# Data quantifying the behaviour of macro and trace elements along the feed – manure – treated waste continuum in pig production

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Data Article

# Data quantifying the behaviour of macro and trace elements along the feed – manure – treated waste continuum in pig production

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ABSTRACT

Manure from animal production is commonly spread on agricultural soil as an organic fertiliser to provide macro and trace elements to crops. However, some trace elements can accumulate in the soil and become toxic to plants and microorganisms. These elements include copper (Cu) and zinc (Zn), which can be applied in large quantities when pig manure is spread. The feeding strategy and manure management (e.g. through treatment chains) are two mechanisms identified to better control the use of these elements, but their fate from the feed to the soil in pig production remains poorly documented. Better understanding the fate of Cu and Zn, as well as that of other trace and macro elements, along the feed – excreta – waste chain is required to develop alternative ways to reduce their environmental impacts. This dataset provides insight into the composition (Cu, Zn and other trace and macro elements) of organic products along two contrasting manure management chains: (1) only storage or (2) in-building separation, anaerobic digestion (AD) of solids, and digestate drying. Feed, raw slurry, liquid and solid

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phases after separation of the manure and AD products were sampled and then analysed to measure their total compound contents.



Specifications Table

| | |
|---|---|
| Subject | Animal Science, Waste Management and Disposal |
| Specific subject area | Feed, manure and treated waste composition in pig production |
| Data format | Raw |
| Type of data | Tables |
| Data collection | Samples of pig feed were obtained from Cooperl, the feed supplier for the farms from which manure samples were collected. Samples were ground in a blender (1 mm) and stored at 4 °C until analysis.<br>Organic products, including raw slurry, liquid and solid manure after in-building separation, the substrate mixture for anaerobic digestion (AD), raw digestate and dried digestate were sampled four times during two months in 2021. Raw slurry and the liquid and solid phases were collected from storage locations. The substrate mixture and raw and dried digestate were sampled directly from a pipe on an AD unit. Samples were then freeze-dried, ground in a blender and stored at 4 °C until analysis.<br>Data were acquired using traditional physico-chemical analyses and equipment, including oven drying, furnace calcination, mineralisation, the Dumas method, a Buchi MultiKjel and inductively coupled plasma optical emission spectrometry. |
| Data source location | Samples were collected from two pig farms in western France (Farm 1: Eréac, 48° 16′ 29.4” N, 2° 20′ 51.1” W; Farm 2: Plénée-Jugon 48° 22′ 41.7” N, 2° 21′ 58.3” W) in the department of Côtes-d’Armor (Bretagne, France) and from an AD unit (48° 28′ 54.5” N, 2° 29′ 59.5” W) in the same department. |
| Data accessibility | Repository name: Recherche Data Gouv, Data INRAE, Pegase<br>Data identification number: https://doi.org/10.57745/JOB6YM |

## 1. Value of the Data

- Little research has been performed on the fate of elements, especially copper (Cu) and zinc (Zn), from feed, through pig manure, and then to organic products that are spread on soil. This dataset provides mean chemical characteristics of organic products throughout the manure management chain in pig production: feed, raw slurry, liquid and solid waste from the separation of urine and faeces under slats using a V-shaped scraper, the substrate mixture for AD, raw digestate and dried digestate.
- These data can be useful for agricultural researchers and engineers to develop strategies that improve manure management and use of pig manure.
- Researchers could use these data to improve or calibrate/evaluate models that simulate dynamics of elements in pig production.
- These data could form part of a future database on the fate of trace elements in an entire chain of feed and manure management, which could be useful for constructing models to predict trace-element flows from the feed to the soil in order to assess the influence of pig production and manure management.

## 2. Background

The review of the literature revealed that, as far as we know, there are no studies assessing the fate of copper (Cu) and zinc (Zn) throughout the pig production, and then on the feed-animal-manure-treated waste continuum. In fact, several studies focus on the scale from feed to manure, studying the effect of feed content on concentrations in manure. Similarly, several studies evaluated the fate of Cu and Zn on the scale from manure to products after waste treatment (composting, anaerobic digestion…), without providing information on dietary levels. The aim of compiling this dataset was therefore to have a field approach to complete the literature on the whole pig industry.

