PEER REVIEWED

Effects of Feeding High Manganese Rice Straw on the Mineral Status of Beef Cattle

G.A. Nader, *MS*[1]; **S.P. Doyle,** *PhD*[2]; **J.M. Connor,** *MS*[3]; **J. Maas,** *DVM, MS, DACVN, DACVIM*[4]
[1] *Cooperative Extension, University of California, Yuba City, CA 95991*
[2] *College of Agriculture, California State University, Chico, CA 95929*
[3] *University of California, Sierra Foothill Research and Extension Center, Browns Valley, CA 95918*
[4] *Veterinary Medicine Extension, School of Veterinary Medicine, University of California, Davis, CA 95616*

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Abstract

The objective of this study was to determine the effects of feeding rice straw containing high concentrations of manganese (Mn) to beef cattle on liver Mn concentration and its potential to interfere with other minerals. Open, crossbred cows (N = 12) in good health were randomly assigned to one of three treatment group diets: oat hay (control), rice straw containing 550 ppm Mn and rice straw containing 770 ppm Mn. High quality alfalfa hay was supplemented at the same amount to each group to ensure adequate energy and protein intake. Blood, serum and liver samples were taken from each animal at day 0, 49 and 93 and analyzed for trace mineral and heavy metal content. Liver Mn concentrations for the group receiving 770 ppm Mn rice straw were significantly higher than for the control group at both day 49 and day 93 ($P < 0.05$). Liver Mn concentrations for the 550 ppm Mn group were significantly higher than for the control group at day 93 ($P < 0.05$). Liver Mn concentrations among the two rice straw treatments were not significantly different from each other. Serum sodium (Na) levels in cows fed the 770 ppm Mn rice straw were significantly higher than the animals fed 550 ppm rice straw at day 49 ($P < 0.05$); however, there appeared to be no significant difference at day 93. There was no significant difference among treatment groups for other trace mineral and heavy metal concentrations. While it appeared cattle fed rice straw maintained higher liver Mn concentrations relative to control cattle, these concentrations were within the reference range of 2-6.5 ppm. There were no significant differences among treatment groups for average daily gain. No practical impact on the mineral status of cattle fed high Mn rice straw was observed over the 93-day period.

Résumé

L'objectif de cette étude était de déterminer l'effet de distribuer de la paille de riz riche en manganèse aux bovins de boucherie sur la concentration en manganèse du foie et sur le potentiel d'interférence avec d'autres minéraux. Des vaches vides de race croisée en bonne santé (N = 12) ont été allouées aléatoirement à l'un des trois traitements suivants : foin d'avoine (témoin), paille de riz contenant 550 ppm de manganèse et paille de riz contenant 770 ppm de manganèse. La même quantité de foin de luzerne de haute qualité a été ajoutée à la ration de chacun des groupes pour s'assurer que l'apport en énergie et en protéines était adéquat. Des échantillons de sang, de sérum et de foie ont été prélevés de chaque animal aux jours 0, 49 et 93 et analysés pour déterminer le contenu en macroéléments et en métaux lourds. La concentration en manganèse du foie dans le groupe alimenté avec de la paille de riz contenant 770 ppm de manganèse était significativement plus élevée que dans le groupe témoin aux jours 49 et 93 ($P < 0.05$). La concentration en manganèse du foie dans le groupe alimenté avec de la paille de riz contenant 550 ppm de manganèse était significativement plus élevée que dans le groupe témoin au jour 93 ($P < 0.05$). La concentration en manganèse du foie n'était pas différente entre les deux groupes recevant de la paille de riz riche en manganèse. La concentration sérique du sodium chez les vaches alimentées avec de la paille de riz contenant 770 ppm de manganèse était significativement plus élevée que celle chez les vaches alimentées avec de la paille de riz contenant 550 ppm de manganèse au jour 49 ($P < 0.05$) bien qu'il n'y avait pas de différence au jour 93. Il n'y avait pas de différence entre les trois groupes au niveau de la concentration des autres macroéléments et métaux lourds. Bien que l'alimentation avec de la paille de riz riche en manganèse augmentait la concentration en manganèse du foie chez les bovins de boucherie par rapport au groupe témoin, les concentrations obtenues étaient quand même dans les normes acceptables de 2-6.5 ppm. Il n'y avait pas de différence entre les groupes au niveau du gain de poids quotidien. Aucune répercussion pratique sur le bilan minéral des bovins alimentés avec de la paille de riz

riche en manganèse n'a été observée pendant les 93 jours de l'expérience.

