CAHIERS FRANÇOIS VIÈTE

Série III – N° 2

2017

From Bench to Brand and Back: The Co-Shaping of Materials and Chemists in the Twentieth Century

Edited by

Pierre Teissier, Cyrus C. M. Mody,

Brigitte Van Tiggelen

Centre François Viète

Épistémologie, histoire des sciences et des techniques

Université de Nantes - Université de Bretagne Occidentale

Imprimerie Centrale de l'Université de Nantes

Juin 2017

Cahiers François Viète

La revue du *Centre François Viète*
Épistémologie, Histoire des Sciences et des Techniques
EA 1161, Université de Nantes - Université de Bretagne Occidentale
ISSN 1297-9112

cahiers-francois-viete@univ-nantes.fr
www.cfv.univ-nantes.fr

Depuis 1999, les *Cahiers François Viète* publient des articles originaux, en français ou en anglais, d'épistémologie et d'histoire des sciences et des techniques. Les *Cahiers François Viète* se sont dotés d'un comité de lecture international depuis 2016.

UNIVERSITÉ DE NANTES

ISBN 978-2-86939-244-3

CONTENTS

Cahiers François Viète, série III, 2, 2017, p. 69-91

Twentieth Century Fertilizers in France from Natural Mixing to Artificial Making (1890-1970)

Philippe Martin*

Abstract
Compound fertilizer is a material composed of a mixture of primary nutrients. The physical constitution and presentation of compound fertilizer evolved from the nineteenth to the twentieth century. This material was originally the subject of purely empirical knowledge, but later it gradually attracted chemists, who developed it in confrontation with agronomists and farmers. In return, in the interwar period compound fertilizer gave the chemical community a sense of mission: to solve the "urgent need" to increase fertilizer consumption and to make the product "rational" with respect to transport costs, storage stability, ease of use, and, of course, agronomical efficiency. This paper traces the confrontation of actors and technical and industrial changes that guided the development of compound fertilizer in France from 1890 to 1970.

Keywords: fertilizers, agriculture, adulteration, industry, productivism, chemical innovation.

Résumé
Mélange d'éléments fertilisants majeurs, l'engrais composé est un matériau, qui évolua dans sa constitution physique et dans sa présentation du XIX^e^ au XX^e^ siècle. Initialement issu d'un savoir-faire technique empirique, ce matériau est progressivement investi par les chimistes, qui le façonnent en confrontation avec les agronomes et les agriculteurs. En retour, ce matériau oriente la communauté des chimistes, qui se sent investi, dans l'Entre-deux-guerres, d'une mission face à l'impérieuse nécessité d'accroître la consommation d'engrais : fabriquer un produit « rationnel » en termes de coût de transport, de stabilité au stockage, de facilité d'épandage et bien sûr d'efficacité agronomique. Cet article retrace les confrontations des acteurs et les changements techniques et industriels qui guident l'évolution des engrais composés en France de 1890 à 1970.

Mots-clés : engrais, agriculture, falsification, industrie, productivisme, innovation chimique.

* Centre François Viète d'Épistémologie, d'Histoire des Sciences et des Techniques, Université de Nantes.

IN THE FIELD of fertilizers at the turn of the 20th century, chemists felt that they were the bearers of a benevolent mission, especially through the development of superphosphate fertilizers. This was explained to farmers by the Compagnie de Saint-Gobain, one of the two biggest French fertilizer manufacturers (along with Etablissements Kuhlmann). "The use of chemical fertilizers chemical is no longer in effect a simple convenience for agriculture: it is an absolute necessity."[1] With superphosphate, a straight fertilizer, the heavy chemical industry had gained a foothold in the fertilizer industry, yet chemical fertilizers still only played a supporting role. The major fertilizer remained farmyard manure, a "natural" fertilizer compound *par excellence* for the farmer – a farmer who often prepared his own mixed fertilizers. Manufactured compound fertilizers were suspected of adulteration and were virulently hated by French agronomists. As one agronomist, Achilles Müntz, said in 1890: "The decrease in the purchase of fertilizer formula is the true measure of the spread of agricultural science throughout the countryside" (Müntz & Girard, 1891, p. 407).[2] Yet eighty years later, in the 1970s, manufactured compound fertilizers accounted for 67% of consumption of fertilizers in France. Today, agronomists recommend them. The production plants of fertilizers are imposing, for chemical fertilizers have become commodities across multiple continents and the volume of fertilizer consumption has become massive.

Compound fertilizer is a mixture of the primary nutrients (nitrogen, phosphoric acid, and potassium), in contrast to straight fertilizer, which consists of a single element. From the nineteenth to the twentieth century, fertilizer materials have evolved in their chemical compositions (organic, mineral and synthetic compounds) as well as their formulations (powders, granules, pellets). Such an evolution raises issues associated with the social construction of a product: agronomists, chemists, and industrialists all confronted each other in negotiating product quality, standardization, and the opposition between natural and artificial (Jas, 2000; Cohen, 2011). This case also highlights the collaboration of chemists and industrialists in technology transfers to solve a series of "reverse salients" to advance the industry and best meet demand (Caron, 2010; Hughes, 2004).

---

[1] "L'emploi des engrais chimiques n'est plus en effet désormais pour l'agriculture une simple convenance : c'est une impérieuse nécessité (Saint-Gobain, 1911)." All the translations of the quotations are from the author with slight revisions of the editors.

[2] "La décroissance de l'achat des engrais à formule est la véritable mesure de la diffusion des sciences agricoles dans les campagnes."

This chapter tackles the co-shaping of fertilizer materials and the professional identity of chemists, industrialists, agronomists, and farmers. I examine, first, the origins of compound fertilizers. This reveals the cause of the distrust between agriculturalists and industrialists and the posture of chemists in this confrontation. I then ask how chemists inserted themselves into the manufacture of compound fertilizers and how they appropriated the needs of farmers in order to offer new products. I explore, finally, the solutions that were proposed by manufacturers and chemists to meet surging demand from farmers in the 1950s and 1960s, in the context of productivism among the French government and agricultural authorities.