## 3. Data Description

Manure is commonly spread on agricultural soil as organic fertiliser, but some trace elements in it, especially Cu and Zn, can have negative environmental impacts [1]. These elements are added to pig feed to meet the nutritional requirements and promote the health and performance of the pigs. However, more than 90% of ingested Cu and Zn is excreted in pig manure [2], which is then spread on agricultural soil. Feeding management is the main lever to reduce the Cu and Zn contents in pig manure and hence the accumulation of these elements in soils after spreading. Consequently, manure is treated to increase its value as an organic fertiliser. Phase separation treatment concentrates Cu and Zn in the solid phase. V-shaped scraper separation is used to separate urine and faeces inside the building frequently, which decreases their storage time in the building [3] and thus decreases gas emissions inside the building. This type of separation can concentrate 90–95% of Cu and Zn in the solid phase [3]. The fertilising value of this solid phase can be increased through AD, during which several elements (nitrogen (N), phosphorus (P), potassium (K), Cu and Zn) are retained, and the digestate (i.e. the product of AD) obtained can be spread as fertiliser [4,5]. In fact, AD improves the fertility of pig wastes. A commercial bio-organic fertiliser has a total N concentration of 17,1 g/kg DM, total P concentration of 25,4 g/kg DM and total K concentration of 18,0 g/kg DM and AD increase total N content while reducing total P and K content [6,7]. However, AD concentrates Cu and Zn in the digestate due to the loss of organic matter as biogas. Moreover, AD influences the speciation of Cu and Zn and reduces their phyto-availability [8]. In the European Union, since July 2022, the maximum levels of Cu and Zn authorised in organic fertilisers have been reduced to 300 and 800 mg/kg of dry matter, respectively [9]. However, until now, there is no restriction for the spread of raw animal manure concerning these elements. Plants require on average between 5 and 20 mg/kg of Cu [10] and contain between 10 and 100 mg/kg of Zn [11]. Few studies have assessed the complete flow of Cu and Zn from feed, through the animal, to treated products, or the interaction between the pig diet and manure treatment. Increasing understanding of the fate of Cu and Zn through this flow chain could help develop strategies that improve Cu and Zn management in pig production.

Feed samples use in pig farms (Farm 1 and 2, respectively) during the fattening period were obtained from Cooperl, the feed supplier for the two farms. Samples were only one time. Pigs received of the two farms four types of feed: two grower feeds (grower 1 and 2) and two finisher feeds (finisher 1 and 2). The compound contents of these feeds varied (Table 1).

Raw slurry from fattening pigs was sampled from Farm 1. Liquid and solid phases of fattening pig slurry separated using a V-shaped scraper were sampled from Farm 2. In addition,

**Table 1**
Total compound contents of the grower and finisher feeds collected from the feed supplier. DM: dry matter.

| | g/kg | g/kg DM | | | | | | mg/kg DM | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Feed | DM | Ca | K | Mg | Na | P | S | Cu | Mn | Zn |
| Grower 1 | 901 | 6.98 | 6.77 | 1.73 | 2.54 | 4.34 | 2.47 | 21.5 | 71.1 | 107 |
| Grower 2 | 900 | 6.12 | 6.27 | 1.89 | 2.51 | 4.3 | 2.68 | 13.6 | 62.6 | 97 |
| Finisher 1 | 898 | 6.41 | 6.52 | 1.84 | 3.04 | 4.58 | 2.55 | 16.5 | 77.4 | 111 |
| Finisher 2 | 901 | 5.74 | 6.38 | 1.73 | 2.71 | 4.42 | 2.31 | 12.1 | 68.2 | 106 |

**Table 2**
Total compound contents of waste collected from the two farms as a function of sampling period. DM: dry matter.

