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Abstract: The second half of the nineteenth century was marked by the concomitant and entangled processes of the rise of agricultural chemistry and that of the fertiliser trade. Yet, while the two were undoubtedly related, the work of agricultural chemists was not necessarily characterized by the uniform and unequivocal promotion of fertilisers. This article looks at some of the complex ways in which chemists participated in the development of the fertiliser trade by studying how their work was used to ascribe a commercial price to a chemical element. It analyses the contested development of the idea that nitrogen, in particular, could be given a price, and shows how the rise of this quotation lay at the intersection of scientific and commercial considerations. More broadly, it argues that the importance of the new *artificial* fertilisers primarily lay not so much in yield increases as in inaugurating a new regime marked by a more comprehensive quantitative assessment of inputs and outputs, thereby playing a key role in the *industrialisation* of agriculture.

JEL-Codes: N 10, N 13, N 54, Q 11, Q 13

Keywords: fertilisers, nitrogen, chemistry, agriculture, nitrates, Düngemittel, Stickstoff, Chemie, Landwirtschaft, Nitrate

1 Introduction

In 1902, the Agronomic Station of the Calvados and Manche (University of Caen, Normandy) issued a poster which explained to farmers how they should pro-

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ceed when buying fertilisers. They explained that fertilisers contained three important elements – nitrogen, potash and phosphoric acid – and advised farmers to memorize the approximate *price* of these three elements which, in 1902 in Caen, they gave as: nitrogen, 1.60-1.70 fr/kg, potash, 0.48-0.52fr/kg, phosphoric acid, 0.20-0.58fr/kg (depending on the form it came in and whether it was soluble or not).[1] Whenever they bought a fertiliser, farmers should calculate its real value to ascertain whether the price asked for it corresponded to market prices. The poster then went on to illustrate with the example of a mixed fertiliser containing 4 percent ammonia nitrogen, 5 percent potash and 6 percent soluble phosphoric acid. Based on the prices quoted above, farmers should have been able to calculate that 100 kg of this fertiliser were worth 11.80fr.[2]

This poster illustrates how, by the early 20th century, farmers were supposed to be familiar enough with the nature of various chemical elements, but also how these chemical elements had acquired a relatively fixed price, which would have been rather unimaginable 50 years earlier. This article aims at tracing the rise of this type of quotation which ascribed a standard price to chemical elements, by focusing on the question of the price of nitrogen in Great Britain and France in the second half of the nineteenth century. It studies how agronomists played a fundamental role in the commodification of fertilisers which, unlike farmyard manure, presented much more fixed and stable compositions, and thus lent themselves more easily to a form of distant and quantified expertise. The article however shows that the idea of the *price of nitrogen* was an abstraction that was long resisted, even by agricultural chemists. It shows how the rise of this type of quotation was thus the product of the rise of agricultural chemistry, but within a particular commercial context. This paper argues that the importance of the new *artificial* fertilisers lay not primarily in the yield increases that they made possible, but in that they inaugurated a new regime where inputs could be measured quantitatively so as to assess more precisely, as was argued, the nature of profitable investments. By tracing the rise of a new regime marked by a more comprehensive quantitative assessment of inputs and outputs, this paper seeks to analyse how the rise of this abstraction represented a key element in the *industrialisation* of agriculture.

1 Archives départementales de l'Orne, M/1970.

2 The calculation was as follows: total price of 100 kgs of this fertiliser = price of nitrogen (4*1.60=6.40fr) + price of potash (5*0.48=2.40fr) + price of soluble phosphoric acid (6*0.50=3fr).

2 Measuring Nitrogen Content (1850–1870)

If the importance of nitrogenous elements, such as ammonia or *nitrous salts* in plant growth had long been recognised, it was only around 1840 that agricultural chemists started to narrow their focus on this single chemical element and tried to use it to classify various forms of fertilisers based on their proportion of nitrogen.[3] In 1841, French scientist Jean-Baptiste Boussingault argued that the higher the proportion of nitrogen a fertiliser contained, the more efficient it would be: "it is the proportion (of nitrogen) which according to us establishes the comparative value of fertilisers and the mutual equivalences between them".[4] The role of nitrogen in plant growth was far from being a settled question in the 1840s, and in the third edition of his book, *Organic chemistry in its applications to agriculture and physiology* (1843), Justus von Liebig asserted that plants could assimilate nitrogen from the atmosphere, which, if true, would have rendered nitrogenous fertilising superfluous.[5] Liebig came under attack for this from other agricultural chemists such as Jean-Baptiste Boussingault in France or John Bennet Lawes and Joseph Henry Gilbert in Great Britain, but only recanted from his position in 1856. Despite this controversy, nitrogen started to be increasingly used from the very early 1840s as the main indicator used to measure the quality of a fertiliser. Along with another French chemist, Anselme Payen, Boussingault thus published long lists and tables presenting the nitrogen content of a whole range of fertilisers: farmyard manure, different types of straw and oilcakes, animal and human excrements, rags, ground horn, beet pulp, grape marc, effluents of starch factories, feathers, dried blood, etc. Farmyard manure was set as a reference index (with a 100 value), and many other fertilising substances were then ascribed a number, based on their nitrogen content, to measure their value: 15 for wheat straw, 307 for linseed cakes or 194 for cow urine, etc.

These tables were then frequently used, notably by agricultural chemists in Great Britain, to measure the value of fertilisers based on their chemical con-

3 See for example *H. Davy*, Elements of Agricultural Chemistry, in a Course of Lectures for the Board of Agriculture, Philadelphia 1815, p. 56. Davy did not write about nitrogen but about *azote*, using the French name that was still widely used at the beginning of the nineteenth century.

4 *J.B. Boussingault/A. Payen*, Mémoire sur les engrais et leurs valeurs comparées, in: *Annales de Chimie et de Physique* 3, 1841, p. 69.

5 *W.H. Brock*, Justus von Liebig: The Chemical Gatekeeper, Cambridge 1997, p. 148.

tents, and to create grades and scales of comparison.[6] In the context of the rapid development of a larger market for fertilisers, it was increasingly important to be able to assess and compare their commercial value, and nitrogen was increasingly used as the indicator which would render all these fertilisers commensurable. The commercial value of these fertilisers was, however, not included. The diversity of fertilisers, their prices and their proportion of fertilising elements precluded this in any case, and attempts to give a price to nitrogen in various manures (oilcakes, rags, etc.) showed that prices could vary by a factor of 10.[7] These tables comparing the various forms of fertilisers, could however theoretically be used by farmers to calculate which fertilisers presented the best fertilising value/cost ratio, and thus to decide how and when the benefits of purchasing such manures outweighed the costs.