Guano, Fish and "Organo-Mineral" Fertilizers: The Building of Trust in Compound Fertilizers (1890-1920)

- *Mixed Fertilizers: Organic Origin and Empirical Knowledge*

In the 1830s, manufacturers produced fertilizer from mixtures of industrial and urban waste. One of the first "artificial" compound fertilizers in the 1840s was Peruvian Guano, a nitrogen and phosphate fertilizer. However, guano was not manufactured by industry but rather marketed by merchants. Thus, in 1845, the German chemist Justus Liebig partnered with the British industrial James Muspratt and took out a patent for six different fertilizers tailored to six different types of crops in the hope of replacing guano. It was a fiasco: the fertilizer formed a hard crust on the surface of fields. Indeed, Liebig worked in his laboratory and was distant from the field. In addition, he excluded any nitrogen fertilization (Bensaude Vincent & Stengers, 2001, p. 225-226; Jas, 2000, p. 36). The idea nevertheless caught on and in the 1850s manufactured "artificial guano" appeared in France. This was developed by individuals with industrial, agronomic training, such as Edouard Derrien, in Nantes on the Loire estuary in the western part of France (Martin, 2015). Abendroth, a doctor of philosophy and industrialist in Dresden, clearly defined in 1855 the challenges of "artificial guano" in terms of efficiency, consistency, portability, handling, cost, and industrialization of its production:

> 1. That this fertilizer can be provided in sufficient quantity; 2. That it is easily transportable and handling is easy and convenient; 3. That it always contains the main fertilizer ingredients in equal proportions; and 4. The goods,

having all of these conditions, can be established at a reasonable price and in any case lower than the Peruvian Guano.[3]

This definition, contained in a patent, is very interesting because it establishes the main issues that would guide the development of compound fertilizer throughout the twentieth century.

However, it was not until the late nineteenth century and early twentieth century that links were actually woven between chemists and fertilizer. The fertilizer industry at that time relied on the bulk chemical industry for the production of an intermediate required in the production of superphosphate, a product that makes inorganic phosphates assimilable by plants: sulfuric acid. With this product, chemistry entered the arena of compound fertilizers. Besides superphosphate, new forms of fertilizers appeared: "organic-chemical" fertilizers and "dissolved organic" fertilizers, including "guano dissolved" fertilizers in which guano is attacked by sulfuric acid in order to attach ammonia (Couturier & Lucas, sd, p. 49-50). With the discovery of mineral fertilizers, fertilizers made from organic mixtures were gradually displaced by "organic-mineral" fertilizer, a mixture of organic substances, minerals (Chile sodium nitrate, calcium phosphate, potash), and ammonium sulfate. The chairmanship of the Société des Agriculteurs de France by the Marquis Charles Jean Melchior de Vogüé, chairman of the Compagnie de Saint-Gobain from 1901 to 1916 is symbolic of this rapprochement of chemists and agronomy (Anonymous, 1965, p. 76). The manufacturers have guided farmers in their use of fertilizers by providing instruction manuals specifying the dose and the period of application, sometimes with recommendations for spreading, as did, in Nantes, society Pilon Frères, Buffet, Durand-Gasselin for its fertilizer bone (Anonymous, n.d.).

- *Adulteration and Product Quality: Compound Fertilizers Discouraged by the Agricultural Elite*

Since the early nineteenth century, the agricultural elite[4] intensively promoted modern agriculture among farmers in order to cope with an in-

---

[3] "1° Que cet engrais puisse être fourni en quantité suffisante ; 2° Qu'il soit facilement transportable et que le maniement en soit facile et commode ; 3° Qu'il contienne les substances principales d'engrais dans des proportions toujours égales et que 4° La marchandise, présentant toutes ces conditions, puisse être établie à un prix modéré et en tout cas plus bas que le Guano du Pérou" Patents data base of the Institut National de la Propriété Intellectuelle (INPI) http://bases-brevets19e.inpi.fr/, cote 1BB25599.

crease in the urban population. This agriculture was based on the abandonment of fallow in favor of the "mixed farming/cattle breeding" system. The objective was to increase yields per hectare with cattle-manure and, in addition, "artificial fertilizers" (manufactured fertilizer or imports such as Peruvian guano). Although they encouraged the use of fertilizers, these authorities remained wary of manufactured compound fertilizers offered by manufacturers. Compound fertilizers were not well regarded by agronomists: they were seen as including unnecessary ingredients, their prices were high relative to fertilizing capacity, their ready-made formulas were not adapted to all cultures, and they combined ingredients which agronomists felt should be used separately or at different times. In the 1890s, Achille Müntz, Chemistry Laboratory Director of the Institut National d'Agronomie in Paris, recognized the value of mixing fertilizers for the farmer: "With straight fertilizers, nothing is easier than to respond to all cases of agricultural practice; they can be used individually or combined in pairs, in threes, in the desired proportion to obtain maximum results with minimum expenditure"[5] (Müntz & Girard, 1891, p. 392-394). Yet Müntz also condemned manufactured compound fertilizers:

> [Compound] fertilizers offered by businesses must be rejected by the farmer. The farmer seeks to give the soil really useful elements in varying proportions, without having products imposed that do not meet this condition. Agricultural education will increasingly reduce their sales, and already in areas where culture is advanced, its use is restricted. The decrease in the purchase of fertilizer formula is the true measure of the distribution of agricultural sciences in the countryside. (our translation from Müntz & Girard, 1891, p. 407)

Above all, fertilizers, and particularly compound fertilizers, were the subject of fraud and adulteration in the nature, origin, quantity, and quality of components. The road to recognition of compound fertilizers was long and stretched throughout the nineteenth century. The farmer's representations of natural and artificial was continually confronted (Cohen, 2011). In France, chemists such as Adolphe Bobierre (1850) made combating fraud

---

[4] Agronomists, members of agricultural societies, landowners, large landowners, the readers of the *Journal d'Agriculture Pratique* of Alexandre Bixio… (Duby & Wallon, 1976, p. 105-107).

[5] "Avec les engrais simples, rien n'est plus facile que de répondre à tous les cas de la pratique agricole ; on peut les employer isolément ou les combiner deux à deux, trois à trois, dans la proportion voulue pour obtenir le maximum de résultats avec le minimum de dépenses".

their workhorse. Appointed "chimiste-vérificateur en chef" in Loire-Inférieure, Bobierre was in charge of controlling the trade in fertilizers by application of the prefectorial decrees of February 23 and April 6, 1850. Through his many books on the fraud of the fertilizers, he sensitized the public authorities to these questions and contributed to the establishment of the fertilizer investigation of 1864, which gave rise to the first French law of 1867. While not immediately restoring confidence, , the law of 4 February 1888 corrected malfunctions in this first law by making it possible for the farmer to analyze a sample of fertilizer in experiment stations. This law created a new transaction mode in the fertilizer market in which the alliance of science (chemistry in this case) and the French state played a major role (Jas, 2000, p. 294-310). Chemists were no strangers to agronomic experiment stations; rather, they intervened downstream from the design of fertilizers by improving analysis and quality control among manufacturers.

