

REPORT

OF THE

THIRD RESEARCH CO-ORDINATION MEETING

OF THE

FAO/IAEA CO-ORDINATED RESEARCH PROJECT

ON

**THE USE OF IRRADIATED SEWAGE SLUDGE TO INCREASE
SOIL FERTILITY AND CROP YIELDS AND TO PRESERVE
THE ENVIRONMENT**

22 - 26 JUNE 1998

**ESTAÇÃO AGRONÓMICA NACIONAL
QUINTA DO MARQUÊS
OEIRAS, PORTUGAL**

Prepared by

Phillip Chalk
Scientific Secretary

**Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture
Soil and Water Management & Crop Nutrition Section**

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1. Introduction

The Third Research Co-ordination Meeting (RCM) on the agricultural use of irradiated sewage sludge took place in Oeiras, Portugal, with Dr. Eugénio Mendes Ferreira, a Research Contract Holder, acting as the local organiser. The RCM was attended by ten Research Contract Holders¹ and five Research Agreement Holders². Participants were lodged at the Hotel Alvorada, Estoril, and commuted by train to the RCM venue in Oeiras.

The opening ceremony on Monday June 22 was attended by Dr. José Antonio Amaro, Deputy Director of the host institution, Estação Agrónomica Nacional, Dr. José Carvalho Soares, Presidente, Instituto Tecnológico e Nuclear, and by approximately ten Portuguese scientists.

The first two days of the RCM consisted of Technical Sessions where participants presented the results obtained since the Second RCM which was held in Cairo, 14 - 18 September 1996. On the third day, participants visited a municipal solid waste recycling and composting plant (Tratolixo S.A.) in Carcavelos and the Radiation Technology Unit of the Nuclear and Technological Institute of the Ministry of Science and Technology in Sacavém. The latter facility houses a Cobalt-60 source for the sterilization of various materials, including sewage sludge.

The final Technical Session was held during the morning of the fourth day. This was followed by a Session in which progress towards achieving CRP objectives was reviewed and a common format for the presentation of data was devised. The final Session, chaired by the Scientific Secretary, focused on the conclusions reached so far in the CRP and on recommendations for future work.

¹Since the second RCM in Cairo, Dr. Fernando Esparza Garcia, the Research Contract Holder in Mexico, informed us that he would no longer participate in the CRP because of inadequate funds. Also Dr. Shao Jian Zheng, the Research Contract Holder in China, could not attend the RCM due to insufficient time to complete the formalities for travel. The Research Contract Holder in India, Dr. T. J. D'Souza, has retired and has been replaced by Dr. V. V. Athalye.

²Professor M. Chino attended the RCM in place of Professor K. Kumazawa, the Agreement Holder from Japan. Dr. Martin Gerzabek attended the RCM in place of Dr. Ferdinand Koch, the Agreement Holder from Austria.

2. Programme

Monday, 22 June

09:00 - 09:15	Official Opening
09:15 - 09:45	Remarks by the Scientific Secretary
09:45 - 10:15	Coffee Break

Session I **Chairman: E. M. Ferreira** (Portugal)

10:15 - 11:10	M. Gerzabek (Austria) “Use of sewage sludge - nitrogen availability and heavy metal uptake into rape”
11:10 - 12:05	C. Magnavacca (Argentina) “Safe re-use of irradiated sewage sludge to preserve the environment”
12:05 - 13:00	S. Ahmed (Bangladesh) “Isotope-aided studies on the effects of radiation processed sewage sludge application on crop yields and bioavailability of heavy metals in Bangladesh soils”
13:00 - 14:00	Lunch Break

Session II **Chairman: H. Harms** (Germany)

