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The Importance of Trace Elements in Animal Nutrition

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1. History of discovery of essential trace elements
2. Comparison of international recommendations for trace element supply for pigs
3. Examples of manganese deficiency in pigs and rabbits
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8. Concluding remarks

Discovery of the essentiality of trace elements for mammals

Element	Discovered	Element	Discovered
1. Iron (Fe)	17^{th} century	9. Chromium (Cr)	1959
2. Iodine (I)	1820	10. Tin (Sn)	1970
3. Copper (Cu)	1928	11. Vanadium (V)	1971
4. Manganese (Mn)	1931	12. Fluorine (F)	1972
5. Zinc (Zn)	1934	13. Silicon (Si)	1972
6. Cobalt (Co)	1935	14. Nickel (Ni)	1974
7. Molybdenum (Mo)	1953	15. Lead (Pb)	1974
8. Selenium (Se)	1957	16. Arsenic (As)	1976

Research milestones for the trace element zinc

1869 RAULIN discovers the essentiality of zinc for *Aspergillus niger*

1934 TODD et al. induce *zinc deficiency symptoms* in growing *rats*

1940 KEILIN and MANN show for the first time an essential biochemical function of zinc for the activity of the enzyme *carbonic anhydrase* in erythrocytes

1955 VALLEE und NEURATH identify *carboxypeptidase A* from bovine pancreas as the second zinc metalloenzyme

1955 TUCKER und SALMON show that the widely occurring *parakeratosis* of pigs and especially those fed with maize soybean rations is caused by zinc deficiency (because of low bioavailability of zinc from phytate complex)

1957 MARGOSHES und VALLEE isolate *metallothionein (MT)* from equine kidney

1961/63 PRASAD et al. describe *zinc deficiency in humans* for the first time

1973 *Acrodermatitis enteropathica* of humans is discovered by MOYNAHAN as a genetic defect of zinc absorption

1985 MILLER et al. describe the function of zinc in *„zinc fingers“* (proteins binding DNA and regulating gene expression)

1992 HEMPE und COUSINS characterize the role of *cysteine rich intestinal protein (CRIP)* in zinc absorption

Functions of zinc

Zinc in enzymes and other proteins

-There are more than 1000 zinc dependent enzymes and other proteins

Zinc and hormones

-Storage of insulin

-Improving stability of growth hormone

Zinc and nucleic acids, zinc and gene expression

-stabilizing of histones

-DNA and RNA polymerases are zinc metallo-enzymes

-several transcription factors are zinc metallo-proteins

Zinc and the immune system

-The thymus hormone thymuline, converting thymocytes into active T lymphocytes, is zinc dependent

-In zinc deficiency the activity of T helper cells and of natural killer cells is reduced

Antioxidative properties of zinc

-Protection from oxidation and stabilization of thiol groups of enzymes and proteins

-Induction of metallothionein as a potential antioxidant

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Trace element recommendations for pigs according to different committees from France (INRA), Great Britain (ARC, AFRC), Germany (GfE), and USA (NRC)

	INRA 1989			ARC 1981		AFRC 1990		GfE 1987			NRC 1998		
	mg/kg feed			mg/kg dietary DM				mg/kg dietary DM			mg/kg feed (90 % DM)		
	piglets	growing pigs	sows	up to **x** kg live weight	sows	growing boars	adult boars	piglets	growing pigs	breeding sows and boars	piglets up to 20 kg	growing pigs	breeding sows and boars
Fe	100	80	80	60 x=20	-	50	50	80-120[a]	50-60[a]	80-90	80-100[a]	40-60[a]	80
Zn	100	100	100	50 x=90	-	100	100	80-100	50-60	50	80-100	50-60	50
Mn	40	40	40	4-16 x=90	10	15	10	15-20	20	20-25	3-4	2	20
Cu	10	10	10	4 x=90	-	4	4	6	4-5	8-10	5-6	3-4	5
I	0.6	0.2	0.6	0.16 x=90	0.5	0.5	0.5	0.15	0.15	0.5-0.6	0.14	0.14	0.14
Se	0.3	0.1	0.1	0.16 x=90	-	0.2	0.2	0.2-0.3	0.2	0.15-0.2	0.25-0.3	0.15	0.15
Co	0.1-0.5	0.1	0.1	-	-	-	-	-	-	-	-	-	-

[a] the higher values in the column are valid for the animals with the lower live weight

Trace element requirements of pigs according to the recommendations of the NRC (6th to 10th edition)

mg/kg feed (90 % DM)							
	6th edition 1968	7th edition 1973	8th edition 1979	9th edition 1988		10th edition 1998	
				Piglets [a] and growing pigs	Breeding sows and boars	Piglets [a] and growing pigs	Breeding sows and boars
Iron (Fe)	80	80	40-150 [a]	40-100 [a]	80	40-100 [a]	80
Zinc (Zn)	50	50	50-100	50-100	50	50-100	50
Manganese (Mn)	20	20	2-4 [b]	2-4	10	2-4	20
Copper (Cu)	6	6	3-6	3-6	5	3-6	5
Iodine (I)	0.2	0.2	0.14	0.14	0.14	0.14	0.14
Selenium (Se)	0.1	0.1	0.10-0.15	0.10-0.30	0.15	0.15-0.30	0.15

