Utilization of fortified cubes to deliver trace minerals and monensin in forage-based diets

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Ominski, K. H., Boadi, D. A. and Wittenberg, K. M. 2006. **Utilization of fortified cubes to deliver trace minerals and monensin in forage-based diets**. Can. J. Anim. Sci. **86**: 291–298. The potential benefits of mineral or monensin delivery through forage cubes vs. free-choice were investigated in Simmental × Charolais pregnant cows and their calves. Thirty-six mid-gestation cows (615 ± 21 kg) placed in 18 pens were initially depleted of liver Cu reserves by feeding a TMR containing 100 mg Mo kg^{-1} DM and 4 g S kg^{-1} DM for 42 d, allowed to stabilize on a low Mo, Cu and S diet for 42 d and were then used in a mineral uptake study. Experimental diets containing chopped grass-hay were fed ad libitum with one of the following three alfalfa-barley grain cubes at 2 kg $head^{-1}$ d^{-1}: (1) no addition of mineral and ionophore (Free Choice); (2) addition of mineral and no ionophore (+M Cube); and (3) addition of mineral and ionophore in the form of monensin (+M+I Cube). Mineral intake and mineral status (through liver biopsy and blood sampling) were monitored over a 16-wk feeding period, which included the first 6 wk post-calving. Dry matter intake by Free Choice cows prior to calving was higher than that by +M Cube and +M+I Cube fed cows ($P < 0.05$). Pre- and post-calving mineral intake (g pen^{-1} d^{-1}) by Free Choice cows was 31.6% higher than +M Cube and +M+I Cube fed cows ($P < 0.01$). The coefficient of variation for day-to-day and pen-to-pen variation for cows consuming free choice mineral was 81 and 36%, respectively. There was no variation in supplemental mineral intake for +M Cube and +M+I Cube fed cows due to complete consumption of all forage cubes offered. Dietary treatment did not influence mean serum Cu and Zn concentration or plasma ceruloplasmin oxidase (Cp) activity of cows ($P > 0.05$). However, liver Cu concentration (mg kg^{-1}) of +M+I Cube fed cows tended to be higher than for the other treatment groups ($P = 0.06$). Calf ADG at 6 wk of age was not affected by dietary treatment of dams ($P > 0.05$). Copper and Zn status of calves at 6 wk of age was not different among dam dietary treatments. However, plasma Cp activity declined more rapidly in +M+I Cube calves compared with +M Cube calves ($P < 0.05$), which may be attributed to the presence of monensin in the +M+I Cube diet of late gestation cows. Fortified cubes may be used as an effective means of eliminating the variability in mineral intake associated with free choice consumption with no detrimental effect on mineral status of cows and their suckling calves.

Key words: Forage cubes, trace minerals, monensin, pregnant cows, calves

Ominski, K. H., Boadi, D. A. et Wittenberg, K. M. 2006. **Administration d'oligoéléments et de monensin grâce à ces cubes de fourrage enrichis**. Can. J. Anim. Sci. **86**: 291–298. Les auteurs ont examiné l'utilité potentielle de cubes de fourrage plutôt que de l'alimentation libre pour administrer des oligoéléments et du monensin à des vaches Simmental × Charolais gravides et à leurs veaux. Pour cela, ils ont commencé par épuiser les réserves hépatiques de Cu de 36 vaches (615 ± 21 kg) en milieu de gestation en leur servant pendant 42 jours une ration mixte contenant 100 mg de Mo et 4 g de S par kg de matière sèche (MS). Ensuite, ils ont stabilisé le métabolisme des animaux avec une ration à faible teneur en Mo, en Cu et en S durant le même laps de temps avant d'entreprendre leur étude sur l'absorption des oligoéléments. Les rations expérimentales employées à cette fin se composaient de foin de graminées haché servi à satiété ou d'un des trois cubes de luzerne et d'orge que voici, servis à raison de 2 kg par animal et par jour : (1) pas d'oligoéléments ni d'ionophores (alimentation libre), (2) addition d'oligoéléments sans ionophores (cubes +O) et (3) addition d'oligoéléments et d'ionophores sous forme de monensin (cubes +O+I). Les auteurs ont surveillé l'absorption et le bilan des oligoéléments (par biopsie du foie et prélèvements sanguins) durant la période d'engraissement de 16 semaines, qui incluait les six semaines suivant le vêlage. Avant la mise bas, les vaches nourries à satiété ont absorbé plus de matière sèche que celles recevant les cubes +O et +O+I ($P < 0,05$). Avant et après le vêlage, les vaches nourries à satiété ont absorbé 31,6 % plus d'oligoéléments (g par enclos et par jour) que celles nourries avec les cubes +O et +O+I ($P < 0,01$). Le coefficient de variation des vaches recevant des oligoéléments à satiété s'élève respectivement à 81 % et à 36 % d'une journée ou d'un enclos à l'autre. Les auteurs n'ont pas relevé de variation au niveau de l'absorption des oligoéléments chez les vaches recevant des cubes +O et +O+I, ces derniers ayant été absorbés en totalité. Le type de régime n'exerce aucune influence sur la concentration moyenne de Cu et de Zn dans le sérum ni sur l'activité de la céruloplasmine oxydase (Cp) dans le plasma des vaches ($P > 0,05$). Toutefois, la concentration de Cu (mg par kg) a tendance à être plus élevée dans le foie des vaches recevant les cubes +O+I que dans celui des vaches des autres groupes ($P = 0,06$). Le régime alimentaire de la mère n'affecte pas le GQM des veaux de six semaines ($P > 0,05$). Le bilan du Cu et du Zn des veaux de six semaines reste le même, peu importe le traitement administré à la mère. Néanmoins, l'activité de la Cp plasmatique diminue plus rapidement chez les veaux des mères recevant les cubes +O+I que chez ceux des mères nourries de cubes +O ($P < 0,05$), ce qui pourrait résulter de la présence de monensin dans la ration des vaches nourries de cubes +O+I à la fin de la gestation. L'utilisation de cubes enrichis pourrait stabiliser l'absorption des oligoéléments plus que ne le permet l'alimentation libre sans que le bilan des oligoéléments en souffre pour autant chez la mère et les veaux nouveau-nés.

