Historiographies of Plant Breeding and Agriculture

Dominic J. Berry
London School of Economics

There are unique opportunities that plant breeding and agriculture offer the historian of biology, and unique ways in which the historian of biology can inform the history of plant breeding and agriculture (Harwood, 2006. Phillips and Kingsland, 2015). There are also of course questions and challenges that the study of agricultural sites share with the study of other biological sites, such as those in medicine (Wilmot 2007. Woods et al. 2018), the environment (Agar and Ward 2018), and non-agricultural industries (Bud 1993). Indeed, in some instances the agricultural, medical, environmental, and biologically industrial will be one and the same. This is to say nothing of what agricultural sites share in common with histories of science beyond biology, but that is a broader discussion I can only mention in passing (Parolini 2015). This chapter will first address what agriculture has in common with themes that cut across this handbook, before turning in Part 2 to issues, problems, and questions that stem from agriculture's particular features, ending in Part 3 with paths for future work. The chapter therefore treats the intersection of biology and agriculture as demanding its own integrated attention, the two parts making up a larger historiographical whole. There are a number of reasons to give agricultural sciences and technologies this kind of autonomy from the historiography of biology at large. First, it reminds us to question the nature, direction, and extent of influence that biological science and agriculture have had on one another. Second, it promotes a more symmetric understanding of the knowledges that have mattered for biological science and agriculture. This is particularly important because so much of the history of biological science in agriculture has been about establishing the authority of scientific expertise over agriculture, often in competition with other kinds of expertise distributed throughout farming. If we did not approach agricultural contexts symmetrically we might end up recapitulating the very arguments we are meant to be analysing. Third, it establishes a healthier and more distant vantage point for the historian, keeping the existing historiography of biology at arms length, allowing us to better observe its deficiencies and assumptions.

Aside from giving autonomy to the agricultural in histories of biology, there is another broad historiographical point to make. Historians of biology and agriculture have to strike a balance between which historiographical lineage they dedicate their work to, or indeed, whether they see themselves contributing to both histories of biology and agriculture simultaneously. In some respects this issue is itself unique to agriculture, for if we look at the other topics in this handbook only one or two other chapters are asked to compete with completely different sets of scholarly lineages in their telling, these including Tracy Teslo on Race and Ethnicity, Marsha Richmond on Women, and Ana Barahona on the transnational. Yes, other kinds of historian and scholar may make important interventions on the history of eugenics, Darwinism, and biotechnology, but when it comes to these topics nobody is in a position to outbid the historian of biology. Agriculture is different, both in content, thanks to the variety of experts that it enrols across a very wide range of potential specialist areas, and also in terms of the historiographical landscape in which it sits, because agriculture has indeed belonged to whole other kinds of historian, be they social historians, economic historians, or historians of agriculture and the environment.

Ultimately all my talk of ownership and bidding is petty, and of course even in those topics that seem primarily the concern of the historian of biology other historical traditions and branches of scholarship are constantly being drawn in. What I mean to convey is that: historians of biology have been late to agriculture; their insights have not always been understood as relevant or complementary to the history of agriculture; historians of agriculture seem to be getting on all too well without the historian of biology; and that if the recent growth in interest amongst historians of science into the agricultural is to be maintained and consolidated then interdisciplinary awareness is essential. Here historians of biology offer a suite of valuable opportunities for historians of agriculture, be it through all the techno-imagining that goes into broader agricultural debate, or the chance to rethink social and economic relations on the farm, the meanings embodied in agricultural spaces, organisms, and communal practices, or as Jonathan Harwood has so brilliantly shown, through the issue of global food security (Harwood 2012). But agriculture also demands a sensitivity and humility from the historian of biology, to know when multiple epistemologies are in play, multiple historiographies, and therefore how to translate any new historical understanding into a form that matters for defined audiences. These audiences should include not only historians of science but also those working on and in agricultural industries.

Part 1: Plant breeding and agriculture in the historiography of biology

Agricultural history matters for an array of themes that cut across the history of biology. I will confine myself only to a select number of the topics covered by this handbook, but one could also write sections on agriculture and the mathematization of biology, agriculture and nutrition/food science, agriculture and ecology/environmental sciences. Indeed the latter is something I will return to in Part 3, as an issue that is becoming increasingly central to historians of biology, one in which agriculture can and should play a large role.

Darwin and the breeders

It is well known that plant and animal breeders were hugely important for the development of Darwin's research (Secord 1985). Breeders were not only a key community in his expansive network of correspondents, but plant and animal breeding also provided evidence, theories, and resources. It is worth beginning here because if we can appreciate the extent of the community of breeders, alongwith the expansion and sharing of their knowledge and industry throughout the late eighteenth and early nineteenth century (Derry 2003. Matz 2011. Russell 1986. Wood and Orel 2001), then we are more adequately prepared for our later discussions of Mendelism and genetics, not because these histories connect linnearly, but because we need to understand the depth and breadth of hereditarian thought long before anything like Mendelian genetics entered the scene. Developing a good understanding of the relationship between agriculture and Darwinism is also an excellent way to acclimatise the historian of biology to the value added by taking agriculture seriously. For instance, if we failed to do so, then we might be left assuming that Darwin turned to breeding communities after the Beagle voyage because their selection practices made for a teachable analogy with selection events in nature. But this is not how his research actually unfolded (Hodge and Kohn 1985), and as Bert Theunissen has argued, the assumption that Darwin's interests in domestic breeding mattered first and foremost for the making of such an analogy has masked both the variety of questions that breeding could actually illuminate and also Darwin's selectivity towards the features of breeding practice he was prepared to recognise

(Theunissen 2012). Our understanding of Darwin and his theorising has been materially altered by giving priority to the context in which he worked, and the importance of agriculture within it.

The most significant feature of domestic breeding for Darwin was the evidence it supplied of the necessary preconditions for variation (Hodge and Radick 2003, 4-5).[1] The changes in plants and animals achieved by breeders took place in environments outside of nature: in gardens, coops, stables, glasshouses, and on farms. It was the environmental setting of domestication, so Darwin came to argue, which increased an organism's capacity to transmute. This increased variability would then become available to the breeder for management and manipulation (Winther 2000). From this vantage point we immediately begin to see how very different were Darwin's views on heredity in comparison to evolutionary theorising today, and that agricultural contexts were not just an analogical thought experiment, but rather contained important information about biological development, physiology, and their interconnections with generation. The close relations between organism and environment (Baranski and Peirson 2015. Ritvo 1987. Woods 2017.) have had multiple significances for biology and society, business, and politics, and also for those maintaining an empire, areas that will be returned to in Part 2.

A more general lesson that emerges from work on the history of breeding and Darwinism, one that is important to appreciate about breeding and breeders in any historical period, is that it is a pursuit steeped in epistemic anxiety (Lidwell-Durnin 2018). A breeder might be looking at the wrong parts of plants and animals, in the wrong ways, with the wrong apparatus, in the wrong kind of space, for the wrong length of time, with the wrong periodicity, and so on. But the history of breeding is not one of people fretting. Instead we find different kinds of actor (professional and amateur breeders, farmers, scientists) working in a wide range of social contexts (domestic private and public gardens, greenhouses, farms, universities), all developing prescriptions, theories, and techniques to govern their practices. Many were also sufficiently convinced of the value of their findings and understanding that they shared them through meetings, correspondence, and publications. Anxieties, as I couched them, have typically only been drawn upon during public deliberations and disputes about what *actually* works and why. These are the kinds of argument that become acute when a new idea or technique seems to undermine widely held understandings and practices, devaluing all those earlier schemes as 'misguided', with implications for the socio-epistemic status of their initial promoters: if the new understanding is accepted, then erstwhile wizards can be turned into fools or charlatans. All of this remains true in the present, and should be borne in mind throughout the rest of the chapter.

Mendel and genetics

The single most important topic prompting historians of biology to take an agricultural turn has been the origins, reception, and development of Mendelism and genetics. The number of comprehensive studies of agriculture and science that have been motivated by interest in Mendelism and genetics is formidable, at least in comparison to any other topic at the intersection of biology and agriculture. That genetics retains such a privileged position is perhaps by now problematic (Müller-Wille and Rheinberger 2012. Wilmot 2007), but it is nevertheless the case that early work on these questions by historians of biology in the

[1] Gregory Radick was the first person to suggest that I read Darwin on these terms, and I remain grateful for his sharing this insight.

1980s and 1990s has gone on to provide a foundation that today supports more general enquiry into the relations between agriculture and biological science.

As with Darwin, many historians now draw direct links between the context of Gregor Mendel's research and industries horticultural, agricultural, and pastoral (Gliboff 2015. Müller-Wille and Orel 2007. Wood and Orel 2005). These histories have considerably revised earlier interpretations that had painted Mendel as a proto-geneticist, one focussed solely on discerning laws of nature through clever experimental design. Instead "it is much more likely that the direction of Mendel's hybridization research was guided by the strong agricultural interests around him" (Allen 2003). As we shall see shortly, practical breeding and the commercial production of agricultural seeds would also go on to be essential for the firm establishment of genetics, a science which many of its founders famously traced back to Mendel, on grounds that are equally famously problematic (Olby 1979. Sapp 1990.) If Mendel was responding to a wide ranging set of persons who at the end of the nineteenth century were developing means and methods for understanding several different aspects of heredity, then we had surely better expand our search, to emphasise the variety of questions pursued at the intersection of biology and agriculture over time, regardless of later gene-centred developments. Staffan Müller-Wille and Christina Brandt have made this argument in an introduction to their recent edited collection on heredity, in which agriculture features heavily (Müller-Wille and Brandt 2016. See also Chapter 5 this volume). Once again, recognising and attending to agriculture directly, rather than for the sake of appreciating Mendelism or some other candidate breakthrough, has substantially revised our histories of biology.