[a] the higher values in the column are valid for piglets

[b] breeding pigs 10 mg/kg

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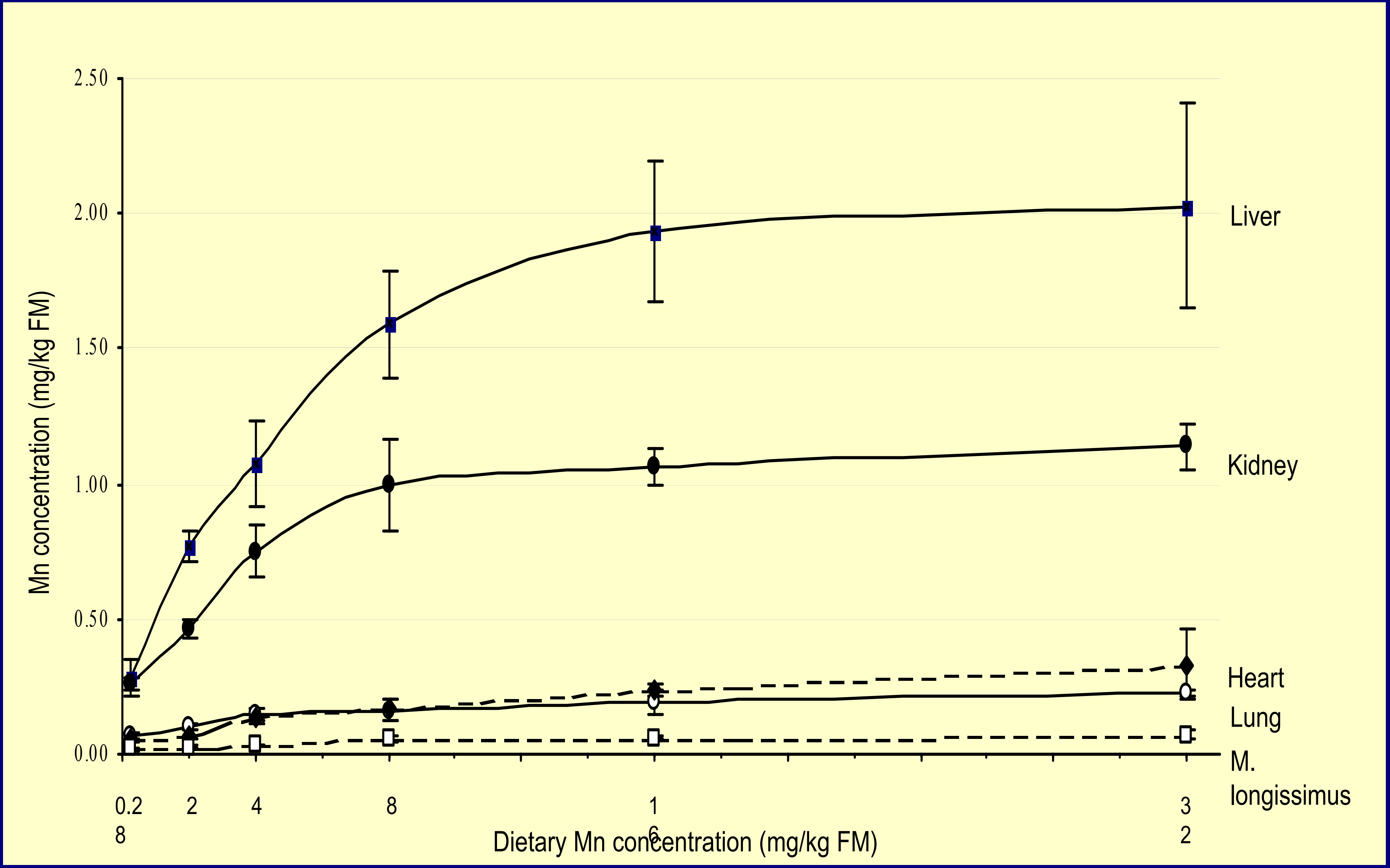
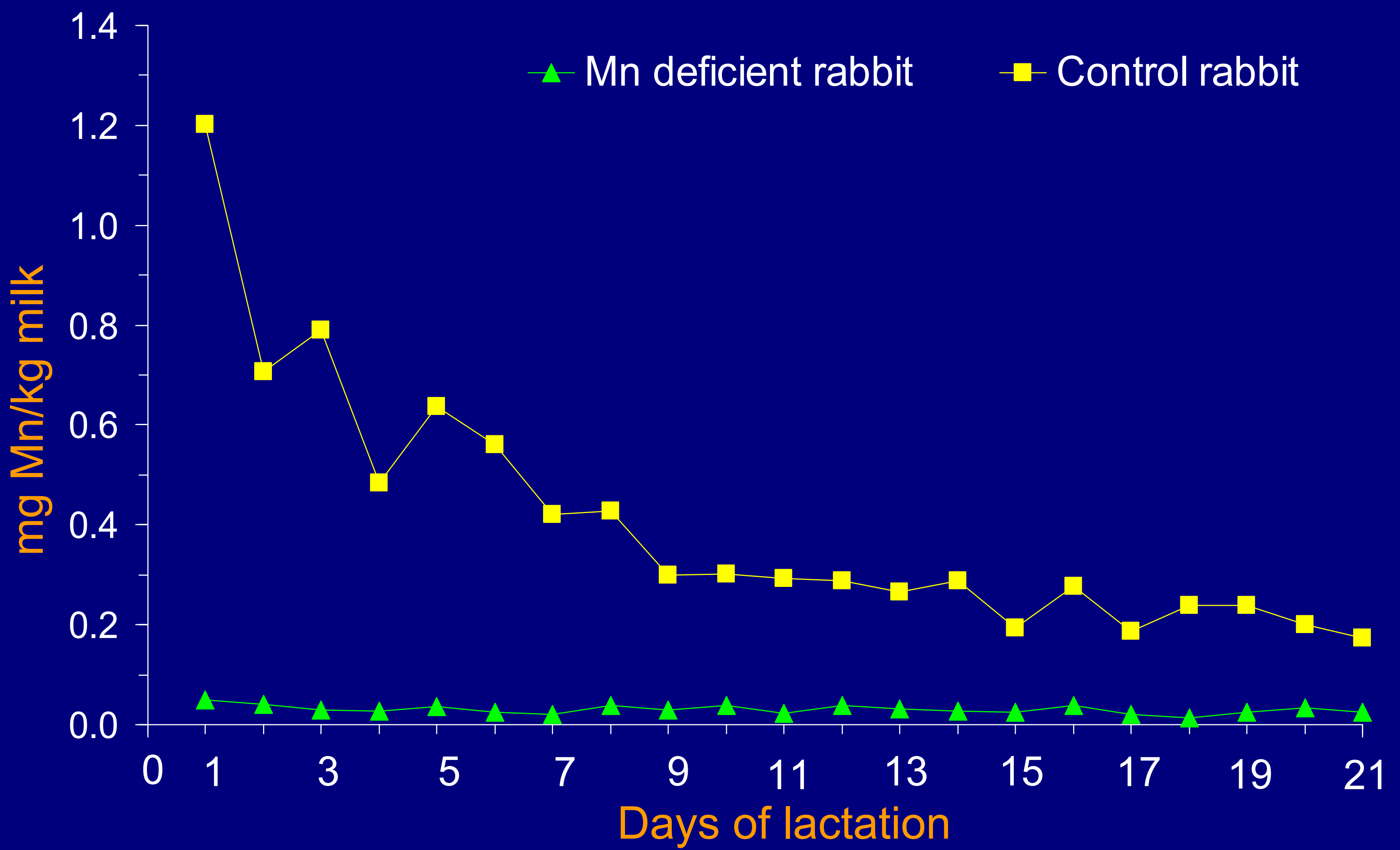


