W-170 COOPERATIVE REGIONAL RESEARCH PROJECT

# CHEMISTRY AND BIOAVAILABILITY OF WASTE CONSTITUENTS IN SOILS

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OFFICIAL

PROJECT NUMBER: W-170 (Rev.)

TITLE: **CHEMISTRY AND BIOAVAILABILITY OF WASTE CONSTITUENTS IN SOILS**

DURATION: October 1, 1999 to September 30, 2004

## STATEMENT OF THE PROBLEM:

Disposal of residual waste products is a problem that requires practical scientific information to determine if the residual constituents can be safely reused without harming the environment or unfavorably impacting nutrient and trace element pathways. Land application of a variety of residual materials is known to be an effective means of recycling organic matter and plant nutrients, but must be done prudently to avoid degradation of the soil as a medium for plant growth. W-170 committee members are proposing to enhance ongoing research through the evaluation of biogeochemical cycling of plant nutrients, the movement of trace elements into the food chain, and the long-term bioavailability of trace elements in residuals and residual-amended soils. Research will continue to focus on information related to the EPA 503 rules in order to provide support for risk assessment of land-applied biosolids. Numerous long-term studies by W-170 members have been, and are currently being, conducted to address the hypothesis that sequestered metals will be released as the biosolid organic matrix is mineralized. Residual materials will be emphasized in the W-170 continuation project so that waste utilization is done in a manner that protects the sustainability of U.S. agriculture.

## JUSTIFICATION:

The agronomic benefits from the use of various inorganic and organic residuals have long been recognized in agriculture, horticulture, and reclamation. These materials can provide nutrients, improve soil physical properties, and/or liming value. There is a considerable knowledge base regarding the beneficial reuse of manures and biosolids, but many other residual materials are also potentially recyclable. Some additional residual materials that have been amended to soils include: municipal solid waste (MSW) composts, yard wastes, cement kiln dusts, pharmaceutical biomass, brewery wastes, flue-gas desulfurization by-products, drinking water treatment residuals, wood ash, and food-processing wastes. With the costs of incineration and disposal in landfills increasing dramatically, the quantity and variety of residuals that are being considered for land application is also increasing. Several key issues have been examined in past W-170 research, such as: 1) determining the availability of plant nutrients in the residuals; 2) determining the bioavailability of trace elements in the residuals and soil-residual mixtures; and 3) determining the content and fate of other contaminants, e.g., pathogens, xenobiotics, and salts, in the residual materials. Efforts are underway to incorporate land application of residuals with assessment of soil quality (Sims and Pierzynski, 1998). The W-170 Committee and its predecessors (W-124 and NC-118) have been actively involved in research and regulatory aspects. As recently as 1998, a sub-committee of W-170 provided a critical peer review of an EPA risk assessment for the land application of cement kiln dust. The W-124 and W-170 committees were extensively involved in the development of the EPA 503 national sludge rule (USEPA, 1993), and continue to be involved in the refinements of that rule.

Despite the knowledge base that exists, new issues demand further research as more regulations are being written and new concerns arise. Several examples will illustrate this point. The EPA 503 national sludge rule provided limits for the concentrations of 10 trace elements (As, Cd, Cu, Cr, Hg, Mo, Ni, Se, Pb, and Zn) in biosolids, and limits on the annual and cumulative loadings of the trace elements to soils. The W-170 Committee continues to build the data base for elements such as Cr, Mo and As to address critical gaps in our knowledge related to these trace elements. Further, subsequent to the publication of the rule and the pathway analysis used in the risk assessment, the protectiveness of certain aspects of the rule was called into question (McBride, 1995; Schmidt, 1997). The major issue of concern was the long-term bioavailability of trace elements in biosolids-amended soils. The W-170 Committee continues to address this issue by utilizing data from several long-term biosolids studies and by working toward the development of new techniques for assessing trace element bioavailability in soils. Yet another issue revolves around the chemistry and bioavailability of P in waste residuals and residual-amended soils, which is increasing in importance as national or state regulations are being proposed or enacted that will limit application rates for residuals based on P rather than on N. Accordingly, the next five-year W-170 project proposes to address several emerging issues such as: 1) Utilization of new and novel residual materials; 2) Expanding the data base, when warranted, for trace elements such as Cr, Mo, As, and Se for risk assessment for biosolids and for all trace elements for other organic and inorganic residuals that may be used in agriculture, horticulture, or reclamation; 3) Methods development for estimating trace element bioavailability in residuals and residual-amended soils; 4) Assessment of long-term bioavailability of trace elements in residual-amended soils, and; 5) Chemistry and fate of plant nutrients, particularly P, in residuals and residual-amended soils.