When it comes to genetics and agriculture the literature is vast. Geographically the discussion has primarily focussed on the United States, a few European countries including France, Germany, the Netherlands, Italy, and the United Kingdom, and more recently China and Japan. Because all of this material can contribute to global histories of plant breeding and agriculture, I have compiled all the works that I know of into Table 1, organised according to primary geographical focus and a broad periodisation.[2] Though some of these histories address multiple countries I have not repeated entries, so the table should only be used as a rough guide. Historical accounts clearly aspiring to an international perspective are collected under 'International'. It is inevitable that my criteria for selection are imperfect. Perhaps the most important lesson we might take from this exercise and the growth of the historiography of agricultural genetics, is that these works can and should now be used to explore biology in a more diffuse way, recognising genetics as only one specialism, practiced around the world in ways that were not homogenous, a specialism which is by now perhaps most interesting as continuous or discontinuous with practices and knowledge that do not begin and end with genetics. In truth this is precisely how some of the histories in this table have already treated genetics, as an entry point.

Table 1: Historical research at the intersection of agriculture and genetics, organized according to primary geographical focus and approximate period

[2] My considerable thanks to Berris Charnley, who helped make sure I missed as little as possible, and Jonathan Harwood, who many years ago shared with me his lists of historians working across agriculture and genetics. Also thanks to the History of Science Society's IsisCB database which helps keep us all uptodate.

China	Early C20th	Lavelle 2016.
	Late C20th	Jiang 2017. Schmalzer 2016.
Denmark	Early C20th	Müller-Wille 2007. Müller-Wille 2008.
France	Early C20th	Bonneuil 2006. Bonneuil 2008. Bonneuil and Thomas 2010. Gayon and Zallen 1998.
Germany	Early C20th	Gliboff 2016. Harwood 1997. Harwood 2000. Wieland 2006.
	Mid C20th	Elina, Heim and Roll-Hansen 2005. Gausemeier 2010. Harwood 2010. Heim 2003. Saraiva and Norton Wise 2010.
International	Early C20th	Berry 2014c. Bonneuil 2016. Campos and von Scherwin 2016. Harwood 2004. Harwood 2016. Onaga 2010. Saraiva 2016.
	Early-late C20th	Harwood 2012.
Italy	Early C20th	Iori 2013.
	Mid C20th	Saraiva 2010.
India	Mid C20th	Saha 2013.
	Late C20th	Baranski 2015a. Baranski 2015b.
Japan	Early C20th	Fujihara 2018. Onaga 2016. Iida 2016.
Mexico	Early C20th	Barahona, Pinar, and Ayala 2005. Barahona and Robles 2001.
	Mid C20th	Harwood 2009. Matchett 2006.
Netherlands	Early C20th	Theunissen 2008.
	Early-late C20th	Maat 2001.
South Korea	Late C20th	Tae-ho 2018.
Spain	Mid C20th	Camprubí 2010.
Sweden	Early C20th	Ackerman and Fröier 1948. Åkerberg 1986. Müller-Wille 2005. Roll-Hansen 1997. Roll-Hansen 2000.
United Kingdom	Early C20th	Berry 2014a. Berry 2014b. Berry 2018. Brassley 2007. Button 2017. Charnley 2011. Charnley 2013a. Charnley 2013b. Charnley 2013c. Charnley 2016. Holmes 2017a. Holmes 2017b. Holmes

		2018a. Marie 2004. Olby 1989. Olby 2000. Opitz 2011. Palladino 1993. Palladino 1994. Palladino 2002. Radick 2013.
	Mid C20th	Palladino 1990. Parolini 2012. Peirson 2015. Wilmot 2007. Holmes 2018b.
	Late C20th	García-Sancho 2015. Myelnikov 2017.
United States	Early C20th	Allen 2000. Carlson 2005. Campos 2015. Cook 1997. Curry 2016b. Kevles 1980. Kimmelman 1983. Kimmelman 1987. Kimmelman 1992. Kimmelman 1997. Kimmelman 2006. Tyrell 2015.
	Early-mid C20th	Derry 2012. Derry 2016. Fitzgerald 1990. Fitzgerald 1993.
	Early-late C20th	Curry 2016a. Henke 2008. Kloppenburg 1988.

Within this literature I can highlight two key areas. The first is the creation of genetic expertise and its institutionalisation, which was a fundamentally agricultural enterprise. The model study which broke this ground was Barbara Kimmelman's investigation of American genetics (Kimmelman 1987), work which is equally significant for tying together agriculture, genetics, and eugenics, to be discussed in the next section. Kimmelman's foundations have been subsequently built upon by an array of historians working on numerous geographical contexts (Berry 2014b. Bonneuil 2006. Charnley 2011. Fitzgerald 1990. Harwood 2012. Iida 2016. Iori 2013. Maat 2001. Olby 1991. Olby 2000. Onaga 2016. Palladino 2002. Saraiva 2016). The availability of all of this material surely now demands a stronger international comparative approach. Harwood has also supplied an important summary and final assessment on the evidence for Mendelian genetics' impact on breeding, which goes deeper than many earlier studies into the technical differences between breeding approaches and where Mendelian expertise could or could not have intervened. In the final analysis, so he argues, Mendelian genetics simply could not have had too considerable an impact on the practice of agricultural plant breeding, at least not until late into the twentieth century, by which point the extent to which genetics was 'Mendelian' is itself debatable (Harwood 2016).

The second key area that I have room to address here is agriculture's significance for the history of intellectual property (IP) in biology, both before and subsequent to the emergence of genetics. Inspired by Daniel Kevles' pioneering work (Bugos and Kevles 1993. Kevles 2007), which he was also asked to make suitable for international policy makers (Kevles 2002), and building on other essential interventions from legal scholars attending to biology and IP law (Dutfield 2003. Pottage 2006), historians have demonstrated the fundamental importance that agricultural plants and animals have had for the origins and development of intellectual property rights in biological things and organisms (Berry 2014a. Charnley 2013a. Charnley and Lawson 2017. Charnley and Radick 2013. Fullilove 2017. MacLeod and Radick 2013. Parasarathy 2017. Radick 2013) The precise role played by genetics, geneticists, and legislators in the development of IP, and the role of IP in the development of genetics, remains an interesting topic of debate, and offers historians of

biology an excellent case study for exploring how scientific ideas are made in tandem with social and legal conventions.

Eugenics and biotechnology

Barbara Kimmelman was one of the first historians of biology to demonstrate the close connections between agriculture, genetics, and eugenics (Kimmelman 1983). Looking in particular at the membership of professional breeder associations and elite leaders of both genetics and eugenics at their origins, Kimmelman found considerable overlap between these groups, along with common cause. Historians of biology have since deepened the connections between eugenics and agricultural biologies, finding them in conservation movements (Allen 2013. Uekötter 2006), concern regarding national degeneration in food supply and people (Berry 2015a. Lovett 2007. Roll-Hansen 1989), and popular sports such as thoroughbred racing (Thurtle 2002. Tyrell 2015). Recent studies have demonstrated the importance of taking agricultural sites as seriously as those in human genetics if we are to understand how people and other organisms as materials of the state are remade for modernist agricultures and sciences (Bonneuil and Thomas 2010. Flitner 2003. Saraiva 2016). For the historian of biology working on agriculture, eugenics is an ever-present theme, in part because the analogies, metaphors, and evidence for eugenics have always been bound up with agriculture, but also because when dealing with the improvement of agricultural animals and plants the territory is potentially eugenic from the get go. Rather than worrying about what is or is not eugenic per se, what we should take away from the historiography of eugenics is that reproduction, animal and plant stewardship, breeding programmes, and so on, these are all inherently and inescapably political (Palladino 1987). The question then becomes: what arrangement do we want, and to benefit whom? Eugenics is also then, and much more straightforwardly, about economics.

It should be well understood by now that biotechnology refers to a particular historical formation of biological science and technology emergent after the second world war (Bud 1993). This has not stopped others from using the term to describe much earlier periods, and indeed conjure up a long history of biotechnology from the ancient past to the present (Berry 2018). If there are indeed significant features of production, relations between humans and other organisms, breeding, and so on, that can be traced over thousands of years, then they need to be specified and thoroughly demonstrated. Otherwise the historical imagination is simply serving wish fulfillment. Within the historiography of biology Sarah Franklin's study of sheep breeding and cloning, with particular attention to the case of Dolly, has reinvigorated discussion of the links between science and the state, between research and policy (Franklin 2007). Where García-Sancho has emphasised the significance of the history of research at Edinburgh that eventually led to the birth of Dolly (García-Sancho 2015), Myelnikov has stressed the need to go beyond shallow politico-economic readings of the Thatcher government's science policy and its impact on agricultural biotechnology (Myelnikov 2017). There are then multiple cultures of biotechnology, many having relations with or stemming from agricultural breeding, all of which are in need of appreciation, just as appreciate multiple cultures of agricultural and biological science more broadly. To navigate them we will need, as Jean-Paul Gaudillière has argued, to become sensitive to new angles of analysis, one of his proposals being attention to historical 'ways of regulating' that distinguish between professional, administrative, industrial, and consumerist/activist modes of regulation (Gaudillière 2009). Further historical works that matter for agricultural

biotechnology, but which addresses politics and economics from a more macro level, are considered in Part 2.

Part 2: Plant breeding and agriculture for the history of biology

In addition to the above themes, there are important questions that can be imported or piped into the history of biology most efficiently through attention to plant breeding and agriculture. Some of the areas covered in Part 1 will reappear here, though in a different light. It is the opportunity to juxtapose or switch between seeing organisms, institutions, and actors as biological, technological, environmental, agricultural, and scientific, that produces much of the added value gained by looking at the history of biology and agriculture together.

Bio-agricultural economics and politics

The work of any biological scientist dedicated to agricultural questions takes place within a particular political and industrial setting. That setting provides its own incentives and is composed of multiple kinds of power relations. In order for the historian of biology to appreciate these aspects of their case, they need to be aware of some of the principle ways in which agricultural science and technology have been understood as influencing farming. For these purposes, one of the most significant research programmes developed in the historiography of agriculture and biological science, is that of Jack Kloppenburg in his now iconic *First the Seed* (Kloppenburg 1988). Analysing the ways in which science and technology more generally intervene in agricultural contexts, his argument centres around the means by which seeds have undergone a process of commodification, and the role of scientists within this process. Written around the same time, commodification was also a central feature of Deborah Fitzgerald's history of plant breeding and the origins of hybrid corn (Fitzgerald 1990). These kinds of study, and others that have followed since, demonstrate the ways in which commercial opportunities have influenced the direction of scientific research, and the longstanding shared interests of academic breeders with agri-business. While this kind of argument is now commonplace in broader histories of biological science in the twentieth century, as for instance in biomedicine, the particularities of agriculture make their investigation all the more urgent. Unlike the majority of the products emerging from medicine, the products of agricultural science are not intended to have their use and circulation confined to a network of highly scrutinised institutions (hospitals etc.) and professionals. Instead the products of agricultural science are intended for use within a broad, heterogenous, loosely aligned set of communities, a set of communities that are already functioning and circulating extant products. I am suggesting that in terms of competition between different kinds of valuation, and the differential power relations between the producers and consumers of science, then the commodities of agricultural science have a more far-reaching impact than in those other places where biological science becomes biological business. Or at the very least, agriculture provides a more idealised setting for the historian of biologies' investigation.