Effect of different dietary manganese supply for 45 days on the manganese concentration in organs of piglets at 29 kg live weight (n = 6 x 6)



Mn concentration in the milk of a Mn deficient rabbit (0.60 mg Mn/kg dietary DM) compared to a control animal (35 mg Mn/kg DM)

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Trace element recommendations for dairy cattle according to NRC (2001) and GfE (2001)

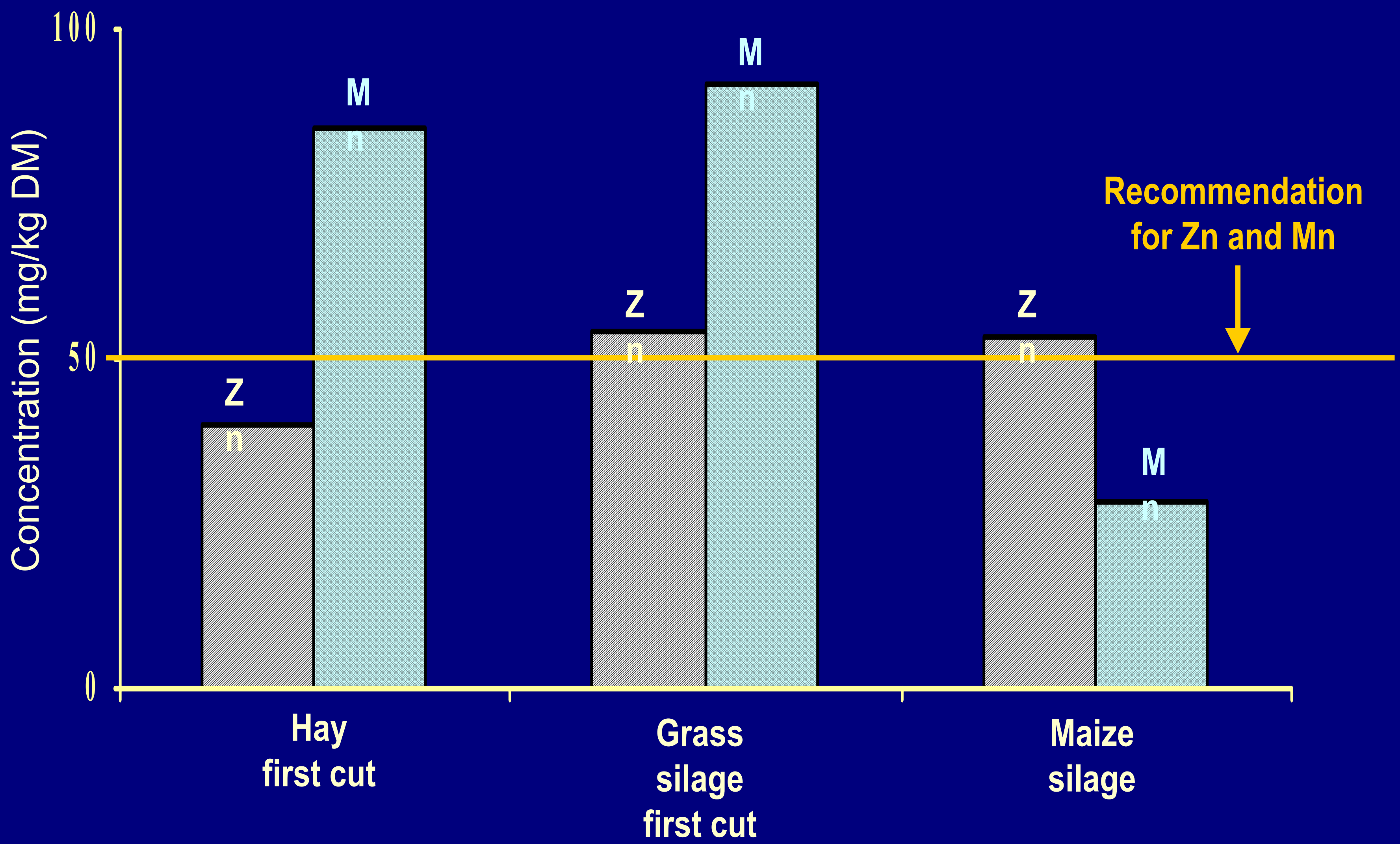
Trace element	NRC 7th ed. (2001) mg/kg feed (90 % DM)		GfE (2001) mg/kg dietary DM	
	Heifers	Dairy cows	Heifers	Dairy cows
Manganese (Mn)	22	(13-14)	40-50	50
Zinc (Zn)	32	43-55	40-50	50
Iron (Fe)	43	(12-18)	50	50
Copper (Cu)*	9 -10	11-13	10	10
Iodine (I)	0.30	0.4-0.6	0.25	0.50
Cobalt (Co)	0.11	0.11	0.20	0.20
Selenium (Se)	0.30	0.30	0.15	0.20

* High dietary Mo, sulphur, and Fe can interfere with Cu absorption increasing the copper requirement

