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# Scientific Theory and Agricultural Practice: Plant Breeding in Germany from the Late 19th to the Early 20th Century

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**Abstract.** The paper deals with the transformation of plant breeding from an agricultural practice into an applied academic science in the late 19th and early 20th centuries Germany. The aim is to contribute to the ongoing debate about the relationship between science and technology. After a brief discussion of this debate the first part of the paper examines how pioneers of plant breeding developed their breeding methods and commercially successful varieties. The focus here is on the role of scientific concepts and theories in the agricultural innovation process. The second part turns towards the strategies by which agronomists tried to establish plant breeding as an academic discipline and themselves as the new experts for breeding research and varietal development. Again, the focus is on the interplay of scientific theory and agricultural practice. It is argued that in order to better understand the transformation of plant breeding into an applied academic science we have to take different levels into account, i.e. the levels of organizations, individuals and objects, at which science and technology interact.

**Keywords:** genetics, Germany, history, plant breeding, science/technology relationship

## Introduction

Over the course of the 20th century science and technology became increasingly linked due to the promise of military power and economic prosperity. Today, the boundaries between science and technology are sometimes hard to discern. Biology is a case in point. For many people – including advocates as well as opponents of genetic engineering – the invention of recombinant DNA technology in the mid-1970s marks the dawn of a new age in which biology is undergoing a fundamental transformation. According to this stance, biology is no longer only about the scientific understanding of life but also about its technical manipulation. A new entity seems to emerge often called "techno-science" in which the production of scientific knowledge and technological artifacts are only two sides of the same coin.[1]

This phenomenon is not as new as it appears, however. An analysis of plant breeding in the late 19th and early 20th centuries Germany suggests that the coupling of scientific understanding and technical manipulation is a long standing issue in the life sciences. From the mid-1880s, after progressive farmers had empirically developed new methods to breed commercially successful varieties, agronomists sought to establish plant breeding as an academic discipline. Through institutional, cognitive and political strategies they turned the agricultural practice of breeding into what they understood as an "applied science," commercial varieties into scientific objects, and themselves into the new experts for breeding research and varietal development. In order to better comprehend the recent transformations of biology due to the rise of genetic engineering we have to extend the scope of the discussion and deepen our historical understanding of the science/technology relationship within the life sciences.[2]

By providing in some detail a case study of early plant breeding in Germany I hope to contribute to the ongoing debate about the science/technology relationship. My concern is with the question of how an agricultural practice, i.e. a technology, was transformed into an academic discipline understood by their proponents as an applied science. The analysis of this transformation lays a particular focus on organizations, individuals and objects. Following Ida Kranakis[3] and others, I consider these categories different levels of interaction between science and technology. Organizations such as large farms, agricultural colleges and state owned breeding institutes offered a physical space for breeding research and varietal development. Moreover, organizations such as agricultural societies served as a communication platform for farmers, plant breeders and agricultural scientists thereby facilitating the

[1] For the term "technoscience," see, e.g., Pickstone, 2000, pp. 13–15 and 162–188.

[2] Much of recent historical work on agricultural research deals with the science/technology relationship and analyzes in one way or the other the interplay of genetic theory and plant or animal breeding. See, for instance, Allen, 2000; Cooke, 1997; Fitzgerald, 1988; Kimmelman, 1997; Palladino, 1990, 1993, 1994, and 1996; Paul and Kimmelman, 1988; Roll-Hansen, 2000; for Germany, see Harwood, 1997; Wieland, 1999, 2000, and 2004; see also Wood and Orel, 2001, 2005 for animal breeding in the early 19th century.

[3] Kranakis, 1992, pp. 178–179; for details, see the next section.

knowledge flow between these groups. The category of individuals refers to the level of the human actor who played an important role in the transformation process under consideration. For example, progressive farmers not only developed new varieties but also contributed to the knowledge of natural scientists, and academic breeders tried for a theoretical framework for the evaluation and improvement of breeding methods and plant varieties. The category of objects finally calls attention to the plant varieties private and academic breeders dealt with. Starting their "career" in the context of agriculture, cereals and other crops successively became objects of experimental inquiry, first by progressive farmers and then by agricultural scientists. With their transfer from the farm to academia plant varieties turned into scientific objects. They became what Hans-Jörg Rheinberger called "epistemic things," i.e. they became part of experimental systems, generated questions, initiated research processes, and asked for new or refined concepts and theories.[4] And yet, these scientific objects also remained commercial varieties. As we will see, it is only by taking these different levels of interaction between science and technology into account that we can fully understand the role of scientific theory for agricultural practice.

The paper is organized as follows. After a brief discussion of the science/technology relationship the paper turns towards the increase in agricultural productivity in 19th century Germany. The section deals with the rise of commercial plant breeding and the background of its pioneers. By focusing on the work of the commercial breeders Wilhelm Rimpau and Ferdinand von Lochow, the next section analyzes the role of scientific concepts and theories in the agricultural innovation process. The question to be asked here is: How did 19th century breeders develop their methods and varieties? There follows a discussion of the emergence of academic plant breeding that was tightly linked to the work of Kurt von Rümker who defined its disciplinary program. Looking at the reception of Wilhelm Johannsen's pure line theory the penultimate section asks again for the role of scientific theory this time concerning the academic breeders. They sought a theoretical foundation for their field in order to legitimize it as a university discipline. But as we will see mediating between scientific theory and agricultural practice was anything but an easy task. Finally, some general conclusions are drawn regarding plant breeding and the science/technology relationship.

[4] See Rheinberger, 1997, pp. 28–31.

**The Science/Technology Relationship**

Historians of science and in particular historians of technology have been investigating the science/technology relationship since the 1950s.[5] In the beginning, their work was motivated by the attempt to mark their professional terrain, i.e. to make a distinction between the relatively new history of technology and the more established history of science. Much focus was thus on the question of whether science drives technology or technology drives science. But in such a general formulation, the question remained unanswered. Each example that supported one stance could be confronted with an example supporting the other. Still, the discussion was not without reason. We learned a lot about the peculiarities of science and technology, the knowledge and practices related to each and the many ways in which the two can interact. Most important, the "linear model" that dominated much of post-war thinking about the science/technology relationship was called into question. The linear model claimed a sharp boundary between basic and applied research.[6] While basic research was thought to produce and validate scientific theories without considering any practical use, applied research (and development) should translate the findings of basic research into new technology. The model therefore implied a firm hierarchy between basic science and technological innovation. As Vannevar Bush put it more than half a century ago: "Basic science is the pacemaker of technological progress."[7]

More recent concepts of the science/technology relationship dismiss the idea of a sharp boundary and a firm hierarchy between basic and applied research. Although both types of research can exist in a "pure" form, it would be wrong to assume that research must be *either* inspired by the quest for fundamental understanding *or* by the consideration of applied use. Rather, research can simultaneously be guided by both goals. Donald Stokes called this type of research "use-inspired basic research" and placed it between "pure basic research" and "pure applied research."[8] It is arguable whether a great deal of work done these days in the field of molecular biology falls into Stokes's category

[5] For an overview, see Staudenmaier, 1985, pp. 83–120. For more recent approaches to the science/technology relationship, see the contributions in Kroes and Bakker, 1992; see also Agazzi, 1998; Brooks, 1994; Cordero, 1998; Faulkner, 1994, and Stokes, 1997.
[6] Cf. Stokes, 1997, pp. 1–57.
[7] Cited ibid., p. 3.
[8] See ibid., pp. 58–89.

of use-inspired basic research. And the same holds true for most of the plant breeding research with which this paper deals.

