Studies in History and Philosophy of Biological and Biomedical Sciences 43 (2012) 225–231

Contents lists available at SciVerse ScienceDirect

Studies in History and Philosophy of Biological and Biomedical Sciences

journal homepage: www.elsevier.com/locate/shpsc

Albert Howard and the mycorrhizal association

Merlin Sheldrake

University of Cambridge, Clare College, Trinity Lane, Cambridge CB2 1TL, United Kingdom

ARTICLE INFO

Article history:
Received 2 July 2011
Received in revised form 24 October 2011
Available online 22 November 2011

Keywords:
Albert Howard
Mycorrhizal fungi
Agricultural science
Intermediary
Colonial India
Hybridisation
Compost

ABSTRACT

Albert Howard worked as an imperial agronomist for the British Government in India. Following his retirement in 1931, he returned to England and embarked on a passionate global campaign to reform agricultural practices. Central to Howard's project was the mycorrhizal association, a symbiotic relationship between plant roots and subterranean fungi, believed to play an important part in plant nutrition. I show that there are a number of close parallels between Howard's work in India and his portrayal of the mycorrhizal association, and argue that Howard used these fungi to naturalise his imperial project. Understood in this way, these mycorrhizal and imperial associations reveal ways that Howard was able to negotiate the boundaries between the local and global, England and India, science and agriculture, institute and village, and soil and plant. In contrast to Thomas Gieryn's work on hybridisation at the cultural boundaries between science and non-science, I concentrate on Howard's use of intermediaries to negotiate and articulate specific boundaries within his imperial project. Arguing that this approach reveals limitations in Gieryn's hybrid framework, I suggest that a focus on Howard's dependence on intermediaries draws attention to the discontinuities between entities, besides the dynamic ways that they might be coupled.

> Can mankind regulate its affairs so that its chief possession—the fertility of the soil—is preserved? On the answer to this question the future of civilization depends.
> Albert Howard, *An Agricultural Testament*.

1. Introduction

In 1905, Albert Howard took up the post of Imperial Economic Botanist to the Government of India, and moved with his wife Gabrielle, to the Agricultural Research Institute at Pusa. In his twenty six years spent in India, Howard worked to breed new varieties of wheat and cotton, improve cultivation practices and revise systems of agricultural organisation and distribution. Most notably, as founding Director of the Institute of Plant Industry at Indore, Howard developed the Indore Composting Process, a method for efficiently recycling the breakdown of natural wastes into well-rotted humus, used to maintain the fertility of agricultural land. Like many of Howard's agricultural projects, the Indore Process was inspired by his observation of indigenous farming practices.[1]

Following retirement and his return to England in 1931, Howard, embarked on a global campaign to promote organic farming methods and the use of compost. He set himself in strong opposition to researchers at the Rothamsted Experimental Station for Agricultural Research, and argued that artificial manures could not possibly be substituted for organic fertilisers, insisting that soils required more than just the replenishment of nitrogen, phosphorus and potassium. Organic fertilisers (such as well-rotted compost) contributed to the structure and life of the soil, which, crucially, supported the health and productivity of crops, besides the animals and people that consumed them.[2] The main connective medium between soil and plant, Howard claimed, were mycorrhizal fungi, which formed filaments that joined the soil and plant roots,

E-mail address: merlinsheldrake@gmail.com

[1] Howard (1953, chap. 1) and Gieryn (1999, p. 235, 314).

[2] *Ibid.*; *Ibid.*

1369-8486/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.shpsc.2011.10.034

and underpinned healthy crop growth. In damaging this fungal connection, according to Howard, artificial fertilisers prevented the healthy transmission of nutrients from the soil into the crop.

Howard's battle with the Rothamsted researchers was ongoing. His evangelical stance on compost led him to communicate his ideas to many in non-scientific circles, and his antagonism towards the Rothamsted-based scientists can be seen to shape much of his later work. Particularly striking is his forceful rhetoric, which gained its traction partly from its relation to the contemporary organicist movement, in which notions of The Soil, The Organism, and ecological connectivity took on symbolic power. David Matless has characterised mid-twentieth century organicism as a 'political, aesthetic and ethical regard for the world' based on holistic interconnection,[3] and describes the priority given to soil in organicist discourse, over, for example, water and air. Soil frequently served as a 'base element' that could refract arguments about 'agriculture, nationhood, health, morality and spirituality'.[4]

Howard's relationship to the organicist movement went deeper, however, his 'dissident' science being used frequently to uphold organicists' vision of ecological and social interconnectivity.[5] This was illustrated by the organicist writer and agronomist, Lord Northbourne in Look to the Land (1940). Northbourne passionately folded the 'economic' and 'scientific' aspects of composting and manuring into the 'wonder and beauty and poetry of living' and urged his readers to see the 'poetry in the ever-recurring process of the conversion of ordure and decay into utility and beauty'.[6] For Guy Theodore Wrench, organic waste, 'shamefully misnamed', needed 'a poet to realise what beauty it contained'. The organicist spokesman and poet, Harold Massingham described an experience of his compost heap, in which he had been able to sense 'the immensity of Sir Albert Howard's conception of the endless circulation of organic matter through soil, plant and animal and back again' in a 'continuous chain of interwoven living processes'.[7]