Mots clés: Cubes de fourrage, oligoéléments, monensin, vaches gravides, veaux

Abbreviations: **AAS**, atomic absorption spectrophotometer; **ADF**, acid detergent fiber; **BF**, body fat; **BW**, body weight; **Cp**, ceruloplasmin oxidase activity; **CP**, crude protein; **DM**, dry matter; **DMI**, dry matter intake; **PPD**, p-phenylenediamine dihydrochloride; **TMR**, total mixed ration

Advancements in forage production and preservation techniques have allowed many cattle producers to significantly improve the quality of forage used in their wintering feeding programs. Beef producers on the Canadian prairies now have the option of feeding all-forage rations that can meet most nutrient requirements of gestation cows and backgrounded cattle. Many cow-calf producers view the low infrastructure and labor cost associated with feeding a 100% forage diet as an opportunity to retain ownership and to utilize alternative marketing strategies for their weaned calves. Although forages can provide sufficient quantities of energy and protein, they may be lacking in micronutrients which require supplementation (Cockwill et al. 2000).

Trace minerals and feed additives are typically considered for inclusion in the formulation of diets used in Western Canadian beef cattle operations. For example, Cu and Zn are typically supplemented in Western Canadian cattle diets (Boila 1989) due to either low concentrations of these essential trace minerals or the presence of antagonistic minerals in farm-grown forages. In addition to ionophores, enzymes and anti-bloating agents are examples of additives that may be supplemented to cattle consuming forage-based diets. A limited ability to regulate intake of these minerals and additives can prevent optimal utilization or discourage inclusion in the diet altogether.

Options for the delivery of minerals and additives for forage diets are limited. Use of water supplements (Miller 1990) is not suitable for most minerals or additives and is generally considered to require high infrastructure costs. Tait and Fisher (1996), in reviewing the literature, indicated that supplemental nutrients or additives may be provided on a free-choice basis when incorporated into molasses blocks, liquid licks or in a granular form. Free-choice mineral feeding assumes that animals will consume quantities sufficient to satisfy mineral requirements; however, numerous studies have shown animal-to-animal and day-to-day variability in intake and over or under consumption of mineral supplements (Rode et al. 1994; Tait and Fisher 1996; Cockwill et al. 2000). Over consumption can lead to toxicity, unnecessarily high excretion, environmental issues and high production costs, while under consumption can limit production and increase economic losses. The limitations of free-choice feeding of supplements become even more critical when used as a means of delivering medications where specific daily dosages are needed for efficacy and avoidance of toxicity (Rode et al. 1994). Consequently, producers wishing to employ 100% forage rations are limited in options for efficient delivery of trace elements or feed additives to cattle.

Technologies developed for the processing of forages into pellets and cubes has increased market options for Canadian forages. Technology for processing of forage into cubes exists in many parts of North America including Western Canada, with the majority of product targeting export markets. Forage cubes are relatively dust-free, are easy to transport or handle relative to baled hay and, therefore, could readily be utilized in the industry (McNelly 1988). Newer technologies allowing the inclusion of concentrates and other ingredients, improved palatability of cubes and less feed wastage (McNelly 1988) suggest that forage cubes could be an effective means of delivering minerals and feed additives.

The objective of the study was to compare the trace mineral consumption and status of late gestation and lactating beef cows and their calves when mineral supplements were delivered via forage cubes with or without monensin vs. minerals provided on a free-choice basis.