| | % | g/kg DM | | | | | | | | | | mg/kg DM | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Waste product | DM | Ash | VS | N tot | N-$NH_4$ | Ca | K | Mg | Na | P | S | Cu | Mn | Zn |
| **Raw slurry (Farm 1)** | | | | | | | | | | | | | | |
| 1 | 1.4 | 579 | 421 | *NA* | 0.91 | 18.3 | 153 | 5.4 | 68.3 | 9.0 | 10.1 | 188 | 299 | 572 |
| 2 | 1.2 | 583 | 417 | *NA* | 1.14 | 17.7 | 205 | 4.0 | 89.6 | 7.7 | 12.0 | 153 | 223 | 381 |
| 3 | 2.2 | 449 | 551 | *NA* | 2.20 | 15.3 | 132 | 5.0 | 63.2 | 7.9 | 11.5 | 199 | 305 | 612 |
| 4 | 1.6 | 507 | 493 | *NA* | 1.38 | 10.0 | 155 | 3.0 | 77.0 | 5.1 | 10.3 | 99 | 122 | 231 |
| **Mean** | **1.6** | **530** | **470** | *NA* | **1.41** | **15.3** | **161** | **4.3** | **74.5** | **7.4** | **11.0** | **160** | **237** | **449** |
| **Standard deviation** | **0.4** | **64** | **64** | *NA* | **0.56** | **3.8** | **31** | **1.1** | **11.6** | **1.7** | **0.9** | **46** | **85** | **177** |
| **Solid phase (Farm 2)** | | | | | | | | | | | | | | |
| 1 | 23.4 | 170 | 830 | 3.52 | 5.48 | 22.7 | 21.9 | 10.1 | 8.4 | 13.4 | 8.0 | 180 | 502 | 785 |
| 2 | 23.0 | 166 | 834 | 3.16 | 3.19 | 22.8 | 19.3 | 10.3 | 7.0 | 16.1 | 5.8 | 185 | 498 | 791 |
| 3 | 24.6 | 182 | 818 | 3.37 | 4.38 | 19.3 | 20.8 | 8.4 | 6.5 | 9.62 | 6.2 | 364 | 448 | 734 |
| 4 | 25.4 | 179 | 821 | 3.78 | 3.29 | 24.8 | 20.5 | 10.9 | 7.7 | 15.1 | 6.7 | 185 | 493 | 750 |
| **Mean** | **24.1** | **174** | **826** | **4.09** | **3.46** | **22.4** | **20.6** | **9.9** | **7.4** | **13.6** | **6.7** | **229** | **486** | **765** |
| **Standard deviation** | **1.1** | **8** | **8** | **1.08** | **0.26** | **2.3** | **1.1** | **1.1** | **0.8** | **2.9** | **1.0** | **91** | **25** | **27** |
| **Liquid phase (Farm 2)** | | | | | | | | | | | | | | |
| 1 | 2.5 | 497 | 503 | *NA* | 3.39 | 9.2 | 140 | 8.5 | 57.6 | 16.0 | 32.4 | 56 | 146 | 249 |
| 2 | 2.1 | 588 | 412 | *NA* | 4.09 | 8.2 | 132 | 6.3 | 60.8 | 7.3 | 35.9 | 40 | 90 | 154 |
| 3 | 2.6 | 451 | 549 | *NA* | 2.84 | 5.9 | 156 | 7.8 | 56.2 | 2.4 | 38.5 | 40 | 52 | 97 |
| 4 | 2.3 | 520 | 480 | *NA* | 3.04 | 8.8 | 152 | 7.2 | 62.0 | 45.0 | 30.0 | 46 | 96 | 148 |
| **Mean** | **2.3** | **514** | **486** | *NA* | **3.34** | **8.0** | **145** | **7.4** | **59.1** | **7.7** | **34.2** | **46** | **96** | **162** |
| **Standard deviation** | **0.2** | **57** | **57** | *NA* | **0.55** | **1.5** | **10.9** | **0.9** | **2.7** | **5.9** | **3.8** | **8** | **39** | **63** |

substrate mixture for AD, raw digestate and dried digestate were sampled from an AD unit that had received the solid phase from Farm 2, among other substrates. The substrates for AD included the solid phase from farms equipped with a V-shaped scraper (30% of the mixture's mass), combined with agro-industrial waste (i.e. slaughterhouse waste and processing water). Dried digestate is obtained after nitrogen recovery by stripping and evapo-concentrating raw digestate. Samples were taken four times, at two-week intervals. The total compound contents of the organic products are given in Tables 2 and 3. To facilitate comparison of the treatment phases (V-shaped scraper vs. AD vs. stripping and evapo-concentration), mean contents for the four sampling periods for each product were also calculated.

