Ann. Rev. Phytopathol. 1978. 16:19–30

J. C. ARTHUR: THE MAN AND HIS WORK

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INTRODUCTION

Joseph Charles Arthur (1850–1942) was a remarkable man. He decided early on a career in botany and proceeded with unremitting persistence to reach that goal. By any standard he succeeded. His writings (51) totaled 289 papers and books. The first journal paper (2) was published in 1886 and the last one (32) in 1936; the first book (31) was published in 1893 and the last one (30) in 1934 when Arthur was 85. Certainly, as F. D. Kern wrote, "The life and work of Dr. Arthur should serve as a great inspiration to ambitious young workers. A pioneer spirit, real resistance to discouragement, industrious habits, sound scholarship, unflagging persistence, and singleness of purpose led Dr. Arthur to high achievement." (51)

Arthur was a gentleman of the old school, dignified, courteous, precise of speech, and careful of grooming; a man of small stature but large presence. His wife called him Joseph, but I never heard others, including F. D. Kern, a lifelong friend, address him other than as Dr. Arthur. I cannot imagine even the most blatant first-name-caller using "Joe." He enjoyed the social life of the community and is said to have been an accomplished tap dancer. He always was engrossed in the project of the time. He did not dwell on past accomplishments, nor did he bewail the passing of the good old days. Arthur was 80 years old when I, a graduate student, became associated with him. For the next four years we worked on the manuscript of the *Manual* (30). I found him to be kindly, tolerant, and fair. He knew that I knew little about the rust fungi, yet he considered my suggestions. If evidence was adequate, he would rewrite the part involved. This impressed me greatly.

0066-4286/78/0901-0019$01.00

There is evidence that Arthur was open-minded when young. In 1883 (5), when matching Schweinitzian descriptions with specimens, he wrote: "In the former he says the septum is situated *exactly in the middle* of the spore. . . . A glance under a common microscope . . . reveals there is *not even a shadow* of a septum. How is such an egregious blunder to be reconciled with the accuracy characteristic of science and scientific men?" But "upon reflection" he decided that there must be an explanation. So he viewed dry spores with an objective of 75 X, "and the key to the mystery was discovered." At that magnification, the apically thickened wall simulated a septum. Arthur had learned that a man's work can be judged fairly only in terms of the period in which he worked.

Arthur achieved several firsts. He was first alphabetically in the first class to graduate from Iowa State College in 1872. He was appointed first botanist in the New York Agricultural Experiment Station at Geneva and was also the first botanist in the Purdue University (Indiana) Agricultural Experiment Station.

Arthur was a charter member of the Botanical Society of America, the American Phytopathological Society, the Mycological Society of America, and the American Association of University Professors. He was a member of the American Philosophical Society, the Academy of Natural Sciences of Philadelphia, and, at times, of several other societies. Arthur (10) initiated, and then served as chairman of, the Madison Botanical Congress of 1893. He earned his PhD at Cornell University in 1886. Honorary degrees were conferred by the State University of Iowa, Iowa State College, and Purdue University.

ARTHUR'S CONTRIBUTIONS

Arthur's principal contributions may be divided into three groups: phanerogamic plants (1872–1884), plant diseases and their control (1885–1900), and life cycles and systematics of the rust fungi (1901–1936).

Studies of Phanerogamic Plants

Young people often become interested in wild flowers, and Arthur was no exception. When his parents moved to Iowa, he was about seven years old but he was impressed with the scene. From his home " . . . the boy could see the sun set over the billowy prairies that extended as far as the eye could see without a tree or any evidence of man's disturbance. . . . Among the small spring flowers there occurred a slender buttercup. . . ." A plant was moved to the garden where it produced an abundance of double flowers. The influence of the environment in shaping his career could be overemphasized. But the desire to be a botanist was strong, although his parents neither encouraged nor understood, because "... botany could not be made to bring in enough to keep a cat alive."[1]

Arthur's first publication (2) concerned the double-flowered buttercup. It was followed by a series entitled "Contributions to the Flora of Iowa" (e.g. 6). For a man destined to work with obligate parasites, the experience provided excellent background. Arthur had a penchant for observing and reporting. While an instructor at the University of Wisconsin, he reported (3) that the pumpkin stem was excellent for teaching structure. "The fibro-vascular bundles are open, two-sided bundles, but peculiar in having an additional phloem portion on the axial side." He also observed (4) that the arrangement of tendrils in the buds of garden cucurbits varied according to the species.

