Requirements, Feed Supplementation and Toxicity Assessment of Essential Trace Metals such as Selenium, Copper, Zinc and Vanadium

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ABSTRACT

To obtain better reproductive efficiency in cows, plasma Se concentration is suggested to be more than 70 ppb. To attain such a high plasma Se concentration the dietary Se concentration must be increased to 0.3 ppm by Se supplementation. In order to supplement Se it is necessary to amend the present law that designates all Se-containing substances as toxic and prohibits the Se usage for feed supplementation. The governmental guidance for Cu and Zn supplementation to swine rations are questionable from a nutritional standpoint because the recommended upper Cu supplementation level is too low to be effective for the improvement of body weight gain and feed efficiency in growing and fattening pigs, and the recommended upper Zn level in composts is also too low, which makes the Zn supplementation to swine rations almost as difficult. However, the Zn requirement for pigs is relatively high and Zn is essentially nontoxic. V also faces the dichotomy of being either an essential nutrient or a radical-producing element accumulated in the kidneys.

INTRODUCTION

Most nutritionally essential trace metals face the dichotomy of being either essential or toxic. In this paper the requirements and toxicity of selenium (Se), copper (Cu), zinc (Zn) and vanadium (V) were considered as well as problems encountered in their supplementation to animal feeds. In the researches of trace metals, the balance studies are inadequate tools to determine animal requirements[1]. At best, they estimate the amount of an element in a specific diet that maintains the existing pool size of the test animal. Now the old paradigm that dominated the past nutrition researches called "the paradigm of dissection" is going to be replaced by the new paradigm[2]. In the new paradigm the division of elements into essential and toxic categories is being replaced by the concept of the total dose-response curve. Another problem lies in trace metal supplementation to animal feeds. Trace metals such as Se are designated as toxic

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substances by a Japanese law that was established in 1965. This law states that any compound containing Se cannot be used as a feed supplement. Moreover, recently-modified Environmental Standards prohibit the accumulation of Se in soils and waters, which will make the Se supplementation more difficult in the future as shown in the case of the U.S.A.[3,4]. Not only Se but also other trace metals such as Cu and Zn show similar problems in their supplementation to animal feeds.

MATERIALS AND METHODS

The original data were taken from our previous reports; Se requirements[5,6], Cu and Zn supplementation for pig rations[7], experimental method using the chick embryo assay[8] and experiments on V[9,10].

RESULTS AND DISCUSSION

Requirement of Se in lactating cows

It has been established that all Japanese pasture/roughage plants are deficient in Se[11-14]. According to Ishida and Kawashima[15], the mean Se concentration is 0.028 ppm in dry matter and in Hokkaido, Kinki, Chugoku and Shikoku districts most Se values are below 0.02 ppm. In Hokkaido white muscle disease had been found in calves, lambs and foals[16-18].

In order to know the Se adequacy in cows and calves various indexes such as blood, plasma or serum Se concentration and blood or plasma glutathione peroxidase activity have been adopted and the most suitable index may be plasma Se concentration because of the better analytical reproducibility and the lower effect of sample deterioration[19]. In Fig. 1 the relationship between plasma Se concentration (Y

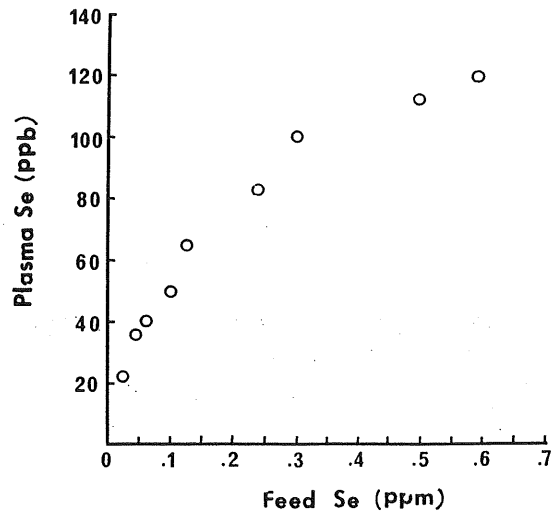

Fig. 1. Relationship between total feed Se concentration (ppm in dry matter) and plasma Se concentration of lactating cows (ppb).

ppb) of lactating cows and dietary Se concentration (X ppm) in total dry matter are shown using the published data[20-24]. In these works sodium selenite was used as a supplement. An equation: $Y = 133 + 32 \ln X$ is deduced, which shows that at dietary Se concentrations of 0.1, 0.2 and 0.3 ppm plasma Se concentrations become 59, 81 and 94 ppb, respectively.