Thomas Gieryn has used Howard to build a picture of the 'pliability and suppleness' of the cultural space of science, arguing that it was through cultural hybridisation that Howard was able to renegotiate the boundaries of his science. Whether in hybridising traditional knowledge and scientific experiment, India and Europe, or humans and soil, Gieryn suggests that Howard skilfully developed cultural fusions that could give credibility to his 'new' science.[8] But while Gieryn focusses on the hybridisation that took place on the cultural boundaries between science and non-science, I concentrate on Howard's use of intermediaries to negotiate and articulate specific boundaries within his imperial project. In exploring the commonalities between Howard's work in India, and his use of the mycorrhizal association, a clearer picture of Howard's understanding of both these boundaries and his imperial project emerges.[9] This approach also reveals limitations in Gieryn's hybrid framework. Hybridisation implies a fusion between previously separate entities. A focus on Howard's dependence on intermediaries draws attention to the discontinuities between entities (if they were fused, no intermediaries would be required), besides the dynamic ways that they might be coupled.

2. Howard's imperial agricultural science in India

Howard was critical of the fragmented, bureaucratic and departmentalised organisation of agricultural research in India and made a number of modifications to agricultural practices and organisation over the course of his career. Understanding agricultural science to be an applied subject, Howard concerned himself with more than the breeding of varieties and development of techniques, broadening his focus to include the restructuring of seed markets and distribution, fruit packing and display, the installation of dams and hydroelectric power stations, railway reform, and large scale rural development.[10]

One of his biggest objections was the division of the subject between local and central agricultural institutes, and the accompanying administrative problems and inefficiencies.[11] As it stood, provincial institutes were expected to work on problems peculiar to a region, while the smaller number of central institutes performed long- and wide-range research 'of a more or less fundamental character', besides reporting on the results of the provincial research institutes. In Howard's view, this 'artificial division' between long-range and local problems, between fundamental and local research was founded on misunderstanding. To justify this division, Howard argued, the functions of these two types of research institute had to be defined and separated to prevent overlap. However, overlap and inefficiency were unavoidable, despite attempts to provide satisfactory definitions of these two classes of research. This was not for lack of trying, Howard argued, but because of the folly of any such disciplinary division.[12] To make such distinctions was to 'erect walls where, from the nature of the case, the rule should be - no walls'.[13] Agricultural research could and should not be carved up according to conventional disciplinary templates.

Howard's problem with this division between central and local research was based on his understanding of agricultural practices as inherently local phenomena. With regard to crops and their problems, it was 'not the plant alone that has to be studied but the plant in relation to its environment'.[14] He was not alone in this view. One of his contemporaries, Martin Leake, Economic Botanist to the Government, and Principal of the Agricultural College in Cawnpore, argued that agriculture was the 'successful handling of the plant in relation to soil and climate'. Not only did 'local conditions themselves form the subject-matter of investigation', but this study of local conditions was a 'special feature' of agricultural research in which, 'probably more than in any other class', 'the lines of investigation cut across the commonly accepted divisions of science'. Agricultural research required local knowledge. As such, division of research into central and local was obstructive and misguided.[15] While Leake focussed on the importance of physical conditions, such as soil and climate, Howard stressed the importance of all aspects of

[3] Matless (2001, pp. 356–357).
[4] Matless (1998, p. 106).
[5] *Ibid*., p. 110.
[6] Northbourne (1940, p. 71).
[7] Cited in Matless (1998, p. 108).
[8] Gieryn (1999, p. xi, 15, 335).
[9] Agricultural science may constitute a key component of imperial rule. It has been argued that agricultural science and technology may 'serve as powerful instruments' for maintaining social orders, and 'for inculcating subjectivities' associated with these orders, and that in this way they may constitute a 'fundamental instrument of governmentality'. This is discussed with reference to Imperial China in Bray (2008, p. 327).
[10] Gieryn (1999, pp. 278–285).
[11] Howard & Howard (1929a, p. 58).
[12] Ibid. p. 59.
[13] Ibid. p. 60.
[14] Howard (1924, p. 186).
[15] Leake (1918, p. 600).

their environment, whether 'the soil in which it grows', 'the conditions of village agriculture under which it is cultivated' or 'the economic uses of the product',[16] paying particular attention to the 'village as a whole, to its people, to their ideas, and to their general condition and outlook'.[17] Even the irrigation of crops was not a simple matter, lying 'far outside the province of the engineer' and embracing 'not only the health and well-being of the people but also the main facts of rural economy as well as the problem of maintenance of the fertility of the soil'.[18] Unlike other kinds of science, the findings of agricultural research could not be expected to work everywhere, in principle.[19]