With the need for sulfuric acid to produce superphosphates and dissolved guanos, chemists were increasingly present in the manufacture of fertilizers. Many factories joined a workshop for the production of sulfuric acid with the process of lead chambers, which required the presence of a chemist. The product quality constraints would, moreover, lead the most manufactured factories to install a chemical analysis laboratory headed by a chemist. The importance of the role of chemists in the branch of compound fertilizers would take a new turn in the interwar period.

Complex Fertilizer Pellets: Chemists' Recognition of and Slow Progress Down the Path Towards an Integrated Product (1920-1950)

- *Farmers' Strong Demand for Fertilizers around 1920*

After World War I, the demand for fertilizers from French farmers strongly increased. This need was linked most of all to material shortages due to the war, but it was also based in a need to compensate for the lack of labor (dead, wounded, rural exodus) (Dumoulin, 1988, p. 175-180). The trend that began before the war continued and was strengthened with the need to increase agricultural productivity using mechanization, seed selection, and fertilizers (Duby & Wallon, 1977, p. 178). In the department of Loire-Inférieure, the Société d'Agriculture de France and local agricultural unions, such as the Syndicat central des agriculteurs de Loire-Inférieure, supported an approach to increasing yields and production intensification that involved purchasing fertilizer together and mechanizing fertilizer application (Anonymous, 1928). The fertilizer distributors were promoted for small farming by agricultural unions. By the late 1920s, agronomists awaited fertilizer in granular form to facilitate mechanized spreading: "We must hope that the industry strives to produce all fertilizers in granular form, which greatly facilitates their distribution."[6] These compounds provided fertilizer to farmers, savings in transport costs, handling, storage, and spreading. They were all the more desirable given that the available labor was less.

With fertilizer production becoming an important branch of chemistry, major chemical groups moved closer to the world of agriculture. Manufacturers set up "experimental fields" ("*champs d'expériences*") as demonstration plots of the effect of fertilizers (Cerf & Lenoir, 1987, p. 32). So, Compagnie de Saint-Gobain created, in 1926, the Bureau Central de Renseignement Agricole et de Propagande and organized cropping trials systematically from 1927 onward. The borders among agronomists, chemists, and industrialists began to dissolve as their responsibilities began to interfere and overlap.

- *The Slow Appropriation of Pellet Fertilizers by Chemists*

In the 1920s and 1930s, the issue of synthetic ammonia was solved (Travis, 2015), opening new perspectives in the field of chemical fertilizers. With nitrogen now available and cheap it was possible to consider binary or ternary compound fertilizers. To facilitate the consumption of fertilizer and expand its market, the issues raised by Müntz in the late nineteenth century, were placed on the agenda of the chemical community: how to remove inert substances and lower prices? The result was an increase in the concentration of fertilizers and limitation of the use of sulfuric acid which requires expensive handling and processing of iron pyrites. These issues were discussed in France in several meetings of the Congrès de Chimie Industrielle (Industrial Chemistry Congress). The inorganic chemist Camille Matignon (1930) explained the task of chemists and industry:

> The current trend in the fertilizer industry is to eliminate all inert substances. These contain substances which are often expensive because of their origin and transport, or of no or insignificant interest for plants. Thus the industry is oriented toward the search for concentrated fertilizer with high-analysis materials, formed from phosphoric acid itself, by its union

[6] "On doit souhaiter que l'industrie s'efforce de produire toutes les matières fertilisantes sous cette forme granulée, qui facilite beaucoup leur distribution" (Anonymous, 1929).

> with ammonia or with potassium hydroxide and ammonia.[7] (Matignon, 1930, p. 84)

He added that this was the international issue that "dominates the heavy chemical industry"[8] (p. 84), especially in the United-States, Germany, England, Russia, Poland, and Italy. Indeed, the question of nitrogen had been replaced by that of phosphoric acid (Hackspill, 1929). These questions were accompanied by three issues: granulation, hygroscopicity, and effectiveness (Ross *et al.*, 1927). To use the terminology of Thomas Hughes (2004), it was a "reverse salient" that chemists sought to overcome. Renowned chemists with expertise in nitrogen, such as the Frenchman Georges Claude or the Italian Giacomo Fauser (1934), tackled the problem. Matignon, a scientist renowned for his work with fertilizers, took part as well. He proposed several synthetic processes used in the composition of fertilizers. As a professor at the College de France he also organized a course, and numerous meetings, on issues affecting agriculture and fertilizers (Lestel, 2008, p. 363-367).

In the 1910s, several chemists proposed solutions regarding the ammoniation of superphosphate, notably Wilson and Haff in the US (Keenen, 1930) and Von Gerlach in Germany (Matignon, 1923). But all faced a disadvantage: retrogradation of phosphoric acid. The chemists of Compagnie de Saint-Gobain invented and put on the market in 1924 a phospho-nitrogen fertilizer named "superam". Their "homogeneity [was] far greater than that of a simple mixture, and [their] dryness of characters and upper friability comparable to those of the best dried and ground superphosphate"[9] (Matignon, 1923, p. 216). In the US, the American Cyanamid Company acquired Ammo-Phos Corp, which produced "Ammophos" (phosphoric acid and cyanamide) (Haynes, 1949, p. 21-25). These lines of research highlight the competition among chemists, with national antagonisms in the background. Camille Matignon contrasted the creation of "superam" against German research which resulted in a product that was not

[7] "La tendance actuelle, dans l'industrie des engrais, est d'éliminer de ceux-ci toutes les substances inertes qu'ils contiennent, substances souvent coûteuses par leur origine et leur transport, d'un intérêt nul ou insignifiant pour les plantes. Aussi est-on orienté dans la recherche des engrais concentrés, formés à partir de l'acide phosphorique lui-même, par son union avec l'ammoniaque ou avec la potasse et l'ammoniaque."

[8] "domine toute la grande industrie chimique."

[9] "homogénéité beaucoup plus grande que celle de simple mélange, et des caractères de siccité et de pulvérulence supérieurs à ceux des meilleurs superphosphates séchés et broyés."

as good. Similarly, he highlighted the ways in which ammosphos was nationally specific to the US: as he said, it "has the disadvantage of a phosphoric acid concentration which is in opposition to the customs of French agriculture"[10] (Matignon, 1923, p. 217).

This initial line of research led to a high concentration product (highest percentage of nitrogen and phosphoric acid), which limited the use of sulfuric acid but did not remove it completely. It was only later, with the use of nitric acid, that this was achieved. One solution was the direct reaction of nitric acid with calcium phosphate, but that presented technical problems (foam caused by a byproduct of the reaction, calcium nitrate) (Gardinier, 1974, p. 84-86). The intermediate solution of Saint-Gobain chemists was to implement a process called "sulfonitrique" in which sulfuric acid transforms lime into calcium sulfate and prevents the occurrence of calcium nitrate and foam. For their part, the Etablissements Kuhlmann exclusively used nitric acid, but employed a particular highly concentrated Russian phosphate from Kola instead of Moroccan phosphate (Ross, 1931). In Europe these were known as "complex fertilizers" since at least two elements were combined in a chemical reaction.

