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RESEARCH ARTICLE

Experimental bioclimatology and prospects of agricultural modernization at the CNRS phytotron, France, 1953–1988

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Abstract

Built in Gif-sur-Yvette in the 1950s, the phytotron of the Centre national de la recherche scientifique provided plant physiologists with a set of enclosed growth rooms in which several climatic constituents of the environment could be simultaneously and separately controlled. This article examines the polyvalence of the French phytotron to explore the economic and political entanglements of experimental reasoning in mid-twentieth-century plant physiology. As Gif scientists embraced phytotrons as a means for developing an 'experimental bioclimatology', not only did they introduce into the laboratory an understanding of climate as a complex of agents likely to affect plant life, but also they sought to map scientific findings on productive pursuits during a period of intense agricultural modernization. The horticultural and agronomic applications envisaged were aimed at the timing of climate-sensitive biological events, but also at the expansion of productive areas within and outside metropolitan France, particularly in the context of late colonial and international dry-land development agendas. This case study of phytotronists' agricultural imagination highlights a techno-scientific conception of climate steeped in biology, tied to the limits and potential of plant life in time and space, and regarded as either a deficiency to be corrected or a resource to be harnessed.

In 1954, the French Centre national de la recherche scientifique (CNRS) allocated more than a quarter of its 800 million francs in equipment appropriations to the construction of an imposing plant physiology laboratory called Phytotron.[1] This was also the name of a new type of scientific equipment with international momentum. The prototype had been inaugurated in 1949 on the initiative of physiologist Frits W. Went at Caltech, Pasadena, under the official name 'Earhart Plant Research Laboratory'. As described in the works of Toby Appel, David Munns and Sharon Kingsland, Caltech's phytotron spurred a technology-intensive 'laboratory movement'.[2] Similar facilities were erected in Belgium, the Soviet Union, Sweden and Japan. All phytotrons made it possible to create conditioned artificial

[1] Denis Guthleben, *Histoire du CNRS de 1939 à nos jours*, Paris: Armand Colin, 2013, p. 175.

[2] Toby A. Appel, *Shaping Biology: The National Science Foundation and American Biological Research, 1945–1975*, Baltimore: Johns Hopkins University Press, 2000, pp. 183–6; David P.D. Munns, *Engineering the Environment: Phytotrons and the Quest for Climate Control in the Cold War*, Pittsburgh: University of Pittsburgh Press, 2017; Sharon E. Kingsland, *A Lab for All Seasons: The Laboratory Revolution in Modern Botany and the Rise of Physiological Plant Ecology*, New Haven, CT: Yale University Press, 2023. The expression 'laboratory movement' is taken from Sharon E.

climates, whose state and changes were produced at will, on a reduced scale and in enclosed spaces. Backed by complex, more or less automated machinery at the cutting edge of heating, ventilation, air-conditioning and lighting technologies, these facilities provided experimenters with all sorts of reproducible climatic combinations to study their effects on the growth and development of plants.

The director of the CNRS at the time, physicist Gaston Dupouy, reportedly wanted the French facility to be 'large, complex and refined'.[3] He entrusted its design, creation and direction to botanist Pierre Chouard. Erected between 1955 and 1957 in Gif-sur-Yvette, south of Paris, where the CNRS was establishing a complex of biological laboratories, the big French phytotron became practically operational in 1962–3. In the mid-decade, it comprised a phytotron proper, with a set of twenty large climatized rooms, some artificially lit, others sunlit. To this were added 'super-greenhouses' – a set of less-strictly controlled compartments, air-conditioned units of around 1.50 cubic metres, a chromatic illuminator and laboratory facilities to accommodate the forty or so researchers.[4]

Tracing the history of controlled-environment experimental systems, as Kingsland and Munns have argued, drawing historians' attention to a neglected junction between the histories of the life sciences, technology and the environment, helps to recover the development of biological investigations that, so equipped, have focused on whole-organism–environment relations.[5] It is partly for this reason that Kingsland described the Caltech phytotron as a case of hybridization 'between laboratory and field cultures', which claimed relevance to ecology, horticulture and agronomy, as well as 'a countercultural movement against the reductionist trends of molecular biology'.[6] Munns rather stressed a 'conservative' movement of 'appropriation by the plant sciences of the ideals of the physical sciences', including the basic/applied divide.[7] Studying the Swedish phytotron, Sabine Höhler has also described it as a cultural space, foregrounding the play of scales within modelling practices, from 'indoor science', to Swedish modernization policies, to 'international forest improvement agenda'.[8]

The history of phytotrons provides an entry point for examining the persistence of 'the "environment" as a biologically relevant variable', and, as an integral part of this, the diversity of scientific approaches and conceptions of climate in the mid-twentieth century.[9] It further illustrates the intertwined histories of climatic engineering and physiology documented by Michelle Murphy, Gregg Mitman and Matthew Farish, which led to the

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Kingsland, 'Frits Went's atomic age greenhouse: the changing labscape on the lab–field border', *Journal of the History of Biology* (2009) 42(2), pp. 289–324, 292.

[3] 'Laboratoire du Phytotron: Rapport d'activité scientifique', 30 May 1974, Archives nationales, Pierrefitte-sur-Seine (subsequently ANP), CNRS laboratories files, 20140644/37 Laboratoire du Phytotron (2) (subsequently 20140644/37), 13.

[4] [Pierre Chouard?], 'Le laboratoire du Phytotron du Centre national de la recherche scientifique', 1 September 1965, ANP, CNRS biological sciences laboratories files, 20160194/669, LP 2461, 2–4.

[5] David P.D. Munns, 'The age of biology: when plant physiology was in the center of American life science', *History of Science* (2020) 59(4), at https://doi.org/10.1177/0073275320954123 (accessed 24 June 2023); Kingsland, *A Lab for All Seasons*, op. cit. (2), p. 33.

[6] Kingsland, 'Frits Went's atomic age greenhouse', op. cit. (2), p. 289.

[7] David P.D. Munns, '"The awe in which biologists hold physicists": Frits Went's first phytotron at Caltech, and an experimental definition of the biological environment', *History and Philosophy of the Life Sciences* (2014) 36(2), pp. 209–31, 219; Munns, 'The phytotronist and the plant phenotype: plant physiology, Big Science, and a Cold War biology of the whole plant', *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences* (2015) 50, pp. 29–40, 36.

[8] Sabine Höhler, 'Earth, a technogarden: planting for the planet in Sweden's first phytotron, 1950–1970', *Geschichte und Gesellschaft* (2020) 46(4), pp. 706–28, 709, 706, 722.

[9] R. Ashton Macfarlane, 'Wild laboratories of climate change: plants, phenology, and global warming, 1955–1980', *Journal of the History of Biology* (2021) 54(2), pp. 311–40, 320.

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development of empirical, laboratory-based research into the biological and health effects of climatic conditions at micro scales.[10] In this perspective, this article draws attention to a view of phytotrons as a means of developing an 'experimental bioclimatology', in which climate was to be studied as a complex of agents likely to affect plant life rather than an abstraction based on statistical averages.[11] Alongside the development of mathematics-driven models and simulations of a rapidly changing global physical phenomenon, the phytotron movement thus materialized and updated an ancient notion of climate as an 'agency', which, as James Fleming and Vladimir Jankovic have observed, was not reducible to its modern definition as the typical atmospheric conditions of a given location or region.[12] The case of the CNRS phytotron also highlights that this eminently relational notion of climate has been embedded in a post-war techno-scientific paradigm of economic and social progress equated with the improvement and increase of plant production. Although this facility was primarily intended to serve fundamental research, it drew justification from its potential contribution to the modernization and development of horticulture and agronomy in the country and across the world. The article studies the sources and content of the agricultural imagination of Gif's phytotronists to explore their conception of climate and its operationalization. It focuses on the practice-oriented research programmes that they developed in the 1960s, and examines the interventions in climate–organism relationships that phytotronics prescribed, emphasizing their temporal modalities, from acceleration to desynchronization. It also discusses the geographical extension of experimental reasoning in post-war plant physiology, particularly its entanglement with domestic late colonial and international agendas for dry-land development. Throughout the different programmes examined, the article highlights a techno-scientific conception of climate steeped in biology, which was tied to the limits and potential of plant life in time and space, and regarded as either a deficiency to be corrected or a resource to be harnessed. Additionally, as Höhler pointed out, research in phytotrons yields insights into the simultaneously conceptual and technical delimitation of the biologically relevant environment, with this case exemplifying the neglect of biotic factors by phytotronists, especially 'living soils'.[13]

I trace the agricultural imagination of Gif's phytotronists through mainly institutional primary sources, including the archives of the Phytotron Laboratory and the Sahara Research Center of the CNRS, as well as Chouard's papers and published literature. I start by examining the functions attributed to phytotrons, exploring, after Munns and Kingsland, the connotations of this neologism. Alongside the analogy with the physicists' cyclotron, there was another interpretation of the term, relating it to *arotron*, the Greek word for plough. I then show that this double reference mirrored Chouard's career, which spanned scientific and applied research. How Gif's phytotronists envisaged their contribution to the

[10] Michelle Murphy, *Sick Building Syndrome and the Problem of Uncertainty: Environmental Politics, Technosciences, and Women Workers*, Durham, NC: Duke University Press, 2006; Gregg Mitman, *Breathing Space: How Allergies Shape Our Lives and Landscapes*, New Haven, CT and London: Yale University Press, 2007; Matthew Farish, 'Creating Cold War climates: the laboratories of American globalism', in John R. McNeill and Corinna R. Unger (eds.), *Environmental Histories of the Cold War*, Cambridge: Cambridge University Press, 2010, pp. 51–84.