In Howard's view, social, cultural and economic concerns were a part of agricultural science, which as a discipline could not be viewed in isolation any more than the plants it studied. It was of 'supreme importance' that the 'Indian village and its fields' should be dealt with 'as a single subject'.[20] This was a science concerned with practices that had economic value, and unless its new methods could be communicated to the 'cultivators', and 'welded permanently into the rural economy', there was little point to the enterprise.[21] However, it was not just local cultivators that could learn from the findings of organised agricultural research. Howard saw the flow as two-way, as he reminded the audience at his Presidential Address to the Thirteenth Indian Science Congress in 1926, describing some of the many 'lessons which agriculture has taught and is still teaching the scientific investigator'. Both science and agriculture had 'profited from the association' between them.[22] Agriculture 'must be simultaneously looked at from the point of view of the cultivator and of the student of science'.[23] Useful knowledge could pass in both directions. The relationship was to be viewed as mutually beneficial.

Howard's design for the Institute of Plant Industry at Indore was based on these views. First, as stated in its objectives, its purpose was to break down a disciplinary distinction, pursuing both fundamental research, and the production of improved cotton varieties for the region.[24] Second, Howard worked to closely co-ordinate the 'association' between 'the scientific and agricultural aspects of the work'. As Director, he saw himself as an intermediary, and his job as one of 'welding these two aspects of one subject into a real working unit', avoiding the opposition that tended to develop between the scientific and agricultural staff employed 'in all institutions of this nature'. To this end he positioned the laboratories and farm buildings side by side,[25] and developed demonstration technologies that would bring 'the cultivator and the results together'.[26] Third, he placed great emphasis on education and demonstration, attributing any previous progress in imperial agricultural science to 'demonstration and persuasion carried on by men touring in the districts'.[27] These were not just features of the new Institute, but organising principles. Howard did not pursue connectivity for its own sake, but as a means to a practical end.

'The art of demonstration and of inducing cultivators to adopt improvements', Howard asserts, 'is as important as that of research'.[28] It was through the establishment of networks of trained demonstrators that Howard was able to mobilise his findings, and negotiate between the local conditions of the Institute and surrounding villages and states. He insisted that it was not enough just to 'bring the results to the notice of the people'.[29] They must become 'willing partners'.[30] The whole country-side must 'demonstrate the results'.[31] However, given that the men and women, 'on whom all developments in Indian agriculture must depend' could 'neither read nor write',[32] all persuasion would have to be done in person. These 'demonstrators' would have to function as intermediaries, circulating between the Research Institutes and the cultivators working in the surrounding region. Demonstrators would not be effective if 'regarded almost as a stranger' by cultivators. Rather, they must be people who are 'in sympathy with him, who understand his point of view, who speak his language, wear his dress, and who can live in his village'. But they must also 'possess the education and knowledge necessary' to understand their role: to move smoothly between the contrasting cultures and epistemologies of the research institute and village, translating between them while retaining their ability to operate in both domains.[33]

Howard created this new role to his own specifications. That no-one was qualified to play this part was one of Howard's 'greatest difficulties': 'the ideal agents for future work in the countryside' would not only 'have to be trained',[34] but acknowledged and remunerated as part a 'separate and honoured profession'.[35] He employed two approaches. First, he used the 'labour force of the Institute as a training ground' to 'export every year a number of trained workmen'. Such men, 'needed in large numbers', would train for at least a year, passing 'through the various sections of the Institute' before becoming 'available for service in the States'.[36] The second approach was to hold cultivators' meetings at the Institute's demonstration farm, the first of which took place in January 1928. Groups of cultivators from eleven neighbouring States were sent by the State Agricultural Departments, and housed nearby. Investment in good roads means that the cultivators might be 'transported to and from the Institute daily in motor lorries'. Following the first cultivators' meeting, the Institute received a 'growing stream of visitors'. Visiting cultivators from the villages would frequently stay and 'work for a time to learn new methods' before returning home. The Institute at Indore soon began to demonstrate how to demonstrate. State Agricultural Departments opened their own

