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Concepts, Actors and Practices from the Past to the Present

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10. Managing knowledge in ‘systematised plant breeding’: Mendelism and British agricultural science, 1900–1930

Berris Charnley

INTRODUCTION

> Dr. C. D. Darlington, in opening the meeting, said that genetics owes a debt to plant and animal breeding both for its foundation and its development. If the purpose of agriculture in the future is to be the highest production, genetics will have the opportunity of repaying this debt. The object of the symposium was to discuss whether genetics has the capacity to do so.[1]

This was how *Nature* recorded the opening pleasantries of the Genetical Society’s 1944 symposium on the ‘Application of Genetics to Plant and Animal Breeding’. The theme is instantly recognisable even if the perspective is an unusual one. From the turn of the century, geneticists, or Mendelians as they were initially known, defined themselves in contrast to traditional plant and animal breeders. Furthermore, these early geneticists promised a revolution which would improve the lot of their breeder counterparts. This is why Darlington’s perspective is unusual; surely by 1944 at least some of the promises of the early geneticists should have paid off? The idea that in the early part of the century science led the way; that attention to science, and in particular genetics, led to an improvement in the way breeders went about their business, would have been familiar to *Nature’s* readers.[2] Yet by Darlington’s lights, and those of the assembled participants at the symposium, the question of how much genetics could give to the breeders was still an open one.

The relationship between Mendelian theory and plant breeding has, over the years, been characterised in a number of different ways. In his 2005 book, *Technology’s Dilemma,* Jonathan Harwood gives an intriguing alternative analysis of the development of agricultural education and research in

Germany from 1860 to 1934. Harwood's overarching concern is to explain the tendency of most institutes at which agricultural science (including plant breeding) developed to put a greater emphasis on the importance of basic science to the exclusion of practical knowledge (Harwood, 2005: 26). Harwood's model for explaining the development of this trend identifies three relevant contexts which influenced an institute's overall science or practice-orientation. These contexts are (1) academe, consisting of the 'constellation of other academic institutions making up the system of higher education'; (2) geography, literally the physical features of an institution's location; and (3) the politico-economic situation, formed by the state bodies and constituencies with which the institute interacted (Harwood, 2005: 69). Each institute's response to the exigencies of these contexts defined the emphasis it placed on either science or practice as foundational. Harwood argues that in Germany in this period status striving within academe was the most influential force on the development of research. As a result German institutes tended to drift towards the higher academic status inferred on science-orientated work. This motivation was largely unchecked by geographic and politico-economic pressures. At these science-oriented institutes there was a strong belief that science would revolutionise practice, indeed that science was the only way to improve practice.

Harwood suggests that a similar drift might have occurred, for the same reasons, in British agricultural research and education around Cambridge University's School of Agriculture, such that the orientation in the school was also predominately scientific:

> At Cambridge University's School of Agriculture R.H. Biffen was convinced that breeding practice could only be improved by applying and further developing the Mendelian theory. … he felt that utilitarian considerations need play no part in guiding research in agricultural science (Harwood, 2005: 26).

Undoubtedly, the importance of science to the new Mendelian research programme was frequently elevated by Biffen, and his colleagues Thomas Wood and William Bateson. I argue, however, that before 1930, practical knowledge and practical outcomes were important to Mendelians in ways which seemed obvious to Darlington and the other participants of the Genetical Society's symposium. Many Mendelians started out working in horticultural and agricultural science or came to these contexts during their careers (Olby, 2000a; 1989; 1991; Palladino, 1993; 1994). Mendelism was viewed by many such workers as a partly practical endeavour; doing Mendelism, at least some of the time, meant getting one's hands dirty and talking to the breeders. However, instead of simply reasserting the importance of practical knowledge to many British Mendelians, I argue further, that early Mendelian work often cut across the divide between science and practice projected by the very same workers. In managing their knowledge production and the use of that knowledge Mendelians were more instrumental than ideological about the usefulness of practical knowledge.

