John McColl Bremner: A Heritage for Understanding Soil Nitrogen, Organic Matter and Biomass *

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Abstract

John M. Bremner (Jack) a Scottish native completed a university degree with honors in chemistry at Glasgow. His professional career was divided into two temporal parts: the first 13 years at Rothamsted in England, and the last 35 at Iowa State University. He spent extended study periods in Germany, Austria, Yugoslavia, Australia and Japan during his career. At Rothamsted he realized that he needed new procedures and techniques better to study soil organic matter, so he developed, tested and published them along with a new understanding of the chemical nature of soil organic matter emphasizing the role of nitrogen. He adopted chromatography as a key tool for chemical studies, and honed his skill in identifying the critical questions and planning experiments to answer them. Surrounding himself with talented students and local and international scientific colleagues in Iowa, his laboratory continued the characterization of soil organic matter, employing N-15, and expanded its investigations to include sulfur and phosphorus as well as nitrogen transformations. This led to an understanding of nitrogen and sulfur losses from soils, and also the sorption of compounds from the atmosphere. The laboratory demonstrated that nitrous oxide is lost during nitrification of ammonium, and that volatilization of organic compounds of sulfur predominates over hydrogen sulfide in sulfur loss from soil. These studies led to the role of extracellular enzymes from the biomass in transformations occurring in soil organic matter and a clearer relation of these losses to fertilizer nitrogen use. His chemical methods were consolidated and published in monographs, making them globally available. The students and scientific colleagues who listened to his instruction and were guided in his laboratory represent a direct living influence that continues today.

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* Inspired by the memory of and admiration for Jack Bremner and the opportunity offered by Dennis R. Keeney and H. H. Cheng; presented in Houston, Texas, October 6, 2008.

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Introduction

The first thing that occurred to me when charged with this opportunity to tell of Jack Bremner's influence while in our department was: Why would an established and eminently successful scientist at a world renowned institution like Rothamsted in England come to the middle of North America far away from family and friends? One answer might be that he spent five months among us before deciding to move but: Why did he pick Iowa State for a major part of his travel grant time in preference to several highly regarded universities in this country? These questions may never be completely answered, but a review of what we had done in the field of soil bacteriology and organic matter may help to understand.

Soil bacteriology was a field of study and in the curriculum of the Agronomy Department since its creation in 1902, as part of the School of Agriculture. Soil Bacteriology as a separate course was identified in 1906 a second course added in 1909 and a special problems and an advanced special problems course in soil bacteriology were first offered in 1915. No doubt that the latter two were necessary for Charles Davis and Paul Emerson to receive doctorates in soil bacteriology in 1917, the first two in Agronomy and the second and third Ph. D. degrees granted by the College. Study of soil bacteriology was identified for graduate study along with soil physics and soil fertility from the beginning in the 1890s. Even as early as 1891, the College Catalogue described a junior course in agricultural chemistry as including "...mechanical and chemical sources of available nitrogen, the 'nitrogen gatherers,' nitrification, reduction of nitrates, losses of nitrogen, its conservation on the farm". (After Robert M. Collins 1953; History of Iowa State College, a dissertation in the Iowa State University Library)

It is not clear why the early interest in soil bacteriology, but I am reminded that Louis Pasteur lived until 1895, so that study of bacteria was a very fresh topic--the thing for everyone to do--and immediately more evident than the discoveries of Mendel in genetics. The fact that the first two doctorates granted in our department were in soil bacteriology can be associated with the presence of Percy E. Brown on the soils faculty from 1912 and professor from 1914. He received his degree from Rutgers University, became interim head of the department

at the beginning of the great depression in 1931, and head the next year and held that position until he died in 1937. He had to perform some amazing feats of reassignment and retrenchment to maintain the integrity of the department. It is interesting to note in passing that the department also offered graduate study in "soil humus". Research in Soil Humus and a Conference in Soil Humus were first offered in 1914 and continued until 1919. R. H. Walker directed graduate research in soil bacteriology in 1931-32, and then joined the agronomy faculty and remained until 1936. A. G. Norman joined the faculty as professor in 1937 and remained until 1946. (After R. M. Collins 1953.) There was a thread of soil bacteriology courses, research and faculty members from the earliest years of federally supported experimentation in our College.