Introduction

Feeding rice straw to beef cattle on foothill ranges has become an option for producers during certain periods of the year. It can provide a relatively inexpensive source of forage for beef cattle, and can be nutritionally effective in certain circumstances. It has also been used in dairy dry-cow rations and dairy heifer replacement diets as 5 to 8% of the ration (dry matter [DM] basis) to add bulk or rumen stimulation with wet or fine diets. During routine forage analysis of rice straw, the content of manganese (Mn) is often very high relative to animal requirements. In a series of samples taken from 21 lots of rice straw, eight lots had Mn concentrations of 1,000 mg/kg (ppm) or higher on a DM basis.[4]

The National Academy of Sciences suggests that the maximum tolerable level of Mn in beef cattle diets is 1,000 ppm.[5] Limited research suggests that excess dietary Mn can decrease absorption of copper (Cu),[3] and can cause anemia characterized by decreased hemoglobin production and decreased tissue stores of iron (Fe).[1] This study was designed to evaluate the potential for rice straw with high concentrations of Mn fed to beef cattle to 1) result in accumulation of Mn in liver or blood, 2) interfere with Cu or Fe storage, and 3) cause any other changes in mineral status.

Materials and Methods

Cattle

Twelve adult beef cows housed at the University of California's Sierra Foothill Research and Extension Center (SFREC) were selected for this trial. The cows were not pregnant and were in good health. Cows were randomly assigned to one of three treatment groups. Blood, serum and liver samples were collected from each animal at the beginning of the trial (day 0), at day 49 and at day 93. Individual body weights were obtained for each animal on days 0, 38, 49 and 93.

Experimental Diet and Treatment Groups

Rice straw was used as the base diet in two groups, and oat hay was used as the base diet in the control group. The forage analyses, including Mn concentration, are listed (Table 1). High quality alfalfa hay was supplemented at the same amount to each group to ensure adequate energy and protein intake, and to simulate the limited amount of good-quality green feed available for range cattle during the typical Sierra Nevada foot-

Table 1. Forage nutrient values.

	Rice straw 770	Rice straw 550	Oat hay	Alfalfa
Dry matter, %	90.7	90.5	88.8	89.6
Ash, %	16.1	18.1	7.7	11.3
Organic matter, %	83.9	81.9	92.3	88.7
Crude fat, %	2	2.1	3	3.3
Crude protein, %	6.1	5.4	7.1	21.2
Acid detergent insoluble protein, %	10.9	10.2	4.8	4.2
Available protein, %	89.1	89.9	95.2	95.8
Acid detergent fiber, %	49.2	48.1	35	27.3
Neutral detergent fiber, %	66.7	66.4	57.9	34
30 hr *in vitro* NDF digestibility, %	34.1	40.3	36.9	47.2
Nonfibrous carbohydrate, %	9.2	8	24.3	30.1
Digestible dry matter, %	62.7	62.7	62.5	80.8
Calcium, %	0.28	0.27	0.52	1.50
Phosphorus, %	0.088	0.094	0.51	0.30
Potassium, %	1.7	1.7	2.5	2.5
Magnesium, %	0.22	0.20	0.32	0.30
Copper, ppm	3.8	3.4	6.8	8.8
Iron, ppm	180	180	390	250
Manganese, ppm	**770**	**550**	**54**	**31**
Zinc, ppm	24	20	36	11
Selenium, ppm	< 0.25	< 0.25	< 0.25	< 0.25
Sodium, ppm	2700	450	3200	850
Sulfur, ppm	1300	720	2900	2600
Molybdenum, ppm	< 0.25	< 0.25	0.94	3.2
Chloride, ppm	10000	6600	5300	2800

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hill winter grazing period. Cows fed the oat hay were designated as the control group (Group 1). One rice straw contained 550 ppm Mn, and animals fed this material were designated as "rice straw 550" (Group 2). The other rice straw contained 770 ppm Mn, and animals fed this feed were designated as the "rice straw 770" group (Group 3).