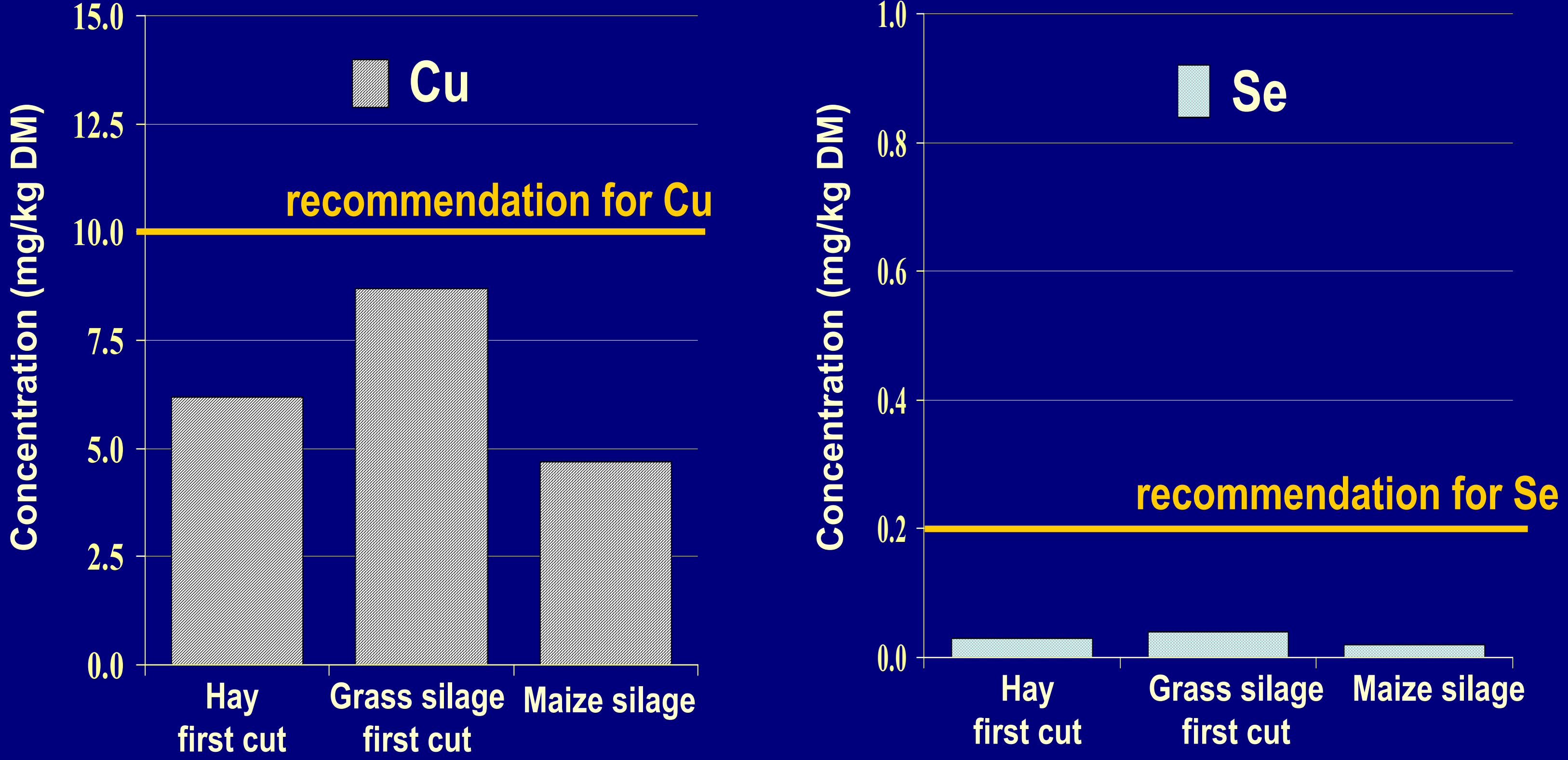
Utilization of trace elements for milk production in dairy cows

Element	Recommendation for dairy cows * mg/kg dietary DM	Intake with a ration of 25 kg dietary dry matter (mg/d)	Mean concentration in milk * mg/kg	Excretion via milk at 40 kg milk/day	
				mg/day	in % of intake
Iron (Fe)	50	1250	0.55	22.0	1.8
Manganese (Mn)	50	1250	0.05	2.0	0.16
Zinc (Zn)	50	1250	4.0	160.0	12.8
Copper (Cu)	10	250	0.15	6.0	2.4
Iodine (I)	0.50	12.5	0.07	2.8	22.4
Cobalt (Co)	0.20	5.0	0.001	0.04	0.8
Selenium (Se)	0.20	5.0	0.015	0.6	12.0

* GfE (2001)



Zinc and manganese concentrations in forages (BLT Grub 1998-2001) compared to recommendations for dairy cows (GfE 2001)



Copper and selenium concentrations in forages (BLT Grub 1999-2002) **compared to recommendations for dairy cows** (GfE 2001)

Recommendation of trace elements in rations for goats (GfE 2003)

Trace element	Recommended concentration* (mg/kg dietary DM)
Manganese (Mn)	60-80
Zinc (Zn)	50-80
Iron (Fe)	40-50
Copper (Cu)	10-15
Iodine(I)	0.30-0.80
Cobalt (Co)	0.15-0.20
Selenium (Se)	0.10-0.20

* The higher values are valid for growing lambs (Zn, Fe, Se), diets high in molybdenum and sulphur (Cu) and for reproductive goats in the presence of goitrogens (I)

Trace element recommendations for poultry (GfE 1999)

Trace element	Recommended concentration (mg/kg dietary DM)			
	Chicken	Pullets	Layers	Broilers
Iron (Fe)	100	70	100	100
Manganese (Mn)	60	50	50	60
Zinc (Zn)	50	40	50	50
Copper (Cu)	7	6	7	7
Iodine (I)	0.50	0.40	0.50	0.50
Selenium (Se)	0.15	0.15	0.15	0.15

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EU feed regulations for maximum levels of zinc and copper in pig feeds

Element	Concentration in mg per kg feed on the basis of 88% DM			
	until 25.1.2004		from 26.1.2004	
	pigs up to 16 weeks	pigs older than 16 weeks	pigs up to 12 weeks	pigs older than 12 weeks
Zinc (Zn)	250	250	150	150
Copper (Cu)	175	35	170	25