14:00 - 14:55	M. Chino (Japan) “Phytoavailable estimates and the various fractional forms of five heavy metals in an Andosol with a long-term history of sewage sludge application”
14:55 - 15:50	V. Athalye (India) “Assessment of irradiated sewage sludge for macro- and micronutrients, heavy metals and pesticide residues under different soil-crop systems”
15:50 - 16:20	Coffee Break
16:20 - 17:15	J. Prasatsrisupab (Thailand) “The use of irradiated wastewater sludge cake as a source of nitrogen for maize”

Tuesday, 23 June

Session III	Chairman: M. Chino (Japan)
09:00 - 09:55	H. Harms (Germany) “Bioaccumulation and metabolic fate of sewage sludge derived organic xenobiotics in plants”
09:55 - 10:50	M. Dumitru (Romania) “Use of nuclear techniques for evaluating agricultural use of sewage sludge and environmental protection”
10:50 - 11:20	Coffee Break
11:20 - 12:15	R. El-Motaium (Egypt) “Increasing crop production of sandy soils by using radiation processed and composted sewage sludge and municipal solid wastes”
12:15 - 14:00	Lunch Break

Session IV	Chairman: M. Gerzabek (Austria)
14:00 - 14:55	S. McGrath (U.K.) “The risks of application of sewage sludge to land - European experience”
14:55 - 15:50	C. F. Ishak (Malaysia) “Agricultural use of sewage sludge in Malaysia”
15:50 - 16:20	Coffee Break
16:20 - 17:15	F. Azam (Pakistan) “Utilization of sewage sludge for enhancing agricultural productivity”

Wednesday, 24 June **Field visit** (organised by Dr. Ferreira)

Thursday, 25 June

Session V	Chairman: S. McGrath (U.K.)
09:00 - 09:55	A. Chang (U.S.A.) “Chemistry and bio-availability of heavy metals in sewage sludge treated soils”
09:55 - 10:50	E. M. Ferreira (Portugal) “The use of sewage sludge as a fertilizer in pasture”
10:50 - 11:20	Coffee Break
11:20 - 12:15	M. Mitrosuhardjo (Indonesia) “Effect of irradiated sewage sludge on N and P uptake by chilli (<i>Capsicum annuum</i> L.) and edible nightshade (<i>Solanum melongena</i>)”
12:15 - 14:00	Lunch Break
Session VI	Chairman: A. C. Chang (U.S.A.)
04:00 - 15:30	Review of progress towards achieving CRP objectives and summary of data
15:30 - 16:00	Coffee Break
16:00 - 17:30	Analysis of summarized data and future activities

Friday, 26 June

Session VII	Chairman: P. M. Chalk (IAEA)
09:00 - 10:30	Conclusions and recommendations of the third RCM
10:30 - 11:00	Coffee Break
11:00 - 12:45	Conclusions and recommendations of the third RCM (continued)
12:45 - 13:00	Closing

3. Abstracts of presentations.

3.1 Isotope-aided studies on the effects of radiation processed sewage sludge application on crop yields and bioavailability of heavy metals in Bangladesh soils.

Sultana Ahmed, M.B. Hossain, S.M. Rahman, M.I. Ali and T. Alam

The effects of application of non-irradiated and irradiated sewage sludge on wheat yields, heavy metal accumulation in soils and crops and the residual effect of sewage sludge on a succeeding rice crop was studied in two experiments, one non-isotopic and the other using ^{15}N isotope, on a dark grey floodplain soil (Haplaquept) in Bangladesh.

Gamma-irradiation (5kGy) significantly decreased the total bacterial counts in sewage sludge, and completely eliminated pathogenic bacteria, indicating the possibility of safe use of irradiated sewage sludge in crop production. There was a progressive increase in grain yield with higher rates of sludge application which was relatively higher in irradiated compared with non-irradiated sludge treatments. The highest N contribution from sludge was recorded by the application of 400 kg N / ha from irradiated sludge.