In addition to commercial interest, other historians have focussed on the ways in which agricultural scientists have become materially enrolled in the pursuit of nationalist agendas. This is clear in both histories of agricultural science under fascism (Bonneuil 2010. Camprubí 2010. Gausemeier 2010. Harwood 2010. Saraiva and Norton Wise 2010. Saraiva 2016) and in democracies with long traditions of nationalism, paternalism or technocracy (Charnley 2016. Olby 1991. Curry 2016c. Harwood 2012). An additional layer of significance

for understanding biological diversity as a resource (Bonneuil in press) is added by imperial contexts, be it for scientists whose work constitutes part of the imperial project, or for the administrators of colonial states, or indigenous scientists and farmers (Baranski 2015b. Bonneuil 1999. Charnley 2013b. Kumar 2012. Maat 2001. Woods 2017). The role played by agricultural scientists within more general governmental strategies for control of food supply and aid, particularly throughout the Cold War, have also come to receive much needed attention (Perkins 1997). The period commonly referred to as the 'Green Revolution' has come to receive substantial historiographical revision (Kumar et al. 2017). For instance the impact and legacy of key figures such as Norman Borlaug, who is otherwise championed as single-handedly bringing an end to cycles of starvation, has been hugely over-exaggerated. Not only did the dwarf varieties for which he became famous owe "their existence to the skill of Japanese farmers a century earlier" (Harwood 2018) but his real impact occurred at the level of influencing Indian political and agricultural officials (Baranski 2015b).

Our discussion of the institutionalisation of biological science within different kinds of political context, the creation and circulation of new commodities within and across empires, has quite naturally brought us to the question of knowledge. The historian of biology attending to plant breeding and agriculture cannot afford to concentrate solely on knowledge produced and promoted by people who identified as agricultural scientists. Here again then agriculture holds a wider lesson for the history of biology more generally.

Bio-agricultural knowing

Speaking historiographically, if there is one overriding feature of the biology of agricultural plants and animals that historians have found either promoted, or demanded, a particular kind of epistemological posture distinctive to plant breeding and agriculture, it is their tendency to vary. Variability between generations and during development appears time and time again as a fundamental fascination or epistemological problem. We saw this earlier with Darwin, but here I will first turn to genetics, before broadening our horizons. Paolo Palladino's revisionist analysis of the knowledge claims made by geneticists in the context of commercial plant breeding have remained central to historiographical debate and discussion. He not only demonstrated that geneticists did not influence the schemes of breeders as immediately or straightforwardly as some historians of agriculture and agricultural science had made out, but that they were more than comfortable asserting the value of their own knowledge of plant variability and the influences upon it (Palladino 1993. Palladino 1994. Palladino 2002). In addition, Kimmelman was early to argue that working with agricultural materials, and closely alongside commercial plant breeders and farmers, contributed to making agricultural genetics a distinctive community and strand of thought within genetics more broadly, one that took whole-organism variability more seriously than other kinds of genetics, a position that some agricultural geneticists themselves argued explicitly (Kimmelman 1992. Kimmelman 1997). To give two final genetic examples, it was plant variability in the field that according to Pauline Mazumdar eventually shook R.A. Fisher's otherwise strong commitment to the insignificance of environmental influence on inheritance (Mazumdar 1992, 124). Likewise, Gregory Radick has shown how demonstrations of authority over the extent of variability provided excellent opportunities for geneticists such as William Bateson to publicly consolidate their new science and its productivity (Radick 2013). Numerous other examples could be listed.

Moving beyond genetics, we have also learnt how important geographical biological variation has been for inspiring systematic analysis and mapping of economically significant plants and animals. Such was the aim of German *Oekonomie* as has been explored by Denise Phillips in the eighteenth and early nineteenth century (Phillips 2015), and in nineteenth century botanical distribution mapping (Güttler 2015). Indeed virtually all of the chapters in the collection from which these two examples are taken are to some extent dealing with biological variability. In addition, most if not all of these chapters also demonstrate how knowledge of variability was widely shared amongst scientists, farmers, local processors, and other actors, who could be called upon to provide specific knowledge regarding faraway corners, supply local labour for agricultural experiments, or corroborate analytical findings through their own testimony. The fact of variability, and the fact of diverse lay and elite knowledges regarding biological variability, are perhaps linked, because candidate explanations for variability are always necessarily limited and typically non-exclusive. Chauvinistic and scientistic understandings of variability may emerge from time to time, particularly when a new professional class or a new scientific discipline seeks to establish itself. But historians have nevertheless continuously found that personal knowledge and appreciation of organisms in local environments has always rushed back in, to the extent they ever really left. We should not have to render such knowledge natural, or bucolic, or innocent, or unscientific (especially given how centrally important it has been for the development of all agricultural biological science) in order to appreciate it. As it would therefore be inaccurate, not to mention patronising, to distinguish between scientific and non-scientific epistemologies, how else might we analyse these kinds of knowing?

Sometimes the categories of local knowledge or craft knowledge have been suggested, but neither of these adequately capture the body of knowledge communicated amongst practitioners and passed between generations. Helen Tilly has supplied one valuable alternative through attention to the history of colonial science in Africa. There she introduces the concept of ‘vernacular science’, which is meant to characterise local indigenous knowledge while avoiding historiographical treatments of such knowledge as to some degree romantic (Tilley 2011, 122). The long history of vernacular knowledge and its direct contributions to imperial and postcolonial science and industry attests to ways in which indigenous knowledge is sought and erased simultaneously (Bil 2018. Schiebinger 2004). It may be that one way in which such erasure would become less likely, is if the concept of vernacular knowledge was applied equally to the farming and breeding communities to be found inside imperial powers, rather than only to those within colonised states. Doing so meshes nicely with Harwood’s analytical distinction between different plant breeding strategies as more or less ‘cosmopolitan’ or ‘local’, a distinction which is intended to be equally applicable to programmes in any national context. A cosmopolitan approach aims at producing a novel plant which can be marketed as suitable for growing in any environment. Meanwhile a local breeding strategy aims at refining a varieties’ suitability for a particular location (Harwood 2012, 45). We can therefore add that a local strategy would also be more amenable to vernacular knowledge than a cosmopolitan one. Building up our historiographical picture in this way provides a richer landscape in which to situate histories of biological science, directing our attention to features that we might otherwise fail to see. It also provides clear ways in which the work of agricultural scientists in the field is dependent on, and constitutive of, broader social relations.

Bio-agricultural field science

Historical attention to agricultural science has the capacity to radically alter our conceptions of how biological research is conducted, by what experimental means, and with what relations between practice and understanding. One clear reason for this is that so much of agricultural science takes place in spaces designed differently from laboratories, which have otherwise been taken as the quintessential arenas of modern science. While this feature is not unique to agriculture, it is nevertheless the case that greater attention to agricultural experimentation has only just begun, and is therefore due to receive much more systematic attention (Parolini 2015). Working with examples largely outside of the territory of agriculture, Robert Kohler has done the most to bring the field sciences to historians of biology (Kohler 2002). Precisely how the historian can and should understand the field sciences in themselves and in relation to other kinds of scientific space remains an interesting open question which historians of biology can more actively explore (Ekerholm et al eds. 2017. Vetter 2016). For instance, it is clear that historical actors have at times used and abused idealised notions of 'field' versus 'laboratory'. These kinds of idealisation have typically revolved around putative differences between how a setting enables different kinds of interaction with nature. It is supposed, for instance, that a laboratory setting tries to make itself 'nowhere' so that an experiment taking place in Helsinki could just as easily be taking place in Jamaica, while a field ideal aspires to make the most out of the specificities of place. It is also clear that holding up field and laboratory ideals and putting them in tension with one another has been a productive strategy for biological scientists looking to design new kinds of space, such as Frits Went's mid twentieth-century phytotron (Kingsland 2009), an expensive kind of resource that often received direct financial support from agricultural industrialists and food processors (Munns 2017). But there are also good reasons to want to avoid making a typological distinction between lab sites and field sites, instead attending to how shared epistemic motivations can be enacted just as heterogeneously within laboratories and fields as between them (Berry 2015b). And though the questions of the importance of place specificity are more easy to appreciate in the field (Shavit and Griesemer 2009), they also feature in their own ways in biological laboratories (Shavit and Ellison 2017).

Agriculture has a further benefit when it comes to historical attention to biology in the field, in that there is already a well established and ongoing historiographical exploration of how direct engagement with a field site mattered for the epistemic and social authority of scientists, administrators, and farmers. To give two recent examples, Abigail Woods has defined aspects of this kind of interaction with the field as 'learning by doing' in work on nineteenth century veterinary research and administration (Woods 2013), and the historical literature on 'book farming' and its tensions with the field has continued to expand (Fisher 2018). Lijing Jiang has also stressed the ways in which direct engagement between biologists and widely dispersed communities throughout China, modelled on social arrangements already developed by agricultural scientists, enabled not only collecting expeditions but also the opportunity to directly associate a biologist with *China* as embodied in its particular landscapes and natural history. "Chinese biologists regarded the physical labor involved in fieldwork and experimentation as providing an antidote to the old habit of book learning believed to be based on "empty philosophy," which was thought to have hampered China's growth" (Jiang 2016, 165). In what ways have different kinds of space contributed to the making of sciences that are expected to bring about a material difference

in farming? What cultures and traditions of experimentation have contributed to agricultural science, and how has the biological understanding thereby developed been associated with, or ignored by, more general biology? Any investigation of plant breeding and agriculture will necessarily encounter these issues.