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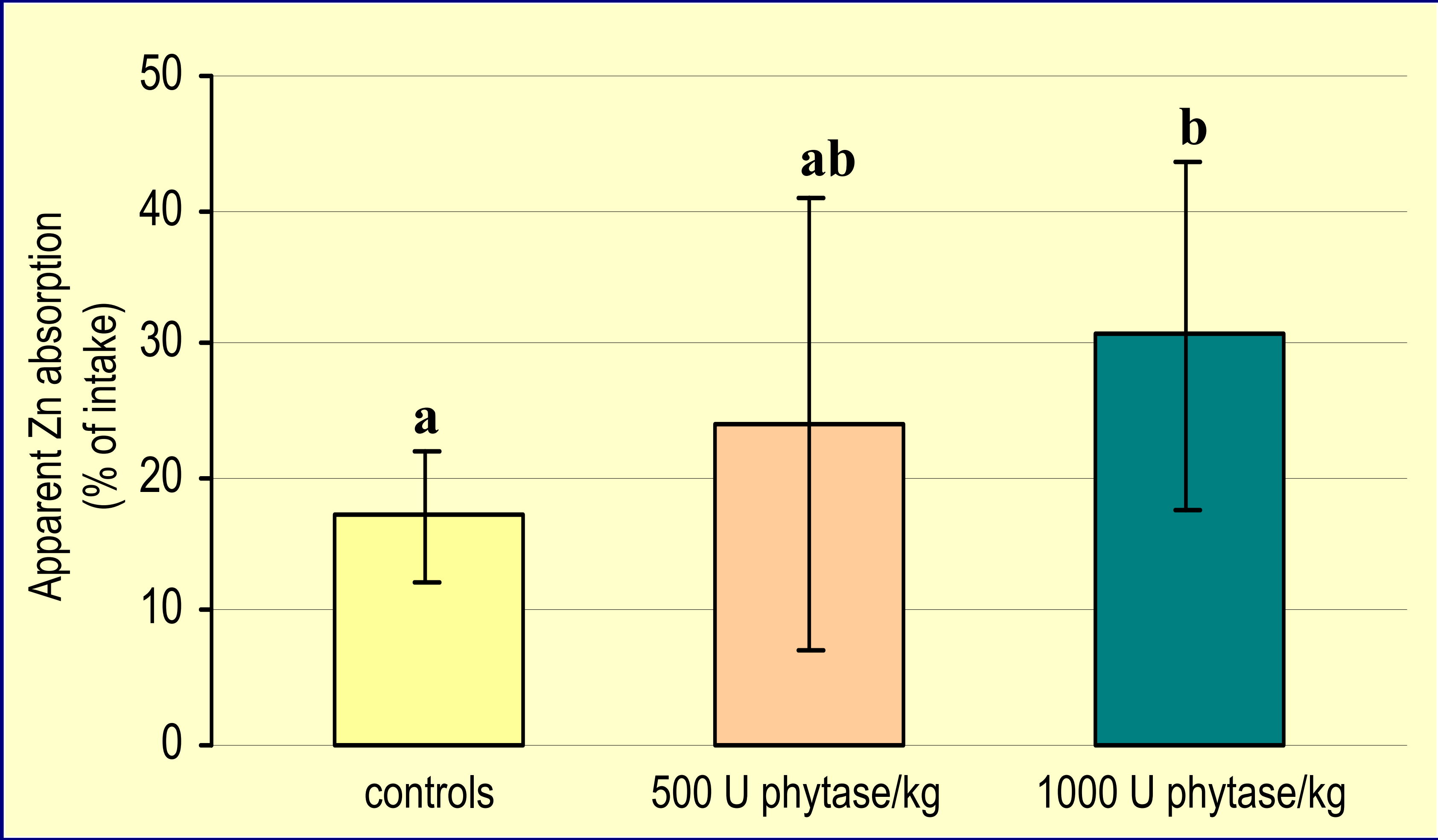

Effect of microbial phytase supplementation to a maize soya diet (60 mg Zn/kg) on the apparent absorption of Zn in piglets

(n = 3 x 8; live weight 12 kg)

(PALLAUF, HÖHLER and RIMBACH 1992)

Effect of the addition of microbial phytase to a phytate-rich diet (16 mg Zn/kg) based on soy protein isolate and corn starch on apparent zinc absorption and zinc status of growing rats

Gr.	Diet: Feeding regimen	Diet: PA:Zn (molar)	Diet: Phytase (U/kg)	Apparent Zn absorption (%)	Zinc status after 21 days on trial: Plasma Zn (µg/ml)	Zinc status after 21 days on trial: ZBC* (%)	Zinc status after 21 days on trial: ALP# (mU/ml)
I	ad libitum	**25:1**	—	**37.2**±5.3[a]	**0.87**±0.21[a]	**76.0**±6.0[a]	**316**±70[a]
II	pair-fed to I	**25:1**	**1000**	**62.9**±2.2[b]	**1.21**±0.08[b]	**66.2**±2.1[b]	**423**±49[b]
III	ad libitum	**25:1**	**1000**	**66.4**±5.6[b]	**1.15**±0.11[b]	**67.2**±3.2[b]	**400**±84[b]

(RIMBACH and PALLAUF 1993)

* Percent unsaturated plasma zinc binding capacity

Plasma alkaline phosphatase activity

Different letters within the same row indicate significant differences between the groups

Relative bioavailability of zinc sources (*Zn sulphate = 100*) evaluated by different parameters of response (AMMERMAN et al. 1995)

Source	Poultry	Pigs	Cattle	Sheep	Rats
Zn acetate					100
Zn chloride	100	100			
Zn sulphate	100		100	100	100
Zn carbonate	105		60	110	
Zn chelated					
Zn citrate					100
Zn lysine		100			
Zn methionine	125	100		100	
Zn oxide	100 (55)	50	100	70	
Zn piccolinate					105
Zn proteinate	100				

Relative biological value of zinc sources evaluated by tibia ash content in different species (JONGBLOED et al. 2002)

Zinc compound	Species		
	Pig	Ruminants	Broiler
Zinc sulphate	100	100	100
Zinc carbonate	98	58	93
Zinc chloride		42	107
Zinc oxide	92	95	67
Zinc amino acid chelate	102	102	131

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Selenium and vitamin E deficiency disorders in different animal species

- Systemic disorders and necrotic degenerations -

Disease	Animal species	Affected tissue	Preventive role of selenium	Preventive role of vitamin E
• liver necrosis	rat, mouse, pig	liver	+	+
• renal failure, renal degeneration	rat, mouse, pig	tubuli contorti		+
• anemia	monkey, rat , pig	bone marrow		+
• hemolysis	chicken, rat, rabbit	erythrocyte membrane	+	+
• encephalomalacia	chicken	cerebellum		+
• exudative diathesis	chicken	capillary wall	+	+
• retarded growth	monkey, rat		+	
• impaired hair growth	monkey, rat	hair follicle	+	