[16] Howard & Howard (1929a, p. 1).
[17] Howard & Howard (1929b, p. 31).
[18] Howard (1926, pp. 178–179).
[19] Schaffer et al. (2009, p. xxii).
[20] Howard & Howard (1929b, p. 83).
[21] Ibid. p. 58.
[22] Howard (1926, p. 171).
[23] Howard (1924, p. 187).
[24] Howard & Howard (1929a, p. 4, 39).
[25] Ibid. p. 9.
[26] Ibid. p. 54.
[27] Howard & Howard (1929b, p. 57).
[28] Howard & Howard (1929a, p. 60).
[29] Howard & Howard (1929b, p. 58).
[30] Ibid. p. 84.
[31] Howard & Howard (1929a, p. 38).
[32] Howard & Howard (1929b, p. 57).
[33] Howard & Howard (1929b), Star & Griesemer (1989), p. 389–93), Schaffer (2009, p. xix; p. 84–5) and Raj (2010, p. 515–6).
[34] Ibid. pp. 84–85.
[35] Howard & Howard (1929a, p. 60).
[36] Ibid .pp. 52–53.

demonstration farms in several of the Central India States. In such cases, the State Officers in charge of the work were 'sent to the Institute for a definite period of training', that they might 'thoroughly understand the work they have to do among the people'.[37] The reasons for this success were economic. This was knowledge that could be translated into edible wealth via the soil. Demonstrators were brokers, and could profit from mediating a transaction of valuable agricultural knowledge between disparate parties.

The expansion of the boundaries of imperial agricultural science to include demonstration allowed Howard clearly to articulate and schematise the role of the intermediary. These demonstrating go-betweens were recognised to perform a role 'equally important' as research,[38] and were consequently made a visible part of Howard's imperial science.[39] Howard acknowledged that these intermediaries were individual agents, anchored in their own lives with their own backgrounds, interests and specialised skills, and that it was these qualities that would make them effective demonstrators. At the same time however, he portrays them as a passive technology, a deployable workforce united by their shared purpose, in need of supervision and not to be trusted entirely. They were both active agents and a purpose-built social apparatus, both local residents and tools for imperial expansion, both visible and anonymous, individual and generic. When framed as the latter, Howard becomes the ingenious intermediary inventing and operating a piece of social machinery. When framed as the former, the individuals themselves become the intermediaries, their movement defining a frontier zone.[40] In casting the role of the demonstrating intermediary as distinct from both researchers and villagers, Howard underscored the division of labour present in his imperial science, and drew attention to the distance between the domains that they were intended to bridge. Like a bridge, these intermediaries would connect while defining a separation, a separation that spoke for the importance of the connection. The worlds of Research Institute and village could be coupled but not fused.

3. Howard's mycorrhizal association

On his return to England in 1931, Howard set to work globally publicising his Indore system of composting. He argued that the application of composted waste matter, or humus, to agricultural land would produce higher quality crops than artificial manures, and increase resistance to disease.[41] In 1936, Howard came across the mycorrhizal association.[42] Occurring in 'wild and cultivated plants' growing 'in habitats so different as the high Alps and the salt marsh', the mycorrhizal association was understood to be a symbiosis in which certain soil fungi and plant roots co-inhabit the boundary between plant roots and the soil, forming 'regular and intimate associations'. Strands of the subterranean fungal mesh, or mycelium, would 'infect' plant roots, growing into the plant cells.[43] Howard first learned of the mycorrhizal association from the mycologist Mabel C. Rayner's 'remarkable' study of the mycorrhizal responses of conifers.[44] Rayner gave evidence that the mycorrhizal habit played 'a significant part in the nutrition of coniferous trees',[45] and provided for Howard a 'full and sufficient' explanation of the rapid impact of humus application on crop quality and health, which until this point he had had 'considerable difficulty understanding'.[46] While mycorrhiza were good for plants, and humus good for mycorrhiza, artificial fertilisers were found to disrupt the mycorrhizal association.[47] Howard made the mycorrhizal association a key link in his argument, bridging his claim that humus worked (practice), and his explanation of why humus worked (theory); his claim that artificial fertilisers were deleterious, and his explanation of why they were deleterious.[48] In his campaign, mycorrhizal fungi played the role of his demonstrators in India; coupling agricultural research and agricultural practice, knowledge that with knowledge how, local indigenous knowledge with scientific knowledge.

Howard rapidly positioned himself as an mediating figure in an global network of mycorrhizal exchange. He arranged for root samples of a wide range of crops from around the world, grown with and without humus, to be sent to Rayner ('a well-known authority on mycorrhiza') for microscopic examination. Rayner compiled technical reports commenting on the details of mycorrhizal infection.[49] Howard analysed and publicised the descriptions contained in the reports. 'For the interpretation of these laboratory results', Howard states clearly in his introduction to An Agricultural Testament, 'I am myself solely responsible'.[50] Howard operated in the space between the agricultural scientists and plantation owners who prepared and sent the samples, and the expertise of Dr. Rayner who observed them. Whether sugar cane roots from India, Louisiana and Natal; cotton and rice roots from Central India; tea roots from Ceylon; vine roots from Provence; or coffee roots from Travancore and Costa Rica, Howard described plants grown with humus to be healthier, of higher quality, and have greater incidence of mycorrhizal infection than those grown without.[51] Like the networks of demonstrating intermediaries in India, the fungi became a tool to negotiate an expansion of his field of influence, this time on a global scale. Through Howard, mycorrhizal fungi connected the mycologist in England with cultivators worldwide, 'reconciling at one bound science and the age-long experience of the tillers of the soil as to the supreme importance of humus'.[52] It was not just cultures of research and agricultural practice that could be linked by these fungi, however. As Howard announced, the mycorrhizal association was 'not confined to one particular forest crop'. It occured 'in most if not all of our cultivated plants'. It was 'probably universal'.[53] A lot was at stake. It was on these fungi that 'the health and well-being of mankind must depend'.[54]