[11] Jean-Paul Nitsch, 'Les phytotrons et la bioclimatologie expérimentale', in Maurice Fontaine (ed.), *Physiologie*, Paris: Gallimard, 1969, pp. 1602–1617.

[12] Spencer R. Weart, *The Discovery of Global Warming*, Cambridge, MA: Harvard University Press, 2003; James R. Fleming, *The Callendar Effect: The Life and Work of Guy Stewart Callendar (1898–1964)*, Boston, MA: American Meteorological Society, 2007; Paul N. Edwards, *A Vast Machine: Computer Models, Climate Data and the Politics of Global Warming*, Cambridge, MA: The MIT Press, 2009; James R. Fleming and Vladimir Jankovic, 'Introduction: revisiting *Klima*', *Osiris* (2011) 26(1), pp. 1–15, 2.

[13] Höhler, op. cit. (8), p. 715; Céline Pessis, 'Histoire des "sols vivants"', *Revue d'anthropologie des connaissances* (2020) 14(4), at http://journals.openedition.org/rac/12437 (accessed 5 June 2023).

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modernization of plant production in post-war France is described and illustrated in the third section. In the fourth section, I look beyond the laboratory to the scientific and political rationale that underpinned Chouard's soil-less cultivation experiments in the Sahara at the twilight of French colonial rule in Algeria. Finally, I examine the difficulties – financial, institutional and epistemological – that hampered the realization of the ambitions formulated for the CNRS phytotron.

Accelerating physiological discoveries and innovations in applications

Formed from the prefix *phytos* (plant) and the suffix 'tron', as were the cyclotron and other particle-physics devices, the neologism 'phytotron' was coined by Caltech biologists. It connoted instrumental gigantism and technological sophistication, and, as Munns has argued, a commitment to catch up with the cultural model of basic research in the post-war physical sciences.[14] These large, costly scientific facilities were aimed at reducing biological variability and ensuring the repeatability of a phenomenon by exercising technological control over the plant environment, with a view to elevating plant biology to the envied status of an exact science. Kingsland has recently observed that the rhetoric of comparison with the cyclotron also likened phytotrons to '*accelerators*', highlighting another understanding of control as the key to scientific 'efficiency'.[15]

For Chouard, who headed the CNRS phytotron until 1975, the relevant reference was rather drawn from physiology. In his view, 'there is no phytotron until there is a set of *several* enclosures in which several factors of the milieu can be controlled *simultaneously* and *independently*'.[16] This definition was stretched towards a methodological project, that of applying to the study of plants the rules of experimental physiology laid down by Claude Bernard, namely 'analyzing separately, at the beginning, the effects of different values of one parameter, then another etc., and afterwards the correlation between several parameters varying simultaneously'.[17] Phytotrons were engineered to implement an experimental 'way of knowing' how the whole plant functions, between analysis and synthesis, at a distance from more descriptive branches of botany, as well as from mathematical modelling in ecology and statistical treatment of historical series of data in agricultural research.[18]

If we want to approach phytotrons in their various functions, it is useful to look more closely into the 'environment' of the plant to be manipulated through them. The environment is an inclusive notion, under the banner of which a series of elements and phenomena surrounding different parts of plants can be nested as in a Russian doll. However, not all of them were treated as agents in phytotrons. Gif phytotronists, for instance, 'dispens[ed] with soil as such'.[19] It had been replaced by cultivation systems on easily disinfected inert materials – such as vermiculite, glass wool or sterilized cultivation mixtures. Phytosanitary protection took precedence over the influence of soil microbial life. Therefore they mainly considered the abiotic environment of the aerial parts of plants. Among the factors making up this environment, the physical phenomena considered essential or dominant for growth and development were given priority: light in terms of quality, intensity and duration; air

[14] Munns, 'The phytotronist and the plant phenotype', op. cit. (7).

[15] Kingsland, op. cit. (2), pp. 52, 60–1, original emphasis.

[16] 'Le laboratoire du Phytotron', 1 September 1965, ANP, 20160194/669, LP 2461, 1, original emphasis.

[17] Pierre Chouard and Nicolas de Bilderling, 'Brief analysis of the proceedings of the symposium: use of phytotrons and controlled environments for research purposes, Durham–Raleigh (U.S.A.) 22–27 May 1972', *Phytotronic Newsletter* (1972) (3), pp. 3–15, 4.

[18] John V. Pickstone, *Ways of Knowing: A New History of Science, Technology and Medicine*, Manchester: Manchester University Press, 2000.

[19] Nitsch, op. cit. (11), p. 1603.

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temperature and humidity; and to a lesser extent its chemical composition. In other words, phytotrons proceeded from 'the desire to know the role of each climatic factor on plant life'.[20] Chouard explicitly characterized them as 'simulators of climates'.[21]

Phytotrons surely provided experimenters with 'plants raised under controlled conditions and reproducible at any time of the year', with a more or less standardized phenotype.[22] But it was just as important, if not more so, that they provided facilities for studying plant responses to the separate or combined action of climatic factors. As stated during a meeting of the steering board of the CNRS phytotron in 1970, 'it is underestimating the phytotron to consider it as a kind of greenhouse in which one prepares plants all alike, and then work on something other than the actions of temperature and light'.[23] To paraphrase Ankeny *et al.*, here the organism's surrounding climatic circumstances were not to be controlled to simply be 'ignored', by minimizing the share of variability ascribable to them. On the contrary, plant functions were to be 'situated', and the physical conditions of their environment considered an integral 'part of the phenomenon' under study.[24]

In considering how the omnibus notion of the environment was particularized in phytotrons, we find that their conception and uses made climate 'a living reality and not just an abstraction based on averages'.[25] In the words of the first deputy director of the CNRS phytotron, Jean-Paul Nitsch, they were the tool for realizing an 'experimental bioclimatology', materializing climate as an agency, which not only surrounds plants but exerts an influence on their growth and development.[26] What are the role and relative influence of climatic factors in the formation of floral organs, in fruit set and in crop yields? These bioclimatic questions, long held by practitioners and revived by colonial resource exploitation, had already been researched in agricultural meteorology since the first half of the twentieth century.[27] We find their echo in a little-known interpretation of the term 'phytotron', different from the one that analogized it as equipment for 'dissecting the mechanisms of the plant as the cyclotron did the atom'.[28] For Chouard, the word 'could also mean: "to draw from the plant all that it can provide by the means and artifices of man", in reference to the Greek word Arotron, the swing plough, an instrument for drawing from the soil all that man can bring out of it'.[29]

This meant an experimental facility for accelerating scientific discoveries of climatic influences and for deriving innovations in applications to prepare for cultivation, most

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[20] Pierre Chouard, Roger Jacques and Nicolas de Bilderling, 'Phytotrons et phytotronique', *Endeavour* (January 1972) 31(112), pp. 41–5, 41.

[21] 'Le laboratoire du Phytotron', 1 September 1965, ANP, 20160194/669, LP 2461, 1.

[22] Centre national de la recherche scientifique, *Groupe des laboratoires de Gif-sur-Yvette*, Paris: CNRS, 1967, p. 81.

[23] 'P.V. de la 2ème séance du Comité de direction du laboratoire du Phytotron 16 avril 1970', n.d., ANP, CNRS laboratories files, 20140644/36 Laboratoire du Phytotron (1) (subsequently 20140644/36), folder 'Comité de Direction 16/04/1970', 3.