The chapter begins with a panoramic overview of the construction and expansion of a nationally important system of interconnected institutes and organisations established and run by Biffen, Wood and Bateson. The emergence of British Mendelism in the context of the Biometrician-Mendelian debates is now the focus of a large historical literature (Sturtevant, 1966; Dunn, 1965; Provine, 1971; Kevles, 1980; Olby, 1985; Bowler, 1989; Richmond, 2001; Carlson, 2003). Much less attention has been paid to the consolidation of Mendelism and the longer history of Mendelians educating, researching, publishing and producing (Buttolph, 2008). In Biffen, Bateson and Wood's work there are marked similarities to Thomas Edison's involvement in electrification, vividly described as system building activity by historian of technology Thomas Hughes (Hughes, 1983; 1987: 51–82; 2004).[3] Following up on this insight, and moving beyond Hughes's focus on the individual to a focus on the individual in their institutional setting, the second half of this chapter analyses the growth of Mendelism as system building activity, showing the systemic features that emerged as new institutes were founded and connected together. Two further amendments to a strictly *Hughesian* analysis are made in what follows. The first is to highlight the importance of intellectual property rights; Mendelian breeders were deeply concerned to maintain the reputation and good standing of their varieties in a complex economy of credit where their varieties' success or otherwise reflected back on their professional positions and the theory they deployed. Second comes the importance of consumers, as not merely passive recipients of Mendelian products, but as a source of practical knowledge upon which Mendelians relied will be explored. Finally, the chapter will focus in on specific instances of practice-orientation in this system showing that the relationships between science and practice embodied in early Mendelian work were much more fluid than those described by either Darlington or Harwood. Mendelians relied on practical knowledge more than they sometimes let on and furthermore were deeply concerned with managing the products of their work.

THE AGRICULTURAL CONTEXT OF EARLY GENETICS

When William Bateson brought Gregor Mendel's work to Britain he did so from a peripheral position at Cambridge University, without a chair or a departmental home (Richmond, 2001). Aware of his outsider status, Bateson came to make alliances with other marginalised groups at the University.[4] Initially working with the female students at Newnham College, he published, researched and also began giving classes on Mendelian theory. Two young lecturers from the University's newly established Agricultural Department, Thomas Wood and Rowland Biffen, were among Bateson's first students at these classes. When Biffen and Wood returned to the Agricultural Department's Burgoyne's Farm, they began working on showing that Mendelian inheritance applied not only to peas but also to characteristics in other organisms. On the department's farm Wood's work aimed at showing that the inheritance of face colouring in sheep conformed to a Mendelian pattern. Biffen likewise showed that the inheritance of various characters in wheat could be interpreted within a Mendelian framework. In the following years Bateson and Biffen became longstanding friends, the older man sending a copy of his 1902 *Mendel's Principles of Heredity, a Defence* (Bateson, 1902) to Biffen, whose work received an honorary mention in the book.[5]

Wood's and Biffen's work, published early, formed an important part of the evidential proof of Mendelism that Bateson sought to amass from 1901. Mendelian sheep and wheat made appearances at the 1904 Cambridge meeting of the British Association for the Advancement of Science and the Royal Horticultural Society's 1906 Third International Conference on Hybridisation and General Plant-Breeding.[6] Wood's and Biffen's experiments featured heavily in Bateson's 1909 *Principles of Mendelism,* the first half of which was a compendium of Mendelian experimental results, and Reginald Punnett's multi-edition, bestselling, *Mendelism* (Bateson, 1909; Punnett, 1905). On these occasions of public display, photographs of Wood's sheep and Biffen's wheat were ideal evidence with which to display the wider applicability of Mendelian theory. These were images from which Mendel's famous ratios could be easily read by a variety of audiences.

Biffen studied many different features of wheat plants. Some, like rachi length, or glume formation were economically unimportant; however, Biffen also worked on disease resistance, yield, time of ripening and strength. Believing that each of these economically important characters was inherited in a Mendelian fashion, Biffen set about breeding new types of wheat. Knowledge that the inheritance of these characters followed a definite pattern allowed Biffen, so he claimed, to rationalise his crosses:

> Breeding has entered upon a definite stage, … order can be traced in a subject which hitherto has appeared chaotic. The breeder has now to recognise that new breeds can be built up with certainty by recombining characters (Biffen, 1906: 63).