MATERIALS AND METHODS

Animals and Management

Thirty-six multiparous Simmental and Charolais crossbred cows in their second trimester of pregnancy averaging 614.8 ± 20.9 kg (mean ± SE) were selected from the Agriculture and Agri-Food Canada herd in Brandon, Manitoba, on the basis of breeding date, with all cows bred over a 7-d period. Cows were brought to the University of Manitoba Glenlea Research Station, 20 km south of Winnipeg, Manitoba and placed in 18 pens (two cows per pen) to compare the method of delivery of mineral on daily mineral consumed, day-to-day and pen-to-pen variation, liver and blood parameters of cows and their calves. Cows were bedded on barley straw which was low in trace minerals and water was offered ad-libitum. Cows received 2 500 000 IU vitamins A and 375 000 IU vitamin D by injection at the start of the depletion phase and again 4 mo later. Animals were cared for in accordance with the principles outlined by the Canadian Council on Animal Care (1993).

Pre-experimental Period

To study mineral uptake by cows it was necessary to initially deplete cows of liver Cu reserves. This was achieved by providing cows with a Cu-depleting [barley silage and barley grain (85:15 DM basis)] TMR containing 100 mg Mo kg^{-1} and 4 g S kg^{-1} , DM basis (Wittenberg and Boila 1988) for 42 d. Following the depletion phase, cows were fed low Cu (3.3 mg kg^{-1}, DM basis) chopped hay for a 42-d period to stabilize body Cu metabolism prior to assigning animal to diets for the repletion phase (experimental period).

Experimental Period

All experimental diets included chopped grass hay (CP = 9.6%; ADF = 41.2%; Cu = 7.2 mg kg^{-1} DM basis), fed ad libitum, and one of the following three alfalfa-barley grain cubes (Table 1) fed at 2 kg $head^{-1}$ d^{-1}: cubes containing no added mineral, monensin or salt (Free Choice); cubes containing 32 mg kg^{-1} and 103 mg kg^{-1} DM added Cu and Zn, respectively, 1.7% cobalt-iodized salt and no added ionophore (+M Cube); and cubes containing 35 mg kg^{-1} and 111 mg kg^{-1} DM added Cu and Zn, respectively, 1.7% cobalt-iodized salt and 127 mg kg^{-1} DM, added monensin as Rumensin® (+M+I Cube). A commonly used mineral supplement Hi C-N-Z (1:1) mineral (Feed-Rite Ltd., Winnipeg, MB) was used as the Cu and Zn source in the cube formulation (Table 1). The same mineral supplement, Hi C-N-Z (1:1) mineral was blended (48:52, as fed basis) with Co-I salt, and offered, using 50-cm-diameter circular mineral feeders placed in feed bunks, to cows assigned to the Free Choice dietary treatment.

Daily feed offered and orts were recorded for each pen and DMI determined weekly. Free choice mineral intake was measured weekly. In addition, daily intake of free

Table 1. Ingredient and chemical composition of forage cubes[z] used in experimental period (DM basis)

	Free Choice	+M Cube	+M+I Cube
Ingredients			
Alfalfa (%)	86.9	86.6	86.6
Ground barley grain (%)	13.1	10.1	10.0
Supplemental mineral (%)[y]	–	1.6	1.6
Cobalt-iodized salt (%)[x]	–	1.7	1.7
Rumensin® 200 (%)	–	–	0.1
Chemical composition (DM basis)			
Dry matter (%)	97.3	97.8	97.9
Crude protein (%)	15.9	15.7	16.6
Acid detergent fiber (%)	35.0	34.8	33.3
Calcium (%)	1.23	1.38	1.40
Phosphorus (%)	0.20	0.40	0.41
Sodium (%)	0.04	0.52	0.57
Zinc (mg kg^{-1})	20.2	103.0	111.3
Manganese (mg kg^{-1})	25.9	99.0	106.1
Copper (mg kg^{-1})	7.5	32.2	34.5
Iron (mg kg^{-1})	126.5	284.0	302.0
Molybdenum (mg kg^{-1})	<2.0	<2.0	<2.0
Monensin (mg kg^{-1})	<4.0[w]	<4.0[w]	126.5

[z]Free Choice = no mineral or ionophore in cube; +M Cube = mineral and no ionophore in cube; +M+I Cube = mineral and ionophore in cube. Cubes were manufactured by Tirol International Marketing Inc., AB.
[y]Mineral (Hi C-N-Z) contains (as fed basis): Ca, 16%; P, 16%; K, 0.2%; Mg, 0.03%; S, 0.2%; Fe, 320 mg kg^{-1}; I, 125 mg kg^{-1}; Mn, 5300 mg kg^{-1}; Cu, 4000 mg kg^{-1}; Se, 60 mg kg^{-1}; Co, 50 mg kg^{-1}; Zn, 10 000 mg kg^{-1}; Fl, 2000 mg kg^{-1}; vitamin A, 200 000 IU kg^{-1}; vitamin D, 45 000 IU kg^{-1}; vitamin E, 40 IU kg^{-1}.
[x]Cobalt-iodized salt contains (as fed): NaCl, 99%; I, 150 mg kg^{-1}; Co, 100 mg kg^{-1}.
[w]Lowest level of detection.

choice minerals and of cubes was monitored over a 10-d period starting in week 4 of the experimental period to examine variability in mineral intake.

