

The significance of Peruvian guano in British fertilizer history (c.1840–1880)

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Abstract

Peruvian seabird guano was first imported into Britain in bulk in 1840 where, due to its uniquely high nitrogen content, it was enthusiastically received by farmers and scientists. Many came to perceive it as crucial in boosting soil nutrients to achieve levels of agricultural production to feed the rapidly rising and urbanizing population, despite intense scientific disagreements over the use of nitrogenous fertilizers. The ‘guano age’ (1840–80) coincided with a high farming era and an acceleration in the application of scientific principles to agriculture including the implementation of chemical technologies. This article puts Peruvian guano centre stage due to its unique concentration of chemical nutrients and its re-identification as an artificial fertilizer. It examines how, in losing its natural identity, it became a facet of chemical technology and assumed significance as ‘more than a fertilizer’ in its direct and indirect influence on emerging ideas of agricultural sustainability.

This article addresses the introduction of new agricultural fertilizers into nineteenth-century Britain and the sometimes too narrow understanding of the role of ‘guano’. It demonstrates how the bulk importation of Peruvian seabird guano as a soil fertilizer was significant not only in ‘real’ terms as a fertilizing agent, but also in scientific and agricultural narratives of this period. Guano’s soaring popularity in the 1840s and 50s led to its widespread use, particularly by high farmers.¹ Figure 1 illustrates how Peruvian guano imports rose steadily in the 1840s and peaked in the 1850s at over 300,000 tons per annum. As a proportion of British imports were re-exported to Europe, guano consumption peaked in the 1850s at over 200,000 tons per annum. British agricultural chemists discovered that, of all global seabird guanos, Peruvian has the highest nitrogen content. Figure 2 illustrates how, due to high demand, guanos were sourced from other locations, but all of these proved to be less nitrogenous. In 1860 Peruvian guano contained five times as much nitrogen as exported Chilean nitrates, although by 1870, as the quality of reserves dwindled, this had reduced to two-fold.² Vaclav Smil notes that Peruvian guano was the most important commercial nitrogen fertilizer from 1840 to 1870.

¹ High farming is defined as increased intensity cultivation through increased inputs of capital and labour: F. M. L. Thompson, ‘The second agricultural revolution, 1815–1880’, *EcHR* 21 (1968), pp. 62–97. It encompassed greater use of machinery, infrastructure and fertilizers,

technical changes in crop rotation, livestock improvement and greater market orientation.

² Vaclav Smil, *Enriching the earth: Fritz Haber, Carl Bosch and the transformation of world food production* (2001), p. 43.

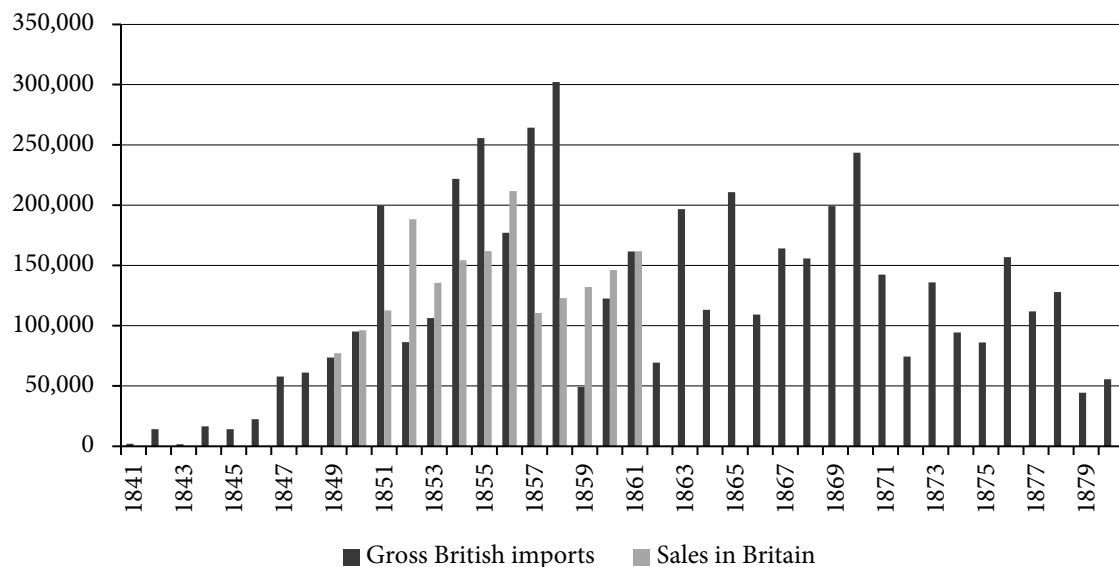


FIGURE 1. Peruvian guano gross imports in tons into Britain (some onward transport to Europe) and British sales during Gibbs' monopoly (1843–1861)

Source: Constructed by the author from tabular data provided by W. Mathew, *The house of Gibbs and the Peruvian guano monopoly* (1981), p. 252. Sales in Britain are from the Gibbs' incomplete data sets: Antony Gibbs & Sons Collection, London Metropolitan Archive, CLC/B/012/MS11047; 11057; 11057A. L. J. Kinsley, 'Guano and British Victorians: an environmental history of a commodity of nature' (unpubl. PhD thesis, University of Bristol, 2020), p. 73.

The unique habitat of Peru's 'guano birds' occurs where the concurrence of arid climate and nutrient upwelling from depth creates a rich marine environment.³ Here, birds have evolved to feed on the high availability of oily anchoveta fish and produce copious amounts of nitrogen-rich excrement unique to Peruvian shores. In turn, due to the very low rainfall of the region, this excrement retains its otherwise easily leached nitrogen and accumulates in quantity. Its dry, powder-like form enables low-cost extraction by hand, as illustrated by the of mid-nineteenth-century sailing ships queuing to receive guano shovelled down chutes by indentured labourers.⁴

Guano was not just a material phenomenon. By the 1840s chemistry was established as the dominant science for agriculture, and this nitrogen-rich and somewhat exotic fertilizer became the focus of intense interest among agricultural chemists and part of their engagement in wider public debate about agricultural progress.⁵ From 1840, coincidental with the beginning of the guano age, agricultural chemists began to focus on the agricultural importance of nitrogen and the proportion it made up in fertilizers was increasingly used to

³ The Peruvian cormorant (either known as *Phalacrocorax bourgainvillii* or *Leucocarbo bougainvilliorum*), was colloquially known as 'guanay'. The Peruvian booby and pelican also contributed to the guano reserves.

⁴ E. D. Melillo, 'The first green revolution: debt peonage and the making of the nitrogen fertilizer trade,

1840–1930', *American Historical Rev.*, 117 (2012), p. 1040; L. J. Kinsley, 'Guano and British Victorians: an environmental history of a commodity of nature' (unpubl. PhD thesis, University of Bristol, 2020), p. 85.

⁵ P. M. Jones, 'Making chemistry the 'science' of agriculture c.1760–1840', *Hist. of Science* 54 (2016).

classify them.⁶ Thus Peruvian guano contributed to the classification of agricultural fertilizers based on their nitrogen content and was frequently used as a benchmark in manure field trials. Section I examines the role Peruvian guano played in the search by agricultural chemists to discover how plants access nitrogen, and how this influenced British farmers in their application of novel fertilizers. After observing guano use in Peru in the 1830s, Jean Baptiste Boussingault set up field trials in Alsace (commencing in 1836) to assess how plants used nitrogen. The results of these trials were ground-breaking and the first step towards understanding the importance of leguminous plants in the nitrogen cycle.⁷ Despite Justus von Liebig's considerable influence on agricultural chemistry in Britain in the 1840s, his long-lasting misjudgement about the importance of nitrogenous fertilizers and disagreement with John Bennet Lawes and Henry Gilbert would call this nitrogen-focused discourse into question in the 1840s and 1850s. Yet in the end Liebig's mineral fertilizer, containing no nitrogen, failed to threaten guano use and was a commercial failure.⁸

The increasing application of scientific approaches to practical farming, particularly through Victorian high farming, were reflected in the Royal Agricultural Society of England's (RASE) motto 'Practice with science'. Nicholas Goddard notes that a review by the Society of this motto in 1856 concluded that, 'guano had done more than anything else to get rid of the prejudice against science amongst ordinary farmers and commented that those who had first ridiculed its application soon boasted about how many tons they had applied.'⁹ Indeed, Smil argues that the guano mania of the 1850s resembled the world crude oil market of the 1970s.¹⁰ Arguably, later concerns about 'peak oil' were preceded by fears of 'peak guano' a century earlier.¹¹ Ultimately, guano reserve depletion, the nitrate War of the Pacific (1879–83) and cheap imports of corn all contributed to a decrease in guano use and an end to the guano age in the late 1870s.

Despite its obviously natural origins, agricultural chemists and farmers classified this substance as an artificial fertilizer alongside industrial by-products and chemically manufactured manures. 'Artificial' was then universally applied to any fertilizer produced off-farm. Only much later, notably with the industrial fixation of nitrogen in 1909, did this term become confined to factory-made chemical fertilizers. Efficacious, powder like and highly portable, Peruvian guano was utilized in the nineteenth century in a similar way to its factory-made successors. It gave farmers a taste of what was to come, and stimulated chemists' search for the ideal fertilizer. This is probably why some historians have tended to focus on this aspect of its materiality, as a precursor to the chemical age.¹² However, it is a naturally produced substance and a vital constituent of a marine ecosystem and avian habitat, which was intensely degraded by mid-nineteenth-century extraction and export.¹³

⁶ A. Page and L. Herment, 'The price of nitrogen at the end of the nineteenth century', *Jahrb. f. Wirtschaftsg* 62 (2021), p. 51.