This question of assessing the commercial value of fertilisers became all the more important as the 1840s saw the very rapid rise of one nitrogenous fertiliser: Peruvian guano. By the late 1840s, around 100,000 tons were imported into Great Britain each year.[8] With the rise of the guano trade, it was essential to assess the fertilising value of this new manure, and many farmers and experimenters presented the results of their comparative trials. Most of these relied not on chemical analysis but mostly on measuring the increase in yields resulting from the application of guano, in order to assess the extent to which the use of guano could be profitable. The problem with these trials is that they were mostly individual and local cases. More importantly, they afforded no indication as to the considerably varying quality of guano, and the sale of adulterated or *inferior* products was the source of frequent concern. It was thus necessary to measure precisely the content of the various guanos on the market and to focus on the three elements that mattered in guano (ammonia, phosphate of lime and potash) in order to be able to compare the value of guano to other forms of fertilisers.[9] It is thus significant that if guano did not figure in the tables published by Boussingault and Payen, it was included in a second article published a year later.[10]

6 *H. Davy*, Elements of Agricultural Chemistry, Glasgow 1844, p. 247; *J.T. Way*, On the Composition and Money Value of the Different Varieties of Guano, in: Journal of the Royal Agricultural Society of England 10, 1849, p. 197.
7 *A. de Gasparin*, Cours d’agriculture, Paris 1846, p. 548.
8 *F.M.L. Thompson*, The Second Agricultural Revolution, 1815-1880, in: The Economic History Review 21/1, 1968, p. 78.
9 *Way*, Composition.
10 *J.B. Boussingault/A. Payen*, Mémoire sur les engrais, deuxième mémoire, in: Annales de Chimie et de Physique 6, 1842, pp. 449-464.

3 Giving a Standard Price to Ammonia

Guano increasingly became the most discussed input and the pivot of a new regime of measurement which could provide an index, and a price, to fertilising elements, and the late 1840s saw some of the earliest attempts at giving an abstract price to ammonia (NH_3, a compound of nitrogen and hydrogen). British agronomist J. B. Lawes calculated in 1847 that half a ton of guano, purchased at a cost of £ 5 would yield 120 lbs of ammonia, which made ammonia at a price of 10d per lb.[11] The problem with Lawes' calculation was that, as seen before, the price and nitrogen composition of guano were subject to frequent variations. J. T. Way, Consulting Chemist to the Royal Agricultural Society, attempted therefore to find another way to set an average price for ammonia and to compare the value of ammonia as contained in guano with other forms of ammonia. For this he chose to focus on sulphate of ammonia, a by-product of the gas and coal industries. The sulphate of ammonia industry was still in its infancy in the 1840s and it was only in the late nineteenth century that it started to be produced on a massive scale.[12] Yet, there were already a few works producing it in England, and Way thought that this industry was bound to become increasingly important: "the gasworks of England are destined some day, and probably before long, to become auxiliary to the production of food by supplying the farmer abundantly and cheaply with ammonia".[13] Way chose to focus on sulphate of ammonia for two reasons: its main advantage was, first of all, its rather stable proportion of ammonia, which Way put at 22.7 percent. Secondly, as opposed to guano or farmyard manure, sulphate of ammonia contained no other fertilising element than ammonia. It could therefore be used as a standard measure to assess its commercial value in a rather straightforward way, and Way thus valued ammonia at 6d per lb, which became accepted as the *benchmark price* in the 1850s, to compare and rank the value of different fertilising substances, and especially the various types of guano.[14]

Boussingault's experiments in the 1830s had sprung mainly from a concern in increasing yields and food supply. In Great Britain in the 1850s, however, the attempts to fix a commercial value to ammonia and nitrogen were primarily driven by another motive: if one could give an average price to nitrogen, under

11 *J.B. Lawes*, On Agricultural Chemistry, in: Journal of the Royal Agricultural Society of England 8, 1847, p. 256.

12 Management of the Gas Works, in: *Manchester Times*, 30.07.1842.

13 *Way*, Composition, pp. 219-220.

14 See for example Irish Farmer's Gazette and Journal of Practical Horticulture, 11.02.1854.

any kind of form, this would go a long way towards the transformation of agriculture into a more industrial endeavour, where one could measure inputs and outputs to assess more accurately the nature of profitable investments. As the author of a French guide for the purchasing of manure put it, the main problem with agriculture was unpredictability and the difficulty to evaluate precisely investment returns: “The clothmaker knows exactly the amount of wool and cotton needed to manufacture a metre of cloth. Could the most enlightened farmer, at the moment, tell exactly how much nitrogen, phosphoric acid and potassium are necessary to produce a hectolitre of wheat?”[15] In an era marked by increased competition due to declining shipping costs and the gradual removal of barriers to free trade (repeal of the Corn Laws in 1846 in Great Britain, Cobden-Chevalier Treaty between Great Britain and France in 1860), agricultural chemistry positioned itself as a crucial provider of information on the profitability of fertiliser expenditure.

The primary task of agricultural chemistry was therefore not so much to increase yields but mostly to discover “fixed rules”, trustworthy information which would reduce uncertainty and encourage capital investment.[16] One agricultural chemist committed to such as vision was J. C. Nesbit, who was a consulting chemist and the Principal of a College of Agriculture and Chemistry at Kennington near London. Tellingly, Nesbit used the same comparison with the textile industry as in the previous quote and argued that the importance of the new *artificial* or *purchased* fertilisers was not so much in the increase in food supply which they brought about, but in that they inaugurated a new regime where inputs and outputs and their respective prices could be measured quantitatively.