To evaluate performance, cows were weighed at regular intervals prior to calving, 24 h post-calving, and at 3 and 6 wk post-calving. Back fat (BF) thickness measurements using real-time ultrasonography (Aloka SSD500, 5.0 MHz probe, Aloka Co. Ltd., Japan) were taken at the start of the experimental period and before calving. Calves were weighed 24 h after birth and at three and 6 wk of age.

Liver and Blood Sampling

Mineral status (Cu and Zn) of cows and their calves was monitored during the 16-week feeding trial. Liver biopsies (g) were taken randomly from eight cows on day 0 of the repletion phase to determine liver Cu depletion and from all cows at 3 wk post-calving. Liver biopsies were taken according to the procedure described by Smart and Northcote (1985). Blood samples were collected into silicon coated and sodium heparinized vacutainer tubes for serum and plasma recovery, respectively. Tail vein blood samples from cows were collected on day 0, day 21, day 42 of the experimental period and at 3 and 6 wk post-calving. Blood samples were collected via the jugular vein from calves at 3 and 6 wk of age. Blood samples were centrifuged at 2500 × g for 20 min. Serum and liver samples were frozen at –20°C until analyzed for Cu and Zn concentrations. Plasma was frozen immediately and stored (–20°C) until analyzed for ceruloplasmin oxidase (Cp) activity, a Cu-containing enzyme frequently used as an index of Cu status (Stephenson et al. 1997).

Liver and Blood Analyses

The analyses of minerals in liver and blood were performed at the Manitoba Agriculture, Food and Rural Initiatives, Veterinary Services Branch, Winnipeg, Manitoba. Copper and Zn concentrations in the liver were analyzed using the Association of Official Analytical Chemist (AOAC) method no 985.40 (AOAC 2000), where 1 g of liver tissue was digested overnight at 60°C in 5 mL HNO_3, then diluted and measured by atomic absorption spectrophotometer (AAS). The AOAC methods no. 983.24 and no. 991.11 were used to analyze serum Cu and Zn, respectively. For Cu analysis, serum was diluted (1 + 1) with H_2O, and Cu determined by AAS using standard solutions prepared in 10% glycerol. With regards to Zn analysis, serum was placed in polypropylene tubes, diluted (1 + 5) with 0.03% aqueous Brij 35 and Zn was determined by flame AAS using standard solutions prepared in the same matrix. Plasma samples were analyzed for Cp activity according to the modified procedure (Wittenberg and Boila 1988) of Smith and Wright (1974), using purified p-phenylenediamine dihydrochloride (PPD) as a substrate. Plasma enzyme activity was determined from the rate of PPD oxidation, $\Delta A\ min^{-1}$, with a rate of color development at 540 nm using a spectrophotometer (Beckman DU–8).

Statistical Analyses

Mineral and DM intake, BW, ADG, BF of cows and calves, and liver Cu were analyzed by analysis of variance using GLM in SAS Institute Inc. (1996) using the model:

$$Y_{ij} = \mu + D_i + \varepsilon_{ij},$$

where Y_{ij} = trait under consideration; μ = overall mean; D_i = diet and ε_{ij} = experimental error. Blood parameters were analyzed by analysis of variance using PROC MIXED in SAS Institute Inc, (1996) using the model:

Table 2. Effect of dietary treatment[z] on beef cow and calf performance

Parameters	Free Choice	+M Cube	+M+I Cube
		Cow performance	
No. of cows	12	12	12
Initial cow wt. (kg)	615.2 ± 20.9	618.2 ± 20.9	611.1 ± 20.9
Intake, DM basis (kg head^{-1} d^{-1}) [y]			
Hay			
Pre-calving	10.7 ± 0.2*a*	10.0 ± 0.2*b*	10.0 ± 0.2*b*
Post-calving	13.5 ± 1.2	15.6 ± 1.2	12.1 ± 1.2
Cube			
Pre-calving	1.6 ± 0.05	1.6 ± 0.05	1.6 ± 0.05
Post-calving	1.8 ± 0.01	1.8 ± 0.01	1.8 ± 0.01
Total			
Pre-calving	12.3 ± 0.2*a*	11.6 ± 0.2*b*	11.7 ± 0.2*b*
Post-calving	15.3 ± 1.2	17.4 ± 1.2	13.7 ± 1.2
Mineral intake (g pen^{-1} d^{-1})	82.3 ± 4.6*a*	56.2 ± 0.0*b*	56.2 ± 0.0*b*
ADG (kg head^{-1} d^{-1})			
Day 0 to 24 h post-calving	–0.3 ± 0.2	–0.1 ± 0.2	–0.2 ± 0.2
24 h to 6 wk post-calving	0.5 ± 0.3	0.2 ± 0.3	0.2 ± 0.3
Overall	0.1 ± 0.1	0.03 ± 0.1	0.02 ± 0.1
Initial back fat (mm)	3.1 ± 0.6	3.0 ± 0.6	3.1 ± 0.6
Change in back fat (mm)[x]	–0.4 ± 0.3	–0.3 ± 0.3	–0.5 ± 0.3
		Calf performance	
No. of calves	12	14	11
Calf weight (kg)			
Birth	40.6 ± 1.5	39.0 ± 1.6	41.6 ± 1.7
3 wk	72.0 ± 3.0	66.9 ± 2.7	72.9 ± 3.0
6 wk	94.9 ± 3.8	86.8 ± 3.4	94.9 ± 3.8
ADG (kg head^{-1} d^{-1})			
Birth to 6 wk	1.2 ± 0.1	1.1 ± 0.1	1.2 ± 0.1

[z]Free Choice = no mineral or ionophore in cube; +M Cube = mineral and no ionophore in cube; +M+I Cube = mineral and ionophore in cube.
[y]DMI data reflects the first 4 wk of experimental period, post-calving DMI data reflects 2 wk after all cows had calved.
[x]From day 0 to day 42.
a, b Means across treatments with different letters differ (P < 0.05).

$$Y_{ijk} = \mu + D_i + T_j + DT_{ij} + \varepsilon_{ijk},$$

with cow (treatment) used as the random variable, where Y_{ijk} = trait under consideration, μ = overall mean, D_i = diet, T_j = time; DT_{ij} = diet × time interaction and ε_{ijk} = experimental error. Means were separated by Bonferonni means separation test at the 5% level of significance. Means for the 10-d mineral intake monitoring was separated by a *t*-test at P < 0.05. Two sets of twin calves were born to cows assigned to the +M Cube treatment. Results of a statistical model that considered single vs. twin calves showed no differences. Therefore, no distinction was made for single and twin calves during statistical analyses of calf parameters in the data reported. Data from a calf that was removed from the experiment due to unrelated illness were not included; however, data from the dam were included in all analyses.

RESULTS AND DISCUSSION

Mineral Intake and Performance

There was no refusal of the forage cubes offered at 2 kg head^{-1} d^{-1} for any of the three experimental diets over the course of the trial. Hay DMI and total DMI (hay + cubes) prior to calving was higher (P < 0.05) for the cows receiving the Free Choice treatment compared with those receiving +M Cube and +M+I Cube treatments (Table 2). Lowered total DMI observed in +M+I Cube could potentially be attributed to the inclusion of Rumensin® (Sprott et al. 1988); however, there is no explanation for the increased hay intake of cows fed mineral free choice vs. the +M Cube treatment. Mineral intake (g pen^{-1} d^{-1}) during the 16-wk trial by cows consuming free choice minerals was 31.6% higher than (P < 0.01) cows fed minerals in the forage:barley grain cubes.

Mineral intake of cows receiving mineral on a free-choice basis ranged from 21.6 ± 16.1 to 210.0 ± 16.1 and averaged 65.5 ± 8.7 g pen^{-1} d^{-1} during the period of daily monitoring. The mean mineral intake for +M Cube and +M+I Cube fed cows was 56.2 g pen^{-1} d^{-1}. There was no variation in mineral intake associated with the latter treatment groups as animals consistently consumed all cubes offered to them. Mineral source was not a contributing factor to differences in intake as a commonly used supplement; Hi C-N-Z (Feed-Rite Ltd.) was used in cubes as well as offered on a free-choice basis. As the study did not include calves more than 6 wk of age, forage and cube consumption by calves was negligible.

Average daily mineral intake of cows fed free-choice minerals was higher than the other treatment groups (Table 2). The day-to-day variation in mineral intake was 81% (P < 0.001), while the pen-to-pen variation was 36% (P = 0.002) for the animals fed mineral in a free-choice basis. This high variability in mineral intake agrees with the gen-