^{15}N isotope-aided studies showed that wheat grain yield increased from irradiated sewage sludge by 19.5 % on average as compared to non-irradiated sludge treatments. The highest percentage of wheat-N derived from sewage sludge (18.6 %) was recorded for 400 kg sludge-N / ha in the irradiated treatment. There were considerable variations in % N contributions from sewage sludge between non-isotopic and isotopic experiments. The isotopic method is considered to be more accurate for estimation of the N contribution from applied sludge. Although wheat yields responded positively to sludge application, the grain yield was less than that obtained with 100 kg N / ha from urea.

Marginal differences in physicochemical properties of post-harvest soil were observed. Metal concentrations in wheat plants were low and varied in different treatments. A residual effect of sewage sludge on the yield of rice following wheat was also recorded.

3.2 Assessment of irradiated sewage sludge for macro- and micronutrients, heavy metals and pesticide residues under different soil-crop systems.

T.J. D'Souza, V.V. Athalye, V. Ramachandran and D.U. Patel

Repeated application of normal (non-irradiated) sewage sludge and irradiated sewage sludge to microplots established on an Inceptisol with successive maize-green gram-maize-green gram cropping sequence indicate that no yield differences could be obtained between the two types of sludges. Further, sludge applications at incremental levels did not result in increased crop yields.

The macronutrients nitrogen, phosphorus and potassium, and micronutrients and heavy metal contents also showed no differences. Data on soil analysis before and after harvest of the four successive crops did not show appreciable variations in the various soil parameters. It is therefore concluded that the efficacy of both the normal and irradiated sewage sludges is at par and no deleterious or toxic effects have been noticed either in the soil or in the crops.

3.3 Utilization of sewage sludge for enhanced agricultural productivity.

Farooqe Azam

Irradiated sewage sludge had a significant beneficial effect on dry matter production in wheat and rice. However, the response of maize was not very positive and the root growth was particularly affected by high levels of fertilizer N as well as sludge. When sewage sludge was applied together with ¹⁵N-labelled fertilizer, a significant increase in the uptake of unlabelled N in wheat was observed. This increase could either be from the sewage sludge itself or resulted from enhanced mineralization of native soil N. Sewage sludge was also found to have a conservational effect on fertilizer N, the plant uptake of which increased in the presence of sludge. The two N sources (sewage sludge and chemical fertilizer) seemed to have a synergistic effect on dry matter accumulation by plants and an optimum combination could be reached to

obtain maximum benefits from the two nutrient sources. However, sewage sludge did cause an enhanced uptake of heavy metals, which may be of concern.

3.4 Chemistry and bioavailability of heavy metals in sewage sludge-treated soils.

Andrew Chang

Our investigations on metal accumulation in sewage sludge-treated soils is aimed at further understanding of the chemistry of sewage sludge-borne metals and implications with respect to metal availability to plants. Four lines of investigation have been followed:

- (i) Plant uptake of metals from sewage sludge-treated soils - plateau or time bomb? (Chang et al., 1997)
- (ii) Metal absorption by non food chain crops grown on sewage sludge treated soils (Scora and Chang, 1997)
- (iii) Fate of sewage sludge-borne metal solid phases in soils (Candalaria and Chang, 1997)
- (iv) Solubility of sludge-borne metals in relation to mineralization of organic C (Hyun et al., 1998).

Chang, A. C., Hyun, Hae-Nam, and A. L. Page. 1997. Cadmium uptake for Swiss chard grown on composted sewage sludge treated field plots: Plateau or time bomb? *J. Environ. Qual.* 26:11-19.

Scora, R. W. and A. C. Chang. 1997. Essential oil quality and heavy metal concentration of *Mentha peperita* grown on a municipal sludge-amended soil. *J. Environ. Qual.* 26:975-979.

Candalaria, L. M. and A. C. Chang. 1997. Cadmium activities, solution speciation and solid phase distribution in cadmium nitrate and sewage sludge treated soil systems. *Soil Sci.* 162:722-732.