> “The introduction of artificial manuring has inaugurated a new era in the art of farming. Most cotton manufacturers, we know, turn over their money every two or three weeks, and are exceedingly careful not to lay out a penny on which they cannot realise a profit; and I would impress upon you, that if you proceed on the old system, when you have the means of determining exactly how much manure you require, you are only wasting your capital and losing your interest. […] Is it not foolish to administer at once to the soil as much as would suffice for three, or four, or five crops […]?”[17]

Building upon the work of previous agricultural chemists, Nesbit argued that the value of manures varied in proportion with their nitrogen content and that

15 *A.L. Dudouy*, Guide pratique pour le choix, l’achat et l’emploi des matières fertilisantes, Paris 1866, p. 48.
16 *Lawes*, Agricultural Chemistry, p. 226.
17 *J.C. Nesbit*, Agricultural Chemistry and the Nature and Properties of Peruvian Guano, London 1856, p. 28.

the percentage of nitrogen could be considered as "as a correct indication of manuring value".[18] Using this nitrogen content, Nesbit, like previous agricultural chemists, could build scales of comparison between guano and other forms of fertilisers, which led him to explain that one ton of guano was equivalent to 33 ½ tons of farm-yard dung or 21 tons of horse dung. By using Way's estimate of the price of ammonia (6d. per pound), Nesbit then proposed tables to enable farmers to assess the commercial value of the fertilisers they purchased. These accounting tables of nitrogen could be used not only to compare guano and other forms of fertilisers but also guano and animal feed. With these tables, farmers could use the information on nitrogen to assess and calculate beforehand what could be a profitable investment. In France, this type of argument was voiced mostly by Georges Ville who, from his chair at the Versailles Agronomic Institute, propounded what he called his "doctrine of chemical fertilisers". Like Nesbit, Ville argued that the main advantage of chemical fertilisers was the stability of their composition, which meant that their prices could be set with "certainty": "with chemical fertilisers, everything is known: the composition, the nature, the price of each element, the cost of mixing, etc".[19] It is significant that Ville and Nesbit were both highly critical of the use of farmyard manure, which they thought of as an outdated form of fertilising: first of all, farmyard manure did not contain enough ammonia. But more significantly, the problem with farmyard manure was its unstable and varying character which rendered it very ill-adapted to their project of industrialising agriculture, which relied on a more accurate quantitative assessment of inputs and outputs, of investments and profits.[20] For the advocates of artificial fertilisation, the main advantage of the new era of artificial fertilisation was thus not so much the increase in yields which they offered but the possibility they allowed of measuring precisely inputs and outputs, this information being crucial to turn agriculture into an industrial endeavour through a quantitative and commercial assessment of factors of production.

18 *Ibid.*, p. 87.

19 *G. Ville*, Les engrais chimiques: entretiens agricoles donnés au champ d'expérience de Vincennes, Paris 1869, pp. 294-299.

20 *Nesbit*, Agricultural Chemistry, p. 25.

4 A Useful Abstraction?

By the early 1860s, *artificial* fertilisers, because of their more stable composition, were thus beginning to replace farmyard manure as the standard measure of value for the evaluation of the different fertilising constituents. This may for example be seen in the debates which occurred in Great Britain around the potential fertilising and commercial value of sewage. Upon the setting up of the new sewage network in London, various attempts were made to assess the commercial value of the sewage of the metropolis, and most computations to assess this economic value focused on nitrogen or ammonia content.[21] It was for example estimated that the daily excrements of London's population contained the equivalent of 42 tons of ammonia, which was then compared to the equivalent amount contained in guano in order to ascribe a money value to sewage.[22]

However, the calculations which equated the excrements of the populations of London with so many tons of imported guano were in fact frequently proposed by enthusiastic supporters of the agricultural recycling of London's excrements, such John Mechi or Edwin Chadwick, and mostly as a way to publicize their cause.[23] Yet, these types of computations were often rejected by most agricultural chemists, even by Way, who deplored the uses made of his earlier attempts to fix an abstract price to nitrogen.[24] Leading chemist Augustus Voelcker denounced the futility of these "theoretical calculations" which could have "no practical bearing" since they did not take into account the diluted nature of this element, nor the fact that output would be constant while demand for fertilisers was mostly seasonal.[25]

It must thus be emphasized that despite the rise of quantitative assessments attempting to give a benchmark price to nitrogen, most agronomists remained extremely cautious about the value of these abstract forms of calculation. First-

21 See for example Discussion on the Sewage of London, in: Journal of the Royal Society of Arts 3/122, 1855, pp. 311-325.

22 See for example *J. Liebig*, Utilisation of Sewage, in: Journal of the Royal Society of Arts 11/561, 1863, pp. 656-657; *A. Millot*, Etude sur l'assainissement des grandes villes, in: Journal d'agriculture pratique, de jardinage et d'économie domestique 33/2, 1869, p. 878.

23 Fertilising Properties of Sewage, in: The British Farmer's Magazine 51, 1866, p. 304.

24 *Metropolitan Board of Works:* The Agricultural Value of the Sewage of London Examined in Reference to the Principal Schemes Submitted to the Metropolitan Board of Works, London 1865, p. 25.

25 *Ibid.*, p. 23. On recycling and agriculture see *L. Herment/T. Le Roux,* Recycling: the Industrial City and its Surrounding Countryside, 1750-1940, in: Journal for the History of Environment and Society 2, 2017, pp. 1-24.

ly, agricultural chemists developed a more nuanced view of the role of nitrogen in the 1850s. From the publication of Boussingault's tables, it had been repeatedly emphasized that plant nutrition did not depend solely on nitrogen, and that other substances, and amongst these firstly phosphates, had to be taken into account when assessing the commercial value of purchased manures.[26] This agronomic re-evaluation of the importance of nitrogen was not unrelated to changing trade circumstances: it was indeed occurring at a time of declining grain prices and rising nitrogen prices (the price of guano increased from £ 10 a ton in the early 1850s to £ 13 in 1856).[27] As a result of this, it became increasingly obvious that guano had to be used sparingly and that it was ill adapted to grow turnips and other root crops. Agricultural chemists thus argued that it paid "better to purchase superphosphate and similar manures for the root crops than to buy nitrogenous manures for the white crops", thereby downplaying the former importance ascribed to nitrogen.[28]

Beyond these more sober assessments of the value of nitrogen as a universal indicator of manuring and commercial value, objections were raised against the theoretical calculations ascribing a commercial value to a chemical element or compound. Even Way, whose calculations had been used by others to set the theoretical price of nitrogen, was extremely doubtful about the possibility to "fix with any degree of exactness the value of" a chemical element and increasingly insisted on the "difficulties lying in the way of a perfect valuation of manure".[29] Way insisted that all forms of nitrogen, in ammonia, in nitrate or in undecomposed animal excrements, could probably not be made commensurable: "we know that all these forms are very valuable, but we cannot yet be said to know the exact relative value of a given quantity of nitrogen in any one of them compared with another".[30] What was more, Way rejected the idea that the *effect* of nitrogen could be quantitatively measured, as there were many variables to take into account: the physical condition of a manure, the type of crops, the climate, the state and the chemical composition of the land were indeed