[24] Rachel A. Ankeny, Sabina Leonelli, Nicole C. Nelson and Edmund Ramsden, 'Making organisms model human behavior: situated models in North-American alcohol research, since 1950', *Science in Context* (2014) 27(3), pp. 485–509, 500.

[25] Henri Geslin, 'Les plantes et le climat (quelques aspects particuliers des buts et des méthodes de la bioclimatologie agricole)', *International Journal of Bioclimatology and Biometeorology* (1958) 2(Pt 2, sect. B1), pp. 1–15, 5.

[26] Nitsch, op. cit. (11), p. 1602; Fleming and Jankovic, op. cit. (12), p. 2.

[27] Giuditta Parolini, 'Weather, climate, and agriculture: historical contributions and perspectives from agricultural meteorology', *WIREs Climate Change* (2022) 13(3), e766, at https://doi.org/10.1002/wcc.766 (accessed 16 June 2024).

[28] Jean-Paul Nitsch, 'Un laboratoire de bioclimatologie: le Phytotron', *La Nature* (1953) (3221), pp. 272–8, 273.

[29] Pierre Chouard, 'Introduction', in Pierre Chouard and Nicolas de Bilderling (eds.), *Phytotronique: Science, technique et recherches sur les rapports entre l'environnement et la biologie des végétaux: Compte-rendu de la Table ronde tenue avec L'aide de l'UNESCO, Londres 30–31 Juillet 1964*, Paris: CNRS Editions, 1969, pp. 1–3, 1.

notably in horticulture, with which plant physiology had shared a 'common epistemological space' around questions of plant organogenesis and ontogenesis since the nineteenth century, but also in agronomy.[30] As will be shown in the next section, this double reference mirrored Chouard's career, which straddled the worlds of botany, plant production and public administration.

Pierre Chouard, from botany to the 'food front'

Born in Paris in 1903, Chouard conducted his university studies in natural and physical sciences at the Faculty of Paris and at the Ecole normale supérieure. His thesis on 'types of development of the vegetative apparatus in Scilla', defended in 1930, was a morphological study leaning towards physiology. This trend in his work became more pronounced in the course of his successive academic assignments. From 1932 to 1935, he was a professor at the National School of Horticulture in Versailles, where he tried to stimulate flowering with female animal hormones.[31] At the same time, he became editor-in-chief of the *Revue horticole*, a position he held until 1950. He joined the Bordeaux Faculty of Science in 1935, where he enjoyed the use of a large personal garden and a greenhouse to extend his experimental studies on factors that stimulate growth and flowering to photoperiodism. Chouard returned to Paris in 1938 to take the chair of agriculture and agricultural production in their relations with industry at the Conservatoire national des arts et des métiers (CNAM). He reportedly tried to establish experimental cultures wherever he could, in the gutters of the honour courtyard, or in a greenhouse 'heated and lit by electricity offered and installed in his garden in L'Haÿ-les-Roses by the Union de l'Électricité de Paris, in recognition of lectures on the agricultural and horticultural uses of electricity'.[32] In 1941, the CNAM eventually annexed to his laboratory a large plot of land with buildings in Colombes, near Paris.

In the meantime, however, the Second World War had broken out, and as Chouard recalled in 1948, 'passive defense absolutely forbade me from continuing the trials on photoperiodism involving night lighting; and on the other hand I had to devote myself to this "food front" where, from the inside, the task was to help all French people escape the plan of subjection by famine.'[33] He had early on been called to work on food and supply problems with the director of the Centre national de la recherche scientifique appliquée, mineralogist Henri Longchambon. While continuing to teach at the CNAM, Chouard also worked on the organization of familial gardens, in collaboration with the Secours national, an assistance organization that had been placed under the authority of the Vichy régime.[34] From 1943 to 1944 he reportedly established a 'liaison' between that organization, the Libération-vengeance resistance movement, and the Conseil national de la Résistance's Supply Commission.[35] His collaboration with the new food supplies authorities became official after the war; from August 1944 to 1949 he served as scientific adviser to the relevant ministers and high commissioners.[36]

[30] Cristiana Oghina-Pavie, 'Horticulture et physiologie végétale au début du XIXe siècle: Un espace de savoir partagé', *Bulletin d'histoire et d'epistémologie des sciences de la vie* (2011) 18(2), pp. 113–29, 115.

[31] Pierre Chouard, 'Coup d'oeil sur les facteurs de stimulation chez les plantes, leur rôle actuel et futur en agriculture', May 1948, Pierre Chouard papers (subsequently PCP), ANP, F/23/403, folder 'Etudes et écrits divers sur l'agriculture et la botanique', 5–6.

[32] Jean Lavollay, 'Pierre Chouard au Conservatoire national des arts et métiers', in Roger Jacques (ed.), *Etudes de biologie végétale: Hommage au Professeur Pierre Chouard*, Paris, 1976, pp. 17–22, 19.

[33] Chouard, op. cit. (31), 9.

[34] Lavollay, op. cit. (32), p. 21.

[35] Jean-Louis Hamel, 'Pierre CHOUARD', *Bulletin de la Société botanique de France* (1986) 133(4–5), pp. 311–17, 315.

[36] Lavollay, op. cit. (32), p. 22.

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Chouard's functions during and after the war likely consolidated his inclination towards a biology that was receptive to social and economic needs, as suggested by his general public writings and talks of the period. These addressed household keepers as well as the country's elite, ranging from food conservation in times of restrictions to national plans for agricultural renovation.[37] At the end of the decade, he wrote a plea for a massive increase in agricultural productivity with Longchambon. It called for 'the subordination of all economic programs to the most rapid recovery' and increase of agricultural production, by at least 50 per cent compared to pre-war average levels, in order to compensate for past shortfalls, make up for the deficit in North Africa, and meet new food requirements.[38] Notwithstanding the predominance of small-scale family farming, they tried to demonstrate that investment in the sector was the responsibility of the state, and that it was more profitable than any other. Drawing on engineering language, they used energy units to estimate the calorific value of average annual plant production, draw equivalences with coal consumption, and convince readers that the margin for increasing plant resources was much higher than the margins for other energetic raw material. This brochure was widely distributed in academic, professional and policy circles, right up to General de Gaulle and the first president of the Fourth French Republic, Vincent Auriol.[39] The special position that Chouard had carved out for himself, at the crossroads of basic sciences and socio-economic preoccupations, was cemented in 1953, when he was appointed at the Sorbonne to the only chair of plant physiology and elected to the Academy of Agriculture.

Understanding plants' climatic desiderata to manipulate their spatio-temporal complexities

In the post-war decades, as France became a 'planning state', efforts were effectively made to modernize not only industry but also agriculture.[40] Agricultural planning became one aspect of the system of 'indicative' planning developed by the Commissariat général du plan, established in 1946 'to bring France up to the productivity levels of advanced capitalist economies'.[41] Rather than imposing 'a centralized production program', French-style planning set quantified goals, 'and then used the weapons of government investment and fiscal policy to encourage private enterprise to work toward those goals', as Clough, Moodie and Moodie explained.[42] Christophe Bonneuil, Frédérique Thomas and Olivier Petitjean specified that the development of these policies was heavily influenced by 'industrial thought patterns': 'volume, yield, and standardization' were the planners' watchwords as they sought to make agriculture a major sector of the French economy, and establish the country as an export power.[43] The emphasis was put on the intensification of mechanization

[37] Pierre Chouard, *La conservation familiale des fruits et légumes et autres denrées alimentaires*, Paris: La Maison rustique, 1944; 'Voies nouvelles du progrès scientifique en agriculture et ses conséquences économiques et sociales', 5 March 1948, PCP, ANP, F/23/403, folder 'Etudes et écrits divers sur l'agriculture et la botanique'.

[38] Henri Longchambon and Pierre Chouard, *Rénovation agricole ou faillite*, Lyon: Imp. Automatique, n.d, p. 5.

[39] Henri Longchambon and Pierre Chouard to General de Gaulle, 19 October 1948; Vincent Auriol to Henri Longchambon, 12 August 1948, PCP, ANP, F/23/403, Folder 'Rénovation agricole et faillite'.

[40] Christophe Bonneuil, Frédéric Thomas and Olivier Petitjean, *Semences: Une histoire politique: Amélioration des plantes, agriculture et alimentation en France depuis la Seconde Guerre mondiale*, Paris: Editions Charles Léopold Mayer, 2012, p. 35.