All forages were chopped using a tub grinder. The three groups of cows were housed in a dry lot with a covered feeding area and were fed twice daily. Four cows were randomly assigned to each treatment pen. The forages were weighed daily, and were mixed when placed in cement feed bunks. Feed consumption was checked twice each day and as the cows adjusted to the forages, the mixture was changed to adjust for the increased *ad libitum* intake. The ration was adjusted to increase rice straw intake or oat hay intake, and to decrease the amount of alfalfa fed over time during the trial. The relatively high weight gains in the first 38-day period occurred because it took some time to increase the rice straw and oat hay intake relative to the alfalfa hay. The amount of alfalfa hay fed daily was equal to the rice straw or oat hay by day 60.

Forage Analysis

Forage samples were ground to pass a 1 mm sieve and analyzed for nutritional components. The DM content was determined by drying at 275°F (135°C) for four hours, followed by equilibration in a desiccator.[2] The organic matter (OM) content was calculated as weight lost upon ignition at 1112°F (600°C), and the neutral detergent fiber (NDF) and acid detergent fiber (ADF) content were determined using reagents and methods as described by Van Soest *et al.*[10] The crude protein (CP) was measured by the Kjeldahl method,[2] protein solubility was measured by incubating samples in borate phosphate buffer at ambient temperature, and CP insoluble in AD (ADICP) was measured by Kjeldahl analysis of ADF.[2] Crude fat was determined using ether extraction in the Tector Soxtec (HT6) system.[2] *In vitro* rumen degradable NDF (dNDF) was determined by incubation of samples in buffered rumen fluid for 30 hours under anaerobic conditions at 102.2°F (39°C). After incubation, samples were refluxed with neutral detergent solution to remove bacterial contamination, and the undigested residue was used to calculate digestibility of NDF. Calcium, phosphorus, magnesium, potassium, sodium, iron, zinc, copper, manganese, molybdenum and cobalt levels were determined using a Thermo Jarrel Ash IRIS Advantage Inductively Coupled with Plasma Radial Spectrophotometer. Samples were ashed in a muffle furnace at 932°F (500°C) for four hours, and 3 ml of 6N HCL was added to the ash residue and evaporated to dryness on a hot plate at 212° to 248°F (100 to 120°C). Minerals were extracted with an acid solution ($1.5N\ HNO_3 + 0.5N\ HCL$) and determined using an IRIS Advantage Spectrophotometer.

Animal Liver, Serum and Plasma Analysis

On days 0, 49 and 93, blood, serum and liver specimens were taken from each cow. Blood samples collected in trace mineral-free ethylenediamine tetraacetate (EDTA)-containing tubes,[a] and serum samples collected in trace mineral-free tubes without additives[b] were obtained by venapuncture. Blood in the EDTA tube was used for selenium (Se) analysis. Blood in the tube without additive was allowed to clot for 60 minutes at room temperature, and serum was collected by centrifugation and used for trace mineral and heavy metal analyses. Liver samples were collected via percutaneous biopsy.[6,c] Cattle were administered 6 million units procaine penicillin G[d] subcutaneously to prevent bacillary hemoglobinuria at the time of the liver biopsy procedure.

The animal samples were analyzed for minerals, trace minerals, heavy metals and selenium concentration by inductively coupled argon plasma emission spectroscopy[9] at the University of California's Animal Health and Food Safety (CAHFS) Laboratory.[c]

Statistical Analysis

Data were analyzed using analysis of variance (ANOVA) for a completely randomized design, fitting initial blood, serum or liver mineral concentrations as a covariate.[f] Multiple comparisons were made using Scheffe's pairwise comparison of means.[7,8,f]

Results

Animal Performance

There were differences ($P < 0.05$) in weight gains between Group 2 and both Groups 1 and 3 at day 49, but by day 93 no differences in weight gain were seen (Table 2). Over the duration of the trial, cattle fed oat hay gained 45 lb (20.5 kg) and 42 lb (19.1 kg) more than did those fed 770 rice straw and 550 rice straw, respectively, but this was not statistically significant.

Mineral Concentrations in Liver and Blood Samples

Mineral values for all animals remained within the reference range for each mineral with the exception of the liver Mn concentration in the control group (Group 1) on days 49 and 93, which dropped below the reference range (Table 3). Liver Mn concentrations for the group receiving 770 ppm Mn rice straw were significantly higher than the control group at both day 49 and day 93 ($P < 0.05$). Liver Mn concentrations for the 550 ppm group were significantly higher than the control group at day 93 ($P < 0.05$). Liver Mn concentrations

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Table 2. Body weight and average daily gain for cows fed oat hay (Control, Group 1), rice straw containing 550 ppm Mn (Group 2) and rice straw containing 770 ppm Mn (Group 3).