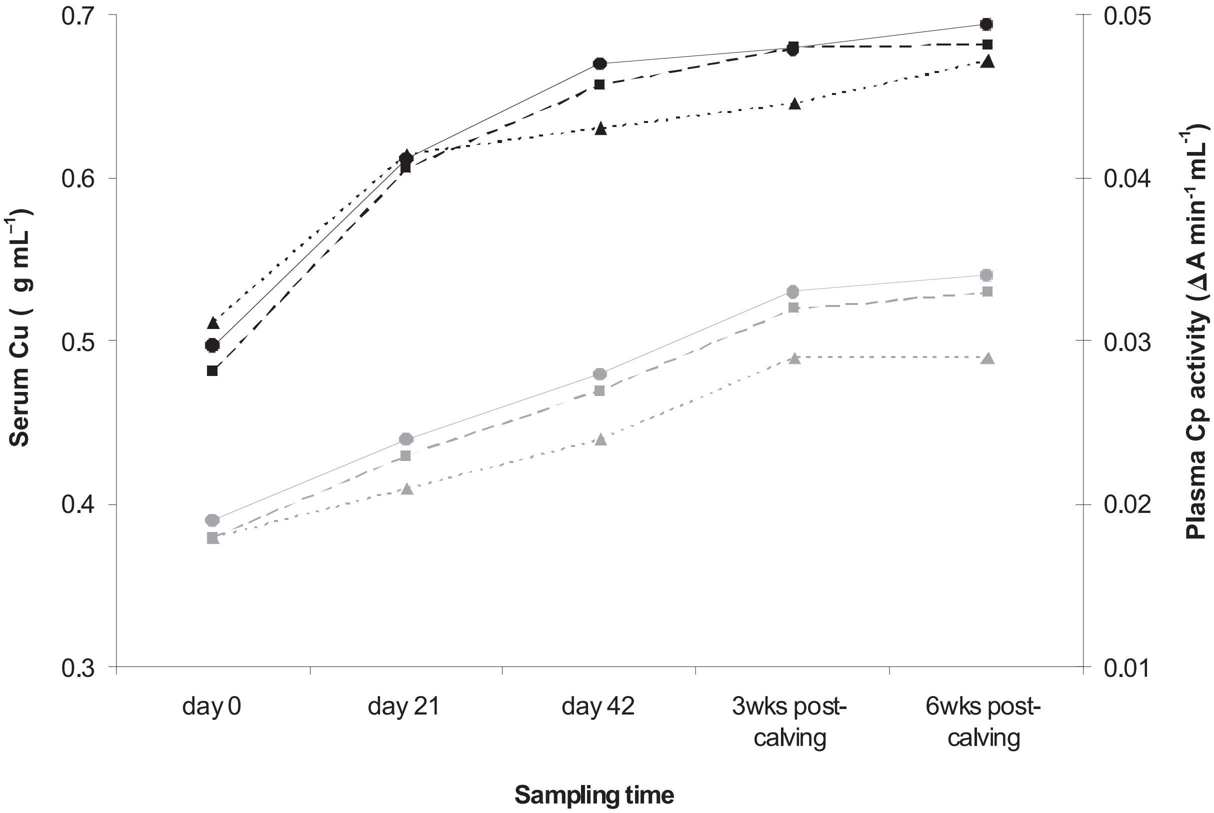

Fig. 1. Effect of mineral delivery system on serum Cu concentrations and plasma ceruloplasmin (Cp) activity rates of cows before and after calving (n = 12). Serum Cu (μg mL^{-1}) SE = 0.023. Plasma Cp activity (△A min^{-1} mL^{-1}) SE = 0.001 [-▲-, Free Choice (Cu); -■-, +M Cube (Cu); -●-, M+I Cube (Cu); -▲-, Free Choice (Cp); -■-, +M Cube (Cp); -●-, +M+I Cube (Cp)].

Table 3. Effect of dietary treatment on liver and blood parameters of gestating and lactating beef cows

Parameters	Cow liver Cu (mg kg^{-1} DM basis)[z]	Cow serum Cu conc. (μg mL^{-1})	Cow plasma Cp activity (ΔA min^{-1} mL^{-1})	Cow serum Zn conc. (μg mL^{-1})
Diet[y]				
Free Choice	100.42 ± 9.63	0.62 ± 0.03	0.024 ± 0.001	0.84 ± 0.02
+M Cube	90.16 ± 9.63	0.63 ± 0.03	0.027 ± 0.001	0.81 ± 0.02
+M+I Cube	123.42 ± 9.63	0.62 ± 0.03	0.026 ± 0.001	0.85 ± 0.02
Time				
Day 0		0.50 ± 0.02*c*	0.018 ± 0.001*d*	0.97 ± 0.02*a*
Day 21		0.61 ± 0.02*b*	0.023 ± 0.001*c*	0.86 ± 0.02*b*
Day 42		0.65 ± 0.02*a*	0.026 ± 0.001*b*	0.79 ± 0.02*c*
3 wk post		0.67 ± 0.02*a*	0.031 ± 0.001*a*	0.76 ± 0.02*c*
6 wk post		0.68 ± 0.02*a*	0.032 ± 0.001*a*	0.77 ± 0.02*c*
Diet × Time				
P value	NA	0.99	0.93	0.95

[z]Liver samples were taken 3 wk post-calving.
[y]Free Choice = no mineral or ionophore in cube; +M Cube = mineral and no ionophore in cube; +M+I Cube = mineral and ionophore in cube.
a–d Means within each parameter followed by different letters differ ($P < 0.05$).