When plasma Se concentration is less than 30 ppb, calves show an apparent Se deficiency such as white muscle disease, and to protect against such deficiency the Se concentration in total ration must be increased to 0.1 ppm. However, according to previous reports[22,25-28], plasma Se concentrations of more than 70-80 ppb are recommended for protecting cows against reproductive failures, mastitis and viral infection. According to our research[5], lactating cows with a higher plasma Se concentration at 50 days post-partum tended to show a higher conception rate and lower incidence of reproductive disorders, as shown in Table 1. In this study plasma Se concentration in 101 unsupplemented cows (control group) was 73.6 ± 12.2 (SD) ppb and with Se-containing yeast or sodium selenite being supplemented in the treatment group. If 70 ppb is a minimum plasma Se requirement for lactating cows, 39% of the lactating cows of the control group in Tohoku, Honshu and Kyushu districts required Se supplementation.

Table 1. Relationship between plasma Se concentration and reproductive performance in high-producing Holstein cows[5].

Plasma Se (ppb)	No. of cows inseminated	Conception rate (%) *	Retained placenta (%)	Reproductive disorders (%) **
less than 69	40	62.5	17.5	42.5
70-79	40	67.5	14.3	22.9
80-89	35	68.6	14.3	34.3
90-99	31	74.2	12.9	35.5
more than 100	18	77.8	11.1	27.8

*Number of pregnant cows in total cows during 20 weeks postpartum

**Included cystic follicle, silent heat, metritis, luteal cyst, ovarian quiscence and ovulation failure

Toxicity of Se and its environmental effect

In our experimental system using chick embryos[8] an aqueous solution of sodium selenite (0-4 μmol) was administered into the air sacs of fertile chick eggs 14 days after incubation and were incubated for a further five days. Liver Se concentration increased linearly as the amount of selenite administration increased (Fig. 2). The amount of selenite causing 50% mortality was about 0.5 μmol per egg, which was comparable to those of Cu (II) and V (IV).

In cows the true Se absorption from forage ration is 10-16%[29] and when a large amount of Se is administered, kidney Se concentration becomes higher than liver Se concentration[30]. The rate of Se

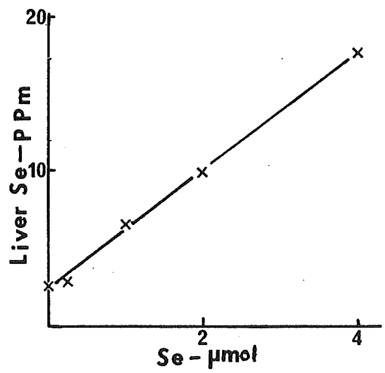

Fig. 2. Relationship between administration rate of sodium selenite (μ mol/egg) to 14 days fertile eggs and hepatic Se concentration (ppm in dry matter) of 19 days chick embryos.

absorption in lactating cows may be less than that of non-lactating cows because of a higher reducing condition in the former animals' rumen[27].

Whether Se compounds excretd into urine and feces will become an environmental hazard or not is a recent point of debate. Female mallards fed a high Se diet show impaired reproduction[31]. However, Se compounds contribute in decreasing the toxicity of methylmercury in Japanese quail[32]. China is a country in which both Se deficiency and toxicity have been observed not only in animals but also in humans[33]. Se compounds are more easily solubilized in alkali soils than in acid soils and most Japanese soils are rather acidic.

Cu supplementation as a growth promoter for pigs

It has been conventional practice in many countries to use Cu (as $CuSO_4$) at the rate of 200-250 ppm in swine diets as a cheap and effective feed additive for improving the performance of growing pigs[34,35]. The liver is a storage organ of Cu, and to avoid the excessive accumulation of Cu, excessive Zn and Fe compounds are also supplemented into swine rations because such minerals as Zn and Fe may antagonistically decrease the Cu absorption and hepatic Cu accumulation. Since the growth-promoting effect of excess Cu disappears in the presence of Tylosin and Olaquindox, the acting mechanism of Cu may be similar to that of antibiotics or antibacterials[36].

