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Bioavailability of selenium in 'Jose' tall wheatgrass (*Thinopyrum ponticum* var 'Jose') hay as a substitute for sodium selenite in the diets of dairy cattle

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HIGHLIGHTS

- Se-enriched TWG hay was used as an alternative Se supplement for dairy cattle.
- Several indices were used to asses Se bioavailability.
- Blood and milk Se suggest a higher Se bioavailability for TWG vs. SS.
- However, more supplemental Se was retained (not expressed in feces) by SS cows (72.5%) vs. TWG cows (55.1%) which suggested higher Se bioavailability for SS.
- Collectively, results suggest that the Se in TWG hay had comparable bioavailability to Se in the base diet and can be used as a value added forage.

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ABSTRACT

Due to its potential toxicity to wildlife, selenium (Se) is a highly regulated trace element in the San Joaquin Valley (SJV) of California. Tall wheatgrass (TWG) is a Se-accumulating, salt tolerant forage suitable for cropping systems which re-use agricultural drainage waters. Utilization of TWG hay as an alternative Se supplement for dairy cattle could reduce the importation of 'new' Se into the SJV in the form of sodium selenite (SS) diet supplements. Our study used Se-enriched (4.65 mg/kg DM) TWG hay as a Se source for lactating dairy cows and measured Se accumulation in milk, blood, urine and feces to assess its bioavailability using several indices. Using a 3 × 3 Latin Square design, three pens of ~310 cows each were fed a similar total mixed ration over 4 week periods, except for Se which was higher in TWG and SS diets (0.53 and 0.65 mg/kg DM) vs. Control diet (0.35 mg/kg DM). Feeding Se-enriched TWG increased blood Se by 6.4% over Control; whereas SS increased it by 4.8%, suggesting higher Se bioavailability for TWG vs. SS. Marginal Se outputs in milk, feces and urine were judged to be better indicators of bioavailability as they estimate Se specifically from supplemental SS or TWG hay. In milk, TWG cows expressed 3.0% of supplemented Se vs. 0.6% for SS cows, supporting higher Se bioavailability for TWG. In contrast, more supplemental Se was retained and not expressed in feces by the SS cows (72.5%) vs. TWG cows (55.1%) which suggested higher Se bioavailability for SS. Based on published guidelines, Se intakes were 'adequate' for cows in all treatment groups, but milk and fat production increased with Se supplementation suggesting that Control cows were Se-deficient to some extent. Collectively, results suggest that the Se in TWG hay had comparable bioavailability to Se in the base diet.

Abbreviations: ADF, acid detergent fiber; CAHFS, California Animal Health and Food Safety; CP, crude protein; DCPAH, Diagnostic Center for Population and Animal Health; DDGS, dried distiller's grains with solubles; DHIA, Dairy Herd Improvement Association; DM, dry matter; EDTA, ethylenediaminetetraacetic acid; EE, ether extract; FDA, Food and Drug Administration; NDF, neutral detergent fiber, aNDF, amylase-treated NDF; aNDFom, aNDF expressed without residual ash; NDFom, NDF expressed without residual ash; NRC, National Research Council; OM, organic matter; SCC, somatic cell count; Se, selenium; SeCys, selenocysteine; SeMet, selenomethionine; SeO_2, selenium dioxide; SG, specific gravity; SS, sodium selenite; TMR, total mixed ration; TWG, 'Jose' tall wheatgrass; WW, wet weight.

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1. Introduction

The San Joaquin Valley (SJV) of California has over three million acres of high cash value tree, vine and vegetable crops which require a reliable supply of irrigation water to be productive. Most of these crops are salt-sensitive and, with drought conditions in California in recent years, alternative water sources are crucial to maintain agricultural production and to avoid overdraft of groundwater which is being used in higher amounts as surface water deliveries decline. In the western SJV, agricultural drainage water and shallow groundwater can be used for irrigation, but these sources are often saline and may contain high concentrations of trace elements such as selenium (Se) and boron. Salinity is a constraint to crop production although, with appropriate management, saline waters can be used to irrigate salt tolerant food crops and forages. Forages are particularly good choices for saline irrigation since grasses with relatively high levels of salt tolerance are commercially available, such as 'Jose' tall wheatgrass (*Thinopyrum ponticum* var. 'Jose'), bermuda grass (*Cynodon dactylon*), creeping ryegrass (*Leymus triticoides*), Paspalum (*Paspalum vaginatum*) (Suyama et al., 2007a,b) and Puccinellia (*Puccinellia ciliata*) (Ashraf and Yasmin, 1997; Suyama et al., 2007a). Indeed, given the severity of the current and projected irrigation water shortage in California, due in part to population increase and potential climate change, it is likely that forages will be irrigated with waters having some degree of salinity, some of which will contain high levels of Se.

The salinity problem in the western SJV is due to the marine parent material of the soil, salts in imported irrigation water and, in some areas, the presence of shallow groundwater (Letey and Oster, 2002). To lower perched water tables, subsurface drainage systems were installed in the 1950's to 1970's in some agricultural lands in the western SJV to intercept saline groundwater and carry it away from the irrigated areas. A master drain, the "San Luis Drain", was partially constructed in the early 1970's to transport and dispose of saline drainage water from the western SJV to the Sacramento–San Joaquin Delta, but it was never completed due to federal budget constraints and environmental concerns. Instead, its construction ended near the Kesterson Reservoir where the drainage water was allowed to pond and evaporate. Embryonic deformities and deaths of migratory waterfowl and fish were discovered in 1983 and linked to elevated Se levels in the water stored in the reservoir (Ohlendorf et al., 1986). This led to immediate closure of the San Luis Drain and subsequently drainage water discharge into local waterways was prohibited. No outlet is available to remove salt and trace elements from the soil and discharge of agricultural drainage water to the San Joaquin River or to evaporation ponds has been reduced since the closure of the San Luis Drain.

