Nutritional and growth-promoting levels of zinc in pigs: effects on performance and on the environment

J.Y. Dourmad

INRA Agrocampus Ouest – UMR Pegase - France
Content

• Context
• Zn an essential element for life
  – Role of Zn
  – Determination of Zn requirement in pigs
  – Biodisponibility of Zn sources
• Zn a growth-promoting factor
  – Effects on performance
  – Mechanism of action
• Zn excretion and environment
  – Effect of excess Z on the environment
  – Zn retention and excretion
  – Mechanistic models
• A holistic approach of Zn nutrition of pigs
Context

• **Increasing world animal production**
  – Competition for resources and land
  – Impact on the environment
  ⇒ Need for a sustainable development

• **Zn in animal nutrition**
  – Required to cover animals requirement
  – A limited resource at world level
  – Zn in manure may have harmful effects on the environment
    ⇒ regulation of feed Zn and Cu in EU and other countries
    ⇒ regulation on Zn an Cu contents in organic fertilizers
  – Improper use may contribute to the development of microbial resistance to Zn and antibiotics in the gut and in soils

• **Need for a holistic approach of Zn nutrition of pigs**
A holistic approach of Zn nutrition

- Limited resource
- Animal performance and health
- Environmental impacts
- Economic performance
- Microbial resistance
Content

• Context

• **Zn an essential element for life**
  – Role of Zn
  – Determination of Zn requirement in pigs
  – Biodisponibility of Zn sources

• **Zn a growth-promoting factor**
  – Effects on performance
  – Mechanism of action

• **Zn excretion and environment**
  – Effect of excess Z on the environment
  – Zn retention and excretion
  – Mechanistic models

• **A holistic approach of Zn nutrition of pigs**
Role of Zn

- **Zn ≈ 2100 mg in a pig of 100 kg BW**
  - Muscles (≈60%), bones (≈30%), organs (≈10%)
- **Involved in about 300 metalloenzymes**
  - Expression of genes (RNA-DNA polymerase...)
  - Metabolism (carbohydrates, lipids, protein)
  - Associated with insulin
  - Bone accretion (Alkaline phosphatase)
  - Epithelial tissue integrity
  - Control of oxidative stress (superoxyde dismutase) (Cu Zn SOD)
  - Immunity (prolification of T lymphocytes)
  - Protein digestion (carboxypeptidase A et B)
- **High levels of Zn**
  - Epithelial morphology of the intestine
  - Appetite (ghrelin secretion)

Revy et al., 2003
NRC, 2012
Role of Zn

• **Signs of Zn deficiency in all pigs**
  – Parakeratoses (skin, collagen syntheses)
  – Loss of appetite (gustine)
  – Diarrhea (height of intestinal villosity)
  – Immuno depression
  – Decreased growth rate (RNA and DNA polymerase)
  – Decreased feed efficiency
  – Reduced levels of plasma Zn, alkaline phosphatase, albumin

• **Sign of Zn deficiency in sows**
  – Prolonged farrowing
  – Reduced prolificacy and piglets weight and Zn status
  – Reduced Zn in milk

Revy et al., 2003
NRC, 2012
Where can we find zinc for human nutrition

Canada food guide
Where can we find zinc for pig nutrition?

- Most of feed ingredients below the requirement
- A need to add zinc to the diet
Determination of Zn requirement

Slope-response curves with different Zn supplies

Zn requirement:

- $44 \text{ mg/d}$
- $100 \text{ mg/kg}$

Revy et al., 2005
DOI: 10.1111/j.1439-0396.2005.00576.x
Determination of Zn requirement

Revy et al., 2005
DOI: 10.1111/j.1439-0396.2005.00576.x
Determination of Zn requirement

Revy et al., 2005
DOI: 10.1111/j.1439-0396.2005.00576.x
Meta-analysis of the effect of Zn supply in piglets (34 experiments)

Schlegel, 2010
https://pastel.archives-ouvertes.fr/pastel-00536407
Zinc requirement of pigs