Assuming the compatibility of basic and applied research is very much in line with the idea of science and technology as overlapping realms of two social activities. Although distinguished by their principal goals, i.e. the generation and validation of scientific knowledge vs. the production and use of technological artifacts, science and technology can build an area of intersection. As Ida Kranakis suggested, this area may be defined in terms of "organizational structures, bodies of knowledge, traditions of practice, communities of practitioners, etc."[9] Modelling the science/technology relationship in this way not only offers a multitude of dimensions for inquiry but also allows for a highly dynamic view. Accordingly, the relationship between science and technology – the area of intersection – can be understood as the outcome of a historical process that is context dependent and variable over time, space, and the science or technology at stake.[10] As a result, historians are increasingly interested in the concrete factors shaping and the various mechanisms mediating the science/technology relationship. To cite Paolo Palladino: "Greater rewards are to be had by focusing [...] on specific debates over the relationship between particular sets of practices that we now relate to one another as science and technology and asking when, how, and why they ever became so linked."[11]

## The Rise of Commercial Plant Breeding in Germany

Nineteenth century Germany witnessed a tremendous increase in agricultural productivity, often described as an "agricultural revolution." It was a response to the rising demand for agricultural commodities and the intensifying competition on the agricultural market. Demand was mainly driven by two factors. First, the German population significantly grew in the 19th century amounting to about 68 million people at the eve of WW I. Since this development particularly affected urban areas, more and more people were unable to produce their food themselves and had therefore to rely on the market. Second, the rise of the food and

[9] Kranakis, 1992, pp. 178–179.

[10] Mayr, 1976, has already argued that the concepts of science and technology themselves have to be understood as historically variable.

[11] Palladino, 1993, p. 303. Palladino, who formerly argued for a social constructionist's view at the science/technology relationship, recently put social determinants into perspective by emphasizing the importance of the individual actor for the understanding of historical processes; see Palladino, 2002.

fermentation industries created specialty markets and prompted a growing demand for agricultural supplies. The sugar industry became an important customer for sugar beets, the milling and baking industry for wheat and rye, the brewing industry for barely, the fermentation industry for potatoes and so on. Thanks to private and industrial demand, German agriculture experienced an economic boom from the mid-1840s. It ended in the 1870s when German farmers faced intensive competition from abroad, in particular from lower-cost producers in Russia and North America, due to the internationalization of the agricultural market. Although the German government applied tariffs on imported grain in 1879 and substantially increased the rates of duty in 1885 and 1887, prices constantly fell from the 1870s to the 1890s.[12]

In order to meet these challenges farmers worked to improve their productivity. Since arable land was limited, they had to intensify production, i.e. to produce higher yields from a given area of land. Their success is well illustrated by the yield development of wheat, rye, barley, and oats shown in Table 1. It was based on a range of new technologies, the most important of which was the use of commercial fertilizers, which became available in huge amounts and at relatively low prices after the middle of the 19th century. As Hugo Thiel (1839–1918), a high ranking official from the Prussian Ministry of Agriculture, retrospectively wrote: "It was a time, in which we believed that there was no limit to the increase of yields thanks to the ever growing availability of cheap commercial fertilizers."[13] Other important factors were new crop rotation systems and soil management technologies. And last but not least, intensification was facilitated by newly bred crop varieties, which converted these readily available commercial fertilizers into higher yields to meet the demands of the rising food and beverage industries.

When commercial plant breeding accelerated in the second half of the 19th century, the German agricultural research system was already well developed. Along with agricultural colleges and institutes at universities a productive network of agricultural experiment stations existed, which also offered advisory service to farmers. Nevertheless, the birthplace of systematic plant breeding was not academia but the large farms in the Prussian province of Saxony and the adjoining territories. In this region, agricultural rationalization and modernization were

[12] See Perkins, 1981, and van Zanden, 1991; for a more general account of the history of German agriculture in this period, see, e.g., Rolfes, 1976, and Henning, 1988.
[13] Thiel, 1904, p. 9 (my translation).

*Table 1.* Development of the average yield performance of cereals in Germany (100 kg per ha)[14]

| Average of the years | Wheat | Rye | Summer barley | Oats |
|---|---|---|---|---|
| About 1800 | 10.3 | 9 | 8.1 | 6.8 |
| 1848–1852 | 12.3 | 10.7 | 11.2 | 10.9 |
| 1878–1882 | 14.6 | 11.6 | 15.8 | 14.1 |
| 1888–1892 | 15.8 | 11.7 | 15.8 | 14.5 |
| 1898–1902 | 18.5 | 14.8 | 18.1 | 17.1 |
| 1908–1912 | 20.7 | 17.8 | 20.1 | 19 |
| 1918–1922 | 16.9 | 13.6 | 15.2 | 14.5 |

moving forward rapidly.[15] Farmers soon realized that their traditionally grown crop varieties had productivity limitations that could not be overcome even with commercial fertilizers. Moreover, the industrialization of the food and beverage businesses necessitated specific qualities traditional varieties could not provide. For instance, the brewing industry pressed for malting barley of great uniformity and with low nitrogen content since high levels of nitrogen could cause several problems in the brewing process. As a consequence, farmers looked for higher yielding cereal varieties with specific qualities and imported them from abroad, in particular from England and France. Because they were not well-adapted to the environmental conditions of Germany, imported varieties often failed to meet the high hopes of farmers who soon started breeding their own varieties.

Who were the German pioneers of cereals breeding? The list includes such people as Otto Beseler (1841–1915), Otto Cimbal (1840–1912), Ferdinand Heine (1840–1920), Ferdinand von Lochow (1849–1924), Wilhelm Rimpau (1842–1903) and Friedrich Strube (1847–1897).[16] In general, they were owners of large country estates and belonged to a new and wealthy class of agricultural entrepreneurs. They considered themselves as agents of agricultural modernization and managed their farms in line with rationalization principles. Though not all of them graduated, many went – at least for some semesters – to university or college to study agriculture. They were interested in science and technology, and keen to experiment. As representatives of the rural elite, they were committed to politics and were opinion leaders in agricultural societies. Within the group of large landholders who had a strong influence on politics in Imperial Germany they represented the most

[14] Figures from Bittermann, 1956, pp. 34–35; the significant decrease indicated by the last row is due to the effects of WW I, but figures are still well above 1848–52 levels.

[15] See, e.g., Müller, 1979.

[16] For details, see the references cited in Wieland, 2004, p. 35.

progressive branch. At first, cereals breeding was but one strategy among others to improve the productivity of their farms. But with the growing success of their activities, these pioneers turned their farms into seed firms. As a result, a prosperous breeding and seed industry came into being that sold its products not only all over Germany but also to many other European countries.

When farmers began to improve their grain systematically through breeding in the 1860s/1870s, they had to start more or less from scratch. They might have gained some confidence in their undertaking from the breeding of animals such as sheep and cattle that was already well developed in the mid-19th century, or the breeding of fruit trees and vegetables.[17] But in general, the empirical basis upon which they could draw was very small. Crop breeding was a subject one could hardly get information about in German agricultural journals or textbooks. Agricultural research was dominated by chemistry and the question of how soil fertility could be improved. Although sugar beets had been bred for a while, due to biological differences the knowledge generated was hardly applicable to grain.[18] In addition, sugar beet breeding mainly profited from technologies that allowed for the exact measurement of the beet's sugar content – a problem that was not relevant in cereals breeding. As for the developments abroad, the work of foreign cereals breeders such as Frederic Hallett and Patrick Shireff was mostly spread by word of mouth. Moreover, the few written reports on their work could serve as an incentive to start cereals breeding but certainly not as a sort of do-it-yourself manual. And even natural scientists, who had been researching sexuality and hybridization in plants since the 18th century, could offer little help. Generally speaking, their knowledge was too abstract and therefore unsuitable for the problems plant breeders were confronted with in their day-to-day work.

