only on concentration, but also on DMI. Although cows experienced a depression in DMI prior to parturition, MP balance remained positive the entire prepartum period for CP and RUP. National Research Council (1989) CP concentration was adequate in meeting MP requirements based on estimates of pregnancy MP requirement by Bell et al. (1995) and absence of production responses.

Although increasing prepartum RUP increased MP supply and balance, all cows were in positive balance. Lack of response to RUP could be due to prepartum diet energy density, which was greater than NRC (1989) recommendations. Metabolizable protein from bacteria would have been lower if diets contained NRC (1989) energy density recommendations and conditions would have been more favorable for RUP response.

REFERENCES

- Bauman, D. E., and J. M. Elliot. 1983. Control of nutrient partitioning in lactating ruminants. In: T. B. Mepham (Ed.) *Biochemistry of Lactation*. p 437. Elsevier, Amsterdam, The Netherlands.
- Bell, A. W. 1995. Regulation of organic nutrient metabolism during transition from late pregnancy to early lactation. *J. Anim. Sci.* 73:2804-2819.
- Bell, A. W., R. Slepatis, and R. A. Ehrhardt. 1995. Growth and accretion of energy and protein on the gravid uterus during late pregnancy. *J. Dairy Sci.* 78:1954-1961.
- Bertics, S. J., R. R. Grummer, C. C. Cadorniga-Valino, and E. E. Stoddard. 1992. Effect of prepartum dry matter intake on liver triglyceride concentration and early lactation. *J. Dairy Sci.* 75:1914-1922.
- Carson, V. M., N. L. Whitehouse, K. Kolinsky, B. D. Garthwaite, M. S. Piepenbrink, and C. G. Schwab. 1998. Interactions of prepartum and postpartum feeding of rumen inert amino acids on lactational performance of Holstein cows. *J. Dairy Sci.* 81(Suppl. 1):295(Abstr.)
- Garthwaite, B. D., C. G. Schwab, and B. K. Sloan. 1999. Low crude protein diets may work in prepartum cows. *Feedstuffs* 71:11-14.
- National Research Council. 1989. *Nutrient Requirements of Dairy Cattle*. 6th revised ed. Natl. Acad. Sci., Washington, DC.
- National Research Council. 1996. *Nutrient Requirements of Beef Cattle*. 7th revised ed. Natl. Acad. Sci., Washington, DC.
- Putnam, D. E., and G. A. Varga. 1998. Protein density and its influence on metabolite concentration and nitrogen retention by Holstein cows in late gestation. *J. Dairy Sci.* 81:1608-1618.

- Russell, J. B., J. D. O'Conner, D. G. Fox, P. J. Van Soest, and C. J. Sniffen. 1992. A net carbohydrate and protein system for evaluating cattle diets: I. Ruminant fermentation. *J. Anim. Sci.* 70:3551-3561.
- SAS® System for Mixed Models. 1996. R. C. Littell, G. A. Milliken, W. W. Stroup, and R. D. Wolfinger, ed. SAS Inst., Inc., Cary, NC.
- Santos, J. E. P., E. J. DePeters, P. W. Jardon, and J. T. Huber. 1998a. Effect of prepartum crude protein level on performance of multiparous Holstein cows. *J. Dairy Sci.* 82(Suppl.):120(Abstr.)
- Santos, J. E. P., E. J. DePeters, P. W. Jardon, and J. T. Huber. 1998b. Effect of prepartum crude protein level on performance of primiparous Holstein cows. *J. Dairy Sci.* 82(Suppl.):120(Abstr.)
- Sniffen, C. J., J. D. O'Connor, P. J. Van Soest, D. G. Fox, and J. B. Russell. 1992. A Net carbohydrate and protein system for evaluating cattle diets: II. Carbohydrate and protein availability. *J. Anim. Sci.* 70:3562:3577.
- Van Saun, R. J., S. C. Idleman, and C. J. Sniffen. 1993. Effect of undegradable protein amount fed prepartum on postpartum production in first lactation Holstein cows. *J. Dairy Sci.* 76:236-244.
- Wu, Z., R. J. Fisher, C. E. Polan, and C. G. Schwab. 1997. Lactation performance of cows fed low or high ruminally undegradable protein prepartum and supplemental methionine and lysine postpartum. *J. Dairy Sci.* 80:722-729.

Table 4.1. Nutrient composition of prepartum and postpartum forages.

Nutrient	Prepartum		Postpartum	
	Corn Silage	Grass Hay	Corn Silage	Alfalfa Silage
DM, % as-fed basis	36.9	85.8	34.0	50.4
NE _L , Mcal/kg of DM ¹	1.52	1.09	1.51	1.40
CP, % of DM	7.2	9.2	7.8	18.0
ADF	20.1	42.5	23.8	33.3
NDF	38.4	74.2	41.6	45.0
Ca	0.21	0.28	0.23	1.45
K	1.03	1.91	1.06	2.48
Mg	0.13	0.21	0.19	0.31
P	0.20	0.20	0.21	0.24
S	0.10	0.19	0.11	0.27
Cu, mg/kg DM	5	6	6	12
Fe	212	111	164	210
Mn	21	116	26	31
Zn	24	13	22	21

¹Equations were used to calculate the NE_L (Mcal/kg of DM) content of corn silage ($0.807 - 0.0051\text{ADF}$), grass hay ($2.2415 - 0.0262\text{ADF}$), and alfalfa silage ($0.949 - 0.00957\text{ADF}$).

Table 4.2. Nutrient and ingredient composition of prepartum and postpartum diets.

Nutrient	Prepartum				Postpartum
	LL	LH	HL	HH	
	----- % of DM -----				
DM, % as-fed	49.4	50.2	49.5	50.4	55.3
NEL, Mcal/kg	1.49	1.51	1.49	1.51	1.67
CP	12.1	12.1	15.1	15.1	17.2
RUP, % of CP ¹	31.0	46.7	29.0	42.3	37.8
ADF	23.0	22.0	23.1	22.1	18.2
NDF	40.3	39.8	40.1	39.6	28.3
NFC ²	37.5	38.1	34.6	35.1	42.8
Ca	0.3	0.5	0.3	0.5	0.97
K	1.3	1.1	1.5	1.2	1.15
Mg	0.2	0.2	0.2	0.2	0.27
Na	0.03	0.09	0.03	0.09	0.33
P	0.3	0.4	0.3	0.4	0.51
S	0.2	0.2	0.2	0.2	0.29
Cu, mg/kg DM	10	8	11	9	16
Fe	168	224	176	230	184
Mn	49	45	52	47	20
Zn	41	40	44	43	29
Ingredient					
Corn Silage	56.5	54.5	56.4	54.0	26.2
Grass Hay	22.7	21.9	22.6	21.7	
Ground Corn	9.6	15.9	3.1	9.4	
Soybean Meal	10.8	0.0	17.5	7.0	8.1
Prolak ³	0.0	7.2	0.0	7.5	3.6
Mineral ^{4,5}	0.4	0.5	0.4	0.4	1.4
Alfalfa Silage					18.2
High Moisture Corn					28.6
Whole Cottonseed					12.5
Limestone					0.7
Sodium Bicarbonate					0.7

¹Calculated. NRC (1989) values were used for all ingredients except Prolak, which was assumed 65% RUP as % of CP.