New and novel residual materials are continually being considered for land application or for horticultural uses. Commercial blending of a variety of residual materials to produce “synthetic” soils for reclamation and horticultural uses is increasing dramatically. Unprocessed animal manures have been studied extensively, but these materials are being processed or amended more often in an attempt to improve aesthetic issues, reduce volume, or to decrease plant nutrient content or availability (e.g., alum amendment). Composting is being used on a wider variety of materials that are then considered for land application. These new situations warrant study as the appropriate land application guidelines are developed, and to fully understand the risk/benefit issues associated with each material.

Development of the USEPA 503 rule relied on an extensive data base for trace elements such as Cd, Cu, Cr, Ni, Pb, and Zn in biosolids-amended soils. A shortage of data still exists for elements such as As, Hg, Mo, and Se that needs to be addressed. For example, the original EPA 503 rule provided a cumulative load limit for Mo of only 18 kg/ha, based on limited data, which would have made Mo a very restricting element for land application programs. Conversely, there is a legitimate concern about Mo-induced Cu deficiency (molybdenosis) in livestock that could develop if the Mo limit were not restrictive enough. To set a limit that is sufficiently protective without being unnecessarily restrictive requires a data set that encompasses a wide range of soil and climatic conditions. The only study that has significantly added to this data base since the EPA 503 rule was written is being conducted by a member of the W-170 group (Nguyen and O’Connor, 1997). In addition, there are growing concerns about trace elements in other organic residual materials that have not received much attention in the past. Examples include Cu and Zn in swine manure and As in poultry manure.

To improve our understanding of the fate and transport of trace elements in residuals and residual-amended soils, the methods for assessing trace element bioavailability need refinement and development. A variety of useful new methods are available that have either not been applied to the objectives of this project or have been applied only to a limited extent. The bioavailability, fate and transport of trace elements in residual-amended soils is influenced by the chemical form of the elements: organic versus inorganic, solid phase versus adsorbed, solubility of trace element solid phases, coprecipitation with other mineral phases, etc., and little is known about how trace elements are actually partitioned into the various chemical forms. Sequential extraction techniques and solubility equilibrium studies have been of some value, but recently developed or improved techniques, such as analytical electron microscopy and the synchrotron-based methods like microprobe extended x-ray fine structure (EXAFS), x-ray absorption near-edge spectroscopy (XANES), and microprobe x-ray fluorescence, offer considerable promise and have been used on trace element problems to a limited extent. In addition, procedures more specific to data necessary for risk assessment, such as the physiologically-based extraction technique (PBET, Ruby et al., 1996), which is an *in vitro* method for assessing the bioaccessibility of Pb and As in soils to humans, have not been adequately utilized for residual-amended soils and may be quite useful (Rodriguez et al., 1998).

The degree of protectiveness provided by the EPA 503 national sludge rule has been criticized from several fronts. One is the possibility that the organic C added with the biosolids will eventually oxidize allowing increased trace element bioavailability over time, a factor that was not considered in the risk assessment for the regulations (McBride, 1995). This phenomena has been called the “time-bomb” hypothesis and has generated considerable discussion in the scientific community and some public opposition to land application of biosolids. This hypothesis is already being considered by the W-170 committee by utilizing long-term biosolids studies (Chang et al., 1997; Brown et al., 1998) and will continue to be addressed in future work. A second concern relates to the possibility of more subtle effects of trace elements on soil microbial populations (McGrath et al., 1995). Based on these and other issues related to trace element bioavailability, we are required to improve our methods for assessing the bioavailability of various constituents in residuals and residual-amended soils. For example, trace element phytoavailability can be predicted fairly well with routine soil extractants for a given soil/residual combination, but we do not have a method that performs satisfactorily across a wide range of soil and climatic conditions.

Much of the earlier work by W-124 and W-170 committee members focused on the availability of N in organic residuals for crop use. These efforts fulfilled the need of determining the agronomic loading rate for biosolids mandated by the EPA 503 regulations, and the methods that were developed are applicable to many residual materials. Further refinements are still needed as it becomes more important to accurately determine agronomic loading rates. It is well established that applying most residual materials based on N results in over application and accumulation of P in soils. This has become an important issue recently as concerns about P and water quality increase (Sharpley et al., 1994). One result has been the development of regulations stipulating that land application of residuals be based on P availability. Also of interest is the reduction of P concentrations in soils that have received large amounts of residuals so that the threat to surface waters is reduced. In both cases, our understanding of P chemistry is incomplete. Even on an applied level, there is a need for data relating P loading rates from residuals to changes in soil test P levels and then for determining the agronomic and environmental significance of those levels.