[37] Ibid. pp. 8, 55–56.
[38] Howard & Howard (1929a, p. 61).
[39] This contrasts with the general tendency of the sciences to make intermediaries and networks of circulation invisible in the decades following 1800, as discussed in Schaffer (2009, pp. xxi–xxx).
[40] Kohler (2002, pp. 15–16).
[41] Howard (1945, chap. 1).
[42] Howard (1940), p.x.
[43] Rayner (1939, pp. 171–172).
[44] Howard (1940, p.x) and Howard (1945, chap. 1).
[45] Rayner & Neilson-Jones (1944, pp. 134–135).
[46] Howard (1937, 1945, chap. 1).
[47] Howard (1940, p. 60).
[48] Howard (1940, p. x) and Howard (1945, chap. 1).
[49] Howard (1938, p. 310).
[50] Howard (1940, p. x).
[51] Howard (1940, pp. 61–2, 68, 82, 85).
[52] Ibid. p. 168.
[53] Ibid. p. 166.
[54] Ibid. p. 25.

Most of Howard's discussion of mycorrhiza occurs in books and lectures, with relatively little coverage in scientific papers. In the same way that he had made his networks of demonstration visible in India, the mycorrhizal association was a linking entity that had to be made visible to as wide an audience as possible, both scientists and non-scientists. Popular publication was a way for Howard to position himself as a demonstrating intermediary, besides giving him more expressive license than scientific papers would permit. This may account both for his rhetorical force, and the breadth of his coverage (from Provençal anecdote, to personal experience with an apple tree in his garden, to field trial in Costa Rica). Howard was careful to account for this license, building room for his interpretation within the existing corpus of mycorrhizal research by casting the major questions as open, reminding his readers that there was no 'complete scientific explanation' of the working of this 'remarkable' symbiosis, the details of which were 'still being investigated and discussed'.[55]

Howard characterised mycorrhizal fungi as a medium of connectivity across the plant-soil boundary. They are presented as conductive spaces, as mediating the transit of 'nutrition' and 'health' from soil to plant. Mycorrhizal fungi 'directly connect the humus in the soil with the roots of the crop';[56] offer a 'rapid and protected passage' by which nutrients may enter the plant;[57] constitute 'Nature's channels of sustenance' between the soil and the plant;[58] provide a way that the soil and sap of a tree might be 'joined up';[59] and by which nutrients may 'circulate between soil and crop'.[60] Mycorrhizal fungi are presented not just as nutritional conduits, but major factors in the maintenance of plant health. They are 'one of Nature's ways of helping the plant resist disease',[61] and are vessels for the 'transmission of disease resistance from the fertile soil to the plant'.[62] In Howard's language we also see an acknowledgment of the discontinuity between domains of soil and plant. They are not in themselves one, but must be connected by a separate entity. The fungi operate at the boundary between soil and plant; they constitute a zone of contact. In this sense, the representation of mycorrhiza as essentially connective elements serves both to link domains, and to remind us that this connection is necessary besides important. By association, anything that assists or damages the mycorrhizal relationship is similarly rendered necessary and important. In both connecting and defining separation, the role of mycorrhizal fungi in the soil echoes that of the demonstrator in India.

Howard was unusual in the emphasis he gave to this aspect of the symbiosis. In contemporary literature on mycorrhiza, the association was frequently characterised as a relationship between plant and fungus, a perspective that contrasted with Howard's understanding of them as connecting plant and soil. This focus on the conjunction between plant and fungus was present in morphological and physiological work as well as ecological study. Specialised organs were described as mediating connectivity between plant and fungus.[63] Connections between toadstools and trees were identified as taking place through the medium of the soil.[64] By contrast, in Howard's understanding it was the connection between plant and soil that was central, a connection that took place through the medium of the fungus. While some mycologists did understand mycorrhizal fungi to be couplers between plant and soil, this was a view that had been folded into a long-running debate about the role of mycorrhizal fungi in plant nutrition.[65] Were the fungi parasitic on the plant, or did both partners benefit? Where did the 'balance of power' lie?[66] By the time Howard became interested in mycorrhiza it had been generally established that the relationship was mutually beneficial,[67] and that the fungi did conduct nutrients from the soil into the plant. However, most mycologists did not privilege this connection as much as Howard, and frequently drew attention back towards the plant-fungus interaction and the dynamics of the symbiosis.[68] Rayner, Howard's closest ally in the mycological world, agreed with him that the mycorrhizal association was of great importance in plant nutrition and health (in a paper in the Empire Cotton Growing Review, Rayner set out her 'deliberate opinion' on the matter, expressing confidence in 'the correctness of the main conclusions' proposed by Howard).[69] However, in her popular work Trees and Toadstools (1945), there is only a single statement referring to a 'direct connection' between the plant and soil.[70]