Myopathies caused by selenium and vitamin E deficiency

Disease	Animal species	Affected tissue	Preventive role of selenium	Preventive role of vitamin E
• nutritive muscular dystrophy	chicken, rat, rabbit, guinea pig , pig, monkey	skeletal muscle	a)	+
• nutritive muscular dystrophy	beef calf, beef cattle, sheep		+	
• stiff lamb disease	newborn lamb	skeletal muscle	+	
• mulberry heart disease	pig	heart muscle	+	+

a) may reduce severity

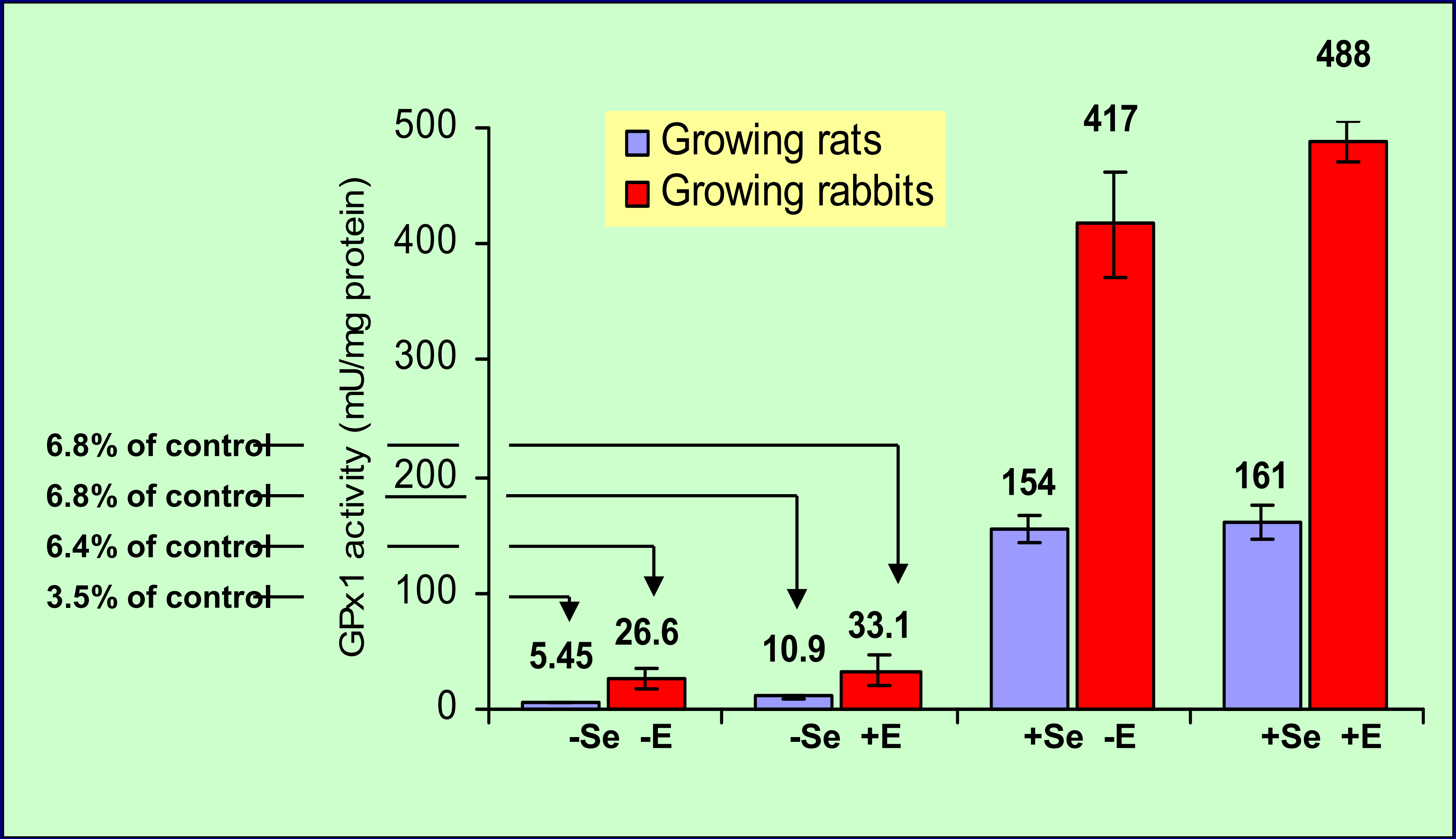
Reproductive disorders in selenium and vitamin E deficiency

Disease	Animal species	Affected tissue	Preventive role of selenium	Preventive role of vitamin E
• fetus resorption	cattle, sheep, rat	embryonic vascular system	+	+
• retained placenta	cattle	placenta	+	b)
• testicular degeneration	rat, rabbit, hamster, dog, pig, monkey	testicular tissue	+	+
• sterility	rat, mouse bull, boar	sperm, sperm capsule	+	