These emerging issues will be addressed with the following research objectives: 1) Characterize the chemical and physical properties of residuals and residual-amended soils; 2) Evaluate methods for determining the bioavailability of nutrients, trace elements, and organic constituents in residuals; 3) Predict the long-term bioavailability of nutrients, trace elements, and organic constituents in residual-amended soils.

## RELATED CURRENT AND PREVIOUS WORK:

### **Objective 1**: Characterize the chemical and physical properties of residuals and residual-amended soils.

Earlier work on characterizing chemical properties of residuals and residual-amended soils utilized relatively simple measurements such as total elemental concentrations or fractions extracted with routine soil testing procedures. Similar work still needs to be performed for new residual materials where data is lacking. These materials include waste office paper, lake weeds, water treatment residuals, flue-gas desulfurization products, cement kiln dusts, biotechnology residuals, wood ash, and others. More recent work has attempted to refine our characterization methods by making detailed measures of specific soil chemical properties. Candarlaria and Chang (1997) determined that the majority of Cd introduced into soil as biosolids-born Cd remained in the sludge with only a small portion transferred to solution and to the soil solid phases, yet solution speciation of Cd was similar from sludge and Cd nitrate sources. As the number of soil-residual combinations continues to increase, our needs to characterize them will also increase.

### **Objective 2**: Evaluate methods for determining the bioavailability of nutrients, trace elements, and organic constituents in residuals.

Research on the bioavailability of nutrients in residuals and residual-amended soils has focused on N, in part because its availability is most often used to determine appropriate application rates. Nitrogen is still an important topic as a wider variety of residuals are considered for land application (Motavilli and Diambra, 1997). There has been increased interest in P because of water quality concerns and the prospect of P-based application rates for residuals has been proposed both nationally and in some states. Earlier work by W-170 members characterized inorganic and organic P in residuals and residual-amended soils using electron microscopy and NMR (Hinedi and Chang, 1989; Pierzynski et al., 1990). Little work of this nature has been published since, and with the increased interest in P, more research is needed. For example, the use of alum and other residuals to reduce the bioavailable of P in soils and residual-amended soils has been studied, although little is known about the changes in P solid phases brought about by the amendments (Moore and Miller, 1994; Peters and Basta, 1996). The utility of some recent innovations in assessing P bioavailability need to be evaluated for residuals and residual- amended soils. These include iron oxide strip extractable P and assessments of the degree of P saturation (Moore et al., 1998).

Research on assessing the bioavailability of trace elements in residuals and residual-amended soils has not fully taken advantage of developments in advanced spectroscopic techniques or procedures for assessing trace element bioavailability in contaminated soils. Examples include the determination of oxidation speciation for S or Mn *in situ* using XANES, a synchrotron radiation based technique (Schultze et al., 1995; Fendorf and Sparks, 1996), and the estimation of bioaccessible Pb and As in soils for mammals using a physiologically-based extraction test (Ruby et al., 1996). Given the interest in long-term bioavailability of trace elements (discussed below), there is a strong need for research in determining the chemical forms of trace elements in residuals and residual-amended soils and for methods useful for risk assessment.

### **Objective 3**: Predict the long-term bioavailability of nutrients, trace elements, and organic constituents in residual-amended soils.

Bioavailability of metals in soils is higher when the source of the metals are salts rather than metals in biosolids. This “protective” effect of the biosolids was factored into the risk assessment performed for the EPA 503 national sludge rule. A recent paper challenged this premise by hypothesizing that the protective effect of the biosolids was due to the organic C additions and that this effect would diminish with time as the organic C oxidized in the soil (McBride, 1995). If this hypothesis is correct, the implication is that the EPA 503 regulations are not sufficiently protective. Several papers have been published, in response to this concern, and have presented data that do not show increases in plant available metals over times of 15 to 20 years (Chang et al., 1997; Brown et al., 1998). In particular, the study of Brown et al. (1998) demonstrated that the C losses that occurred with time after biosolids applications ceased did not accompany increases in Cd bioavailability. Brown et al. hypothesized that the protective effect of the biosolids was at least partly due to inorganic constituents in the biosolids and not entirely to organic C. The results of their research made the importance of long-term field studies with biosolids apparent. While both sides have presented compelling arguments, additional research is needed to address the issue, as well as similar questions that exist for residuals other than biosolids.

## Related Regional Research Projects

Regional Research Projects with complementary objectives will be monitored for applicable results, and coordination with these projects will be fostered by exchange of annual reports and by invitation of representatives to our annual meetings. The following projects are the most closely related to our proposed project.