26 *A. de Gasparin*, De la Valeur des engrais, in: Journal d'Agriculture Pratique 5, 1852, p. 5; *Dudouy*, Guide pratique.
27 *W.M. Mathew*, The House of Gibbs and the Peruvian Guano Monopoly, London 1981, p. 135.
28 *A. Voelcker*, Chemical Composition and Commercial Value of Norwegian Apatite, Spanish Phosphorites, Coprolites, and other Phosphatic Materials used in England for Agricultural Purposes, in: Journal of the Royal Agricultural Society of England 21, 1860 p. 351.
29 *J.T. Way*, On the Value of Artificial Manures, in: Journal of the Royal Agricultural Society of England 16, 1856, pp. 533-534.
30 *Ibid.*, p. 534.

very important and had an impact upon the way artificial fertilisers were used by plants.[31]

The period 1850-1870 was therefore mostly marked by diffidence towards the crudest forms of computation and chemical reductionism among agricultural chemists who were often very cautious and sceptical of some of the early attempts to "fix a standard price on nitrogen".[32] British agricultural chemist Augustus Voelcker, for example, argued that chemists could not take into account all the various factors influencing the result of manuring and remained somewhat dubious of the attempts to fix a price onto chemical elements.[33] Likewise in France, Ville's *doctrine* was heavily debated and rejected by most agricultural scientists, such as Risler or Grandeaux.[34] Adolphe Bobierre, who had set up the first French laboratory devoted to the analysis of fertilisers in Nantes, was for example vocal in his criticism of those who wanted to turn agriculture into "arithmetics".[35] Like Voelcker and many others, Bobierre argued that the value of fertilisers depended on many variables (nature and chemical composition of the soil) and rejected the idea that it was possible or meaningful to assess precisely the commercial value of phosphoric acid or nitrogen.[36] Most agricultural chemists accordingly rejected the calculations assessing the value of farmyard manure solely upon its nitrogen content and argued that it remained the "perfect manure", thanks to the complexity of its chemical composition as well as to its physical role in improving the soil.[37]

31 *A. Voelcker*, The Commercial and Agricultural Value of Artificial Manures, in: *idem*, Four Lectures on Farmyard Manure, Artificial Manures, Barren and Fertile Soils, Oil-Cakes, etc., London 1857, p. 29.

32 *T. Baldwin*, On the Application of Artificial Manures, and on the Money Value of Manures, in: The Journal of the Royal Dublin Society 2, 1859, pp. 312-313.

33 *Voelcker*, Value of Artificial Manures, p. 35.

34 *J.P. Legros*, Georges Villes et sa Guerre pour les engrais chimiques, in: Bulletin de l'Académie des Sciences et Lettres de Montpellier 27, 1996, p. 122. Nevertheless, Ville, as Joulie, was a mentor and an example for the manufacturers of chemical fertilisers. See for example the biography of Ville in: *L'Engrais*, 20.11.1891, p. 738. See also *La culture intensive illustrée*, 1.10.1901, p. 35. These two publications were linked with the most important French producers of phosphates and superphosphates.

35 *A. Bobierre*, Du Phosphate de chaux et de son emploi en agriculture. Leçons professées à l'École préparatoire des sciences et des lettres de Nantes, Paris 1861, p. 35. *N. Jas*, Au Carrefour de la chimie et de l'agriculture: Les sciences agronomiques en France et en Allemagne, 1840-1914, Paris 2001, pp. 60-61.

36 *Bobierre*, Du Phosphate, p. 45.

37 *Idem*, Simples notions sur l'achat et l'emploi des engrais commerciaux, Paris 1870, p. 51.

All in all, the first attempts to compute and compare the value of different manures based on their nitrogen content originated in a will to make very diverse commodities comparable according to a simple criterion in an expanding market. Attempts to give a fixed price to nitrogen however met with considerable doubts and reservations against the crudest forms of chemical reductionism as proposed by Nesbit or Ville. The 1870s and 1880s would nevertheless be marked by the rise of the *price of nitrogen* as a convenient and widespread convention, which was achieved mostly with the decline of guano and its replacement by nitrate of soda and sulphate of ammonia as the two main nitrogenous fertilisers.

5 The Decline of Peruvian Guano

After the guano boom of the 1850s and 1860s, the 1870s were a difficult period for the guano trade. Imports of Peruvian guano to Britain, for example, had reached a peak of 300,000 tons in 1858 and had remained at a fairly high level until 1870, when nearly 250,000 tons were imported. But due to increased costs, competition and declining quality, guano imports fell rapidly with only slightly more than 50,000 tons imported in 1880.[38] Guano continued to be widely used in Europe and in North America but it was increasingly questioned as its quality was reassessed by scientists, and secondly two new nitrogen fertilisers appeared and spread very quickly, especially in Europe. The discovery of new beds of guano on the Pacific Islands and in the Caribbean prompted a reassessment of the quality and benefits of using different types of guanos. As opposed to the Peruvian guano which was valuable mainly for its nitrogen contents,[39] the new beds were rich in phosphorus, and were used to manufacture superphosphates. Throughout the last quarter of the nineteenth century and the beginning of the twentieth century, guanos from Christmas Island (in the Indian Ocean), Jarvis, Baker and Malden (in the Pacific), Curaçao, or Californian guano, for example, were sent to Europe or the East coast of the USA, to be processed in superphosphate factories.[40] While these new sources of guano may have caused confusion

38 *Mathew*, House of Gibbs, p. 252.
39 The nitrogen content of Peruvian guano was due to the very dry climate which permitted the preservation of nitrogen.
40 On the US see *W.T. Jordan*, The Peruvian Guano Gospel in the Old South, in: Agricultural History 24/4, 1950, pp. 211-221; *R.A. Wines*, Fertilizer in America: From Waste Recycling to Resource Exploitation, Philadelphia 1985; *T.W. Shick/D.H. Doyle*, The South Carolina Phosphate Boom and the Stillbirth of the New South, 1867-1920, in: The South Carolina Historical

in the mind of farmers, the main problem for traders during the 1870s was due to the very composition of Peruvian guano.