I shall illustrate this point in the following section by the work of Wilhelm Rimpau and Ferdinand von Lochow – two individual actors who shaped early German plant breeding more than any other of their contemporaries. More than just a successful plant breeder, Rimpau was the intellectual emblem of his profession. Since he systematically

[17] For animal breeding, see Wood and Orel, 2001; see also Orel, 1996, chapter 2, for an overview of hereditary concepts and breeding practices up to the middle of the 19th century.

[18] The most obvious difference is that the sugar beet life cycle is 2 years. During the first year a thick root is built containing the concentrated sugar that is consumed in the second year by the growth of flowers and seeds. Thus, you can have either the sugar or the seed. In contrast, cereals are annual plants. There is no principal difference between grain for sowing and grain for consumption.

reviewed the agricultural and biological literature of the time for knowledge useable for the improvement of breeding techniques and because of his own intensive publishing, Rimpau's work is a real treasure trove for the analysis of the science/technology relationship in 19th century plant breeding. von Lochow is known for developing a highly effective breeding technique that dominated cereals breeding in Germany far beyond WW I. Moreover, thanks to his technique von Lochow achieved a rye variety that was exceptionally successful judged by its spread throughout many European countries.

## The Role of Scientific Theory in Late 19th century Breeding Practice

Born in 1842 at the Domäne Schlanstedt, a state property in the Prussian Province of Saxony, Wilhelm Rimpau was the son of an entrepreneurially minded farmer and advocate of agricultural modernization.[19] His uncle, Theodor Hermann Rimpau (1822–1889), is well known among German historians of agriculture for the invention of techniques that allowed for the cultivation of marshlands. Thus, Rimpau was deeply familiar with agriculture from his early childhood. After leaving school, Rimpau did a 2 year-apprenticeship with a farm and enrolled thereafter at the agricultural college in Bonn-Poppelsdorf. Among his teachers was the renowned plant physiologist Julius Sachs (1832–1897), to whom Rimpau owed a strong interest in the natural sciences and a lifelong passion for experimentation. After passing his exams and a further semester of agricultural studies in Berlin, Rimpau went on an educational trip to England and Scotland to learn more about modern farming. Back in Germany he joined his father and developed the Schlanstedt property according to the principles of intensive agriculture.

Along with farming Rimpau carried out many studies related to such diverse fields of agricultural concern as meteorology and mechanical engineering. He systematically researched the physiological basis of plant breeding and attempted to improve breeding knowledge and methods.[20] An active member of various associations Rimpau became involved with the German Agricultural Society (Deutsche Landwirtschaftsgesellschaft), which was dominated by progressive farmers from Middle and North Germany. The Society's objective was to promote domestic agriculture through the dissemination of practical and

[19] For the biography of Rimpau, see von Rümker, 1903, and Thiel, 1903, 1904.
[20] For a bibliography of Rimpau's work, see von Rümker, 1926, pp. 385–387.

scientific knowledge. In 1886, only 1 year after its founding, Rimpau initiated the building of a section exclusively devoted to plant breeding. Offering a communication platform for commercial breeders, agricultural scientists and farmers, this section became an important institution for the development of early plant breeding. It not only facilitated the knowledge flow between those groups who were interested in plant breeding but also organized field trials to evaluate the performance of new varieties. Coordinated and supervised by agricultural scientists these trials were designed to help farmers to choose between available varieties and to create an incentive for plant breeders, who could use the results for promotional purposes. More generally speaking, the breeding section served as an organizational structure that allowed for the interaction of science and technology.[21]

Rimpau started cereals breeding in 1867 to increase the yield of a rye variety called Probsteier Rye, which was cultivated in the Schlanstedt area. Like all traditionally grown cereals, i.e. landraces, this rye was not a single variety but – as we would put it today – a heterogeneous mix of different biotypes. Through repeated mass selection of the "best plants," Rimpau tried to produce more homogenous varieties with improved characteristics. About 10 years after having started, he had to admit that he had achieved very little by this method.[22] The plants in his breeding plot did not differ from the original variety. He suspected that cross-pollination of his rye through neighboring fields had caused this failure. In a move typical of his problem-solving style, Rimpau thoroughly reviewed the available botanical literature in order to learn more about pollination and fertilization in grain and in particular whether rye was an in- or out-breeder. In the work of botanists such as Johann Gottlieb Koelreuter (1733–1806) and Christian Konrad Sprengel (1750–1816), who pioneered research on plant sexuality, he found some information on these issues.[23] But he criticized these authors for generalizing from single varieties to the whole genus. From his point of view, they did not sufficiently take into account the small but important biological differences among grass and grain varieties. Since other botanists (including his former fellow student Eugen Askenasy) could offer only limited help, Rimpau started his own research program on pollination and fertilization in grain.

[21] For details, see Wieland, 2004, pp. 56–64.
[22] Rimpau, 1877a.
[23] For the work of Kölreuter and Sprengel, see Hoppe, 1998, pp. 386–396, and Olby, 1985, pp. 1–20.

As a first outcome, Rimpau could demonstrate that many rye varieties grown in Germany were self-sterile and cross-fertile.[24] In accordance with these results, he transferred his breeding plot to a place where unintended cross-pollination from neighboring fields could be excluded. Using mass selection, whereby seed from a number of individuals with the desired traits is selected, pooled and planted to form the next generation, he obtained a new rye variety within a few years. It was substantially improved and successfully commercialized on the seed market. While breeding and selling his so-called Schlanstedter Rye, Rimpau further pursued his research program. Through a series of sophisticated experiments and microscopic studies, he was able to produce a substantial body of knowledge about the physiology of reproduction in grain. In an article from 1882, he gave a detailed summary of his research and discussed it against the background of what was known at the time about pollination and fertilization in grain.[25] He particularly emphasized the diversity of reproduction modes among grain varieties. According to Rimpau, rye varieties typically propagated through cross-pollination and cross-fertilization, although he acknowledged some exceptions. In contrast, he classified wheat, oats, and barley as self-pollinating and self-fertilizing grains, but highlighted again the possibility of exceptions. In fact, Rimpau warned his readers of generalizations of the kind he criticized in the work of botanists such as Koelreuter and Sprengel.

As the Schlanstedter Rye opened the way to Rimpau's success as commercial plant breeder, his experimental studies on cross- and self-fertilization guided him towards the general problem of cross-breeding and the underlying principles of heredity. Again, there were academic antecedents who pioneered this line of research, which, since the times of Carl von Linné (1707–1778), had been linked to botanical systematics. Koelreuter's and Sprengel's aforementioned work on sexuality must be seen against this background, particularly the question of whether species are fixed, natural entities or mere artificial constructs. The same applies to the work of Karl Friedrich Gärtner (1772–1850) who, prompted by a prize competition by the Dutch Academy of Science in Haarlem, researched the possibilities of speciation through cross-breeding.[26]

However, it was not until the second half of the 19th century that hybridization research questions (such as the inheritance of individual characters and the role of maternal and fraternal germ plasma) gained

[24] Rimpau, 1877b.
[25] Rimpau, 1882.
[26] See Hoppe, 1998, pp. 388–389, and Olby, 1985, pp. 21–39.

