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Authors

Davy, Josh S
Forero, Larry C
Shapero, Matthew WK
[et al.](#)

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Mineral status of California beef cattle¹

Josh S. Davy,^{*,2} Larry C. Forero,[†] Matthew W. K. Shapero,[‡] Devii R. Rao,[§] Theresa A. Becchetti,[#] Carissa Koopman Rivers,[¶] Jeffery W. Stackhouse,[¶] Kasey L. DeAtley,^{**} and Bret R. McNabb^{††}

*University of California Livestock Advisor Tehama, Glenn, Colusa Counties, Red Bluff, CA 96080; †University of California Livestock Advisor Shasta, Trinity Counties, Redding, CA 96002; ‡University of California Livestock Advisor Ventura and Santa Barbara Counties, Ventura, CA 93003; §University of California Livestock Advisor San Benito, Monterey, Santa Cruz Counties, Hollister, CA 95023; #University of California Livestock Advisor Stanislaus, San Joaquin Counties, Modesto, CA 95358; ¶University of California Livestock Advisor, Siskiyou County, Yreka, CA 96097; ¶University of California Livestock Advisor Humboldt, Del Norte Counties, Eureka, CA 95503; **Professor of Animal Science, California State University, Chico, Chico, CA 95926; and ††Professor of Clinical Livestock Reproduction, UC Davis School of Veterinary Medicine, Davis, CA 95616

ABSTRACT: Optimal mineral nutrition is required for cattle reproduction, immune function, and structural development. Formal evaluation of the current mineral status of California beef cattle is currently lacking. In 2017, a survey was initiated that evaluated a panel of 10 different minerals in 14 counties across California. Samples were collected from 555 cattle at 50 different ranches. Region of the state significantly affected herd mineral status. Herd use of supplements was also significant, and increased most blood levels of the mineral(s) targeted for supplementation. Forage source was idiosyncratic on its effect of mineral status. Previous blood survey data showed selenium to be widely deficient in California

cattle in the 1970s and 1980s, but in this case, it was generally adequate in all areas of California. This indicates a good producer understanding of where supplementation is needed. Copper deficiency was more widespread in the southern region when compared with further north. Zinc deficiency was seen ubiquitously statewide, with 36% of animals being deficient. Manganese has been largely ignored in California. This study is the first known documentation of manganese levels in the state. Sampling found 92% of cattle fell below critical manganese levels. However, further research to better define manganese critical levels is probably warranted. The status of other minerals is presented.

Key words: beef, cattle, manganese, mineral, selenium, supplementation

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²Corresponding author: jsdavy@ucanr.edu

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INTRODUCTION

Proper mineral nutrition is important for many aspects of beef cattle production, including reproduction (Hurley and Doane, 1989; Graham, 1991; Van De Weyer et al., 2011), immune response (Makimura et al., 1993; Nicholson et al., 1993; Spears, 2000; Salles et al., 2014), and

structural integrity (Hidiroglou, 1979a; Hansen et al., 2006; Wilde, 2006). These are some of the most important traits in beef cattle management (Taylor and Field, 1999) throughout all stages of life and various aspects of the cattle industry. Adequate mineral levels are not only important to maintain the health of the lactating cow (Grunes et al., 1970; Horst et al., 1997), but also the calf as minerals are transferred through the placenta to the fetus (Gooneratne et al., 1989; Abdelrahman and Kincaid, 1993) and through colostrum and milk to the newborn calf (Rao, 1963). Adequate cow mineral levels are necessary for this transfer to occur. If the transfer does not occur, the newborn calf can become immune compromised, deformed, and exhibit reduced vigor when compared with other calves with an appropriate mineral status (Rao, 1963). Herd mineral status has the potential to affect the entire sector of cow-calf production.

Selenium has been one of the most widely researched minerals in California. Early selenium studies in California documented deficiencies in as many as 60% of cattle sampled (Williams, 1980; Dunbar et al., 1988). The following decade, with efforts to supplement selenium in place, Dargatz and Ross (1996) evaluated a small population of cattle in California as a subset of a large national sampling endeavor that assessed the selenium status of breeding age beef cows. Their results found that less than 10% of Western state cattle fell below adequate selenium levels. Recently, Davy et al. (2016) found that, when implemented, multiple methods can be successful in correcting selenium deficiency.