Through technological metaphors the agency of the fungus is variously subordinated to the elemental agencies of plant and soil. The most commonly recurring epithet is the 'living fungous bridge' that connects the 'humus in the soil' and the 'sap of plants', a phrase used at least five times in An Agricultural Testament.[71] We see variations on this theme in the form of the 'living bridge',[72] 'rich living threads', and 'living fungous threads'.[73] Even more pronounced is Howard's portrayal of mycorrhizal fungi as 'a piece of living machinery'[74] provided by Nature 'for joining up a fertile soil with the plant', and by which means the plant and soil may 'come into gear'.[75] The fungus is the living means to a connective end. Rhetorically figured as technologies ('bridges', 'threads', 'machinery'), the fungi are passive. At Nature's behest, they accomplish a necessary task to the benefit of plant and soil. Like Howard's 'trained' and 'exported' Indian workforce, they appear as the tool of the intermediary rather than as intermediaries themselves.

However, just as the demonstrating go-betweens in India depended on their individual personalities to be effective, the mycorrhizal fungi are also cast as purposeful active agents, that may profit in their role as mediators between the plant and soil. In

[55] Ibid. p. 24, 168.
[56] Howard (1940, p. 166).
[57] Howard (1937).
[58] Howard (1938, p. 310).
[59] Howard (1945, chap. 2).
[60] Ibid. chap. 13.
[61] Howard (1937).
[62] Howard (1945, chap. 7).
[63] Rayner (1927, pp. 58–62) and Butler (1939, p. 289).
[64] Rayner (1945, chap. 3).
[65] Rayner (1927, p. 1, 18, 52) and Rayner (1945, chap. 3).
[66] Rayner (1927, p. 217).
[67] Ibid. p. 204; Butler (1939, p. 298).
[68] Rayner (1927, p. 204, 217) and Butler (1939, p. 290, 298).
[69] Rayner (1939, pp. 178–179).
[70] Rayner (1945, chap. 3).
[71] Howard (1940, p. x, 25, 37, 99, 223).
[72] Ibid. p. 25.
[73] Howard (1945, chap. 1).
[74] Ibid. chap. 7; Howard (1940, p. 61).
[75] Howard (1940, p. 168) and Howard (1942).

one instance, it is by means of the mycorrhizal fungi that 'the marriage of a fertile soil and the tree it nourishes' is 'arranged'. Howard describes the fungus as facilitator of this 'intimate contact',[76] a matchmaker or go-between in the original sense of the word.[77] In another instance, humus in the soil is said to affect the plant 'by means of a middleman - the mycorrhizal association'.[78] These metaphorical associations present mycorrhizal fungi as brokers, and are congruent with organicists' writings on the 'soil economy'. In this view, David Matless describes, 'soil becomes the root of economy as well as of everything else'.[79] 'Soil capital' is constantly replenished in the cycling of nutrients between humus in the soil and living organisms.[80] Howard frames the soil as a store of 'natural wealth' representing 'centuries of accumulation',[81] while organic waste is considered to be 'wealth seeking investment'.[82] If inadequate consideration was given to rules of return, the soil would become 'impoverished'.[83] In Howard's understanding, mycorrhizal fungi brokered the transaction of organic capital between the plant and the humus in the soil.

The force of Howard's rhetoric derives partly from its relation to the contemporary organicist literature on life and death. Mycorrhizal fungi were not just about organic profit. Rather, as denizens of the soil, they spoke for a living earth. Lady Eve Balfour, a leading proponent of organicism and founding president of the Soil Association, proposed that 'our attitude to the soil is dependent on our attitude to life in general'.[84] Humans were part of this ecological picture, and had to be understood in relation to a soil 'teeming with life', life that could be, and must not be killed.[85] Viewed in this context, Howard's portrayal of mycorrhizal fungi as 'living bridges', 'channels' and spaces of circulation, may be seen to join the realm of the soil with that of the plant, which in turn sustained humans and all other life.