Francis E. Clark joined our faculty in Agronomy as a USDA collaborator and graduate student mentor in 1946 at which time we had projects on Nitrogen Fixation by Soybeans, Nitrogen Transformations in Decomposing Plant Materials, Microbial Conditions in Some Iowa Soils, and Effects of Various Substances on Soil Populations. The project on Retting of Hemp that had involved A. G. Norman had just been closed. Clark remained until 1954 when the USDA transferred him from Ames. W. V. Bartholomew was appointed as Research Associate Professor in 1947 and first published on the use of the heavy isotope of nitrogen in fertilization in 1950. He remained at Iowa State until 1957 and then joined North Carolina State. Don T. Parker, a USDA Collaborator was assigned to Iowa State in 1955 to continue work in soil organic matter until accepting a position with the Department of Defense in 1963. L. R. Frederick was appointed as Associate Professor in 1955, mostly devoted to undergraduate teaching.

The departure of Bartholomew in 1957 left the department without a departmental appointee dedicated mostly to research in soil microbiology (a new designation since 1949). The department undertook directed searches, to seek experienced scientists in bacteriology and microbiology but was not successful in enticing them to join us at Iowa State. By this time, we had started talking about "soil microbiology and biochemistry", as the general field of effort in this unseen biological part of soils. Good fortune smiled on us because John M. Bremner in Great Britain was awarded a Rockefeller Foundation grant to spend twelve months visiting U.S. universities and research

centers in 1957-58. These were to be "involved in research on the chemistry, biochemistry, and microbiology of soils" (Bremner). He chose to spend five months in our department, "four months at the University of Illinois and three months visiting universities and research institutes in California, Oregon, Washington, Minnesota, New York, Maryland and North Carolina" (Bremner, unpublished file). Before leaving Iowa State in 1957, W. H. Pierre, the department head, offered Jack a tenured position in our department. He indicated that he was happy at Rothamsted and had not considered immigrating to the United States.

In Jack's words, "Dr. Pierre did not take no for an answer and said that he would contact me again after my return to England in 1958. By that time my wife and I had so enjoyed our experiences traveling in the U.S. that we reconsidered Dr. Pierre's offer and decided to accept it. This was a difficult decision to make because we were both happy working at Rothamsted and we had many relatives and friends in Britain but we never found any reason to regret our decision." We had the wonderful experience of having a happy immigrant family in our community. We were sorry to have them leave to more a comfortable situation upon retirement; somewhere near their settled family members and an opportunity to golf all year around.

This exercise of reviewing the status of soil bacteriology, microbiology and organic matter in the Agronomy Department and at Iowa State since late in the nineteenth century may give some insight into why someone like John Bremner would have chosen to join the faculty here—even why he may have chosen to spend the greatest part of his Rockefeller Travel Grant with us. We had been involved in these topics for a long time, and had multiple investigators in place most of the time, but there certainly were institutions with equally admirable or perhaps even better track records —I am not qualified to judge. But Jack did choose to make an extensive visit here, he and his family appreciated the community reception they all received, we did need a leader in this field, and once becoming acquainted with his potential W. H. Pierre relentlessly pursued Bremner's appointment. It seems that a confluence of all these is what brought the "Bremner Era" to us and to the U.S. He may also have thought that the impact of his work might be greater if performed in the U.S., and we had an open position.

By his own admission, he did not have assistants available when the potential of paper chromatography emerged, and there certainly was not any specialized equipment he could use. He had to develop it himself—a not too different situation faced by all working on the frontiers of science. He did not say anything about his laboratory, but it could not have been more primitive or Spartan than those in agronomy in the late 1950's even though we occupied the newly built space in 1952. The laboratories were dusty, because of single pane windows, there was no air cooling and the variation in temperature during the winter depended upon the location in a laboratory. We did however have an interior room that eventually was air conditioned to accommodate a mass spectrograph and there was a major capability in mass spectrometry elsewhere on the campus. In addition there were several established faculty members who were anxious to engage his skills to solve problems centering on nitrogen chemistry in soil, be they with organic matter, residue decomposition, nitrogen uptake, fertilizer use or nitrogen fixation.

In addition, he had the skilled collaboration of A. P. Edwards, a dedicated soil chemist who directed much of the analytical work involving N-15 and I am certain Jack had the promise of graduate assistants, the first of whom completed the doctorate in 1964 and they flowed through his program until the late 1980s. In the mid seventies, he had a talented collaborator in M. A. Tabatabai with experience in the field and with sulfur, and who played a major role in the study of sulfur chemistry, and the enzymology affecting nitrogen, sulfur and phosphorus. From this association was spun a new departmental research initiative in soil enzymology, now a widely recognized field of research. As fate would have it, Jack was able to move into laboratories of his own design late in 1987 as he was approaching retirement, and was seeing his last three graduate students completing their studies. As his publication record shows, he did not publish his last paper until completing papers with graduate students in 1993 and 1994, and published three more of as sole author in 1995, 1996 and 1997; Appendix A. He gave a full measure of his effort to our department, leaving few matters in suspense.