²Calculated non-fiber carbohydrates.

³H. J. Baker and Bro., Inc., New York

⁴Prepartum mineral-vitamin mix contained 15% Ca, 8.5% Cl, 2% Mg, 5.5% Na, 9% P, 0.0026 % Co, 0.0690 % Cu, 0.1300 % Fe, 0.2600 % Mn, 0.0052 % Se, 0.4500 % Zn, 273 KIU A/kg DM, 55 KIU D/kg DM, and 682 IU E/kg DM.

⁵Postpartum mineral-vitamin mix contained 16% Ca, 5.8% Cl, 3.5% K, 2.2% Mg, 6.5% Na, 6.5% P, 3.2% S, 0.0003 % Co, 0.0132 % Cu, 0.0265 % Fe, 0.1100 % Mn, 0.0005 % Se, 0.1325 % Zn, 14 KIU A/kg DM, 9 KIU D/kg DM, and 114 IU E/kg DM.

Table 4.3. Parameter least square means for crude protein and rumen undegradable protein.

Item	Crude Protein				Rumen Undegradable Protein				CP	RUP
	12%		15%		30%		45%			
	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE		
n	20		24		24		20			
Prepartum										
Lactation	2.0	0.3	2.3	0.2	2.2	0.2	2.1	0.3	0.55	0.79
d on Diets	33.3	1.3	32.5	1.1	32.3	1.1	33.5	1.3	0.66	0.49
BW, kg	468	3	458	3	459	3	467	3	0.01	0.01
BCS	3.49	0.03	3.48	0.03	3.47	0.03	3.50	0.03	0.68	0.39
DMI, kg/d	9.1	0.2	8.5	0.2	8.7	0.2	8.9	0.2	0.08	0.45
DMI, % of BW	2.00	0.04	1.88	0.04	1.92	0.05	1.96	0.05	0.09	0.54
DMI Decline, %	-2.7	2.4	-5.7	2.2	-1.4	2.2	-7.1	2.3	0.36	0.09
CP Intake, g/d	1138	34	1327	30	1215	30	1250	34	0.01	0.77
MP Requirement, g/d	616	7	621	6	616	6	621	7	0.67	0.60
MP Supply, g/d	987	28	960	25	886	25	1060	28	0.48	0.01
MP Bacteria, g/d	613	15	560	13	586	13	587	15	0.02	0.93
MP RUP, g/d	373	14	400	12	301	12	472	14	0.16	0.01
MP Balance, g/d	366	28	334	25	268	25	433	28	0.40	0.01
Postpartum										
BW, kg	397	2	389	1	392	1	394	2	0.01	0.27
BCS	2.88	0.02	2.80	0.02	2.87	0.02	2.81	0.02	0.01	0.06
DMI, kg/d	14.9	0.4	15.2	.04	15.1	0.4	15.0	0.4	0.70	0.98
4% FCM, kg/d	28.9	1.3	29.3	1.0	29.5	1.0	28.7	1.3	0.83	0.67
Milk Yield, kg/d	26.6	1.0	26.8	0.9	27.0	0.9	26.3	1.0	0.88	0.58
Fat, %	4.88	0.11	4.67	0.09	4.65	0.09	4.91	0.11	0.17	0.09
Fat Yield, g/d	1235	62	1238	52	1243	52	1230	63	0.98	0.88
Protein, %	3.60	0.05	3.62	0.04	3.57	0.04	3.65	0.05	0.74	0.22
Protein Yield, g/d	925	37	952	31	955	31	922	38	0.59	0.51

Table 4.4. Parameter least square means for crude protein by undegradable protein.

Item	Crude Protein								CP*RUP P <
	12%				15%				
	30%		45%		30%		45%		
	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE	
n	11		9		13		11		
Prepartum									
Lactation #	2.1	0.4	2.0	0.4	2.3	0.4	2.2	0.4	0.87
d on Diets	32.2	1.7	34.3	1.6	32.4	1.9	32.5	1.6	0.57
BW, kg	463	3.8	472	4.1	454	3.4	461	3.7	0.74
BCS	3.42	0.04	3.57	0.03	3.52	0.04	3.44	0.04	0.07
DMI, kg/d	8.1	0.3	9.4	0.3	8.5	0.4	8.5	0.3	0.33
DMI, % of BW	1.94	0.06	2.06	0.07	1.90	0.06	1.86	0.06	0.24
DMI Decline, %	-3.7	3.1	-1.8	3.6	0.9	3.0	-12.4	3.0	0.04
CP Intake, g/d	1098	44	1117	51	1333	42	1321	44	0.33
MP Requirement, g/d	617	9	615	10	615	9	626	9	0.45
MP Supply, g/d	882	36	1092	42	891	35	1028	36	0.34
MP Bacteria, g/d	603	19	624	22	568	18	551	19	0.35
MP RUP, g/d	279	18	468	21	323	17	477	18	0.34
MP Balance, g/d	261	36	472	42	274	34	394	36	0.24
Postpartum									
BW, kg	398	2	396	3	385	2	392	2	0.05
BCS	2.88	0.03	2.88	0.03	2.87	0.03	2.81	0.03	0.08
DMI, kg/d	15.1	0.5	15.0	0.6	15.0	0.5	15.3	0.5	0.75
Milk Yield, kg/d	26.8	1.2	25.1	1.5	27.3	1.2	26.2	1.3	0.83
4% FCM, kg/d	29.0	1.6	28.8	2.0	29.9	1.5	28.6	1.6	0.74
Fat, %	4.60	0.13	4.90	0.18	4.69	0.13	4.66	0.13	0.33
Fat Yield, g/d	1219	75	1252	100	1267	71	1208	76	0.58
Protein, %	3.61	0.06	3.55	0.08	3.53	0.06	3.71	0.06	0.08
Protein Yield, g/d	959	45	891	60	951	43	953	46	0.49

Table 4.5. Parameter least square means for parity and season.