4. Imperial and mycorrhizal associations

Howard's work in India is closely mirrored in his portrayal of mycorrhizal fungi. There are a number of associations, whether between the mutually beneficial relationship of science and indigenous agricultural practice, and of plant and fungus (in its role as conductor of nutrients and health from the soil); the demonstrators as linking the places of theory and practice, and mycorrhiza as linking Howard's theory with his practice; demonstrators and mycorrhiza both as means to negotiate expansion between local, regional or global scales, and as delineating and confusing the boundaries between them;[86] Howard as interdisciplinary intermediary in his expanded science in India, and in similar capacity in his mycorrhizal research in England; and in the active and passive qualities of both the demonstrators in India and mycorrhizal fungi.

These reflections are both revealing of Howard's understanding of his imperial project, and a part of it. Howard saw in the mycorrhizal association a recapitulation of his modified agricultural science in India, and used the fungi to naturalise his imperial project, grounding his work in what was seen to occur in nature. This naturalising tendency is further evidenced by his aversion to artificial manures. These, Howard lamented, would 'lead inevitably to artificial nutrition, artificial food, artificial animals, and finally to artificial men and women'.[87] That the template of his imperial agricultural science could be articulated through the mycorrhizal association was guarantor of its validity. As a project it was congruent with natural workings of Nature, and thus set apart from the fragmented agricultural sciences that he criticised. The mycorrhizal association was fundamental to the lives of everybody everywhere. It validated his approach, and in its universality provided a platform for the global expansion of his local methods.

There is a recurring tension between the significance that Howard attributes to local and global phenomena. A plant must be understood as product of a peculiarly local environment. At the same time, all plants, everywhere, respond to humus. Agriculture must be simultaneously looked at from the point of view of local cultivators and of the student of science.[88] Demonstrating go-betweens must be active agents, individuals, able to fit in with the local customs of a village, and at the same time a generic and anonymous workforce, 'exported' from Institutes by Howard. Mycorrhizal fungi are both brokers, deliberately mediating transactions between the plant and soil, and a passive technology, deployed by a purposive Nature. Depending on which perspective is emphasised, the demonstrator, fungus, Howard, and Nature all seem to take on the role of intermediary. This is not because any of them cease to be intermediaries. It is just that in Howard's hands they are made more or less visible in different contexts. Given that Howard firmly positions intermediaries as a part of his science, the different ways that he chooses to make them visible can tell us something about his perception of the task in hand and reflect his understanding of the boundaries that he had to negotiate.

These tensions also draw attention towards Howard's hybridising tendencies. Given that local conditions were paramount, any exported notion (whether from the farm buildings to the lab buildings at Indore, or from the Indore Institute to the neighbouring village, or from Howard to the whole of humanity) had to be subject to hybridisation in different places to be re-localised. Gieryn emphasises that this hybridisation is a sort of boundary work, a re-staking of the frontier between science and non-science. But the notion of hybridisation closes the gap between the 'merged' cultures. Howard's intermediaries reveal the ways in which the gap could not been closed, and the processes by which Howard had to acknowledge and negotiate these boundaries as part of his heterodox imperial project. In looking at the coupler (whether human or fungal) we may see the way in which complete fusion has not taken place, a nuance that may be obstructed by the classification of hybrids. It also shows that these boundary negotiations may take place within a given conception of the cultural space of science, not just on the margins. In confusing and rearranging boundaries, Howard's work illustrates that what is marginal is not always clear, and that the points of contact between science and non-science may be too variable to constitute a single, identifiable boundary. Like the hybrid notion, a focus on science versus

[76] Howard (1945, chap. 2, 7).
[77] Schaffer (2009, p. ix).
[78] Howard (1945, chap. 7).
[79] Matless (1998, p. 113).
[80] Massingham (1941, p. 129).
[81] Howard & Wad (1931, chap. 2) and Howard (1945, chap. 3, 5).
[82] King (1913, p. 68).
[83] King (1911, p. 241) and Broadbent (1943).
[84] Balfour (1943, p. 194).
[85] Ibid. p. 17.
[86] Finnegan (2008, p. 385).
[87] Howard (1940, p. 37).
[88] Howard (1924, p. 187).

non-science may serve to obscure the internal character of the boundaries more than reveal them.

5. Concluding remarks

Howard reordered the boundaries of his imperial agricultural science to include the social and economic elements of a crop's environment. In doing so, he made networks of demonstration and mediation a visible feature of his science, and was clearly able to articulate and schematise the role of the intermediary in his imperial work. Back in England, Howard used mycorrhizal fungi to explain why humus positively affected the growth and disease resistance of crops. Howard understood the fungi to be intermediaries, mediating exchange between plant and soil, and was able to naturalise his imperial project using the mycorrhizal association. Through Howard's portrayal of mycorrhizal fungi, we may learn something about the way he perceived the role and scope of his imperial science. While Gieryn draws attention to the hybrid nature of Howard's work, a focus on his networks of intermediaries reveals that Howard frequently bridged rather than eliminated gaps. The way that Howard chose to naturalise his imperial project reveals blockages and flows in the circulation of natural (and artificial) knowledge, and provides new vantage on the study of boundary issues in the history and sociology of knowledge.