Part 3: Plant breeding and agriculture for future histories of biology

In this section I highlight three particular areas of research that seem ripe for the attention of the historian of biology. All three have been subject to recent and rigorous interdisciplinary activity, opening up exciting potential future paths for work in the history of biology that either parallel, critique, or piggyback on these efforts. All three also happen to follow the lead of historians of technology, who have been amongst the most innovative in recent years when it comes to understanding agriculture and its relations with science and technology.

Global histories

We are still not in a position to draw upon historical investigations of biological science and agriculture from all continents (see also Barahona this volume). The most obvious gap is that while we have accounts of administration in Africa, historians and anthropologists addressing plant breeding and agriculture in this continent typically have not pursued the role of biological science in particular, but rather scientists and administrators in general (Hodge 2007). The exceptions are Bonneuil on Senegal (1999), and Saraiva on Ethiopia and Mozambique (Saraiva 2016), alongside some studies of the history of science and botany which from time to time stray into the agricultural (Drayton 2000). Nevertheless, even with these kinds of large gap still remaining to be addressed, it is heartening to see how much of the globe has by now received attention from historians of biology in agricultural mode. As with many other areas in the history of science and technology, historians of biology can and should now use these foundations in order to secure the resources needed for the production of global histories of plant breeding and agriculture. One way in which we could begin to conceptualise these efforts would be through the very recent historiographic innovation of ‘cropscapes’, as developed by historians of technology Francesca Bray, Barbara Hahn, John Bosco Lourdusamy, and Tiago Saraiva. While their full treatment is currently awaiting publication, and so it is somewhat premature to be discussing it here, the scope and scale of their project is significant enough for historians of biology addressing agriculture, that ignoring it would be to make this handbook immediately outdated. Elements of their programme can be gleaned from Bray’s recent co-edited collection on rice (Bray et al. 2015), and Hahn’s earlier investigation of tobacco (Hahn 2011), which will be drawn upon in a different context shortly. The following paragraph is based on a forthcoming journal article that the authors have been kind enough to share ahead of publication. While cropscapes constitute an analytical perspective that goes well beyond the typical bounds and ambitions of most histories of biology, the history of biology is nevertheless particularly well placed to contribute to them, and be seen within them.

To begin with, the authors define a cropscape as “firstly a concept encompassing the constellation of elements that are brought together to make a specific crop in a specific time and place, and secondly, as a tool to analyse the sum of movements and forces that produces and reproduces the working set of elements, as well as the capacity or incapacity of crops and their assemblages to travel” (Bray et al. Draft MS). The history of biology is implicated here in a number of ways. First, agricultural scientists and agriculture-facing

biologists have been directly responsible for the making and unmaking of crops and the pests, symbionts, cultivators - human and nonhuman - that go into making a specific crop. Second, the elements of different cropscapes around the world have been the locus of attention of agricultural research and extension. Third, and as these authors themselves highlight, agricultural plant scientists and breeders have been exceptionally dedicated to making organisms travel from their points of origin, finding ways to ensure they extend their crop life into new environments. Aside from these direct connections with cropscapes, some of these author's programmatic prescriptions are also particularly attractive for historians of biology. It is not enough, for instance, for historians to continue pointing out how particular crops that now matter for western diets and industries were originally found through international exploration and extraction. Instead any history of biology that does not attempt to at least keep one eye on that crop in its original location, at the same time as investigating the new life of that organism in imperial centres, has not really told the history of that crop at all. To give an example, it is one thing to know how important were repeated trips to South America for research and breeding of potatoes throughout the twentieth century, but if we only focus on the results of those trips in, for instance, the UK, and do not attend to ongoing maintenance and research in Peru throughout that same period, then we have been unhelpfully selective in our historicization of the plant. Such a prescription may also help us when delivering historical research into the present, complete as it is with governance instruments such as the Convention on Biological Diversity and the Nagoya Protocol. Lastly, some of our recent and most thoroughgoing accounts of crop movement and development in the history of biology may already be cropscapes *avant la lettre*. Bray et al. themselves point to Courtney Fullilove's history of commercial wheat production (Fullilove 2017), and we might also add Phillip J. Pauly on horticulture's role in colonising the United States (Pauly 2007), or Rebecca Woods on the international circulation of sheep breeds (Woods 2017), or Berris Charnley on the significances of genetics for empire building (Charnley 2013b), or Sabine Clarke's focus on sugarcane production for understanding the colonial and postcolonial history of the Caribbean (2018). Cropscapes just may well be the ideal vehicle for making global histories of biological science, plant breeding, and agriculture.

Environment

Historians of biology invested in plant breeding and agricultural science cannot afford to be left behind as historians of the environment and technology set about co-producing a new scholarly discourse (Agar and Ward. 2018. Jørgensen, Jørgensen and Pritchard 2013. Reuss and Cutcliffe 2010. Russell et al. 2011. Vetter 2016). No matter what level of the bioagricultural sciences one looks at, be it parasitology, botany, microbiology, you name it, these can be realised as fundamentally environmental. Take Jon Agar's recent suggestive 'eight ways of combining environmental and technological history' (Agar 2018). These range from ways in which environments are inputs into technological systems (agriculture supplies essential examples), to the environment as something changed or damaged by technological processes (again, agriculture is key), to environmentalism and the environment as something untouched (you can see the point I am making). Situating biological work in such contexts can achieve many of the same ends that I highlighted above for global histories, but at smaller and national scales (Uekötter 2014). A cropscape eye view is complementary with, if not part of, environmental history making.

It might be worried that these approaches essentially replace history of biology with environmental history and histories of large technological systems. But this is not so. For as I explained at the beginning of Part 2, much of the value to be gained by looking at biological science and agriculture at one and the same time, is the ability to chop and change between different historiographical perspectives. We might then wish to dedicate ourselves to understanding the development of, for instance, novel techniques for crop identification, and then consider what interaction those who developed such techniques had with their immediate surroundings, and the impact of their work on environments or industries at large. It is through biological materials that we can weave our historical accounts (Clarke and Fujimura 1992), provided we remember to make ample room for any given material's multiple semiotics. That they will have multiple semiotics is one reason why we will never be able to replace history of biology, for biological science is one of the most important, exciting, and surprising machines for making meaning that we could hope to alight on.

Biology and technology

Completing the trifecta of future paths for the history of biology and agriculture that also happen to entwine it closer with the history of technology, is the suggestion that historians of biology can productively integrate their work with the historiography of technology more generally. This runs all the way down from environments and technological systems, to organisms and the things they are made of. The motivations for making these suggestions are only tangentially related to the more recent history of agricultural science, in which certain actors claim to have remade biology as technology (Campos 2010. Scott, Berry, Calvert 2018). Being able to respond to such actors does not require that historians of biology understand technology better. But that some historical actors have at various times in the past and present interpreted their materials as much in terms of technology as biology, does inspire curiosity as to what elements of the historiography of technology may well serve our ends. More straightforwardly, the suggestion that an agricultural plant or animal also shares features with objects we would more readily identify as technologies is not in and of itself redundant or monstrous. Admitting this, it is perhaps no surprise that throughout this overview of the history of agriculture and plant breeding that I have often had need to call on the history of technology. Nor am I being particularly original in making this suggestion. For instance, Helen Curry has argued strongly that "it is impossible to understand early genetic technologies apart from the broader history of American technology and innovation. Genetic technologies were completely entangled with other areas of innovation, both in their material production and in the outcomes anticipated from them" (Curry 2016a, 3). This is a position that bears resemblances to Luis Campos' findings regarding the proliferation of radium mutation research in biology (Campos 2015), and the modernism of agricultural organisms attended to throughout Tiago Saraiva's *Fascist Pigs* (2016). Earlier Barbara Hahn had already demonstrated how attention to the various technologies of tobacco cultivation and processing could provide insights into the making of agricultural commodities, with implications for the value of botanical knowledge (Hahn 2011). And even earlier Robert Kohler had emphasised the potential need to understand how organisms can become technologies, in his case for the purposes of experimental practice (Kohler 1994, 6).

My suspicion is that one reason why interest in agricultural science amongst historians of biology has tended to wax and wane, is due to too ready a willingness to dismiss those parts of organisms that look technological rather than scientific. Even though

historians of biology typically demur from admitting this selectivity because they are smart enough to know that hard and fast distinctions between the importance of science and technology are difficult to defend, I nevertheless suspect that a prejudice resides here. This prejudice betrays our historical material which is at once scientific and technological, however we choose to define those terms or put them together. Those who wish to see investigation of agriculture and plant breeding continue to flourish amongst historians of biological science would therefore do well to collaborate with historians of technology.

Conclusion

I should begin my conclusion with two apologies. The first is that I can only read and write in English. There is a world of excellent scholarship beyond my reach, and which you can only learn about by following references to the various special issues and edited collections that I have cited. This deficiency no doubt warps my understanding of how this historiography has developed. The second is that agriculture here has been decidedly arable. Fisheries (Evenden 2004. Jiang 2017. Schwach and Hubbard 2009), scientific management of pests (Palladino 1996. Sayer 2017), forestry (Paskins 2018. Sivaramakrishnan 2008), and animal health and husbandry (Brown and Gilfoyle eds. 2010) deserve more attention than they have been granted, and will have to be faced another day.

The autonomy that I gave agriculture at the outset might be thought only an annoying rhetorical tool, enabling rival historians to always ask for *more* no matter how diligently a historian of biology has pursued the agricultural. It also seems to demand that when choosing the scholarly lineage to which we each dedicate our work, that we have to decide between *either* the history of biology *or* agriculture, rather than something interdisciplinary. Might we not instead hope that through integration between history of biology and history of agriculture, some new kind of historian will emerge, one primed to tackle these issues from the outset, and able to lead both fields in exciting new directions? But this might be a misguided hope. I do not imagine many of the scholars minted in such fashion would be particularly highly prized by either side, and they would probably struggle to find independent funding. Assuming this to be an accurate reading of the current institutional situation, it is therefore worth recapping the value of recognising agriculture's distinctiveness from the history of biology.