Although Dargatz and Ross (1996) sampled only a small subset of California cattle, it may be that beef cattle manager's supplement strategies had successfully corrected the high level of deficiency found in earlier work. This study includes a greater number of California cattle to help further determine the current extent of selenium deficiency.

Though some data exist on selenium, almost no information exists on the status of other minerals in California beef cattle. For example, although manganese deficiency has been linked to subsequent calf deformities and hindered reproductive performance (Hidiroglou, 1979b; Hidiroglou et al., 1990), the mean serum manganese levels in California cattle are unknown. There are no known formal or informal evaluations of the status of manganese. Other common minerals such as zinc and even copper have not been investigated beyond local veterinary screening to diagnose poor animal performance, and this information is not formally documented.

Given the potential consequences of inadequate mineral availability, it is important to understand what deficiencies are occurring in California cattle. This is the first formal survey to address herd mineral status, evaluating multiple minerals, and spanning the breadth of California. Sampling occurred throughout California, from Siskiyou County to Los Angeles County. In a study design encompassing the diversity of California grazing beef cattle production, the results are reported for the current status of selenium, manganese, calcium, copper, iron, magnesium, phosphorus, potassium, sodium, and zinc.

Table 1. Beef cows and herds sampled in each of the 14 California counties and associated regions

| County | Head/county | Region | Herds/region | Head/region |
|---------------|-------------|-----------------------------------------------|--------------|------------------|
| San Joaquin | 40 | Central | 12 | 120 |
| San Benito | 50 | Central | | |
| Alameda | 30 | Central | | |
| Siskiyou | 40 | Intermountain | 7 | 70 |
| Shasta | 50/30 | Northern foothills/Intermountain ^a | 23 | 230 |
| Humboldt | 30 | Northern foothills | | |
| Yuba | 10 | Northern foothills | | |
| Tehama | 90 | Northern foothills | | |
| Colusa | 20 | Northern foothills | | |
| Glenn | 30 | Northern foothills | | |
| Inyo | 10 | Southern | 13 | 135 ^b |
| Los Angeles | 10 | Southern | | |
| Ventura | 40 | Southern | | |
| Santa Barbara | 75 | Southern | | |
| Total | | | 50 | 555 |

^aThe higher elevations of Eastern Shasta County were counted as intermountain.

^bIn Southern California, 73 head were not sampled for manganese due to funding depletion.

MATERIALS AND METHODS

Herd Selection

Sampling herds were selected with the intent of getting a representation from west to east in each of the four regions that included the high elevation intermountain area of Northern California, the low elevation foothills of Northern California, Central California, and Southern California (Table 1). A total of 555 head were sampled from 50 different herds.

For herds to qualify, it was required that they had been on the same forage source and mineral program for at least 4 mo. This often meant that sampling was done toward the end of the season if cattle were moved to different areas for summer and winter pasture. Cooperators provided at least 10 head of breeding age cows or heifers. No calves, steers, or bulls were included in the trial. Cooperators selected the animals to be sampled but were instructed to choose groups that were representative of the ranch as a whole.

Sampling

Three samples were collected from each of the 10 animals in all herd locations (one herd had 15). The first was an EDTA whole-blood selenium sample, and the second and third were collected using trace element sodium heparin tubes (BD Vacutainer ref. 368381) to avoid introducing zinc into the sample. All blood samples were collected from the tail vein. The two trace element samples from each animal were centrifuged on site and the serum placed into cryogenic vials. One serum sample would be analyzed for manganese and the other for a standard mineral panel including calcium, copper, iron, magnesium, phosphorus, potassium, sodium, and zinc. Samples were put on ice and shipped overnight the same day of collection to the California Animal Health and Food Safety Lab at UC Davis for testing.

While on site, each cooperator was surveyed to determine the current mineral program, and labels were collected from loose salt supplements. Because it was impossible to quantify consumption, a metric of yes or no was determined based on whether a mineral or salt supplement had been provided

to the sampled cattle. Grazing on either irrigated pasture or rain-fed rangeland for the previous 4 mo was documented to determine whether forage source affected cow mineral levels.