Hyun, Hae-nam, A. C. Chang, D. R. Parker, and A. L. Page. 1998. Cadmium solubility and phytoavailability in sludge-treated soils: Effects of soil organic carbon. *J. Environ. Qual.* 27:329-334.

3.5 Phytoavailable estimates and the various fractional forms of five heavy metals in an Andosol with a long-term history of sewage sludge application.

F.M. Salas, M. Chino, H. Masujima and K. Kumazawa

Plant available estimates of five heavy metals in an Andosol with a long-term history of sludge application were evaluated through chemical extraction and analysis by inductively coupled plasma atomic emission spectrophotometry (ICP-AES). The soil samples were subjected to sequential extraction with 0.005 M ammonium-DTPA, 0.1 N HCl and 0.005 M DTPA. The various fractional forms of cadmium, copper, nickel, lead, and zinc metals were assessed after extraction. The concentrations of the various metal fractions were determined and their distributions in various plots treated with sewage sludges were correlated as affected by the phytoavailable heavy metal estimates (PAE) extraction.

The soil samples which were first extracted with ammonium-DTPA showed higher values of water soluble and exchangeable heavy metal fractions. Diethylenetriaminepentaacetic acid reagent (DTPA), on the other hand, affected the residuality of the heavy metals. Similarly, ammonium-DTPA and HCl tend to reduce the residuality of the cadmium metal. The three phytoavailable extractants gave lower values of the oxidizable and reducible metal fractions; but higher values of the carbonate heavy metal fractions were observed. Indeed, the result obtained implies transformation of various heavy metal forms to indicate that once the different forms and their distribution are perturbed in the soil environment, a corresponding new distribution of various heavy metal forms would be attained, possibly to counteract the effect brought about by the disturbance, which in proportion may not be the same as in the previous state.

With the varying changes in the pattern of fractional heavy metal distribution in four treatment plots after phytoavailable chemical extraction, an equation representing the phytoavailable estimates of the five heavy metals can not be generalised with respect to the various forms of Cd, Cu, Ni, Pb and Zn metals.

3.6 Use of nuclear techniques for evaluating agricultural use of sewage sludge and environmental protection

Mihail Dumitru, Doina Plaxienco, Ariadna Alexandrescu, Eugenia Gament and Dumitru-Marian Moteli

The sewage sludge from the waste water treatment plants in Timisoara and Pitesti has a high content of organic matter and nutrients. The heavy metal contents are below the maximum admissible limits for agricultural use of sewage sludge in Romania. Therefore, it can be accepted as a fertilizer for agriculture.

Averaged data from the three years of experimentation on a Haplic Phaeozem (phreatic phase) in Timisoara show the beneficial effect of sewage sludge fertilisation on maize. Compared with the unfertilised crop, the yield increased from 10 % for 10 t/ha addition of sludge to 39 % for 100 t/ha. The N₁₂₀P₈₀ mineral fertilisation assured an average yield increase of 39 %.

Application of 100 t/ha municipal sewage sludge from Timisoara did not induce important changes in the chemical characteristics of soil or in heavy metal contents of maize grains and leaves.

No statistically significant changes in either maize yield (grains, leaves, husks and stems) or in its N content and N derived from fertilizers occurred in the first year of experimentation with irradiated and non-irradiated sewage sludge on a Haplic Phaeozem at Teleorman.

No significant modifications of the chemical characteristics of soil occurred after application of low doses of sludge (up to 400 % of the recommended N rate, i.e., about 20 t/ha) within a 2 year period.

Fertilization with higher rates of sewage sludge significantly influenced the yield of grain and straw of oats. The highest yield was obtained at the maximum dose of sewage sludge. Application of two consecutive annual doses of 20 t/ha assured a yield level approximately equal to that given by 100 kg fertilizer-N / ha. The percentage of N derived from N fertilizer applied to oats was reduced by 4 - 5 %, irrespective of irradiated or non-irradiated sludge application. However, unlike in the first year of experimentation, an important percentage (8 -26 %) of N came from the sewage

sludge. The fraction of N derived from sludge was higher for irradiated than non-irradiated sludge.