First, we do not think of there being one history of biology unfolding over time, even as we offer up our work as part of that collective endeavour. Given this multiplicity, the existence of an additional historical tradition in parallel to the history of biology, sometimes overlapping, other times diverging sharply, is not only manageable but also fruitful, because the relationship sharpens shared questions about organic growth, care, knowledge, value, health, maintenance, situatedness, biological time, and a whole host of other problems provoked by living things. Second, business historians, economic historians, social historians, historians of rural life, and all those who have investigated farms and farming, have been discussing biological things even when the biology of those things was not central to their own analysis. We can therefore think of all this scholarship as a reservoir of biological thought, perception, and evaluation, one which is available for the historian of biology to exploit or bring to their aid. Doing so might not be so easy if we were expected to find ways to assimilate these arguments into our own analytical framework, as would be one aim of interdisciplinarity. Third, history has witnessed attempts to render entire parts of the agricultural enterprise a science, be it a science of economics, of heredity, of chemistry, you

name it. In some cases these ambitions have been totalising - to make them a science and only a science. While I think historians of biology are perfectly capable of submitting such ambitions to critical analysis on their own terms, it might help to also have something called a 'historian of agriculture' close by, providing a scrutiny of their own. Some historians of science can at times adopt and project the voice of scientific actors, just as historians of agriculture can sometimes wittingly or unwittingly speak on behalf of farmers. These predilections are sometimes healthy, other times pathological. Recognising what might distinguish agricultural history questions from history of science questions, and retaining expertise in them respectively, is no doubt mutually beneficial and a way of mitigating the worst excessesses, by providing a check on unreasonableness.

This chapter has been designed as a primer, one that sensitizes newcomers to the intersection of the history of biology and the history of agriculture. Where I have explained that a particular theme or question has been thoroughly explored, I should not be read as arguing 'to the point of saturation'. New cases and angles of analysis are emerging all the time providing ample opportunity for revisionism in even the most well-trod spaces. We have yet to see, for instance, where the integration of queer theory into ecocriticism and environmental humanities may lead us historiographically (Sandilands 2014. Gray, Giley, and Johnson 2016). We are fortunate to have one clue in the shape of Luis Campos' work on sexuality for understanding twentieth century plant genetics (Campos 2010), but vastly more awaits to be discovered. I have made the case for the importance of three particular areas in the future of the history of biology and agriculture: global histories; history of the environment; and the intersection of biology and technology. If we are able to find the resources for global histories of biological science then we can learn the who, how and what has been taken to matter for different states independently and as a whole regarding agricultural life and production, and the kinds of biological science that they have inspired. I have also highlighted the need for a fuller integration of the history of agricultural science and industries with the history of the environment. Historical claims regarding capitalisation, commercialisation, and biological technology look starkly different when approached from the history of biology and the history of the environment. Last, I have emphasised that agricultural contexts provide a suite of cases for fuller exploration and understanding of the relations between biology, biological science, and technology. There are deeply significant conceptual issues at stake regarding organisms, science, and technology, and we can champion the history of plant breeding and agriculture's value for addressing them. Doing so also brings historial work into service in the present, for so much contemporary discourse is designed to swiftly conflate biology and technology only either to ignore plant breeding and agriculture's past, or invent one for it that serves narrow interests.

Acknowledgements

My thanks to the editors for inviting this chapter, and for providing detailed improving feedback. My thanks also to Berris Charnley and Gregory Radick for reading earlier drafts and offering insightful criticisms and suggestions for improvement. This chapter was written while the author was Research Fellow on the Narrative Science project, www.narrative-science.org and received funding from the ERC under the European Union's Horizon 2020 research and innovation programme (grant agreement No. 694732).

Bibliography

Ackerman, A, O. Tedin and K. Fröier. 1948. *Svalöf 1886-1946: History and Present Problems*. Lund: Carl Bloms Boktryckeri.

Agar, Jon. 2018. “Technology, environment and modern Britain: historiography and intersections.” In *Histories of Technology, the Environment, and Modern Britain*, edited by Jon Agar and Jacob Ward. London: UCL Press, 1-21.

Agar, Jon and Jacob Ward. 2018. *Histories of Technology, the Environment, and Modern Britain*. London: UCL Press.

Åkerberg, Erik. 1986. “Nilsson-Ehle and the development of plant breeding at Svalöf during the period 1900-1915.” *Hereditas* 105:1-5.

Allen, Garland E. 2000. “The reception of mendelism in the United States, 1900-1930.” *Comptes Rendus de l'Académie des Sciences - Series III* 323:1081-1088.

Allen, Garland E. 2003. “Mendel and modern genetics: the legacy for today.” *Endeavour* 27:63-68.

Allen, Garland E. 2013. “Culling the Herd”: Eugenics and the conservation movement in the United States, 1900-1940.” *Biology Faculty Publications* Paper 6:1-69. http://openscholarship.wustl.edu/bio_facpubs/6

Barahona, Ana and Ana Lilia Gaona Robles. 2001. “The history of science and the introduction of plant genetics in Mexico.” *History and Philosophy of the Life Sciences* 23:151-162.

Barahona, Ana, Susana Pinar and Francisco J. Ayala. 2005. “Introduction and institutionalization of genetics in Mexico.” *Journal of the History of Biology* 38:273-299.

Baranski, Marci. 2015a. “The wide adaptation of Green Revolution wheat.” PhD diss., Arizona State University.

Baranski, Marci. 2015b. “Wide adaptation of Green Revolution wheat: International roots and the Indian context of a new plant breeding ideal, 1960–1970.” *Studies in History and Philosophy of Biological and Biomedical Sciences* 50:41-50.

Baranski, Marci and B.R. Erick Peirson. 2015. “Introduction: Contexts and concepts of adaptability and plasticity in 20th-century plant science.” *Studies in History and Philosophy of Biological and Biomedical Sciences* 50:26-28.

Berry, Dominic. 2014a. “The Plant Breeding Industry After Pure Line Theory: Lessons from the National Institute of Agricultural Botany.” *Studies in the History and Philosophy of the Biological and Biomedical Sciences* 46:25-37.

Berry, Dominic. 2014b. “Genetics, statistics, and regulation at the National Institute of Agricultural Botany, 1919-1969.” PhD diss, University of Leeds.

Berry, Dominic. 2014c. “Bruno to Brünn; or the Pasteurization of Mendelian genetics.” *Studies in History and Philosophy of Biological and Biomedical Sciences* 48:280-286.

Berry, Dominic J. 2015a. “Agricultural Modernity as a Product of the Great War: The Founding of the Official Seed Testing Station for England and Wales, 1917–1921.” *War & Society* 34:121-139.

Berry, Dominic J. 2015B. “The resisted rise of randomisation in experimental design: British agricultural science, c.1910-1930.” *History and Philosophy of the Life Sciences* 37:242-2260.

Berry, Dominic. 2018. “Plants are technologies.” In Histories of Technology, the Environment, and Modern Britain, edited by Jon Agar and Jacob Ward. London: UCL Press, 161-185.

Bil, Geoff. 2018. “Indexing the Indigenous: Plants, Peoples and Empire in the Long Nineteenth Century.” PhD diss., University of British Columbia.

Bonneuil, Christophe. 1999. “Penetrating the natives: Peanut-breeding, peasants and the colonial state in Senegal (1900-1950).” *Science, Technology and Society* 4:273-302.

Bonneuil, Christophe. 2006. “Mendelism, Plant Breeding and Experimental Cultures: Agriculture and the Development of Genetics in France.” *Journal of the History of Biology* 39:281-308.

Bonneuil, Christophe. 2008. “Producing Identity, Industrializing Purity: Elements for a Cultural History of Genetics”. In *A Cultural History of Heredity IV: Heredity in the Century of the Gene*. Berlin: Max Planck Institute for the History of Science, 81-110.

Bonneuil, Christophe. 2016. “Pure lines as industrial simulacra: A cultural history of genetics from Darwin to Johannsen.” In *Heredity Explored: Between Public Domain and Experimental Science, 1850–1930*, edited by Staffan Müller-Wille and Christina Brandt. Cambridge, MA: The MIT Press, 213-242.

Bonneuilt, Christophe. In press. “Seeing nature as a ‘universal store of genes’: How biological diversity became ‘genetic resources’, 1890-1940.” *Studies in History and Philosophy of Biological and Biomedical Sciences*. https://doi.org/10.1016/j.shpsc.2018.12.002

Bonneuil, Christophe and Frederic Thomas. 2010. “Purifying Landscapes: The Vichy Regime and the Genetic Modernization of France.” *Historical Studies in the Natural Sciences* 40:532-568.

Brassley, Paul. 2007. “Cutting across nature? The history of artificial insemination in pigs in the United Kingdom.” *Studies in History and Philosophy of Biological and Biomedical Sciences* 38:442-461.

Bray, Francesca, Peter A. Coclanis, Edda L. Fields-Black, and Dagmar Schäfer, eds. 2015. *Rice: Global Networks and New Histories*. Cambridge: Cambridge University Press.

Bray, Francesca, Barbara Hahn, John Bosco Lourdusamy and Tiago Saraiva. Draft MS. “Cropscapes and history: reflections on rootedness and mobility.”

Brown, Karen and Daniel Gilfoyle eds. 2010. *Healing the Herds: Disease Livestock Economies, and the Globalization of Veterinary Medicine*. Athens, OH: Ohio University Press.

Bud, Robert. 1993. *The Uses of Life: A History of Biotechnology*. Cambridge: Cambridge University Press.

Bugos, Glen and Daniel J. Kevles. 1992. “Plants as intellectual property: American law, policy and practice in world context.” *Osiris* 7:119-148.

Button, Clare. 2017. “James Cossar Ewart and the origins of the Animal Breeding Research Department in Edinburgh, 1895-1920.” *Journal of the History of Biology* https://doi.org/10.1007/s10739-017-9500-0

Campos, Luis A. 2010. “Mutant Sexuality: The Private Life of a Plant.” In *Making Mutations: Objects, Practices, Contexts*, edited by Luis Campos and Alexander von Schwerin. Berlin: Max Planck Institute for the History of Science.