eral observation of variability associated with mineral offered on a free-choice basis (Tait and Fisher 1996; Cockwill et al. 2000). Rode et al. (1994) reported high variability in intake for grazing heifers offered a free-choice salt/mineral mix, with a coefficient of variation of 32.1 and 29% in year 1, and 29.0 and 38.8% in year 2, for heifers on mineral with and without lasalocid, respectively. Tait et al. (1992) recorded free-choice mineral intakes by individual steers ranging from 6 to 330 g d^{-1} over 14 d. Forage cubes were offered to cows immediately after TMR was fed in a

1.7 m long feed bunk and were preferentially consumed relative to the TMR. Although there was some competition at the feed bunk in this study, feeding facilities on individual commercial operations may have greater competition between cows, and operators will have to consider options, whether ground or feed bunk feeding, that allow all animals access to cubes at the time of delivery if amount of cube offered is restricted, as was the case in this study.

Cows' average daily gain from the start of the trial to 1 d post-calving ranged from –0.1 to –0.3 kg (Table 2). The negative value can be attributed to the weight of calf, placenta and fluids lost at calving. Feeding minerals free-choice or incorporated into forage cubes did not ($P > 0.05$) affect weight gain or change in back fat thickness in late pregnancy beef cows even though cows on free-choice mineral consumed 7% more feed and 46% more mineral supplement than other treatment groups. It may be that precision of weight and body fat measurement was inadequate to detect these differences. Calf BW and ADG at 6 wk of age were not influenced by dietary treatment of dam ($P > 0.05$). On the contrary, Lemenager et al. (1978) observed that calves on pasture reared by monensin-fed cows gained weight more rapidly than controls even though milk yield was not affected by monensin supplementation. This was attributed to the fact that calves consumed some of the monensin supplemented to their dams on pasture. Recent work completed by Kopp et al. (2004) shows that milk yield and milk composition are not affected by monensin supplementation of lactating beef cows.

Cow Mineral Status

The marginal range for serum Cu levels in cattle is difficult to define; however, Underwood and Suttle (2001) have suggested that animals in the range of 0.19 to 0.58 μg mL^{-1} have a high probability of current or future dysfunction. A common reference used by Canadian veterinary diagnostic labs (Puls 1994) suggests that animals with serum Cu levels below 0.50 μg mL^{-1} are deficient to marginal in Cu status. Cows started the experimental period (day 0) with marginal or deficient serum Cu concentrations, averaging 0.50 ± 0.02 μg mL^{-1} (Fig. 1). Ceruloplasmin typically represents 80 to 90% of serum copper, and is sometimes recommended as a diagnostic aide in situations where ruminants have been exposed to excess molybdenum. Ceruloplasmin activity is an accurate measure of Cu status when Cu is limited, because the Cp-binding sites become unsaturated at low Cu intakes (Stephenson et al. 1997). For all dietary treatments, serum Cu concentrations and plasma Cp activity began to rise sharply once copper was replenished in the diet prior to calving and continued to increase post calving (Fig. 1), with no differences ($P > 0.05$) between treatments in the rate or extent of increase (Table 3). Serum Cu concentrations were within an adequate range during the experimental period (Puls 1994).

Underwood and Suttle (2001) suggest that the marginal band for assessing risk of Zn deprivation is 0.4 to 0.6 μg mL^{-1}. Cow serum Zn concentrations on day 0 of the experimental period were 1.0 μg mL^{-1} and declined to 0.8 μg mL^{-1} during the course of the trial (Table 3). Rate of decline and extent of decline were not ($P > 0.05$) influenced by dietary treatment.

Table 4. Effect of dietary treatment of cows on the blood parameters of their calves

Parameter	Serum Cu conc. (μg mL^{-1})	Plasma (Cp) activity (ΔA min^{-1} mL^{-1})	Serum Zn conc. (μg mL^{-1})
Diet[z]			
Free Choice	0.62 ± 0.03	0.024 ± 0.001*ab*	1.04 ± 0.04
+M Cube	0.59 ± 0.02	0.027 ± 0.001*a*	1.01 ± 0.04
+M+I Cube	0.54 ± 0.03	0.022 ± 0.001*b*	0.96 ± 0.04
Time			
3 wk post	0.59 ± 0.01	0.026 ± 0.001*a*	1.07 ± 0.02*a*
6 wk post	0.58 ± 0.01	0.022 ± 0.001*b*	0.96 ± 0.02*b*
Diet × Time			
P value	0.60	0.04	0.86

[z]Free Choice = no mineral or ionophore in cube; +M Cube = mineral and no ionophore in cube; +M+I Cube = mineral and ionophore in cube.
a, b Means within each parameter followed by different letters differ ($P < 0.05$).