### Sewage Sludge/Manure

S-275: Animal Manure and Waste Utilization, Treatment, and Nuisance Avoidance for a Sustainable Agriculture

### Contaminants

S-280: Mineralogical Controls on Colloid Dispersion and Solid-phase Speciation of Soil Contaminants

### Trace Elements

W-184: Biogeochemistry and Management of Salts and Potentially Toxic Trace Elements in Arid-zone Soils, Sediments and Waters

## OBJECTIVES:

1. Characterize the chemical and physical properties of residuals and residual-amended soils

2. Evaluate methods for determining the bioavailability of nutrients, trace elements, and organic constituents in residuals.

3. Predict the long-term bioavailability of nutrients, trace elements, and organic constituents in residual-amended soils.

## PROCEDURES:

### Objective 1

(Contributing States: AR, CA, CO, FL, GUAM, HI, IA, IN, KS, MWRDGC, OK,

PA, TX, USDA/CA, USDA/MD, WSU, WY)

**Task 1. Evaluation of Nutrient Contents in Residuals and Residual-Amended Soils.**

Studies will be conducted to evaluate the nutrient chemistry in a variety of materials (AR, CO, FL, GUAM, HI, IA, IN, KS, MWRDGC, WSU, WY). The chemistry and mineralogy of P from a variety of P sources including water-treatment residuals, commercial fertilizers, biosolids, animal wastes, etc., and combination of these materials will also be examined in great detail. Nutrient chemistry of biotechnology by-products, N and P plant uptake, and soil pH effects N availability will be determined by IA. Various electron microscopic techniques will also be evaluated in P adsorption studies with mixed water-treatment/biosolid materials. CA has developed a procedure to extract P from organic and inorganic waste material for $^{31}$P NMR analysis and will apply this technique to assay P in the material used by AR, CO, FL, GUAM, HI, IN, KS, WSU, WY in their experiments.

Investigations involving the utilization of several residual materials for land application to agricultural soils under different environmental conditions will be conducted. Current efforts are examining the effects of residual treatment methods on N availability in soils with different properties. Collaborations among several groups (GUAM, HI, NRCS) will involve the development of management methods for animal residuals to specific soil types to evaluate recommendations for animal waste use and application, to reduce the potential for groundwater contamination, and to determine the fate of applied N.

**Task 2. Determination of Residual Trace Element Chemistries and Soil Quality Impacts.**

Several states (FL, HI, IA, KS, OK, USDA/MD, WSU, WY) will continue to evaluate the impact of biosolids on oxyanion (e.g., Mo, P, As, Se and others) retention/release/mobility in soils. Studies will also be conducted to evaluate the forms and bioavailability of several oxyanions. Traditional adsorption isotherms and "single point" isotherms will be developed on greenhouse and field-equilibrated biosolids-amended soils. We will characterize oxyanion solubility and form(s) in residuals and residuals-amended soils. Common extractants (e.g., water, Mehlich I, etc.) as well as others (e.g., P sequential extraction schemes) will be evaluated. Existing field studies will be monitored to detect oxyanion movement with depth in both weakly- and strongly-adsorbing soils.

We will continue to evaluate the chemical properties of residual-amended soils in heavy metal remediation studies (KS, WSU). Initially, the concentration of heavy metals in residual materials (e.g., mining tailing and industrial products such as P fertilizer, lime, and micronutrient fertilizer) will be determined. The solubility of metals in soils as affected by repeated additions of soil amendment and soil pH will also be determined. Sequential extractions will be performed, in addition to other methods, to characterize the transformation of metals in the soils as affected by the quantity and type of residuals and soil amendments added.

**Task 3. Examination of Physical Properties of Residuals and Residual-amended Soils.**

Laboratory and field studies will be conducted to evaluate the influence of residuals alone and in combination with other materials on soil physical properties (KS, TX, MWRDGC, USDA/CA, WY). Physical properties of residual-amended soils will be characterized to evaluate changes over time.

Attempts will be made to concentrate trace metals in soils by particle size and density separations to facilitate mineralogical characterization. Composted waste residuals will also be used to enhance Ca migration and exchange in sodic soils and acidic minespoils (PA). Compost application with gypsum-containing flue gas desulfurization residuals are expected to increase Ca migration and exchange in sodic soils and acidic minespoils thereby enhancing restoration of these degraded systems. Their impact on Ca transport and exchange with other metals as well as their effects on soil properties and plant growth will be studied. Infiltration and movement of residual constituents will be examined under different irrigation systems.