some independence from the problem of the species concept. For example, based on cross-breeding experiments, the French botanist Charles Naudin (1815–1899) described the uniformity of the first hybrid generation and the segregation of characters in the second one. He concluded that plant hybrids are mosaics of individually transferred characters. And of course, there was Charles Darwin (1809–1882) who enthusiastically collected the many observations of plant and animal breeders (including Rimpau) relating to the problems of heredity and variability. Darwin formulated his "pangenesis hypothesis," a rather speculative concept that – as he himself noted – shed very little light on hybridization problems though it was in accordance with the empirical facts.[27] In general, up until the end of the 19th century, there was a wide range of unconnected hereditary concepts sometimes informed by empirical observations, but mostly based upon broad speculation. For the plant breeder who wanted to control the transfer of individual characters or develop theoretically informed breeding strategies these concepts were of little help since their prognostic value was rather limited. In addition, Rimpau criticized the naturalists' strong neglect of cultivated plants, the experimental work on which was negligible at that time.[28]

All in all, from the perspective of plant breeders, the situation was anything but satisfying. Considering the lack of theories or concepts that could account for the behavior of hybrids, cross-breeding was quite a challenge. But although hard to handle and very uncertain regarding the outcome, this technique had a powerful appeal since it might allow breeders to combine the characters of different varieties in a new one. A major goal of German cereals breeders was, for instance, to overcome the inadequacies of the Squarehead, a highly productive wheat variety from England that was ill-adapted to the climatic conditions of Germany. Crossing the Squarehead with well-adapted German wheat varieties was thought to be a solution to this problem. In contrast, selection techniques were bound to the limited set of characters of a single variety. Breeders could only increase or decrease these characters through continued selection but not add new ones. It might therefore not be surprising that many plant breeders experimented with cross-breeding. Their success was demonstrated by a series of new varieties entering the seed market.

Rimpau started cross-breeding in 1875 when he sought to combine the characters of productive English and hardy German wheat. Again,

[27] See Rheinberger, 1983, especially p. 211.
[28] Rimpau, 1877a, p. 193.

the initial outcome of this attempt was rather disappointing. Rimpau decided therefore to learn more about the guiding principles of the heredity process. As he did before, he screened the available literature by natural scientists for suitable knowledge and additionally conducted his own crossing experiments. Hoping for revealing insights into the heredity process he even undertook species crosses. While much of his breeding work was primarily done in order to learn more about the subject, some crosses produced new varieties such as Rimpau's früher Bastard (Rimpau's early Bastard) that combined early maturity of American wheat varieties with the high yields of English wheat varieties and was successfully sold on the seed market. Rimpau published his cross-breeding work in 1891. Primarily a detailed summary of his findings, the article also drew some general conclusions. The author described the uniformity of the first hybrid generation after crossing two different varieties. The overall character of this generation's individuals was mostly intermediary, i.e. right between the characters of the parental plants, but it could also more resemble the mother or father plant. In contrast, the individuals of the second hybrid generation revealed a wide variety of characters including those of either of the parental plants, the combination of both, and a wide range of intermediates.[29] As Rimpau noted himself, these findings were in line with the contemporary knowledge about the behavior of hybrids. But by systematically extending this knowledge to grain and even species hybrids[30] between wheat and rye Rimpau once more demonstrated his status as a pioneer of German plant breeding. Furthermore, through his experimental work he anticipated the transformation of cereals varieties from commercial into scientific objects which later on became an important aspect of plant breeding moving from the farm to academia.

Considering both the breadth and profundity of his experimental work, Rimpau certainly stood out from his fellow breeders. He was very much the amateur scientist, but one who could still compete in many fields with the professional scientist at universities. As a matter of fact, Leipzig University tried to appoint Rimpau to its chair of agriculture in 1888. Rimpau, however, declined. Despite his scientific interests, he was most of all an agricultural entrepreneur and commercial breeder. The purpose of his research was 19th century agriculture and its specific technological as well as economic challenges and not the academic dispute over the validity of scientific theories and concepts. Generally speaking, Rimpau's work demonstrates that plant breeding understood

[29] Rimpau, 1891, pp. 337–338.
[30] See Figure 1.


*Figure 1.* Rimpau's Wheat/Rye Hybrid from 1888.[31]

as a technology gained little from science. Although he intensively searched the scientific literature Rimpau could find little of use to cope with the problems emerging from his attempt to improve cereals through mass selection and cross-breeding. Rather, it was science or, to be more precisely, the scientific study of reproduction and hybrids that was driven by technological questions.

The commercial context of research and development conducted by private breeders is particularly evident in the work of Ferdinand von Lochow. He was born in 1849 at the Petkus estate about 60 km in the south of Berlin.[32] As many sons of the Prussian aristocracy, after finishing school, von Lochow wanted to become a high-ranking military officer, but had to quit the service after a severe injury in 1872. As a consequence, he took an agricultural apprenticeship and enrolled

[31] Hillmann, 1910, p. 274; the two ears on the left are from the mother plant (wheat) and father plant (rye), the third ear represents the uniformity of the first hybrid generation and the five ears on the right were found in the second hybrid generation.

[32] For the biography of von Lochow, see Aufhammer, 1970, and von Rümker, 1925.

thereafter at the University of Halle. In Halle, Julius Kühn (1825–1910) had established Germany's first university institute for agricultural science, which soon became a leading center for academic research and learning in the field. von Lochow finished his studies in 1875 and – after a short employment as an agricultural inspector – used his newly acquired skills to run Petkus, which up until then was a relatively traditional farm. In order to intensify production, he started cereals breeding in 1881. Like Rimpau, von Lochow was somewhat dissatisfied with the yields he gained from the cultivation of traditional rye varieties and attempted to improve them through mass selection. However, he soon developed his own very efficient technique that will be discussed in the next section. Through this technique von Lochow achieved a rye variety named Petkuser Rye that significantly outperformed the so far known rye varieties and subsequently became Germany's most cultivated rye. It laid the foundation for von Lochow's flourishing seed company with subsidiaries throughout Europe. A commercially successful breeder, von Lochow was also the member of many agricultural associations and engaged in agricultural politics.

How did von Lochow come to his breeding technique? It was a well known fact among breeders that plants could differ a lot between successive generations. Parental plants obviously did not pass on all their visual and behavioral characteristics to their progeny. Hence, plant breeders' success highly depended on their ability to tell hereditary and non-hereditary characteristics apart, i.e. to identify traits which could be relied upon to breed true. There again, the knowledge natural scientists could offer to the breeder was of little use. As aforementioned, their concepts of heredity were largely speculative and often lacked an empirical basis. Moreover, they contradicted each other. The opposing concepts of the well-known zoologists Ernst Haeckel (1834–1919) and August Weismann (1834–1914) were typical of late 19th century biology. While the first argued for the Lamarckian idea of acquired characteristics, the latter denied this possibility by claiming the existence of a fundamental difference between soma and germ cells.[33] For plant breeders, these academic disputes were of little relevance. Most of them disagreed with Lamarckian concepts,[34] but this did not help when plants had to be selected for breeding (Figure 2).

von Lochow had been confronted with the problem of hereditary vs. non-hereditary characteristics ever since he had started improving rye. In order to cope with it, he developed a breeding method that – both

[33] See, e.g., Sohn, 1996, and Churchill, 1987.
[34] Zirnstein, 1977, p. 63.