Peruvian guano was supposed to contain 13 to 15 percent of nitrogen. With such a steady proportion of nitrogen it was possible to assess the value of the nitrogen compound. In France, for example, with a price of 30-35 francs per metric quintal (in France), one kilogram of nitrogen could be estimated at about 2.40 francs or 2.70 francs. But the best beds of guano were gradually exhausted, and the nitrogen content decreased, which made the price of nitrogen soar. Beyond the issue of the price of the nitrogen content, this instability raised concerns about the manurial value of guano. In 1874, the *Journal d'agriculture pratique* launched a vast campaign to discredit the guano sold by Dreyfus, the main European agent in the 1870s. To support its claims, it quoted British agricultural chemists such as Lawes and Augustus Voelcker among others, and published the result of the analyses of 33 samples of Peruvian guano made by Professor Antonio Raimondi, who headed the analytical chemistry department at the University of San Marcos in Lima. The value of a ton of guano varied greatly from less than 50 francs to more than 430 francs, while the average content of phosphoric acid was found to be 15.92 percent, and that of nitrogen 5.13 percent, some samples containing almost no nitrogen.[41] As the *Journal d'agriculture pratique* pointed out: "Either Peruvian guano is a standard product, with a stable and clear composition, then we do not understand why MM Dreyfus brothers refuse to guarantee its contents; or else, its composition is fluctuant, and in this case, the agents of the Peruvian government can not sell it at a standard price, whatever it contains."[42]

6 Getting Rid of Instability

To avoid the problem of the unstable composition of guano, Dreyfus decided to manufacture guano with sulfuric acid, after a process patented by Ohlendorff in

Magazine 86/1, 1985, pp. 1-31; *J. Skaggs*, The Great Guano Rush: Entrepreneurs and American Overseas Expansion, New York 1994.

41 *L. Grandeau*, Le Guano du Pérou, in: Journal d'Agriculture Pratique 38/2, 1874, p. 207,

42 Chronique agricole, in: Journal d'Agriculture Pratique 38/1, 1874, p. 782. Among the French scientists who condemned guano, Grandeau played a major role. On the influence of Grandeau on French agriculture see *Jas*, Au Carrefour. The Peruvian government made a contract with European firms to sell at a fixed price the guano they were allowed to extract form the beds. The most famous contractor was Gibbs see *Mathew*, House of Gibbs.

Germany in the early 1860s. A £ 500.000 joint company was created, in association with Ohlendorff of Hamburg and Schroeder of London, in order to sell what was called "dissolved guano".[43] This new fertiliser had a stable composition, and could thus be sold with a guarantee. The commodification of fertilisers depended in the end upon two closely linked parameters: the stability of their composition and their agronomic valuation. If these two preconditions were met, it was possible to assess the economic value of the fertiliser. But to do so, it was necessary to proceed to a trustworthy chemical analysis, and the company insisted upon the fact that "the analyses would be performed by Dr. A. Voelcker in London and other leading chemists on the continent" which shows how the commodification of fertilisers was closely linked with the development of chemical expertise.[44] In 1877, after the controversy, Dreyfus thus committed to selling their guano at "21 shillings for each *unit of nitrogen* and 5 shillings and 6 p. for each unit of phosphoric acid".[45] Yet it is important to mention that this type of convention and labelling were meant for traders only but did not apply to farmers, which led some to argue that farmers "had gained nothing in this new type of commodification", since intermediaries were still under no obligation to indicate the nitrogenous content of their products.[46]

It is sometimes argued that the increasing use of mineral fertilisers during the last quarter of the nineteenth century was due to the increasing repudiation of organic fertilisers. What this controversy over guano, and the rise of the "leading chemists" reflects, however, is mostly that, irrespective of the nature of fertilisers (organic, mineral, synthetic), the very nature of every kind of fertiliser had to be defined exclusively by a stable chemical content. In France, the completion of the purely chemical definition of fertilisers was achieved by law on February 4th 1888. In 1867, a vote had been passed in France to curtail the extent of frauds in the fertiliser trade, but it was immediately deemed inefficient and useless since it did not require merchants to indicate the chemical content of their products.[47] Hence a new law was passed in 1888 and, this time it specifically required traders to indicate the contents in nitrogen, phosphoric acid and potash of fertilisers: "The content in fertilising elements shall be indicated in

43 Archives du Monde du Travail, Lille, 28 AQ 18 & 19.
44 Ibid. In France, J.-A. Barral, chemist and former director of the *Journal d'agriculture pratique,* promoted the new fertiliser.
45 Chronique agricole, in: Journal d'Agriculture Pratique 41/1, 1877, p. 712.
46 *G. de Capol*, De la Méthode expérimentale en agriculture, in: Mémoires de la Société d'Agriculture, Sciences et Arts d'Angers 23, 1882, p. 431.
47 Law of July 27, 1867; *H. Joulie*, Guide pour l'achat et l'emploi des engrais chimiques, Paris 1876, pp. 406-407. On the law of 1884, see *Jas*, Au Carrefour, pp. 293-325.

terms of the weight of nitrogen, phosphoric acid and potash contained in 100kgs of the commodity billed as delivered, with an indication of the nature and state of combination of these elements".[48]

It is also interesting to note that Article 5 listed many exceptions to the law as the latter requirement did not apply to "farmyard manure, faeces, composts, nightsoil and sewage sludge, waste from markets, spent brewer's grains, kelp and other marine plant, fresh slaughterhouse waste, marl" and other products which were sold as fertilisers, but whose valuable contents in phosphoric acid, nitrogen and potassium could not be fully determined by chemists.[49] They were therefore not included in the legislation because of the instability of their composition.[50] Similarly, in Great Britain, a Fertilisers and Feedingstuffs Act was passed in 1893, which required traders to produce an invoice indicating the nutrient content of their products.[51] This process may be seen in most European countries and in the USA, so that by the end of the 1880s, chemists had become central in the determination of what could be labelled and sold as a real fertiliser.

7 The Emergence of New Nitrogen Fertilisers

Most organic fertilisers were excluded from the law, but guano, for example, was not, nor were superphosphates made from bones. The organic or inorganic nature of a fertiliser was thus not essential in their inclusion into the legal regime of fertilisers. What was essential, was stability of chemical composition, and of nitrogen content in particular, as illustrated by the increasing use of the valuation of fertilisers in terms of *units* of nitrogen. This did not preclude, however, the continuing decline of guano.[52] In 1890, less than 5,000 metric tons of guano were imported in France, while imports of guano in Great Britain in the late 1880s represented only 5 percent of their value in the late 1860s. The market collapsed throughout Europe

48 Law of February 4, 1888. *Bulletin des lois* de la République française 36/1147, 1888, p. 2.

49 Ibid.

50 For amendments, the three chemical compounds listed by the law are irrelevant.

51 *B. Dyer*, Fertilisers and Feeding Stuffs; their Properties and Uses. With the full text of the Fertilisers and Feeding Stuffs Act, 1893, London 1903.