⁷ J. B. Boussingault, *Rural economy in its relations with chemistry, physics and meteorology*, trans. George Law (New York, 1865), pp. 255, 342. First published as: *Economie Rurale* (1843).

⁸ J. Liebig, *Principles of agricultural chemistry: With special reference to the late researches made in England* (1855), pp. 48–50.

⁹ N. Goddard, *Harvests of change: The Royal Agricultural Society of England, 1838–1988* (1988), p. 90.

¹⁰ Smil, *Enriching*, p. 42.

¹¹ Kinsley, 'Guano and British Victorians', p. 190.

¹² F. M. L. Thompson, 'Agricultural Chemical and Fertiliser Industries', in E. J. T. Collins (ed.), *The agrarian history of England and Wales* [hereafter *AHEW*], VII, 1850–1914 (2 vols, 2000), II, pp. 1020–1.

¹³ A. J. Duffield, *Peru in the Guano Age* (1877), p. 89.

As evident from James Caird's survey and first-hand accounts of farmers in the 1850s, guano provided more than a gateway to a world of artificial chemicals. Its use also helped to facilitate a greater appreciation of the benefits of good farmyard manure management. This is addressed in Section II. Guano's high nutrient content promoted crop growth, but the bulky organic matter in well managed farmyard manure both fertilized and conditioned a soil. This 'conditioning' ability to improve soil structure and texture remained highly valued and was something that guano could not provide, as is also the case with chemically manufactured fertilizers.

Section III addresses the contradictory impact of guano extraction seen in terms of environmental and agricultural sustainability. On the one hand, the guano trade massively disrupted the coastal ecosystems of Peru and widened, to global proportions, an already apparent rift in nutrient cycles. This rift, created by the extraction of nutrients, including the harvesting of crops, from one place and moving them to another was already long in evidence at a smaller scale in the supply of food to towns and the importation of oil cake from the European continent. Liebig was probably the first scientist to articulate this, and his idea of rift was briefly picked up by Marx.¹⁴ The size of the guano trade rift has been the focus of recent scholarly discussion.¹⁵

On the other hand, guano also helped to provoke what we would understand as environmentally sensitive thinking. While many chemists sought the ideal chemical fertilizer and tended to view soils purely as a receptacle for such a substance, they were increasing their knowledge of nutrient cycles, a knowledge that would strengthen the view that nutrient wastage was a problem and nutrient balance mattered. Alongside farmers, they noted the negative impacts of guano over-application. Section III also addresses how, through its high profile, guano stimulated and gave its name to the development of solutions to sewage problems. Successful attempts to realise this additional opportunity for home-produced excremental fertilizers, in the form of 'humanure', would have helped to reclose rifts in the nutrient cycle. This dual, sustainable solution for public health and agriculture did not immediately come to fruition, but arguably influenced twentieth-century sewage treatment.

I

Peruvian guano's sustainable use by indigenous people is well reported in Spanish literature and scholarly research. Its name was derived from the Quechuan term 'wanu', a general Inca term for dung. With a particularly high nitrogen content, it is also rich in phosphates, two of the key nutrients required for plant growth as recognized in Inca guano conservation and sustainable community use for centuries. For them, it was highly culturally significant.¹⁶

¹⁴ J. Liebig, *Chemistry in its applications to agriculture and physiology* (1843), p. 165; K. Marx, 'The process of capitalist production as a whole', in *Capital: A critique of political economy*, ed., F. Engels (3 vols, 1867, repr. 1974), III, p. 813.

¹⁵ J. B. Foster, 'Marx's theory of metabolic rift: Classical foundations for environmental sociology', *American J. Sociology* 105 (1999); B. Clark and J. Foster, 'Ecological

imperialism and the global metabolic rift: unequal exchange and the guano/nitrates trade', *International J. Comparative Sociology* 50 (2009); M. Schneider and P. McMichael, 'Deepening, and repairing, the metabolic rift', *J. Peasant Stud.* 37 (2010); Kinsley, 'Guano and British Victorians', p. 12.

¹⁶ G. T. Cushman, *Guano and the opening of the Pacific world* (2013), pp. 1–7.

Spanish colonizers tolerated and influenced the local trade as evident in artefacts such as the Bollaert slab with its intertwined Inca and Spanish Christian symbolism.¹⁷ In 1840, after two decades of political and military turmoil following Spanish rule, the nascent Peruvian state came to view guano as a cash cow and took the first step in guano's capitalist commodification by privatizing Peru's guano reserves for mass extraction and bulk export.¹⁸ British merchants, most notably Antony Gibbs and Son, with an established presence in Peru since the 1820s, found themselves well placed to export guano to Britain's hungry fields. The Gibbs family held the monopoly for exports to Britain and on to Europe for nearly 20 years.¹⁹ A limited resource, guano was transported over vast distances, re-categorized as an artificial fertilizer and, in becoming a capitalist commodity, its sustainable use ceased.

While eighteenth-century Spanish literature on Peru's guano reserves received little international attention, Alexander von Humboldt succeeded where this had failed.²⁰ Succumbing to its ammoniacal pungency (1804) while observing the bustling guano trade in Callao, he sent samples to Parisian colleagues for analysis. Their results, published in 1806, were cited by Humphry Davy in his British Board of Agriculture annual lectures and resulting seminal textbook on agricultural chemistry (1813).²¹ In bringing together many European experiments carried out during the late eighteenth and early nineteenth centuries, Davy reinforced the idea that the system of nature was circulatory and therefore soil exhaustion needed to be addressed by replacing nutrients.²² This history of investigating the food of plants and qualities of the soil has been explored by environmental historians and historians of science, notably Paul Warde and Peter Jones.²³ Guano's first significant arrival in Britain in 1840 conveniently coincided with an explosion in publications on agricultural chemistry. The early recognition of the nitrogen in Peruvian guano led to its use in field trials as a benchmark nitrogenous manure. This bestowed upon it a vibrant influence in scientific research into plant use of nitrogen through such trials.²⁴

Boussingault's field trials on rotations in Alsace (1838–41) revealed the ability of leguminous crops to accumulate soil azote (nitrogen) from the atmosphere. Wheat crops following legumes in rotations markedly increased.²⁵ Experienced farmers had already been using leguminous plants in crop rotations and green manures, but Boussingault's work scientifically reinforced

¹⁷ 'Bollaert slab' [https://www.britishmuseum.org/collection/object/H_1859-0322-1]; L. Kinsley, 'The Bollaert slab: a fertile discovery', *The Hispanic-Anglosphere* [<https://hispanic-anglosphere.com/online-exhibitions/the-bollaert-slab-a-fertile-discovery>].

¹⁸ W. Mathew, *The house of Gibbs and the Peruvian guano monopoly* (1981); Kinsley, 'Guano and British Victorians', pp. 44–96.

¹⁹ Kinsley, 'Guano and British Victorians', ch. 2.

²⁰ G. J. Leigh, *The world's greatest fix: a history of nitrogen and agriculture* (2004), p. 80.

²¹ A. Laugier, 'Xxi. Extract of a memoir of Messrs. Fourcroy and Vauquelin upon guano', *Philosophical Magazine, Series 1* 24 (1806), pp. 126–31; H. Davy, 'Elements of agricultural chemistry: A course of lectures for the Board of Agriculture', *The Monthly Magazine* 35

(1813), p. 598; H. Davy, *Elements of agricultural chemistry* (1813), pp. 263–5.

²² P. Warde, *The invention of sustainability: nature and destiny, c.1500–1870* (2018), pp. 243–53.

²³ Jones, 'Making chemistry'; Warde, *Invention*; Page and Herment, 'Price of nitrogen'.

²⁴ A. Page, "'The greatest victory that the scientist has won in the fight against nature": Nitrogenous fertilizers in Great Britain and the British empire, 1910s–1950s', *Hist. of Science* 54 (2016), p. 388; Jones, 'Making chemistry', p. 190. 'Manure' was then commonly used for any soil-fertilizing substance.