In 1902 Biffen began working in close collaboration with a group called the Home Grown Wheat Committee (HGWC). This was a small but long running effort partly funded by the National Association of British and Irish Millers and partly funded by the Board of Agriculture. The Committee's raison d'être was to support the small inland millers of Britain. Supporting inland millers was also, the Committee's secretary A. E. Humphries argued, the best way to rehabilitate the country's wheat growing industry. Wheat growing in Britain was far more intensive than anywhere else in the world, yields were far higher, but so were production costs. As a result, imported wheat grown for a fraction of the price in the New World dominated the British national market.[7]

The British wheat industry's problems did not end there. Imported wheat was not only cheaper to produce but it was also of a different type. The Number 1 Manitoban flour produced from Canadian wheat made a more voluminous fluffy loaf, and this apparently was what the public wanted. This quality of producing aerated white bread was called strength, flour and wheat were said to be strong or weak depending on the type of bread they produced. Millers at the big ports had ready access to cheap and strong imports. Inland millers on the other hand had to pay rail carriage to get strong wheat from the ports and do their best to bulk it out with weak wheat available locally. As a result many inland millers were going bankrupt and farmers were selling their weak wheat for lower prices still for chicken feed or biscuit making. Humphries argued that if strong wheat could be grown in Britain, farmers would get higher prices and inland millers would make better profits. This was the heart of the problem, strong wheat varieties from other countries could be grown in Britain but their yield was far lower than the average weak British variety. Biffen, believing that strength was inherited in a Mendelian fashion, began working closely with Humphries at the Department's farm and Humphries' mill on making a high yielding strong wheat variety which could be used to produce an 'All-English' loaf. The agricultural context of early Mendelian work was beneficial to the young discipline twice over: first in providing space on Burgoyne's Farm in which early results could be expanded and secondly in providing a problem which Mendelians came to position themselves against. Mendelism, they claimed, could save Britain's ailing wheat industry.

'A FORCE OF PROGRESS IN THE AGRICULTURAL WORLD'

In 1907 Wood, who was also working with the HGWC, took the Chair of Agriculture at Cambridge.[8] In the following year a new chair in agricultural botany was created for Biffen. Student numbers at the department doubled between 1899 and 1910 and several new members of staff were taken on. Continuing this expansion, the department became a School of Agriculture, opened officially by the Duke of Devonshire on 26 April 1910, in purpose-built premises adjoining the Botany School. A formal banquet was held in the evening to celebrate the school's opening and the new buildings were put on display during the day beforehand. The spacious new buildings (which cost £17,500 – raised by private donations) contained chemical, botanical and physiological laboratories, lecture rooms and private research areas (Board of Agriculture, 1912–1913: 7). At the opening Biffen's and Wood's work on wheat strength and Mendelian inheritance was on display in the new laboratories. At the evening ceremony, Biffen and Wood sat at the high table and Bateson and his wife Beatrice also attended as honoured guests.[9]

The School began looking for a new farm and the lease was acquired on one owned by Trinity College. At 250 acres, Gravel Hill Farm on Huntingdon Road was considerably larger than Burgoyne's Farm. This extra space allowed Biffen to begin multiplying up stocks of his first new variety of wheat, Little Joss, in preparation for distribution to farmers. Little Joss was a direct result of Biffen's initial work on modes of inheritance. The variety contained a new recombination of disease resistance and high yield; two characterisitics which had not previously been available in the same plant. The variety remained in cultivation until the 1930s and when Biffen was given the Darwin Medal by the Royal Society in 1920, Little Joss figured large in the Society's reasoning.[10] In 1911 Bateson announced to the Agricultural section M of the British Association for the Advancement of Science:

> Of the work which is making the Cambridge School of Agriculture a force for progress in the agricultural world the remarkable researches and results of my late colleague, Professor Biffen, based as they have been on modern discoveries in the pure sciences of breeding, occupy a high and greatly honoured place (Bateson, 1912: 587).