	Day 0	Day 38	Day 49	Day 93
Average body weight (lb)				
Oat hay (Group 1)	1145	1248	1302	1300
Rice straw 550 ppm Mn (Group 2)	1080	1149	1180	1193
Rice straw 770 ppm Mn (Group 3)	1086	1156	1210	1196
Average daily gain (lb)				
Oat hay (Group 1)	—	2.71	4.91	-0.045
Rice straw 550 ppm Mn (Group 2)	—	1.82	2.82	+0.296
Rice straw 770 ppm Mn (Group 3)	—	1.84	4.91	-0.318

among the rice straw treatments were not significantly different. Serum Na levels in the animals fed the 770 ppm Mn rice straw were significantly higher ($P < 0.05$) than the animals fed 550 ppm rice straw at day 49; however, there appeared to be no significant difference at day 93. The serum Na levels were within the reference range for all animals on all dates. There was no significant difference among treatment groups for all other trace mineral and heavy metal concentrations. While it appeared cattle fed rice straw maintained higher liver Mn concentrations relative to control cattle, these concentrations were within the reference range of 2-6.5 ppm. The liver concentrations of heavy metals (arsenic, cadmium, mercury, lead and molybdenum) were not different between groups, and were all below the reference range of potential toxicity.

Discussion

Cattle fed rice straw (Groups 2 and 3) had a higher liver Mn concentration on day 93 compared to the cattle fed oat hay (Group 1). The Mn content in the rice straw was obviously much higher than the Mn concentration in the oat hay and alfalfa hay (Table 1). Additionally, the overall Mn content of the Group 1 cattle diet was much closer to the minimum Mn requirements of beef cattle.[1,5] Thus, the Group 1 cattle may have been receiving a diet marginally deficient in Mn. This may account for the difference in liver Mn concentration between Group 1 cattle at day 93 compared to the other groups. Nonetheless, the very high Mn amounts consumed by the Groups 2 and 3 cows did not result in abnormal Mn accumulation in the liver of the cattle fed rice straw.

The serum Na concentration of Group 3 animals was higher than Group 2 animals on day 49; however, Na values for all groups were within the reference range at all sampling dates. These slightly higher serum Na concentrations may be due to the higher concentration of chloride (Cl) in the 770 ppm Mn straw. Serum Na values could possibly be higher if serum Cl concentrations (not measured in this trial) were elevated, as Na and Cl are major ions in maintaining electrical neutrality in the extracellular fluid.

Neither rice straw or oat hay are high in energy or protein, and thus weight gains cannot be expected to be high in a feeding trial such as this. The value of both types of forages is to help maintain body weight in open or early-bred beef cows at a low cost. Results of this study support that assumption.

This trial suggests that the high Mn content of rice straw may not represent a risk of Mn accumulation or Mn toxicity in beef cows supplemented for 93 days. It is possible that the Mn in rice straw has relatively low bioavailability compared to inorganic Mn or Mn in other feedstuffs. While rice straw is not considered high-quality forage, it can apparently be fed safely to cattle with regard to Mn accumulation and mineral balance for 93 days. The only tendency observed was for cattle fed the rice straw to maintain liver Mn concentrations within the reference range versus the control group cattle where the liver Mn concentrations fell below this range.

Conclusions

This trial suggests that the NRC maximum tolerable concentrations of Mn may not be applicable to the forms found in rice straw. Additionally, there was no practical impact on the mineral status of cows fed high Mn rice straw versus the control group (oat hay) cattle.

Endnotes

[a] B-D 6527, Becton-Dickinson, Rutherford, NJ.
[b] B-D 6525, Becton-Dickinson, Rutherford, NJ.
[c] Schackelford-Courtney bovine biopsy instrument, Sontec Instruments, Englewood, CO 80112.
[d] Agri-Cillin®, procaine penicillin G 300,000 units per ml, Agri Laboratories, Ltd, St. Joseph, MO 64503.