²⁵ J. Boussingault, *Rural economy* (1865), pp. 255, 342; Richard Aulie, 'Boussingault and the nitrogen cycle', *Proc. American Philosophical Soc.* 114 (1970), pp. 447–9.

this practice. Boussingault was the first to suggest nitrogen 'fixation' by an intermediary, coming close to revealing the role of bacteria in legume root nodules, in identifying what he called 'mycodermes'. Nonetheless, nitrogen-fixing bacteria remained undiscovered until 1887, a year after his death.²⁶ Boussingault's findings were reported in papers from 1836 and finally in his two volume *Economie rurale* in 1843. The reception and significance of his work in Britain is evident in the quick translation of his book and its many editions. In confirming that animals sourced nitrogen from plants and their nitrogen-rich excrement boosted soil fertility, Boussingault endorsed the use of Peruvian guano, indeed any nitrogen-rich fertilizer, and the use of legumes in fodder. He produced some of the most comprehensive manure tables of the 1840s.²⁷

However, fuelled by his skill as a self-publicist, the most famed agricultural chemist of this moment was Justus Liebig. Liebig's first significant appearance in Britain, as visiting lecturer for the British Association for the Advancement of Science (BAAS) in 1837, laid the foundation for his ensuing widely read and quickly translated publication *Organic chemistry in its application to agriculture and physiology* (1840).²⁸ In 1840, an understanding of photosynthesis, the origins of plant carbon, criticism of humus theory and some understanding of the role of minerals in plant metabolism was already in place. W. H. Brock argues that Liebig's book was in fact a much less finished work than Boussingault's *Rural economy*, and Liebig would produce many revised editions and change his opinions over time, provoking some hot-tempered discourse.²⁹ Liebig's work weighed strongly against early nineteenth-century thinking that believed plant nutrition was provided by an organic particle or vital force. He proposed that organic life could process inorganic materials, and his work advanced the thinking on the need to manage the circulation of such inorganic elements as a major challenge for agriculture, remaining optimistic that science could produce an 'unbounded increase in organic life'.³⁰ Early contributors to the RASE's *Journal* drew extensively on his work, including his plant ash analysis and his conclusions that soil constituents removed in cropping should be restored to feed resulting depleted soils. This is what Liebig described as a 'system of robbery' in a literal translation of the German, which was scientific recognition of the break in nutrient cycles.³¹ His early recognition of the loss of valuable nutrients via human and animal excretion into city sewers after their removal from farms in crops provided an added dimension to the sewage debates of the 1850s and '60s. These gathered momentum in the 1850s after many cholera outbreaks in British cities due to poor sanitation. Liebig bemoaned the high cost of Peruvian guano imports when he felt the agricultural solution was to be found in local sewers.³²

²⁶ J. Boussingault, *Rural economy* (1845), pp. 47–9; Boussingault, *Rural economy* (1865), pp. 238, 344, 274.

²⁷ Boussingault, *Rural economy* (1845), pp. 391–3.

²⁸ J. Liebig, *Organic chemistry in its applications to agriculture and physiology* (1840).

²⁹ W. H. Brock, *Justus von Liebig: the chemical gatekeeper* (1997), pp. 148–9, 166.

³⁰ Warde, *Invention*, pp. 301–2; Nick Hopwood *et al.*, 'Cycles and circulation: a theme in the history of

biology and medicine', *Hist. and Philosophy of the Life Sciences* 43 (2021), p. 22.

³¹ Goddard, *Harvests of change*, pp. 87–9; Erland Mårald, 'Everything circulates: agricultural chemistry and recycling theories in the second half of the nineteenth century', *Environment and Hist.* 8 (2002), p. 73.

³² J. Sheail, 'Town wastes, agricultural sustainability and Victorian sewage', *Urban Hist.* 23 (1996), p. 193.

Liebig's mineral theory was in part an expression of his misgivings about Albrecht Thaer's humus theory from the beginning of the century, which drew on the idea of vital, organic particles as the food of plants.³³ Warde contextualizes this in arguing that Liebig did not entirely demolish Thaer's idea, but reformulated it in terms of the need to circulate inorganic elements, rather than organic molecules.³⁴ Nevertheless, in arguing that organic matter was unnecessary for soil fertility unless it contained minerals, Liebig potentially threatened the use of all nitrogen-rich manures, including guano and farm animal manures.³⁵ In 1843, he argued that field fertility could not be enhanced by nitrogenous manures, deducing that nitrogen only came into the soil directly from the atmosphere dissolved in rain and maintained this view until 1856.³⁶ Liebig's mineral manure, containing no nitrogenous material, was a commercial failure and tarnished his reputation in Britain.³⁷

Doubting the ability of farmers to understand the science of agriculture, Liebig also favoured theory over field experimentation for discovering the ideal fertilizer. He argued that field experiments tended to be too generalized to accommodate the variation in local conditions, but he did initially advocate the idea of an ideal fertilizer, in his case, containing minerals only.³⁸ Scottish chemist and co-founder of the BAAS, James Finlay Weir Johnston, countered this and argued that science 'had no duty to practical agriculture' to enable 'any' crop growth on 'any' soil or soil substitute – it 'will not do' to advocate a 'universal medicine'. Critical of Liebig's aggressive approach to practically acquired agricultural knowledge, Johnston argued that it required an intimate knowledge of soil type to correctly tailor a manure to local circumstances and increase its productivity.³⁹ Also disagreeing with Liebig's views on nitrogen, he encouraged farmyard manure and guano use and became widely viewed as a guano expert within scientific circles.⁴⁰

As Jones points out, the kind of unsystematic field experimentation prized by Johnston had been in evidence since the mid-seventeenth century.⁴¹ Johnston criticized chemists for delaying agricultural improvements through neglecting both experimental agriculture and the diffusion of practical knowledge.⁴² Concerned, like Liebig, about accuracy, he nevertheless encouraged farmers to carry out field tests, providing comprehensive advice for farmers on soil sample analysis and instructions on the application of many manurial substances.⁴³ Supported by farmer premiums from the RASE and the Highland and Agricultural Society of Scotland, Johnston published over one hundred pages of farmers' field experiments (1842–43). Most used guano as a benchmark fertilizer.⁴⁴ His *Experimental agriculture*, aimed at farmers, included

³³ J. Liebig, *Letters on modern agriculture* (1859), pp. ix, 1–22.

³⁴ Warde, *Invention*, pp. 301–6; Mårald, 'Everything circulates', p. 67.

³⁵ J. Liebig, *Organic chemistry*, p. 72; Jones, 'Making chemistry', p. 193.

³⁶ J. Liebig, *Principles of agricultural chemistry* (1855) p. 115; Liebig, *Letters on modern agriculture*, pp. 213–14; Page and Herment, 'Price of nitrogen', p. 51.

³⁷ Jones, 'Making chemistry', p. 194.

³⁸ Liebig, *Principles of agricultural chemistry*, p. 47.

³⁹ J. Johnston, *Contributions to scientific agriculture* (1849), p. 55.

⁴⁰ 'Report of the Sixth Ordinary Meeting, Wednesday 21 December 1853', *J. Soc. Arts* 2 (1853), p. 87.

⁴¹ Jones, 'Making chemistry', pp. 175, 193.

⁴² J. Johnston, *Lectures on the applications of chemistry and geology to agriculture* (1847), pp. 14–17.

⁴³ J. Johnston, *Instructions for the analysis of soils* (1847).

⁴⁴ J. Johnston, *Applications* (1841), Appendix, 'Suggestions for experiments in practical agriculture'.

robust advice, and urged diligence in their field trials, while his *Catechism of agricultural chemistry* for schoolteachers ran to no less than 33 editions.⁴⁵

While unregulated farmer trials gave cause for concern among the new generation of agricultural chemists, John Bennet Lawes, founder of Rothamsted Agricultural Experimental station (1843) and his partner, Liebig-trained chemist, Henry Gilbert, were able to achieve a higher degree of standardization in their own field trials. These experiments, on 'agriculturally exhausted land', defined as the tail end of a rotation before manure application, compared the efficacy of different manures on different crops (and remain in progress at Rothamsted today).⁴⁶ Before they published their first trial results in 1851, politician and reforming agriculturist Philip Pusey produced a journal article ratifying them as 'scientific', disproving some aspects of Liebig's mineral theory and demonstrating the suitability of ammonia (as a source of nitrogen) for corn crops and phosphates for turnips. Pusey argued that the expensive, logistically complex importation of highly nitrogenous Peruvian guano, and its high availability in the 1850s, was delaying attempts to fix nitrogen in a chemical fertilizer.⁴⁷

Like Liebig, Lawes argued that the soil contributed little, if anything, to crops, 'acting only as a reservoir' for applied manures, regarding food production as an industrial manufacturing process.⁴⁸ In 1843, Lawes synthesized the only successful chemically manufactured fertilizer to date, his much-replicated superphosphate, and used the profits to fund his work at Rothamsted. This did not out-compete Peruvian guano but achieved success where Liebig's mineral fertilizer had failed. Following publication of Lawes and Gilbert's results, a long exchange of public and hot-tempered correspondence with Liebig followed.⁴⁹ While Lawes and Gilbert recognized the efficacy of Peruvian guano, particularly in suggesting that Liebig's mineral manure would benefit from its addition, it assumed no singular importance in their results. However, in ratifying Boussingault's work, they boosted use of all nitrogenous fertilizers, including Peruvian guano.⁵⁰ In the late 1850s, Liebig eventually conceded that Peruvian guano was useful as a supplement on specific crops, and that it and farmyard manure were superior to Chilean nitrates, due to their additional mineral content.⁵¹ His concerns that continued use of guano, or any highly nitrogenous manure, might lead to exhausted soils without careful attention to

⁴⁵ J. Johnston, *Experimental agriculture, being the results of past and suggestions for future experiments in scientific and practical agriculture* (1849), pp. v–vii, 4–5; J. Johnston, *A catechism of agricultural chemistry and geology* (1845), pp. 38–9.

⁴⁶ J. B. Lawes and J. H. Gilbert, 'On Agricultural Chemistry: especially in relation to the Mineral Theory of Baron Liebig', *JRASE* 12 (1851), p.4.

⁴⁷ P. Pusey, 'On the progress of agricultural knowledge over the past eight years', *J. Royal Agricultural Society of England* [hereafter *JRASE*] 2 (1850), pp. 382–92.

⁴⁸ J. Lawes, *Is higher farming a remedy for lower prices? Being the substance of a lecture delivered before the East Berwick Agricultural Association* (1879), p. 6.