Studies of Plant Diseases

FIRE BLIGHT Arthur entered the field of plant pathology when he was appointed botanist in the New York Agricultural Experiment Station at Geneva. He proceeded with diligence, publishing ten papers during 1884–1887. The most important studies dealt with pear blight. Baker (36) reviewed and evaluated these and concluded "that Arthur, rather than Burrill, first presented convincing proof that bacteria could cause plant disease, and this was in 1884–1885." The convincing proof cited by Baker was hinted at by Arthur (7): "The priority of demonstrating parasitic bacteria in plants belongs to an American. In 1880, two years before Dr. Wakker's announcement of bacteria in hyacinth, Professor T. J. Burrill of Illinois presented a paper ... demonstrating the invariable presence of characteristic bacteria ... in pear blight ... and that the disease may be transmitted from tree to tree in inoculation. Since then the bacteria have been isolated and cultivated in artificial media, and the statement of the original paper fully confirmed." In August 1885, Arthur (8) made two series of six serial transfers each using a sterilized infusion of corn meal. The inoculum was "a very small fragment of wood taken from the inner portion of a diseased limb of Flemish Beauty pear.... The inoculation of each of the other cultures of the series was successfully made with a small drop of the one preceding. From the last culture a drop was transferred to a puncture in a ripe Bartlett pear. In both cases the pears were soon filled with the disease." He also filtered an infusion through an earthenware vessel. The infusion, when introduced into a green Bartlett pear, blighted the fruit but

[1]From "Why a Botanist," an essay read before the Parlor Club of Lafayette, Indiana. Copy in the Arthur Herbarium, Purdue University.

the filtrate did not. In December he (9) concluded, "No stronger proof is needed that bacteria are solely responsible for the disease."

Arthur moved to Purdue University in 1887 as the first botanist in the Agricultural Experiment Station, a position that required his continued concern with diseases. He gave primary attention to diseases of cereals and potatoes.

POTATO SCAB Arthur (14) and Bolley (38) came in neck and neck with the use of formalin as a fungicide. Bolley was first, his publication being dated March and Arthur's June, unless one credits a newspaper bulletin (13) in February as establishing priority, as I do not. Presumably it was issued before the regular bulletin so that farmers could treat seed pieces that spring. Later, Arthur (15) states that formalin "was first tested with some fullness ... by Professor H. L. Bolley." Bolley used it to control cereal smuts and Arthur to control potato scab. Bolley (38) writes, "It promises to excel as a medium of efficient and easy smut control." Arthur (14) states, "The present bulletin makes what is believed to be the first announcement, or even suggestion, of a preventive having the good qualities of corrosive sublimate without its bad ones. . . ." Probably neither man knew of the other's work.

Arthur conducted trials in the greenhouse in the winter of 1895–1896, and these gave good control of potato scab. In 1896 he planted in ground that had been cropped with potatoes for the seven preceding years. He concluded that there was no doubt about formalin being a preventive of scab. He recommended soaking the tubers 2 hr in a solution of one half pint of 40% formalin in 15 gal water, before cutting and planting them.

CORN SMUT Corn smut was given special attention. Because of the successful use of hot water to control smut of wheat, Arthur (11) tried it on corn seed and found to his surprise that " . . . there is no prospect that the . . . treatment will be found serviceable. . . ." He also dusted seed with spores at planting time and found that no infection resulted. Later (12), he concluded that any part of the growing plant could be infected. He decided that destroying immature smut boils would be most effective; he also found that spraying with Bordeaux mixture was better than with ammoniacal copper carbonate, but he questioned the economics of the treatments. Only after completing this work did Arthur (35) find that Tillet proved in 1776 that smut spores on the seed were harmless. Arthur further found that Brefeld (39, 40) had reported experiments that proved the possible points of infection and the spores that were responsible. But Arthur & Stuart (35) gave as good an account of the fungus and the disease as any prior to Christensen (41).

Studies of the Plant Rust Fungi

LIFE CYCLES Arthur's most valuable contributions concerned the rust fungi. Anyone wishing to know the rust flora of North America must use the *North American Flora* (22) and the *Manual* (30). This will not change soon. Numbers do not measure the worth of a man's work, but numbers show that Arthur dominated uredinology in North America. Data from the *Flora* show that 29 of the genera accepted were named by Arthur. He was using the life cycle genera, proposed in 1906 (21). Cummins (45) accepted 16 genera named by Arthur, but only 8 named by other Americans, and 7 of these were men who had been associates of Arthur. Again, 309 of the accepted species in the *Flora* were named by Arthur.