- **Depends on diets-related factors**
  - **Phytic acid**: Significant correlation between total Zn content and Phytic acid content of feed ingredients
  - **Ca**: only in case of large supplies
  - **Factors affecting pH in stomach**: effect of solubility of Zn

- **Phytase enzyme has a significant contribution to zinc supply => effect on requirement**
  - 25-30 mg for 500 IU of microbial phytase (Revy et al, 2005)
  - 20-25 mg for 500 IU of microbial phytase (Jongbloed, 2012) (meta-analyses)
# Recommendations for total Zn requirements in different countries

<table>
<thead>
<tr>
<th></th>
<th>&lt;11</th>
<th>11-25</th>
<th>25-50</th>
<th>50-135</th>
<th>Gestation</th>
<th>Lactation</th>
<th>Boars</th>
</tr>
</thead>
<tbody>
<tr>
<td>NRC (US, 2010)</td>
<td>100</td>
<td>80</td>
<td>60</td>
<td>50</td>
<td>100</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>GfE (DE, 2006)</td>
<td>100</td>
<td>80</td>
<td>50-60</td>
<td>50-60</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>INRA (FR, 1989)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>MTT (FI, 2013)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>IFZZ (PL, 1993)</td>
<td>70-150</td>
<td>70-150</td>
<td>50-80</td>
<td>50-80</td>
<td>50-100</td>
<td>50-100</td>
<td></td>
</tr>
<tr>
<td>Agroscope (CH, 2013)</td>
<td>60-100</td>
<td>60-100</td>
<td>45-80</td>
<td>45-80</td>
<td>45-80</td>
<td>45-80</td>
<td>45-80</td>
</tr>
<tr>
<td>Maximum in EU</td>
<td><strong>150</strong></td>
<td><strong>150</strong></td>
<td><strong>150</strong></td>
<td><strong>150</strong></td>
<td><strong>150</strong></td>
<td><strong>150</strong></td>
<td><strong>150</strong></td>
</tr>
</tbody>
</table>
Bioavailability of different Zn sources

Comparison of slopes between a tested and a reference Zn sources (ZnSO$_4$ 7H$_2$O)

Bioavailability = slope “tested” / slope “reference”

Revy et al., 2002
Bioavailability of different Zn sources

- **ZnO**
  - 55 to 90% of ZnSO$_4$
  - "<": 3 studies; "=": 1 study

- **AA-Zn chelate**
  - "=": 1 study

- **Zn-methionine complex**
  - 77 to 120% of ZnSO$_4$
  - ">": 1 study; "=": 3 studies; "<": 1 study

- **Zn-lysine complex**
  - 80 to 110% of ZnSO$_4$
  - "=": 4 studies; "<": 1 study

The higher availability from organic sources is mainly observed in presence of phytate => suggests an effect on Zn solubility
Content

• **Context**
  – Role of Zn
  – Determination of Zn requirement in pigs
  – Biodisponibility of Zn sources

• **Zn a growth-promoting factor**
  – Effects on performance
  – Mechanism of action

• **Zn excretion and environment**
  – Effect of excess Z on the environment
  – Zn retention and excretion
  – Mechanistic models

• A holistic approach of Zn nutrition of pigs
Effect of pharmacological levels of Zn

- **Pharmacological effect of ZnO**
  - Poulsen (1989): weaning piglets, 3000 ppm ZnO for 14d
  - Confirmed in many studies since that time

- **Observed effects**
  - Reduced post weaning scouring/diarrhea
  - Improved weight gain and feed efficiency (associated with or without reduced diarrhea)
  - However some studies failed to observe any positive effect

- **Cumulative effect with Cu supplementation?**
  - Depending on the studies

- **Cumulative effect antibiotic supplementation?**
  - Yes according to Hill (2011)

⇒ Suggest different mechanisms of action
Effects of pharmacological level of ZnO on occurrence of diarrhea in weaning piglets