⁴⁹ R. Aulie, 'The mineral theory', *Agricultural Hist.*

48 (1974), pp. 377–8; 'Agriculture: The composition of plants', *Aberdeen J.*, 23 July 1851, p. 7; Liebig, *Principles of agricultural chemistry*; J. Lawes and J. Gilbert, *Reply to Baron Liebig's 'Principles of agricultural chemistry'* (1855); Kinsley, 'Guano and British Victorians', pp. 120–3.

⁵⁰ Lawes Agricultural Trust, 1847–1900, *The letters of Sir John Bennet Lawes to Sir Joseph Henry Gilbert*, 3 July 1876, Rothamsted Research Library and Archives 2008: J. Lawes and J. Gilbert, 'Liebig and the Mineral Theory', *JRASE* 24 (1863); J. Lawes, J. Gilbert and E. Pugh, *On the sources of the nitrogen of vegetation: with special reference to the question whether plants assimilate free or uncombined nitrogen* (1862).

⁵¹ J. Liebig, *Letters on modern agriculture* (1859), pp. 60, 162, 168–9.

ANALYSES OF DIFFERENT VARIETIES OF GUANO.

	Angamos Guano.	Angamos Guano.	Peruvian Guano.	Chilian Guano.	Bolivian Guano.	Saldanha Bay Guano.	Sharks' Bay Guano.
Moisture	10.90	12.55	9.30	20.46	16.00	17.92	14.47
Organic Matter, &c.	67.36	61.07	57.30	18.50	13.16	14.08	7.85
Sand, &c.	1.04	5.36	0.75	22.70	3.16	2.80	14.47
Phosphates	16.10	13.76	23.05	31.00	60.23	59.40	29.54
Alkaline Salts, &c.	4.60	7.26	9.60	7.34	7.45	5.80	33.67*
	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Nitrogen (equal to)	19.95	18.24	15.54	4.50	2.11	0.63	0.35
Ammonia	24.19	22.12	18.87	5.47	2.56	0.76	0.47

* 49.54 per cent. of this was Gypsum.

The above are Analyses made at the Kennington Laboratories. The samples were from cargoes received in London within the last six months. The Chilian and Bolivian Guanos are much inferior to those formerly imported, in consequence, we believe, of all the finer qualities having for some time been worked out.

FIGURE 2. Analyses of different types of guano

Source: J. C. Nesbit, *On Peruvian guano: Its history, composition and fertilizing qualities; with the best mode of its application to the soil* (1856), p. 28.

additional nutrients eventually became more widely accepted. This is evident in the practical experience of farmers, who also became concerned about over luxuriance of crops at the expense of the fruiting part.⁵²

Peruvian guano's popularity led to attempts at replication as early as 1843, evident in Johnston's inclusion of modified and replicated guanos in his field test records.⁵³ Johnston's results therefore acknowledged the early chemical mixing and alteration of guanos and he revealed a significant further step in guano losing its 'naturalness' and its 'redesign' as a new commodity. Alteration also occurred in the form of adulteration and this, along with the importation of seabird guanos from locations other than Peru, led to a demand for the services of analytical chemists to assess the quality of guano and other manures. As evident in the proliferation of targeted advertisements in agricultural press, farmers, agricultural societies, and estate managers sought the services of chemists to assess guano purity, and such purity was part of merchants' sales pitch to justify their guano prices.⁵⁴ Chemists also used guano in

⁵² Ibid., pp. 182-3; J. Mechi, *How to farm profitably* (1860), p. 274; William Good, *The theorists confuted or the practical farmers vindicated: with a reply to Mr Mechi* (1851), p. 207.

⁵³ Johnston, *Lectures* (1844), Appendix 4, 4.1, 4.3, 4.4.

⁵⁴ An edition of Nesbit's, *The history and properties* can be found in the Tyntesfield archive owned by

William Gibbs, company director of Antony Gibbs and Sons, who held the monopoly on British guano imports. Advertisements for Nesbit's assaying services were included in these publications: J. Nesbit, *On agricultural chemistry and the nature and properties of Peruvian guano* (1854), frontispiece.

their own fertilizer mixes and many made attempts to replicate it.⁵⁵ While university-educated analytical chemists, such as A. Voelker and J. T. Wray, worked for agricultural societies, high demand led many chemists to develop careers outside elite circles.⁵⁶ John Nesbit was such an example and an important linchpin in the history of guano's development as a commodity. Benefiting from public scientific lectures and societies for the dissemination of scientific education, he analysed and mixed manures, set up Kennington Agricultural College, exhibited at the Great Exhibition, and produced popular publications on guano.⁵⁷

Nesbit addressed variations between guanos of differing provenance (see Figure 2). Johnston argued that Britain's wet climate and seabirds could neither produce quality guano, nor in quantities suitable for exploitation.⁵⁸ Thus, early on its commercial exploitation in Britain, we find fears of the depletion of guano reserves, which led to sea voyages to discover other sources outside Peru. Such a belief in the possibility of substitution matches well with geographer, Noel Castree's analysis of 'abstraction' in the capitalist commodification of nature. All seabird guanos are rich in phosphates, but the Peruvian product proved to be unique in both its high nitrogen content and levels of accumulation.⁵⁹ Influenced by Rothamsted's results, Nesbit provided instructions for the suitability of different guanos for different crops.⁶⁰

The use of chemical knowledge increased the confidence of many farmers in their ability to increase food production and guano was an important part of their toolkit. In the 1840s, farmers were adjusting to the push for greater productivity, new logistics provided by rail transport, and an 'advice explosion' created by scientists and agricultural societies. These provided an important context for the vogue for new fertilizers like guano and superphosphates. The 'advice explosion' had taken a long time in building, but now took on new dimensions. Warde reports that, by 1800, there were plenty of theoretical explanations for crop growth (albeit sometimes contradictory), widespread debate about plant foods and problems relating to deficiencies, and a recognition of the need to maintain the balance between pasture in its provision of dung, and tillage as its receptacle. In addition to nutrient provision, the conditioning qualities of dung had already been recognized in 'loosening' the soil. Warde also outlines how an image of the ideal farmer as an agricultural reformer and man of science had already been formed by the dawn of the nineteenth century and what was needed now was

⁵⁵ J. C. Nesbit, *Lecture on the application of chemistry to agriculture: delivered at Farnham December 17, 1846, with observations on artificial manures* (1847), pp 4–6.

⁵⁶ Kinsley, 'Guano and British Victorians', pp. 72, 139.

⁵⁷ I. R. Morus, 'Manufacturing nature: Science, technology and Victorian consumer culture', *British J. Hist. of Science* 29 (1996), pp. 403–34; 'Mr J. C. Nesbit's agricultural lecture in Cornwall', *The Farmer's Gazette*, *Nottinghamshire Guardian*, 18 Dec. 1856, p. 6; J. C. Nesbit, *On Peruvian guano: Its history, composition and fertilizing qualities; with the best mode of its application to the soil* (1852 and 1856); J. Nesbit, *On agricultural chemistry and the nature and properties of Peruvian guano* (1856); J. Nesbit, *The history and properties of the different varieties of natural guanous* (1860);

'Nesbit, J. C., Kennington, Exhibitor. Phosphate fossils for manure', in the *Official Catalogue of the Great Exhibition* (2nd edn, 1851), p. 14; 'Mining and minerals', *London Daily News*, 22 May 1851, p. 6; 'Prize lists of the Great Exhibition', *London Daily News*, 17 Oct. 1851, p. 2.

⁵⁸ J. Clark, *Practical instructions for using guano as a manure: illustrated by practical results* (1845), pp. 10–11.

⁵⁹ N. Castree, 'Commodifying what nature?' *Progress in Human Geography* 27 (2003), pp. 273–97; C. Cordle, 'The guano voyages', *Rural Hist.* 18 (2007), pp. 119–33; Kinsley, 'Guano and British Victorians', pp. 17–19.

⁶⁰ Nesbit, *History and properties*, pp. 6, 13–49; 'British Guano equal in quality to Peruvian', *Agricultural Gazette*, 14 Feb. 1846, p. 111; 'Mr John Nesbit', *Illustrated London News*, 19 Apr. 1862, p. 394.

better communication and advice.⁶¹ There is little doubt that agricultural chemists were instrumental in filling this gap, but Liebig, despite being an excellent self-publicist, was a theorist who often questioned the ability of farmers to understand his work. With a rise in the number of agricultural societies and publications, it was scientists like Lawes, Johnston and Nesbit who gave many public lectures and had greater leverage in the translation of theory into practice.⁶²

II

The high farming of the 1840s required considerable capital investment: in fertilizers, machinery, and infrastructure. Guano played its part in this capital-intensive power shift in agriculture.⁶³ Agriculture attracted new wealth, including successful industrial manufacturers, many with a relative lack of experience. For them, guano often appeared to offer a 'quick fix' as an artificial fertilizer. Indeed, its material efficacy helped to bring new and marginal land into production. Some accusations against such new entrants into farming attributed the growing popularity of guano to its use as a status symbol. Farmer and politician, Thomas Gisborne, criticized a lack of cost-benefit analysis applied to high farm capital investment. Bought-in manures, particularly Peruvian guano, were expensive, suffered risky price fluctuations, were easily leached in wet seasons, and less effective in dry summers. He cautioned against overplaying guano's impact and its promotion as a quick and easy fix. This could lead to 'guano mania' and the creation of a 'guano king.' He strongly supported the broad efficacy of good farmyard manure and cautioned against amateurishness, trendsetting, and the use of new manures as their 'pretty toys'. For him, guano use did not always generate profit, and eventually helped to bankrupt many high farmers, as ultimately reflected by the renowned agriculturist, John Mechi.⁶⁴ William Heywood, steward at the estate of Dunham Massey in Cheshire, criticized new entrants using farming as 'a pleasant kind of recreation or amusement that may be indulged in.'⁶⁵ The landowner Lord Kinnaid's exhortation to 'farm high, use guano' also elicits a form of fetish in an over-exaggerated perception of the fertilizer's value among wealthy farmers.⁶⁶ Marx's metaphors of delusion and illusion in the fetishization of a commodity might be seen to interfere with a rational valuation of guano, but it had become more than a fertilizer and achieved a value beyond the monetary.