Campos, Luis A. 2009. “That was the synthetic biology that was.” In *Synthetic Biology: The technoscience and its societal consequences*, edited by Markus Schmidt, Alexander Kelle, Agomoni Ganguli-Mitra and Huib de Vriend. Dordrecht, Heidelberg, London, New York: Springer, 5-21.

Campos, Luis A. 2015. *Radium and the Secret of Life*. Chicago: The University of Chicago Press.

Campos, Luis and Alexander von Scherwin. 2016. “Transatlantic Mutants: Evolution, Epistemics, and the Engineering of Variation, 1903-1930.” In *Heredity Explored: Between Public Domain and Experimental Science, 1850–1930*, edited by Staffan Müller-Wille and Christina Brandt. Cambridge, MA: The MIT Press, 395-415.

Camprubí, Lino. 2010. “One Grain, One Nation: Rice Genetics and the Corporate State in Early Francoist Spain (1939-1952).” *Historical Studies in the Natural Sciences* 40:499-531.

Carlson, Laurie. 2005. “Forging His Own Path: William Jasper Spillman and Progressive Era Breeding and Genetics.” *Agricultural History* 79:50-73.

Charnley, Berris. 2011. “Agricultural Science, Plant Breeding and the Emergence of a Mendelian System in Britain, 1880-1930.” PhD diss, University of Leeds.

Charnley, Berris. 2013a. “Seeds without Patents: Science and Morality in British Plant Breeding in the Long Nineteenth Century.” *Revue Economique* 64:69-87.

Charnley, Berris. 2013b. “Experiments in empire-building: Mendelian genetics as a national, imperial, and global agricultural enterprise.” *Studies in the History and Philosophy of Science* 44:222-233.

Charnley, Berris. 2013c. “Mendelism in British agricultural science, 1900-1930: “Systematised plant breeding.” In *Knowledge Management and Intellectual Property: Concepts, Actors and Practices from the Past to the Present*, edited by Graham Dutfield and Stathis Arapostathis. Cheltenham: Edward Elgar, 200-215.

Charnley, Berris. 2016. “Geneticists on the farm: agriculture and the all-English loaf.” In *Scientific Governance in Britain, 1914-1979*, edited by Charlotte Sleigh and Don Leggett. Manchester: Manchester University Press, 181-198.

Charnley, Berris and Charles Lawson, eds. 2015. *Intellectual Property and Genetically Modified Organisms: A Convergence in Laws*. Farnham: Ashgate.

Charnley, Berris and Gregory Radick. 2013. “Intellectual property, plant breeding and the making of Mendelian genetics.” *Studies in History and Philosophy of Science* 44:222-233.

Clarke, Adele E. and John H. Fujimura, eds. 1992. *The Right Tools for the Job: At Work in Twentieth-Century Life Sciences*. Princeton: Princeton University Press.

Clarke, Sabine. 2018. *Science at the end of empire: Experts and the development of the British Caribbean, 1940-62*. Manchester: Manchester University Press.

Cooke, Kathy J. 1997. “From Science to Practice, or Practice to Science? Chickens and Eggs in Raymond Pearl’s Agricultural Breeding Research, 1907-1916.” Isis 88:62-86.

Curry, Helen Anne. 2016a. *Evolution Made to Order: Plant Breeding and Technological Innovation in Twentieth-Century America*. Chicago: The University of Chicago Press.

Curry, Helen Anne. 2016b. “Speeding up evolution: X-rays and plant breeding in the United States, 1925-1935.” In *New Perspectives on the History of Life Sciences and Agriculture*, edited by Denise Phillips and Sharon Kingsland. Cham, Heidelberg, New York, Dordrecht, London: Springer, 459-478.

Curry, Helen. 2016c. “Atoms in agriculture: A study of scientific innovation between technological systems.” *Historical Studies in the Natural Sciences* 46:119-153.

Derry, Margaret. 2003. *Bred for Perfection: Shorthorn Cattle, Collies, and Arabian Horses since 1800*. Baltimore: Johns Hopkins University Press.

Derry, Margaret E. 2012. *Art and Science in Breeding: Creating Better Chickens*. Toronto: University of Toronto Press.

Derry, Margaret E. 2016. “Chicken breeding: The complex transition from traditional to genetic methods in the USA.” In *New Perspectives on the History of Life Sciences and Agriculture*, edited by Denise Phillips and Sharon Kingsland. Cham, Heidelberg, New York, Dordrecht, London: Springer, 371-393.

Drayton, Richard. 2000. *Nature’s Government: Science, Imperial Britain, and the ‘Improvement’ of the World*. New Haven and London: Yale University Press.

Dutfield, Graham. 2003. *Intellectual Property Rights and the Life Science Industries: A Twentieth Century History*. Farnham: Ashgate.

Ekerholm, Helena, Karl Grandin, Christer Nordlund, and Patience A. Schell. 2017. *Understanding Field Science Institutions*. Sagamore Beach, MA: Science History Publications/USA.

Elina, Olga, Susanne Heim and Nils Roll-Hansen. 2005. “Plant Breeding on the Front: Imperialism, War, and Exploitation.” *Osiris* 20:161-179.

Evenden, Matthew. 2004. “Locating Science, Locating Salmon: Institutions, Linkages, and Spatial Practices in Early British Columbia Fisheries Science.” *Environment and Planning D: Society and Space* 22:355-372.

Fisher, James. 2018. “The master should know more: Book-farming and the conflict over agricultural knowledge.” *Cultural and Social History* DOI: 10.1080/14780038.2018.1492792

Fitzgerald, Deborah. 1990. *The Business of Breeding: hybrid corn in Illinois, 1890-1940*. Ithaca: Cornell University Press.

Fitzgerald, Deborah. 1993. "Farmers Deskilled: Hybrid Corn and Farmers’ Work’.” *Technology and Culture* 34:324-343.

Flitner, Michael. 2003. “Genetic geographies. A historical comparison of agrarian modernization and eugenic thought in Germany, the Soviet Union, and the United States.” *Geoforum* 34:175-185.

Franklin, Sarah. 2007. *Dolly Mixtures: the remaking of genealogy*. Durham and London: Duke University Press.

Fujihara, Tatsushi. 2018. “Colonial Seeds, Imperialist Genes: Hōrai rice and Agricultural Development.” In *Engineering Asia: Technology, Colonial Legacy, and the Cold War Order*,

edited by Hiromi Mizuno, Aaron S. Moore, and John P. Dimoia. London: Bloomsbury, 137-164.

Fullilove, Courtney. 2017. *The Profit of the Earth: The Global Seeds of American Agriculture*. Chicago: The University of Chicago Press.

García-Sancho, Miguel. 2015. “Animal breeding in the age of biotechnology: the investigative pathway behind the cloning of Dolly the sheep.” *History and Philosophy of the Life Sciences* 37:282-304.

Gaudillière, Jean-Paul. 2009. “New wine in old bottles? The biotechnology problem in the history of molecular biology.” *Studies in History and Philosophy of Biological and Biomedical Sciences* 40:20-28.

Gausemeier, Bernd. 2010. “Genetics as a Modernization Program: Biological Research at the Kaiser Wilhelm Institutes and the Political Economy of the Nazi State.” *Historical Studies in the Natural Sciences* 40:429-456.

Gayon, Jean and Doris T. Zallen. 1998. “The Role of the Vilmorin Company in the Promotion and Diffusion of the Experimental Science of Heredity in France, 1840-1920.” *Journal of the History of Biology* 31:241-262.

Gliboff, Sander. 2015. “The Mendelian and Non-Mendelian Origins of Genetics.” *Filosofia e História da Biologia* 10:99-123.

Gliboff, Sander J. 2016. “Breeding better peas, pumpkins, and peasants: The practical Mendelism of Erich Tschermak.” In *New Perspectives on the History of Life Sciences and Agriculture*, edited by Denise Phillips and Sharon Kingsland. Cham, Heidelberg, New York, Dordrecht, London: Springer, 395-413.

Gray, Mary L., Brian J. Gilley and Colin R. Johnson. 2016. *Queering the Countryside: New Frontiers in Rural Queer Studies*. New York and London: New York University Press.

Güttler, Nils. 2015. “Drawing the line: Mapping cultivated plants and seeing nature in nineteenth-century plant geography.” In *New Perspectives on the History of Life Sciences and Agriculture*, edited by Denise Phillips and Sharon Kingsland. Cham, Heidelberg, New York, Dordrecht, London: Springer, 27-52.

Harwood, Jonathan. 1997. “The Reception of Genetic Theory among Academic Plant-Breeders in Germany, 1900-1930.” *Svergies Utsädesförenings Tidskrift* 4:187-195.

Harwood, Jonathan. 2000. “The rediscovery of Mendelism in agricultural context: Erich von Tschermak as plant- breeder.” *Comptes Rendus de l'Académie des Sciences - Series III - Sciences de la Vie* 323:1061-1067.

Harwood, Jonathan. 2004. “Linkage before Mendelism? Plant-breeding research in Central Europe, c. 1880-1910.” In *Classical Genetic Research and its Legacy: The mapping cultures of twentieth-century genetics*, edited by Hans-Jörg Rheinberger and Jean-Paul Gaudilliere. London: Routledge, 9-20.

Harwood, Jonathan. 2006. “Introduction to the Special Issue on Biology and Agriculture.” *Journal of the History of Biology*. 39:237-239.

Harwood, Jonathan. 2009. “Peasant-Friendly Plant-Breeding and the Early Years of the Green Revolution in Mexico.” *Agricultural History* 83:384-410.

Harwood, Jonathan. 2010. “The Fate of Peasant-Friendly Plant Breeding in Nazi Germany.” *Historical Studies in the Natural Sciences* 40:569-603.

Harwood, Jonathan. 2012. *Europe's Green Revolution and Others Since: The rise and fall of peasant-friendly plant breeding*. London and New York: Routledge.

Harwood, Jonathan. 2016. “Did Mendelism transform plant breeding? Genetic theory and breeding practice, 1900-1945.” In *New Perspectives on the History of Life Sciences and Agriculture*, edited by Denise Phillips and Sharon Kingsland. Cham, Heidelberg, New York, Dordrecht, London: Springer, 345-370.

Harwood, Jonathan. 2018. “The green revolution as a process of global circulation: plants, people and practices.” *Historia Agraria* 75:7-31.