The macronutrient (K, Ca, Mg) and heavy metal (Cu, Zn, Pb, Cd) contents of oat plants suffered no adverse effects from sludge application.

In the second year of experimentation fertilization with municipal sewage sludge led to significant increases in maize grain yield.

3.7 Increasing crop production of sandy soils by using radiation processed and composted sewage sludge and municipal solid wastes.

Rawia El-Motaium

Irradiated (5 kGy) and non-irradiated sewage sludge was applied at 4 rates (100, 200, 300 and 400 %) of the recommended rate of fertilizer N to tomatoes. In addition, two controls were included; no fertilizer (zero treatment) and fertilizer N at the recommended rate.

Samples of irradiated and non-irradiated sewage sludge were analyzed for heavy metals and pathogen content. Soil samples were collected at the end of the experiment for soil fertility, soil physical properties and heavy metals analysis. Plant samples (leaf, stem and root) were collected at maturity for biomass, total N, heavy metal and micronutrient analysis. Fruits were harvested at ripening for yield, fruit quality and heavy metal evaluation.

An improvement in soil fertility and soil physical properties in sludge treatments was observed. Soil organic matter and water holding capacity increased and soil bulk density decreased as sewage sludge application rate increased. Heavy metal build-up in the soil and accumulation in tomato leaves (Pb, Cd, Ni, Co, Cr, Cu, Zn, Mn) was not observed, probably because the sewage sludge was low in heavy metals.

Nitrogen available to plants from sewage sludge increased as the sludge application rate increased in both irradiated and non-irradiated treatments. Fruit quality improved greatly by the application of sewage sludge, including % total sugar, % total soluble solids and sugar / acid ratio. Only trace amounts of heavy metals were detected in fruit. Tomato plant yield (including biomass and fruit yield) significantly

increased as the sewage sludge application rate increased. The pathogen content of sludge (*Ascaris ova* and bacteria) was significantly decreased by a dose of 5 kGy of gamma irradiation.

It is concluded that the use of irradiated sewage sludge is beneficial for improving the properties of sandy soils and increasing yield. Its utilization as an organic fertilizer is safe from the point of view of pathogen transmission.

3.8 The use of sewage sludge as a fertilizer in pasture

Eugénio Ferreira, Isabel Viana, Herminia Domingues and Fernando Pires

The residual effect of sewage sludge applied to a Calcaric Cambisol was studied in a field and a pot experiment which were resown with subclover (*Trifolium subterraneum*) and ryegrass (*Lolium multiflorum*). Ammonium nitrate (5 atom % ¹⁵N excess) was applied as a uniform spray to microplots at the rate of 2 kg N / ha, one month after sowing or immediately after each cut.

Dry matter production of the grass increased while that of subclover decreased with increasing rates of applied sludge. In the pot experiment this decrease was only evident at the higher rates of sludge application. ¹⁵N dilution estimates of the % of clover-N derived from fixation and the amount of above-ground N fixed decreased when rates of sludge increased. Sludge application at all rates did not significantly affect the nitrogenase activity or the size of the rhizobial population. Coliform bacteria could not be detected in the soil. The high rates of sludge cannot supply the N requirements of the grass, but can only supplement it. Biological nitrogen fixation can supply the N requirement of the legume, but the low production was due to an unidentified plant nutritional disorder. Chemical analyses of plants and soils confirmed that the disorder was not due to toxic effects of heavy metals.

3.9 Use of sewage sludge - nitrogen availability and heavy metal uptake into rape

M. H. Gerzabek, E. Lombi and P. Herger

The effects of sewage sludge application (sterilized by γ -irradiation or not sterilized) on rape growth and the uptake of N and heavy metals were studied in a three year experiment with large pots in the field.