## 4. Experimental Design, Materials and Methods

### *4.1. Sampling*

Feed samples were obtained from Cooperl, the feed supplier for the farms from which manure samples were collected. The samples were ground in a blender (1 mm) and stored at 4 °C until analysis.

Manure samples from the two pig farms were collected every two weeks for two months (i.e. four sampling periods) in March and April 2021. Farm 1 was a fattening pig system whose raw slurry was stored in an uncovered pit outside the building before being spread. The raw slurry was sampled directly from the pit using a 2 L container. The pit had no mixing system (Fig. 1).

Farm 2 was a farrow-to-finish system that had one fattening building equipped with a V-shaped scraper. The liquid and solid phases from separating the manure from these buildings were stored separately. The liquid phase, stored in a covered pit, was sampled using a 2 L container from a pipe connected to the pit. The solid phase, stored on a covered manure pad, was sampled directly from the pad.

**Table 3**
Total compound contents of waste collected from the anaerobic digestion (AD) unit as a function of sampling period. DM: dry matter.

| | % | g/kg DM | | | | | | | | | | mg/kg DM | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Waste product | DM | Ash | VS | N tot | TAN | Ca | K | Mg | Na | P | S | Cu | Mn | Zn |
| **Substrate mixture for AD** | | | | | | | | | | | | | | |
| 1 | 13.5 | 235 | 765 | 2.97 | 3.85 | 23.4 | 14.2 | 6.9 | 8.1 | 14.0 | 6.7 | 121 | 353 | 747 |
| 2 | 11.1 | 163 | 837 | 2.84 | 3.60 | 17.7 | 11.5 | 5.9 | 6.8 | 11.5 | 5.7 | 103 | 275 | 488 |
| 3 | 11.2 | 213 | 787 | 2.87 | 3.66 | 28.3 | 13.2 | 7.5 | 8.1 | 13.2 | 5.6 | 115 | 354 | 523 |
| 4 | 12.9 | 183 | 817 | 2.67 | 4.59 | 21.8 | 9.6 | 5.4 | 7.0 | 13.5 | 6.5 | 111 | 347 | 589 |
| **Mean** | **12.2** | **198** | **802** | **2.84** | **3.93** | **22.8** | **12.1** | **6.4** | **7.5** | **13.0** | **6.1** | **113** | **332** | **587** |
| **Standard deviation** | **0.2** | **32** | **32** | **0.12** | **0.45** | **4.4** | **2.0** | **0.9** | **0.7** | **1.1** | **0.6** | **8** | **38** | **115** |
| **Raw digestate** | | | | | | | | | | | | | | |
| 1 | 6.8 | 294 | 706 | *NA* | 5.39 | 31.9 | 22.6 | 10.5 | 12.3 | 23.6 | 11.5 | 228 | 531 | 962 |
| 2 | 6.6 | 299 | 701 | 4.49 | 3.78 | 31.9 | 24.6 | 10.5 | 13.3 | 23.4 | 12.3 | 225 | 512 | 906 |
| 3 | 6.9 | 293 | 707 | 4.84 | 3.48 | 29.2 | 21.9 | 9.5 | 11.9 | 21.6 | 11.6 | 221 | 504 | 900 |
| 4 | 6.8 | 291 | 709 | 4.68 | 4.09 | 30.8 | 20.9 | 10.1 | 13.7 | 22.6 | 11.7 | 228 | 518 | 924 |
| **Mean** | **6.8** | **294** | **706** | **4.67** | **4.19** | **30.9** | **22.5** | **10.2** | **12.8** | **22.8** | **11.8** | **225** | **516** | **923** |
| **Standard deviation** | **0.14** | **3** | **3** | **0.18** | **0.84** | **1.3** | **1.6** | **0.46** | **0.85** | **0.93** | **0.3** | **3** | **11** | **28** |
| **Dried digestate** | | | | | | | | | | | | | | |
| 1 | 70.9 | 295 | 705 | 1.31 | 3.48 | 34.2 | 21.5 | 11.5 | 14.3 | 25.8 | 14.3 | 247 | 572 | 1011 |
| 2 | 73.5 | 307 | 693 | 3.96 | 3.58 | 33.0 | 21.3 | 10.7 | 15.8 | 23.8 | 23.2 | 235 | 537 | 969 |
| 3 | 75.4 | 291 | 709 | 5.04 | 3.85 | 33.1 | 17.0 | 10.9 | 11.9 | 23.7 | 24.9 | 237 | 548 | 974 |
| 4 | 94.8 | 282 | 718 | 0.94 | 3.37 | 34.3 | 16.8 | 11.4 | 11.4 | 24.6 | 15.9 | 239 | 555 | 962 |
| **Mean** | **78.6** | **294** | **706** | **2.81** | **3.57** | **33.6** | **19.1** | **11.1** | **13.4** | **24.5** | **19.6** | **240** | **553** | **979** |
| **Standard deviation** | **10.9** | **10** | **10** | **2.00** | **0.20** | **0.7** | **2.6** | **0.4** | **2.1** | **0.9** | **5.2** | **5** | **14** | **22** |