Item	Parity				Season				Parity	Season
	1		2+		Warm		Cool		P <	
	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE		
n	18		26		23		21			
Prepartum										
Lactation	1		3.4	0.2	2.1	0.2	2.2	0.3	0.01	0.94
d on Diets	34.1	1.3	31.8	1.1	33.5	1.2	32.3	1.2	0.20	0.52
BW, kg	437	2.9	489	2.4	455	2.4	470	2.9	0.01	0.01
BCS	3.54	0.03	3.43	0.02	3.49	0.03	3.48	0.03	0.02	0.73
DMI, kg/d	7.4	0.2	10.2	0.2	9.2	0.3	8.4	0.3	0.01	0.03
DMI, % of BW	1.74	0.04	2.15	0.06	2.06	0.05	1.83	0.05	0.01	0.01
DMI Decline, %	-4.5	2.4	-4.0	2.0	-2.5	2.2	-6.0	2.3	0.88	0.30
CP Intake, g/d	1046	36	1420	25	1287	31	1178	34	0.01	0.03
MP Requirement, g/d	632	7	604	6	617	6	620	7	0.01	0.73
MP Supply, g/d	820	30	1126	23	1020	25	926	28	0.01	0.02
MP Bacteria, g/d	508	15	666	12	610	13	563	14	0.01	0.03
MP RUP, g/d	313	14	461	12	410	12	363	13	0.01	0.02
MP Balance, g/d	179	25	522	28	402	25	299	28	0.01	0.01
Postpartum										
BW, kg	361	2	424	2	395	2	390	2	0.01	0.02
BCS	2.83	0.03	2.88	0.02	2.84	0.03	2.86	0.03	0.14	0.49
DMI, kg/d	12.6	0.4	17.5	0.4	15.2	0.4	14.9	0.4	0.01	0.69
Milk Yield, kg/d	22.6	1.0	30.8	0.8	26.4	0.9	27.0	0.9	0.01	0.62
4% FCM, kg/d	24.1	1.3	34.1	1.0	27.9	1.2	30.3	1.2	0.01	0.18
Fat, %	4.80		4.76		4.60		4.96		0.80	0.02
Fat Yield, g/d	1021	64	1452	50	1176	57	1297	62	0.01	0.15
Protein, %	3.56	0.05	3.66	0.04	3.46	0.05	3.77	0.05	0.13	0.01
Protein Yield, g/d	766	39	1111	30	877	35	1001	34	0.01	0.02

Table 4.6. Multiparous parameter least square means for crude protein and rumen undegradable protein.

Item	Crude Protein				Rumen Undegradable Protein				Parity*	Parity*
	12%		15%		30%		45%		CP	RUP
	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE	P <	
n	13		13		13		13			
Prepartum										
Lactation	3.2	0.3	3.6	0.3	3.5	0.3	3.3	0.3	0.49	0.71
d on Diets	32.6	1.5	30.9	1.5	31.6	1.5	31.9	1.5	0.57	0.63
BW, kg	486	3	492	3	494	3	484	3	0.01	0.01
BCS	3.36	0.03	3.51	0.03	3.46	0.03	3.41	0.03	0.01	0.03
DMI, kg/d	10.7	0.3	9.7	0.3	10.2	0.3	10.2	0.3	0.33	0.25
DMI, % of BW	2.27	0.07	2.02	0.07	2.12	0.08	2.17	0.09	0.24	0.06
DMI Decline, %	-2.9	2.8	-5.1	2.9	-1.7	3.0	-6.3	2.7	0.81	0.73
CP Intake, g/d	1332	39	1507	40	1423	40	1416	39	0.77	0.37
MP Requirement, g/d	597	8	612	8	607	8	601	8	0.24	0.25
MP Supply, g/d	1156	32	1095	33	1046	33	1206	32	0.36	0.74
MP Bacteria, g/d	704	22	626	19	674	17	657	17	0.22	0.35
MP RUP, g/d	453	16	469	16	372	16	549	16	0.58	0.74
MP Balance, g/d	560	32	483	33	483	33	605	32	0.24	0.98
Postpartum										
BW, kg	426	2	422	2	426	2	422	2	0.13	0.02
BCS	2.91	0.03	2.83	0.03	2.85	0.03	2.89	0.03	0.70	0.01
DMI, kg/d	17.7	0.5	17.2	0.5	17.0	0.5	17.9	0.5	0.25	0.10
Milk Yield, kg/d	31.3	1.2	30.2	1.2	31.4	1.1	30.1	1.2	0.33	0.65
4% FCM, kg/d	34.5	1.5	33.7	1.5	34.8	1.4	33.3	1.5	0.50	0.68
Fat, %	4.70	0.12	4.82	0.12	4.77	0.12	4.75	0.13	0.04	0.06
Fat Yield, g/d	1465	70	1440	70	1483	68	1421	73	0.75	0.55
Protein, %	3.64	0.06	3.68	0.06	3.65	0.06	3.67	0.06	0.79	0.34
Protein Yield, g/d	1125	42	1096	42	1133	41	1088	44	0.27	0.82

Table 4.7. Primiparous parameter least square means for crude protein and rumen undegradable protein.

Item	Crude Protein				Rumen Undegradable Protein				Parity*	Parity*
	12%		15%		30%		45%		CP	RUP
	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE	\bar{X}	SE	P <	
n	7		11		11		7			
Prepartum										
d on Diets	34.0	2.1	34.2	1.7	33.0	1.5	35.1	1.5	0.57	0.63
BW, kg	450	5	424	4	423	4	450	4	0.01	0.01
BCS	3.63	0.05	3.45	0.04	3.48	0.04	3.60	0.04	0.01	0.03
DMI, kg/d	7.6	0.4	7.3	0.3	7.2	0.3	7.7	0.4	0.33	0.25
DMI, % of BW	1.73	0.06	1.75	0.06	1.72	0.06	1.75	0.06	0.24	0.06
DMI Decline, %	-2.6	3.8	-6.4	3.2	-1.1	3.1	-7.1	3.8	0.81	0.73
CP Intake, g/d	944	55	1147	46	1007	46	1084	55	0.77	0.37
MP Requirement, g/d	636	11	629	9	625	9	640	11	0.24	0.25
MP Supply, g/d	816	36	825	35	727	47	913	38	0.36	0.74
MP Bacteria, g/d	522	19	493	18	497	24	518	20	0.22	0.35
MP RUP, g/d	294	22	331	18	230	18	395	22	0.58	0.74
MP Balance, g/d	172	46	186	37	97	37	261	45	0.24	0.98
Postpartum										
BW, kg	367	2	356	2	358	3	366	2	0.13	0.02
BCS	2.85	0.04	2.76	0.03	2.88	0.03	2.73	0.04	0.70	0.01
DMI, kg/d	12.2	0.6	13.1	0.5	13.1	0.5	12.1	0.6	0.25	0.10
Milk Yield, kg/d	21.9	1.5	23.4	1.3	22.7	1.3	22.2	1.5	0.33	0.65
4% FCM, kg/d	23.3	2.1	24.9	1.6	24.1	1.6	24.1	2.1	0.50	0.68
Fat, %	5.06	0.18	4.53	0.13	4.52	0.13	5.07	0.18	0.04	0.06
Fat Yield, g/d	1006	103	1035	77	1002	77	1039	103	0.75	0.55
Protein, %	3.56	0.08	3.56	0.06	3.49	0.06	3.63	0.08	0.79	0.34
Protein Yield, g/d	725	62	808	46	777	46	755	62	0.27	0.82