Mobile fractions of Cd, Cu and Zn increased significantly in the substrate due to sewage sludge treatments. However, heavy metal transfer into rape plants did not respond clearly. Rape growth was clearly enhanced in the first and third year due to sewage sludge applications. The average N-utilisation by rape from sewage sludge in a three years period decreased from 7.4 % (first year) to 1.8 % (second year) and to 1.1 % (third year), resulting in an overall utilization of 10.3 % of sewage sludge-N by rape plants. Irradiation of sewage sludge did not result in any significant effect on the investigated parameters.

3.10 Bioaccumulation and metabolic fate of sewage sludge derived organic xenobiotics in plants.

Hans Harms

The application of sewage sludge and biowastes to agricultural land is generally the most economical outlet for sludge and organic wastes and provides an opportunity to recycle beneficial plant nutrients and organic matter to soil for crop production. However, these waste matrices also contain hazardous heavy metals and organic pollutants which enter food chains and are of great concern to the public. Some compounds have recently attracted great attention because of their estrogenic effects.

Nonylphenol is one of those compounds known to be an environmental hormone. Therefore, uptake and metabolism of 4-N-P in crop plants may have strong impacts on food quality. In two papers:

Bokern, M. and Harms, H. Environ. Sci. and Technol., 31, 1849-1854 (1997) and

Bokern, M., Raid, P. and Harms, H. Environ. Sci. and Pollut. Res., 5, 21-27 (1998)
we report on the toxicity, uptake and metabolism of 4-n-nonylphenol in cell
suspension cultures, root cultures and intact plants under septic and aseptic conditions.

Fluoranthene is the most abundant polycyclic aromatic hydrocarbon (PAH) and
has been reported to be mutagenic and carcinogenic. PAHs are recognised as the main
pollutants of biowaste composts at a range of 0.7 to 3 mg/kg dry weight. Prolonged
use of such composts in agriculture and horticulture can lead to a gradual increase of
these pollutants in soils and thereby to the food chain. Therefore it is important to
know the bioavailability of these xenobiotics for plants and their further metabolic
fate. Data on this have been published in

Kolb, M. and Harms, H. Proceedings of ECO-INFORMA'97, October 6-9, 1997.
Information and Communication in Environmental and Health Issues, pp. 301-307.

Polychlorobiphenyls are industrial chemicals which, because of their extensive
use, their high persistence and their toxicity are of great concern. They accumulate in
food chains and are hazardous to humans. Plants are able to take up PCBs by their
roots from soils and from atmospheric deposition by their leaves. In previous studies
we showed that plants are able to metabolize PCBs by hydroxylation. The metabolism
rate depends on the chlorination grade and the substitution pattern as well as on the
plant species. In the paper

Bock, C. and Harms, H. Organohalogen Compounds, 28, 53-57 (1996)

we report on the phytotoxicity, the metabolism and the characterization of metabolites
of 2-chlorobiphenyl (PCB 1), 2,2',5,5'-tetrachlorobiphenyl (PCB 52), and the 3,3',4,4'-
tetrachlorobiphenyl (PCB 77) in various plant cell cultures.

3.11 Agricultural use of sewage sludge in Malaysia

Che Fauziah Ishak, Rosenani Abu Bakar, Halimi Mohd. Saud,
Zaharah Abd. Rahman, Ahmad Sahali and Hj. Tani

A field experiment was conducted for a period of three maize cycles to determine
the effect of gamma irradiation on the availability of organic N and trace elements in
sewage sludge. The initial irradiated (IR) and non-irradiated (NIR) sludge application

rate was 0, 150, 300, 450 and 600 % of the recommended fertilizer-N rate of 140 kg/ha. A residual study was conducted for the second maize cycle. The IR and NIR sludge was once again applied during the third maize cycle at rates of 0, 100, 200, 300 and 400 % of the recommended fertilizer-N rate.