*Figure 2.* Ferdinand von Lochow screening his Petkuser Roggen.[35]

elegantly and efficiently – allowed for classification of plant characteristics according to whether they were reliably passed on from parents to offsprings. With the commonly used method of mass selection, plant breeders selected seed from individuals which showed the desired characteristics, pooled the seed, and eventually planted it to grow the next generation. In doing so plant breeders hoped for a gradual improvement of their varieties. von Lochow also selected seed from individuals but did not pool it. Rather he planted the seed of each individual in a separate plot. In addition, he carefully kept records about the origin and specific characteristics of each individual used or produced in the breeding process. This book-keeping made the comparison of each progeny with its maternal plant possible and therefore permitted the identification of those characteristics which were definitely

[35] Dade, 1913, p. 287.

transmitted from one generation to the next. Since only individuals who guaranteed a transmission of desired characteristics were chosen to form a breeding line, the method very efficiently led to a relatively homogenous variety. von Lochow's method had already been used by the French plant breeder Louis de Vilmorin (1816–1860) who applied it to sugar beets.[36] Although von Lochow was thus neither the first nor the only one to develop this technique, it became widely known as the "German method of selection" thanks to the work of agricultural scientist and academic breeder Carl Fruwirth (1862–1930), who has written an influential, multi-volume handbook on breeding.

von Lochow gave several accounts of how he developed his breeding method.[37] We certainly need to be cautious with such self-descriptions. In this case, these accounts seem a bit too straightforward since they highlight success and neglect failure. But what one can nevertheless derive from reading them is that von Lochow developed his breeding method by means of trial and error procedures, and systematic experimentation. And even though his method seems to anticipate the difference between phenotype and genotype that was established much later, it was not theory-based. Considering the heterogeneous body of hereditary concepts in late 19th century biology, this should come as no surprise. As a matter of fact, the German method of selection was not legitimized by any scientific concept or theory but by the commercial success of new grain varieties, above all von Lochow's Petkuser Rye. As this variety spread all over Germany and beyond, the German method of selection also gained high acceptance among commercial breeders who relied on it into the interwar period.

After the turn of the century, leading proponents of Mendelism such as Erich von Tschermak claimed that, before the rise of Mendelian genetics, plant breeding was an unsystematic endeavor governed by chance and chaos, and characterized by sterility and setbacks.[38] According to this stance, only scientific theory was able to turn plant breeding into an efficient technology able to create economic prosperity. As we have seen this claim is certainly not true. The best known 19th century plant breeding was both systematic and successful. Through experimentation commercial breeders developed many improved grain varieties as well as a set of efficient techniques to breed them. Furthermore, they created a body of knowledge about hereditary phenomena that helped them to deal with the problems of their work. That scientific

[36] Drouin, 1994, and Gayon and Zallen, 1998.
[37] See, e.g., von Lochow, 1900a, b.
[38] Tschermak, 1902.

theories and concepts played only a very marginal role for plant breeding practice was not because commercial breeders were not interested in the work of natural scientists. On the contrary, breeders such as Rimpau looked thoroughly for useful knowledge; but scientific theory offered little orientation. To be sure, it was not by chance that most of the successful German pioneers of cereals breeding went to an agricultural college or university institute before starting their business. Rimpau would not have been able to conduct his research on grain sexuality and inheritance without a proper academic training in the biological sciences. And von Lochow's method of selection and in particular his use of a breeding book also reveals the influence of science where detailed record keeping is a standard procedure of experimenting. But it was the scientific approach in general that helped the commercial breeders to develop their varieties and methods, rather than a particular scientific theory or concept.

However, plant breeding did not remain exclusively a domain of agricultural practice. Alongside the commercial breeder emerged the academic breeder who was based in agricultural colleges, universities, and public institutes. These organizations built a space for plant breeding that strikingly differed from the farm. While the latter was defined in economic terms agricultural colleges, universities and public institutes sought for an extension of scientific knowledge and its mobilization for the improvement of agriculture. In the two decades before the First World War, plant breeding was thus transformed into an "applied science" defined by scientific experts while the commercial breeder was re-defined by the same group as a lay person exercising a more limited expertise in a circumscribed sphere of agricultural practice.

## From the Farm to Academia

As previously discussed, when farmers started cereals breeding the German agricultural research system was already well developed.[39] Pioneered by physician and farmer Albrecht Daniel Thaer (1752–1828) agricultural colleges were founded all over Germany in the early 19th century. While these colleges were for some decades the leading institutions for higher learning and research, agricultural science gradually moved to the universities. This was due to the rise of agricultural chemistry. Justus Liebig (1803–1873), the most prominent proponent of

[39] For a general account of the history of agricultural science in Germany, see Klemm, 1979 and 1992.

agricultural chemistry, quite successfully argued that students of agriculture had to be thoroughly trained in the natural sciences and that this could only be achieved through the integration of agricultural studies into the universities. A consequence of this line of argument was the establishment of the agricultural institute led by Julius Kühn at the University of Halle in 1863 followed soon by the founding of many other institutions of this kind. Already during the 1850s, a network of publicly funded agricultural experiment stations had come into being adding to the somewhat limited research capacities of the agricultural colleges (and later established university institutes). A contemporary survey of the German agricultural research system from 1871 lists seven agricultural colleges, 11 agricultural institutes or chairs at universities, and about 50 agricultural experiment stations.[40]

Although agricultural science encompassed a wide variety of subjects from business operations to cattle breeding, research at these institutions was above all shaped by the influence of agricultural chemistry. This is particularly true for the crop and soil sciences which tried for an application of chemical principals to farming in order to improve yield. Due to the agricultural scientists' preoccupation with chemistry, other subjects developed only slowly or even stagnated. It was therefore not until the late 1880s, when the growing number of newly bred grain varieties could hardly be ignored any longer, that agricultural scientists put plant breeding on their agenda.

An outstanding figure in the early decades of academic plant breeding was Kurt von Rümker (1858–1940) who may be seen as its founding father.[41] As the son of a Prussian landowner von Rümker's way to agriculture was somewhat predetermined. After an agricultural apprenticeship he studied agriculture in Halle, Bonn-Poppelsdorf and Hohenheim, repeatedly interrupted by jobs with farms. In 1888, he finished his studies in Halle with a doctoral thesis on cereals breeding supervised by Julius Kühn. Only a year later von Rümker qualified as university lecturer in Göttingen, where he gave the first series of lectures exclusively focused on plant breeding. Also in 1889, he published his book *Anleitung zur Getreidezüchtung auf wissenschaftlicher und praktischer Grundlage* (Introduction to Cereals Breeding on a Scientific and Practical Basis) that not only offered a comprehensive and systematic overview of breeding techniques but also insisted that agricultural scientists should turn their attention towards plant breeding. von Rümker argued that plant breeding was to be incorporated into agricultural

[40] Cited in Klemm, 1979, p. 208.
[41] For details on von Rümker, see Wieland, 2004, pp. 65–76.

science in order to substitute exact scientific research for pure empirical development. Much more a discipline builder than an ingenious scientist, von Rümker tightly bound his career to the objective of establishing plant breeding as an academic discipline.

To understand fully von Rümker's role as discipline builder, one must draw together two significant lines of argumentation developed by him in two series of papers.[42] One line of argument focused on the need for a differentiation of agricultural science into independent disciplines, the other one on the theoretical and methodological basis of plant breeding. According to von Rümker, the growing complexity of agricultural science called the ideal of universalism proposed by such eminent figures as Kühn into question. Since university lecturers were, in contrast to this ideal, no longer able to adequately cover the rapidly expanding complexity of agricultural science they rather should specialize in one field of knowledge. This was more than an argument about the organization of teaching. Indeed, von Rümker demanded the dismantling of traditional university institutes of agriculture into subject-specific institutes endowed with their own budget and resources. More than that, he actually realized this form of organization at Breslau University, where he divided the "old" agricultural institute into three independent and subject-specific institutes in 1889.[43] von Rümker subsequently became director of the Institut für Pflanzenproduktionslehre (Institute of Plant Production Science). While after this rearrangement plant breeding was represented in the Breslau agricultural curriculum as an independent field of teaching (von Rümker offered general and specialized series of lectures on the subject), its institutional status was enhanced in 1911 through the creation of a plant breeding unit. Although not independent from the institute this unit mirrored von Rümker's efforts to improve the status of academic plant breeding and to distinguish it clearly from crop science.