Despite copious publicity for guano and the high availability of field trial results, an accurate assessment of where and how farmers used it is problematic. In the absence of reliable quantitative data, farmer-produced primary sources, including James Caird's two controversial pamphlets on high farming (1849 and 1850) and his agricultural survey of England (1850–51)

⁶¹ Warde, *Invention*, pp. 243–64.

⁶² J. F. W. Johnston, *Lectures to tenants and others on the estate of the Duke of Northumberland, Alnwick, 25 November 1843* (1843); J. B. Lawes, *Scientific agriculture with a view to profit: Read before the Maidstone Farmers' Club, December 15th, 1870* (1889).

⁶³ D. Worster, 'Transformations of the Earth: Toward an Agroecological Perspective in History', *J. American Hist.* 76 (1990), p. 1090.

⁶⁴ Thomas Gisborne, *Essays on agriculture* (1854).

⁶⁵ W. Heywood, *High farming. how far is it expedient? Let nature answer* (1867), pp. 2–41.

⁶⁶ T. Ross, *Lord Kinnaid's letter to his tenantry on profitable investment of capital or 11 years practical experience in farming, answered by Thomas Ross, farmer Wardheads and revised, Lord Kinnaid* (1849); G. Troup (ed.), 'High farming', *Tait's Edinburgh Magazine*, 17 Jan. 1850, pp. 44–9.

shed some superficial light on this issue.⁶⁷ Caird's ceaseless campaigns for the gathering and reporting of agricultural statistics were not to be realized in England until the mid-1860s, and this realization did not include data on manure use.⁶⁸

While Peruvian guano was valued for its portability and nitrogen content, farmyard manures remained highly valued for their nutrients with the added benefits of their bulky organic content to soil texture and structure. Farmyard manures generally maintained nutrient cycling within farm boundaries at lower costs than expensive imported fertilizers. As Boussingault's manure tables indicate, however, many manures were already imported into the farm when guano arrived. Off-farm industrial by-products, some imported from continental Europe, including sawdust, oil cakes, abattoir products such as dried blood, bones, glue, and food processing by-products, including animal black, were used alongside traditional animal manures.⁶⁹

Caird's well-read high farm study (Auchness Farm, Wigtown, 1849), while attracting strong support from *Tait's Magazine*, was highly criticized by 'Cato the Censor' (James Strachan Barty) writing in *Blackwood's Magazine* in 1850. This is echoed in a disagreement between Lord Kinnaid, of Rossie Priory on the Carse of Gowrie estate, and his tenants, which also elicited a response from Barty.⁷⁰ While recognizing guano's efficacy, Barty was critical of its additional use by some as a political and status-building tool. Even *Tait's* criticized the more confrontational Lord Kinnaid of 'rather standing by and shouting than lending any great hand. His shout is 'Farm high, and use guano,' being a far abler writer than a farmer.'⁷¹

Barty maintained that guano frequently caused over-luxuriance and 'the productive powers of the soil', had limits beyond which 'you cannot go with safety. A point when mother earth revolts against the voracious avarice of her child, and spurns from her the exotic stimulants of art.' He portrayed Auchness farm as a case study of over-investment, arguing that its manure costs, up-scaled nationally, required an exponential increase in guano and bone imports. Indeed, Peruvian guano's popularity eventually waned due to a combination of factors. It was viewed as a high-cost fertilizer which, according to the Gibbs' company records fluctuated between £24 and £26 per ton in 1841, levelling out to £10–£12 per ton for most of the 1840s and 50s. Other farmers learned that over-application of guano caused over-luxuriance in crop leaves and stems causing drooping and low productivity of 'fruiting' heads.⁷² In the case of nitrogen-rich Peruvian, they also learned that nitrogen is easily leached from soils and therefore feared it had only short-term potency. As seabird guano is a finite resource,

⁶⁷ J. Caird, *High farming under liberal covenants, the best substitute for protection* (1849); J. Caird, *High farming vindicated and farther illustrated* (1850); J. Caird, *English agriculture in 1850–1851* (1852).

⁶⁸ Caird, *English agriculture*, p. 474; 'Agricultural statistics', *Essex Standard and General Advertiser for the Eastern Counties*, 1 Mar. 1854, p. 4; J. Caird, 'On the agricultural statistics of the United Kingdom', *J. Statistical Soc. London* 31 (1868), pp. 127–45; M. Overton, 'The critical century? The agrarian history of England and Wales 1750–1850', *AgHR* 38 (1990), p. 185–6.

⁶⁹ Boussingault, *Rural economy* (1845), pp. 391–3;

Liam Brunt, 'Where there's muck there's brass: The market for manure in the Industrial Revolution', *EcHR* 60 (2007), pp. 340–3.

⁷⁰ Caird, *High farming* (1849); Cato the Censor (James Strachan Barty), 'Caird's high farming harrowed', *Blackwood's Edinburgh Magazine* 67 (1850), pp. 447–75; Ross, *Lord Kinnaid's letter*; J. S. Barty, *Peter Plough's letters to the Right Honourable Lord Kinnaid on high farming and free trade* (1850), pp. 36, 38–9.

⁷¹ Troup (ed.) 'High Farming', p. 44.

⁷² Barty, *Peter Plough's letters*, p. 36.

the depleting numbers of guano birds, due to the destruction of their habitat, could not keep up the high demand for their excrement in the mid-nineteenth century and fears of resource depletion abounded. Liebig highlighted the dangers of farmer dependence on a limited resource.⁷³

Caird carried out his agricultural survey of 32 counties of England, sponsored by *The Times* of London, in 1850 and 1851.⁷⁴ There is no obvious sampling procedure. Farms visited included many larger landed estates and those of wealthy new entrants, no doubt keen to be interviewed about their improvements. County samples varied, including in-depth accounts of agriculture on two or three larger estates, and research sites such as the Royal Agricultural College at Cirencester, and Lawes' work at Rothamsted. The county of Staffordshire, for example, included nine large estates and several tenant farms on each of those estates. Caird travelled widely and made general observations on practice on smaller farms. He also interviewed farm agents, some local processors, and manufacturers. In the absence of reliable statistics, something Caird later campaigned for, a regional keyword search within this survey, of crop type, manures and method used, reveals, at a superficial level, regional distinction in agricultural practice.⁷⁵ Caird concluded that – while the Norfolk four-course rotation remained popular, particularly on lighter soils – rotations with more stages, including root crops, other green crops and corn (white) crops, were becoming a feature of 'improvement' on heavier soils. The number of rotations varied with regional soil and climate as did the balance between arable and livestock farming, which was still frequently combined.⁷⁶ Clover, trefoils and vetches were used in pasture, as fodder and as green manure. Clover provided many acres of amenity and fragrance usefully countering the stench of the guano fields.⁷⁷ Sainfoin use was falling, whereas the use of peas and/or beans was increasing in rotations.

The survey finds large quantities of guano being applied to root crops, mostly used as fodder. Folding on root crops was also common for dual-purpose feeding and fertilizing. Lawes' findings on the importance of nitrates for corn crops were only just emerging and the use of nitrate rich Peruvian guano on corn crops is little reported. As pointed out by Mathew, much Peruvian guano was initially wasted on root crops, which would have benefited more from phosphatic fertilizers.⁷⁸ Nevertheless, farmers applied guano and farmyard manure to green and root crops with the logic that corn crops always followed in rotation, making use of remaining nitrate residues. How plants accessed nitrogen was being hotly debated at the time, so to a great extent decision making rested on the knowledge, skill and expertise of each farmer. This was particularly evident on smaller western family farms, where guano was

⁷³ Liebig, *Letters on modern agriculture*, p. 186.

⁷⁴ Caird, *English agriculture*. The frontispiece provides a map of county divisions by farming type and average wages.

⁷⁵ For a detailed summary, see Kinsley, 'Guano and British Victorians', pp. 172–4.

⁷⁶ Caird, *English agriculture*, pp. 501–3; Paul Brassley, writing in 'Arable Systems', in Collins (ed.), *AHEW*, VII, I, pp. 456–71, concludes that Caird's survey shows a concentration of arable, with sheep on lighter soils, which required greater manuring and more livestock

farming, particularly cattle on heavier soils. It also reveals a high proportion of mixed arable and livestock, particularly dairy and arable on lower lying land.

⁷⁷ L. Raven-Hill, 'Our Spring Poet', *Punch [Historical Archive]*, 30 Apr. 1902, p. 316; G. Chorley, 'The agricultural revolution in northern Europe, 1750–1880: nitrogen, legumes, and crop productivity', *EcHR* 34 (1981); T. Kjaergaard, 'A plant that changed the world: the rise and fall of clover 1000–2000', *Landscape Research* 28 (2003).

⁷⁸ Mathew, *House of Gibbs*, p. 179.

carefully used in rotations. A mixed farming approach through rotation remained common, with animal husbandry strong in the west and north. The introduction of more highly bred animals, with purpose-built indoor winter stabling, enabled integrated manure collection and storage systems.