CHAPTER V: EFFECTS OF DIETARY IRON ON COPPER METABOLISM AND MILK PRODUCTION IN HOLSTEIN AND JERSEY CATTLE

ABSTRACT

An experiment was conducted to investigate the effects of dietary Fe on Cu status and milk production. Twelve Holstein and 12 Jersey multiparous cows ($\bar{X} \pm SD$; 70 ± 4 days in milk) were assigned at random to diets containing 0 or 500 mg $\text{FeCO}_3/\text{kg DM}$ in a 2 x 2 factorial plan. Diets contained corn grain, corn silage, soy hulls, whole cottonseed, soybean meal, animal-marine protein blend, and minerals. Diets were supplemented with 10 mg $\text{CuSO}_4/\text{kg DM}$ and differed only in Fe supplementation. The basal diet contained 210 mg Fe and 9 mg Cu/kg DM. The experimental period was 90 d. Hepatic and plasma Cu, Fe, and Zn were determined on 0, 45, and 90 d samples. Hepatic Cu did not differ for breeds (481 vs. 493 $\mu\text{g/g DM}$ for Holstein and Jersey, respectively) or Fe supplementation (474 vs. 499 $\mu\text{g/g DM}$ for 0 and 500 mg Fe/kg DM, respectively). For Jerseys, hepatic Fe was greater for cows receiving supplemental Fe (254 $\mu\text{g/g DM}$) compared to controls (184 $\mu\text{g/g DM}$). Hepatic Zn did not differ for breeds or Fe supplementation. Plasma Cu was greater for Jerseys (0.72 $\mu\text{g/ml}$) compared to Holsteins (0.61 $\mu\text{g/ml}$). Plasma Zn and Fe did not differ for breeds or Fe supplementation. Iron supplementation did not affect 4% FCM or efficiency of production. Dietary Fe did not affect Cu status of Holstein and Jersey cows in this experiment. (Key words: copper, iron, Holstein, Jersey)

INTRODUCTION

Copper toxicosis has occurred in U.S. Jersey herds over the last several years. These herds were supplementing Cu below the maximum tolerable level recommended by the National Research Council (NRC, 1989) (R. W. Hemken, 1996, personal communication). Du et al. (1996a) reported that Jersey hepatic Cu was greater than in Holsteins, although copper toxicosis did not occur. However, this difference was not shown in other trials comparing these two breeds (Du et al., 1996b; French et al., 1997).

Interference by antagonist may have precluded differences in hepatic Cu of Holsteins and Jerseys (Du et al., 1996b; French et al., 1997). Jerseys have been shown to metabolize iron differently than Holsteins (Du et al., 1996a; French et al., 1997), although the mode of action of iron as a copper antagonist has not been established. The interaction of iron and copper in ruminants may be potentiated by the formation of FeS in the rumen and presence of S^{2-} in the abomasum (Suttle et al., 1984). However, Fe has been shown to be a potent Cu antagonist in monogastrics (Bremner and Price, 1985; Yu et al., 1994). Previous studies with cattle dosed orally with ferric hydroxide (Campbell et al., 1974), with calves fed ferrous carbonate (Humphries et al., 1983; Humphries et al., 1985) and with lambs fed ferrous carbonate (Prabowo et al., 1988) indicate that high dietary iron can reduce copper status without concomitant increases in dietary sulfur.

The literature lacks experiments dealing with the effects of high dietary iron on copper status in lactating cows. More importantly, little is known about the difference between Jerseys, a breed known to metabolize copper and iron differently (Du et al., 1996a; French et al., 1997), and other breeds of dairy cattle with respect to the interactions of dietary iron and copper status. Therefore, the objective of this experiment was to examine the effects of supplemental Fe on hepatic and plasma mineral profiles of lactating Holstein and Jersey cattle.

MATERIALS AND METHODS

Twelve multiparous Holsteins and twelve multiparous Jerseys were assigned at random to treatments in a 2 x 2 factorial plan. Main effects were breed (Holstein and Jersey) and Fe supplementation (0 or 500 mg/kg DM). Cows were blocked (n = 6) by days in milk ($\bar{X} \pm SD; 70 \pm 4$) in a randomized complete block design. Randomization was restricted to ensure equal numbers of each breed within each block. Cows were housed in free stalls and individual intakes were measured using the Calan gate system (American Calan, Northwood, NH). Pre-experimental management was similar for all cows. The experimental period was 90 d.

The diet (5.1) was formulated to meet nutrient requirements according to NRC (1989) recommendations and fed once daily as a TMR. Diets differed only in concentration of Fe and were supplemented or not with 500 mg Fe/kg DM as ferrous carbonate. Ferrous carbonate was chosen for its intermediate bioavailability compared to ferrous sulfate and ferric oxide (Ammerman et al., 1967), and should closely mimic availability of Fe from forages. Diets were supplemented with 10 mg Cu sulfate/kg DM in addition to Cu normally contained in feeds. Dry matter of corn silage was determined weekly by drying at 60°C in a forced air oven and diets were adjusted accordingly. Samples of ingredients were taken weekly and composited monthly for determination of nutrient composition by Virginia Tech Forage Testing Laboratory (Blacksburg, VA).

Liver samples were taken *via* biopsy at the beginning of the experiment and at 45 and 90 d, rinsed in saline, and stored at -20°C for later analysis of copper, iron and zinc concentration. Liver samples were prepared for analysis by a modified wet-ashing procedure as described by Du et al. (1996a). Copper, iron and zinc content were analyzed by atomic absorption spectrophotometry (Instrumentation Laboratory, S11 Thermo Jarrel Ash Corporation, Franklin, MA) at 324.8, 248.3 and 213.9 nm wavelengths respectively.

Blood samples were collected into heparin containing tubes from the jugular vein at the beginning of the experiment and at 45 d intervals during the 90 d experimental period. Blood samples were centrifuged at 5000 x g for 15 min. Plasma samples were stored at -20°C until analysis. Plasma samples were diluted two-fold with nanopure water, and analyzed for Cu, Fe and Zn concentration with atomic absorption spectrophotometry.

The experimental data were analyzed using the mixed models procedure of SAS (1996) for analysis of variance with breeds (Holstein or Jersey) and Fe supplementation (0 or 500 mg/kg DM) as main effects in a 2 x 2 factorial block arrangement of treatments. In addition, the model included all interactions and replication. Measures of liver and plasma minerals at d 0 were used as a covariate to give appropriate adjusted means. Differences were considered significant at $P < 0.05$. The linear model used was:

$$y_{ijklm} = \mu + \beta(x_i - \bar{x}) + \rho_i + \alpha_j + \tau_k + \alpha\tau_{jk} + C\left(\begin{matrix} i \\ j \end{matrix}\right)_l + \gamma_m + \alpha\gamma_{jm} + \tau\gamma_{km} + \alpha\tau\gamma_{jkm} + \varepsilon_{ijklm}$$

where μ is the overall mean;

$\beta(x_i - \bar{x})$	is the regression coefficient for initial hepatic and plasma mineral concentration;
ρ_i	is the effect due to i-th block (i=6);
α_j	is the effect due to j-th level of Fe (0 or 500 mg/kg DM);
τ_k	is the effect due to k-th breed (Holstein or Jersey);
$\alpha\tau_{jk}$	is the interaction of the j-th level of Fe with the k-th breed;
$C_{(ijk)_l}$	is the effect of the l-th cow within the i-th block, j-th level of Fe, and k-th breed;
γ_m	is the effect of the m-th day;
$\alpha\gamma_{jm}$	is the interaction of the j-th level of Fe with the m-th day;
$\tau\gamma_{km}$	is the interaction of the k-th breed with the m-th day;
$\alpha\tau\gamma_{jkm}$	is the interaction of the j-th level of Fe with the k-th breed with the m-th day;
ϵ_{ijklm}	is the residual error.

