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The phytotronist and the phenotype: Plant physiology, Big Science, and a Cold War biology of the whole plant

David P.D. Munns

Department of History, John Jay College, The City University of New York, 524 W. 59th St., New York, NY 10019, USA

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ABSTRACT

This paper describes how, from the early twentieth century, and especially in the early Cold War era, the plant physiologists considered their discipline ideally suited among all the plant sciences to study and explain biological functions and processes, and ranked their discipline among the dominant forms of the biological sciences. At their apex in the late-1960s, the plant physiologists laid claim to having discovered nothing less than the "basic laws of physiology." This paper unwraps that claim, showing that it emerged from the construction of monumental big science laboratories known as phytotrons that gave control over the growing environment. Control meant that plant physiologists claimed to be able to produce a standard phenotype valid for experimental biology. Invoking the standards of the physical sciences, the plant physiologists heralded basic biological science from the phytotronic produced phenotype. In the context of the Cold War era, the ability to pursue basic science represented the highest pinnacle of standing within the scientific community. More broadly, I suggest that by recovering the history of an underappreciated discipline, plant physiology, and by establishing the centrality of the story of the plant sciences in the history of biology can historians understand the massive changes wrought to biology by the conceptual emergence of the molecular understanding of life, the dominance of the discipline of molecular biology, and the rise of biotechnology in the 1980s.

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1. Introduction

In 1965, volume three of Doubleday's new, glossy *Encyclopedia of the Life Sciences* arrived in the mailboxes of enthusiastic readers of popular science. Volume two had shown them the world of animals, and now the next installment promised remarkable vistas from the world of plants. The book's introduction noted that plants formed the foundation of life on earth because they convert the sun's energy into organic matter, permitting all insect, animal, and human life to exist. Readers learned startling facts of nature like, "cold conditions are necessary to break the dormancy of seeds" in peaches and apples, illustrated by a photograph showing that apple seeds exposed to cold germinated, while ones kept at constant temperature did not (Chouard & Nitsch, 1965, p. 97). Scientists had discovered such facts, readers were told, via remarkable new scientific facilities called phytotrons, climatrons, and biotrons. Around the height of Cold War technological optimism, readers may have been struck by such evocatively named facilities and, the authors certainly hoped, recognized them as the modern face of plant science. The authors, Pierre Chouard and Jean-Paul Nitsch, believed that these grand laboratories of plant science were at last breaking open the study of the environment's effects on plants. For Chouard and Nitsch, the directors of *le grand phytotron* outside Paris, it was the "reproducible … experimental conditions" of phytotrons that revealed the "basic laws of the physiology of plants" (Chouard & Nitsch, 1965, p. 103).[1]

Beginning with heated greenhouses, a variety of instruments, facilities, and programs gave plant physiologists increasing degrees of control over the growing environment of plants since the late-nineteenth century: one corner of the laboratory revolution

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E-mail address: dmunns@jjay.cuny.edu.

[1] For the French C.N.R.S. phytotron at Gif-sur-Yvette see Chouard (1969), pp. 1–3, and Chouard & de Bilderling (1975). For a brief biography of Chouard, see Champagnat (2012), pp. 61–102. For a view of technological optimism in France, see Bess (1995), pp. 830–862; and Hecht (2009). As Wisnioski (2012) and Wolfe (2014), chap. 7 valuably explore, the technological optimism of the 1950s and 60s was thrown into sharp relief by the cultural crisis of confidence in science of the late-1960s and early 1970s.

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sweeping science (de Chadarevian, 1996). "The use of equipment where external conditions can be controlled in physiological studies is as old as plant physiology itself," noted the Dutch plant physiologist Theodore Alberda as he surveyed the field in the late 1960s (Alberda, 1970, p. 591). Historians of biology are aware of one famous early controlled environment laboratory, the Vivarium that opened in 1903 in Vienna. As Deborah Coen explored, the Vivarium's founders, Hans and Karl Przibram, aimed at the "mastery of the environment." Their laboratory served to concretize their belief that "precision would soon be the driving force in biology" akin to the physical sciences (Coen, 2006, p. 498). Subsequently, many facilities for controlling environments in biological experimentation appeared in guises such as Herman Spoehr's rudimentary constant-temperature chambers built at the Carnegie Institution's department of plant biology in the 1930s (Craig, 2005, pp. 62–63).[2] By the mid-1950s, a variety of chambers, rooms, and facilities to control some array of climatic factors had spread throughout the plant sciences. Otto Frankel, chief of Australia's major plant research group, the Division of Plant Industry, observed on his grand tour through the United States that "controlled environment facilities are now, at least to some degree, part and parcel of every of every botanical institution."[3]

Frankel witnessed, and then helped, a technological revolution take over the plant sciences. Between 1949 and the 1970s, phytotrons emerged as centralized and cybernetic laboratory spaces; another aspect of the broad joining of technology and biology.[4] The first phytotron, officially named the Earhart Plant Research Laboratory, was the creation of famed plant physiologist Frits Went and opened in 1949 at the California Institute of Technology (Caltech) (Kingsland, 2009; Munns, 1999, 2014). Subsequently, in just under thirty years, over thirty countries eventually built phytotrons, the largest examples being in France, the Soviet Union, and Australia (Evans, Wardlaw, & King, 1985). The Americans built the most, nearly a dozen, including the prominent examples at Duke, Yale, North Carolina State, and Michigan State Universities, as well as the national Biotron at the University of Wisconsin–Madison (Appel, 2000, pp. 183–186). Meanwhile a host of smaller examples occupied large portions of research budgets in Sweden, New Zealand, Canada, Hungary, Germany, the Netherlands, India, and Japan. In all phytotrons, new fluorescent tube lighting, heralding control of light spectrums and intensities, joined with new air-conditioning systems and control over temperature, new systems of humidity control, nutrient standardization, photoperiod control, sterilization protocols, and measurable air-flow. At their center, new computer systems gave control of control (Chouard, 1969; Downs, 1980; Went, 1957a).