The Advent of John M. Bremner

John McColl Bremner was the youngest of seven children born to Archie and Sarah Bremner in Dumbarton, Scotland January 18, 1922. His primary and secondary education was at Dumbarton Academy, from which he continued at the University of Glasgow majoring in organic chemistry and compiled a brilliant record (First Class Honors in Chemistry). Following graduation in 1944 and a year as a Carnegie Research Scholar, he was persuaded to join the Chemistry Department at Rothamsted "to initiate a program of research to characterize the organic complexes in soil" in 1945. His first paper published in 1946 gave the first evidence of metalloorganic complexes in soil. At that time less than one percent of the organic matter in soils had been chemically identified. At Rothamsted he discovered that most analytical techniques learned in organic chemistry were not applicable to studies of soil organic matter (Bremner, IHSS Life Histories). In his words, "none of the techniques available to organic chemists at that time were likely to be of significant value if applied to the humic acids and other complex organic materials in soils."

Fortunately, paper and gas chromatography techniques were just being developed, and he quickly adopted and adapted these for the study of soil organic matter. This is more easily said than done as "no equipment for paper chromatography was available when I started...." His apparatus was rigged of "drain pipes and long sections of glass tubing modified to serve as troughs for the organic solvents and hold the large sheets of Whatman filter paper sheets in place." The sheets were too large to handle alone and he had no assistant. He solved this because, "I had...a very talented girl friend, Mary Williams ... in the Microbiology Department..., and she provided valuable assistance...." He met her while playing tennis and field hockey on the Rothamsted teams, and they married in 1950. He narrowly missed being credited for use of ninhydrin (used to locate amino acids) in fingerprinting because two investigators in London had beaten him to publication.

His subsequent publications on the estimation of "amino acids and amino sugars in soils and humic acids" led to invitations to several laboratories in Europe and he spent four months with Wolfgang Flaig at the Federal Research Center for Agriculture in Braunschweig, West Germany.

These methods of analysis were critical to advancing the knowledge of soil organic matter, soil nitrogen and biochemical reactions and changes in soils.

Jack Bremner was author or co-author of over 300 papers including 32 chapters in books during his career and all but 29 were published while a faculty member in Agronomy at Iowa State (Appendix A). This is not surprising as about half of his life from birth until retirement, and about two-thirds of his professional career was spent there. Jack achieved greatness in soil biochemistry in spite of his self-admitted speech impediment he called "stammer" with which he was afflicted from five-years old, but wrote "it has always disappeared during party time". Nevertheless he addressed individuals and groups with chalk or pencil in hand and some writing surface to make his points with clarity that is not often achieved by others. Two of his colleagues told me that this impediment was overcome when he addressed the Pontifical Academy of Sciences in 1968 by having his wife, Mary, read it to him through an ear piece and apparently he repeated and delivered his paper without incident.

A member of an academic institution in Iowa, he was expected to teach and mentor graduate students in soil microbiology and biochemistry, to engage and serve interested individuals elsewhere in academe and in the private sector. He was expected to conduct research on soil organic matter and the soil biomass by studying nitrogen compounds, and the reactions and interactions resulting from the presence of the stabilized and living organic components in soils among themselves and soil minerals, and with the environment and growing plants. This provided him the opportunity further to develop procedures for determining and elucidating nitrogenous compounds that form vital components in soils. In succeeding years, there developed a need to seek external funding for his work and he was expected to pursue any opportunities that would advance the scientific understanding of the "living soil". He lived up to all expectations.

J. P. Quirk, of Australia, adopted a categorization of the research work of Bremner in a letter supporting his nomination for the Bouyoucos Soil Science Distinguished Career Award in 1982 prepared by Charles A Black. I will adopt this plan, and augment it to include other categories

of Jack's responsibilities as an academician and his activities.