Statistical Analysis

Using Statgraphics (StatPoint Technologies, Inc., 2009), individual models were run for each mineral level with categorical variables of region (Table 1), mineral supplementation (Table 2), and forage source (irrigated pasture or dryland range; Table 2). Mineral supplementation (yes or no) was broken into four different constituents of selenium supplementation (only ran with selenium level), copper supplementation (only run with the copper level), salt supplementation (only run with the sodium level), and broad supplementation (run with all other mineral levels). Selenium supplementation was defined as either a selenium oral bolus given within 1 yr (duration of benefit; Maas et al., 1994), a selenium injection given within the previous 45 d (duration of benefit; Davy et al., 2016), or a loose salt or liquid supplement containing the equivalent of at least 2 mg/hd/d estimated consumption. Copper supplementation included supplementation programs that had a copper bolus given within a year or a loose salt mix containing at least a 3,000 mg/kg equivalent with a mix designed at a 28 g/d consumption. Salt supplementation included any supplement that provided free-choice salt year round. Broad supplementation was loose salt mixtures that contained a broad spectrum of minerals that were also provided year round. Because criteria was usually met, broad supplement mixes often also qualified as selenium and copper supplements. Where categorical variables were found significant ($P < 0.05$), Fisher least significant difference test was run to separate means at the 5% level. Pearson product moment correlations were run for all mineral levels to examine whether antagonisms could be found within blood values of minerals.

RESULTS

Region was significant for selenium ($P < 0.01$), copper ($P < 0.01$), zinc ($P = 0.04$), magnesium ($P = 0.01$), calcium ($P < 0.01$), phosphorus

Table 2. Number of cattle in each supplement group and by forage source

| | Selenium supplement | Copper supplement | Broad supplement | Salt supplement | Forage source | |
|-----|---------------------|-------------------|------------------|-----------------|-------------------|-------|
| | Count | Count | Count | Count | | Count |
| Yes | 320 | 330 | 260 | 350 | Range | 425 |
| No | 235 | 220 | 295 | 205 | Irrigated pasture | 130 |

Table 3. Least square means of cow mineral levels by California region

| Region | Selenium, mg/mL | Copper, mg/mL | Zinc, mg/mL | Magnesium, mg/mL | Manganese, ng/mL |
|--------------------|--------------------|---------------|-------------|------------------|------------------|
| | LSM | LSM | LSM | LSM | LSM |
| Intermountain | 0.15b ¹ | 0.99c | 0.81a | 22.5c | 3.26a |
| Northern foothills | 0.18c | 0.98c | 0.87b | 21.7ab | 3.25a |
| Central | 0.11a | 0.92b | 0.90b | 21.1a | 3.64a |
| Southern | 0.26d | 0.78a | 0.88ab | 21.8bc | 2.56a |
| Statewide | 0.18 | 0.92 | 0.87 | 21.7 | 3.35 |

| Region | Calcium, mg/mL | Phosphorus, mg/mL | Potassium, mg/mL | Iron, mg/mL | Sodium, mg/mL |
|--------------------|----------------|-------------------|------------------|-------------|---------------|
| | LSM | LSM | LSM | LSM | LSM |
| Intermountain | 101b | 55a | 4.9a | 1.50b | 147d |
| Northern foothills | 96a | 62b | 5.4a | 1.40b | 142a |
| Central | 100b | 67c | 4.2a | 1.30a | 145c |
| Southern | 100b | 65bc | 4.2a | 1.28a | 143b |
| Statewide | 99 | 62 | 4.7 | 1.36 | 144 |

¹Within a column, means with a similar letter are not significantly different at 95%.

Table 4. Percentage of whole-blood and serum samples below adequate levels

| Mineral | Adequate level ¹ | Intermountain | Northern foothills | Central | Southern | Statewide |
|------------|-----------------------------|------------------------|--------------------|---------|----------|-----------|
| | | % below critical level | | | | |
| Selenium | 0.08 mg/mL | 3 | 4 | 28 | 2 | 12 |
| Copper | 0.8 mg/mL | 1 | 13 | 31 | 55 | 28 |
| Zinc | 0.8 mg/mL | 47 | 35 | 23 | 40 | 36 |
| Magnesium | 18 mg/mL | 9 | 3 | 11 | 7 | 7 |
| Manganese | 6 ng/mL | 96 | 90 | 92 | 97 | 92 |
| Calcium | 80 mg/mL | 0 | 1 | 0 | 3 | 2 |
| Phosphorus | 45 mg/mL | 23 | 11 | 3 | 4 | 9 |
| Iron | 1.3 mg/mL | 34 | 33 | 62 | 65 | 52 |
| Potassium | 3.9 mg/mL | 9 | 18 | 9 | 18 | 16 |
| Sodium | 135 mg/mL | 0 | 8 | 15 | 9 | 10 |

¹Adapted from Puls (1988); Wikse et al. (1992); Dargatz and Ross (1996); Kincaid (2000); and based on the recommendations of the California Animal Health and Food Safety Lab, UC Davis.