Though it must be left to future work to explore, during the 1980s, phytotrons were forgotten like encyclopedia volumes left on coffee tables or shelved in bookcases. But at their height in the late-1960s, phytotrons seemed the modern face of the plant sciences. Alberda described the, to him, commonplace facility: "today," he reminded his audience, "a number of so called growth rooms and/or conditioned glass houses are often built together to form what is usually called a phytotron. Such units make it possible to study plant behaviour in its broadest sense under a diversity of climatic conditions where it is possible to vary each factor without appreciably altering the others" (Alberda, 1970, p. 591). Plant scientists generally considered phytotrons the most complete expressions of environmental control and many, like Chouard, readily advertized the fact. Frankel, for instance, returned to Australia from his tour of the United States convinced that antipodean plant science required a phytotron, and had it built by 1962 (Munns, 2010). Also in 1962 Went told a conference audience how a "tool" like his phytotron appealed to numerous "branches of the Plant Sciences" and their quest for the "understanding of the living plant" (Went, 1962, p. 378). A French phytotronist intoned how the phytotron served to "dissect the mechanisms of the plant as the cyclotron had the atom" (Augier, 1972, p. 4). In the future, biologists would one day also need a "marinetron" for water biology, said Donald Griffin, the discoverer of echolocation.[5] Chouard confidently prophesized that biology was "entering … a Phytotronic era" (Chouard, 1974, p. 5).

This paper describes a particularly dramatic moment of the technological revolution in biology: the moment when plant physiologists claimed the discovery of the "basic laws of physiology" via phytotrons. As we shall see, that claim was situated and legitimated within a number of interrelated contexts. Firstly, from the early twentieth century, plant physiologists considered their discipline ideally suited to study and explain biological functions and processes, and ranked their discipline among the dominant forms of the biological sciences from the 1920s onwards. Indeed, between 1949 and the mid-1970s, the confidence of many plant physiologists was bolstered by both private industry and public governments' support for phytotrons, and by the increasing availability of the facilities to the global plant science community.

Secondly, phytotrons were as much experimental as cultural spaces. Phytotrons invoked the cyclotrons of high-energy physics as an expensive and interdisciplinary style of science centered on massive instruments. Using phytotrons, plant physiologists constructed the object of biological study itself: the phenotype, via big science. The meaning and experimental form of the phenotype was shaped by both the phytotron as instrument and the community of plant scientists assembled in the phytotron's controlled spaces. That community, including agriculturalists, botanists, foresters, horticulturalists, and especially the plant physiologists, all accepted that the phenotype could be controlled and made, as Chouard said, a "reproducible" and "experimental" object. Across the plant sciences, the phenotype was generally understood as the sum of an organism's genes and environment.[6] A phytotron permitted both of

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[2] Other disciplines like biochemistry also stressed more stable environments at constant temperatures in which to run new ultracentrifuges and electrophoresis apparatuses; on the eve of the second world war adjustable controlled chambers stabilized the "best-equipped biochemical research facilities in Germany and the world" said the director of the Kaiser Wilhelm Institute for Biochemistry in Berlin Rheinberger (2010), p. 131. At the same time, physiological ecology was developing (or at least dreaming of) controlled environment laboratories. See Kingsland (2009), pp. 293–299.

[3] O. H. Frankel, 'Report on a visit to the USA May 3–Aug 3, 1955, under the auspices of a grant from the Carnegie Corporation of New York.' Copy in James Bonner papers, file 'Australia.' Archives. California Institute of Technology. p. 34.

[4] Of especial relevance and resonance here is the story of computing and biology. See November (2012); Garcia-Sancho (2012), and also Rasmussen (1997a). More broadly see Creager & Landecker (2009).

[5] 'Biotron Conference,' Dec 10–12, 1959. Biotron Papers, Series 06/80, Box 1, file 'Biotron Conference' Archives, University of Wisconsin–Madison. p. 35.

[6] This broad conceptual statement appears ubiquitously. For Went's co-author, Kenneth Thimann, stated the principle in 1957 as "Hereditary potentialities" joined with "Environmental Factors" to create the "Internal Physiological and Biochemical Processes and Conditions" which only then would become expressed as "Plant Growth and Development." Thimann argued that physiologists well knew that plants not only grew at radically different rates in various climates but that the internal processes of plants were often just as significantly affected. See 'Thimann Report,' attached to Thimann to the Secretary of the AIBS, March 13, 1957. In Phytotron Records, box 2. Duke University Archives. p. 4. Also in France, the later deputy director of *le grand phytotron*, N. de Bilderling offered the concept as a mathematical product expression, "Phenotype = genotype x environment" de Bilderling (1974), p. 16, I have chosen to follow the more common usage of a sum expression following the use of Jan Zeevaart, namely "GENOTYPE + ENVIRONMENT = PHENOTYPE", in Zeevaart (2009), p. 4. Zeevaart was a colleague of Anton Lang, the successor of Frits Went as the director of the Caltech phytotron. Zeevaart and Lang moved to the Michigan State University to found the Plant Research Laboratory in 1965 on the back of A.E.C funding. As major plant research institution since then, the facility has recently begun expanding climate controlled chambers.