## Objective 2

(Contributing States: AR, CA, CO, FL, HI, IN, KS, MWRDGC, OK, PA,
USDA/CA, USDA/MD, WSU, WY)

### Task 1. Evaluation of Nutrient and Trace Element Bioavailabilities in Residual-Amended Field and Greenhouse Studies.

We will measure the adsorption of P from different residual P sources (alone, in mixtures, and in soils), by employing equilibrium studies (AR, CO, FL, HI, KS, USDA/CA). The goal of this research is to find residual treatments where all the P is adsorbed. Studies will also determine P concentrations in runoff from agricultural fields amended with organic residuals. These studies will include plot-level research, with watershed-level studies planned for the future research. Management practices and the use of conventional and advanced P soil tests to evaluate P release from residuals, plant bioavailability, and transport into surface water will be studied. Nitrogen and P release from biosolid/manure residuals will be studied to determine mineralization, bioavailabilties, and transformations of N and P over time (MWRDGC, PA). Relationships between net P addition and changes in soil test P and degree of P saturation will be determined.

Greenhouse, plot, and large-field studies will be conducted to evaluate effects of residual amendments on plant uptake (leaves and grain) of trace elements (heavy metals, oxyanions) for several growing seasons and with different crops (FL, IN, KS, USDA/MD, WY). Plant availability will be correlated with soil metal concentrations to determine: a) residual bioavailability of the metals in the sludge after several years of crop growth, and b) the ability of the soil-chemical extraction procedures to predict plant uptake. Plant uptake of oxyanions will be related (correlated) to various measures of oxyanion load, including total metal load, extractable metal load, and knowledge of oxyanion "form" or speciation. Lettuce or other types of crops will be planted, and the amount of metals accumulated in the plants will be determined. The relationship between the quantity of metal soluble in dilute salt solution and metal uptake will be used to elucidate the metal availability in various types of soil amendments.

CA will work with a local waste recycler that collects outdated beverages from manufacturers and retailers and converts the contents into ethanol through fermentation and distillation. Following the distillation, the still-bottoms are processed in an evaporative drier that produces a high-solids animal feed and approximately 80,000 gallons/day of evaporative condensate. This condensate has a low pH (~3.5) and a BOD that averages 1200 mg/L, mostly due to volatile organic acids, like acetic acid. This study will address the movement of dissolved organic matter in a soil receiving very high concentrations of soluble BOD in a low pH wastewater and its effects on P and trace elements availability to plants and mobility in soil profile.

### Task 2. Laboratory Studies and Soil Testing Approaches Involving the Evaluation of Residual Constituent Bioavailabilities.

Laboratory studies will be used to continue development of methods, such as the FeO coated filter paper and in-vitro gastrointestinal chemical procedures, for determination of the bioavailable of nutrients and trace elements (CA, KS, OK, WSU). Physiologically-based extraction techniques for determining bioavailable Pb and As will be applied to residual-amended soils. Studies on P mineralization in residual-amended soils will be conducted (KS). Laboratory studies will also be conducted to characterize residual decomposition kinetics, while field studies will be used to assess bioavailability of N and P. Laboratory evaluation of the biosolids in these field trials for quality, decomposability, and bioavailability of N and P will complement these field trials. CA will used archived biosolid-amended soil samples of a 16 year field experiment to develop a two stage N mineralization model. Soils receiving varying rates of different residual amendments will be analyzed for the quantity of metals soluble in dilute salt solution.

## Objective 3

(Contributing States: ARMY, CA, CO, IN, KS, PA, USDA/MD, USDA/MN)

### Task 1. Prediction of Nutrient Bioavailability in Long-Term Residual-Amended Soils.

Long-term studies will continue to be monitored to determine nutrient bioavailability (CO, PA, USDA/MN). A biosolids-dryland wheat study in CO will attempt to predict long-term availability of N where biosolids are continually applied. The long-term bioavailability and movement of P (>5000 kg/ha/yr of biosolids-borne P were applied to the area for 20 years) and trace metals within a large watershed in MN where biosolids were applied from (1974-1993) will also be continued. A digital elevation model will be constructed to establish water routing, and soil testing conducted to evaluate nutrient and metal movement across the MN watershed landscape. Runoff will be measured and analyzed to quantify losses of nutrients and trace metals out of the watershed. Soil and crop samples from fields that have received several applications of biosolids (cumulative applications of up to 50 tons/acre) in 15 PA counties will be analyzed for various trace elements to determined recoveries compared to calculated cumulative loadings, downward transport of trace elements, and plant uptake coefficients.