($P < 0.01$), iron ($P < 0.01$), and sodium ($P < 0.01$), but not for manganese ($P = 0.86$) or potassium ($P = 0.45$). Means and standard errors of mineral levels in each region can be viewed in Table 3. Critical mineral levels are noted in Table 4.

Southern California cattle appeared notably higher in selenium than the rest of the state. Conversely, the same geographic location's copper levels were lower on average than the rest of California. Calcium was highest in the higher elevation intermountain area of Northern California. Conversely, phosphorus was the lowest in this same area. Like phosphorus, zinc was also the lowest in the intermountain area, but low levels of zinc were common statewide. Iron levels were the lowest in Central and Southern California when compared with other regions. Although region was significant for sodium and magnesium levels, the differences were small.

When comparing forage source, irrigated pasture showed higher levels of sodium (least squares meaning [LSM] 145 vs. 143; $P < 0.01$) over dryland range, respectively. Conversely, dryland range shown slightly higher levels of selenium (LSM 0.19 vs. 0.17; $P < 0.02$), magnesium (LSM 22 vs. 21; $P < 0.01$), and potassium (LSM 5.9 vs. 3.4; $P < 0.01$) over irrigated pasture, respectively. Forage source did not affect copper ($P = 0.28$), zinc ($P = 0.35$), manganese ($P = 0.10$), calcium ($P = 0.30$), phosphorus (0.61), or iron ($P = 0.77$) levels.

The addition of a copper supplement significantly increased copper levels (LSM 0.96 vs. 0.88; $P < 0.01$). Whether a selenium supplement was fed was not significant for whole-blood selenium levels ($P = 0.05$). When a broad (loose salt) mineral was fed year round, significant increases in manganese (LSM 4.7 vs. 2.0; $P = 0.03$), potassium (LSM 5.6 vs. 3.8; $P = 0.02$), and zinc (LSM 0.89 vs. 0.84; $P = 0.04$)

were seen compared with nonsupplemented cattle, respectively. This was not true for calcium ($P = 0.23$), phosphorous ($P = 0.34$), iron ($P = 0.86$), or magnesium ($P = 0.85$). The addition of a salt supplement did not significantly affect sodium levels ($P = 0.18$). Sodium deficiency was not common.

Correlations between mineral levels can be seen in [Table 5](#). Although some were significant, all mineral levels showed relatively weak correlations between each other. It is unlikely that minerals with antagonistic relationships can be identified using blood sampling.

DISCUSSION

This study evaluated herd mineral levels across California. There is potential bias in that managers with an interest to participate may have higher than average concern with their herd mineral program. These could be the managers who had subsequently put more thought and effort into supplementation. However, there were a number of herds without a mineral program included as well. The data reflect

a large sample size across the state that provides the most up to date look at serum and whole-blood mineral levels available. In addition, deficiencies in most minerals existed ([Table 4](#)).

Likely the least California surveyed mineral in the panel was manganese. Very little was previously known about the extent of deficiency in California beef cattle. This was one of the few minerals that did not vary based on region. Serum manganese was uniquely constant across the state.

[Kincaid \(2000\)](#) states marginal levels are between 5 and 6 ng/mL, and adequate levels should exceed 6 ng/mL. If this is a correct target, adequate levels were roughly attained by only 8% ([Table 4](#)) of California cattle.