Caird maintained that mixed farming approaches often better suited British landscapes and would help to meet rising demand for meat and dairy products. He recommended increasing grassland, meat and vegetable production, better husbandry providing more employment opportunities, and decreasing land in corn production, due to the threat of foreign competition. Caird believed that that new 'artificial' like guano would result in increased corn production despite a reduction in tilled land, also maintaining that northern and western rich grasslands and well-manured crop fields, already producing corn in rotation, would be excellent insurance as a reservoir for short-term corn production in times of crisis.⁷⁹ As well as noting improved farmyard manure management, he reported rotations ranging from four to seven cycles with crop sequences reflecting local variations in landscapes including geology, soils, gradient, altitude, aspect, water availability in its different forms, sunlight and microclimate in general. Such variations are abundant over short distances in British landscapes. So, while science played a role in increasing efficiencies in all areas of agriculture, local knowledge mattered.

Caird's survey demonstrated where guano boosted productivity and brought more land into cultivation. Guano's greater use on the Cotswolds boosted soil productivity beyond the richer soils of the Vale of Gloucester, where he criticized 'backward' practices. Effectively used on higher land in West Cumberland and Derbyshire, it also boosted wheat production on poorer Yorkshire Wold soils and more generally on clays. A double application of guano on poorer Northumbrian Cheviot soils yielded an equivalent crop to a single application on richer soils. He argued for greater guano application on thin chalk soils in Buckinghamshire. In all cases, the greater production, collection, and improved management of farmyard manure achieved better results on lower-lying, easily accessible land. Overall, Caird's survey revealed that farmyard manure and use of legumes in rotation received more mentions than guano, which was closely followed by sheep folding (see Figure 3). The use of bones was less frequently mentioned and superphosphate less still, indicating that guano was a more significant supplementary fertilizer. Agricultural night soil use reduced considerably in the mid-nineteenth century as sanitary reform decreased the use of cess pools in cities, and a wider range of fertilizers became available.⁸⁰

Where capital was available for investment in farm infrastructure, machinery and fertilizers, more guano and superphosphate were used. Caird made scant reference to the already well-publicized Tiptree Farm, Essex, owned by successful self-publicist, John Mechi, who made his fortune as a cutlery and razor manufacturer. His work and ideas exemplify how novice, but aspiring, high farmers behaved, and how they were received in the agricultural community. He constructed his manor house and model farm in 1841 and his lectures and annual nationwide convocations of agriculturalists were widely featured in the press and periodicals.⁸¹ In the

⁷⁹ Caird, *English agriculture*, pp. 269, 276, 289, 323, 486–7.

Victorian Literature and Culture 30 (2002), p. 356.

⁸⁰ M. Alan, 'From cess pool to sewer (1848–1880)',

⁸¹ 'The annual gathering at Mr. Mechi's Farm, Tiptree Hall', *The Examiner*, 24 July 1852, p. 471.

	DAIRY/GREEN CROP REGIONS		CORN REGIONS		OVERLAP REGIONS	
	Mentioned as used	Not mentioned	Mentioned as used	Not mentioned	Mentioned as used	Not mentioned
Farmyard Manure/Town dung	13	2	14	2	3	1
Leguminous crop in rotation	12	3	14	2	4	0
Guano	10	5	8.5	7.5	2	2
Folding (mostly sheep)	10	5	7	9	2	2
Bones	6	9	5.5	10.5	0	4
Superphosphate	4	11	3	13	2	2
Night soil	2	13	1	15	0	4

FIGURE 3. Comparative use of guano with other methods of soil fertility improvement, 1850–51

Source: L. J. Kinsley, 'Guano and British Victorians: an environmental history of a commodity of nature' (unpubl. PhD thesis, University of Bristol, 2020), p. 176.

1840s, Mechi believed guano to be the most important manure, enabling him to cultivate marginal heathland and clay.⁸² However, after such heavy investment, guano did not bring him the long-term profits he anticipated.

Mechi's early practice was criticized by farmers like William Good, who had worked at the 'dung-face' for far longer. Good maintained that soil health was compromised by the over-application of concentrated nutrients. He believed that guano, although benefiting crop growth, subsequently left soils in poorer condition than traditional tillage. Tempered by his acknowledgement that guano performed well on bringing poorer soils into production, he argued that farmers would be 'unable to replace that which they had taken.' Good voiced growing concerns about guano's shelf-life. After its initial success, Good argued that farmyard manure then proved to be more beneficial as guano 'forced' crops too hard, leading to a 'diseased crop', 'premature ripeness' and 'drooping at the root'. In tune with growing public concern, he reiterated concerns about dwindling guano supplies.⁸³ Good's main gripe was not against improvement *per se*, but that new self-promoting entrants into farming lacked agricultural skill.

Learning through practice, Mechi eventually concluded that guano was no more valuable than cattle urine. He criticized urine wastage and invested heavily in liquid manure production, urine collection tanks and piped systems.⁸⁴ Like generations of skilled farmers before him, Mechi came to realize that farmyard manure was essential for heavy land as it 'acts mechanically as well as chemically – loosening the soil'. Nevertheless, he continued to use Peruvian guano to bring poorer and distant soils into production, and as a supplemental fertilizer, but moved his focus to animal manures, installing covered yards to replace open

⁸² J. Mechi, *A series of letters on agricultural improvement* (1845), pp. 15, 21, 23–4, 42, 55–6, 121.

⁸³ Good, *Theorists confuted*, pp. 176, 186, 191–2, 207, 263.

⁸⁴ British Library, 7074.k.35, Mechi, John Joseph, 1844,

'Letters on agricultural improvement' (Six Letters), Letter 3, 5; J. Mechi, *Copy of a paper on the subject of British agriculture read before the Society of Arts on 22 November 1850* (1850), p. 8; Mechi's experience in *drainage* (1847), p. 14; Mechi, *A series of letters*, pp. 47, 95.

dung heaps. Mechi calculated that he later manured at half the cost of the guano he had initially used.⁸⁵

In summary, after the initial rush to often over-apply guano, guanos from different origins were more carefully tailored to different crop types using the lessons learned from scientific field trials and the observations of farmers who used it. More experienced farmers balanced their guano application against improved standards of farmyard manure production and storage. Guano became more commonly used to kick-start marginal land into production, and as supplementary manure in improved crop rotations alongside the efficient collection, storage, and management of farmyard manures.

III

Whilst this article focuses on debates about the use of guano in Britain, it was also available as a commodity in North America and Europe, and many examples of parallel thinking, and much cross fertilization of ideas can be found.⁸⁶ Indeed, the focus of environmental scholars of guano in recent decades has been towards the western hemisphere and the global implications of nutrient cycle disruption and the unsustainable impacts of mining and export.⁸⁷ The guano trade was the first global example of long-distance fertilizer transport in bulk and considerably widened an already evident nutrient rift. In this, guano birds acted as unwitting agents in colonial expansion via trade, labelled 'ecological imperialism' by Crosby.⁸⁸ This was a two-way process, opened up by the Peruvian government when they privatized their guano resources for profit. Equally British merchants saw this as a profit-making opportunity, using their own resources to export them over long distances to increase food production for the urbanizing labour force. After an initial period of high demand, British farmers soon discovered the negative impacts of misuse on certain crops, high prices and the greater benefits of well managed farmyard manures to soil texture and structure. Fears of adulteration, complexities in the logistics of sourcing guano and fears of diminution of guano reserves would in turn contribute to the emerging recognition of the dilemma of sustainability.

British farmers would have benefited from taking more notice of the literature noting the carefully measured use of guano by indigenous farmers in Peru.⁸⁹ Liebig's criticism of British high farming's appetite for fertilizers included his famed portrayal of Britain 'hanging like a vampire on the neck of Europe' in raiding war graves for bones, and his recognition of the high wastage of nutrients in run-off.⁹⁰ These views were widely shared by other chemists and began to filter through to agricultural practice. The beginnings of concern about the widening rift between humans, nutrients, and soil evident in the writing of Liebig reflects the emergence of

⁸⁵ Mechi, *How to farm profitably*, p. 124.

⁸⁶ J. Johnston, *Notes on N. America* (2 vols, 1851); R. A. Wines, *Fertilizer in America: from waste recycling to resource exploitation* (1985).

⁸⁷ Cushman, *Guano*; Melillo, 'First green revolution', pp. 1028–60; Clark and Foster, 'Ecological imperialism', pp. 311–44; Schneider and McMichael, 'Deepening, and

repairing', p. 477.

⁸⁸ A. W. Crosby, *Ecological imperialism, the biological expansion of Europe, 900–1900* (sec. edn, 2004), pp. 10, 11.

⁸⁹ Kinsley, 'Guano and British Victorians', pp. 45, 56, Leigh, *The world's greatest fix*, pp. 78–80.