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Table 3. Mean (± standard deviation) mineral concentrations in serum, blood and liver of cows fed oat hay (Control), rice straw containing 550 ppm, or rice straw containing 770 ppm.*

Analysis	Treatment	Day 0	Day 49	Day 93	Reference range
Serum Ca, mg/dl	Control	9.0 ± 0.3	8.3 ± 0.3	7.8 ± 0.3	7.5-11.0
	550	9.0 ± 0.3	8.6 ± 0.2	8.3 ± 0.2	
	770	8.5 ± 0.7	8.5 ± 0.6	8.0 ± 0.5	
Serum Cu, ppm	Control	1.1 ± 0.1	0.8 ± 0.1	0.9 ± 0.1	0.8-1.5
	550	1.0 ± 0.1	0.7 ± 0.0	0.9 ± 0.1	
	770	1.0 ± 0.1	0.7 ± 0.1	0.8 ± 0.1	
Serum Fe, ppm	Control	1.8 ± 0.3	1.6 ± 0.3	1.4 ± 0.4	1.3-2.5
	550	1.4 ± 0.2	1.6 ± 0.2	1.4 ± 0.2	
	770	1.4 ± 0.2	1.6 ± 0.2	1.5 ± 0.1	
Serum Mg, mg/dl	Control	2.4 ± 0.1	2.0 ± 0.2	2.1 ± 0.1	1.8-3-5
	550	2.5 ± 0.1	2.1 ± 0.2	2.1 ± 0.0	
	770	2.4 ± 0.3	2.2 ± 0.2	2.0 ± 0.2	
Serum P, mg/dl	Control	5.2 ± 0.2	6.2 ± 1.1	5.9 ± 0.9	4.5-7.5
	550	4.9 ± 0.4	5.9 ± 0.8	6.9 ± 0.9	
	770	4.8 ± 1.2	6.3 ± 1.4	7.1 ± 1.0	
Serum K, mEq/L	Control	4.4 ± 0.5	4.4 ± 0.2	3.9 ± 0.2	3.7-5.5
	550	4.4 ± 0.2	4.5 ± 0.2	4.3 ± 0.2	
	770	4.2 ± 0.4	4.6 ± 0.1	3.9 ± 0.4	
Serum Na, mEq/L	Control	156 ± 2	146 ± 2	143 ± 2	135-155
	550	156 ± 2	144 ± 1	145 ± 1	
	770	150 ± 4	148 ± 1	144 ± 2	
Serum Zn, ppm	Control	0.9 ± 0.1	0.9 ± 0.0	0.9 ± 0.3	0.8-1.4
	550	0.9 ± 0.1	1.0 ± 0.1	0.9 ± 0.1	
	770	0.8 ± 0.1	0.8 ± 0.0	0.8 ± 0.1	
Blood Se, ppb	Control	197 ± 17	184 ± 15	173 ± 12	80-350
	550	191 ± 23	187 ± 28	174 ± 26	
	770	169 ± 47	163 ± 47	156 ± 41	
Liver Se, ppm	Control	0.32 ± 0.01	NA	0.28 ± 0.06	0.15-1.5
	550	0.32 ± 0.02	NA	0.30 ± 0.08	
	770	0.28 ± 0.04	NA	0.29 ± 0.06	
Liver Cu, ppm	Control	46 ± 23	49 ± 22	39 ± 9	25-100
	550	44 ± 5	43 ± 10	52 ± 8	
	770	60 ± 39	63 ± 33	77 ± 33	
Liver Fe, ppm	Control	96 ± 5	103 ± 22	88 ± 7	45-300
	550	96 ± 8	102 ± 6	88 ± 24	
	770	96 ± 17	100 ± 39	72 ± 9	
Liver Mn, ppm	Control	3.1 ± 0.2	2.3 ± 0.1	2.0 ± 0.4	2.5-6.0
	550	3.4 ± 0.5	2.8 ± 0.4	2.9 ± 0.3	
	770	3.0 ± 0.5	3.0 ± 0.3	2.8 ± 0.3	
Liver Zn, ppm	Control	30 ± 3	31 ± 3	33 ± 6	25-100
	550	30 ± 1	28 ± 1	32 ± 4	
	770	29 ± 2	30 ± 1	33 ± 5	

* Liver mineral concentrations are reported on a wet-weight basis.

[e] CAHFS-Davis Laboratory, West Health Sciences Drive, Davis, CA 95616

[f] Statistix 8®, Analytical Software, Tallahassee, FL 32317

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