One trial found skeletal deformities in calves were only noted when serum levels dropped below 2.5 ng/mL ([Hidioglou et al., 1990](#)). Although they did not quantify the effects of manganese on reproduction, which is important ([Hidioglou, 1979b](#)), it may hint that critical serum levels may not need to exceed 6 ng/mL. [Table 6](#) depicts the percentage of cattle by region and state that would be deficient

Table 5. Correlations of mineral levels

| | Calcium | Copper | Iron | Magnesium | Manganese | Phosphorus | Potassium | Selenium | Sodium | Zinc |
|----------------|---------|--------|-------|-----------|-----------|------------|-----------|----------|--------|-------|
| Calcium | | 0.23 | 0.12 | -0.01 | 0.09 | 0.02 | -0.02 | -0.24 | 0.36 | 0.11 |
| <i>P</i> value | | <0.01 | 0.01 | 0.90 | 0.05 | 0.62 | 0.68 | <0.01 | <0.01 | 0.01 |
| Copper | 0.23 | | 0.02 | -0.08 | 0.13 | -0.19 | -0.07 | -0.12 | 0.18 | 0.03 |
| <i>P</i> value | <0.01 | | 0.74 | 0.10 | <0.01 | <0.01 | 0.14 | 0.01 | <0.01 | 0.48 |
| Iron | 0.12 | 0.02 | | 0.22 | 0.05 | 0.01 | -0.14 | 0.07 | 0.08 | 0.26 |
| <i>P</i> value | 0.01 | 0.74 | | <0.01 | 0.27 | 0.86 | 0.00 | 0.11 | 0.08 | <0.01 |
| Magnesium | -0.01 | -0.08 | 0.22 | | 0.02 | -0.13 | 0.03 | 0.20 | 0.05 | 0.16 |
| <i>P</i> value | 0.90 | 0.10 | <0.01 | | 0.71 | 0.01 | 0.55 | <0.01 | 0.24 | <0.01 |
| Manganese | 0.09 | 0.13 | 0.05 | 0.02 | | 0.10 | -0.02 | 0.09 | -0.03 | 0.48 |
| <i>P</i> value | 0.05 | 0.00 | 0.27 | 0.71 | | 0.03 | 0.61 | 0.05 | 0.56 | <0.01 |
| Phosphorus | 0.02 | -0.19 | 0.01 | -0.13 | 0.10 | | -0.08 | -0.04 | 0.09 | 0.22 |
| <i>P</i> value | 0.62 | <0.01 | 0.86 | 0.01 | 0.03 | | 0.07 | 0.43 | 0.05 | <0.01 |
| Potassium | -0.02 | -0.07 | -0.14 | 0.03 | -0.02 | -0.08 | | 0.24 | -0.26 | 0.01 |
| <i>P</i> value | 0.68 | 0.14 | <0.01 | 0.55 | 0.61 | 0.07 | | <0.01 | <0.01 | 0.77 |
| Selenium | -0.24 | -0.12 | 0.07 | 0.20 | 0.09 | -0.04 | 0.24 | | -0.19 | 0.12 |
| <i>P</i> value | <0.01 | 0.01 | 0.11 | <0.01 | 0.05 | 0.43 | <0.01 | | <0.01 | 0.01 |
| Sodium | 0.36 | 0.18 | 0.08 | 0.05 | -0.03 | 0.09 | -0.26 | -0.19 | | 0.08 |
| <i>P</i> value | <0.01 | <0.01 | 0.08 | 0.24 | 0.56 | 0.05 | <0.01 | <0.01 | | 0.09 |
| Zinc | 0.11 | 0.03 | 0.26 | 0.16 | 0.48 | 0.22 | 0.01 | 0.12 | 0.08 | |
| <i>P</i> value | 0.01 | 0.48 | <0.01 | <0.01 | <0.01 | <0.01 | 0.77 | 0.01 | 0.09 | |

Table 6. Percentage of manganese serum levels below potentially differing critical levels

| Critical level (ng/mL) | Intermountain | Northern foothills | Central | Southern | Statewide |
|------------------------|----------------------------------|--------------------|---------|----------|-----------|
| | % below potential critical level | | | | |
| 6 | 96 | 90 | 92 | 97 | 92 |
| 5 | 94 | 85 | 86 | 97 | 88 |
| 3.5 | 81 | 69 | 76 | 95 | 77 |
| 2.5 | 40 | 42 | 58 | 74 | 52 |

by intervals starting from 6 ng/mL and lowering to 2.5 ng/mL. Although the percentage of deficient cattle drops by 40% if critical levels were only required to be 2.5 ng/mL, still 52% of cattle would be considered deficient. Cattle in the trial were not tracked to determine subsequent breeding interval or potential calf deformities. It was beyond the scope of this survey to quantify all the other production aspects that would affect these metrics.