Academic instruction and mentoring

Dr. Bremner's main contributions in teaching at Iowa State during his career were to develop and teach a highly regarded graduate course in advanced soil biochemistry. This course had not been offered before and no text was available so he emulated the "best teacher" he had at Glasgow, who used "a lot of handouts and visuals". Looking back on the experience he wrote, "I probably distributed too much material at each lecture because my students had exceptionally large notebooks at the end of the course." While the course was heavily biochemistry with little emphasis on microorganisms, he never lost sight of the fact that the enzyme systems in soils with which he also dealt, mostly were the result of microbiological activity. Jack writes that he had 14 years of research experience but never had taught a course before being confronted with teaching advanced soil biochemistry. During the latter part of his tenure among us, he was charged with organizing the graduate student and faculty seminar. His primary function and the one taking most of his time was the mentoring and training 22 of his own graduate students; the first completing a dissertation in 1964 and the last in 1989. Five or these were from different countries with a diverse set of backgrounds. Countless other graduate students were affected through consultation on research problems and his service on their graduate program-of-study committees in agronomy and in other disciplines. His success is manifested by the fact that many of his former students have risen to prominence in soil science both here and abroad, and have been recognized with fellowships and awards by our own societies. (A list of former students, in order of the year of completion, the degree and the dissertation title is in Appendix B.)

Jack first had an informal mentor in his brother Alex who steered him into a degree program in chemistry instead of in English and history, which were his first inclinations. It was Alex who convinced him to enter a competition for scholarships at Glasgow, and he received one of the ten highest awarded in 1940. He wrote, "I had no mentor when working towards a Ph. D. degree from the University of

London because mentoring during this degree was rare in Britain....” This experience must have sharpened in him the need for a good mentor in a major professor for graduate research. Concerning his students he wrote, “I obtained a great deal of satisfaction from watching the development of my graduate students during their M. S. and Ph. D. research and it was a real pleasure for me to follow the achievements of these students since leaving ISU. Among these were “deans, directors of research centers or heads of departments at universities, several have served as presidents of the American Society of Agronomy and the Soil Science Society of America, and many have received major research awards from these societies.” He might be described as a thoughtful, disciplined, challenging and demanding mentor for his graduate students and others he taught. Apparently he did not watch the time of day when working on a proposal, paper or experiment.

Even though he did not have a formal mentor during his formative years, he did write of two role models that seemed to set his standards both for writing and for his research efforts. He wrote, “... I had great admiration and respect for scientists who developed techniques that permitted breakthroughs in research or wrote with great grace and clarity, and I encouraged my graduate students to read papers by these scientists. I recall that when the first really large cash award for scientific writing was created, it was given to G. Evelyn Hutchinson, the author I had been recommending to my graduate students for the high quality of his articles.” When searching the literature for potential useful procedures to use in studying soil organic matter, on another occasion he wrote, “... I came across the publications of Donald D. Van Slyke, who developed numerous methods for blood analysis while working at the Rockefeller Institute in New York. I greatly admired his work because he subjected the methods he developed to very rigorous tests for both accuracy and specificity and was an exceptionally thorough researcher.” A sense of what others have written about Jack can be found in these passages he wrote about those inspiring him.

His presence here was a magnet to draw international scholars to Ames to study and work with him. He served as a research advisor to those requesting to work with him. These included scientists from Australia, China, England, Finland, Germany, Japan, India, Malaysia, Pakistan, Portugal, Russia, Scotland, Sweden, and Switzerland. Many

of these scientists have achieved recognition and prominent positions in their home countries or in international organizations. Three of his post doctoral associates from abroad lead large research centers. In other cases he went abroad to provide instruction as he did in Yugoslavia to lecture on the use of N-15 in soil research and at the University of Costa Rica where he lectured on nitrogen, sulfur and phosphorus cycles to a group of Latin American scientists. In addition he was an external examiner for doctoral degrees for the University of London, University of Adelaide, University of New England, University of Queensland, University of Western Australia, and University of the West Indies. These international interactions on five continents first acknowledged the prominence he had in his research field, but brought recognition and international visibility to our department and university and added to the "ripples" his professional influence created in this and in other ways and venues.