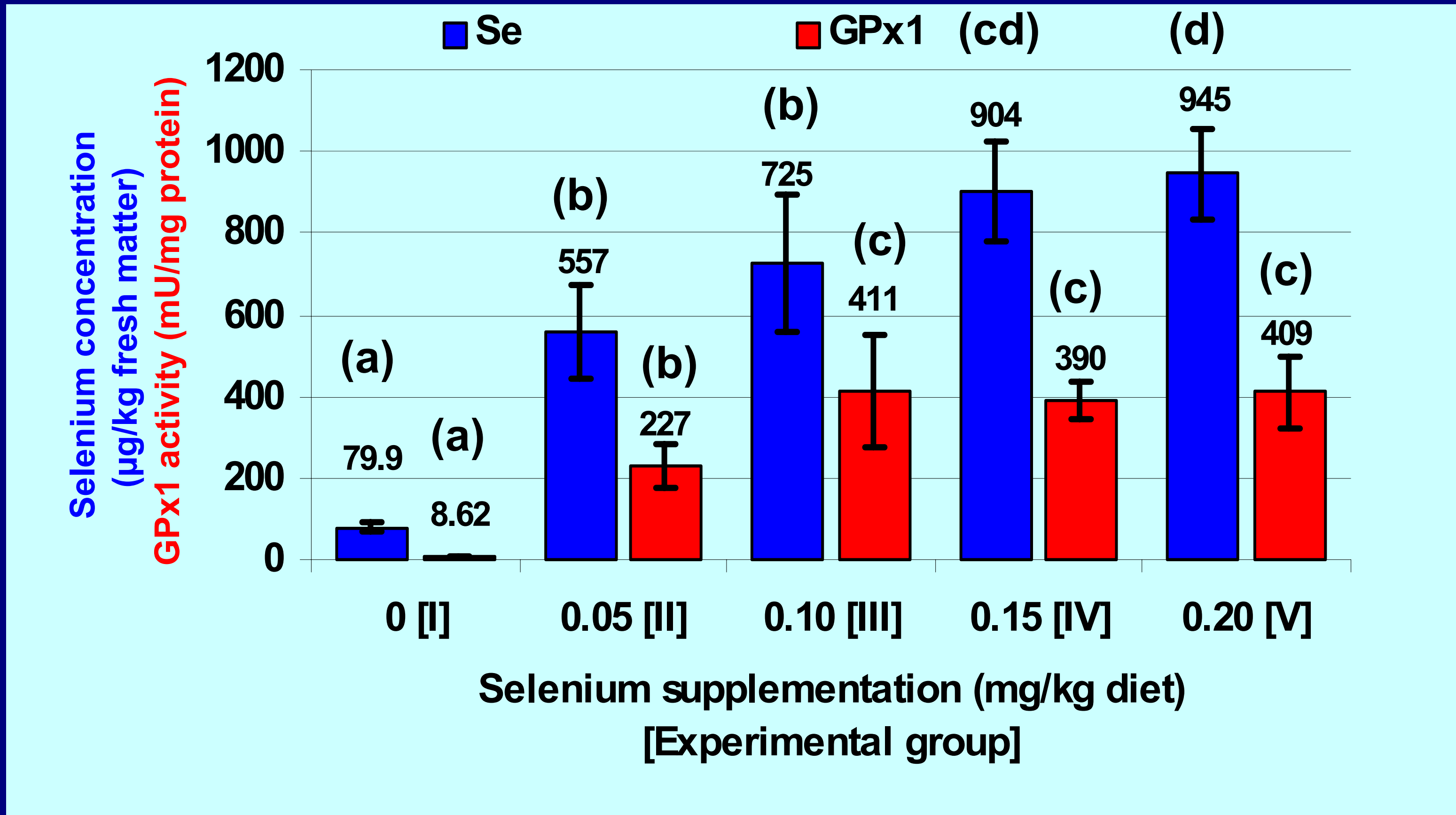
b) participation assumed

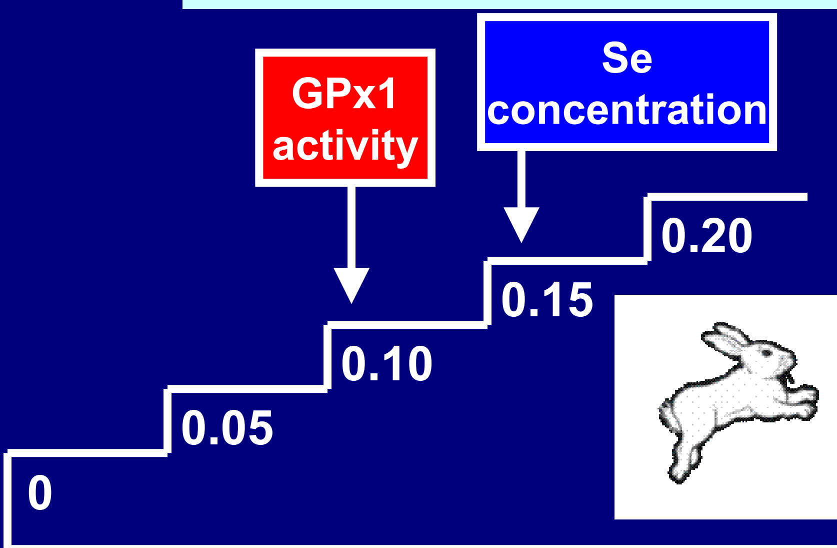
Functional selenoproteins of mammals containing selenium in a seleno-cysteine residuum (adapted from GLADYSHEV and HATFIELD 1999)

	Selenoprotein	Function
1	Glutathione peroxidase 1 = GPx 1 (cellular glutathione peroxidase, cytosolic glutathione peroxidase)	Glutathione dependent hydroperoxide removal
2	Glutathione peroxidase 2 = GPx 2 (gastrointestinal glutathione peroxidase, GPxGI)	Glutathione dependent hydroperoxide removal of intracellular and foodborn hydroperoxides
3	Glutathione peroxidase 3 = GPx 3 (plasma glutathione peroxidase, pGPx)	Glutathione dependent hydroperoxide removal, antioxidant
4	Glutathione peroxidase 4 = GPx 4 (phospholipid hydroperoxide glutathione peroxidase, PHGPx)	Phospholipid hydroperoxide removal
5	Thyroid hormone deiodinase 1 = D 1 (Monodeiodinase 1, MDI 1)	Conversion of T4 to T3, inactivation of T3 and T4
6	Thyroid hormone deiodinase 2 = D 2 (Monodeiodinase 2, MDI 2)	Conversion of T4 to T3
7	Thyroid hormone deiodinase 3 = D 3 (Monodeiodinase 3, MDI 3)	Inactivation of T3 and T4
8	Thioredoxin reductase (TR1)	NADPH dependent reduction of thioredoxin
9	Selenophosphate synthetase 2 (SPS2)	Synthesis of selenophosphate
10	Selenoprotein P (Sel P)	Antioxidant, selenium storage, distribution of selenium between tissues ?
11	Selenoprotein W (Sel W)	Redox function, especially in muscle, selenium storage in muscle ?
12	15 kDa selenoprotein	Protein folding ?