Fortunately, manganese appears to be a mineral that can be influenced by supplementation. The uniform geographic nature of the serum levels may have improved the statistical significance of supplementation. Nevertheless, least square mean values show nearly two and a half times higher manganese levels in supplemented cattle. This is encouraging because it demonstrates that although this mineral is potentially widely deficient around the state, supplementation can help alleviate deficiency. More research into the potential production changes, such as conception intervals and rates, would be valuable in assessing the economic relevance and potential need for manganese supplementation in California.

Copper levels were probably elevated over what might be seen with liver samples. It has been shown that liver levels must be depleted before blood results will reflect a lowering of copper (Engel et al., 1964; Claypool et al., 1975; Tessman et al., 2001). Adequate serum copper levels may not accurately reflect the true copper status of the cow. To minimize false adequate readings, sampled cattle (within herd) were on the same mineral program and forage source for a minimum of 4 mo. Some additional bias in high copper serum levels may exist because serum levels rise during late pregnancy (Yokus and Cakir, 2006). Because nearly all herds were sampled prior to the third trimester this potential bias is likely very small. At the least 28% of cattle statewide falling below the adequate level is probably a best-case scenario (Table 4), with the highest concern being the central and southern portion of the state. These areas should carefully consider supplementation strategies that can increase copper levels.

Low zinc levels can lead to poor performance and health of both cows and calves (Enjalbert et al., 2006). All geographic regions had relatively high numbers of cattle that fell below an adequate level (23% to 47%; Table 4). Nearly half of the cattle sampled in the intermountain area were deficient. As with manganese and copper, supplementation appears to significantly elevate serum levels. Further research into zinc supplementation strategies would be useful in California.

Although iron appeared lower than guidelines in many samples, it is uncertain if there are any associated health problems that result. Baring extreme deficiency, lower levels may be beneficial as excessive levels in the diet can antagonize copper and lead to increased incidences of infection (Spears, 1995). Spears (1995) also stated that high parasite loads may cause low iron levels, though this was not investigated in the present study. Calcium, phosphorus, magnesium, and iron levels were not influenced by supplementation. This was surprising because magnesium supplementation was common to alleviate grass tetany concerns. The deficiencies in calcium and phosphorus were not severe, and although regional differences existed, it appeared forage diets were generally adequate for both these macro minerals in most cases. Multiple geographic areas could lessen mineral supplementation cost by not including phosphorus (Corah, 1995). Unlike dairy cattle that commonly experience milk fever due to calcium deficiency (Goff, 2008), deficiency was rare in the California beef cattle sampled regardless of geographic area. Although less than 20% potassium deficiency existed, if low potassium levels are detected, it appears possible to see a response to supplementation.

Of all the minerals tested, selenium differences were the most dramatic by geographic region. Southern California selenium levels were nearly double that of the average of all other regions, even though almost no cattle were supplemented (Table 3). Thus, supplementation in the southern region does not seem warranted. Other areas appear more difficult to define and even statistically bring out the effects of supplementation. It appears that deficiency can be localized even within our defined geographic areas. Cooperators seemed to understand where deficient areas existed and were taking steps to supplement where needed. This was particularly apparent where in many cases a selenium bolus was the only supplementation program implemented. The amount of deficiency in this survey was very similar to Dargatz and Ross (1996) and much lower than previous work. Though it still exists, education efforts appear successful in managing the majority of selenium deficiency in California.

This survey provides a broad overview of California beef cattle mineral levels. There is a need for further research to help define critical levels for interpretation. Clearly defined critical levels are difficult to obtain, and even those presented here could be debated. Most mineral supplementation research in California has been devoted to selenium, but given the relatively low deficiency rates

compared with zinc and manganese, shifting efforts to investigating these minerals would be prudent. Even though there is necessary work to be done on further developing critical levels, this survey reports the most up to date look at the current mineral blood levels throughout California.