Outreach and service to the profession

Jack devoted a tremendous amount of time to reviewing and editing manuscripts for scientific journals and monographs. He has reviewed papers for journals including Science, Nature, Analytical Biochemistry, Geophysical Research Letters, Journal of Geophysical Research, Analytical Chemistry, Tellus, Environmental Science and Technology, and most major national and international journals related to soil science. He was an associate editor for Soil Science Society of America Proceedings, the regional editor for Soil Biology and Biochemistry and as consulting editor for Agrochimica and Journal of Soil Science. He served on the editorial board for the American Society of Agronomy monograph, "Nitrogen in Agricultural Soils". Also included in his service activities, he reviewed projects for the National Science Foundation, Research Applied to National Needs, Energy Research and Development Administration, the Environmental Protection Agency, United States Department of Energy, and the United States Department of Agriculture, and was prepublication evaluator for two reports commissioned by the United States National Academy of Sciences. Bremner published widely in specialized and more general scientific international journals, but he also served many of them in the reviewing and editing processes, again emphasizing the high regard others had for his capabilities and judgment.

Research on soil organic matter and other organic components (what others have written)

Regarding chemistry of organic matter J. P. Quirk wrote, "At the stage when he commenced these studies in the mid-forties, our knowledge of organic matter was very poor indeed. As a result of his work on the extraction of organic matter, its composition and its macro-molecular properties we now have a deeper appreciation of the attributes of soil organic matter and the profound role it has in influencing soil fertility. This research formed an essential back ground to his later studies concerned more particularly with organic matter as a substrate for micro-organism attack in relation to nutrient cycles."

D. S. Jenkinson, at Rothamsted, supported Quirk's assessment when he concluded that Bremner laid the foundations for his subsequent work during the thirteen years at Rothamsted. In particular he pointed to identifying and then measuring alpha amino acid nitrogen, amino sugar nitrogen and fixed ammonium nitrogen in soil. Jack must have been unusual even at Rothamsted because Jenkinson wrote: "His style of work, with its drive, enthusiasm and emphasis on careful analytical work, is still part of Rothamsted folk-lore." This was after he had been gone for 25 years! Had he stopped at this point it seems evident that his development of chemical analytical methods and elucidation of the nature of soil organic matter would have been a major contribution to soil science, but there was much more that he found to do.

Concerning Nitrogen and Sulfur Chemistry of Soils, Quirk added, "His studies of the nitrogen and sulphur chemistry of soils in relation to their release from organic matter and also in relation to the complex reaction sequences involving soil micro-organisms, extra-cellular enzymes and added fertilizer materials have been especially influential in understanding the nitrogen and sulphur economy in agricultural systems."

Development of Techniques for Analysis

Quirk continued, "Dr. Bremner is an unusually gifted and imaginative analyst and has developed a range of techniques some involving considerable sophistication, which are now used throughout the world."

It was widely recognized that there was a dearth of analytical methods; even Jack commented that the methods he learned in organic chemistry were of little use in study of soil organic matter. His answer to lack of methods led him to develop and thoroughly test his own under many circumstances. He had the understanding and insight to ask the critical questions and design experiments to address them, and was always careful not to apply his findings beyond the data in hand. Not content to keep the analytical methods in his own laboratory, he generously contributed to chapters in ***'Methods of Soil Analysis'*** in the first, second and third editions. A former president of SSSA, Victor Kilmer characterized him thus: "Jack Bremner is the soils man's [sic] Bureau of Standards" (after, C. A. Black, unpublished observations). The publication of tested and dependable methods of analyses in these monographs, and his study of soil organic matter made it possible for hundreds around the globe to examine this substance in a completely new light. The lucid publication of these methods represented the capstone of this one dimension of his genius.

Quirk paid his highest tribute to the work of Jack Bremner when he wrote: "Dr. Bremner's contribution in any one of these areas would place him amongst the world's leading soil scientists and indeed his total achievement must place him amongst a handful of distinguished soil scientists in this century." This was written ten years before Jack retired; he was not done yet. F.J. Stevenson at the University of Illinois echoed these sentiments when he wrote: "His pioneering research on [nitrogen and sulfur transformations in soil] has revolutionized current thinking on the nature, origin, and source of nitrogen and sulfur constituents in the atmosphere."

Opening the door to studying enzymes in soils

Bremner was responding to problems with the use of urea as a fertilizer when he was drawn to his work on urease. He and his students first developed and tested analytical

methods for determining urease activity in soil and this led to studying how to inhibit urease activity. His was described as a "simple accurate method to estimate urease activity" by Dennis Keeney. This provided for a highly relevant understanding in fertilization practice, because urea had rapidly become the major solid and fluid form of nitrogen fertilizer used in grain and forage production. It helped to explain why the results with surface applied urea were not always the same as with ammonium nitrate or ammonium sulfate, two other common forms of fertilizer nitrogen. It also pointed to the fact that inhibition of ammonification may be as important in reducing the emission of nitrous oxide to the atmosphere as it is in sparing applied nitrogen in soils.