The life cycle classification had some good and some poor results. Dietel (47) enumerated the disadvantages. The system caused an undesirable increase in the number of genera and a fragmentation of established genera. Potentially, each genus could be split into four or more genera according to the number of spore forms in the life cycle. What is known now as *Puccinia* was split into *Dicaeoma, Eriosporangium, Argomyces, Allodus, Bullaria,* and *Micropuccinia* in the *Flora. Puccinia* was left dangling as a form genus to house species whose life cycles were unknown or could not be anticipated. Not all genera could be treated thus because some did not have life cycle variants. But, monumental as is the *Flora,* its utility is diminished because of the genera used. Almost no one accepted the system, and Arthur abandoned it when he wrote the *Manual.*

On the positive side, the system spotlighted the kinds of life cycles and led to the concepts of uredinoid aecium, aecidioid telium, and correlated species. The concept of the uredinoid aecium came from Christman (42), who stated, "It is . . . my chief . . . purpose . . . to bring out the resemblance between the true aecidium and the primary uredo. That the spores in the two cases are . . . morphological equivalents cannot be doubted." Later, Arthur (26) used the terms *stylosporic* or *uredinoid aecia* and finally (28) established the form-genus *Uraecium* as equivalent to *Aecidium, Peridermium,* etc.

The idea of correlated species was introduced by Orton (55) to show a close relationship between species of *Puccinia* and *Uromyces.* In the *Flora,* the concept was broadened to include reduced life cycle forms (e.g. species of *Micropuccinia*), and these were indicated by notations below the specific descriptions. In the *Manual,* Arthur took the logical last step and numbered only the putative parental species, and listed under them the derivatives. For example (pp. 131–132), No. 17 *Puccinia interveniens,* a heteroecious species, is followed by unnumbered *P. graminella,* an autoecious demicyclic species, *P. sherardiana,* a microcyclic species, and *Endo-*

phyllum tuberculatum, an *endo* species. This emphasizes relationships but confuses the uninitiated user. Jackson (50) probably was influenced in the study of the origins of life cycles by exposure to the system used at Purdue.

THE SPERMOGONIUM Arthur described the spermogonium more than was usual, stating the position in the host tissue and something of the morphology (22), although he decided earlier (18) that spermogonial characters have little or no generic value. He, as others, discounted its function: ". . . the spermogonium is an isolated organ with functions not yet conjectured. . . ." (18) Yet, after concluding that wheat infected by aeciospores produced uredinia for only a short time and then telia rapidly, whereas infections by urediniospores continued to produce uredinia for a long period and telia only slowly, Arthur (16) concluded "that the aecium with its accompanying speromogonia represents the original sexual stage . . . and that it still retains much of its reinvigorating power." So he came as close to the answer as anyone before Craigie (43). Arthur's emphasis on the spermogonium led to an evaluation (48) of the organ taxonomically and phylogenetically. Earlier (58), it had been suggested that the spermogonium was as conservative to change as the telium. Savile (57) has predicted that the spermogonium will be accorded increasing importance in the taxonomy of the Uredinales.

DISSEMINATION Arthur had thoughts about the aecia of widely distributed species. He (16) believed that extermination of barberry would eliminate stem rust, but he admitted that urediniospores from the south might blow north to infect the whole country. Also, he concluded (16): "The extended production of uredospores in any grass or sedge rust, possibly any sort of rust . . . may indicate . . . that the aecidium is rare or absent in that vicinity." With regard to maize rust he wrote (17), "It would seem possible for the rust in northern regions to be wholly distributed by uredospores . . . from a locality sufficiently far southward to permit the corn plant to survive the winter." He lived long enough to learn that the aecia on *Oxalis* are not important in epidemiology. Arthur clearly entertained the idea of distance dissemination.

GERM PORES The number and arrangement of the germ pores of urediniospores are now included in most descriptions of species and are diagnostically dependable. Germ pores were described and illustrated by the Tulasnes (59), but consistent use of them in descriptions was started by Arthur & Holway (34). In the *Flora,* Arthur routinely described the number and arrangement of the pores and used them in keys. Attention to pores advanced knowledge of speciation in the grass rust fungi more than other features (33). While illustrating the *Manual,* I became convinced that the changes in numbers and arrangements of pores followed a trend. Data compiled subsequently (44) demonstrated the trend.