Research was also done on combinations of potassium nitrate (NK), in particular by the German firms Thorssell and Kristensson (IO) and Kali-Industrie Aktiengesellschaft, and by Whittaker and Lundstrom of the Bureau of Chemistry and Soils in the US Department of Agriculture (USDA) (Ross, 1931). For his part, the French chemist Georges Claude invented "potazote" which became famous among agronomists and agricultural unions, as shown by the *Bulletin du Syndicat Central des Agriculteurs de Loire-Inférieure*: "science itself has not disdained to address the problem of combined fertilizer, since the great scientist Georges Claude, to whom we already owe the most elegant method of making synthetic ammonia, has also endowed us with a remarkable combined fertilizer" (Anonymous, 1934).[11]

But with these new fertilizers with high-concentration materials, it was also more difficult to maintain the hygroscopic properties when in powder form, which led to the development of granular fertilizers (Slack, 1967, p. 19). Fertilizers in granular form also appeared for other technical reasons: handling hazards, unstable products, and poor preservation in

---

[10] "présente le désavantage d'une concentration en acide phosphorique qui heurte les coutumes de l'agriculture française. "

[11] "la science, elle-même, n'a pas dédaigné de s'occuper du problème de l'engrais combiné, puisque le grand savant Georges Claude, auquel nous devons déjà le procédé le plus élégant de fabrication de l'ammoniaque synthétique, nous a également doté d'un engrais combiné remarquable."

stores. The first work on granular fertilizers was carried out in the US in 1922b y the Bureau of Soils (Hardesty & Ross, 1938). For cyanamide the handling of the powder is dangerous for the fingers, so the presentation in pellet form was intended to aid its passage through mechanical distribution apparatus (Daviet, 1988, p. 596-597).

As explained by Raymond Berr (1930), ammonium nitrate and phosphate would provide excellent nutrients to produce compound fertilizers. They gave pellets of a "complete" ternary (NPK) fertilizer, as did Alvin Mittasch, head of German Oppau laboratories of BASF with the "Nitrophoska" (Thompson *et al.*, 1949). The creation of Nitrophoska in Germany pushed the Mines Domaniales to undertake research, at the request of the French Agriculture Minister, Henri Queuille (Anonymous, 1927, p. 541). One can see here, clearly, that competition between France and Germany guided the research strategies of French chemists and which would elevate them as national heros if they succeeded. It also led them to explore other ways to limit the use of sulfuric acid. A joint subsidiary of Mines domaniales and Kali-Sainte-Thérèse, the Société d'Étude pour la Fabrication et l'Emploi des Engrais Chimiques, was created in 1928 to conduct research and industrial tests for the manufacture of chemical fertilizers derived from potash. Pierre Jolibois, professor of chemistry at the École nationale supérieure des mines de Paris, became the Scientific Director of this research society (Lestel, 2008, p. 272). One of the first results obtained was the development of a method allowing the use of hydrochloric acid produced by the manufacture of potassium sulfate for the manufacture of dicalcium phosphate (Torres, 1999, p. 78).

- *The Mechanization of Chemical Industry: The First Production Units of Complex Fertilizer Pellets*

In the compound fertilizer sector, building production units for compound fertilizer in granular form was the most promising innovation. Forming a compound fertilizer with separate pellets for each nutrient caused additional costs compared to complete granulation all at once. The French chemical groups developed their own granulation processes, but they also relied on technology transfers for techniques that were more efficient than their own processes. Saint-Gobain placed its first granulated complex fertilizer factory in Rouen (Seine-Maritime) in 1932 (Daviet, 1988, p. 589-601). In its ammonium phosphate production unit, Saint-Gobain used the American Dorr process to produce phosphoric acid and ammonium phosphate. The start of the unit was very laborious and eventually the process was abandoned in favor of the production of phosphoric acid alone (7 tons per day) (Detuncq, 1966, p. 3-8; Nielsson, 1986, p. 228-229). Subsequently, in 1934, an ammonium nitrate production unit was put into service to produce ammonium nitrate, but also to enrich nitrogen compound fertilizers (Daviet, 1988, p. 589-601). We see a technical system take shape here, which would develop rapidly in the 1960s in France: ammonium nitrate and complexes fertilizers. From the Société d'Étude pour la fabrication et l'Emploi des Engrais Chimiques, the Société Chimique des Potasses d'Alsace (SCPA) gave birth to the Potasses et Engrais Chimiques (PEC) plant in Grand-Couronne (Seine-Maritime) in 1929 under the direction of Marcel Massenet, to manufacture, among other things, bi-calcium phosphate. From 1933, it began producing ternary fertilizers containing nitrogen. Liquid ammonia was converted by oxidation of nitric acid, used to prepare the ammonium nitrate which, added to the chloride or sulfate of potash and bi-calcium phosphate, allowed the manufacture of compound fertilizers. Continuing his research, the technical team led by Jean Dessevre developed, in 1937-1938, a new process for obtaining a high-concentration fertilizer (38% nutrients) (Torres, 1999, p. 78, p. 104-105).

Innovation of fertilizers in granular form was therefore the result of a cluster of innovations of technological processes (Caron, 2011, p. 30): synthesis of ammonia, phosphoric acid manufacture, manufacture of nitric acid at lower cost thanks to inexpensive ammonia, manufacture of ammonium phosphate, but also mechanization of agriculture with fertilizer distribution apparatus.

- *Agronomists Change their Views on Compound Fertilizers*

In France, the control of fertilizers came from the fraud department[12] and the increasing demand by growers for systematic analyses by agronomic stations, which forced the industry to improve the quality of the composition of fertilizers (Roux, 1933). The agricultural engineers of the Services Agricoles Départementaux eventually came to promote compound fertilizer in preference to straight fertilizers (Gardinier, 1974, p. 100-101). In an exchange with the Académie d'Agriculture in 1939, agricultural engineers recommended them (Lenglen, 1939). The professor of École d'agriculture de Grignon, Lucien Brétignière explained that "while we still taught at the beginning of this century the prohibition of compound fertilizer, today we recognize, without question, the benefits of these fertilizers provided, of course, they are honestly made, affordable, and that the for-

[12] Foundation of the fraud department in France by decree of 21 October 1907 for the application of the law of 1 August 1905 (Jas, 2000, p. 317-320).

mulas of these fertilizers are simpler and more straightforward"[13] (Lenglen, 1939). Agronomist Albert Demolon further described their agronomic efficiency:

> recent experiments in fertilization highlighted the key idea that there is a close solidarity in cooperative action among the various nutrients. Thus the increase of nitrogen that would have brought disappointment if there had been no wider use of potash and phosphate fertilizers, and vice versa. We can therefore consider that the compound fertilizer, binary or ternary as appropriate, shall normally provide the maximum manure effect.[14] (Lenglen, 1939)

Chemists have succeeded in offering compound fertilizers that meet the industrial constraints of cost, transport, and storage and the farmers' need for concentration and simplification of spreading. Now favorable to compound fertilizers, agronomists supported their approach. The way was open for a ramp-up of compound fertilizers in the 1950s and 1960s.