RESULTS

Results are presented in Table 5.2. Dry matter intake for breeds responded differently to Fe supplementation. Holsteins receiving supplemental Fe consumed more DM and FeCO₃ than Jerseys receiving supplemental Fe, while breed intakes did not differ for cows receiving no supplemental Fe. Intake of Fe was similar for Holsteins and Jerseys receiving no supplemental Fe. Dry matter intake as % of BW and BW^{0.75} were greater for Jerseys. Iron intake per kg of BW and BW^{0.75} were greater for Jerseys and cows receiving supplemental Fe.

Iron supplementation did not influence milk yield, 4% FCM yield, or milk fat percent. Milk protein concentration was greater for cows receiving supplemental Fe. Yield of 4% FCM per unit of DM consumed did not differ for breed or Fe supplementation. Milk yield declined throughout the experiment and was greater for Holsteins. Milk fat and protein percentages were greater for Jerseys.

Hepatic Cu of cows was adequate throughout the experiment (Underwood, 1977). Liver Cu concentration was similar for breeds and Fe supplementation and increased during the experiment. Liver Fe concentration was greater for Jerseys receiving Fe supplementation compared to Holsteins receiving Fe supplementation. Liver Zn did not differ for breeds or Fe supplementation.

Plasma Cu concentration was greater for Jerseys and was similar for Fe supplementation. Plasma Fe concentration was similar for breeds and Fe supplementation. Likewise, plasma Zn concentration was similar for breeds and Fe supplementation.

DISCUSSION

Holsteins generally consume more DM than Jerseys, although nutrient intake per unit of BW is greater for Jerseys. In the current experiment, Fe intake per unit of BW was greater for Jerseys. This could explain differences in hepatic Fe (Du et al., 1996a; French et al., 1997)

previously reported for these breeds. Differences in nutrient intake per unit of BW may also explain greater hepatic Cu for Jerseys (Du et al., 1996a).

Supplemental Fe did not influence yield of 4% FCM or efficiency of production. Decreased milk production and digestibility were observed in cattle dosed orally with 60 g Fe(OH)₃/d (Coup and Campbell, 1964). Cows in the current experiment were consuming less Fe, 17.6 g FeCO₃/d. Average daily gain (Standish et al., 1969; Standish et al., 1971) and feed efficiency (Standish et al., 1969) were reduced in steers receiving FeSO₄, a form shown to have higher bioavailability than FeCO₃ based on serum Fe (Ammerman et al., 1967).

Iron supplementation, as ferrous carbonate, did not affect Cu status in this experiment, which differs from previous reports (Humphries et al., 1983; Humphries et al., 1988; Prabowo et al., 1988). Humphries et al. (1988) and Humphries et al. (1983) reduced hepatic Cu to deficiency levels in heifers receiving 150 and 800 mg FeCO₃/kg DM, respectively, compared to controls. In addition, Prabowo et al. (1988) reported decreased hepatic Cu in wethers receiving 1,200 mg FeCO₃/kg DM compared to controls.

In many experiments (Bremner and Young, 1981; Humphries et al., 1983; Humphries et al., 1985; Humphries et al., 1988) that showed reduced liver Cu with increasing Fe, dietary Cu was below recommendations for those species. In other experiments (Standish and Ammerman, 1969; Standish and Ammerman, 1971), Fe supplementation reduced hepatic Cu of animals receiving adequate dietary Cu. In ruminant experiments (Prabowo et al., 1988; Standish and Ammerman, 1969) where hepatic Cu of control animals exceeded 250 µg/g DM, Fe supplementation in excess of 1,200 mg/kg DM was needed to elicit a decrease in hepatic Cu. However, when hepatic Cu of control animals was less than 100 µg/g DM (Humphries et al., 1985; Humphries et al., 1988), Fe supplementation of 250 mg/kg DM or lower decreased hepatic Cu. Hepatic Cu of animals in the current experiment exceeded 450 µg/g DM. Therefore dietary Fe concentration may not have been great enough to elicit a change in hepatic Cu.

A significant interaction existed for breed x Fe supplementation. Iron supplementation increased Jersey hepatic Fe. Others reported that supplementation of Fe at or greater than 1,000 mg/kg DM increased hepatic Fe (Prabowo et al., 1988; Standish and Ammerman, 1969; Standish and Ammerman, 1971). The exact mechanism whereby Fe metabolism of Jerseys differs from Holsteins is not known but may be similar to that of Cu. Due to the limited ability of the body to excrete Fe (Morris, 1987), differences may occur during absorption. Genetic differences in efficiency of Cu absorption have been shown in sheep (Wiener et al., 1978; Woolliams et al., 1983), and based on Hepatic Fe in the current experiment, genetic differences in the metabolism of Fe likely exist between Holstein and Jersey cattle. However, differences in intake of Fe per unit of BW may contribute to greater hepatic Fe of Jersey cattle.

Hepatic Zn did not differ for breeds, although Du et al. (1996a) reported greater hepatic Zn in Holsteins compared to Jerseys. Plasma Cu was greater for Jerseys ($P < 0.05$) and similar to previous reports relating a genetic difference in plasma Cu (Du et al., 1996a; French et al., 1997). Plasma Fe and Zn did not differ for breeds or Fe supplementation ($P > 0.05$). Du et al. (6) reported that plasma Fe and Zn were similar for these breeds. In addition, dietary Fe did not affect serum Fe of wethers (Prabowo et al., 1988).

IMPLICATIONS

Supplemental Fe as ferrous carbonate did not affect hepatic Cu of Holstein and Jersey cows. Copper supplementation at 10 mg CuSO₄/kg DM, in addition to Cu naturally contained in

feedstuffs, was adequate in maintaining normal hepatic Cu in this experiment. Holstein and Jersey breeds metabolize Cu and Fe differently based on plasma Cu and hepatic Fe, respectively.