Selenium is a natural soil constituent that is widely distributed in soils in the western United States (Bauer, 1997). In the western SJV, Se is abundant in some soils; but in the eastern SJV, soils are very low (i.e., 10 to 100 ppb; Burau, 1985) in Se because of their granitic parent material which contains few native salts or trace elements. Suyama et al. (2007a) evaluated forages grown on high Se soils irrigated with saline–sodic drainage water containing high levels of Se, and a later experiment evaluated some of these forages in a greenhouse study (Suyama et al., 2007b). Overall, among the large number of forages examined, 'Jose' tall wheatgrass (TWG) was the forage of choice, as it had the highest salt tolerance, forage quality and dry matter (DM) yield. Under frequent irrigation with Se-enriched drainage water, TWG generally accumulated 6 to 7 mg Se/kg in the hay DM (Suyama et al., 2007a).

California is home to ~1.8 million lactating dairy cows with three quarters of them located in the SJV (CDFA, 2013), thus creating a large demand for local forages and feeds. For these animals, Se is both an essential nutrient and a potential toxicant because the margin between its nutritional requirement and toxic effects is unusually narrow among the trace minerals. Previous research evaluated Se accumulation in beef cattle grazing Se-enriched 'Jose' tall wheatgrass and found that beef cattle could graze these pastures for 6 months without developing signs of Se toxicity (Juchem et al., 2012). As an alternative to bringing cattle to these Se-enriched pastures, TWG hay could be cut and brought to dairy farms in the eastern SJV where Se is generally added to dairy rations, often in the form of sodium selenite (SS). Thus the Se-enriched TWG could be used as a value-added organic Se supplement in the diets of cattle raised in Se-deficient areas, such as the eastern SJV. This would have the desirable environmental benefit of translocating Se within the SJV, rather than bringing 'new' sources into the valley in the form of Se feed supplements for cattle.

This study examined whether Se-enriched TWG hay is a bioavailable Se source for dairy cattle by determining Se accumulation in milk, whole blood, fecal matter and urine in order to compare the bioavailability of Se in TWG hay vs. the industry standard, SS. The study used three measures to estimate Se bioavailability: whole blood, apparent whole tract Se digestibility, and marginal Se outputs. We also assessed the impacts of higher Se levels in the diet, provided in TWG hay or SS, on milk production and udder health. If acceptably high bioavailability of Se in TWG could be demonstrated, then the use of Se-enriched TWG hay as a supplemental animal feed could be a translocation option for Se from the western to the eastern SJV, thereby reducing the importation of 'new' Se into the SJV in the form of dietary supplements for dairy cattle.

2. Materials and methods

2.1. Plant material used

Baled hay from pastures of tall wheatgrass (*T. ponticum*, var. 'Jose') grown at the Panoche Water District (near Firebaugh, CA, USA) were utilized. These forages were growing in mature stands which had been irrigated with saline agricultural drainage and tail waters for more than 5 years. The tall wheatgrass was cut and harvested after the second heading. After baling, it was sampled with a hay probe (Sierra Testing Service, Acampo, CA, USA) 9 times and immediately submitted to the University of California Analytical Lab (Davis, CA, USA) for Se analysis by vapor generation, inductively-coupled plasma emission spectroscopy (VG-ICP; Tracy and Moeller, 1990) in order to confirm its expected Se level in the range of 5 to 6 ppm of DM.

2.2. Experimental design, animals, and management

The animal feeding experiment was conducted from February to May, 2012 on a commercial dairy farm located near Hanford (CA, USA). There were three dietary treatments: (1) Control (baseline diet Se, targeted at 0.3 to 0.4 mg Se/kg of DM in the normal feedstuff), (2) supplemental Se in the form of Se-enriched tall wheatgrass hay (TWG) added to the diet at 4.6% of DM and (3) supplemental Se in the form of a sodium selenite (SS) premix (10 g SS/kg ground corn) at 4.3 g/kg DM in the TMR. Both Se supplements were designed to increase the dietary Se level by 0.3 mg/kg of DM over the control. Three similar pens, each having ~310 primiparity, pregnant, mid-lactation dairy cows were used. The experiment was a 3 × 3 Latin square design consisting of the three dietary treatments and three pens. A dietary treatment was randomly assigned to each of the pens prior to the first period and the treatments were rotated after 28 and 56 d to ensure that each pen of cows sequentially received all dietary treatments. Each pen had 297 free stalls bedded with dried manure solids and 295 accessible head gates. Cows were allowed access to dry lots and had water available ad libitum.

All cows were milked three times a day in a double 35 herringbone parlor. The cows were milked sequentially in the order of pen 25, 26, 27 starting at 07:30 h. When the cows returned to their respective pens after the morning milking, head-locks had been set to facilitate animal examination for health and reproductive status. The cows were 'locked' for 45 to 60 min daily to facilitate these normal activities.

Farm management moved some cows in and out of experimental pens as needed (e.g., to hospital pens if determined necessary), but