Rise of Compound Fertilizers: Chemists and Engineering Companies (1950-1970)

- *Mechanization and Agricultural Productivism*

The trend that started in the interwar period increased in the 1950s in France: farmers wanted to simplify crop operations and searched for high-concentration fertilizers which would reduce transportation costs, handling, and spreading. The extension of motorization, reducing the presence of horses, further reduced the amount of natural/animal manure on

[13] "alors qu'on enseignait encore au début de ce siècle la prohibition des engrais composés, aujourd'hui, on reconnaît, sans conteste, les avantages de ces engrais, à condition, bien entendu, qu'ils soient honnêtement fabriqués, à un prix abordable, et que les formules de ces engrais soient de plus en plus simples."

[14] "les expériences récentes sur la fertilisation ont mis en relief cette idée force qu'il y a une solidarité d'action étroite entre les divers éléments fertilisants. C'est ainsi que l'accroissement des apports d'azote n'aurait donné que des déceptions si parallèlement il n'y avait pas eu utilisation plus large des engrais potassiques et phosphatés et inversement. On peut donc considérer que l'engrais composé, binaire ou ternaire suivant les cas, assure en principe à la fumure son effet maximum."

farms (Anonymous, 1946). Agricultural authorities[15] strongly encouraged farmers to take this path. Industrialization discourse in farming was part of the modern and productivist postwar movement (Pessis *et al.*, 2013): "Compound fertilizer is the ambassador of rational fertilization"[16] (Chambre Syndicale Nationale des Fabricants d'Engrais Composés, 1952, p. 43). This product was "rational" in terms of transport cost, storage stability and ease of spreading (figure 1).

This increase in dose was made possible, in particular, thanks to progress in plant breeding and mechanization. In the interwar period, wheat varieties with long straw lacked the rigidity to withstand heavy fertilization rates. By the end of the 1940s, new varieties were selected with solid straws which would not fall due to heavy fertilization (Pambrun, 2009, p. 35). The need for ternary compound fertilizers can also be explained by the expansion of spring crops (barley and corn), which have a short growing cycle and need to receive the three primary nutrient elements together rather than separately (Chambre Syndicale Nationale des Fabricants d'Engrais Composés, 1962, p. 48-49).

This discourse of intensive agriculture was not unanimously shared and increasingly received a rough ride. At the end of the era we are examining, one of the champions of productivism in the 1950s, the French agronomist René Dumont, renounced his positions on intensive use of fertilizers (Séjeau, 2004; Dumont et de Ravignan, 1977, p. 268-270). The organic movement emerged, particularly in England in the 1930s with Albert Howard (Conford, 2002), and in the late 1960s it moved in step with the development of the counterculture (Hughes, 1989, p. 443). This movement again raises the question of natural and artificial. In France, organizations such as the Fédération Nationale des Syndicats de Défense de la Culture Biologique et de Protection de la Santé des Sols, advocate a return to the origins of organic compound fertilizers. The federation condemned the "use of all chemicals that are synthetic pesticides or mineral fertilizers and promotes the full and exclusive use of organic fertilizers and products derived from them" (Anonymous, 1974).[17]

---

[15] The Institut National de Recherche Agronomique (INRA), established in 1949, the Centres d'Études Techniques Agricoles (CETA), on the initiative of farmers, appeared from 1944 (Cerf & Lenoir, 1987, p. 34).

[16] "l'engrais composé est l'ambassadeur de la fertilisation rationnelle".

[17] "l'utilisation de tous les produits chimiques qu'ils soient pesticides de synthèse ou engrais minéral et prôn[ant] l'utilisation intégrale et exclusive des engrais organiques et des produits issus de leur transformation."

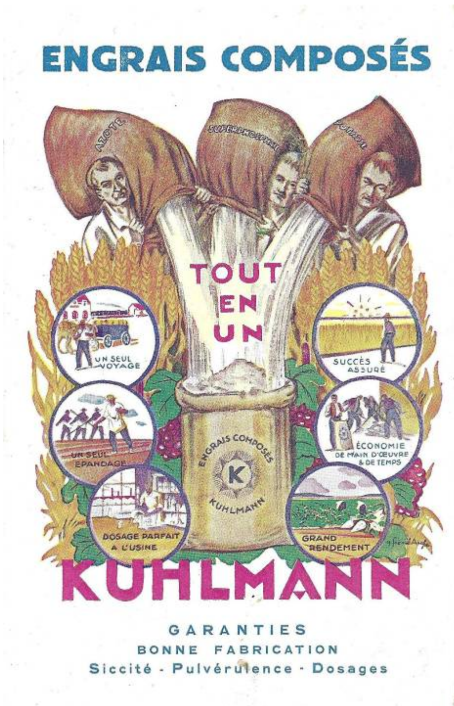

Figure 1 - Promoting the rationality of compound fertilizers of Etablissements Kuhlmann. (Source: Advertising postcard. s. d. Author's private collection)

- *Expansion of Manufacturing Units of Fertilizer Pellets Compounds*

Research on compound fertilizers which was undertaken by chemists in the interwar period led to the first production units in France just before World War II, but only fully bloomed after the war. Industrial achievements expanded due to the initiative of chemical engineering companies under the leadership of the French government and the Plan de Modernisation et d'Équipement[18] and using new materials such as hydrocarbons for nitrogen components (Anonymous, 1950).

Developed in the United States in the interwar period, chemical engineering took off in France in 1950 after the return of US productivity

[18] The Plan de Modernisation et d'Équipement was a governmental administration set up in France after 1946 to plan the economic development of the country. Its role was to coordinate the actions of private and public industries with a view to achieving the economic and industrial objectives set by the French state.

missions under the Marshall Plan (Ndiaye, 2001, p. 77). In the 1950s and 1960s, chemical companies gradually expanded their industrial research laboratories (Anonymous, 1953) and created chemical engineering conglomerates. In 1949, the Établissements Kuhlmann constituted a chemical engineering company as a subsidiary, the Société Technique d'Entreprise Chimique (STEC) (Léger, 1988, p. 130-131). They justified this creation thus: "Because of the considerable development of the chemical industry, various companies are continually called upon to use specialized design offices, with an experienced technical staff to design and implement projects related to the expansion and the creation of factories" (Kuhlmann, 1958, p. 48).[19] It was the same for SCPA, who in 1958 decided to create an engineering subsidiary to sell the "process PEC" manufacturing complex fertilizers, which was designed before the war (Torres, 1999, p. 222).