This is where the second line of argument comes in. To establish plant breeding on a disciplinary or sub-disciplinary level as an independent field, it was necessary to look at its theoretical and methodological basis. von Rümker argued that plant breeding has "to take root in the soil of pure science" and if it turns out that this soil differs from neighboring fields one could claim its independence as a system of theories. Linking plant breeding to the biology of reproduction and the study of heredity he could indeed clearly distinguish it from neighboring fields, most of all from crop science. Using the metaphor of economics,

[42] See, in particular, von Rümker, 1895 and 1897.
[43] von Rümker, 1904, pp. 1–3.

von Rümker highlighted the difference between the two fields this way: "Plant breeding creates a capital on which crop science seeks to pay an interest rate as high as possible." And he hoped that as soon as "this young discipline is accepted as something independent [...], one will not hesitate to generally grant room and funds for carrying out independent research and a place in the curriculum of agricultural studies equal to the place owned by general and specialized studies of stockbreeding."[44]

By linking plant breeding to the study of heredity von Rümker explicitly construed the former as an "applied science," the theoretical status of which was however anything but settled at the time. Nevertheless, von Rümker was quite successful regarding the institutionalization of academic plant breeding. As a growing number of agronomists devoted their material and intellectual resources to the field, plant breeding largely took hold within the agricultural research and education system before WW I. Although an integral part of crop science rather than an independent discipline, plant breeding was researched and taught at many agricultural colleges and university institutes. But it was the public research sector and not the university system where academic plant breeding first gained some institutional independence. In South Germany, where commercial plant breeding was non existent in the late 19th century, special institutes were founded by the states of Bavaria, Baden, and Württemberg. These so-called Landessaatzuchtanstalten (i.e. state owned breeding institutes) were to stimulate private activities in plant breeding by offering scientific and technical advice. In addition, they conducted their own breeding research and even developed new plant varieties. Comparable to the breeding section of the German Agricultural Society the Landessaatzuchtanstalten served as an organizational structure that supported the knowledge exchange between farmers, commercial breeders and agricultural scientists.[45]

A community of academic breeders had come into being at the turn of the 20th century. However, the academic status of plant breeding remained doubtful as long as it lacked a theoretical and methodological foundation. For the commercial breeder, the lack of suitable theories was an annoying gap. For the academic breeder it was nothing less than a threat to his very existence. It is therefore hardly surprising that academic breeders were anxious to enlarge the body of theoretical knowledge. As in many other countries, in Germany too, they showed great interest in the new field of Mendelian genetics. Articulating the feelings of many of his contemporaries, von Rümker pointed out: "The

[44] von Rümker, 1895, quotes on pp. 70, 86, and 77 (my translations).
[45] For details, see Wieland, 2004, pp. 79–102.

rediscovery and revitalization of Mendel's findings is certainly a great and very important advancement of the whole field of heredity and variation studies.''[46] Nevertheless apart from conferring a general scientific legitimacy, it was unclear what Mendel's laws, de Vries's mutagenesis theory and Johannsen's pure line theory – to name the most important concepts of the new genetics – actually meant for the plant breeder. And as we will see in the following section, solving this problem was not an easy task. I shall focus here on Johannsen's pure line theory since it challenged practical breeding knowledge in Germany much more than Mendel's or de Vries's findings and can therefore tell us a great deal about the science/technology relationship.

## The Reception of Johannsen's Pure Line Theory Among German Academic Plant Breeders

In 1903 Wilhelm Johannsen (1857–1927), plant physiologist at the agricultural college of Copenhagen, published his pure line theory and claimed its universality.[47] The pure line concept implied that selection within so-called pure lines, i.e. the progeny of a single self-fertilizing plant, was totally ineffective regarding the alteration of the line's ''type.''[48] Johannsen based his theory on a set of sophisticated experiments with the common bean *Phaseolus vulgaris*. For example, he selected for the heaviest and lightest individuals in the progeny of a single bean plant. Repeating this procedure through several generations and analyzing the achieved individuals with the instruments of biometrics, Johannsen could only detect a change of the average weight of the progeny in the beginnings of his experiment. After a very few generations, the effect vanished. Hence, he concluded that once a pure line was established continued selection could not alter its type. Johannsen carried out his research against the background of the much discussed question as to the effectiveness of selection.

Although Johannsen, in his 1903 booklet, did not discuss the consequences of his theory for breeding methods, its commercial relevance was obvious.[49] From the plant breeders' perspective Johannsen called the effectiveness of such highly valued techniques as the German

[46] von Rümker, 1905, p. 239 (my translation).
[47] Johannsen, 1903.
[48] Based on this line of research Johannsen later on developed the genotype concept. See Churchill, 1974; Roll-Hansen, 1978, and Wanscher, 1975.
[49] See also Kim, 1991.

method of selection into question. Given the success of this method, however, scientific theory and agricultural practice seemed to contradict each other. Who was better suited to explain or research this obvious gap between theory and practice than the academic breeders? Indeed, for them Johannsen's theory was not only a challenge but also an opportunity to demonstrate their scientific expertise and to prove the need for their emerging discipline. Setting the pure line theory on their research agenda, academic breeders tried to mediate between the worlds of scientific theory and agricultural practice.[50]

In a first move, academics such as Carl Fruwirth, Kurt von Rümker and Carl Kraus (1851–1918) drew upon the data collected in their own breeding experiments to check whether subsequent selections among single, self-fertilizing plants were able to change a line's type or not. As Fruwirth, then head of the Württemberg Landessaatzuchtanstalt, noted this was not without problems since the data were drawn from breeding practices that had been aimed at new commercial varieties. In contrast, Johannsen carried out "pure scientific experiments."[51] Although there was a link between these two practices, the modes of data collecting and the overall aims differed significantly. For the academic breeders the linkage of experimental data and theory was an undertaking ex post. Put differently, this linkage retrospectively transformed a commercial variety into a scientific object, turned it into an epistemic thing that raised more questions than could be answered by doing so. The problems emerging from this course of action are evident in the work of Carl Kraus.

Rector of the agricultural college in Weihenstephan near Munich, Kraus started cereals breeding at the end of the 19th century and continued this work after the establishment of the Bavarian Landessaatzuchtanstalt in 1902. One of his aims was to improve the Freisinger Gerste, a traditionally grown barley variety that was used by the local brewing industry. Through successive selections of individual plants he hoped to achieve a variety insensitive to frequently changing conditions of weather and nutrition. Linked to this line of work Kraus collected a huge set of biometrical data, which he used in 1909 to discuss the question "whether continued selection within pure lines of self-fertilizers [...] had any effect or not."[52] Like Fruwirth, Kraus acknowledged that using data from practical breeding in order to discuss a theory was not

[50] See Harwood, 1997, pp. 189–190; for a thorough discussion of the various positions among academic breeders, see also Zirnstein, 1977, pp. 165–175.

[51] Fruwirth, 1907, p. 281.

[52] Kraus, 1909, p. 465 (my translation).

without problems. He argued that in contrast to Johannsen's experiments, he had to look at a very large set of characters in his breeding work. Moreover, this set of data showed some gaps which he had to bridge by estimations derived from his breeding notes.