In the year before this speech to the agricultural section, Bateson had taken on a new role as director of the John Innes Horticultural Research Institute (JI) based at Merton in Surrey. This was arguably the place where, '[r]esearch in Mendelian heredity was first given permanent institutional support in the U.K.'.[11] In 1909 Biffen was asked to join a working committee to fill the post of director. After receiving some 30 applications Bateson was chosen for the role without formal interview. The committee were so keen to get Bateson for the job that they arranged a £1,000 salary and allowed him to realign the institute's mandate so that research rather than education would become the main focus of a programme that he 'dominated' (Olby, 1989: 507). Bateson transferred much of his research wholesale from Cambridge, and a steady flow of students moved between Merton and Cambridge. Biffen also sat on the board at the JI and regularly attended its meetings. Over the following years Bateson and Biffen worked together on several JI based projects including a journal, *Heredity*, and the Genetical Society.

Back at Cambridge and now securely entrenched in their positions, Wood and Biffen applied to a newly instigated government fund for money to create two new research institutes in the school. The Development Commission which they applied to, with the support of the Board of Agriculture, was created in 1910. It was established to regulate the expenditure of a £1 million fund intended to resuscitate rural areas of Britain, through harbour drainage, land reclamation, stimulating rural industry and agricultural research and education (Olby, 1991: 515). The apparent success of Little Joss was used as evidence for the need for a specialised Plant Breeding Institute (PBI). In 1912 the commission made a grant of £18,000 available to the School to establish two new institutes; Biffen was made director of the PBI, Wood director of an Animal Nutrition Institute. Biffen swiftly turned the PBI, based in the farm adjacent to the School's Gravel Hill Farm, into a centre of Mendelian varietal production. As Biffen put it in his report to the Board of Agriculture in 1915, 'A great deal of the work is now of a routine nature, and the results, consisting mainly of records of yields of new varieties, which may or may not be put on the market later, are of too little general interest to publish' (Board of Agriculture, 1915: 59).

In 1916 a new variety was ready to be put on the market. Yeoman represented the culmination of Biffen's work with the Home Grown Wheat Committee. It was a new recombination of strength and high yield. The creation of this new variety also brought with it a problem: how was Biffen to distribute the seeds to farmers? If he distributed on a small scale, as he had with Little Joss, then only some farmers would benefit. Conversely, if he released the variety to seed companies to multiply and sell on in bulk he might be accused of lining the industry's pockets with the fruits of publicly funded research (Wellington and Silvey, 1997: 6). To solve this problem, Biffen, working with the plant breeder E. S. Beaven and the seed dealer William Hasler, established the British Seed Corn Association (BSCA). Ten shares each were sent to Hasler, Biffen and Wood in 1914 to formally establish the Association.[12] The BSCA was intended to be the head of a network of licensed seed dealers and growers who became agents of the Association upon payment of a fee and a percentage of their sales. The Association was responsible for certifying seed from producers of new varieties as genuine novel improvements, and then distributing them to dealers and growers. When Yeoman was ready, Biffen gave Hasler 200 quarters of seed to distribute. Biffen was very much concerned with managing the release of his new varieties not least because their reputation was now so intimately associated with his own and that of Mendelian theory. However, in 1917, while Biffen was seconded to the Food Production Department at the Board of Agriculture, the BSCA disappeared.[13]

After the War, Biffen continued with his efforts to distribute seeds in collaboration with the head of the Food Production Department (the Controller of Supplies): Lawrence Weaver. With Biffen's help and advice Weaver established the National Institute of Agricultural Botany (NIAB) in 1919. Fifty percent of the money came from private donations and the other half from the Development Commission. The main purpose of the Institute was to distribute Biffen's new varieties, and furthermore support him through crop improvement research.[14] NIAB was located on Huntingdon Road in new buildings a stone's throw away from the School of Agriculture and the PBI's farms. Biffen was honorary Vice President of the Institute in its first year's business and although he dropped the position soon after, he remained involved in the Institute's working committees into the 1930s and served as its chief scientific advisor until his retirement in 1936. Wood served as one of Cambridge University's representatives to the Institute's council and one of Biffen's former students at the School of Agriculture and PBI, W. H. Parker, became the Institute's first director.