The manufacture of compound fertilizers, which remained the main market for smaller manufacturers who mainly produced fertilizer mixtures of organic and inorganic materials, expanded strongly in the 1950s and 1960s as large chemical groups invested heavily in the promising market for fertilizer compounds in granular form. Their chemical engineering companies provided this technical change through competing granulation processes. Apart from ammonium nitrate and potassium chloride, which are outside the actual granulation process, the two main fertilizers involved in granulation processes are ammonium phosphate and phosphate nitrate. The latter two products were aimed at different markets in the 1960s, which led to different geographical distributions, technology transfer and different competitive strategies associated with different processes. In Europe, phosphate nitrate grew more than in the United States (25 plants producing 200 to 600 t/d to 1965) with the involvement of many large chemical groups (such as Saint-Gobain or PEC in France, and Norsk Hydro in Norway) (Slack, 1967, p. 121-124). In the US, ammonium phosphate was dominant, with Dorr-Oliver processes in the 1930s and from 1959 the ammoniator-granulator process of the Tennessee Valley Authority[20], which competed with, among others, the "Spherodizer" method of the Chemical and Industrial Corporation (Slack, 1967, p. 111-121).

---

[19] "En raison du développement considérable de l'industrie chimique, les diverses sociétés sont appelées à avoir recours sans cesse davantage aux Bureaux d'Etudes spécialisés, disposant d'un personnel technique expérimenté, pour concevoir et réaliser les projets afférents à l'extension et à la création d'usines".

[20] In the US, Tennessee Valley Authority, a public body set up under the "New Deal" in 1933, played a major role in the development of the use of fertilizers (Sheridan, 1979).

The strong combined demand for complex compound fertilizers and nitrogen fertilizers was embodied in France in the building of major plants producing both complex fertilizers and ammonium nitrate. This massive demand induced technical changes in the synthesis of ammonia with the development of cracking processes for obtaining hydrogen from hydrocarbons (petroleum residues and natural gas), instead of from coke oven gas. It was accompanied by construction of new networks for transportation of raw materials, such as the Lacq gas pipeline network which supplies the French territory, which was deployed under the leadership of the state (Collective, 1998, p. 44). In 1963 the Société Chimique de la Grande Paroisse (Fay, 1969) started a plant in Montoir-de-Bretagne (Loire-Atlantique) to synthesize ammonia and produce ammonium nitrate.[21] In 1973, the plant increased its production capacity by adding a production unit for ternary complex fertilizers with a capacity of 150,000 t/y through the transfer of US technology.[22] For granulation it, in fact, used the "Spherodizer" method of the American Chemical Industrial Corporation (Slack, 1967, p. 117; Hignett, 1985, p. 255). But technology transfer was also made from France to the United States. In 1962, the US company Ortho California Chemical built a plant in Iowa to manufacture 1,000 t/d of complex fertilizers (Anonymous, 1962). This was the third Ortho factory (the first two were in Richmond, California and Kennewick in Washington State) which used nitric acid instead of sulfuric acid to attack the phosphate using the French PEC method.

The growth of large granulated compound fertilizer units around the world has been achieved through the principles of standardized workshops, a market for granulation processes and an abundant and inexpensive source of hydrogen.

- *New Formulations of Fertilizer Production on a Small Scale: "Bulk Blending"*

Apart from the big factories, small units still held on. A dual industry structure existed with a tendency towards concentration: small fertilizer mixing units on the national territory near agricultural areas and large complex fertilizer units, oriented in part to export markets. In 1965 production of compound fertilizers was provided by 224 companies totaling 293 production units. However, production by small plants was low; almost 80% of compound fertilizer produced in France came from 27 companies totaling

[21] AD Loire-Atlantique, 281 W 20, Notice descriptive. AD stands for the archives of one French administrative department, here Loire-Atlantique.

[22] AD Loire-Atlantique, 1373 W 152.

73 plants.[23] This was especially the case for binary phosphate potash fertilizer (potassium slag, super-potassium, phospho-potassium, etc.). "Bulk blending" based on the intermediate product production capacity of large chemical groups, would strengthen the small units in geographic proximity to agricultural production while also providing a tailored response to the needs of the farmer.

The "bulk blending" method of manufacturing compound fertilizer developed quickly in the United States after 1955 (Slack, 1967, p. 20; Hignett, 1985, p. 5-6). It used a simple mechanical mixture of high-concentration elements in pellet form to produce high-analysis fertilizer. The materials used (ammonium sulfate, ammonium nitrate, triple superphosphate, ammonium phosphate, potassium chloride, etc.) were all manufactured as pellets by large chemical companies. The advantages of "bulk blending" were the cost and the proximity of the farmer and his requirements, which offset some of the original disadvantages of homogeneous granular fertilizers that we have seen, namely lack of homogeneity and a tendency toward caking. This industrial model returned to Müntz's idea of designing a custom compound fertilizer for the farmer. In the US, between 1959 and 1964, the number of plants adopting "bulk blending" went from 201 to 1536.

In France, the SCPA decided to engage in "bulk blending" for potash granulation in 1960 (Torres, 1999, p. 158-159). From 1961 onward it operated a binary phospho-potassic granulating production unit in its Strasbourg facilities. Soon after it launched commercialization of that product in partnership with Établissements Delafoy from Nantes and the SCPA production unit installed at Teil (Ardèche). The technology transfer process innovation allowed Delafoy to achieve production. The company Delafoy in Nantes appealed to the engineer Carbona at the Reno Company's Tréport (Seine-Maritime) factory, which had developed and patented a granulation process which "constitutes a considerable technical and commercial progress in enabling not only the maintenance, but also the development, of the market for simple phosphate fertilizers and photopotassiques".[24] Gradually, SCPA developed small regional units for

[23] AN IND 19771633/107, Rapport de M. de La Rochefoucauld, V^{e} Plan de Modernisation et d'Equipement, Commission de la chimie, Groupe des engrais, sous-groupe des engrais composés, avril 1965. AN stands for French national archives.

[24] "constitue un progrès technique et commercial considérable, devant permettre non seulement le maintien, mais aussi le développement du marché des engrais phosphatés simples et photopotassiques", AN IND 19771633/008SCPA, Note

manufacture of compound fertilizer, designed in partnership with local players.