[41] Cédric Durand and Razmig Keucheyan, *Comment bifurquer: Les principes de la planification ecologique*, Paris: Zones, 2024, p. 217.

[42] Shepard B. Clough, Thomas Moodie and Carol Moodie, 'Planning and economic growth: the example of France', in Clough, Moodie and Moodie (eds.), *Economic History of Europe: Twentieth Century*, New York: Walker & Company, 1968, pp. 345–54, 345.

[43] Bonneuil, Thomas and Petitjean, op. cit. (40), p. 36.

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and fertilization, as well as on the use of varieties selected by plant geneticists for their high yield. As such, the accelerated transition to increase agricultural productivity favored the development of agronomic research in France, as epitomized institutionally by the creation of the Institut national de la recherche agronomique (INRA) in 1946.[44]

How did Gif phytotronists envisage their contribution to 'progress' thus conceived? The potential uses of climate-controlled laboratories were numerous and intertwined. These ranged from assisting in variety breeding; to identifying optimum and limiting conditions for growth and development in a given plant; and, once its 'desiderata' had been pinpointed, to finding substitute treatments to artificially induce its responses.[45] Envisioned uses reflected the major climate-related problems of plant production, as delineated by agricultural bioclimatologist Henri Geslin in 1958: the problem of 'expansion of cultivated areas', which required some kind of fine-tuning between varieties and climatic regions, either by 'adapting crops to the milieu' or by determining 'the cultural vocation of lands', and the problem of 'irregularity and instability of harvests', requiring 'direct or indirect action on climate' to either minimize its adverse effects or 'to make most of the opportunities it offered'.[46] Using examples of specific agronomic and horticultural problems considered by Gif phytotronists, I would like to show how this fundamentally rhythmic and place-based understanding of the action of climate came into play in their work, as well as outline the various modalities of techno-scientific interventions it prescribed.[47]

At the top of the list of services that phytotrons were likely to render to agriculture was help with crop selection and improvement. Chouard thought they could contribute to speeding up the time-consuming process of varietal creation by increasing the number of successive generations of material available annually. In the early stages of a breeding programme, during the 'off season', one or two generations of cereals might be housed in their facility, in appropriately conditioned growth rooms. Plant geneticists could then perhaps study three generations per year, where fewer could be obtained in field conditions. Furthermore, the lines obtained could be grown under defined artificial conditions to test their performance against specific selection criteria, such as 'adaptation to certain conditions of temperature, humidity, light, soil, salinity', in order to screen the most promising ones for further selection.[48]

Reducing the interval between two successive generations by skipping the 'bad season' was only one option considered to optimize the time factor in practice-oriented research. Another promise of phytotronics was to provide new and powerful means of influencing the speed and direction in which the physiological stages of the growth and development cycle unfolded.[49] In the 1960s, Chouard's group at the Gif phytotron worked on the physiology of morphogenesis and reproductive development, with a focus on floral induction, investigating the factors preparing for and initiating the floral transformation of a bud. They looked in particular at vernalization, which he defined as 'the acquisition or acceleration of the

[44] Pierre Cornu, Egizio Valceschini and Odile Maeght-Bournay, *L'histoire de l'Inra, entre science et politique*, Versailles: Quae, 2018.

[45] Raymond Bouillenne, 'Phytotrons, appareil à faire des climats, son utilité', extract from *Chaleur & climats* (1958) 17, p. 4; Henry Hellmers, 'Phytotrons: tools for horticultural research', *HortScience* (1969) 4(1), pp. 12–14.

[46] Geslin, op. cit. (25), p. 1.

[47] I am aware of the fragmentary nature of my compositional principle, deliberately selecting examples of different potential practical uses of phytotrons, but I hope that their careful assemblage also highlights a common underlying understanding of bioclimatic relations in terms of place-based rhythms.

[48] Pierre Chouard, 'Note sur les problèmes de recherches appliquées qui pourraient être traitées immédiatement au Phytotron en vue de témoigner d'une rentabilité reconnue', 25 January 1966, ANP, 20140644/36, folder 'Comité de direction 10/02/1966', 1.

[49] 'Rapport sur l'activité du "groupe de M. Chouard" d'octobre 1967 à septembre 1968', 24 September 1968, ANP, 20140644/37, folder 'R.A. 1967–68', 1.

ability to flower by a chilling treatment'.[50] Within this framework, Marie Tran Thanh Van undertook doctoral research with *Geum urbanum*, an 'unpretentious European perennial' known to have a mandatory winter cold requirement to flower.[51] While the coldest room in the facility was still only 10 °C in 1962, she initiated experiments on agents or procedures capable of replacing vernalizing chilling to induce the development of the ability to flower in the younger axillary buds, those located in the axil of each leaf.[52] Her study challenged 'the absolute and specific nature' of this inducing factor, showing that it could be substituted with high mineral nutrition combined with intense luminosity, chemical treatments with gibberellin, or decapitation of the bud located at the apex of the main shoot.[53] After the cold rooms were put into operation, she also found that it was possible to vernalize this apical bud, which, in Chouard and Tran Thanh Van's words, 'had never before flowered in the history of the world'.[54] This feat was achieved by exposing *Geum* to almost a year of cold at 3 °C ± 2 °C, brought down to thirteen weeks only when this treatment was combined with the application of gibberellic acid. These and other results led to the formulation of the hypothesis that the action of cold and its substitutes not only was inductive, but also involved the lifting of inhibitions that blocked the floral evolution of axillary buds, especially that resulting from apical domination.[55] Around 1967, Tran Thanh Van transposed these principles, unravelled in a weed of no economic interest, to ornamental orchids displaying similar behavior in terms of 'their inability to flower in apical bud and the long period preceding floral turn'.[56] Devising a sequence of thermoperiodic, light and nutritional treatments, she succeeded in making *Odontonia* Molière flower in fifteen to eighteen months, instead of three to four years, leading to the patenting of this cultivation process, and interest from the National Agency for the Promotion of Research.[57]

Following the same concern for partial emancipation from external constraints and for increasing not only earliness but also yield, it was hoped to guide practice by determining the optimal conditions under which a given plant grows, flowers or fruits abundantly. The 'multidimensional concept of causality' upheld by phytotronists, while acknowledging the difficulty of explaining bioclimatic relations, was not conducive to a fatalistic attitude towards climate as an intricate force that can only be endured.[58] In trying to establish the relative importance of various external factors, their research implied that it was not the average climate of a region that had to be modified, but only the most important controlling factors. Nitsch, for instance, argued that farmers growing crops outside could use 'physical or chemical artifices' to approximate the optimal values of these factors. He found a prime example of how to 'correct climatic deficiencies' in Went's shading experiments from the

[50] Pierre Chouard, 'Vernalization and its relation to plant dormancy', *Annual Review of Plant Physiology* (1960) 11, pp. 191–238, 193.

[51] Pierre Chouard and Marie Tran Thanh Van, 'Les phytotrons et les progrès techniques de la culture des orchidées ornementales: Premières applications aux Odontonia', *Comptes rendus du 2ème congrès européen de l'orchidée*, Rungis: CNIHP, 1969, pp. 32–8, 32.

[52] Marie Tran Thanh Van, 'Rapport pour le Comité de direction du Phytotron du 25 février 1963', n.d., ANP, 20140644/36, folder 'Comité de direction 25/02/1963', 1–2.

[53] Marie Tran Thanh Van, 'A propos de l'orientation sur commande de la morphogenèse expérimentale', in Jacques, op. cit. (32), pp. 391–405, 397.

[54] Chouard and Tran Thanh Van, op. cit. (51), p. 35.

[55] 'Laboratoire du Phytotron', November 1964, ANP, 20140644/37, folder 'R.A. 1962', 5.

[56] Marie Tran Thanh Van, untitled, September 1967, ANP, 20140644/37, folder 'R.A. 1966–1967', 4; 'Laboratoire du Phytotron, Rapport d'activité scientifique', 24 June 1976, ANP, 20140644/37, 56.

[57] 'Note sur les recherches capables de fournir des applications pratiques et sur les relations avec l'A.N.V.A.R.', n. d., ANP, 20140644/37, folder 'Phytotron Gif', 184–5.