In 1925 NIAB released 2,500 quarters of seed of a new wheat variety produced by Biffen, Yeoman II. The variety was a commercial failure but the point at which it was released represents a high water mark for Mendelian systematisation of plant breeding in Britain. In the years immediately before the arrival of Yeoman II, Biffen, Wood and Bateson were at the height of their powers, presiding over a Mendelian system now firmly established in British agricultural research. However, in the year after the release of Yeoman II, 1926, Bateson died suddenly from heart failure; three years later Wood died equally suddenly. In the intervening years NIAB abandoned its plans for commercial distribution of seeds, largely because of the commercial failure of Yeoman II, and while Biffen remained busy until 1936, in 1931 funding was reorganised under the newly formed Agricultural Research Council. This new government department, modelled explicitly on the Medical Research Council, disrupted many of the structures put in place by Mendelians over the previous 25 years.

MENDELIANS AS SYSTEM BUILDERS

Biffen, Wood and Bateson were responsible for bringing together the resources for creating and then maintaining a system. Mendelian theory, the School of Agriculture, the JI, PBI, BSCA and NIAB were a collection of components which interacted towards these men's aims. Their preoccupation with production marks Mendelians out against a standard research school.[15] Mendelians were specifically interested in the creation and release of agricultural products. Accordingly, we might view Biffen and his colleague's efforts as of a kind with the system builders of his time such as Edison. Biffen's personal involvement with each of the institutions can be seen in Figure 10.1. Shared executive control was not the only form of interaction in this system, however; students and staff circulated freely between institutes. Varieties used for breeding experiments often travelled with workers or were passed to friends and colleagues. Several journals, including *Heredity,* the *Journal of Agricultural Science* and the *Journal of the National Institute of Agricultural Botany*, were established to give staff a platform from which to publish. Furthermore, resources seem to have been shared amongst the system as when Bateson wrote to Biffen in 1914 asking Biffen to grow a sample of seeds for him on spare land at the PBI's farm.[16]

CSA	HGWC	JI	PBI	BSCA	NIAB
Biffen	Biffen	Biffen	Biffen	Biffen	Biffen
Wood	Wood		Wood	Wood	Wood
		Bateson			
Humphries	Humphries			Humphries	Humphries
				Hasler	Hasler
Parker			Parker		Parker

Note: Figure shows the shared executive control at the Cambridge School of Agriculture, Home Grown Wheat Committee, John Innes Research Institute, Plant Breeding Institute, British Seed Corn Association and the National Institute of Agricultural Botany.

Figure 10.1 The Mendelian System

Despite the success of Biffen's Yeoman variety it was noticed to have one failing – a tendency to rogueing. When grown by the field a number of out of type individuals were noticed, often because they grew taller; these were called rogues. Biffen insisted such plants occurred because stocks of seeds became mixed during distribution and harvesting. Such admixture was disastrous for the intended use of Yeoman, if it became mixed with weak wheat, millers would not pay a higher price for its strength. Even worse, the appearance of rogues undermined Biffen's claims that Mendelism could reliably produce stable new varieties. Accordingly Biffen at the PBI, with the HGWC and NIAB set about releasing Yeoman II as a new purified and improved stock of Yeoman. Within the system, the rogues were a classic example of what Hughes calls a 'reverse salient', a problem (in this case with purity) that hindered the advance of the rest of the system.[17] Biffen's response to the problem posed by rogues is indeed indicative of a systematic response, even if it was largely unsuccessful; Yeoman II turned out to be just as prone to producing rogues. However, in the release of Yeoman II, Biffen, working closely with Wood, produced a coordinated response that drew on resources from across the system.

Having seen several instances of practice-orientation within the emergence and development of this system, we can now focus in on just a few that are particularly striking. Biffen was certainly sure of how he wanted the relationship between what he called the 'research' and the 'commercial side' of his work, to evolve. As he explained to Weaver, who had enquired about approaching a contact at the Board of Agriculture on Biffen's behalf:

> If you can persuade Mr 'Linkman' that it is the research side which matters most. I want to get the institute on a permanent basis and that requires an endowment fund rather than bricks or mortar. But if the commercial side appeals to him more, then, I should try to fall in with his views in the hope of making sufficient profits to get an endowment fund together in time.[18]

However, this excerpt also shows Biffen's willingness, in private at least, to undertake both types of work.