Copper liver stores were depleted at the start of the experimental period. Mean liver Cu concentration (mg kg^{-1}, dry basis) on day 0 was 28.1 ± 10.4 (mean ± SE), which was within the deficient range (3.5–35.0 mg kg^{-1}, dry basis) according to Puls (1994). Liver Cu concentrations in cows at 3 wk post-calving tended to be higher ($P = 0.06$) when fed cubes containing mineral and monensin than the other dietary treatments. Rumen protozoa are associated with the generation of sulfides, which can bind to copper in the rumen and precipitate as copper sulfates, reducing availability of dietary Cu. Monensin has been shown to increase liver Cu accumulation in ruminants (Elsasser 1984; Ivan et al. 1992), the potential mode of action being through the reduction of these protozoa populations. Elsasser (1984) has also speculated that ionophores are able to bind divalent minerals and thus influence their absorption. Results presented here support the above studies.

In summary, the repletion and stabilization phases resulted in marginal to deficient levels of cow liver and serum Cu concentrations on day 0 of the experimental period, during which various options of mineral delivery were compared. Although mineral consumption by cows assigned to the free-choice mineral was 46% greater than for cows fed cubes, the rate and extent of serum Cu and Cp increase was the same, suggesting that cubes are a more efficient method of Cu delivery. Similarly, method of mineral delivery did not influence the rate of Zn decline in cow serum during late gestation and early lactation.

Calf Mineral Status

Serum Cu levels ranging from 0.60 to 1.50 are considered to be in an adequate range for calves (Puls 1994). Calf serum Cu concentrations were in the marginal to adequate range during the trial, whereas serum Zn levels were in an adequate range. Serum Cu and Zn concentrations of calves at 3 and 6 wk of age were not influenced by dietary treatment of the dam ($P > 0.05$, Table 4). Calf serum Zn concentration and plasma Cp activity for all treatments declined from 3 to

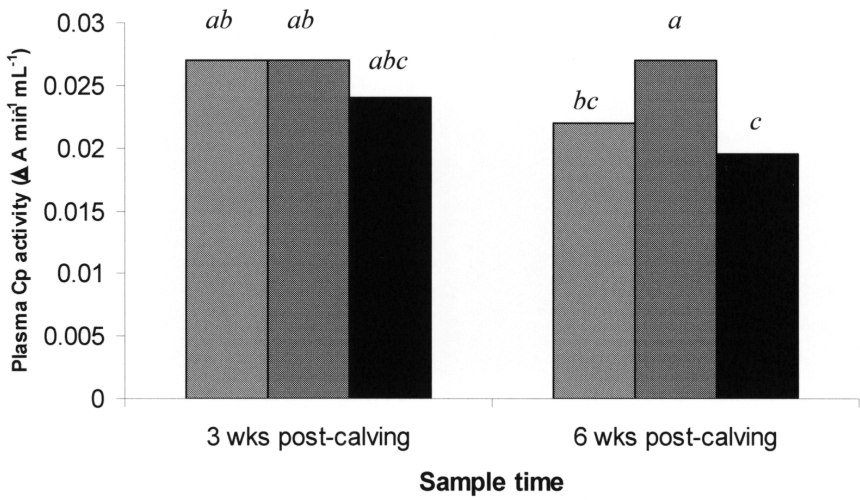

Fig. 2. Effect of mineral delivery system for cows on the plasma ceruloplasmin (Cp) activity rates of their suckling calves at 3 and 6 wk of age. Plasma Cp activity (ΔA min^{-1} mL^{-1}) SE = 0.001. Free Choice: n = 12 (hatched), +M Cube: n = 14, including twins (dots), +M+I Cube: n = 11 (solid).

6 wk of age ($P < 0.05$). There was a significant diet × time interaction observed for calf Cp activity (Fig. 2). Calves suckling cows fed the dietary treatments had similar Cp activity at week 3, but calves suckling cows fed free-choice minerals or cubes containing mineral and monensin had a greater decline in plasma Cp activity by week 6 than calves suckling cows fed cubes containing only minerals. Based on the Cp activity of calves, supplemental mineral offered without ionophore in cubes had the least impact on calf mineral metabolism. It has been noted that, in general, colostral Cu level is not influenced by Cu status of dam (Sikka et al. 2002).

CONCLUSIONS

High variation in mineral consumption was observed when mineral was offered on a free-choice basis compared with delivery through forage cubes. Delivery of minerals using forage cubes ensured consistent Cu and Zn intake at the recommended levels, reducing variation in intake and unnecessary excretion of excess minerals as compared with free-choice. Fortified cubes may be used as an effective means of reducing the variability in mineral intake associated with free-choice consumption with no detrimental effect on mineral status of cows. Further work is required to determine whether addition of monensin in mineral supplements for late gestation or lactating cows presents any threats to mineral metabolism by suckling calves.

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