Conclusion

Initially only the domain of industry and empirical expertise, compound fertilizers were subject to adulteration and fueled farmers' mistrust of agronomists. Chemists gradually intervened in this area through the role of sulfuric acid, which could make certain organic components more assimilable. Placed far downstream from process design and manufacture of the material, they mostly played a role for analysis and control. In the interwar period they took control of the compound fertilizer field from design to production. The question of straight fertilizers versus compound fertilizers became a major issue for the chemical community (both academic and industrial).

Positioned between agriculture and industry, chemists were responsible for restoring confidence in compound fertilizers and bringing about conditions for the growth of consumption. They showed that they understood the needs of farmers by making "compound fertilizer" an integrated material, combining the major nutrients (nitrogen, phosphorus and potassium acid), as well as by solving problems with the concentration, cost, handling, and storage of fertilizers. They did so, in particular, by modifying the presentation of fertilizers. French chemists in academic research, such as C. Matignon or P. Jolibois, or those closer to industrial research, such as G. Claude, were interested in the issues of compound fertilizers. Without being dominant in their research, this work nevertheless reoriented their careers as teachers (C. Matignon's conferences), or stimulated them to new careers in industry (P. Jolibois became scientific director of Potasses et Engrais Chimiques) or revitalized their industrial research (the "potatoze" by G. Claude). Finally, after World War II, the massive development of the production of compound fertilizer in granular form was permitted by the development of a cluster of innovations in industrial processes of granulation which were disseminated and implemented by chemists in chemical engineering companies, and by the availability of hydrocarbon raw materials used to make large volumes of ammonia necessary for the synthesis of nitrogen elements. But in reaching its limits, the system also distanced itself from the consumer. In contrast, the "bulk blending" production model de-

pour le directoire de l'EMC. Réunion du 27 novembre 1968. Le 22 novembre 1968. Association en participation SCPA/Delafoy/Reno à Nantes.

veloped in parallel addressed the cultivator's needs afresh by offering tailor-made industrial fertilizers and geographic proximity.

Over this 80-year period extending from 1890 to 1970, we saw the confrontation of actors and technical changes that have guided the evolution of several kinds of compound fertilizer in France, from a heterogeneous mixture of organic materials to an integrated product, and from a powdered form to a granular form. This evolution has taken place at the global level with the development of granulated compound fertilizer plants depending on the country. Through academic exchanges or technology transfer, chemists and chemical engineering companies from different parts of the world have contributed to this evolution. These changes were accompanied by a changing role for chemists – who have become preeminent in the fertilizer industry – and industrial structures.

Acknowledgment

I would like to thank the two anonymous reviewers for their comments and references.

References

ANONYMOUS (s.d.), *Notice sur les engrais d'os Pilon*, Nantes, Imprimerie Moderne.

ANONYMOUS (1927), "Séance de la Chambre des députés du 25 février 1927", *Journal officiel de la République française. Débats parlementaires. Chambre des députés*, n°22, 26 février, p. 538-543.

ANONYMOUS (1928), "Les distributeurs d'engrais par G. Coupan, Ingénieur-agronome, Professeur à l'École Nationale de Grignon", *Bulletin du syndicat central des agriculteurs de Loire-Inférieure*, n°15, 11 août.

ANONYMOUS (1929), "Epandage des engrais", *Bulletin du syndicat central des agriculteurs de Loire-Inférieure*, n°31, 3 août.

ANONYMOUS (1934), "Engrais simples et engrais composés", *Bulletin du syndicat central des agriculteurs de Loire-Inférieure*, n°13, 31 mars.

ANONYMOUS (1946), "Pourquoi, où, quand et comment employer les engrais ?", *Comptes rendus des séances de l'Académie d'agriculture de France*, Séance du 4 décembre, p. 760-764.

ANONYMOUS (1950), "Un demi-siècle de production d'engrais", *Bulletin des engrais*, n°316 (Un demi-siècle de production et d'utilisation des engrais), p. 4-6.

ANONYMOUS (1953), "Les nouveaux centres de recherches de la Compagnie de Saint-Gobain", *L'industrie chimique*, n°431, juin, p. 164.

ANONYMOUS (1962), "Ortho Starts Up Midwest Fertilizer Plant", *Chemical Engineering News*, vol. 40, n°39, p. 25-28.

ANONYMOUS (1965), *1665-1965, Compagnie de Saint-Gobain*, Paris, Imprimerie Draeger Frères.

ANONYMOUS (1974), "Le 6e Congrès de la Fédération nationale des syndicats de défense de la culture biologique et de protection de la santé des sols", *Le Paysan biologiste*, n°15, novembre-décembre, p. 11.

BENSAUDE VINCENT Bernadette & STENGERS Isabelle (2001), *Histoire de la Chimie*, Paris, La Découverte.

BERR Raymond (1930), "L'évolution de l'industrie des engrais chimiques", *Bulletin de la société d'encouragement pour l'industrie nationale*, juin, p. 483-515.

BOBIERRE Adolphe (1850), *Rapport à Monsieur le ministre de l'agriculture et du commerce sur la question des engrais dans l'ouest de la France*, Nantes, Imprimerie Vve Camille Mellinet.

CARON François (2010), *La dynamique de l'innovation : changement technique et changement social (XVIe-XXe siècle)*, Paris, Gallimard.

CARON François (2011), *Les voies de l'innovation : les leçons de l'histoire*, Paris, Manucius.

CERF Marianne & LENOIR Daniel (1987), *Le développement agricole en France*, n°2371, Paris, Presses Universitaires de France.

CHAMBRE SYNDICALE NATIONALE DES FABRICANTS D'ENGRAIS COMPOSÉS (1952), *L'industrie des engrais composés*, Paris, Imprimerie E. Desfossés-Néogravure.

CHAMBRE SYNDICALE NATIONALE DES FABRICANTS D'ENGRAIS COMPOSÉS (1962), *Emplois des engrais composés. Guide du vulgarisateur agricole*, Paris, La Maison rustique.

COHEN Benjamin R. (2011), "Analysis as Border Patrol: Chemists along the Boundary between Pure Food and Real Adulteration", *Endeavour*, vol. 35, p. 66-73.

COLLECTIVE (1998), *Elf Aquitaine, des origines à 1989*, Paris, Fayard.

CONFORD Philip (2002), "The Myth of Neglect: Responses to the Early Organic Movement, 1930-1950", *The Agricultural History Review*, vol. 50, n°1, p. 89-106.