### Task 2. Evaluation of Time on Trace Element Chemistry in Residual-amended Soils.

Agricultural fields and trace element contaminated sites where residuals have been applied will continue to be monitored (ARMY, IN, KS, USDA/MD). One site in IN was amended with biosolids having fairly high concentrations of heavy metals (284 Cd, 2040 Ni, 6800 Zn, 1200 Cu, and 1070 Pb mg/kg) at rates up to 448 metric tons per hectare since 1976 and the plots cropped in wheat, oats, soybean, and corn. These sites will be intensively sampled and the distribution of metals with depth determined. Chemical fractionation will be used to evaluate total metal concentrations as well as water soluble, exchangeable, and more recalcitrant fractions. An index of availability will be determined by the DTPA extraction procedure. Various methods for estimating bioavailable trace elements including routine soil extractions and sequential extraction procedures will be employed.

CA will characterize the chemical composition of root exudates of plants grown on biosolids-amended soils. Based on the composition of root exudates, CA will develop synthetic root exudates to extract trace metals from biosolid-amended soils (including soils to be studied by IN and KS). The capacity and rate constant of trace metals extracted will be correlated with the uptake of metals by plants grown in respective biosolid-amended soils.

### Task 3. Computer Simulations and Models of Residual Bioavailability

Computer simulations and models will be studied in order to field verify N and P bioavailability of land applied biosolids and organic-waste decomposition (AR, MI, WA).

### Specific Regional Experiments

Some prospective regional projects include: a common biosolid applied to soils at different W-170 member locations, development of new analytical procedures for assessing bioavailability and other characteristics of residual materials, devising processing recommendations and management practices for use of waste materials on turf grass and ornamental plants, and development and validation of computer simulation models to predict the fate of applied nutrients from residual materials. A strength of the W-170 committee is the participation of soil scientists representing a wide range in environmental conditions, many of whom have developed long-term data sets for residual waste applications. Development of new techniques and use of simulation models may help to integrate this data and develop a capability to predict long-term bioavailability of residual materials.

## EXPECTED OUTCOMES:

Scientific-based findings such as those from the W-170 group are essential for regulatory purposes because they assist in developing scientifically-based workable and useful guidelines that manage the beneficial uses of residual waste products in a sustainable manner that is consistent with protecting our environment.

## ORGANIZATION:

The W-170 technical committee will consist of project leaders for the contributing states, the administrative advisor, and CSREES representatives. Voting membership includes all persons with contributing projects; however, only one vote is permitted for each research location.

Co-chairpersons, one from the western and one from the other regions, will be elected at the first authorized committee meeting. The co-chairpersons will serve multiple years, if so desired by project participants, and will be responsible for meeting arrangements, the annual report, coordination of research, compilation of regional research data, and preparation of the renewal proposal. One representative each from the western and the other regions and a secretary will be elected annually. Office terms for annually elected positions begin immediately after completion of the annual committee meeting. An Executive Committee consisting of the co-chairs, the secretary, and the two regional representatives will serve as a guidance body in matters such as new project participant additions and meeting agenda.

In addition to the official project representatives, other researchers with activities that contribute to the project have been and will continue to be invited to participate on a regular basis. These include, among others: Drs. Rufus Chaney, USDA-ARS, Beltsville, MD; Drs. Rob Harrison and Chuck Henry, University of Washington, Seattle, WA; Drs. Tom Granato and Richard Pietz, Metropolitan Water Reclamation District of greater Chicago; Dr. James Ryan, EPA, Cincinnati; Dr. John Walker, EPA, Washington, DC. Representatives of other regional research and coordinating committees, state and federal agencies, and other federations and organizations are invited to attend the annual meetings and will be sent W-170 annual reports.

SIGNATURES

Regional Project Title: **Chemistry and Bioavailability of Waste Constituents in Soils**

George F. Vance — 1-12-99

W-170 Co-Chair — Date

W-170 Co-Chair — Date

1-15-99

Administrative Advisor — Date

Richard C. Heimsch — 3/24/99

CHAIR, REGIONAL ASSOCIATION OF DIRECTORS — DATE

George Cooper — 8/31/99

Administrator, Cooperative State Research,
Education and Extension Service — Date

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ATTACHMENTS:

## PROJECT LEADERS

Regional Project Title: **Chemistry and Bioavailability of Waste Constituents in Soils**

| **Location** | **Principal Investigators** | **Cooperators** | **Specialization** |
|---|---|---|---|
| Experiment Stations Participants | | | |
| Arkansas | J. Gilmour | | Soil science |
| California | A.C. Chang | A.L. Page<br>C.A. Amrhein<br>D.E. Crowley<br>D. Crohn | Agricultural eng.<br>Soil science<br>Soil chemistry<br>Soil microbiology<br>Environmental sci. & biosystems eng. |
| Colorado | K.A. Barbarick | | Soil chemistry |
| Florida | G.A. O'Connor | M.B. Adjei<br>J.E. Rechcigl | Soil chemistry<br>Agronomy<br>Soil quality |
| Guam | P.P. Motavalli | | Soil Science |
| Hawaii | N.V. Hue | | Soil Scientist |
| Indiana | P. Schwab | B.C. Joern<br>C. Johnston | Soil chemistry<br>Soil fertility<br>Soil chemistry |
| Iowa | M.A. Tabatabai | S.J. Henning | Soil chemistry<br>Soil fertility |
| Kansas | G.M. Pierzynski | D. Sweeney | Soil chemistry<br>Soil fertility and management |
| Michigan | L.W. Jacobs | | Environ soil science |
| Oklahoma | N.T. Basta | W.R. Raun | Soil chemistry<br>Soil fertility |
| Oregon | D.M. Sullivan | | Soil science |
| Pennsylvania | R. Stehouwer | H. Elliott<br>J. Chorover | Soil science<br>Waste management<br>Soil chemistry |
| Texas | J. Sloan | | Environ soil science |
| Washington | S. Kuo | J. Harsh | Soil chemistry<br>Soil chemistry |

| | | | |
|---|---|---|---|
| Virginia | G. Evanylo | | Soil fertility |
| | | W.L. Daniels | Soil reclamation |
| | | L. Zelazny | Soil chemistry |
| Wyoming | G.F. Vance | | Soil chemistry |
| USDA Participants | | | |
| USDA-ARS Fresno, CA | H. Ajwa | | Soil chemistry |
| USDA-ARS Beltsville, MD | R.L. Chaney | | Soil/plant relations |
| USDA-ARS St. Paul, MN | R.H. Dowdy | | Soil chemistry |
| USEPA, Denver, CO | R. Brobst | | Soil science |
| USEPA, Cincinnati, OH | J. Ryan | | Soil/plant relations |
| USEPA, Washington D.C. | J. Walker | | Soil science |
| Non-USDA Participants | | | |
| US Army - CRREL[1] | A. Palazzo | | Soil science |
| | | A. Iskander | Soil science |
| MWRDGC[2] | T.C. Granato | | Soil science |
| | | R.I. Pietz | Soil science |
| N-Viro | T.J. Logan | | Soil chemistry |
| Proctor and Gamble | D.C. McAvoy | | Civil engineering |
| Texas Tech University | R. Zartman | | Soil science |
| University of Washington[3] | C.L. Henry | | Environmental eng. |
| | | S.L. Brown | Soil/plant relations |
| | | R.B. Harrison | Soil chemistry |

[1] U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH

[2] Metropolitan Water Reclamation District of Greater Chicago, IL

[3] McIntire-Stennis Institution: College of Forest Resources, Seattle, WA

RESOURCES

Regional Project Title: **Chemistry and Bioavailability of Waste Constituents in Soils**