* with an enterotoxigenic strain of Escherichia coli
Effects of pharmacological level of ZnO on performance of weaning piglets

Hill et al., 2001
Effects of pharmacological level of ZnO on plasma concentration of Zn and Cu

Hill et al., 2001
Zn supply and plasma zinc

Homeostasy
Dietary excess
- Storage in liver, bones, enterocytes ↑
- Absorption ↓
- Bile and pancreatic secretions ↑
  - Urine ↑

Toxicity?
- Saturation of homeostatic mechanisms
- Risk of toxicity in case of long-term supplies
  => reduced feed intake, lethargy, arthritis, Cu deficiency, anemia…
Zn supply and Plasma zinc

Questions the signification of bioavailability results

■ Obtained in the zone of “deficiency”
■ Obtained in the zone of “excess-toxicity”
Effect of different Zn sources at high level on plasma Zn and performance

Some Zn sources would be able to achieve growth promoting effects at lower levels than needed for ZnO.

But they seem to also present a risk of toxicity at lower level.
Mechanisms of action of pharmacological levels of Zn

• Different mode of action have been showed although mechanisms are not completely elucidated
  – Effect on intestinal microbiota: diversity, stability
  – Effect on epithelial barrier: inter-cellular junctions
  – Reduction of adhesion of E Coli to epithelial intestinal cells
  – Improvement of local and systemic immunity
  – Preventive effects / not curative

• Many recent studies indicate the risk of development of microbial multi resistance to zinc and antibiotics
  • Co-selection of antibiotic and metal resistance
  • Increase in the proportion of multi-resistant E. coli
  • Might question the reasonability of zinc feed additives as an alternative to antimicrobial growth promoters
Effect of combination of addition of Zn and Cu as growth promoter

Hill et al. (2000)
1356 piglets
12 herds - 2 weeks post weaning

=> no additivity

Perez et al. (2014)
20 pigs / treatment
4 weeks post weaning

=> some additivity
Content

• **Context**

• **Zn an essential element for life**
  – Role of Zn
  – Determination of Zn requirement in pigs
  – Biodisponibility of Zn sources

• **Zn a growth-promoting factor**
  – Effects on performance
  – Mechanism of action

• **Zn excretion and environment**
  – Effect of excess Zn on the environment
  – Zn retention and excretion
  – Mechanistic models

• **A holistic approach of Zn nutrition of pigs**
Environmental effects of trace elements

• **Accumulation in soils** *(Coppenet et al., 1993)*
  – Zn => +0.41 ppm/year (1973-1988)
  – Cu => +0.37 ppm/year (1973-1988)

• **Toxicity** *(McGratz et al, 1995; Morel 1997)*
  – to plants : 100 ppm Cu, 300 ppm Zn (DM)
  – to microbial activity : 50 ppm Cu, 150 ppm Zn (DM)

• **Transfer to water ecosystems** *(Arzul and Maguer, 1990)*
  – Possible accumulation in rivers and estuarine sediments
Zn content of feed and pig manure

Levasseur et Texier. 2001
Comparison of supply of different nutrients by pig manure and export by wheat

Levasseur et Texier. 2001
Flow of Zn in a “cereal-pig” farm

Dourmad & Jondreville 2008
Trace elements in animal prod sys., 139-142.
Comparison of Zn content of pig manure with different regulations/reference

- **Weaner**
- **Fattening**
- **Lactation**
- **Gestation**

**mg/kg DM**

- **Sewage sludge**
- **Organic fertilizer**
- **EU Ecolabel Cerafel**
Zn retention by pigs

• Body Zn content
  – Zn $\approx 2100$ mg for a pig of 100 kg body weight
  • muscles ($\approx 60\%$), bones ($\approx 30\%$), organs ($\approx 10\%$)
  • $\approx$ to 0.7 kg of a weaner diet with ZnO supp.
  – Zn (mg) = 21 x BW (kg) \ ($n=52$, $R^2 = 0.95$)
Evolution of Zn excretion by pigs according to EU regulation and perspectives (farrow-to-finish farm)