[58] Frits W. Went, 'Plant growth under controlled conditions. V. The relation between age, light, variety, and thermoperiodicity of tomatoes', *American Journal of Botany* (1945) 32(8), pp. 469–79, 479.

https://doi.org/10.1017/S0007087424001535 Published online by Cambridge University Press

1940s.[59] In previous climatized greenhouse experiments, the physiologist had shown that night temperature was the most important factor controlling stem elongation in tomatoes, that it had to be cooler than day temperature, and that it also exerted a significant effect on fruiting. Taking his results to the field, Went tried to obtain early tomatoes during the Californian winter and early spring, when average night temperatures were below the 10 °C threshold limit value for fruit set, but afternoon temperatures reached 15 to 20 °C, close to the optimal dark temperatures. He sought to convert 'part of the afternoon … into a functional night' by covering plants with tarpaper every day, from 3 p.m. until the next morning at 7 to 8 a.m.[60] In further spring experiments, he found that afternoon shading allowed not only the early harvest of ripe fruits, but also a great increase in yield. For example, the fresh weight per plant of Stone tomato plants so treated was 617 grams, compared to 319 grams for uncovered control plants.[61]

The different potential practical uses of phytotrons, here distinguished for clarity, may overlap. Research on optimal and boundary conditions could also facilitate crop selection and innovation by shortening the duration of agronomic trials to determine the adaptability of new varieties to local climates. As the CNRS phytotron was becoming operational, Chouard wanted to illustrate its usefulness for applications, 'also as a way of attracting public interest in [it], more quickly and more reliably than through protracted fundamental research'.[62] He chose to concentrate on the problems of durum wheat. Following Philippe Rousselot, these can be understood as an alignment problem between France's cereal policy, its rapidly changing geography and the ecophysiological requirements of this plant.[63] Pasta manufacturing in the country had been subject to original regulation since a 1934 law requiring the exclusive use of durum wheat semolina. Yet its cultivation in mainland France had been limited. Until the mid-1950s, needs had been met by importing durum wheat from North African territories under French control, which sold their surpluses to France under a special trade regime.[64] However, over the course of the decade, exports from Mediterranean countries declined, and durum wheat trials in mainland France resumed, fuelled by a 1954 law that restored the strict pasta-manufacturing regulation that had been suspended during the Second World War.[65] Against the backdrop of decolonization, this crop was first developed in the south-east and south-west, below latitude 45°, with varieties from Algeria and Tunisia, growing from around sixty experimental hectares to 46,000 hectares in 1960.[66] From a territorial point of view, however, durum wheat cultivation remained limited. Alongside lodging, which bends the stems to the ground, making them difficult to harvest, in colder, wetter climates another risk was the occurrence of a physiological accident, called *mitadinage*. Instead of being glassy, the structure of the durum wheat grain became floury, resulting in lower semolina yields. The combined desires to extend cultivation to the north of the country and to improve yield was conceived as dependent on varietal selection. In 1961, at a meeting of the Academy of Agriculture, Chouard stated that 'with the phytotron which simultaneously provides all possible climates, we will be

[59] Nitsch, op. cit. (28), p. 277.

[60] Frits W. Went, 'Simulation of photoperiodicity by thermoperiodicity', *Science* (1945) 101(2613), pp. 97–8, 97.

[61] Frits W. Went, 'Effects of temporary shading on vegetables', *Proceedings of the American Society for Horticultural Science* (1946) 48, pp. 374–80.

[62] Pierre Chouard, 'Esquisse du programme de recherches pour 1962, mettant en jeu les nouveaux équipements du Phytotron', January 1962, ANP, 20140644/36, folder 'Comité de Direction 9/12/1961', 2–3.

[63] Philippe Rousselot, 'Le blé, le spaghetti et la protéine: Mesures ingénieuses de la consommation des pâtes alimentaires (enquête)', *Terrains & travaux* (2005) 2(9), pp. 109–24, 111.

[64] Communauté économique européenne (CEE), *Economie de la production, transformation et consommation du blé dur dans la CEE*, Série Agriculture (18), Brussels: CEE, 1965, p. 91.

[65] Rousselot, op. cit. (63), p. 111.

[66] CEE, op. cit. (64), pp. 32–6.

able to know the geographical limits suitable for a given variety', as well as to search for the supposed climatic cause of *mitadinage*.[67] In 1962, studies with varieties received from a research centre in Montpellier were thus undertaken at the Gif phytotron. The goal was first to determine 'the best [artificial] conditions for flowering and ripening in less than four months after sowing', then to investigate the temperature and humidity conditions of the most dreaded physiological accidents in these plants under 'two opposite types of Parisian summer climates'.[68]

From reducing the interval between two successive generations to shortening the growth and development cycle itself or growing ripe fruits out of season, many of the envisioned interventions aimed at optimizing the time factor in research and practice. The analogy and 'selling point' of phytotrons as 'accelerators' was not purely metaphorical.[69] They offered experimental opportunities to intervene in the timing of climate-sensitive biological events. As Höhler perceptively observed, such experiments in phytotrons with temporal regimes of light and temperature could connote both seasonality and locality.[70] They were not only aimed at manipulating the rhythms, cycles and calendar of biological activity, but could also cater to the delimitation and extension of a plant's productive area. Taken together, these modalities reveal a concept of climate that was not only geographical, thought of in the plural and place-bound, as shown by Matthias Heymann for 'classical climatology', but also fundamentally temporal.[71] While the climates relevant for plant production may have been considered relatively coherent over time, they were not timeless. Referring to timescales that differed from the broad ones covered by today's global climate change scientists, the climate of physiologists was thought of in terms of daily variations and seasonal periodicities involved in the temporal unfolding of physiological events that was partially open to intervention.

The desert's climatic resources and productivity potential

Matthew Farish has argued that the climatic-engineering technologies made available to scientists in the twentieth century gave a twist to the networks of sites that supported knowledge production in imperial contexts: they 'gave laboratories additional geographic authority and reach, with the result that the world's climatic conditions were increasingly simulated within the confines of domestic territories'.[72] The agricultural imagination of Gif's phytotronists incorporated something of this ideal of the microcosm. Chouard, who after 1945 had been a member of the French Committee of the FAO, justified the expense by the services it was likely to render to agriculture in developing countries as well. In a 1964 televised interview, he explained that the phytotron could be used to understand why rice cultivation was not very productive in densely populated humid equatorial regions compared to Mediterranean countries, or to help the former French colony of Senegal, whose peanut trade was about to be liberalized, find a substitute crop.[73] Specifications for the facility indeed included the construction of a 'tropical room' and a 'Saharan room', which were

[67] Pierre Chouard comments to R. Diehl and M. Dupuy, 'L'azote et le soufre dans la fertilisation du blé dur', *Comptes rendus des séances de l'Académie d'agriculture de France* (1961) 47, pp. 977–92, 981–2.

[68] A. Lourtioux, 'Rapport pour le Comité de direction du Phytotron du 25 février 1963', n.d., ANP, 20140644/36, folder 'Comité de direction 25/02/1963', 1–2.

[69] Kingsland, op. cit. (2), p. 52.

[70] Höhler, op. cit. (8), p. 716.

[71] Matthias Heymann, 'Klimakonstruktionen: Von der klassischen Klimatologie zur Klimaforschung', *NTM Zeitschrift für Geschichte der Wissenschaften, Technik und Medizin* (2009) 17(2), pp. 171–97.

[72] Farish, op. cit. (10), p. 52.

[73] *Au Phytotron de Gif-sur-Yvette*, entrée libre, 28 May 1964, INA.

delayed for budgetary reasons.[74] In fact, it was in the field, in the Algerian desert, that Gif's phytotronists undertook their first research on productivity and physiology in arid climates.