LITERATURE CITED

- Abdelrahman, M.M., and R.L. Kincaid. 1993. Deposition of copper, manganese, zinc, and selenium in Bovine fetal tissue at different stages of gestation. *J. Dairy Sci.* 76:3588–3593. doi:10.3168/jds.S0022-0302(93)77698-5
- Claypool, D.W., F.W. Adams, H.W. Pendell, N.A. Hartmann, Jr, and J.F. Bone. 1975. Relationship between the level of copper in the blood plasma and liver of cattle. *J. Anim. Sci.* 41:911–914. doi:10.2527/jas1975.413911x
- Corah, L. 1995. Understanding basic mineral and vitamin nutrition. In: *Proceedings of the Range Beef Cow Symposium XIV*, 5–7 December 1995. Gering (NE): University of Nebraska–Lincoln.
- Dargatz, D.A., and P.F. Ross. 1996. Blood selenium concentrations in cows and heifers on 253 cow-calf operations in 18 states. *J. Anim. Sci.* 74:2891–2895. doi:10.2527/1996.74122891x
- Davy, J., L. Forero, T. Tucker, C. Mayo, D. Drake, J. Maas, and J. Oltjen. 2016. Efficacy of selenium supplementation methods in California yearling beef cattle and resulting effect on weight gain. *Calif. Agric.* 70:187–193. doi:10.3733/ca.2016a0016
- Dunbar, J.R., B.B. Norman, and M.N. Oliver. 1988. Preliminary report on the survey of selenium whole blood values of beef herds in twelve central and coastal California counties. In: UC ANR, editor. *Selenium contents in animal and human food crops grown in California*. Oakland (CA): Cooperative Extension, University of California Division of Agriculture and Natural Resources, Publication 3330. p. 81–83.
- Engel, R.W., W.A. Hardison, R.F. Miller, N.O. Price, and J.T. Huber. 1964. Effect of copper intake on concentration in body tissue and on growth, reproduction and production in dairy cattle. *J. Anim. Sci.* 23:1160–1164. doi:10.2527/jas1964.2341160x
- Enjalbert, F., P. Lebreton, and O. Salat. 2006. Effects of copper, zinc and selenium status on performance and health in commercial dairy and beef herds: retrospective study. *J. Anim. Physiol. Anim. Nutr. (Berl.)* 90:459–466. doi:10.1111/j.1439-0396.2006.00627.x
- Goff, J. P. 2008. The monitoring, prevention, and treatment of milk fever and subclinical hypocalcemia in dairy cows. *Vet. J.* 176:50–57. doi:10.1016/j.tvjl.2007.12.020
- Gooneratne, S.R., W.T. Buckley, and D.A. Christensen. 1989. Review of copper deficiency and metabolism in ruminants. *Can. J. Anim. Sci.* 69:819–845. doi:10.4141/cjas89-096
- Graham, T.W. 1991. Trace element deficiencies in cattle. *Vet. Clin. North Am. Food Anim. Pract.* 7:153–215.
- Grunes, D.L., P.R. Stout, and J.R. Brownell. 1970. Grass tetany of ruminants. *Adv. Agron.* 22:331–374. doi:10.1016/S0065-2113(08)60272-2
- Hansen, S.L., J.W. Spears, K.E. Lloyd, and C.S. Whisnant. 2006. Feeding a low manganese diet to heifers during gestation impairs fetal growth and development. *J. Dairy Sci.* 89:4305–4311. doi:10.3168/jds.S0022-0302(06)72477-8
- Hidiroglou, M. 1979a. Trace element deficiencies and fertility in ruminants: a review. *J. Dairy Sci.* 62:1195–1206. doi:10.3168/jds.S0022-0302(79)83400-1
- Hidiroglou, M. 1979b. Manganese in ruminant nutrition. *Can. J. Anim. Sci.* 59:217–236. doi:10.4141/cjas79-028
- Hidiroglou, M., M. Ivan, M.K. Bryan, C.S. Ribble, E.D. Janzen, J.G. Proulx, and J.I. Elliot. 1990. Assessment of the role of manganese in congenital joint laxity and dwarfism in calves. *Ann. Rech. Vet.* 21:281–284. Available from <https://hal.archives-ouvertes.fr/hal-00901950>.