However, using data from practical breeding meant not only having to cope with gaps in the set of data but also to confront the great complexity of an agricultural practice with the necessity to reduce complexity to a limited set of variables in the process of theory building. The outcome was an ambiguity of the grain variety that oscillated between a commercial variety and an epistemic object. This is mirrored in the insecure way Kraus evaluated his findings in the light of Johannsen's theory. Regarding the Freisinger Gerste Kraus stated, for instance, a general improvement of the variety's progeny and he pointed at the "real success" that could be seen in the increased homogeneity of the plants in the breeding plot. On the other hand, he had to admit that the "real essence" of the line did not change and the biometrical figures, i.e. the measurable traits, of the ear did not increase. Nevertheless, he claimed that under specific conditions of cultivation the variety produced more uniform ears and thus became "practically much more valuable."[53] And in an article on the same subject published 8 years later, he emphasized that while the biometrical figures of the ear could not be changed through continued selection it would be totally wrong to conclude that these selections did not have any effect at all. As he put it: "The 'breeder's eye' immediately reveals that this is not true."[54] And he concluded, though Johannsen's theory was a major contribution to breeding knowledge, it could not claim universality.

To be sure, from our perspective Kraus's findings fit very well into Johannsen's theory. For instance, the increase of the variety's homogeneity that Kraus called a "real success" can be explained by the assumption that he did not actually work with pure lines. But we can make this assumption because we are well aware about the empirical scope of Johannsen's theory. For Kraus and his colleagues it was exactly this scope that had to be determined, i.e. they had to interpret Johannsen's theory in the light of their findings. From this perspective it is understandable why Kraus resisted Johannsen's claim to universality.

Along with established agricultural scientists such as Kraus a new generation of academic breeders turned towards the pure line theory. Much more than their seniors, this generation sought to get in touch with the new genetics, the methodological approach of which attracted

[53] Kraus, 1909, p. 478.
[54] Kraus, 1917, p. 459.

people such as Ludwig Kießling (1875–1942) and Theodor Roemer (1883–1951). The latter introduced his dissertation by pointing at the rise of the experimental method that he stated turned biology from a speculative into an exact science at the end of the 19th century.[55] Kießling also stressed that he refused to dive too deep into speculations, rather he would adapt Wilhelm Johannsen's and Erwin Baur's point of view that "one should experiment more and theorize less."[56]

For the experimental practice of the academic breeders the adoption of the epistemological stance of Mendelism meant a differentiation between breeding for commercial purposes and breeding for scientific purposes. Indeed, Kießling stated in a report on the activities of the Landessaatzuchtanstalt where he worked as a sort of executive manager that the institute's work had been divided into two branches. One branch aimed at the improvement of varieties as well as a better understanding of breeding techniques, the other's goal was to carry out pure scientific experiments that did not take into account the usability of the varieties achieved.[57] There, plant varieties were no longer seen as products of commercial interest but as epistemological objects used for the advancement of scientific theory. Accordingly, the experimental design was marked by several characteristics including the choice of only a few characters which could be easily traced through successive generations, a highly controlled experimental setting in order to exclude unwanted effects such as accidental cross-pollination, and the use of control experiments such as plus- and minus-selections that helped to reveal variation in the environmental conditions.

Based on this experimental method both Kießling and Roemer were able to reproduce Johannsen's results, i.e. pure lines that remained unchanged despite continued selection. Through strict application of the new genetics' methodology they very successfully transformed the commercial variety into a scientific object, manufactured an epistemic thing called pure line. But while this helped them to prove their experimental skills and demonstrate their professional expertise, its contribution to the overriding question whether selection could help to improve a commercial variety was somewhat limited. Indeed, Kießling was well aware that pure lines were an artificial construct which derived from the experimental setting, though an artificial construct with enormous implications for genetic research.[58]

[55] Roemer, 1910, p. 397.
[56] Kießling, 1915, p. 113.
[57] Kießling, 1912, p. 169.
[58] Kießling, 1915, p. 110.

In sum, Kießling and Roemer confirmed Johannsen's experimental results the practical significance of which remained unclear. Despite intensive experimentation academic plant breeders were not able to reach consensus about the scope and implications of Johannsen's theory. It is therefore interesting to follow the discussion a bit further. While at the end of the 1920s the majority of academic plant breeders generally accepted the pure line theory, the question remained unanswered as to whether commercial breeders actually dealt with pure lines. George Sessous (1876–1962), agricultural scientist at the University of Gießen, argued for instance that commercial breeding lines, which were usually thought to be pure, in fact showed a high degree of genetic variability due to diverse reasons including cross-fertilization in former generations. Consequently, he argued, commercial breeders should keep to the method of continued selection.[59] Erwin Baur (1875–1933), a leading figure of the German genetics community, challenged the applicability of the pure line concept to natural populations from another perspective.[60] In 1924, he published his research on speciation with Snapdragon (*Antirrhinum majus*) to contribute to "unsolved problems of evolution research." Baur emphasized the occurrence of a large number of small mutations in his experimental object, which he argued could lead to new varieties and species. And he concluded that geneticists impressed by Johannsen's theory overvalued the stability of pure lines.[61] Indeed, genetic factors seemed to be not as stable as contemporary geneticists thought. Although Baur's results were very interesting from a geneticist's or evolutionary biologist's point of view, for the commercial breeders they only increased the problem of judging the relevance of Johannsen's theory for practical breeding.

In fact, this problem was not merely a scientific but also practical one. It could therefore not be solved within the epistemological frame of science but only with taking the practical, i.e. the commercial aspects of plant breeding into account. Otto Ziegler, academic breeder at the Bavarian Landessaatzuchtanstalt, argued that one has to differentiate between the practical perspective of the commercial breeder and the theoretical perspective of the geneticist. He claimed: "Genetics does not deal with the problem of the best possible commercial use of a given genotype" and warned of an overemphasis on Mendelian genetics, and its schematic and mathematical way of reasoning.[62] Theodor Roemer

[59] Sessous, 1929.
[60] For the work of Baur, see Harwood, 1993.
[61] Baur, 1924; see, Sohn, 1999, pp. 111–113.
[62] Ziegler, 1930, p. 169 (my translation).

who certainly did not share Ziegler's stance regarding Mendelism, nevertheless adopted the latter's distinction between plant breeding and genetics. When writing a chapter on artificial selection for his co-edited handbook of plant breeding, Roemer argued as follows: While geneticists were seeking a "theoretical proof" for the variability of the genotype, commercial breeders had to ask three questions: first, whether a variation of the genotype was in accordance with the breeder's goal since most variations did not have any value or even decreased the value of a variety; second, whether such a variation occurs in a commercially justifiable period of time, and third, whether it occurs within a population of a commercially justifiable size. The latter two questions aimed at the commercial value of the frequency of variations. If those variations were too scarce, plant breeders could hardly place their bets on them. As a consequence, the meaning of "effective selection" highly depended on the frame of reference; it differed depending on whether one looks at it from a scientific or commercial point of view. Roemer argued that there were indeed some examples of new varieties, which were achieved through continued selection within "pure lines." This could be explained by accidental cross-fertilization and mutations. But from the commercial point of view, he argued, it was more instructive to look at the experience of such breeders as Hermann Nilsson-Ehle who, in forty years of breeding work, did not achieve a single new variety that was owed to natural mutation.[63] Eventually, it was economics not science that offered the reference system to decide about the value of the technique of continued selection and thus the relevance of Johannsen's theory for plant breeding. Put differently, science could help to better understand and improve technology, but the latter remained a system judged by criteria of practicality and profitability, and not truth.