COUTURIER A. & LUCAS J.-H. (sd), *Les engrais. Manuel de l'acheteur et du vendeur*, Paris, Bureau d'études économiques, industrielles et agricoles.

DAVIET Jean-Pierre (1988), *Un destin international : la Compagnie de Saint-Gobain de 1830 à 1939*, Paris, Éditions des archives contemporaines.

DETUNCQ Y. (1966), "Le nouvel atelier d'acide phosphorique à l'usine de Rouen", *Revue d'entreprise Pechiney-Saint-Gobain*, n°17, juin, p. 3-8.

DUBY Georges & WALLON Armand (eds.) (1976), *Histoire de la France rurale. De 1789 à 1914*, Tome 3, Paris, Seuil.

DUBY Georges & WALLON Armand (eds.) (1977), *Histoire de la France rurale. Depuis 1914*, Tome 4, Paris, Seuil.

DUMOULIN Annie (1988), *Les paysans dans la société française. De la Révolution à nos jours*, Paris, Seuil.

DUMONT René & DE RAVIGNAN François (1977), *Nouveaux voyages dans les campagnes françaises*, Paris, Seuil.

FAUSER Giacomo (1934), "L'état actuel et les possibilités d'évolution de l'industrie des engrais chimiques", *Actes du XIV^e^ Congrès de Chimie Industrielle à Paris*, vol. 1, Paris, Chimie & Industrie.

FAY Jacqueline (1969), "Depuis 50 ans dans l'industrie des engrais : la Société Chimique de la Grande Paroisse", *Informations chimie, spécial engrais*, n°79, décembre, p. 43-46.

GARDINIER Lucien (1974), *La profession des engrais de ses origines à nos jours*, Paris, La Maison rustique.

HACKSPILL Louis (1929), "L'industrie des engrais chimiques en France", *VIII^e^ Congrès de Chimie Industrielle, Chimie & Industrie*, vol. 21, n°2 bis, février, p. 86-96.

HARDESTY John O. & ROSS Williams H. (1938), "Factors Affecting Granulation of Fertilizer Mixtures", *Industrial and Engineering Chemistry*, vol. 30, n°6, p. 668-672.

HAYNES Williams (1949), *American Chemical Industry. The Chemical Company*, vol. 6, New York, D. Van Nostrand Company, Inc.

HIGNETT Travis P. (1985), *Fertilizer Manual*, Dordrecht, Kluwer Academic Publishers.

HUGHES Thomas (1989), *American Genesis: A Century of Invention and Technological Enthusiasm,* New York, Viking.

HUGHES Thomas (2004), "Afterword", *Annales historiques de l'électricité*, vol. 1, n°2, p. 173-176.

JAS Nathalie (2000), *Au carrefour de la chimie et de l'agriculture, les sciences agronomiques en France et en Allemagne, 1840-1914*, Paris, Éditions des archives contemporaines.

KEENEN Franck G. (1930), "Reactions Occuring during the Ammoniation of Superphosphate", *Industrial and Engineering Chemistry*, vol. 22, n°12, p. 1378-1382.

KUHLMANN (1958), *Etablissements Kuhlmann*, Paris, Édition Artistique, 27 mai.

LÉGER Jean-Étienne (1988), *Une grande entreprise dans la chimie française : Kuhlmann, 1825-1982*, Paris, Debresse.

LENGLEN Maurice (1939), "L'industrie des engrais composés en France", *Comptes rendus des séances de l'Académie d'agriculture de France*, Séance du 6 décembre, p. 1049-1060.

LESTEL Laurence (2008), *Itinéraires de chimistes : 1857-2007, 150 ans de chimie en France avec les présidents de la SFC*, Paris, EDP Sciences.

MARTIN Philippe (2015), "La production de guano artificiel, une étape dans la professionnalisation des fabricants d'engrais : l'exemple d'Édouard Derrien à Nantes (1840-1860)", *Annales de Bretagne et des Pays de l'Ouest*, vol. 122, n°1, p. 161-190.

MATIGNON Camille (1923), "Un nouvel engrais composé, 'le superam'", *Chimie et industrie*, n°2, p. 216-217.

MATIGNON Camille (1930), "Les progrès de la grande industrie chimique depuis 50 ans", *Le génie civil. 1880-1930, Numéro spécial publié à l'occasion du cinquantenaire de la fondation du "Génie Civil",* novembre, p. 80-88.

MÜNTZ Achile & GIRARD Aimé (1891), *Les engrais*, Tome III, Paris, Librairie de Firmin-Didot et Cie.

MUSSO Pierre (2003), *Réseaux et société*, Paris, Presses Universitaires de France.

NDIAYE Pap (2001), *Du nylon et des bombes. Du Pont de Nemours, le marché et l'État américain, 1900-1970*, Paris, Belin.

NIELSSON Francis T. (1986), *Manual of Fertilizer Processing*, New York, Marcel Dekker Inc.

PAMBRUN Jean-Baptiste (2009), *Des engrais et des hommes : 100 ans de fertilisation et d'épopées industrielles,* Paris, Unifa.

PESSIS Céline, TOPÇU Sezin & BONNEUIL Christophe (2013), *Une autre histoire des "Trente Glorieuses". Modernisation, contestations et pollutions dans la France d'Après-guerre*, Paris, La Découverte.

ROSS William H., MEHRING Arnon L. & MERZ Albert R. (1927), "Recent Developments in the Preparation and Use of Concentrated Fertilizers", *Industrial and Engineering Chemistry*, vol. 19, n°2, p. 211-214.

ROSS William H. (1931), "Recent Development in the Preparation and Use of Fertilizers", *Industrial and Engineering Chemistry*, vol. 23, n°1, p. 19-21.

ROUX Eugène (1933), "Séance du 11 juin 1933", *Comptes rendus des séances de l'Académie d'agriculture de France*, p. 748-756.

SAINT-GOBAIN (1911), *Engrais chimiques des Manufactures de Saint-Gobain,* Alençon, Georges Supot.

SÉJEAU Wilfrid (2004), "René Dumont agronome", *Ruralia*, vol. 15, p. 1-21.

SLACK A. V. (1967), *Chemistry and Technology of Fertilizers*, New York, John Wiley & Sons, Interscience Publishers.

THOMPSON H.-L., MILLER Philip, DOLE F. H. & KAPLAN Abraham (1949), "Properties of Diammonium Phosphate Fertilizer", *Industrial and Engineering Chemistry*, vol. 41, n°3, p. 485-494.
TORRES Félix (1999), *L'envol des cigognes : histoire du groupe EMC*, Paris, Albin Michel.
TRAVIS Anthony S. (2015), *The Synthetic Nitrogen Industry in World War I: Its Emergence and Expansion*, London, Springer International Publishing AG.