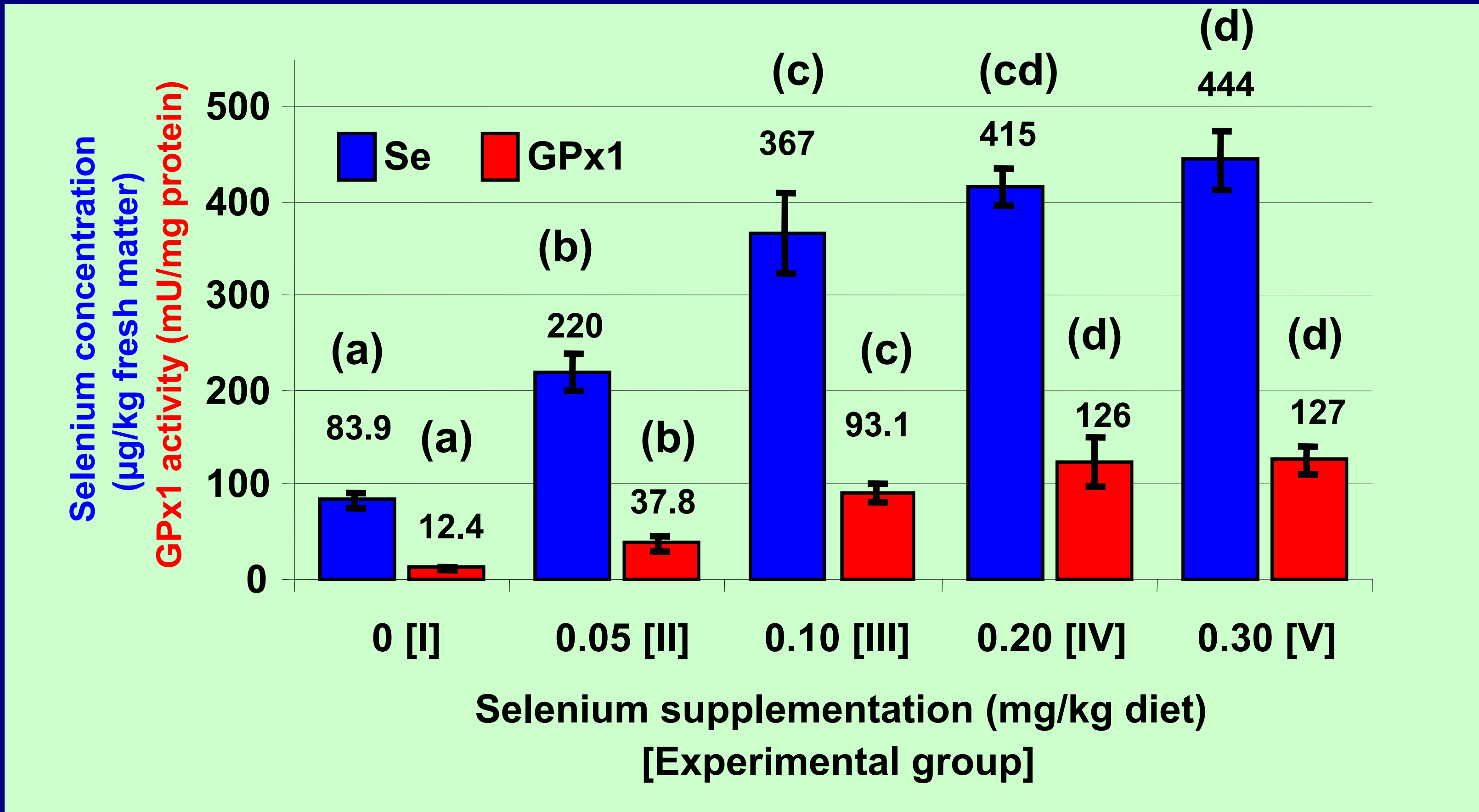


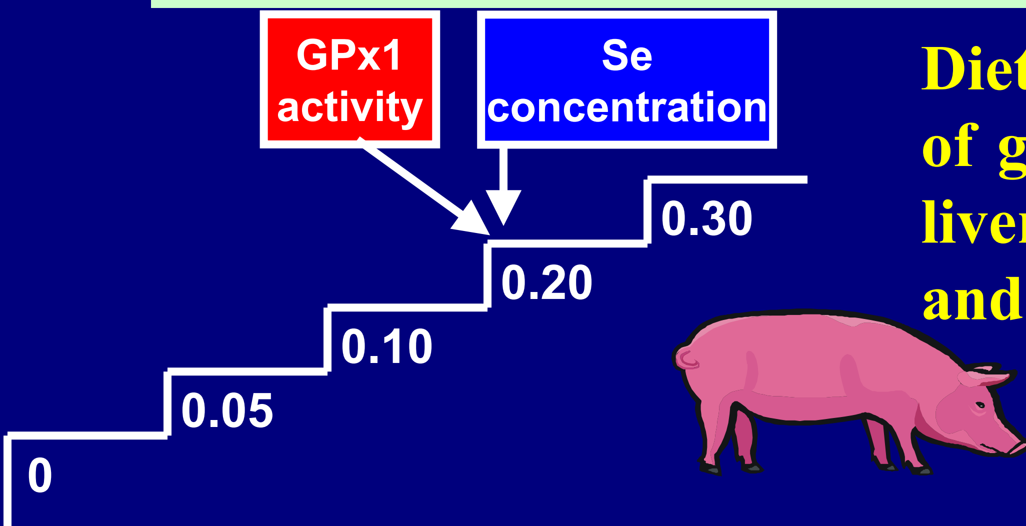
Activity of cellular glutathione peroxidase (GPx1) in the liver of growing rats and growing rabbits after 7 and 10 weeks on selenium and/or vitamin E deficient diets in comparison to selenium and/or vitamin E-supplemented animals





Dietary selenium requirement of growing rabbits determined by liver selenium concentration and activity of liver GPx1





Dietary selenium requirement of growing pigs determined by liver selenium concentration and activity of liver GPx1

Concluding remarks

- Trace elements are important factors in animal and human nutrition and have to be added to animal feed if the native content does not meet the requirement

- The precise detection of trace element requirements and the derivation of recommendations are essential aspects of animal nutrition research

- Knowledge of the native content of feedstuffs and fine tuning of trace element supplementation to avoid an oversupply is crucial not only from an ecological point of view

- Ensuring high availability of the chemical compounds of trace element supplements and also of the native content (e.g. by addition of phytase) is important to reduce trace element excretion via faeces and urine without loss of animal health and performance