**Fig. 1.** The uncovered pit on Farm 1 from which raw slurry was collected.

The substrate mixture for AD, raw digestate and dried digestate were sampled from a pipe on the AD unit of Cooperl the same week that the farms were sampled.

After collection, samples were sub-sampled to measure their dry matter (DM) and volatile solid (VS) contents, and then freeze-dried, ground in a blender (1 mm) and stored at 4 °C until chemical analysis. The remaining samples were stored at −20 °C until analysis.

### *4.2. Chemical analyses*

The DM content of effluent was measured by heating the samples at 103 °C for 24 h, and the ash and VS contents were subsequently measured after calcination at 550 °C for 18 h. The Dumas method was used to measure the N content of the solid phase and AD products (i.e. substrate mixture, raw digestate and dried digestate) using a rapid N analyser (Elementar, Lyon, France) according to the standard method [12]. Total ammoniacal N was measured by steam distillation using a distillation unit (Buchi MultiKjel) and MgO followed by trapping of N in boric acid and back titration of the boric acid using an inline titrator (848 Titrino Plus, Metrohm) and sulphuric acid (0.1 M) according to the standard method [13]. Phosphorus, calcium, magnesium, potassium, sodium, sulphur, Zn, Cu and manganese contents of dried samples were measured using inductively coupled plasma optical emission spectrometry (Agilent 5110, Coutaboeuf, France), according to NF-EN 15621 for feed and NF-EN 16174 for the other samples. All analyses on effluent were performed in duplicate, and on feed in four replicates at INRAE laboratories.

## Limitations

The uncovered pit from which raw slurry was sampled had no mixing system. Consequently, the slurry sampled was not completely homogeneous, and its chemical characteristics in the dataset may not be completely representative.

## Ethics Statement

The authors have read and followed the ethical requirements for publication in *Data in Brief* and confirm that the current study does not involve human subjects, animal experiments or any data collected from social media platforms.

## Data Availability

Data quantifying macro and trace elements behaviour along the feed–manure–treated waste continuum in pig production (Original data) (Recherche Data Gouv, Data INRAE, Pegase)

## CRediT Author Statement

**Emma Gourlez:** Methodology, Investigation, Formal analysis, Writing – original draft; **Fabrice Beline:** Methodology, Validation, Writing – review & editing; **Jean-Yves Dourmad:** Methodology, Writing – review & editing; **Alessandra Rigo Monteiro:** Methodology, Writing – review & editing; **Marine Charra:** Investigation, Writing – review & editing; **Francine de Quelen:** Conceptualization, Funding acquisition, Writing – review & editing.