REFERENCES

- Ammerman, C. B., J. M. Wing, B. G. Dunavant, W. K. Robertson, J. P. Feaster, and L. R. Arrington. 1967. Utilization of inorganic iron by ruminants as influenced by form of iron and iron status of the animal. *J. Anim. Sci.* 26:404-410.
- Bremner, I. and J. Price. 1985. Effects of dietary iron supplements on copper metabolism in rats. Pages 374-376 *in Proc. Int. Symp. Trace Elements in Man and Animals*. 5th ed. Slough, United Kingdom.
- Bremner, I. and B. W. Young. 1981. Effect of variation in dietary iron concentration on copper metabolism in rats. *Proc. Nutr. Soc.* 40:69A.
- Campbell, A. G., M. R. Coup, W. H. Bishop, and D. E. Wright. 1974. Effect of elevated iron intake on the copper status of grazing cattle. *N. Z. J. Agri. Res.* 17:393-399.
- Coup, M. R., and A. G. Campbell. 1964. The effect of excessive iron intake upon the health and production of dairy cows. *N. Z. J. Agric. Res.* 7:624-638.
- Du, Z., R.W. Hemken, and R. J. Harmon. 1996a. Copper metabolism of Holstein and Jersey cows and heifers fed diets high in cupric sulfate or copper proteinate. *J. Dairy Sci.* 79:1873-1880.
- Du, Z., R. W. Hemken and D. S. Trammell. 1996b. Comparison of copper tolerances between Holstein and Jersey steers. *J. Dairy Sci.* 79(Suppl. 1):231(Abstr.).
- French, P. D., D. S. Trammell, and R. W. Hemken. 1997. Copper tolerances of Holstein and Jersey cows receiving whole cottonseed. *J. Dairy Sci.* 80(Suppl. 1):271.
- Humphries, W. R., M. Phillippo, B. W. Young, and I. Bremner. 1983. The influence of dietary iron and molybdenum on copper metabolism in calves. *Br. J. Nutr.* 49:77-86.
- Humphries, W. R., I. Bremner, and M. Phillippo. 1985. The influence of dietary iron on copper metabolism in the calf. Pages 371-373 *in Proc. Int. Symp. Trace Elements in Man and Animals*. 5th ed. Slough, United Kingdom.
- Humphries, W. R., M. J. Walker, P. C. Morrice, and I. Bremner. 1988. Effects of dietary molybdenum and iron on copper metabolism in calves. Pages 309-310 *in Proc. Int. Symp. Trace Elements in Man and Animals*. 6th ed. Pacific Grove, CA.
- Little, R. C., G. A. Milliken, W. W. Stroup, and R. D. Wolfinger. 1996. SAS[®] System for Mixed Models. SAS Inst., Inc., Cary, NC.
- Morris, E. R. 1987. Iron. Pages 79-142 *in Trace Elements in Human and Animal Nutrition*. 5th ed. W. Mertz, ed. Acad. Press, San Diego, CA
- National Research Council. 1989. Nutrient Requirements of Dairy Cattle. 6th rev. ed. Natl. Acad. Sci., Washington, DC.
- Prabowo, A., J. W. Spears, and L. Goode. 1988. Effects of dietary iron on performance and mineral utilization in lambs fed a forage-based diet. *J. Anim. Sci.* 66:2028-2035.
- Standish, J. F., C. B. Ammerman, C. F. Simpson, and F. C. Neal. 1969. Influence of graded levels of dietary iron, as ferrous sulfate, on performance and tissue mineral composition of steers. *J. Anim. Sci.* 29:496-503.
- Standish, J. F., C. B. Ammerman, A. Z. Palmer, and C. F. Simpson. 1971. Influence of dietary iron and phosphorus on performance, tissue mineral composition and mineral absorption in steers. *J. Anim. Sci.* 33:171-178.

- Suttle, N. F., P. Abrahams, and I. Thornton. 1984. The role of a soil x dietary sulphur interaction in the impairment of copper absorption by ingested soil in sheep. *J. Agric. Sci. (Camb.)* 103:81-86.
- Underwood, E. J. 1977. Copper. Pages 56-108 in *Trace Elements in Human and Animal Nutrition* 4th ed. E. J. Underwood ed. Academic Press, New York.
- Wiener, G., N. F. Suttle, A. C. Field, J. G. Herbert, and J. A. Woolliams. 1978. Breed differences in copper metabolism in sheep. *J. Agri. Sci. (Camb.)* 91:433-441.
- Woolliams, J. A., N. F. Suttle, G. Wiener, A. C. Field, and C. Woolliams. 1983. The long-term accumulation and depletion of copper in the liver of different breeds of sheep fed diets of differing copper content. *J. Agri. Sci. (Camb.)* 100:441-449.
- Yu, S., C. E. West, and A. C. Beynen. 1994. Increasing intakes of iron reduce status, absorption and biliary excretion of copper in rats. *Br. J. Nutr.* 71:887-895.

Table 5.1. Ingredient and nutrient composition of diets.

Ingredient	-----% of DM-----
Ground corn grain	30.6
Corn Silage	26.3
Soy hulls	16.0
Whole cottonseed	11.5
Soybean meal	10.3
Prolak	2.3
Limestone	1.3
Mineral premix ¹	1.1
Sodium bicarbonate	0.6
Nutrient	
NE _L , Mcal/kg	1.72
CP, % of DM	17.9
ADF	19.8
NDF	31.1
Ca	0.87
Cl	0.16
K	1.00
Mg	0.25
Na	0.25
P	0.37
S	0.19
Cu, mg/kg DM ²	9.8
Fe ²	193.3
Mn	26.7
Zn	52.9

¹Contains 16% Ca, 6.5% P, 2.2% Mg, 3.5% K, 6.5% Na, 5.8% Cl, 3.2% S, 0.0003% Co, 0.0020% I, 0.0013% Cu, 0.110% Mn, 0.0005% Se, 0.1325% Zn, 13,636 IU A/kg, 9,090 IU D/kg, and 114 IU E/kg. Ingredients include: calcium carbonate, monocalcium phosphate, dicalcium phosphate, salt, sodium bicarbonate, magnesium oxide, magnesium sulfate, potassium sulfate, potassium chloride, sulfur, cobalt carbonate, copper oxide, calcium iodate, ferrous carbonate, manganous oxide, sodium selenite, zinc oxide.

²Does not include supplemental Cu and Fe.

Table 5.2. Least square means of DMI, body weight, Fe intake, milk yield, milk composition, liver minerals, and plasma minerals.

	0 mg supplemental Fe /kg DM		500 mg supplemental Fe /kg DM		SE	P-Values		
	Holstein	Jersey	Holstein	Jersey		Breed	Fe	Breed*Fe
DMI, kg/d	24.4	23.3	26.9	22.1	0.7	0.01	0.39	0.02
DMI, % of BW/d	4.06	5.38	4.23	5.16	0.19	0.01	0.89	0.33
DMI, % of BW ^{0.75} /d	20.1	24.5	19.2	23.4	0.8	0.01	0.99	0.19
BW, kg	607.7	437.6	636.9	428.2	15.8	0.01	0.55	0.25
Fe intake, mg/d	5385	5095	19566	15719	438	0.01	0.01	0.02
Fe intake, mg/kg BW/d	8.9	11.8	30.8	36.7	0.8	0.01	0.01	0.08
Fe intake, mg/kg BW ^{0.75} /d	44.3	53.6	154.3	167.0	3.8	0.02	0.01	0.68
Milk, kg/d	42.1	30.9	43.1	27.9	1.5	0.01	0.53	0.19
4% FCM, kg/d	36.1	34.3	36.0	31.3	1.7	0.08	0.38	0.39
kg 4% FCM/kg DM	1.55	1.54	1.39	1.51	0.05	0.28	0.11	0.25
Fat, %	3.02	4.76	2.92	4.82	0.20	0.01	0.92	0.70
Protein, %	2.94	3.76	3.19	3.92	0.08	0.01	0.02	0.60
Liver Cu, µg/g DM	454.9	493.2	506.6	492.2	23.4	0.62	0.33	0.28
Liver Fe, µg/g DM	184.2	184.5	184.7	254.6	15.2	0.07	0.04	0.05
Liver Zn, µg/g DM	89.8	86.4	101.8	85.8	4.9	0.08	0.29	0.24
Plasma Cu, µg/ml	0.61	0.71	0.60	0.73	0.03	0.01	0.89	0.55
Plasma Fe, µg/ml	2.24	2.00	1.91	1.96	0.13	0.45	0.18	0.29
Plasma Zn, µg/ml	0.70	0.65	0.70	0.63	0.04	0.19	0.92	0.84