As we have seen, applying the new genetics to plant breeding was not a straightforward task – quite the contrary. Moving Johannsen's theory from the context of evolutionary biology to the context of practical plant breeding initially raised more questions than could be answered by doing so. The obvious gap between theory and practice called for the academic breeder who used the opportunity to prove his scientific and technological expertise as well as the growing need for his discipline. More so, since the German genetics community – with the notable exception of Erwin Baur – showed little interest in linking its research to agriculture.[64] Negotiating scientific theory and agricultural practice therefore became the proper business of the academic breeder. But with the growing

[63] Roemer, 1941.
[64] Harwood, 1993.

scientification of plant breeding the improvement of crops became more and more intensive with regard to both intellectual and material resources. So, when the German plant breeding industry suffered from a severe financial crisis in the interwar period, because of lacking property rights on newly bred varieties and other reasons, academic plant breeders were in a good position to take over the claim of leadership not only in the theoretical but also practical aspects of plant breeding.

This development was accompanied by a considerable growth of academic posts and institutions devoted to plant breeding. For instance, at Halle University the agricultural institute founded by Julius Kühn was reorganized in 1920. This step led to the creation of Theodor Roemer's renowned Institute of Crop Science and Plant Breeding which was the home of his widely known research school and a leading institution for cereals breeding in Germany with strong links to the regional plant breeding industry. Similar institutes of "crop science *and* plant breeding" the name of which already indicated the growing status of academic plant breeding were established in the mid-1920 at other universities including Gießen and Leipzig universities. A further milestone for the development of academic plant breeding was the foundation of Erwin Baur's Kaiser Wilhelm Institute for Breeding Research in 1928 that, from its beginning, was internationally known as a stronghold for cutting-edge research in applied genetics. To sum up, the transformation of plant breeding into a scientific discipline, the financial crisis of the plant breeding industry, and the growth of publicly financed plant breeding research finally led to a shift of the locus of innovation from agriculture to academia. There, the plant breeders' responsibility was no longer limited to the generation, validation and application of scientific theories in order to improve breeding technology but extended to the use of this technology for the creation of new varieties to be commercialized by the plant breeding industry.[65]

## Conclusion

The "molecular revolution" of the mid-1970s brought about a new perception of the life sciences which are now considered an important source for the innovation of new technology. As physics and chemistry more than a century before, biology achieved an engineering-like status defined by a tight coupling between the understanding of life and its technical manipulation. This phenomenon is not as new as it appears.

[65] Wieland, 2004, pp. 147–178.

The history of German plant breeding reveals that within the life sciences already in the late 19th and early 20th centuries a strong link has been established between the production of scientific knowledge and technological artifacts. It is attributable to the rise of academic plant breeding. A better understanding of the applied science tradition within biology can therefore contribute to the debate about the current transformations of the life sciences. I suggest that in order to comprehend the relationship between scientific theory and agricultural practice, or more generally between science and technology, we have to take the different levels into account at which these two worlds interact. Doing so not only helps to identify the mechanisms mediating the science/technology relationship but also helps to understand how agronomists transformed the agricultural practice of breeding into an applied science.

The analysis in this paper focused on three levels, i.e. organizations, individuals, and objects. Organizations can be understood as physical or virtual spaces for the interaction of science and technology. Already the country estates of pioneers such as Wilhelm Rimpau who used part of his farmland for scientific experiments can be interpreted in this way. The same holds true for the German Agricultural Society the breeding section of which facilitated the knowledge flow between farmers, commercial breeders and agricultural scientists thereby linking these different social groups. But it was particularly the South German Landessaatzuchtanstalten and later on university institutes that clearly marked plant breeding as a distinct field of academic activity and established permanent structures for the mediation between science and technology. The creation of these organizations was therefore an important aspect of the agronomists' efforts to transform plant breeding into an applied science. It can be interpreted as an institutional strategy. But organizations are more than physical or virtual spaces. Purposefully created they have specific aims and their own logic. Most obvious, while the seed firm's goal is profit the academic institute aimed at the extension of scientific knowledge (and the teaching of students). This difference determined how individual actors belonging to either of these contexts perceived plant breeding and the objects they dealt with.

Agronomists who tried for an academic discipline of plant breeding therefore faced a double problem. Since they understood themselves as mediators between the worlds of scientific theory and agricultural practice they had to serve different social groups, i.e. the commercial breeders and the university biologists or scientists. To receive support from the first group academic breeders had to offer knowledge that helped to cope with the problems commercial breeders were confronted with in their work. The ultimate objective was technical, i.e. to improve breeding methods and crop varieties to be sold on the seed market. If academic breeders had become too theoretical and neglected the needs of commercial breeders they would have lost legitimacy within the world of agriculture. In contrast, to get support from university biologists whose interest in applied research was generally low in Germany at the turn of the 20th century academic breeders had to demonstrate their ability to contribute to theoretical debates. The ultimate objective was scientific, i.e. the production and validation of theories. If the academic breeders had become too practical and ignored the values of university biologists they would have lost legitimacy within the world of academia. Academic breeders therefore had to bridge the gap between these two worlds but make sure at the same time not to blur the boundaries.[66] This is where the level of objects comes in.

Transferring crop varieties from the farm to academia was more than an act of relocation. In the context of the research institute cereals and other crops turned into objects of inquiry used for the extension of scientific knowledge. Of course, the varieties commercial breeders experimented with can be also considered in this way. This is particularly true for the varieties Rimpau used for his research on pollination, fertilization, and cross breeding. But it was academia where the transformation of crop varieties into scientific objects took place on a large scale. There, varieties became part of experimental systems to produce and validate scientific theories. They turned into epistemic objects which challenged established concepts, raised questions, and initiated new research processes. The reception of Johannsen's pure line theory is a case in point. Calling established breeding methods into question Johannsen's theory attracted the interest of academic breeders who researched the scope of the concept. First, academic breeders used data collected during varietal development. But later on they adapted the methodological approach of the new genetics and turned their varieties into objects which became part of carefully designed experiments. Situating their varieties as scientific objects in the theoretical discourse of the new genetics academic breeders could demonstrate the scientific nature of their discipline. Moreover, they could draw a boundary between academic and commercial breeding. And yet, these varieties also remained commercial objects. Academic plant breeders did not ignore that. Rather, they researched new breeding methods and developed new varieties according to the needs of farmers and the food and beverages

[66] See Harwood, 2005, for a general account of the German agronomists' dilemma of being situated between science and practice.

industries. They therefore not only produced scientific knowledge but also technological artifacts, i.e. improved crop varieties which were subsequently put on the seed market by commercial breeders. Oscillating between these two meanings, i.e. scientific vs. commercial object, cereals and other crop varieties served as a means for the academic breeder to mediate between the world of scientific theory and agricultural practice.[67] Moreover, they conferred legitimacy to the academic breeder who had to consider two different social groups in order to successfully establish his discipline as an applied university science.

Organizations, individuals and objects served as mediators between scientific theory and agricultural practice. But what does this relationship look like from an epistemological point of view? Linking theory and practice was not an easy task. Academic breeders had to bring the necessary reductionism of theory building (i.e. genetics) and the overwhelming complexity of empirical practice (i.e. plant breeding) in line. In other words, they were to balance a scientific frame of reference against a technological one, thus, experiencing a sort of cognitive ambiguity. Kraus was not able to solve this ambiguity when he tried to judge the relevance of Johannsen's pure line theory for commercial breeding. It was only through the reformulation of the question that the problem eventually was solved. And as we have seen this reformulation had to take into account that when scientific theories were applied to technology one has to judge these theories not only by criteria of truth but also by criteria of practicality and profitability. There is no hierarchy between theoretical and practical knowledge. But, arguably, this is not peculiar to plant breeding but a motive one can generally find in the history of the applied sciences.

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[67] Thus the cereals and crop varieties of academic breeders were what sociologists called "boundary objects," cf. Leigh Star and Griesemer, 1989.

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