Hahn, Barbara. 2011. *Making Tobacco Bright: Creating an American Commodity, 1617-1937*. Baltimore: The Johns Hopkins University Press.

Heim, Susanne. 2003. *Plant Breeding and Agrarian Research in Kaiser-Wilhelm-Institutes 1933-1945*. Göttingen: Springer.

Henke, Christopher R. 2008. *Cultivating Science, Harvesting Power: Science and Industrial Agriculture in California*. Massachusetts: The MIT Press.

Hodge, Jonathan and David Kohn. 1985. ‘‘The Immediate Origins of Natural Selection.’’ In *The Darwinian Heritage*, edited by David Kohn, 185-206. Princeton: Princeton University Press.

Hodge, Jonathan and Gregory Radick. 2003. “Introduction.” In *The Cambridge Companion to Darwin*, edited by Jonathan Hodge and Gregory Radick, 1-14. Cambridge: Cambridge University Press.

Hodge, Joseph Morgan. 2007. *Triumph of the Expert: Agrarian Doctrines of Development and the Legacies of British Colonialism*. Athens: Ohio University Press.

Holmes, Matthew. 2017a. “From Biological Revolution to Biotech Age: Plant Biotechnology in British Agriculture since 1950.” PhD diss., University of Leeds.

Holmes, Matthew. 2017b. “Changing techniques in crop plant classification: Molecularization at the National Institute of Agricultural Botany during the 1980s.” *Annals of Science* 74:149-164.

Holmes, Matthew. 2018a. “Somatic hybridization: The rise and fall of a mid-twentieth-century biotechnology.” *Historical Studies in the Natural Sciences* 48:1-23.

Holmes, Matthew. 2018b. “Crops in a machine: Industrialising barley breeding in twentieth-century Britain.” In *Histories of Technology, the Environment, and Modern Britain*, edited by Jon Agar and Jacob Ward. London: UCL Press, 142-160.

Iida, Kaori. 2016. “Genetics and “Breeding as a Science”: Kihara Hitoshi and the Development of Genetics in Japan in the First Half of the Twentieth Century.” In *New Perspectives on the History of Life Sciences and Agriculture*, edited by Denise Phillips and Sharon Kingsland. Cham, Heidelberg, New York, Dordrecht, London: Springer, 439-458.

Iori, Luca. 2013. “Agricultural Genetics and Plant Breeding in Early Twentieth-Century Italy.” PhD diss., University of Bologna.

Jiang, Lijing. 2016. “Retouching the past with living things: Indigenous species, tradition, and biological research in Republican China, 1918-1937.” *Historical Studies in the Natural Sciences* 46:154-206.

Jiang, Lijing. 2017. “The Socialist Origins of Artificial Carp Reproduction in Maoist China.” *Science, Technology and Society* 22:59-77.

Jørgensen, Dolly, Finn Arne Jørgensen, and Sara B. Pritchard eds. 2013. Pittsburgh: University of Pittsburgh Press.

Kevles, Daniel J. 1980. “Genetics in the United States and Great Britain, 1890-1930: A Review with speculations.” *Isis* 71:441-455.

Kevles, Daniel J. 2002. *A history of patenting life in the United States with comparative attention to Europe and Canada: A report to the European Group on Ethics in Science and New Technologies*. Luxembourg: Office for Official Publications of the European Communities.

Kevles, Daniel J. 2007. “Patents, protections, and privileges: The establishment of intellectual property in animals and plants.” *Isis* 98:323-331.

Kimmelman, Barbara A. 1983. “The American Breeders’ Association: Genetics and eugenics in agricultural context, 1903-13.” *Social Studies of Science* 13:163-204.

Kimmelman, Barbara. 1987. “A Progressive Era Discipline: Genetics at American Agricultural Colleges and Experiment Stations, 1900-1920.” PhD diss., University of Pennsylvania.

Kimmelman, Barbara. 1992. “Organisms and Interests in Scientific Research: R.A. Emerson’s Claims for the Unique Contributions of Agricultural Genetics.” In *The Right Tools for the Job*, edited by Adele E. Clarke and Joan H. Fujimura. Princeton: Princeton University Press, 198-232.

Kimmelman, Barbara. 1997. “The influence of agricultural practice on the development of genetic theory.” *Svergies Utsädesförenings Tidskrift* 4:178-186.

Kimmelman, Barbara. 2006. “Mr. Blakeslee Builds His Dream House: Agricultural Institutions, Genetics, and Careers 1900-1915.” *Journal of the History of Biology* 39:241-280.

Kingsland, Sharon E. 2009. “Frits Went’s atomic age greenhouse: The changing labscape on the lab-field border.” *Journal of the History of Biology* 42:289-324.

Kloppenburg, Jack. 1988. *First The Seed: The political Economy of Plant Biotechnology*. Cambridge and New York: Cambridge University Press.

Kohler, Robert E. 1994. *Lords of the Fly:* Drosophila *Genetics and the Experimental Life*. Chicago: The University of Chicago Press.

Kohler, Robert E. 2002. *Landscapes and Labscapes: Exploring the lab-field border in biology*. Chicago: The University of Chicago Press.

Kumar, Prakash. 2012. *Indigo Plantations and Science in Colonial India*. Cambridge: Cambridge University Press.

Kumar, Prakash, Timothy Lorek, Tore C. Olsson, Nicole Sackley, Sigrid Schmalzer and Gabriela Soto Laveaga. 2017. “Roundtable: New narratives of the Green Revolution.” *Agricultural History* 91:397-422.

Lavelle, Peter. 2016. “Agricultural improvement at China’s first agricultural experiment stations.” In *New Perspectives on the History of Life Sciences and Agriculture, edited by Denise Phillips and Sharon Kingsland*. Cham, Heidelberg, New York, Dordrecht, London: Springer, 323-344.

Lidwell-Durnin, John. 2018. “The production of a physiological puzzle: how *Cytisus adami* confused and inspired a century’s botanists, gardeners, and evolutionists.” *History and Philosophy of the Life Sciences* 40:48.

Lovett, Laura L. 2007. *Conceiving the Future: Pronatalism, Reproduction, and the Family in the United States, 1890-1938*. Chapel Hill: University of North Carolina Press.

Maat, Harro. 2001. *Cultivating Practice: A history of Agricultural Science in the Netherlands and its Colonies 1863-1986*. Dordrecht: Kluwer.

MacLeod, Christine and Gregory Radick. 2013. “Claiming ownership in the technosciences: Patents, priority and productivity.” *Studies in History and Philosophy of Science* 44:188-201.

Marie, Jennifer. 2004. “The Importance of Place: A History of Genetics in the 1930s.” PhD diss., University College London.

Matchett, Karin. 2006. “At odds over inbreeding: An abandoned attempt at Mexico/United States collaboration to “Improve” Mexican corn, 1940-1950.” *Journal of the History of Biology* 39:345-372.

Matz, Brendan. 2011. “Crafting Heredity: The art and science of livestock breeding in the United States and Germany, 1860-1914.” PhD diss., Yale University.

Mazumdar, Pauline M.H. 1992. *Eugenics, Human Genetics and Human Failings: The Eugenics Society, its sources and its critics in Britain*. Oxon: Routledge.

Müller-Wille, Staffan. 2005. “Early Mendelism and the subversion of taxonomy: epistemological obstacles as institutions.” *Studies in History and Philosophy of Biological and Biomedical Sciences* 36:465-487.

Müller-Wille, Staffan. 2007. “Hybrids, pure cultures, and pure lines: from nineteenth-century biology to twentieth-century genetics.” *Studies in History and Philosophy of Biological and Biomedical Sciences* 38:796-806.

Müller-Wille, Staffan. 2008a. “Leaving Inheritance behind: Wilhelm Johannsen and the Politics of Mendelism”. In *A Cultural History of Heredity IV: Heredity in the Century of the Gene*. Berlin: Max Planck Institute for the History of Science, 7-18.

Müller-Wille, Staffan and Christina Brandt, eds. 2016. *Heredity Explored: Between Public Domain and Experimental Science, 1850–1930*. Cambridge, MA: The MIT Press.

Müller-Wille, Staffan and Vítězslav Orel. 2007. “From Linnaean species to Mendelian factors: Elements of hybridism, 1751-1870.” *Annals of Science* 64:171-215.

Müller-Wille, Staffan and Hans-Jörg Rheinberger. 2012. *A Cultural History of Heredity*. Chicago: The University of Chicago Press.

Munns, David P.D. 2017. *Engineering the Environment: Phytotrons and the Quest for Climate Control in the Cold War.* Pittsburgh: University of Pittsburgh Press.

Myelnikov, Dmitriy. 2017. “Cuts and the cutting edge: British science funding and the making of animal biotechnology in 1980s Edinburgh.” *British Journal for the History of Science* 50:701-728.

Olby, Robert. 1979. “Mendel No Mendelian?” *History of Science* 17:53-72.

Olby, Robert. 1989. “Scientists and bureaucrats in the establishment of the John Innes horticultural institution under William Bateson.” *Annals of Science* 46:497-510.

Olby, Robert. 1991. “Social imperialism and state support for agricultural research in Edwardian Britain.” *Annals of Science* 48:509-526.

Olby, Robert. 2000. “Horticulture: the font for the baptism of genetics.” *Nature Reviews Genetics* 1:65-70.

Onaga, Lisa. 2010. “Toyama Kametarō and Vernon Kellogg: Silkworm inheritance experiments in Japan, Siam, and the United States, 1900–1912.” *Journal of the History of Biology* 43:215-264.

Onaga, Lisa. 2016. “More than metamorphosis: The silkworm experiments of Toyama Kametarō and his cultivation of genetic thought in Japan’s sericultural practices, 1894-1918.” In *New Perspectives on the History of Life Sciences and Agriculture*, edited by Denise Phillips and Sharon Kingsland. Cham, Heidelberg, New York, Dordrecht, London: Springer, 415-437.

Opitz, Don. 2011. “Cultivating genetics in the country: Whittingehame Lodge, Cambridge.” In *Geographies of Nineteenth-Century Science*, edited by David N. Livingstone and Charles W. J. Withers. Chicago: The University of Chicago Press, 73-98.