CHAPTER VI: PREPARTUM DRY MATTER INTAKE PREDICTION EQUATION FOR PREGNANT NONLACTATING JERSEY COWS

ABSTRACT

An equation for predicting prepartum DMI of Jersey cows was developed using the DMI of multiparous Jerseys from 21 to 1 d prepartum. Cows were assigned to one of eight diets beginning 30 d prepartum. An exponential equation was used to describe prepartum DMI. The model was $DMI \text{ as } \% \text{ of BW} = a + b \times e^{(k \times t)}$ where a is asymptotic intercept at time negative infinity, b is the magnitude of decline in DMI, $e^{(k \times t)}$ is the shape of the curve, and t is d prepartum. Coefficients were 2.21, -0.42 , and -0.20 for a , b , and k , respectively. Prepartum DMI ranged from 2.16 to 1.80 as % of BW from 21 to 1 d prepartum. The DMI prediction equation will aid in prepartum diet formulation.

INTRODUCTION

Bovine fetal growth is exponential by age with more than half of total fetal weight being accrued during the last two months of gestation (Ferrell et al., 1976; Prior and Laster, 1979). Therefore, fetal nutrient requirements increase exponentially as gestation progresses. Bertics et al. (1992) reported a 30% reduction in DMI as parturition approached, with most of the decline occurring during the last wk of gestation. The reduction in DMI coincides with increasing fetal nutrient requirements.

Several DMI prediction equations exist for lactating cows. (National Research Council, 1989; Kertz et al., 1991; Fox et al., 1992; Roseler et al., 1997). The prevalence of experiments utilizing lactating cows results in large amounts of information that can be used to generate DMI prediction equations for lactating cows. In contrast, little information concerning DMI of pregnant nonlactating cows has existed until recently (Hayirli et al., 1999).

Accurate prediction of DMI is needed to formulate diets that meet the nutrient requirements of the pregnant nonlactating cow. Hayirli et al. (1999) developed nonlinear DMI prediction equations for pregnant nonlactating Holstein cows. However, information pertaining to prepartum DMI of the pregnant nonlactating Jersey cattle is lacking. Dry matter intake of pregnant nonlactating Jersey cattle likely differs from Holsteins based on differences that exist between lactating Holstein and Jersey cattle. Therefore, the objective of the following experiment was to develop a DMI prediction equation for pregnant nonlactating Jersey cattle.

MATERIALS AND METHODS

In two experiments, 50 multiparous Jerseys were assigned at random to one of four diets 28 to 30 d prior to expected calving. Ingredient and nutrient composition of diets are presented in Table 6.1. Diets 1 through 4 were used in experiment one and diets 5 through 8 were used in experiment two. Experiment one diets were isonitrogenous and ADF, NDF, and non-fiber carbohydrates differed due to differing energy densities. Desired energy densities were achieved by varying dietary concentrations of corn silage, grass hay, and corn. Experiment two diets were isocaloric and contained 12 or 15% crude protein (CP) and 30 or 45% RUP (% of CP). Feed

samples were taken weekly and dried at 60°C for DM determination. Crude protein (CP) and ADF were determined biweekly and CP, ADF, NDF, and minerals were determined monthly on composite ingredient samples by wet chemistry methods (VA Tech Forage Testing Laboratory, Blacksburg, VA).

Cows were group-housed prepartum in a counter-slope barn and individual daily intake was measured by the Pinpointer system (4000B, AIS Corp., Cookville, TN). Prepartum pens were 40.9 m² and limited to a maximum of five cows at any one time. Body weight (Table 6.1) was determined weekly.

A single equation was used to predict DMI since cow numbers receiving different diets were small. Data were fit to the exponential model: $DMI \text{ as } \% \text{ of BW} = a + b \times e^{(k \times t)}$ where *a* is asymptotic intercept at time negative infinity, *b* is the magnitude of decline in DMI, $e^{(k \times t)}$ is the shape of the curve, and *t* is d prepartum. The model was similar to Hayirli et al. (1999). Nonlinear equations were developed using the NLIN procedure of SAS (1996).

RESULTS AND DISCUSSION

Results are shown in 6.2 and 6.3, and Figure 6.1. Prediction equation coefficients were 2.21, -0.42, and -0.20 for *a*, *b*, and *k*, respectively. Prepartum DMI ranged from 2.16 to 1.80 as a % of BW from 21 to 1 d prepartum. The decline in DMI began approximately 1 wk prior to parturition. Compared to Hayirli et al. (1999), DMI as % of BW was greater, the decline in DMI as parturition approached was less, and the decline in DMI occurred later.

IMPLICATIONS

The prepartum DMI prediction equation provides reference in an area where information is lacking. Accurate prediction of prepartum DMI is necessary for determining the nutrient density of diets that meet the needs of the pregnant nonlactating cow. However, further research investigating prepartum DMI in Jersey cattle receiving diets differing in nutrient content is needed.

REFERENCES

- Bertics, S. J., R. R. Grummer, C. C. Cadorniga-Valino, and E. E. Stoddard. 1992. Effect of prepartum dry matter intake on liver triglyceride concentration and early lactation. *J. Dairy Sci.* 75:1914-1922.
- Ferrell, C. L., W. N. Garrett, and N. Hinman. 1976. Growth, development and composition of the udder and gravid uterus of beef heifers during pregnancy. *J. Anim. Sci.* 42:1477-1489.
- Fox, D. G., C. J. Sniffen, J. D. O'Connor, J. B. Russell, and P. J. Van Soest. 1992. A net carbohydrate and protein system for evaluating cattle diets: III. Cattle requirements and diet adequacy. *J. Anim. Sci.* 70:3578-3596.
- Hayirli, A., R. R. Grummer, E. V. Nardheim, P. M. Crump, D. K. Beede, M. J. VandeHaar, L. H. Kilmer, J. K. Drackley, D. J. Carroll, G. A. Varga, and S. S. Donkin. Prediction equations for dry matter intake of transition cows fed diets that vary in nutrient composition. *J. Dairy Sci.* 82(Suppl.):113(Abstr.)
- Kertz, A. F., L. F. Reutzel, and G. M. Thomson. 1991. Dry matter intake from parturition to midlactation. *J. Dairy Sci.* 74:2290-2295.

- National Research Council. 1989. Nutrient Requirements of Dairy Cattle. 6th revised ed. Natl. Acad. Sci., Washington, DC.
- Prior, R. L., and D. B. Laster. 1979. Development of the bovine fetus. *J. Anim. Sci.* 48:1546-1553.
- Roseler, D. K., D. G. Fox, L. E. Chase, A. N. Pell, and W. C. Stone. 1997. Development and evaluation of equations for prediction of feed intake for lactating Holstein dairy cows. *J. Dairy Sci.* 80:878-893.