- Horst, R.L., J.P. Goff, T.A. Reinhardt, and D.R. Buxton. 1997. Strategies for preventing milk fever in dairy cattle. *J. Dairy Sci.* 80:1269–1280. doi:10.3168/jds.S0022-0302(97)76056-9
- Hurley, W.L., and R.M. Doane. 1989. Recent developments in the roles of vitamins and minerals in reproduction. *J. Dairy Sci.* 72:784–804. doi:10.3168/jds.S0022-0302(89)79170-0
- Kincaid, R.L. 2000. Assessment of trace mineral status of ruminants: a review. *J. Anim. Sci.* 77 (E-Suppl):1–10.
- Maas, J., J.R. Peuroi, D.W. Weber, and F.W. Adams. 1994. Safety, efficacy, and effects on copper metabolism of intrarectally placed selenium boluses in beef heifer calves. *Am. J. Vet. Res.* 55:247–250.
- Makimura, S., A. Kodama, M. Kishita, H. Takagi, and K. Adachi. 1993. Secondary antibody response to *Haemophilus somnus* antigen in breeding Japanese black cattle fed selenium-deficient and alpha-tocopherol-fortified diets. *J. Vet. Med. Sci.* 55:871–873. doi:10.1292/jvms.55.871
- Nicholson, J.W.G., R.S. Bush, and J.G. Allen. 1993. Antibody-responses of growing beef-cattle fed silage diets with and without selenium supplementation. *Can. J. Anim. Sci.* 73:355–365. doi:10.4141/cjas93-037
- Puls, R. 1988. Mineral levels in animal health. Clearbrook (BC, Canada): Sherpa International.
- Rao, R. R. 1963. Manganese deficiency and reproductive phenomena in beef cattle and rats [master's thesis]. Pullman (WA): Washington State University.
- Salles, M.S.V., M.A. Zanetti, L.C. Roma, F.A. Salles, A.E.C.S. Azzolini, E.M. Soares, L.H. Faccioli, and Y.M.L. Valim. 2014. Performance and immune response of suckling calves fed organic selenium. *Anim. Feed. Sci.* 188:28–35. doi:10.1016/j.anifeedsci.2013.11.008
- Spears, J.W. 1995. Improving cattle health through trace mineral supplementation. In: *Proceedings of the Range Beef Cow Symposium*, 5–7 December 1995. Gering (NE): University of Nebraska–Lincoln; p. 191.
- Spears, J.W. 2000. Micronutrients and immune function in cattle. *Proc. Nutr. Soc.* 59:587–594. doi:10.1017/S0029665100000835
- StatPoint Technologies, Inc. 2009. *Statgraphics centurion XVI user manual*. The Plains (VA): StatPoint Technologies, Inc. Available from https://cdn2.hubspot.net/hubfs/402067/Manuals/_Statgraphics_Centurion_XVII_User_Manual.pdf?t=1538154350894
- Taylor, R.E., and T.G. Field. 1999. *Beef production and management decisions*, 3rd ed. Upper Saddle River (NJ): Prentice Hall.
- Tessman, R.K., J. Lakritz, J.W. Tyler, S.W. Casteel, J.E. Williams, and R.K. Dew. 2001. Sensitivity and specificity of serum copper determination for detection of copper deficiency in feeder calves. *J. Am. Vet. Med. Assoc.* 218:756–760.

- Van De Weyer, L.M., S.H. Hendrick, and C.L. Waldner. 2011. Associations between prebreeding serum micronutrient concentrations and pregnancy outcome in beef cows. *Am. Vet. M. Ass.* 238:1323–1332. doi:10.2460/javma.2001.218.756
- Wikse, S.E., D. Herd, R. Field, and P. Holland. 1992. Diagnosis of copper deficiency in cattle. *J. Am. Vet. Med. Assoc.* 200:1625–1629.
- Wilde, D. 2006. Influence of macro and micro minerals in the peri-parturient period on fertility in dairy cattle. *Anim. Reprod. Sci.* 96:240–249. doi:10.1016/j.anireprosci.2006.08.004
- Williams, J.D. 1980. A survey into selenium deficiency in cattle in Northern California [master's thesis]. Davis (CA): University of California. p. 55.
- Yokus, B., and U.D. Cakir. 2006. Seasonal and physiological variations in serum chemistry and mineral concentrations in cattle. *Biol. Trace Elem. Res.* 109:255–266. doi:10.1385/BTER:109:3:255