52 In Germany phosphatic guano remained an important item of importation. After 1890, except for some years, the quantities of Peruvian guano imported in Europe were quite low compared to the millions of tons of nitrate of soda imported from Chile.

during the 1880s, as may be seen in the evolution of the importation of fertilisers in Hamburg (see Fig. 1), one of the most important fertiliser markets in Europe.[53]

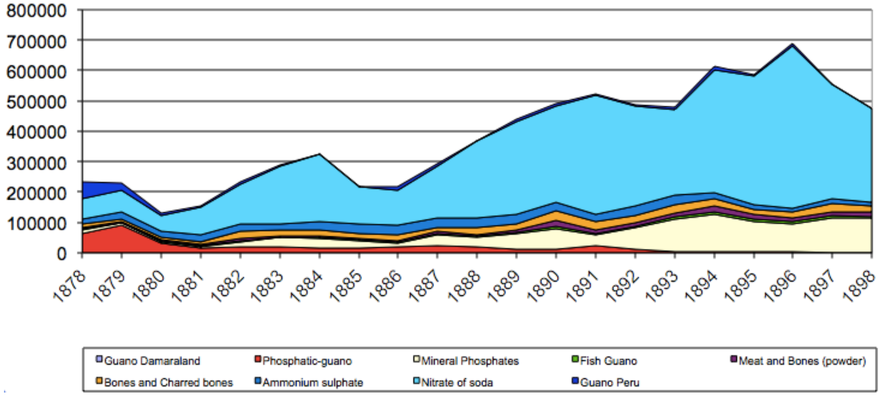

Fig. 1: Importations of Fertilisers to Hamburg, 1878-1898 in 50 kg Quintals. Damaraland guano (also sometimes called Cape Cross guano) came from the German colony *in* South *West Africa (nowadays Namibia)*. Source: *L'Engrais*, several dates.

The 1870s and the 1880s were, on the contrary, marked by the emergence of two new nitrogenous fertilisers: nitrate of soda and ammonium sulphate.[54] Nitrate of soda was available in Peru and Bolivia, and then in Chile after it took over the southern provinces of Peru and Bolivia following the War of the Pacific (1879-83). Until the middle of the 1870s, the importation of nitrate was of relatively minor importance for European countries, but the production of nitrate then soared from 400,000 tons in 1885 to more than 2,000,000 tons in 1910. The main importer of nitrates was Germany, but consumption increased rapidly in Great Britain and even more so in France: from 56,700 and 34,200 thousand tons respectively in 1880, imports increased to 139,000 and 284,000 tons by 1900.[55]

Another nitrogenous fertiliser being increasingly used was ammonium sulphate, a by-product of the coke and gas light industries. After 1863, some Eng-

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53 *Thompson*, Second Agricultural Revolution, p. 76. The very exception was Belgium where the director of the agronomic station of Antwerp promoted actively the guano commercialised by Ohlendorff.

54 For the latter, see Fig. 2.

55 *R. Miller/R. Greenhill,* The Fertiliser Commodity Chains: Guano and Nitrate, 1840-1930, in: *S. Topik/C. Marichal/Z. Frank (Eds.),* From Silver to Cocaine: Latin American Commodity Chains and the Building of the World Economy, 1500-2000, Durham 2006, p. 240.

lish industries were forced to treat their effluents, and ammonium sulphate quickly became the second main nitrogen fertiliser at this time. In the last quarter of the nineteenth century, production in Great Britain expanded rapidly, from around 40,000 tons a year in the late 1860s to more than 250,000 tons in the early 1900s (more than two thirds of which was exported).[56] Germany then also became a major producer, so that by 1910, each of the two countries provided around 40 percent of the world's production (see Fig. 2).

By the early 1880s, these new fertilisers had completely replaced guano as the main sources of off-farm nitrogen. These new fertilisers were undoubtedly far more adapted to the new regime than guano: when Georges Ville had for example supported the use of what he called *chemical* fertilisers in the 1860s, he did not include guano in this definition. The problem with guano lay not only in the variability of its composition but in that it contained other fertilising elements, most notably phosphoric acid. The advantages of sodium nitrate or sulphate of ammonia, by contrast, were that they were "pure" nitrogenous fertilisers, which, when mixed with other forms of fertilisers, meant that farmers could use only what they needed depending on their soils and crops, and "modify and set the composition of their manures" with a much greater degree of precision.[57] It also meant that the price of a unit of nitrogen in these fertilisers was straightforward, as Way had already argued in the 1850s.

It was generally acknowledged that the nitrogen contained in organic material, such as dried blood, hoof and horn meal, fish guano, etc. was not fully assimilated by plants. Thus in the 1880s, there began to appear two distinct prices for nitrogen, one for nitric or ammoniacal nitrogen (between 1.60 and 2 fr), and one for organic nitrogen (between 1.20 and 1.30 fr).[58] Most agricultural chemists in charge of the analyses were, unlike Ville, eager to assert their objectivity and were therefore very prudent in their recommendation of fertilisers. Not willing to appear biased in favour of a particular product, they generally refrained from recommending, or discouraging the use of a particular sort of fertiliser. However, they insisted that their expertise worked better with sulphate of ammonia or nitrate of soda than with guano and other organic fertilisers since the latter were usually complex and the rate of assimilation of nitrogen hard to

56 *Ministry of Munitions of War*, Final Report of the Nitrogen Products Committee, London 1919, p. 20.

57 *Ville*, Les engrais chimiques, p. 197.

58 *Société d'agriculture de Lyon*, Concours régional de 1885, in: Annales des sciences physiques et naturelles, d'agriculture et d'industrie 8, 1885, p. 277; L'Engrais, 14.08.1896, pp. 781-782, which evoked works by Londsley, Deherain and Wagner.