Table 6.1. Cow distribution, body weight, and ingredient and nutrient composition of diets.

	Diet							
	1	2	3	4	5	6	7	8
n	6	6	6	5	7	7	6	7
BW, kg	509	484	488	456	483	474	475	481
	----- % of DM -----							
Ingredient								
Corn silage	23.0	46.7	62.8	46.1	56.5	54.5	56.4	54.0
Grass hay	63.8	37.6	15.2	7.4	22.7	21.9	22.6	21.7
Ground corn	7.7	9.1	14.8	38.4	9.6	15.9	3.1	9.4
Soybean meal	6.9	7.4	7.8	7.3	10.8		17.5	7.0
Prolak ¹						7.2		7.5
Molasses	0.4	0.4	0.4	0.4				
Mineral-vitamin mix ²	0.4	0.4	0.4	0.4	0.4	0.5	0.4	0.4
Nutrient								
DM, % as-fed basis	65.4	52.6	46.4	52.9	49.4	50.2	49.5	50.4
CP	12.1	12.1	12.1	12.1	12.1	12.1	15.1	15.1
RUP, % of CP ³	33.4	31.1	30.0	34.6	31.0	46.7	29.0	42.3
ADF	34.9	28.9	22.8	17.0	23.0	22.0	23.1	22.1
NDF	55.9	47.0	37.9	28.0	40.3	39.8	40.1	39.6
NFC ⁴	17.0	27.7	38.6	50.0	37.5	38.1	34.6	35.1
Ca	0.30	0.29	0.28	0.23	0.3	0.5	0.3	0.5
P	0.28	0.28	0.29	0.31	0.3	0.4	0.3	0.4
NE _L , Mcal/kg DM ⁵	1.25	1.38	1.50	1.63	1.49	1.51	1.49	1.51

¹H. J. Baker and Bro., Inc., New York

²Mineral-vitamin mix contained 15% Ca, 8.5% Cl, 2% Mg, 5.5% Na, 9% P, 0.0026 % Co, 0.0690 % Cu, 0.1300 % Fe, 0.2600 % Mn, 0.0052 % Se, 0.4500 % Zn, 273 KIU A/kg DM, 55 KIU D/kg DM, and 682 IU E/kg DM.

³Calculated. NRC (1989) values were used for all ingredients except Prolak, which was assumed 65% RUP as % of CP.

⁴Calculated non-fiber carbohydrates.

⁵Calculated. Equations were used to calculate NE_L (Mcal/kg) content of corn silage (0.807-0.0041ADF) and grass hay (2.2415-0.0262ADF). NRC (1989) values were used for all other ingredients.

Table 6.2. Regression coefficients for prepartum DMI of Jersey cows.

Coefficient	Estimate	SE
A	2.21	0.04
B	-0.42	0.09
K	-0.20	0.10

Table 6.3. Asymptotic correlation matrix.

	a	b	k
a	1	0.18	0.58
b	0.18	1	0.77
k	0.58	0.77	1

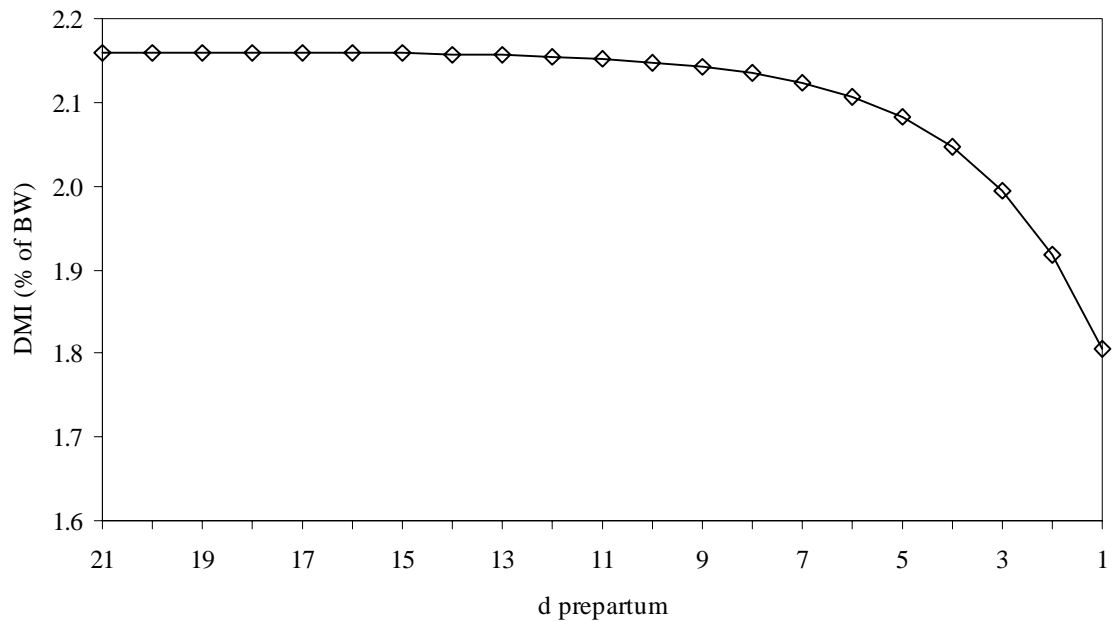


Figure 6.1. Predicted prepartum DMI of Jersey cows.

CONCLUSIONS

In Experiment 1, increasing prepartum diet energy density resulted in a linear increase in milk and 4% FCM yield. It is hypothesized that increases in nutrient intake due to a linear increase in prepartum DMI contributed to increased yield, since postpartum DMI did not respond to prepartum energy density in a similar manner. The decline in Jersey prepartum intake did not occur to the extent as in Holsteins and may have lead to lower NEFA.

In Experiment 2, increasing CP or RUP did not improve productivity. Positive MP protein balance for all cows may have precluded CP and RUP differences. Prepartum DMI was adequate in maintaining nutrient intake although a depression occurred prior to parturition. Prepartum intake would have been less; based on results of Experiment 1, if diets were formulated according to energy requirements and the influences of CP and RUP may have been different.

In Experiment 3, supplemental Fe did not affect Cu status of cows supplemented with 10 mg Cu/kg DM. Iron supplementation rate, source of supplemental Fe, or length of experiment may have prevented differences. However, differences in plasma Cu Holstein and Jersey cattle and differences in Hepatic Fe of Holsteins and Jerseys receiving supplemental Fe indicated that these two breeds differ in metabolism.

In Experiment 4, the prepartum DMI equation indicates that different breed equations are needed for pregnant nonlactating cows. Adequate prediction of prepartum DMI will allow formulation of prepartum diets containing nutrient densities that meet the nutrient requirements of the dry cow.

VITA

The author, Patrick D. French, was born in London, KY on September 10, 1969 and graduated from Laurel County High School in 1987. He graduated with a Bachelor of Science in Accounting in 1992 and a Master of Science in Animal Science in 1996 from the University of Kentucky. Since 1996, he has been pursuing a Doctor of Philosophy in Animal Science at Virginia Polytechnic Institute and State University. The author is a member of Gamma Sigma Delta, American Dairy Science Association, and American Animal Science Association.