More importantly, this urease work helped set the stage for a major directed effort in soil enzymology in our department led by Ali Tabatabai. I am not qualified to speculate where in the history of this discipline the Iowa State initiative fits, but it is evident that this occupies the interests of a vastly increased circle of soil scientists and others. Thus this was a major development in our science attributable to Bremner's influence.

Evolution and sorption of gases by soils

Bremner and his co-workers demonstrated that nitrous oxide could be lost from soils during the oxidation of ammonia in anaerobic soils rather than the reduction of nitrate and this was one of the keys to the nitrogen chemistry in soils. This was a crucial finding as anhydrous ammonia, urea and the ammonium salts were globally common fertilizing materials, and the first predominated in fertilizing the corn crop in Iowa. His findings were relevant to farmers and the fertilizer industry after being interpreted and disseminated by extension agronomists and certified crop advisors. These observations helped better to understand and explain the nitrogen balance (or lack of balance) in cropped and fertilized fields.

Bremner and his co-workers demonstrated that loss of sulfur from soil was in organic sulfur compounds rather than as hydrogen sulfide and could evolve nitrous oxide as a "leak" in the ammonium oxidation process not from microbial denitrification of nitrate that was produced. In addition his work demonstrated that soils also could adsorb gaseous compounds from the atmosphere so they entered the soil

organic matter complex of reactions. This is of major significance in the cleansing of the atmosphere of sulfurous compounds as atmospheric contaminants.

Soil Research Applied to Mundane Demands

The talent, intellect and analytical skills could easily have kept Jack engrossed in basic research related to soil organic matter, humic substances, etc. But he was at Iowa State University with a significant part of faculty effort dedicated to solving problems in production agriculture and translating and extending the necessary information to those who farm or who support farmers. He soon learned that there were several educators and investigators in the department who had reached the limits of their preparation, and were waiting and eager for someone who could help overcome some of the obstacles they encountered. So it is not surprising that several of his early publications from Iowa were with local soil scientists and other former collaborators from abroad, and from Illinois and the Tennessee Valley Authority where he had spent part of his Rockefeller Travel Grant year. The topics ranged from fixed ammonium in soils and the use of nitrogen isotopes in research to the evaluation of new nitrogen fertilizers. The topics pursued by his graduate students and the publications for the next three decades indicated that he still explored some of the basic principles of organic matter and nitrogen chemistry in soils, but he made major contributions to our understanding of year-to-year applications of soil science to farming and serving farmers.

Publications with his graduate students began in 1964 in a paper with Keeney exploring the effect of cultivation on nitrogen distribution in soils, and continued through 1994 with Martens examining the effect of pre-emergence and post-emergence herbicides on urea hydrolysis and nitrification. These applied topics included an index of soil nitrogen availability to crops, urea hydrolysis and significance in use, inhibition of urease action, inhibiting nitrification, urea’s effect on seed germination, phytotoxicity of urea in foliar applications and loss of sulfur from annual manure applications. These all had their roots in the need of farmers to have better information about nitrogen needs, and the changing technology of nitrogen fertilizers. These have become part

of the base of information passed on in agronomy courses and extension instruction throughout Iowa.

One of the most vexing problems, that of soil nitrogen availability was approached by using a different biological test for indexing available nitrogen release. The Iowa State University Soil Testing Laboratory had been using a soil nitrification test with an incubation period of two weeks that had been calibrated with numerous field experiments since the 1950s. While it was superior to other methods of assessing nitrogen needs of crops, it never took wing outside of Iowa State. In competition with commercial tests that did not use a biological test, it was difficult to "sell" the superior test which had a built-in two-week delay in result reporting and recommendation delivery. Farmers and their suppliers wanted the most rapid turn-around time possible after submitting a soil sample for testing and for fertilizer recommendations.

Bremner and his colleagues developed an anaerobic incubation that measured the ammonification rate that required only one week for incubation. While the correlations and calibrations compared favorably with the nitrification test it replaced; even the extra week was not widely accepted. It is true that a biological test on soil requires a different kind of orientation and infrastructure to conduct on a routine basis and may be beyond the operational skills of some personnel. The advent of environmental concerns with nitrogen contamination and the vastly increased cost of nitrogen fertilizers may change matters. If so, the test is available for those who wish to provide a superior test.