Acknowledgements

I would like to thank Helen Macdonald, Nick Jardine, and Patricia Fara for their guidance and feedback.

References

Balfour, E. B. (1943). *The living soil: Evidence of the importance to human health of soil vitality, with special reference to post-war planning*. London: Faber.

Bray, F. (2008). Science, technique, technology: Passages between matter and knowledge in imperial chinese agriculture. *The British Journal for the History of Science, 41*, 319–344.

Broadbent, H. R. (1943). Cited in Howard (1945, chap. 5).

Butler, E. J. (1939). The occurrences and systematic position of the vesicular-arbuscular type of mycorrhizal fungi. *Transactions of the British Mycological Society, 22*, 274–301.

Finnegan, D. (2008). The spatial turn: Geographical approaches in the history of science. *Journal of the History of Biology, 41*, 369–388.

Gieryn, T. F. (1999). *Cultural boundaries of science. Credibility on the line*. Chicago: University of Chicago Press.

Howard, A. (1926). Agriculture and science. Presidential address to the thirteenth Indian science congress, Bombay, January 1926. *Journal of Indian Agriculture, 21*, 171–182.

Howard, A. (1937). *Manufacture of humus from the wastes of the town and village: Lecture at London School of Hygiene and Tropical Medicine*, 17 June, 1937. <http://journeytoforever.org/farm_library/medtest/medtest_refs.html#howard1> (accessed 17.10.11).

Howard, A. (1938). The mycorrhizal relationship in cotton production. *Empire Cotton Growing Review, 15*, 310–311.

Howard, A. (1940). *An agricultural testament*. Oxford: Oxford University Press.

Howard, A. (1942). Soil fertility and health. In Doris Grant, Feeding the Family in War-time, Based on the New Knowledge of Nutrition. Harrap: London. <http://journeytoforever.org/farm_library/medtest/medtest_greenwell.html#howard> (accessed 17.10.11).

Howard, A. (1945). *Farming and gardening for health and disease*. London: Faber & Faber.

Howard, L. M. (1953). *Sir Albert Howard in India*. London: Faber and Faber.

Howard, A., & Howard, G. L. (1929b). *The development of Indian agriculture. India of today*, Vol. 8, (2nd ed.). London: H. Milford: Oxford University Press.

Howard, A., & Howard, G. L. (1929a). *The application of science to crop-production: An experiment carried out at the institute of plant industry, Indore*. London: H Milford: Oxford University Press.

Howard, A., & Wad, Y. (1931). *The waste products of agriculture: Their utilization as humus*. London: H Milford: Oxford University Press.

King, F. H. (1911). *Farmers of forty centuries or permanent agriculture in China, Korea and Japan*. Madison: Wisconsin.

King, F. H. (1913). *The soil: Its nature, relations and fundamental principles of management*. New York: Macmillan.

Kohler, R. E. (2002). *Landscapes & labscapes: Exploring the lab-field border in biology*. Chicago: University of Chicago Press.

Leake, H. M. (1918). The organization of agricultural research in India. *Agricultural Journal of India, 13*, 583–607.

Massingham, H. J. (1941). Introduction. In H. J. Massingham (Ed.), *England and the farmer* (pp. 6–7). London: Batsford.

Matless, D. (1998). *Landscape and Englishness*. London: Reaktion.

Matless, D. (2001). Bodies made of grass made of earth made of bodies: Organicism, diet and national health in mid-twentieth-century England. *Journal of Historical Geography, 27*, 355–376.

Northbourne, Lord W. J. (1940). *Look to the land*. London: Dent.

Raj, K. (2010). Introduction: Circulation and locality in early modern science. *British Journal for the History of Science, 43*, 513–517.

Rayner, M. C. (1927). *Mycorrhiza: An account of non-pathogenic infection by fungi in vascular plants and bryophytes. New phytologist reprint no. 15*. London: Wheldon & Wesley.

Rayner, M. C. (1939). The mycorrhizal habit in crop plants with a reference to cotton. *Empire Cotton Growing Review, 16*, 171–179.

Rayner, M. C. (1945). *Trees and toadstools*. London: Faber and Faber.

Rayner, M. C., & Neilson-Jones, W. (1944). *Problems in tree nutrition: an account of researches concerned primarily with the mycorrhizal habit in relation to forestry and with some biological aspects of soil fertility*. London: Faber and Faber.

Schaffer, S. (2009). *The brokered world: Go-betweens and global intelligence, 1770–1820*. Sagamore Beach, MA: Science History Publications.

Star, S. L., & Griesemer, J. R. (1989). Institutional ecology, 'Translations' and boundary objects: Amateurs and professionals in Berkeley's museum of vertebrate zoology, 1907–39. *Social Studies of Science, 19*, 387–420.