TERMINOLOGY Arthur was much concerned about terminology and nomenclature. In 1905, he (20) proposed (with advice from F. E. Clements) the terms: pycnium, aecium, uredinium, and telium. They applied to the sori and in the sequence in which the sori occurred in the life cycle. Thus, the sorus that accompanied the pycnia could be called an aecium whether it was morphologically of the form genus *Aecidium, Caeoma, Roestelia,* or *Peridermium.* The spores were simply aeciospores. The terms were used in the *Flora.* In the *Manual,* uredinium and urediniospore were replaced by uredium and urediospore, proposed in 1932 (27). This was challenged by Savile (56) because uredium is "etymologically bastard," and uredinium has again been used in recent descriptive manuals (46, 60). I prefer spermogonium, rather than pycnium, because that is what the structures are.

Laundon (53), states that "Urediospores are always . . . borne singly on pedicels." Hence, *Coleosporium* and *Chrysomyxa* have no uredinial stage but have two aecial stages, one with and one without spermogonia. The aecia accompanied by spermogonia are, naturally, on the aecial host, but the other aecia are on the telial host! And so, confusion reigns among mycologists. Meanwhile, the rust fungi continue to start the life cycle by mating and end it by meiosis.

NOMENCLATURE In matters of nomenclature, Arthur had unorthodox views and, with his usual tenacity, he clung to his views against prevailing opinion. Consequently, the nomenclature of American rust fungi has been anything but stable. Arthur (19) believed that the oldest specific name, to whatever spore stage applied, should be the name of the species. He also believed that Linnaeus' *Species Plantarum* of 1753 should be the starting date of nomenclature. This was in accord with the American *Code of Botanical Nomenclature* (1) drawn up by a commission of which Arthur was a member. This code treated all groups of plants uniformly. The upshot was that many specific epithets used in the *Flora* were illegitimate or became so in terms of the codes adopted by the various botanical congresses. Confusion was multiplied by Arthur's use of the life cycle genera. As an example, *Puccinia graminis* Pers. is in the *Flora* as *Dicaeoma poculiforme* (Jacq.) Kuntze, the epithet taken from *Lycoperdon poculiforme* Jacq., an aecial stage published in 1786.

In the *Manual,* Arthur abandoned the use of aecial names but accepted *Uredo* names in determining priority. His argument (29, 30), supporting *Uredo* names, was that the uredinial stage is sporophytic and hence of the perfect state. Thus, such names were permitted by the rules, which then stated, "The perfect state is that which ends in the teleutospore or its equivalent in the Uredinales." The wording was changed (52) to "The perfect state is that which consists of spores giving rise to basidia in the Uredinales." Perhaps that is the last word.

ALTERNATE HOSTS Related to the taxonomic work, and probably as important, were Arthur's studies that led to proof of aecial stages of heteroecious species. These, as well as the taxonomic studies, were first conducted largely sub rosa, but gained official recognition when Arthur was chosen to prepare the manuscript on the Uredinales for the *North American Flora* (22). With the passage of the Adams Act in 1906, Arthur's work received financial support that permitted travel and assistants. With regard to travel, Arthur (24) stated "... during the extended study of heteroecious species only three times was a discovery of alternate hosts effected that was not the outcome of a previous field observation." Field observations were then tested by greenhouse cultures (inoculations). The extent of this operation is indicated by the statement (24) that 2140 collections which had to be tested for viability were available and that "... about 3750 sowings ... were made, of which about one in seven resulted in successful infection...." As to the numbers of species, Arthur writes "Probably the list includes about one hundred species ... and of the number about eight were heteroecious to one autoecious." Further, "Of the heteroecious species some twenty were verifications ... while about sixty-five provided alternate hosts for species whose life cycle was before unknown...."

So many inoculations required assistants and funding. One man could not make all necessary field observations, and Arthur (24) acknowledged the help of more than 85 correspondents. Baxter & Kern (37) list 17 who were especially helpful. They imply, and I agree, that Ellsworth Bethel was most helpful because he collected with an eye to host associations.

RACES The possibility of races arose early. Arthur named such species as *Puccinia caricis-asteris, P. caricis-erigerontis,* and *P. caricis-solidaginis,* but even then doubted (23) that they were more than variants of one species. After similar experience with what is now treated (46) as *Puccinia recondita,* Arthur considered how to delimit species in such complexes. "It was soon decided that, for the purpose of the Flora, morphological characters must be the final test for species." In the *Manual* he carried groups further. Arthur did not get embroiled in the problem of formae speciales but Mains

(54), using data compiled while at Purdue University, completed an extensive study of specialization in *Puccinia rubigo-vera* (now *P. recondita*).