Between 1958 and 1965, Chouard directed soil-less cultivation trials at the Béni-Abbès research station of the Centre de recherches sahariennes. Located in the north-western part of the Sahara, near the Algerian–Moroccan border, south of Colomb-Béchar, the Béni-Abbès oasis lay in the Saoura valley, which separated the stony Hamada plateau from the sand dunes of the Grand Erg Occidental, and watered a suit of palm groves cultivated by the local population. In this privileged site, the geologist Nicolas Menchikoff had set up a research station in 1942 on behalf of the CNRS, which had been equipped to host studies of the Sahara from a variety of disciplines. When Chouard visited the station in the spring of 1957, it featured a botanical garden and new laboratories complete with 'water, butane gas, electricity in the evening and part of the day, workbenches, microscopes, ecological physiology equipment, a library and a local herbarium'.[75]

Chouard's subsequent experiments in Béni-Abbès with soil-less culture systems irrigated by nutrient solutions, or 'hydroponics', were based on a seemingly paradoxical conviction.[76] Through the analytical prism of plant physiology, arid deserts certainly appeared to be hostile environments, but ones that presented '*the greatest "theoretical" agricultural potentialities in the world*'.[77] This was because, Chouard argued, they held 'enormous potential resources in renewable energy' that were awaiting 'agricultural means and opportunities to be developed'.[78] The climate of the Sahara specifically offered two assets, namely '*a very strong and almost permanent insolation all days of the year*' and '*large daily alternations* [in temperature]'.[79] Over the winter, temperature rose each day to around +15 or +20 °C and fell each night to 0 to 5 °C, while in autumn and spring it varied daily from +30 to +15 °C, rising in summer to over 40 °C by day and never dropping below 25 to 30 °C at night. Went had demonstrated the importance of daily thermoperiodism for some crops: their 'optimum yield being better attained by night-time cooling'.[80] Chouard's aim was therefore to circumvent the main factors limiting the realization of this potential by seeking 'ways of saving water in the Sahara', and 'using the natural "rocks" that abound … instead of "soils" themselves'.[81]

'Climate as a natural resource' just 'waiting to be tapped' was a theme in post-war climatological discourse.[82] According to Matthias Heymann and Clément Gaillard, the metaphor reflected the search for civilian outlets for 'wartime developments in applied climatology' amid growing concerns about the depletion of fossil resources.[83] It was also woven into

[74] 'Etat du Phytotron du C.N.R.S. (janvier 1962) (année 1961)', n.d., ANP, 20140644/36, folder 'Comité de direction 9/12/1961', 5.

[75] Pierre Chouard, 'Le centre de recherches sahariennes de Béni-Abbès et les recherches biologiques et agronomiques au Sahara', *Comptes rendus des séances de l'Académie d'agriculture de France* (1957) 43, pp. 477–88, 479.

[76] Pierre Chouard, *Cultures sans sol*, Paris: La Maison rustique, 1952, p. 8.

[77] Pierre Chouard and Uranie Renaud, 'Mise au point de cultures hydroponiques au Sahara: Premiers résultats obtenus', *Comptes rendus des séances de l'Académie d'agriculture de France* (1961) 47, pp. 992–1014, 992, original emphasis.

[78] Pierre Chouard, 'Peut-on rechercher la mise en valeur agricole au Sahara?', *Rivières et forêts* (1958) 9–10, pp. 74–80, 79.

[79] Chouard and Renaud, op. cit. (77), p. 992, original emphasis.

[80] Chouard, op. cit. (78), p. 75.

[81] Chouard and Renaud, op. cit. (77), p. 993.

[82] Helmut Landsberg, 'Climate as a natural resource', *Scientific Monthly* (October 1946) 63(4), pp. 293–8, 298.

[83] Matthias Heymann, 'Climate as resource and challenge: international cooperation in the UNESCO Arid Zone Programme', *European Review of History* (2020) 27(3), pp. 294–320; Clément Gaillard, 'Le climat est-il une ressource?', *Les cahiers de la recherche architecturale urbaine et paysagère* (2021) 11, at https://doi.org/10.4000/craup.

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the late colonial and postcolonial histories of Western plans for dry-land development. As Heymann has shown, the idea that 'arid climates represented a challenge to be turned into a resource' was adopted by UNESCO when it launched its Arid Zone Programme in 1951, and blended with lingering colonial narratives of desertification to promote international scientific and technical research on the problems of deserts and semi-deserts.[84]

It was during one of the programme's symposia, held in Madrid in 1959 on Plant–Water Relationships in Arid and Semi-arid Conditions, that Chouard presented the first results obtained in Béni-Abbès by Uranie Renaud, who had been hired in 1958 to set up the trials. They reported that it seemed technically feasible, using sand or crushed pebbles watered by sub-irrigation with a nutritive solution, to grow most plants found in temperate zones (tomatoes, lettuces, radishes, cabbages, strawberries and others), even in midsummer. They also estimated that they had consumed roughly one-half to one-third as much water per square metre, for higher yields, as methods ordinarily used in oases. This brief communication concluded on the hopes that these results afforded for a practical desert horticulture, foreshadowing 'the possibility of feeding a larger population with the same amount of water, and despite the limited surface of ordinarily arable soils'.[85]

The development of the Sahara was an objective officially shared by France since the 10 January 1957 law establishing an Organisation commune des régions sahariennes (OCRS), the purpose of which was 'the *mise en valeur*, economic expansion and social promotion of the Saharan areas of the French Republic'.[86] As traced by Pierre Boilley, this new institution derived from an idea that had percolated in public and parliamentary debate since 1951 – that of unifying the Sahara under French dominion.[87] As colonial penetration progressed, this vastness had been divided among three administrations, and between the southern territories of Algeria and Mauritania and the northern parts of French Sudan, Niger and Chad, not to mention the arid parts of Tunisia and Morocco, which became independent in 1956. As the former French Empire began to disintegrate, and signs of potential hydrocarbon wealth in the Sahara subsoils promised energy independence, unification had been defended as a way to keep the entire region under French control. It was only after the discovery of large oil deposits in the Algerian Sahara in 1956, at the beginning of the 'open war' between France and the Algerian National Liberation Front and in the midst of the Suez crisis, that a law was passed. It did not, however, bring about the integration of the French Saharan possessions into a new national territory. The original project was stripped of its political content from the beginning of the OCRS, and increasingly during its brief existence. Instead, it focused on its economic and strategic motivations, wrapped in a reactivated colonial narrative of France's civilizing mission, in which technical experts had replaced religious and military pioneers.[88]

6928 (accessed 15 June 2024); Woodrow C. Jacobs, *Wartime Developments in Applied Climatology*, Meteorological Monographs 1(1), Boston: American Meteorological Society, 1947.

[84] Heymann, op. cit. (83), p. 300; Diana K. Davis, *The Arid Lands: History, Power, Knowledge*, Cambridge, MA and London: MIT Press, 2016.

[85] Uranie Renaud, 'Economie d'eau, au Sahara par la culture en irrigation souterraine sur sables ou graviers', in UNESCO Arid Zone Research, *Plant–Water Relationships in Arid and Semi-arid Conditions: Proceedings of the Madrid Symposium*, Paris: UNESCO, 1961, pp. 327–8, 327.

[86] 'Loi n°57-27 du 10 janvier 1957 créant une Organisation commune des régions sahariennes', *Journal officiel de la République française* (11 January 1957) (9), pp. 578–80, 578.

[87] Pierre Boilley, 'L'Organisation commune des régions sahariennes (OCRS): Une tentative avortée', in Edmond Bernus, Pierre Boilley, Jean Clauzel and Jean-Louis Triaud (eds.), *Nomades et commandants: Administration et Sociétés nomades dans l'ancienne AOF*, Paris: Karthala, 1993, pp. 215–39.

[88] On the history of expertise-based development programmes in Africa during this period see Christophe Bonneuil, 'Development as experiment: science and state building in late colonial and postcolonial Africa, 1930–1970', *Osiris* (2000) 15, pp. 258–81.

On 8 October 1959, Chouard wrote to the minister delegate to the prime minister in charge of Saharan affairs to request financial support for his soil-less cultivation experiments.[89] On 1 August 1960, a convention was signed, which provided for fifty thousand new francs 'to continue and develop the experimentation of these methods so as to determine the economic value of their possible use on a larger scale in the framework of the development of the Sahara'.[90] Chouard's proximate target was European families, who could use these techniques to cultivate a garden. The next envisioned step was extension into 'collective or profit-making operations … for the new settlements being created in the Sahara'. The prospect of hydroponic methods being used by the people of the Saoura for their own benefit was more remote. The locals were considered to be 'insufficiently educated (or for too few generations) in technical and quantitative thought and action' to successfully carry out a culture that was demanding in terms of schedules and dosages.[91] This vision of the unreliable native gardener extended beyond the soil-less cultivation trials. It fed a 'water-intensive' view of the area's cultivation techniques, echoing the desertification narrative that Diana Davis analysed in French colonial discourses, which depicted native land use as inconsiderate and destructive of natural resources.[92]

Renaud carried out six campaigns, initially on her own and then, from 1961–2 onwards, in collaboration with Danielle Scheidecker of the Office de la recherche scientifique et technique outre-mer. They alternated between stays in Béni-Abbès and in the laboratory of plant physiology headed by Chouard at the Sorbonne, where products harvested and substrates used were analysed. Initially, the aim was to develop a hydroponic system adapted to the Sahara, by selecting a suitable substrate, and determining the effects of various water supply methods and rhythms and of various mineral solution compositions on yields. After an interruption in 1962–3 following the independence of Algeria, these trials resumed in 1964, with a more fundamental edge. Efforts were directed at measuring and defining the microclimatic and ecological conditions created by the different cultivation techniques tested (the temperature of the air and of the substratum at different levels, air-evaporation capacity, and so on), along with their physiological consequences.