The rapid ascendency of urea as a solid nitrogen fertilizer carrier brought some problems of losses following application and its apparent effect on growing tissues, be they in germinating seed or deployed foliage. The research led by Jack answered some of the questions relating to why, even though the practical solutions of all of them may have evaded practicality. Still the research pointed to the benefits and the limitations of urea, and one of them, the phytotoxicity, may have been corrected in more careful controls during manufacture. Nevertheless, we know that the hydrolysis apparently cannot be controlled in the field for extended periods of time, and likewise, the field control of nitrification seems not to be feasible for periods long enough to be fully effective in reducing

nitrogen losses as nitrate to soil and surface waters. We have a better appreciation of the limitations imposed by nitrogen, the element, and its compounds as sources of a critical plant nutrient in crop production.

The hope that urea could be made an even more versatile fertilizer continued to the conclusion of Bremner's career as a graduate student mentor. He published papers with two of the last three graduate students in the early 1990's that dealt with the effect of various herbicides on the hydrolysis and other transformations of urea in soils. Previously he had published joint papers on the influence of "pesticides", insecticides and fungicides. These were all a part of his determination to exert effective control of nitrogen transformations in soils to make nitrogen compounds as well as indigenous soil nitrogen better and more lasting sources for plant nutrition. His one patent of a method of inhibiting nitrification of ammonium nitrogen was dated in 1985, a culmination of decades of work on nitrogenous compounds in soils.

Our department has not hesitated in training potential faculty members for its own ranks by way of research associates or graduate students, nor has it refrained from keeping its own former students when opportunities existed or from bringing back former students into critical positions in subsequent years. The records are filled with such examples. Jack, through his training and mentoring of aspiring soil scientists directly or indirectly contributed three dominant members to our soil science faculty. Each has had a brilliant career, reflecting well on their profession and our department. I present them in the order each came under his influence along with a brief contribution each has made at Iowa State University.

Dennis Keeney, began graduate study in 1961 (finishing in 1965), and after a brilliant career at the University of Wisconsin, he returned in 1988 as the first Director of the Leopold Center for Sustainable Agriculture and professor of agronomy. He traveled widely to promote the concept of sustainable agriculture around the globe. During his decade in this position he established the direction for the Center for the future and has given global visibility to sustainable agriculture making the term universally recognized and he continues active in his retirement. The Graduate Program in Sustainable Agriculture and the endowed Wallace Chair in Sustainable Agriculture have their roots

in his leadership in the Center, and through Dennis, a clear connection to Jack.

Ali Tabatabai joined Jack's laboratory in the mid 1960s, and later was continued as a member of the faculty who gave rise to an experiment station project on the study of soil enzymes. He was in the position to undertake this study when the opportunity presented itself for us to launch a significant program to study enzyme systems in soil. Ali's major contribution has been the development of methods of enzyme analyses. This has permitted soil and related scientists to grow in numbers of practitioners in soil enzymology to a point of forming an international organization. Ali provided the keynote address in Prague, Czech Republic for the 2003 quadrennial international meeting of the society. This then is a part of the Bremner legacy not only at Iowa State, but in a global dimension as enzymes are ubiquitous and we now have the ability to assess and appreciate their effects in soil.

The third was Alfred Blackmer, who remained in the department as a faculty member after graduate study completed in 1977, who made major local and national contributions to our understanding of the use of nitrogen fertilizers in crop production and how use can be both economical and sparing of the water quality in the environment. He championed the judicious use of nitrogen fertilizers guided by soil nitrate levels at the beginning of the season and residual nitrate in corn stems at maturity. The effects on the environment, especially on surface- and ground-water, of fertilization practices were always foremost in his mind. Regretfully, Alfred was taken from us prematurely at the height of his career. His influence on farming the corn crop is felt throughout the Corn Belt and beyond. He added to the Bremner legacy and, like the others, has added one of his own in the students he has trained.

The characteristic these three have in common is that they published extensively as co-authors with Jack—ten papers for Dennis and more than 25 and 20 for Ali and Alfred. In addition, all three developed into spirited and fierce competitors with Jack as they initiated and continued their separate careers and all were willing to explore more of the unknown in basic and applied soil science. Thus the ripples of Jack's presence continue in a myriad of

directions here and internationally at a variety at other institutions.