⁹⁰ A. D. Hall, *Fertilisers and manures* (1915), p. 108.

a subtly different concern amongst Victorians, not solely related to landscape, aesthetics, and the beauty of nature, but to the 'health' of the soil beneath their feet. Liebig's first book (1840) contained indications of this thinking, but by his 1843 edition, this idea of the loss of nutrients from farms into city sewers had become clearer. On reading Liebig, Marx also concluded that 'the vitality of the soil is squandered'.⁹¹

Paul Warde argues that soils became the most 'fundamental conundrum' of the mid-nineteenth century. They have remained so ever since. He suggests that it was Justus von Liebig who elaborated a profound critique of civilizations undermining themselves through mismanagement of the soil, a first significant emergence of the idea of the dilemma of sustainability. Warde illustrates how this was already becoming a conventional opinion in the mid-nineteenth century and the observations of many chemists and farmers about their guano use support this view. He argues that the modern problem of agricultural sustainability had arrived and asks: 'could experts successfully engineer the flow of nutrients to a society whose practices systematically endangered its existence?'⁹²

Nevertheless, the dominance of chemists in agricultural science arguably, and paradoxically, engendered the view of guano as artificial with Peruvian as the ideal chemical fertilizer, and enhanced a view of the soil solely as a receptacle for these means. Liebig presented all nutrient cycles as chemical and it was only later that Louis Pasteur led germ theorists in an understanding of micro-organisms as agents of decomposition.⁹³ Darwin's recognition of the importance of biological agency in soils in the 1880s almost coincided with the discovery of nitrogen-fixing bacteria, but failed to contribute significantly to any recognition of the importance of soil organisms, despite a previous and passing reference by Lawes.⁹⁴ Indeed, arguably this understanding only more fully emerged with the organic movement in the 1930s, when Albert Howard's and Eve Balfour's work acknowledged the necessity of the living components of soils for their fertility.⁹⁵ The focus of many agricultural chemists on achieving mono-cropping through chemical technology could hardly be called environmentally sustainable, but this was countered by their increasing concern about increased fertilizer application and nutrient wastage in sewage and agricultural run-off. Guano use aided this important early recognition of environmental problems created by the intensification of food production.

Liebig's criticism of the bulk mass transport of bird excrement halfway round the planet to Britain, where its valuable nutrients were excreted into city sewers, rivers and oceans, became widely accepted.⁹⁶ Johnston supported Liebig's view that 'wealth' was also lost in allowing

⁹¹ Liebig, *Chemistry in its applications*, p. 165; Marx, *Capital*, III, p. 813.

⁹² Warde, *Invention*, pp. 300–4, 329–32; Liebig, *Organic chemistry*.

⁹³ Hopwood *et al.*, 'Cycles and circulation', p. 23; Mårald, 'Everything circulates', p. 72.

⁹⁴ Lawes and Gilbert, 'On Agricultural Chemistry', pp. 30–3; Justus Liebig, Lyon Playfair and John Webster, 'Organic chemistry in its applications to agriculture and physiology', *North American Rev.* 53 (1841),

p. 168; C. Darwin, *The formation of vegetable mould through the action of worms, with observations on their habits* (1883); M. Rossiter, *The emergence of agricultural science: Justus von Liebig and the Americans, 1840–1880* (1975), pp. 20–1.

⁹⁵ A. Howard, *An agricultural testament* (1940, 6th edn, 1950), pp. 35, 42, 48, 76; Eve Balfour, *The living soil* (1943).

⁹⁶ 'Liebig on Sewage', *Essex Standard*, 21 Jan. 1859, p. 2.

liquid manures to run to waste and this was particularly true in the case of Peruvian guano, exacerbated by its highly soluble nitrogen.⁹⁷ Johnston's holistic thinking on nutrient cycling also made a contribution to the emergence of sustainable thinking. Johnston straddled the natural theological/empirical divide in communicating his ideas.⁹⁸ Christopher Hamlin describes this as 'chemico-theology'.⁹⁹ This recognition of Johnston's contributions to the creation of the idea of the 'dilemma of sustainability' is evident in Marx's description of him as 'the English Liebig' and in Mårald's work on circulation.¹⁰⁰

In popularizing Carl Sprengel's 'law of the minimum', Liebig articulated how the efficacy of fertilizers is limited by the availability of the scarcest chemical nutrient, but he also foresaw how continued use of guano could 'impoverish' the land, indicating a growing understanding of the dangers of excess.¹⁰¹ Boussingault also understood the limits of production in soils but, like Johnston, was less convinced that chemical technology could enable the same crop to be grown in the same soil *ad infinitum*. Liebig was not alone in creating a view of soil only as a chemical receptacle, leading some twentieth-century ecologists to hold a view of nineteenth-century chemists as responsible for all the evils of modern industrial, chemically focused agriculture.¹⁰² While guano use contributed to a belief in chemical technology to control nature for food production, it took the industrial fixation of nitrogen by Haber and Bosch in 1909 and the passing of two world wars before this was more fully realized.¹⁰³

Chemists' concerns about soil fertility became widely embraced by Victorians, including by writers like Dickens and Marx. After reading Liebig and Johnston's work, Marx changed his opinions on agricultural potential, arguing 'Constantly growing urban populations crowded together in large cities' cause 'an irreparable break in the coherence of social interchange prescribed by the natural laws of life...as a result the vitality of the soil is squandered'.¹⁰⁴ Agricultural guano use stimulated parallel concerns amongst farmers about fertilizer over-application as they were developing a more detailed understanding of the importance of broader soil health. William Heywood's argument that 'ploughing so deeply and forcing so highly' (other farmers had noted guano's forcing capabilities) 'may in the end terminate in a derangement of nature's order', is another recognition of the dilemma of sustainability.¹⁰⁵

Mechi's later campaign to replace guano with town sewage, reflected the views of Liebig and others and achieved huge publicity.¹⁰⁶ Significantly, he argued, as Liebig did, that 'another century may teach us all agricultural wisdom' through sustainable sewage use and the avoidance of unnecessary expensive imports. The potency of guano's popularity was evident in his use of 'liquid guano' to label town sewage.¹⁰⁷ Nevertheless, while supporting the view that

⁹⁷ J. Johnston, *Elements of agricultural chemistry and geology* (1842), pp. 26, 29, 33.

⁹⁸ J. Johnston, 'The circulation of matter', *Blackwood's Edinburgh Magazine* 73 (1853), pp. 550–60.

⁹⁹ C. Hamlin, 'Providence and putrefaction – Victorian sanitarians and the natural theology of health and disease', *Victorian Stud.* 28 (1985), pp. 401–2.

¹⁰⁰ Marx, *Capital*, III, p. 813; Mårald, 'Everything circulates', p. 68–9.

¹⁰¹ Liebig, *Letters on modern agriculture*, p. 186.

¹⁰² Liebig, *Principles of agricultural chemistry*, p. 47; C. Massy, *Call of the reed warbler: a new agriculture, a new earth* (2017), pp. 158–9.

¹⁰³ A. Page, 'The greatest victory', pp. 384–5.

¹⁰⁴ Marx, *Capital*, III, p. 813.

¹⁰⁵ Heywood, *High farming*, pp. 2–41.

¹⁰⁶ 'Mechi the mourner', *Punch*, 21 Aug. 1858, p. 75.

¹⁰⁷ Mechi, *How to farm profitably*, p. 100.

over-application of ammonia and crop removal led to exhausted soils, his grandiose vision for agriculture remained intensively industrial.¹⁰⁸

With urbanization, our excrement, containing nutrients extracted from agricultural fields, became a spatially concentrated-hazard causing, for instance, cholera outbreaks, which contributed to challenging living conditions in British towns and cities, as evident in Edwin Chadwick's comprehensive report in 1842.¹⁰⁹ This led to the sewage debates of the nineteenth century, which coupled the need for improved sanitation to reduce disease, with achieving a sustainable agricultural solution for the fertilizer problem.¹¹⁰ In Britain, guano use helped to exacerbate a reduction in the application of human excrement directly back into the soil, either from the farm itself or and by night soil cartage from cities. Cartage decreased with a reduction in cesspit use following Snow's observation of their link to cholera.¹¹¹ Liebig's negative view of Britain's importation of large quantities of fertilizer was coupled with his optimism that this could be avoided if sewage was applied to the land. This influenced Chadwick and other sanitarians, but the replacement of cess pits by flushing toilets, to reduce cholera, initially resulted in the transport of sewage into wastewater overflows and out into rivers. While this was viewed as preferable to cholera, it did move the problem downstream and still lost valuable nutrients.¹¹²

British Victorians utilized two main approaches to the production of fertilizers from sewage: irrigation and dry products. Lawes and Gilbert undertook extensive trials in sewage irrigation, notably at Rugby, and many agricultural chemists attempted to put a value on this to assess financial viability.¹¹³ Lawes used guano as a benchmark in this sponsored work on sewage irrigation solutions, and the search for a profit (see Figure 4).¹¹⁴ Despite the high cost of implementation, irrigation was ultimately chosen in place of dry products. Liebig's reference to the use of night soil in Chinese agriculture was picked up by other agricultural chemists, as was Boussingault's inclusion of the Parisian manufacture of poudrette in his manure tables.¹¹⁵

In a strange twist, guano had some influence on the production of dried humanures. Many rushed to manufacture humanure products in the hope of commercial profit and appropriated the term 'guano' as a powerful marketing tool. The power of guano as an idea saw the common usage of 'native guano' for humanure products by medics, sanitation engineers, farmers and the wider public. One humanure manufacturer, the Native Guano Company, formally adopted it for its company name.¹¹⁶ In contributing to the design of joint solutions to public health

¹⁰⁸ 'More talk on town sewage', *Farmers' Magazine*, 3rd Ser. 17 (1860), pp. 253–4.

¹⁰⁹ E. Chadwick, *Report for Poor Law Commissioners to HM Government on the Sanitary Condition of the Labouring Population of Great Britain* (1842).

¹¹⁰ N. Goddard, 'A mine of agricultural wealth: the Victorian and the agricultural value of sewage', *J. Hist. Geography* 22 (1996), pp. 274, 286.