The problem of Cu supplementation lies in an environmental effect. There is a danger of Cu enrichment in soils. The Japanese Government issued a recommendation for feed-manufacturing companies that for suckling pigs of up to 2 months of age, growing pigs of 2-4 months of age and growing-fattening pigs of more than 4 months of age, the maximum Cu supplementation levels must be 125, 50 and 20 ppm, respectively, and the maximum Zn supplementation levels 120, 80 and 80 ppm, respectively. Another recommendation is that the maximum Zn level in soils must be 120 ppm. Compared with the Cu supplementation levels (at least 125 ppm) adopted in most other countries, the Japanese Government's Cu recommendation levels are too low and were not effective on increasing the growth of growing-fattening pigs (our unpublished result). Compared with a harmful soil Zn level of 250-300 ppm[37], the Japanese regulation on soil Zn is also too severe, which makes the Zn supplementation almost as difficult.

Recent problems of V

While many of the V experiments in 1971-1974 determined that V was an essential nutrient, those results were later found to be flawed[38] and only suggested that V has significant pharmacological and in vitro actions. However, more recent experiments also supported the essentiality of V by showing the effects of deficiency such as reproductive failures, aberration in hepatic lipid metabolism, bone growth impairment, nutritional edema and thyroid metabolism changes[38]. The most prominent interest involves the insulinomimetic properties of V[39]. Not only V but also Se has an insulin-like effect[40].

In Fig. 3 the relationship between feed V concentration (X ppm) and kidney V concentration (Y ppb) in laboratory animals such as chicks, rats and hamsters is shown from various sources[41-43]. There

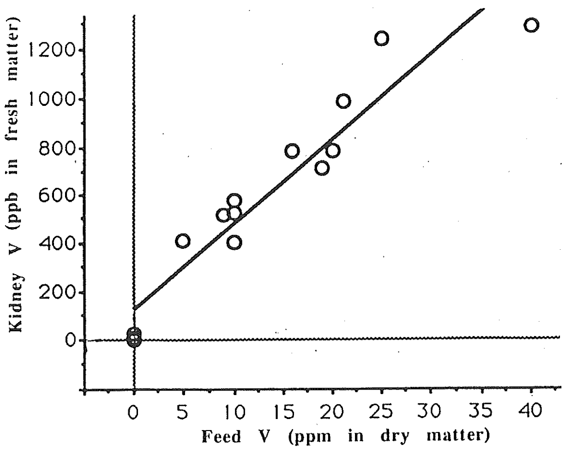

Fig. 3. Relationship between total feed V concentration (ppm in dry matter) and kidney V concentration (ppb in fresh matter) of laboratory animals such as chicks, rats and hamsters.

is a linear equation: $Y = 34.87X + 129.8$. V causes renal disorders[44]. In chick embryos V was accumulated in the leg bones in a dose-dependent way[10]. V (IV) generates hydroxyl radicals that cause the hemolysis of vitamin E-deficient erythrocytes in Hepes buffer[9].

Concluding remarks

In Table 2 requirements and other parameters of Se, Cu, Zn and V are summarized. Requirement of V was estimated from human dietary requirement data[38]. In these metals Zn is the only element that has been proven to be essentially nontoxic[45]. Lactating cows' Se requirement (0.3 ppm in feed dry matter) is much higher than calves' Se requirement of previous feeding standard (0.1 ppm in feed dry matter), which is caused by different criteria used for Se deficiency (reproduction versus white muscle disease).

Table 2. Requirements, supplementation, toxicity and environmental effects of Se, Cu, Zn and V.

	Se	Cu	Zn	V
Requirement (ppm in DM)	0.3	5	50	(0.03)
Maximum supplementation (ppm in DM)	0.3	250	150	(−)
Toxic effect	+	+	−	+
Environmental effect	+	+	−	(+)
Law regulation	+	+	+	−

+ and − mean positive and negative effect, respectively.
The figures or symbols in parentheses are not determined well.

The reproduction is a much more complex phenomenon than white muscle disease, and absorption of Se compounds from the gastro-intestinal tract may be more efficient in calves than in lactating cows. In order to obtain maximum growth rate, the Cu supplementation to swine rations is better to increase to more than 125 ppm, which contributes to an improvement of pigs' performances in more stressful conditions. However, the accumulation of Cu and Zn in composts and/or soils is severely criticized from the environmental point of view. The present situation in Japan is far from solving the dilemma.

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