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## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this data paper.

## References

[1] M.C. McGrath, Implications of applying copper rich pig slurry to grassland; effects on plant and soil, in: P. L'Hermite, J. Dehandtschutter (Eds.), Copper in Animal Wastes and Sewage Sludge, Proc. EEC Workshop, INRA Publisher, Bordeaux, France, 1981, pp. 144–153, doi:10.1007/978-94-009-8503-2_10.

[2] J.-Y. Dourmad, P. Levasseur, M. Daumer, M. Hassouna, B. Landrain, N. Lemaire, A. Loussouarn, Y. Salaün, S. Espagnol, Évaluation des rejets d'azote, phosphore, potassium, cuivre et zinc des porcs, RMT Elevages Environn. (2015) 26 Paris, France.

[3] A. Loussouarn, S. Lagadec, P. Robin, M. Hassouna, Raclage en ≪ V ≫: bilan environnemental et zootechnique lors de sept années de fonctionnement à Guernevez, J. Rech. Porcine 46 (2014) 199–204.

[4] C.E. Marcato, E. Pinelli, M. Cecchi, P. Winterton, M. Guiresse, Bioavailability of Cu and Zn in raw and anaerobically digested pig slurry, Ecotoxicol. Environ. Saf. 72 (2009) 1538–1544, doi:10.1016/j.ecoenv.2008.12.010.

[5] A.C. Amaral, A. Kunz, R.L. Radis Steinmetz, K.C. Justi, Zinc and copper distribution in swine wastewater treated by anaerobic digestion, J. Environ. Manage. 141 (2014) 132–137, doi:10.1016/j.jenvman.2014.03.021.

[6] S. Yun, T. Xing, Y. Wang, R. Chen, F. Han, C. Zhang, M. Zou, Mineral residue accelerant-enhanced anaerobic digestion of cow manure: an evaluation system of comprehensive performance, Sci. Total Environ. 858 (2023) 159840, doi:10.1016/j.scitotenv.2022.159840. 10.1016/j.biortech.2022.126729.

[7] K. Wang, S. Yun, T. Ke, J. An, Y. Abbas, X. Liu, M. Zou, L. Liu, J. Liu, Use of bag-filter gas dust in anaerobic digestion of cattle manure for boosting the methane yield and digestate utilization, Bioresour. Technol. 348 (2022) 126779.

[8] S. Legros, C. Levard, C.-E. Marcato-Romain, M. Guiresse, E. Doelsch, Anaerobic digestion alters copper and zinc speciation, Environ. Sci. Technol. 51 (2017) 10326–10334, doi:10.1021/acs.est.7b01662.

[9] Regulation (EU) 2019/1009 of the European parliament and of the council of 5 June 2019 (2019), https://eur-lex.europa.eu/legal-content/FR/TXT/?uri=CELEX%3A32019R1009.

[10] V. Kumar, S. Pandita, G.P. Singh Sidhu, A. Sharma, K. Khanna, P. Kaur, A.S. Bali, R. Setia, Copper bioavailability, uptake, toxicity and tolerance in plants: a comprehensive review, Chemosphere 262 (127810) (2021) 24, doi:10.1016/j.chemosphere.2020.127810.

[11] I. Gräber, J.F. Hansen, S.E. Olesen, J. Petersen, H.S. Østergaard, L. Krogh, Accumulation of copper and zinc in Danish agricultural soils in intensive pig production areas, Danish J. Geogr. 105 (2005) 15–22, doi:10.1080/00167223.2005.10649536.

[12] Association of Official Analytical Chemists (AOAC), Official Methods of Analysis, AOAC, Arlington, VA, USA, 1990.

[13] APHA, Standard Methods for the Examination of Water and Wastewater, 20th ed., American Public Health Association, Washington, DC, USA, 1998.