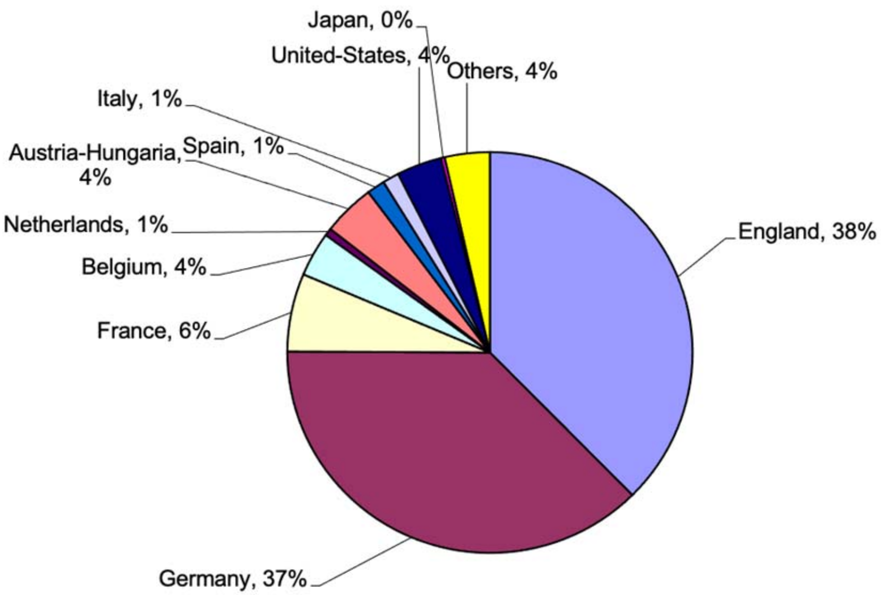

Fig. 2: Share of Production of Ammonium Sulphate in 1908. Source: *L'Engrais*, 21.01.1910, p. 70.

assess.[59] It became increasingly clear, therefore, that nitric and ammoniacal fertilisers were not necessarily *better* from an agronomic point of view, but that they were more dependable and lent themselves to chemical and economic quantification.[60]

8 Substitutability

The chemical composition of the new fertilisers was not the same, and their agricultural uses were different.[61] The nitrogen provided by nitrate of soda was more easily assimilated by plants, but was washed out by heavy rain. It was therefore mainly used during spring for wheat, and was widely used for sugar beetroots. It should also be noted that the rhythm of importation from Chile was the major factor in the time frame of provisioning for Europe. Usually sailboats,

59 *L. Grandeau*, Revue Agronomique, in: Le Temps, 3.11.1885.
60 *Joulie*, Guide, pp. 36-38.
61 The formula of nitrate of soda is $NaNO_3$, ammonium sulfate is $(NH_4)_2SO_4$.

which had to pass the Cape Horn, arrived in Europe in January and February, so the fact that nitrate of soda was preferentially sold during early spring, was not only due to its very nature, but was closely determined by the flow of trade.

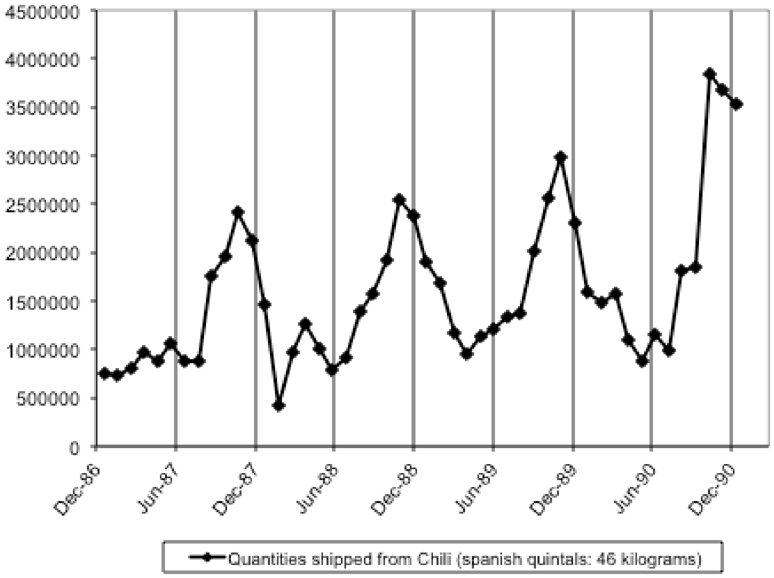

Fig. 3: Exportations of Nitrate from Chile by Month, 1887-1890. The bulk of the exports arrived in Europe between December and March. Source: *L'Engrais*, 15.05.1891, p. 308.

The action of ammonium sulphate, on the other hand, was slower, and it was usually used in autumn. Moreover, it was recommended that ammonium sulphate should not be used as top dressing, but should be placed more deeply. However, despite the different uses of the two fertilisers, their prices were closely linked (see Fig. 4). If we put some short periods aside, the nitrogen contents determined the respective value of each fertiliser. As Fig. 4 shows, the correlation of the prices of the two fertilisers was not perfect. Sometimes, the two prices diverged or conversely converged, but the trends were broadly similar. Between 1880 and 1896, prices decreased, and after the end of the Great Depression prices increased until the end of the 1900s. Beyond the general trend, several periods are very interesting. The first one occurred around 1886-1887, the second one between 1891 and 1893, and the last one at the very beginning of the twentieth century. During these periods, the price of the two fertilisers diverged widely, or conversely converged completely.

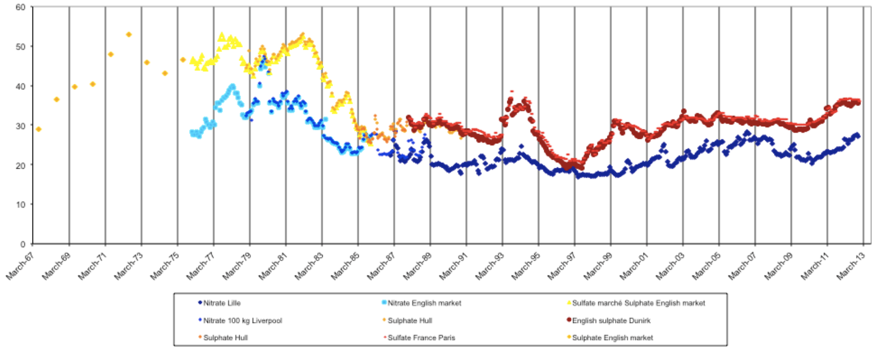

Fig. 4: Price of Ammonium Sulphate and Nitrate of Soda in France, 1875-1913 in Francs by Quintals. Source: *L'Engrais*, Several dates.