¹¹¹ T. Choi, 'Writing the Victorian City', *Victorian Stud.* 43, (2001), p. 567; Goddard, 'Mine of agricultural wealth', p. 275.

¹¹² Sheail, 'Town wastes', p. 191.

¹¹³ *Ibid.*, pp. 201–2.

¹¹⁴ J. B. Lawes and J. H. Gilbert, 'On the composition, value and utilization of town sewage: position of the sewage question', *J. Chemical Soc.* 19 (1866), p. 103.

¹¹⁵ D. Worster, *The good muck: Toward an excremental history of China* (Munich, Rachel Carson Center, 2017).

¹¹⁶ Kinsley, 'Guano and British Victorians', pp. 214–17; The Native Guano Company, *The sewage question settled by the purification of the water and the manufacture from town sewage of a dry and portable manure possessing highly fertilizing properties as effected by the Native Guano Company*, (1870).

Relation of Sewage to Peruvian Guano in amount of Nitrogen reckoned as Ammonia.

If Sewage per head per annum.	Contributing 1,000 tons Sewage.	If 12½ lbs. Ammonia, per head per annum, from all sources.		If 10 lbs. Ammonia, per head per annum, from all sources.	
		1,000 tons Sewage = Guano.	1 ton Guano = Sewage.	1,000 tons Sewage = Guano.	1 ton Guano = Sewage.
Tons.	Persons.	Cwts.	Tons.	Cwts.	Tons.
40	25	16½	1220	13	1525
50	20	13	1525	10½	1900
60	16¾	11	1830	8¾	2290
80	12½	8½	2440	6½	3050
100	10	6½	3050	5¼	3810
200	5	3¼	6100	2¾	7620
1 Person = Guano.		¾ cwt.		½ cwt.	

FIGURE 4. Lawes and Gilbert's comparison of sewage and Peruvian guano in nitrogen content

Source: J. B. Lawes and J. H. Gilbert, 'On the composition, value and utilization of town sewage: position of the sewage question', *J. Chemical Soc.* 19 (1866), p. 103.

and agricultural soil fertility problems, guano became a protagonist in the development of sustainable solutions to convert dried sewage into concentrated, portable fertilizers. This cultural idea of guano's abstraction was a strong driver in sewage solution research and led to many creative attempts to reclaim human excrement in the production of 'native guano' dry fertilizer products.¹¹⁷ However, due to technological challenges, high production costs, and complaints about noxious odours, dry native guano solutions were short-lived. Liebig was disappointed in the failure of British sewage solutions to reclaim human excrement but, as Hamlin concludes, this was exacerbated by 'municipal stinginess' and lack of suitably advanced technology.¹¹⁸ The focus turned to sewage irrigation, which caused problems of its own.¹¹⁹ Solid excremental solutions did not re-emerge until new forms of sewage treatment allowed the wider use of sewage sludge in the late twentieth century.¹²⁰

¹¹⁷ Kinsley, 'Guano and British Victorians', pp. 192–222.

¹¹⁸ Hamlin, 'Providence', p. 411.

¹¹⁹ Sheail, 'Town wastes', p. 209.

¹²⁰ DEFRA and Environment Agency, 'Sewage sludge in agriculture: code of practice', 23 May 2018 [[https://www.gov.uk/government/publications/sewage-](https://www.gov.uk/government/publications/sewage-sludge-in-agriculture-code-of-practice)

[sludge-in-agriculture-code-of-practice](https://www.gov.uk/government/publications/sewage-sludge-in-agriculture-code-of-practice)]; G. McGavin and Zoe Laughlin, 'The Secret Science of Sewage', 2021 [<https://www.open.edu/openlearn/tv-radio-events/tv/the-secret-science-sewage>]. Despite dangerous contamination, new science is enabling its strictly controlled use on soils, as well as its exploitation for energy.

IV

In conclusion, the impact of guano on nineteenth-century agriculture has two contradictory strands. On the one hand, guano was viewed as a chemical tool in the application of scientific technology to agriculture. During the past thirty years, environmental historians, in re-evaluating the global exploitation of guano have also revealed its role in nutrient cycle disruption. On the other hand, its use in Britain also helped to engender an emerging recognition by a wide cross-section of British Victorian society, including medics, sanitarians, and litterateurs, as well as agriculturists and scientists, of the need to work with nature. Guano's sustainable local use by the Inca and their recognition of the need to conserve a finite natural resource was countered by the nineteenth-century guano trade. This led to guano finding itself 'out of place' in an ecosystem far removed from its own and subjected to scientific and agricultural practice which drew nothing from its place of origin. The story of guano's exploitation reveals an overarching aspect of the sustainability dilemma, that of nutrient cycle disruption and the need to achieve sustainable solutions through nutrient balance and cycle re-closure. This supports Warde's argument that the sustainability dilemma had emerged in Britain by the mid-nineteenth century.

Guano did demonstrate the fertilizing qualities of nitrate in a concentrated portable form. Its high nitrogen content influenced the focus by chemists on the importance of nitrogen to plant growth and helped to stimulate a demand for industrially manufactured chemical fertilizers. However, these same chemists and skilled nineteenth-century farmers came to recognize the dangers of nutrient run-off from their soils and reduced crop productivity from overuse of guano. While chemically facilitated mono-cropping was not introduced in Britain in the mid nineteenth century, it was implemented earlier in North America and the plantation agriculture of many British colonies. Indeed, environmental historians attribute significance to guano use in North America, where it was applied in quantity to soils on more uniform geologies than those found in Britain. There, monocrops, such as cotton and tobacco, rapidly came into vogue where soils appeared ready-made to support food production with the help of guano.¹²¹ However, they had never done so before, and now have questionable ability to do so due to over-intensification.

For Britain, in all respects, guano was a very different agricultural tool. As Caird's survey illustrated, despite examples of initial over-application, British farmers generally chose to use guano in moderation, as part of enhanced crop rotations incorporating the high use of leguminous plants and better managed animal manures. Colin Duncan summarized English eighteenth- and nineteenth-century farming as geologically varied, 'constituted out of a mosaic of finely adapted local variations based on cattle and sheep/corn husbandry' and with the tendency to 'generate steady and sustainable improvements in land productivity.' A study of guano use in Britain supports his argument that increased production resulted from more efficient nutrient recycling, improvements in soil structure, better pest management and 'intricate rotations' with the interweaving of 'finely adapted regional breeds of sheep and cattle'.¹²² This was enhanced by

¹²¹ Melillo, 'First green revolution', p. 1044.

¹²² C. A. M. Duncan, 'The centrality of agriculture:

History, ecology and feasible socialism', *Socialist Register* 36 (2000), p. 194.

a greater understanding of the nutrient content of manures, particularly guanos from different origins, through the experiments of agricultural chemists.

In the nineteenth century, a belief in managing nutrient cycles to achieve balance and stability in harnessing soils for production was increasingly offset by a recognition of the threat of human intervention. Concerns about imbalance and instability were stimulated by the use of artificial fertilizers and, in straddling the natural/artificial divide, Peruvian seabird guano highlighted these concerns. With a higher nitrogen content than Chilean nitrates, it was lauded for its role in farmer acceptance of chemical technology. Nevertheless, through its overuse and strong fertilizing power, it contributed to an understanding of the dangers of agricultural intensification and farmers responded accordingly.

The trade certainly damaged Peruvian marine ecosystems and contributed to the emergence of a 'nutrient rift' that spanned parts of the globe, but in the 1860s, guano gave its name to sustainable sewage solutions put forward to close that rift. Despite these later influencing twentieth century sewage treatment, 'dry solutions' were rejected. Instead, attention turned to sewage irrigation, followed by sewage farms where on-farm purification took place in passing sewage through crops.¹²³ John Sheail illustrates how sewage irrigation caused 'sewage sickness' when effluent production outstripped the capacity of land to take it and concerns about parasite infestations on crops emerged. With the development of new artificial sewage treatment methods, he concludes that, by the early twentieth century, 'the concept of sustainability, as applied through the integral management of urban wastes and rural land use, had not only become discredited, but was perceived to be irrelevant to the nation's needs.'¹²⁴ The artificial fixation of nitrogen would have contributed to this view, but this also added to the repercussions of the mid-twentieth-century 'green revolution' with its attendant exponential increase in the manufacture and utilization of chemical fertilizers.

Global soils and climate are now paying the price of the failure to maintain nutrient balance in the twentieth century, as are the guano birds, despite Peru's efforts at conservation.¹²⁵ The history of guano's exploitation reveals more than the interplay and disruption of cycles supporting its production. Its use also contributed, on the one hand, to the development of agricultural chemical technology and associated nutrient cycle disruption. On the other hand, such disruption led guano use to contribute to emerging ideas of the dilemma of sustainability, and the 'idea' of it to be applied to integrated sustainable solutions for agriculture and sanitation. Despite a move away from this in the early twentieth century, sewage sludge technologies saw humanure reintroduction in the late twentieth century, which then became dogged by hormone, antibiotic, heavy metal and plastic contamination. The continued search for improved and sustainable technologies to address this provides a link with the unrealized Victorian attempts to perfect a 'native guano'.¹²⁶

¹²³ Sheail, 'Town wastes', pp. 196, 203.

¹²⁴ Ibid., pp. 202, 210.

¹²⁵ Cushman, *Guano*, pp. 348–9.

¹²⁶ Goddard, 'Mine of agricultural wealth', p. 287.