Palladino, Palo. 1987. “Science for whom? Agricultural development and the theory of induced innovation.” *Agriculture and Human Values* 4:53-64.

Palladino, Paolo. 1990. “The Political Economy of Applied Research: Plant Breeding in Great Britain, 1910-1940.” *Minerva* 28:446-468.

Palladino, Paolo. 1993. “Between Craft and Science: Plant Breeding Mendelian Genetics, and British Universities, 1900-1920.” *Technology and Culture* 34:300-323.

Palladino, Paolo. 1994. “Wizards and Devotees: on the Mendelian theory of inheritance and the professionalization of agricultural science in Great Britain and the United States, 1880-1930.” *History of Science* 32:409-444.

Palladino, Paolo. 1996. *Entomology, Ecology and Agriculture: The Making of Scientific Careers in North America, 1885-1985.* Amsterdam: Harwood Academic Publishers.

Palladino, Paolo. 2002. *Plants, patients and the historian*. Manchester: Manchester University Press.

Parolini, Giuditta. 2012. “Making Sense of Figures”: Statistics, Computing and Information Technologies in Agriculture and Biology in Britain, 1920s-1960s.” PhD diss., University of Bologna.

Parolini, Giuditta. 2015. “Charting the history of agricultural experiments.” *History and Philosophy of the Life Sciences* 37:231-241.

Parthasarathy, Shobita. 2017. *Patent Politics: Life Forms, Markets, and the Public Interest in the United States and Europe*. Chicago: The University of Chicago Press.

Paskins, Mat. 2018. “The woods for the state.” In *Histories of Technology, the Environment, and Modern Britain*, edited by Jon Agar and Jacob Ward. London: UCL Press, 230-251.

Pauly, Philip J. 2007. *Fruits and Plains: The Horticultural Transformation of America*. Cambridge, MA: Harvard University Press.

Peirson, B.R. Erick. 2015. “Plasticity, stability, and yield: The origins of Anthony David Bradshaw’s model of adaptive phenotypic plasticity.” *Studies in History and Philosophy of Biological and Biomedical Sciences* 50:51-66.

Perkins, John H. 1997. *Geopolitics and the Green Revolution: Wheat, Genes, and the Cold War*. Oxford: Oxford University Press.

Phillips, Denise. 2015. “Plants and places: Agricultural knowledge and plant geography in Germany, 1750-1810.” In *New Perspectives on the History of Life Sciences and Agriculture*, edited by Denise Phillips and Sharon Kingsland. Cham, Heidelberg, New York, Dordrecht, London: Springer, 9-26.

Phillips, Denise and Sharon Kingsland, eds. 2015. *New Perspectives on the History of Life Sciences and Agriculture*. Cham, Heidelberg, New York, Dordrecht, London: Springer.

Pottage, Alain. 2006. “Too much ownership: Bio-prospecting in the age of synthetic biology.” *BioSocieties* 1: 137-158.

Radick, Gregory. 2013. “The professor and the pea: Lives and afterlives of William Bateson’s campaign for the utility of Mendelism.” *Studies in the History and Philosophy of Science* 44:280-291.

Reuss, Martin and Stephen H. Cutcliffe, eds. 2010. *The Illusory Boundary: Environment and Technology in History*. Charlottesville: University of Virginia Press.

Ritvo, Harriet. 1987. *The Animal Estate: The English and Other Creatures in the Victorian Age*. Cambridge, MA: Harvard University Press.

Roll-Hansen, Nils. 1989. “Geneticists and the eugenics movement in Scandinavia.” *The British Journal for the History of Science* 22:335-346.

Roll-Hansen, Nils. 1997. “The role of genetic theory in the success of the Svalöf plant breeding program.” *Svergies Utsädesförenings Tidskrift* 4:196-207.

Roll-Hansen, Nils. 2000. “Theory and practice: the impact of mendelism on agriculture.” *C.R. Acad. Sci. Paris, Science de la vie* 323:1107-1116.

Russell, Nicholas. 1986. *Like Engend’ring Like: Heredity and Animal Breeding in Early Modern England*. Cambridge: Cambridge University Press.

Sandilands, Catriona. 2014. “Queer life? Ecocriticsm after the fire.” In *The Oxford Handbook of Ecocriticism*, edited by Greg Garrard. Oxford: Oxford University Press, 305-351.

Saha, Madhumita. 2013. “The state, scientists, and staple crops: Agricultural “Modernization” in pre-Green Revolution India.” *Agricultural History* 87:201-223.

Sapp, Jan. 1990. “The nine lives of Gregor Mendel.” *Experimental Inquiries* 8:137-166.

Saraiva, Tiago. 2010. “Fascist Labscapes: Geneticists, Wheat, and the Landscapes of Fascism in Italy and Portugal.” *Historical Studies in the Natural Sciences* 40:457-498.

Saraiva, Tiago. 2016. *Fascist Pigs: Technoscientific Organisms and the History of Fascism*. Cambridge MA: The MIT Press.

Saraiva, Tiago and M. Norton Wise. 2010. “Autarky/Autarchy: Genetics, Food Production and the Building of Fascism.” *Historical Studies in the Natural Sciences* 40:419-428.

Sayer, Karen. 2017. “The ‘modern’ management of rats: British agricultural science in farm and field during the twentieth century.” *BJHS* 2:235-263.

Schwach, Vera and Jennifer M. Hubbard. 2009. “Johan Hjort and the Birth of Fisheries Biology: the construction and transfer of knowledge, approaches and attitudes, Norway and Canada, 1890–1920.” *Studia Atlantica* 13:22-41.

Schiebinger, Londa L. 2004. *Plants and Empire: Colonial Bioprospecting in the Atlantic World*. Cambridge, MA: Harvard University Press.

Schmalzer, Sigrid. 2016. *Red Revolution, Green Revolution: Scientific farming in socialist China*. Chicago: The University of Chicago Press.

Scott, Deborah, Dominic J. Berry, and Jane Calvert. 2018. “Synthetic biology.” In *Routledge Handbook of Genomics, Health and Society*, edited by Sahra Gibbon, Barbara Prainsack, Stephen Hilgartner and Janelle Lamoreaux. Abingdon: Routledge, 300-307.

Secord, James A. 1985. “Darwin and the Breeders: A Social History.” In *The Darwinian Heritage*, edited by David Kohn, 519-542. Princeton: Princeton University Press.

Shavit, Ayelet and James Griesemer. 2009. “There and back again, or the problem of locality in biodiversity surveys.” *Philosophy of Science* 76:273-294.

Shavit, Ayelet and Aaron M. Ellison, eds. *Stepping in the Same River Twice: Replication in Biological Research*. New Haven and London: Yale University Press.

Sivaramakrishnan, Kalyanakrishnan. 2008. “Science, Environment and Empire History: Comparative Perspectives from Forests in Colonial India.” *Environment and History* 14:41-65.

Tae-ho, Kim. 2018. “Making Miracle Rice: Tongil and mobilizing a domestic ‘Green Revolution’ in South Korea.” In *Engineering Asia: Technology, Colonial Legacy, and the Cold War Order*, edited by Hiromi Mizuno, Aaron S. Moore, and John P. Dimoia. London: Bloomsbury, 189-208.

Theunissen, Bert. 2012. “Darwin and his pigeons: The analogy between artificial and natural selection revisited.” *Journal of the History of Biology* 45:179-212.

Theunissen, Bert. 2008. “Breeding Without Mendelism: Theory and Practice of Dairy Cattle Breeding in the Netherlands 1900-1950.” *Journal of the History of Biology* 41:637-676.

Thurtle, Phillip. 2002. “Harnessing heredity in Gilded Age America: Middle class mores and industrial breeding in cultural context.” *Journal of the History of Biology* 35:43-78.

Tilley, Helen. 2011. *Africa as a Living Laboratory*. Chicago: The University of Chicago Press.

Tyrell, Brian. 2015. “Bred for the race: Thoroughbred breeding and racial science in the United States, 1900-1940.” *Historical Studies in the Natural Sciences* 45:549-576.

Uekötter, Frank. 2006. *The Green and the Brown. A History of Conservation in Nazi Germany*. Cambridge: Cambridge University Press.

Uekötter, Frank, ed. 2014. *Comparing Apples, Oranges, and Cotton: Environmental Histories of the Global Plantation*. Main: Campus Verlag.

Vetter, Jeremy. 2016. *Field Life: Science in the American West During the Railroad Era*. Pittsburgh: University of Pittsburgh Press.

Wieland, Thomas. 2006. “Scientific Theory and Agricultural Practice: Plant Breeding in Germany from the Late 19th to the Early 20th Century.” *Journal of the History of Biology* 39:309-343.

Wilmot, Sarah. 2007a. “Between the farm and the clinic: agriculture and reproductive technology in the twentieth century.” *Studies in History and Philosophy of Biological and Biomedical Sciences* 38:303-315.

Wilmot, Sarah. 2007b. “From ‘public service’ to artificial insemination: animal breeding science and reproductive research in early twentieth-century Britain.” *Studies in History and Philosophy of Biological and Biomedical Sciences* 38:411-441.

Winther, Rasmus G. 2000. “Darwin on Variation and Heredity.” *Journal of the History of Biology* 33:425-455.

Wood, Roger J. and Vítězslav Orel. 2001. *Genetic Prehistory in Selective Breeding: A Prelude to Mendel*. Oxford: Oxford University Press.

Wood, Roger J. and Vítězslav Orel. 2005. “Scientific Breeding in Central Europe during the Early Nineteenth Century: Background to Mendel's Later Work.” *Journal of the History of Biology* 38:239-272.

Woods, Abigail. 2013. “From practical men to scientific experts: British veterinary surgeons and the development of government scientific expertise, *c*. 1878–1919.” *History of Science* 51:457-480.

Woods, Abigail, Michael Bresalier, Angela Cassidy, and Rachel Mason Dentinger. 2018. *Animals and the Shaping of Modern Medicine: One Health and its Histories*. Cham: Palgrave Macmillan.

Woods, Rebecca J. H. 2017. *The Herds Shot Round the World: Native Breeds and the British Empire, 1800-1900*. Chapel Hill, North Carolina: The University of North Carolina Press.