For example, Chouard sought an explanation for an 'aberrant phenomenon', which contradicted the conditions of productivity for tomato and pea that Went had defined in his experimental studies. Against all expectations, these plants remained 'active and productive' at the beginning of the Saharan summer, when the daytime temperature was well above 30 °C during the day, and 20° at night. To bring this phenomenon back within the limits predicted in Went's experiments, Chouard turned to micro-climatological conditions. '[T]he air was so dry, transpiration so intense, and the water supply so active', that 'the actual temperature of the assimilating organs' (leaves and roots) had to be cooler than the air temperature in the shade, approaching the maximum of 30 °C during the day. Likewise, the great dryness of the Saharan summer night implied that, under such conditions, 'transpiration was still very active and able to add its cooling effects to the nocturnal radiations, so that the aerial parts of the vegetation can remain at relatively cool temperatures', below

[89] Pierre Chouard to the minister delegate to the prime minister, 8 October 1959, Archives nationales d'outre-mer, Aix-en-Provence (subsequently ANOM), Fonds OCRS, FRANOM86F (temporary call number) (subsequently FRANOM86F).

[90] 'Convention entre l'Organisation commune des régions sahariennes et le Centre national de la recherche scientifique relative à l'expérimentation et au développement des cultures sans sol au SAHARA', 1 August 1960, ANOM, FRANOM86F.

[91] Chouard and Renaud, op. cit. (77), pp. 996, 995.

[92] Diana K. Davis, *Resurrecting the Granary of Rome: Environmental History and French Colonial Expansion in North Africa*, Athens: Ohio University Press, 2007.

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the nocturnal air temperature.[93] The issue was not only to re-establish the predictive aspirations of plant physiology. Normalizing the Béni-Abbés trials to the climatic conditions for high productivity in horticultural plants was meant to strengthen the notion that the unproductive arid zone concealed another valuable energetic resource, which, unlike fossil fuels, was 'inexhaustible', 'always renewable' and 'dispersed' over an immense surface.[94]

Yet, after 1966, no more campaigns were carried out at the site. Scheidecker and Renaud-Andreopoulos joined a new group at the Gif phytotron devoted to the physiology of mineral nutrition, which, among other topics, addressed salinity issues in collaboration with the University of Tunis. In parallel, the 'Ecology' group investigated the influence of drought on root growth and morphology. Part of the 'physiological metabolism' team that gave Chouard's group a biochemical twist, Camille Hubac studied 'types of drought resistance in relation to amino acid metabolism' in species of *Carex*.[95] The prospect of integrating these various lines of research, and finally obtaining the funds to acquire a fully fledged 'aridity phytotronics', came from a cooperative project with the botany department of the Hebrew University of Jerusalem. It was initiated in 1970 by Israeli botanist Michael Evenari, a specialist in seed germination physiology and desert ecology, whom Chouard had met in 1958 at a conference in Israel and later at UNESCO arid-zone research symposia.[96] Their goal was to use the experimental grids utilized in phytotron work to unravel the physiological causes of phenomena measured in desert plants in the field. It was expected that a better understanding of aridity physiology would lead to 'the possibility of mastering the development of ecosystems in sub-desert countries', with a focus on species of pastoral value, such as *Artemisia herba-alba*.[97]

Rather than developing reduced models of Saharan growing conditions in the enclosed rooms of the phytotron in Gif-sur-Yvette, Chouard had initially expanded an experimentally based understanding of productive areas as those offering optimal rhythms for growth and development into dry lands. From the analytical point of view of plant physiology, one of the largest arid zones on earth was endowed with two riches: light and a temperature regime theoretically favourable to the cultivation of many agricultural plants. The rhetoric of the Saharan climate as an unsuspected reservoir of energetic resources awaiting technical means to be exploited was obviously shaped by the discovery of hydrocarbon wealth in its subsoils, contributing to overturning the cliché of the desert as desolate and unproductive to the benefit mainly of Europeans. Late colonial development plans afforded Chouard opportunities to carry out experiments with soil-less cultivation systems and to confront experimentally based knowledge of climatic conditions for productivity with the behaviour of plants in the field. The return into the laboratory, precipitated by Algeria's independence, did not eclipse applied concerns, or the climatic valorization orientation that underpinned the Béni-Abbès experiments. For instance, by growing plants under extreme but controlled climatic conditions, CNRS phytotronists foresaw the possibility of producing at will increases or decreases in the relative content of certain

[93] Pierre Chouard, 'Activité concernant les cultures hydroponiques au Sahara et les recherches sur la productivité des zones arides en économie d'eau: Campagne 1965 – Projets pour 1966', 25 February 1966, ANP, CNRS laboratories files, 20140644/6 Béni-Abbès-Centre de recherches sahariennes, 1–2.

[94] Chouard, op. cit. (78), p. 74.

[95] 'Rapports pour le Comité de direction', 18 June 1971, ANP, 20140644/37, 78.

[96] Michael Evenari, *The Awakening Desert: The Autobiography of an Israeli Scientist*, Berlin and Heidelberg: Springer-Verlag, 1989.

[97] 'Résumé du projet d'une recherche en coopération entre l'Université de Jérusalem et le Phytotron pour l'étude en commun de la physiologie des plantes du désert et particulièrement du Neguev', n.d., ANP, 20140644/37, folder 'R.A. 1971', 2.

metabolic products, some of which might be of nutritional or economic interest (proteins or alkaloids).

'Greatness or folly of the CNRS?'

Ambitions for the first French phytotron faced a long series of challenges, starting with the financial constraints that affected its realization. After the building was erected with initial funds, CNRS's appropriations for investment fell short of requests. For the 1962–5 quadrennial plan, the laboratory was granted 1.6 million francs, instead of the three million requested, in successive tranches spread over these years.[98] Chouard then deplored that CNRS policy was trapping his laboratory in a 'vicious circle' of 'first proving the usefulness of the Phytotron with partial equipment before being authorized to complete this equipment'.[99] Unforeseen contingencies made the resulting budgetary tinkering and material trade-offs even more complicated. The water distributed by the Société lyonnaise des eaux turned out to be insufficient to supply the compressors needed for the cold rooms. Failing to find a suitable underground water source, they had to rush the construction of a costly atmospheric cooling tower to recycle the cooling water from these compressors in 1961. The piped water in Gif-sur-Yvette was not only insufficient but also polluted. It was loaded with 'mud, organic detritus, excessive amounts of antiseptics, neutral detergents, etc.', calling for additional measures to avoid clogging the machinery.[100] A further frustrated requirement was that the phytotron, once in operation, should not be interrupted. On 18 February 1963, a explosion in a room cost a painter his life, and led to months of work to restore the damaged phytotron rooms and air-conditioning units to working order.[101] The same year, Chouard found that the construction 'companies had not foreseen the appropriate valves to isolate certain cold fluid circuits during the connection of new refrigeration equipment: a one-month shutdown was necessary for each new piece of equipment'.[102] The large number of mechanics and gardeners needed to operate a phytotron also had to be negotiated. The discomfort of phasing in research operations in the constant vicinity of construction sites was compounded by bitter disappointment when nothing was granted in the following quadrennial plan for completion of the facility.

If, from an internal point of view, there was a chronic shortage of financial and human resources, from the outside the investment seemed considerable, at least for biology. Criticism had begun to bubble up – was the phytotron a feat of 'greatness or folly of the CNRS?'[103] As reported in the laboratory's steering board meeting of February 1966: 'Questions are being asked about the budgetary needs of the Phytotron, its management, the research that is being or will be carried out there and its results.' There was even a rumour, vague but threatening, that the phytotron would be frowned upon in government circles. The board then pushed for a reorganization of its teams around selected basic research problems to be tackled cooperatively and on a much smaller number of plants, following the example of geneticists and molecular biologists, who used a few organisms

[98] Pierre Chouard, 'Rapport général sur le Phytotron 10 février 1966–29 septembre 1967', n.d., ANP, 20140644/37, folder 'R.A. 1966–1967', 1.

[99] Pierre Chouard, 'Aperçu de la situation et de l'évolution du phytotron du C.N.R.S., à Gif-sur-Yvette', January 1962, ANP, 20140644/36, folder 'Comité de direction 1962', 1.

[100] 'Rapport présenté au Comité de direction du Phytotron du 25 février 1963', 22 February 1963, ANP, 20140644/36, folder 'Comité de direction 25/02/1963', 4.