- **Former EU regulation + 2500 ppm Zn as GF**
  - Intake: 100 g
  - Excretion: 90 g

- **2003 EU regulation and 2500 ppm Zn as GF**
  - Intake: 60 g
  - Excretion: 50 g

- **2003 EU regulation**
  - Intake: 40 g
  - Excretion: 30 g

- **Perspectives**
  - Intake: 20 g
  - Excretion: 10 g

Intake and excretion values are given in g of Zn per slaughter pig (0-110 kg).
Evolution of Zn content in DM excreta with different scenarios

- Former EU regulation + 2500 ppm Zn as GF
- 2003 EU regulation + 2500 ppm Zn as GF
- 2003 EU regulation
- Perspectives

Sewage sludge
Organic fertilizer
EU Ecolabel
Time to reach 150 mg Zn / kg DM soil with different scenarios

Years to reach 150 mg/kg soil DM

- Former EU regulation + 2500 ppm Zn as GF
- 2003 EU regulation + 2500 ppm Zn as GF
- 2003 EU regulation
- Perspectives

What is sustainable?
Effect slurry treatment on Zn in effluent with the actual EU regulation on Zn in feed
Your current situation

Post-weaning
- FCR post-weaning: 1.75 kg/kg
- Initial weight: 6 kg
- Final weight: 32 kg

- Prestarter feed: 5 kg/pig
- Starter feed: 37 kg/pig
- Zn content - prestarter: 150 ppm
- Zn content - starter: 150 ppm

Balance retention / excretion
- Zn (g/pig)

- Retained: 10 mg/kg
- Excreted: 20 mg/kg
- Excreted (EU): 20 mg/kg

Simulation

Post-weaning
- FCR post-weaning: 1.75 kg/kg
- Initial weight: 6 kg
- Final weight: 32 kg

- Prestarter feed: 5 kg/pig
- Starter feed: 37 kg/pig
- Zn content - prestarter: 2450 ppm
- Zn content - starter: 150 ppm

Balance retention / excretion
- Zn (g/pig)

- Retained: 10 mg/kg
- Excreted: 20 mg/kg
- Excreted (EU): 20 mg/kg

Fattening

- FCR fattening: 2.35 kg/kg
- Weight at slaughter: 115 kg

- Early grower feed: 150 ppm
- Grower feed: 150 ppm
- Finisher feed: 150 ppm

Balance retention / excretion
- Zn (mg/kg DM)

- Retained: 1202 mg/kg
- Excreted: 1155 mg/kg
- Excreted (EU): 171 mg/kg

Zn content in excreta

- Zn in animal waste, mg/kg DM

- Post-weaning: 1202 mg/kg
- Fattening: 1155 mg/kg
- Total: 171 mg/kg

Zn content - early grower: 150 ppm
Zn content - grower: 150 ppm
Zn content - finisher: 150 ppm

Zn content in excreta

- Zn in animal waste, mg/kg DM

- Post-weaning: 1202 mg/kg
- Fattening: 1155 mg/kg
- Total: 171 mg/kg

Zn content - early grower: 150 ppm
Zn content - grower: 150 ppm
Zn content - finisher: 150 ppm

Calculation EU reference
Take-home message

• Zn is an essential element for life and need to be added to pig diets

• Zn requirement
  – Most results obtained on young animals
  – Requirement depends on dietary phytate content
  – Phytase has a significant contribution to “Zn supply”

• Short-term pharmacological supplies of Zn have positive effects on performance of weaning piglets
  – feed intake, growth, diarrhea - mechanisms not well known
  – risk of development of microbial multi-resistance

• accumulation of Zn in soil due to pig manure spreading may have adverse effect on plant and microorganism

⇒ A holistic approach of Zn nutrition of pigs is required (economy, performance, environment, microbial resistance)
Thank you for your attention...