The final influence that Jack had from his "chair" and laboratory in our department came through his work with the short term visitors, faculty and associates who nevertheless spent enough time with him to become immersed in his research and publication program. In some cases it was he that was the associate on hosts' home territory during his significant-term assignments abroad. There are numerous examples of such co-authors of papers in his voluminous list since 1959. Several of these are from abroad but others were domestic and have since occupied important positions in agricultural research units at state and national levels and have also generated "ripples", perhaps "waves" of their own. Not all have continued work in the topics nearest to the interests that Jack had, but they have carried the marks of his commitment, excellence and discipline and their associates at Iowa State with them. Like the scatter of feathers and down emptied from a pillow in the wind from top of a steeple, his influence continues pervasive in soil organic matter, soil nitrogen, humic acid and enzyme research.

External Research Grant Funding

The financial support for faculty members in research at the beginning of Bremner's tenure with us was generally good, with research assistants, travel funds and current expenses fairly well covered. As time went on, the funding from appropriated formula funds through the Hatch Act ceased to increase to keep up with inflation in the 1970s, and indeed there was a national effort to reduce them, so the combination led to a serious lessening of the "buying power" of the appropriated funds. Like others, Jack had to submit proposals for external grants to carry on his work and as a result he was no longer the complete master of what he could explore—what he did explore therefore had to have an interest from those outside the university. Records of these grants and contracts prior to 1980 have been discarded from general accessibility, so we have only the record of such funds for him beginning only late in 1980, or for about the last twelve years of his active career. These accumulated to almost $1.5 million from multiple private companies and public agencies. Regretfully, the university does not have records of research grants before 1980 but I have presented the

sources of funding, the project title and the date first funded in Appendix C.

In addition Jack took part in Regional Project NE-146 entitled "Gains, losses and management of soil nitrogen" from 1984 through 1989 when it was closed. The level if funding is not known but it represents a decision by administration to fund this project in preference to others in the Regional Research part of the Hatch appropriated funding for Iowa, even though the project was registered in the Northeastern Region. It also indicated the high regard that those in that region had for having him as a participant that brought them into regular personal contact with him.

Prominent features of Jack Bremner and his career

1. Bremner's research on nitrogen transformations in soils at Iowa State rested on research beginning at Rothamsted.
2. On the other hand, the work on sulfur transformations and losses in soils was initiated at Iowa State.
3. Without doubt his greatest contribution is the extensive methods of analysis published in papers and three editions in the Soil Science Society of America Monograph series.
4. The preponderance of research on organic matter, nitrogen and biomass in soil rests on his work.
5. He showed the way to, and studied gaseous interchange between soil organic matter and the atmosphere.
6. He also was considered an expert on the chemistry of sulfur and phosphorus in soils.
7. He did not avoid working on mundane challenges of an applied nature.
8. Thanks to him, the study of soil enzymes was developed by M. Ali Tabatabai, and now is global.
9. He welcomed working with scientists across disciplinary, regional or international borders.
10. Consequently he published profusely with his gradate students and colleagues.
11. The clarity of his oral or written exposition was seldom excelled despite his impediment.
12. He gave great visibility to our department and to soil science, internationally.
13. He was elected a member of the National Academy of Sciences in 1984.

14. Jack was a socially gregarious person who was liked by all.

In retrospect

After immersing oneself in the life of Jack Bremner, even superficially, one is lead to speculation and to stand in appreciation of a great life among us that was not without some moments of crises. It prompts me to ask: What if...?

Sarah and Archie Bremner had not begotten a seventh child?

Brother Alex had not encouraged him to go into chemistry?

He had not received a scholarship at Glasgow University?

He had realized the dearth of information about chemistry of soil organic matter?

He had not accepted the position at Rothamsted?

He had not been a tennis player?

He had not encountered Mary Williams at Rothamsted?

He had not been nominated for the Rockefeller Travel Grant?

He had not chosen to spend much of the Grant at Iowa State?

His family loathed the experience in Iowa and the "States"?

Dr. Pierre had not persisted in pursuit of employing Jack?

There were only tolerant but disinterested scientists at Iowa State?

There was no mass spectrometry interest or capability at Iowa State?

Art Edwards was not on the faculty in Agronomy?

He had not encountered key scientists on our campus?

He happened to draw a different set of graduate students?

There were no Soil Science Monographs?

He had not accepted the challenge of traveling abroad?

Jack Bremner's family and he could make only one life-line choice at a time, and it is the unique series of choices and events in his lifetime that placed him among the most prominent of soil scientists, and whose legacy not only encompasses our knowledge of soil organic matter and nitrogen chemistry, but in several other dimensions of soils and our profession. I think we are fortunate that we lived and worked with Jack for several decades.