The price fluctuations of these two fertilisers had an important impact upon their advisability. Despite their very different uses, professional journals and chemists argued that they could be substituted to one another, depending on their respective prices at a given time. In January 1886, the trade journal *L'Engrais* for example explained: "For a long time, nitrate of soda [...] was tolerated rather than recommended, while sulphate of ammonia was recommended by everyone. [...] In the last two years, the commercial competition between these two products has been fierce, there has been a convergence between the prices of their nitrogen unit, at this moment, the price of nitric nitrogen is higher than ammonia nitrogen".[62] The journal thus encouraged farmers to use sulphate as long as this situation lasted. Conversely, on the basis of the same kind of argument, when the price of sulphate soared at the beginning of the 1890s, professional newspapers recommended the use of nitrate.

This illustrates the triumph of chemistry but also shows how this process was inextricably linked to trade considerations, as the commodification of the chemical element nitrogen led to its submission to trading requirements. Although it was widely acknowledged that the forms of fertilisers had, theoretically, different purposes and uses,[63] the article compared the value of the two solely in terms of their nitrogen contents. The reduction of these fertilisers to their purely chemical composition meant that they were competing products on the market and the poster mentioned in the introduction shows that by the early 1900s, nitric and ammoniacal nitrogen commanded roughly the same price.

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62 L'Engrais, 6.02.1886, p. 3. See Fig. 3.

63 See for example *A. Müntz/A.C. Girard*, Les Engrais, Volume II, Paris 1889, pp. 136-138.

Many analyses were conducted in order to evaluate the differences between these two fertilisers but by the late 1890s, the idea that they could substitute one to another was increasingly widespread. In the end, what farmers should be primarily concerned with was checking the price of the nitrogen they were buying in order to assess the profitability of their investments.[64]

These types of calculations were not meant only for the elite readership of scientific publications, and one finds many examples of their popularization in publications meant for a larger audience, such as local newspapers or trade journals. Even in journals meant for a large audience that was not necessarily conversant with chemical symbols, one sees different fertilisers become abstract chemical products, whose effects and profitability could be measured mathematically. One may mention here the example of mathematical problems meant for the children of French farmers published in the newspaper of a farmers' union:

> "The chemical fertilisers called nitrates, which have a very rapid effect, are used to boost the growth of sickly grains; sulphate of ammonia also improves the growth of weak plants, in a slower but more durable way, and its nitrogen is as assimilable as nitric nitrogen. Nitrate of soda, with a 15.5 % nitrogen content, costs 22 francs for 100 kilograms. Sulphate of ammonia, with a 20.5 % nitrogen content, is sold 23.25 francs for 100 kilograms. Calculate the respective amounts that would be spent if using 135 kgs /ha, for a total cultivated area of 3 hectares 5 ares and 7 centiares. Calculate also how much nitrogen would be provided by spending 100 francs on each of these fertilisers."[65]

As nitrogenous fertilisers were the most expensive ones, and at a time of declining commodity prices, it was indeed extremely important for farmers to assess precisely the extent to which their use could be profitable. As grain prices declined in the 1880s, the question was clearly not to increase yields at all costs, but to assess precisely the nature of profitable investments: "When the increase of our produce by means of (minerals and nitrogen) is urged upon our farmers the question whether it will pay is the only one that needs consideration".[66] Experiments demonstrating the profits that could be gained through the use of fertilisers were not new in any way, but the significant point is that they were increasingly presented through the use of the *price of nitrogen*. The most important experiments in that regard were conducted at the Rothamsted experimental station where Lawes and Gilbert showed that 1 pound of nitrogen equat-

64 See *Müntz/Girard*, Les Engrais, p. 292, for a list of references on the experiments made in the 1880s to determine the respective properties and differences between the two fertilisers.
65 Bulletin du syndicat des agriculteurs du Loiret, 15.02.1897, p. 10.
66 *A.J. Mott*, English Farms and the Price of Food, in: The National Review 10, 1887, pp. 529-541, quoted in: Canterbury Journal, Kentish Time and Farmers' Gazette, 5.01.1889.

ed to an increase 5 pounds of wheat.[67] These experiments were then widely expended and publicized, French farmers for example being told in 1891 that 100 kgs of nitrogen could get them 770 frs of wheat, 585 frs of rye, 672 frs of oats, etc.[68] By the end of the nineteenth century, farmers were thus called upon to become *nitrogen accountants*: it was argued that if farmers knew the price of nitrogen at a given moment, the rise in yields expected from the application of a given dose of nitrogen, and the price of commodities, their farming and business decisions could therefore be guided by simple arithmetic operations.

9 Conclusion

One should not, probably, overestimate, the extent to which farmers thought purely and simply in the abstract terms of units of nitrogen. First of all, it should be emphasized that the case of nitrogen was not isolated and that the other fertilising elements such as phosphoric acid and potash were subject to the same kind of commercial valuation. The economic value of the different types of mineral phosphates or phosphatic guanos was thus determined according to their respective contents in phosphoric acid and their prices were routinely published in trade journals. Secondly, sulphate of ammonia for example, although massively produced in Great Britain, was mostly exported to the Continent as British farmers did not trust it. Until at least the end of the First World War, in fact, nitrate of soda and sulphate of ammonia were used on different crops and in different seasons, which shows that farmers did not necessarily consider that all nitrogenous fertilisers were interchangeable.

Yet it is clear that these discussions and calculations were not meant for a restricted few and were widely publicized, as the example of the poster described in the introduction shows. The rise of the *price of nitrogen* remained a contested abstraction throughout this period, but it was increasingly used by the end of the nineteenth century, and came to appear as an entry in agricultural bookkeeping, which could help farmers with their investment and business decisions, in a period of great variability of prices (both of crops and fertilisers). The ideal-type farmer was meant to be aware of the given price of nitrogen and of crops at a particular time, and could then, thanks to the experiments and calculations mentioned above, assess precisely the amount of nitrogenous ferti-

67 From the field, in: Worcester Journal, 13.11.1886.
68 *Müntz/Girard*, Les Engrais, p. 44.

lisers that he could profitably purchase. What this article has thus shown is that before the development of the Haber-Bosch process (1913) and the massive quantities of nitrogenous fertilisers this process made available to farmers in Germany, Britain, France and elsewhere, the guano, nitrate and sulphate of ammonia trades played a critical role in the second half of the nineteenth century. They were instrumental in the development and legitimization of a complex commercial, research and advisory infrastructure, as well as in the acculturation of farmers to chemical elements, the prices and impacts of which (in terms of increased yields) could be ascribed a numerical value. They thus played a key role in the reconfiguration of farming as an industrial activity which, as sometimes argued, could be reduced to a set of equations.

Bionotes

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