| **PARTICIPANTS** | **OBJECTIVES** | | | **RESOURCES** | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | SY<br>%Res/%Ext/%Teach | PY | TY |
| **Arkansas** | | | | | | |
| J. Gilmour | X | X | X | 0.2<br>100/0/0 | 0.2 | 0.1 |
| **California** | | | | | | |
| A.C. Chang | X | X | X | 0.2<br>100/0/0 | 0.5 | 0.25 |
| A.L. Page | X | X | X | 0.25<br>100/0/0 | 0.0 | 0.0 |
| C.A. Amrhein | | X | | 0.1<br>100/0/0 | 0.0 | 0.5 |
| D.E. Crowley | | | X | 0.1<br>100/0/0 | 0.5 | 0.25 |
| D. Crohn | | X | | 0.2<br>20/80/0 | 0.0 | 0.25 |
| **Colorado** | | | | | | |
| K.A. Barbarick | X | X | X | 0.2<br>100/0/0 | 0.8 | 0.2 |
| **Florida** | | | | | | |
| G.A. O'Connor | X | X | | 0.2<br>100/0/0 | 0.5 | 0.5 |
| M.B. Adjei | X | X | | 0.25<br>60/40/0 | 0.0 | 0.0 |
| J.E. Rechcigl | X | X | | 0.2<br>100/0/0 | 0.0 | 0.0 |
| **Guam** | | | | | | |
| P.P. Motavalli | X | X | | 0.1<br>70/30/0 | 0.1 | 0.0 |
| **Hawaii** | | | | | | |
| N.V. Hue | X | X | | 0.4<br>75/0/25 | 0.0 | 0.2 |
| **Indiana** | | | | | | |
| P. Schwab | X | X | X | 0.4<br>100/0/0 | 0.0 | 0.0 |
| B.C. Joern | X | X | X | 0.3<br>50/50/0 | 0.0 | 0.0 |
| C. Johnston | X | X | X | 0.2<br>100/0/0 | 0.0 | 0.0 |
| **Iowa** | | | | | | |
| M.A. Tabatabai | X | | | 0.1<br>78/0/22 | 0.0 | 0.0 |
| S.J. Henning | X | | | 0.1<br>0/25/75 | 0.0 | 0.0 |
| **Kansas** | | | | | | |
| G.M. Pierzynski | X | X | X | 0.2<br>70/0/30 | 0.0 | 0.0 |
| D. Sweeney | X | X | X | 0.1<br>100/0/0 | 0.0 | 0.0 |
| **Michigan** | | | | | | |
| L.W. Jacobs | | X | X | 0.1<br>50/50/0 | 0.0 | 0.25 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Oklahoma** | | | | | | |
| B.T. Basta | X | X | X | 0.1<br>70/0/30 | 0.0 | 0.1 |
| **Oregon** | | | | | | |
| D.M. Sullivan | | X | X | 0.1<br>100/0/0/ | 0.0 | 0.5 |
| **Pennsylvania** | | | | | | |
| R.C. Stehouwer | X | X | X | 0.1<br>20/80/0 | 0.0 | 0.0 |
| H. Elliott | | X | | 0.1<br>65/0/35 | 0.3 | 0.0 |
| J. Chorover | X | X | | 0.1<br>75/0/25 | 0.0 | 0.0 |
| **Texas** | | X | X | 0.25<br>75/25/0 | 0.0 | 0.25 |
| **Virginia** | | | | | | |
| G. Evanylo | | X | X | 0.1<br>50/50/0 | 0.0 | 0.1 |
| W.L. Daniels | X | X | | 0.1<br>100/0/0 | 0.0 | 0.0 |
| L. Zelazny | X | | X | 0.1<br>100/0/0 | 0.0 | 0.0 |
| **Washington** | | | | | | |
| S. Kuo | X | X | | 0.1<br>100/0/0 | 0.0 | 0.0 |
| **Wyoming** | | | | | | |
| G.F. Vance | X | X | | 0.1<br>75/0/25 | 0.1 | 0.1 |
| USDA/EPA Participants | | | | | | |
| **USDA-ARS** Fresno, CA | | | | | | |
| H. Ajwa | X | X | | 0.0 | 0.0 | 0.0 |
| **USDA-ARS** Beltsville, MD | | | | | | |
| R.L. Chaney | X | X | X | 0.0 | 0.0 | 0.0 |
| **USDA-ARS** St. Paul, MN | | | | | | |
| R.H. Dowdy | | | X | 0.1<br>100/0/0 | 0.0 | 0.0 |
| **USEPA -** Denver, CO | | | | | | |
| R. Brobst | X | X | X | 0.0 | 0.0 | 0.0 |
| **USEPA -** Cincinnati, OH | | | | | | |
| J. Ryan | X | X | X | 0.0 | 0.0 | 0.0 |
| **USEPA -** Washington, D.C. | | | | | | |
| J. Walker | X | X | X | 0.0 | 0.0 | 0.0 |
| Non-USDA Participants | | | | | | |
| **US Army - CRREL** | | | | | | |
| A. Palazzo | | | X | 0.0 | 0.0 | 0.0 |
| A. Iskandar | | X | X | 0.0 | 0.0 | 0.0 |
| **MWRDGC** | | | | | | |
| T.C. Granato | X | X | X | 0.0 | 0.0 | 0.0 |
| R.I. Pietz | X | X | X | 0.0 | 0.0 | 0.0 |
| **N-Viro** | | | | | | |
| T.J. Logan | X | X | | 0.0 | 0.0 | 0.0 |
| **Proctor and Gamble** | | | | | | |
| D.C. McAvoy | X | X | | 0.0 | 0.0 | 0.0 |
| **Texas - Texas Tech** | | | | | | |
| R. Zartman | X | | | 0.1<br>100/0/0 | 0.0 | 0.0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **University of Washington** | | | | | | | |
| C.L. Henry | X | X | X | | 0.3<br>100/0/0 | 0.2 | 0.0 |
| S.L. Brown | X | X | X | | 0.4<br>100/0/0 | 0.5 | 0.0 |
| R.B. Harrison | X | X | X | | 0.2<br>100/0/0 | 0.3 | 0.0 |
| **TOTALS** | X | X | X | | 6.0 | 4.0 | 3.3 |