[101] 'Rapport présenté au Comité de direction du Phytotron du 25 février 1963', op. cit. (100), 1–2.

[102] 'Rapport présenté au Comité de direction du Phytotron du 25 février 1963', op. cit. (100), 3.

[103] Pierre Chouard, 'Résumé des éléments à considérer pour discuter la situation générale du Phytotron', 7 February 1966, ANP, 20140644/36, folder 'Comité de direction 10/02/1966', 4.

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functioning as representative models of a biological phenomenon common to a broader class of organisms. In the hope of attracting the attention of government circles, it also recommended that cooperative hosting of external researchers be formalized, and research for applications be developed, while avoiding encroachment on the remit of the other French research institutes that normally dealt with it.[104]

While accepting criticism, Chouard outlined that it would be 'extremely difficult' to meet "'all" the scientific objectives (fundamental and applied) immediately set for the Phytotron', while it was 'suddenly deprived of the resources that had been envisaged for its well-balanced completion'.[105] As such, the initial plan to create an 'all-purpose phytotron combining the use of different systems' had been curbed. While there was an actual phytotron in the mid-1960s, the addition of 'simplified phytotrons' to rough out fundamental and applied problems lagged behind, as did that of small cabinets, which, it was considered, would provide 'practically sufficient approximation for agronomic problems … at a lower price per square meter'.[106] In the early 1970s, Chouard regretted that 'some types of rooms or small cabinets' were still missing, and that 'projects as important as controlling CO2 content or root temperature … could merely be sketched out in makeshift trials'.[107]

Chouard's vision of the phytotron as a "'simulator of climates" or a "reduced model" of growing conditions' also came up against epistemological tensions.[108] Research on durum wheat illustrated the tension existing between the selection of factors accessible to experimental control and the extreme complexity of their interactions, and entanglements in open environments. Surprisingly, *mitadinage* had been negligible in the trial designed to 'imitate a Parisian summer of the coldest and wettest type'. 'The only plausible reason', Chouard explained in 1963, 'is that *mitadinage* must result as much, or even more, from rain wetting wheat ears at certain critical moments, as from the cold or humidity of the air'.[109] But, still unable to reproduce this phenomenon, they added yet another factor to the list of potential culprits, presuming that they had 'to look for a combination of adverse climatic factors and various shortcomings in mineral nutrition'.[110] A related tension arose between the relatively constant and uniform conditions established in phytotrons and the perpetual variability of climatic factors in outdoor conditions. Under artificial lighting, for instance, light was very stable in intensity, unaffected by 'clouds, fog or smog'. Its quality did not vary 'according to the position of the sun on the horizon or the altitude of the location', and its duration was usually regulated by 'instant on/off, with no dimming at all'.[111] The difference between the communities in which plants grew in fields or pastures and research carried out on isolated organisms was not insignificant either.[112] And even if only the most modern greenhouse horticulture was to be considered, exact transposition of the highly precise and costly micro-climatic conditions established in phytotrons remained difficult,

104 'Compte-rendu de la réunion du Comité de direction du Phytotron du 10 février 1996', n.d., ANP, 20140644/36, folder 'Comité de direction 10/02/1966', 1–2, 10–12.

105 'Compte-rendu de la réunion du Comité de direction du Phytotron du 10 février 1996', op. cit. (104), 8.

106 'Rapport présenté au Comité de direction du Phytotron', 22 February 1963, ANP, 20140644/36, 6.

107 'Rapport financier sur le laboratoire du Phytotron', 17 February 1970, ANP, 20140644/36, folder 'Rapport financier de 1969 et à l'orée de 1970', 2.

108 'Le laboratoire du Phytotron', 1 September 1965, ANP, 20160194/669, LP 2461, 1.

109 'Rapport présenté au Comité de direction du Phytotron', 22 February 1963, ANP, 20140644/36, 9.

110 'Pour le Comité de direction du Phytotron le 27 février 1964; Travaux accomplis depuis un an par le groupe de P. Chouard', n.d., ANP, 20140644/37, folder 'R.A. 64–65', 6.

111 Nicolas de Bilderling, 'Phytotrons et environnement dans les espaces climatisés', in Pierre Chouard and Nicolas de Bilderling (eds.), *Phytotronique et prospective horticole: Phytotronique II*, Paris: Gauthier-Villars, 1972, pp. 17–54, 35–6.

112 Lloyd T. Evans, 'Extrapolation from controlled environments to the field', in Evans (ed.), *Environmental Control of Plant Growth*, New York: Academic Press, 1963, pp. 421–37, 430.

as experienced by a contractor who attempted the commercial exploitation of Tran Than Van's orchid cultivation techniques.[113]

Even if the CNRS phytotron was used in the 1970s for research carried out in cooperation with INRA researchers on the amelioration or cultivation of pastoral and pharmaceutical plants, its agricultural role remained, for these various reasons, limited.

Conclusion

When Chouard stepped down as director in 1975, he raised the question of the obsolescence of the equipment. The laboratory was nevertheless renewed several times, first under the direction of Paul Champagnat and then under Roger Jacques. Although the quality of its research was recognized by the CNRS, it remained in material difficulty. The operating costs of the facility had been very high from the outset: in 1964, it 'consumed per month 500,000 [kWh] of electricity, 90 t of coal, 6,000 m^3 of water, 200 125-watt fluorescent tubes and required a technical staff of thirty-two; a square metre of usable space for growing plants cost around 400 francs a month'.[114] After the oil crisis, the ever-increasing cost of fluids was not matched by appropriations, making the laboratory increasingly expensive to run. It was suddenly, but not surprisingly, dismantled. As part of the restructuring of plant biology on the Gif-sur-Yvette campus, a service unit was created in 1987, making its super-greenhouses and air-conditioned enclosures available to all plant biologists in the region, while some of the teams from the former phytotron were integrated in a newly created laboratory. Its closure was finally voted through in 1988.[115]

The history of phytotrons provides insights into the persistence of a biologically informed conception of climate and its operationalization in the mid-twentieth century. While climate research was increasingly becoming a 'physical', 'theory-based' and 'global-scale science', phytotrons enacted a distinctly different, physiology-based and empirically oriented methodological project.[116] When Gif scientists embraced phytotrons as a means for developing an 'experimental bioclimatology', they framed the climatic components of a plant's milieu as agents likely to affect its growth and development. Thus, in the experimental settings and research programmes pursued in phytotrons, an ancient notion of climate as 'agency' resurfaces.[117] It was converted here into a complex of technologically tractable variables, and updated by twentieth-century research on photoperiodism and thermoperiodism. As a result, phytotronists' climate integrated light, spanned shorter (daily and seasonal) timescales than those covered in contemporary climate research, and defined a rhythmic understanding of cultivable areas. The case of the CNRS phytotron indeed also affords opportunities to explore the economic and political entanglements of experimental reasoning in plant physiology during a period of intense agricultural modernization. This expensive facility drew justification from its polyvalence, potentially accelerating discoveries in plant biology and innovations in applications for horticultural or agronomic pursuits. A rhythmic and place-based understanding of climatic influences underpinned the various interventions that phytotronics prescribed, which targeted the timing of climate-sensitive biological events and the expansion or delimitation of productive territories. In France, the late colonial and postcolonial contexts in which the agricultural imagination of phytotronists was forged come to the fore. Its entanglement

[113] 'Note sur les recherches capables de fournir des applications pratiques', n.d., ANP, 20140644/37, 184.

[114] Nitsch, op. cit. (11), p. 1610.

[115] ANP, 20160194/669, folder 'n°002461-IPV'.

[116] Matthias Heymann and Dania Achermann, 'From climatology to climate science in the 20th century', in Sam White, Christian Pfister and Franz Mauelshagen (eds.), *The Palgrave Handbook of Climate History*, New York: Palgrave, 2018, pp. 605–32.

[117] Fleming and Jankovic, op. cit. (12), p. 1.

with Western plans for dry-land development nurtured an understanding of climate as not only a constraint or deficiency to be corrected, but also a resource to be leveraged with ad hoc technical means. Moreover, Chouard's soil-less cultivation experiments in the Algerian Sahara epitomized the neglect of soils and biotic factors in the operationalization of the biologically relevant environment at the CNRS phytotron. In fact, research there could be characterized as triply off-ground, in terms of the selection of factors to be investigated, the cultivation techniques developed, and its aspiration to reach out from the local laboratory, through generalizable knowledge or more problem-specific simulations, to plant resource issues in the country and the world.

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