Moving from the outputs of Mendelian work to the inputs it drew from, if we consider Biffen's two most successful varieties, Little Joss was a spin off from basic research, where knowledge of heredity defined the product. Knowledge about the hereditary pattern disease resistance followed allowed Biffen to 'build' a disease resistant variety. However the disease in question, known colloquially as yellow rust, was not recognised by farmers of the period as a serious threat to their crops. Yeoman, on the other hand, was designed to fulfil a specific purpose. Biffen attempted to breed strong wheats long before it was un-contentiously believed that strength conformed to a Mendelian pattern of inheritance. In fact, Biffen caused something of a controversy when he made the claim again in 1910; there seems to have been no clear consensus on the issue even after the 1916 release of Yeoman.[19] One could hardly argue that knowledge of heredity led to the creation of the variety; instead it was knowledge of a particular agricultural problem, brought to him by Humphries and the HGWC, which directed Biffen's attention in this direction.

Biffen and Humphries saw themselves as champions of the marginalised inland millers. They collaborated together extensively and in 1907 jointly authored a resume of the HGWC's work on strength, in which they specifically recommended 'a many-sided investigation' (Biffen and Humphries, 1907: 1). Mendelian breeding was but one facet of an attack which drew equally on Humphries practical knowledge. Gathering together wheat varieties from around the world and selecting the best was just as important. Furthermore, in order to test a variety's strength Biffen had to bake bread from it, with some skill and consistency.[20] These were skills which he learnt from Humphries. On this point Biffen reported to an Australian peer, William Farrer:

> With regard to the milling side of the situation I am very fortunately situated.
>
> Humphries to whose words you refer has an experimental milling plant, a trained baker and a most extraordinary 'eye' for quality man ever had–all these I draw on fully.[21]

The connection between Biffen and the HGWC was an early one that endured over time; the HGWC offered a constituency to serve, baking and milling facilities, expertise and political support.[22]

While publicly Biffen lauded the new Mendelian breeding at the Institute as a matter of 'routine work', Biffen's eye for one particularly promising new plant from amongst thousands, and his ability to gauge strength by chewing a handful of corn and measuring the viscosity it caused in his saliva, were equally crucial in the new breeding programme. In Biffen's public persona as 'the Wheat Wizard' there is also more than a hint of craftsmanship.[23] Furthermore, after his first 1905 work on modes of inheritance Biffen made only one other contribution to basic genetic knowledge: a follow up on the permanency of the disease resistance character he had observed in his first paper. It would seem that despite his desire to promote the importance of basic science, in his work Biffen was first and foremost a system builder who relied on practical knowledge as well as Mendelian theory in order to breed and distribute new varieties.

CONCLUDING REFLECTIONS

In the British case, a systems approach makes obvious the resources that early geneticists drew from their agricultural context. Viewed from this angle, Darlington's claim that genetics owed a great debt to agriculture for its foundation makes a deal more sense. Contrary to Harwood's analysis, Mendelians drew on a stock of practical knowledge, not least from the HGWC. Biffen's identification of an appropriate problem was derived, along with a great deal of milling and baking know-how from his relationship with Humphries. However, the counter claim, to Darlington's assessment, that genetics repaid that debt through the creation of new agricultural organisms, is also substantiated by recovering Mendelians' systematic activities. Mendelians were very much concerned to manage their new varieties as they went out into the field, through new institutional structures such as the BSCA and NIAB. Moreover, they were well aware that a variety that did badly would reflect badly on themselves and the theory that they championed; hence the release of Yeoman II to counteract problems with Yeoman. Biffen and his Mendelian peers were involved in a many-sided investigation and paid great attention to utilitarian considerations; at least twice over, they allowed such considerations to direct their enquiries and furthermore, they responded to the problems that the agricultural context posed for the integration of their new varieties.