THE HERBARIUM The Arthur Herbarium was started when Arthur was a student and now contains some 85,000 specimens. It is not the largest collection of plant rust fungi, but it is the most studied. North American specimens predominate but there is extensive material from South America, Africa, the Philippines, New Guinea, and China. As a part of the compilation of the *Flora,* an accession list was prepared of the 43,534 North American specimens available when the *Flora* was written. A copy was sent to the New York Botanical Garden and a copy kept at Purdue University.

Arthur and his associates left thousands of measurements, drawings, and notes with the specimens. More recently, hundreds of photomicrographs have been added. The specimens used for and resulting from inoculations also are in the herbarium with the relevant data.

Perhaps because Arthur was involved in formulating the American *Code* (1), which introduced the concept of *type* specimens, most of his and his associates' species had the original specimens marked type or part of type. The type locality of each species was listed in the *Flora,* but this is not equivalent to identifying the holotype, lectotype, or neotype as specified in the *Code* (52). But the designation of types in the Uredinales in North America is more advanced than in most areas of the world.

Arthur did extensive field work relative to life history studies. He did little collecting to find additional species or to extend geographical or host ranges, but some of his correspondents were diligent and discriminating collectors who greatly increased the numbers of specimens and known species. E. W. D. Holway, by his collecting, increased knowledge of the numbers and the distribution of the North American rust fungi more than any other person. Holway's name as author or coauthor of species occurs in the *Flora* (22) some 210 times, the commonest combination being Dietel and Holway which appears 110 times. Most of the type specimens are Holway numbers.

Holway collected 2049 numbers in South America. Arthur (25) states that one fourth were grass rusts, and that 27 species including 12 new species, were new records for South America. The specimens, other than grass rusts, were studied by Jackson and reported in six papers (49). Jackson described 6 new genera and, under joint authorship with Holway, 180 new species. Holway's collections are the most important made by one man in South America. But time was taking its toll, as indicated in a letter to Arthur (25). He wrote: "Likely this is my last long collecting trip. I feel a little aged sometimes. Hard luck, isn't it, just when one is free to do as he pleases."

The tenacity of Arthur about his work can be underscored by reference to a controversy with the Purdue University officials concerning ownership of the herbarium. Arthur considered that the herbarium was his, a point of view not wholly unjustified, because he had financed it as to packets, mounting paper, etc. He[2] states that Experiment Station Director Charles G. Woodbury, who took office in 1917, was the first Experiment Station official to take an interest in the rust studies to the extent of encouragement, new steel cases, and dependable funding. But this happy state of affairs terminated, in Arthur's opinion, when he was told that the herbarium was the property of the Station. Arthur objected[2]: "I asserted my ownership, and to prove it, removed the whole mounted collection to my home. . . ." This action produced a minor crisis but major enough so that W. E. Stone, President of the University, under date of July 19, 1918, notified Arthur to return to the University the rust herbarium and all manuscript, notes, etc that related to the North American Flora. This notification was served by W. W. Weimhardt, Sheriff of Tippecanoe County, Indiana, and the service was acknowledged by Arthur at 4 PM, July 23.

The solution came as an agreement, entered into August 5, 1918, between the Trustees of Purdue University and Dr. Arthur. It stipulated, in part, that Arthur would (*a*) be paid for the herbarium supplies that he had purchased, (*b*) be paid for the part of the herbarium covered by the portion of the North American Flora that antedated the Adams fund project, (*c*) be allowed the privileges of the laboratories, libraries, collections, etc of the Station, and that the collection could be transferred to some other institution if, in the future ". . . it shall be decided that scientific interests would be better subserved by said transfer." The agreement was signed by Vice President W. V. Stewart for the University, and by Joseph C. Arthur. The payment to Dr. Arthur was the munificent sum of $1,000.00. In 1930, the Experiment Station bought Arthur's reprint collection, relating only to Uredinales, for slightly less than $450.00. On both occasions, with his usual good judgment, Dr. Arthur took his wife and traveled in Europe.

Arthur retired formally in 1915. He used the freedom from official duties constructively. Parts 4 to 13 of the *Flora* (22), *The Plant Rusts* (26), and the *Manual* (30) all were published during the next 19 years. I believe that he considered the *Manual* to be the capstone of his career. The next year (1935) Mrs. Arthur died. Thereafter he rarely visited the herbarium. Joseph Charles Arthur died April 30, 1942.

[2]Manuscript entitled "The Purdue Herbarium, basis of the rust project" filed in the Arthur Herbarium.

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