This chapter has argued that it was Mendelian system building activity which connected together such considerations. System talk undoubtedly has its challenges, limits and flaws. Not all early Mendelians saw themselves as involved in system building; casting them as such tends to exaggerate the coherence of change. Bearing these limitations in mind though, there is good reason to think that further analysis of the development of this system within the wider context of industrialisation, the context of Hughes's work on systems, will usefully illuminate new features of the industrialisation of agriculture in the last century.

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NOTES

1. 'Application of Genetics to Plant and Animal Breeding', *Nature,* **153** (1944), 780–3, at 780.
2. For later exemplars of this view see Bell, 1976; Lupton, 1987.
3. Palladino claims to have echoed Hughes' approach in his own work; however, the idea of a technological system is never explicitly at the front of Palladino's analysis (Palladino, 2002: 215).
4. Bateson was also deeply involved in the world of plant breeding and forged strong early links with the RHS; on this relationship see Olby, 2000b. For a view of the relationship from the RHS's perspective see Hurst, 1949.
5. Biffen to Bateson, 4 June 1902 (John Innes Centre archives, Bateson Letters Collection).
6. *Report of the 3rd International Conference on Genetics, Hybridisation and General Plant-Breeding,* Wilks, W. (ed.) (London: Royal Horticultural Society, 1907).
7. See Biffen's evidence to the Selborne post war reconstruction committee for a brief history of the international wheat industry (Board of Agriculture and Fisheries, 1918).
8. For biographical details on Wood see his FRS obituary notice, F. G. H. (1931), 'Obituary Notice: Thomas Barlow Wood 1869–1929', *Proceedings of the Royal Society of London. Series B,* 108: i–iii.
9. Cambridge University Archives, *University Registry Guard Books: Agricultural Education* (Cambridge: Cambridge University, 1909–1922) CUR 108.2 sect. 13.
10. 'Awards of the Royal Society', *Science,* n.s. **52** (1920), p. 633 see also 'Anniversary meeting of the Royal Society', *Nature,* **106** (1920), 452–3; 453.
11. Olby also records the sequence of events surrounding Bateson's Directorship (Olby, 1989: 497).
12. For a rough outline of what the association was intended to look like see, *Terms of Appointment of Agents of The British Seed Corn Association* (Museum of English Rural Life, Reading) TR GUI, and for the initial transfer of shares, Roper to Beaven 15 January 1915 (Museum of English Rural Life, Reading) TR GUI ADD/2 129. See also Palladino, 2002: 41.
13. Hasler to Beaven, 23 August 1916 (Museum of English Rural Life, Reading) TR GUI ADD/2 132.
14. Laurence Weaver, Memorandum on the Establishment of a National Institute of Agricultural Botany 3rd edn., November 1918 (Archives of the National Institute of Agricultural Botany).
15. On the things a research school needs to flourish see Morrell, 1972. Morrell revisits his analysis of research schools in his article on W. H. Perkins Jr. (Morrell, 1993). Although Perkin developed links with commerce, he never retained control of the means of production as Biffen did at Cambridge.
16. Biffen to Bateson, 4 March 1914 (JIC Archive, Bateson Letters Collection).

17. 'Reverse salient' was originally a military metaphor, used to describe the areas in an advancing front which lag behind the advance (Hughes, 1987: 51).
18. Biffen to Weaver, 3 December 1917 (Archives of the National Institute of Agricultural Botany, 1917–1921 funding folder).
19. See Biffen (1910), at 86–101 and correspondence between Biffen and Charles Saunders in the same volume pp. 218–24.
20. The same applies to disease resistance; you actually have to grow the wheat to tell if it is immune. In both cases Biffen had to develop considerable practical skills or consult farmers and bakers.
21. Biffen to Farrer, 9 January 1905. Reprinted in Sutherland, 2001: 176.
22. See Humphries' evidence at what became known as the Linlithgow inquiry (Ministry of Agriculture and Fisheries, 1923: 75–86).
23. See the press cuttings collections at the John Innes Centre archive (PBI collection) and Archive of the National Institute of Agricultural Botany (Press cuttings collection).

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