For the first cycle, there were no significant differences in the N yields between different rates as well as between the IR and NIR sludges due to the high variability in the dry matter yield. This is probably due to the spatial heterogeneity of the soil itself. In this cycle, higher amounts of N were taken up with higher sludge application rates (up to 450 % of N recommended fertilizer-N rate). This is probably because, initially, the higher mineralized N available in the sludge was not vulnerable to immobilization. The N yield for the second cycle (residual study) was about half of the first cycle. For the third cycle, there was a slight increase in N yield up to 200 % of the recommended N rate. Further increase in sludge rate did not increase the available N for crop uptake. This seemed to indicate the inhibitory effect of high sludge rates on N mineralization. Also, there was lower total N taken up in the control plot, indicating decreasing availability of soil N.

There was no significant difference in the uptake of trace elements by grain between IR and NIR sludge treatments. There was an increase in the total soil Cd, Cu, Pb and Zn concentrations after the first maize cycle but these concentrations decreased before the third crop was grown.

3.12 Safe re-use of irradiated sewage sludge to preserve the environment

Cecilia Magnavacca

Ascaris ova, an indicator parasitic species, was eliminated by a radiation dose lower than 2 kGy. Enteric viruses like Echo and Cocksackie were successfully isolated from the sludge samples, and then inactivated with radiation doses of about 3 kGy. The absorbed radiation dose proposed for the Sewage Sludge Irradiation Project in Argentina (3 kGy) is evidently sufficient to disinfect sludges for being reused as fertilizers.

The accumulation of trace metals in surface soil did not increase sufficiently to justify deeper sampling. Nevertheless, samples up to 30 cm depth were analysed and the concentrations were far below the limits after three annual applications of sludge. The Aqua Regia extractant was not as efficient as the Nitric-Fluorhydric-Perchloric extractant for some metals (Cr, Zn).

Our research has conclusively shown that irradiated sewage sludge was a better source of N compared with non-irradiated sludge for certain crops. Irradiation causes ammonium release in the sludges making N more available for sugarcane and lettuce. The benefits in sugarcane are important because this crop is cultivated in most of the areas surrounding the Sewage Sludge Irradiation Plant at Tucuman, Northwestern Argentina.

3.13 The risks of application of sewage sludge to land - European experience

S. P. McGrath

Investigations of soil-plant transfers of Cd and Zn and impacts on important soil bacteria in long-term field experiments at two sites in Europe are reported here. This paper also gives results of studies on the sensitivity of bacteria of the genus *Rhizobium* to heavy metals.

Concentrations of Zn and Cd in the tops and storage roots of carrot in 1963, 1984 and 1985, and of red beet in 1983-85 were related to the concentrations of CaCl₂- and EDTA-extractable metals and total Zn and Cd in soils, respectively. In all cases, the relationships were linear, showing no sign of a plateau.

In the long-term experiments at Braunschweig and Woburn, negative effects on survival of symbiotic bacteria occur at concentrations of Zn which do not harm plant growth, indicating that some soil organisms may be more sensitive to Zn in sludge-treated soils than crops.

3.14 Effect of irradiated sewage sludge on N and P uptake by chilli (*Capsicum annuum* L.) and edible nightshade (*Solanum melongena*).

M.M. Mitrosuhardjo, S. Syamsu and Harsaya

The effect of irradiated (cobalt-60 source; dose rate of 4 to 5 kGy) and non-irradiated sewage sludge on the yield and N uptake by chilli (*Capsicum annuum*) and edible nightshade (*Solanum melongena*) was studied in field plots (Oxisol) in 1996/1997. Yields (fresh fruit and dry weight) of both species increased with increasing rates of irradiated and non-irradiated sludge (120 to 480 kg sludge-N/ha). However the yields achieved were generally less than those obtained with 120 kg urea-N/ha. N uptake similarly increased with increasing rates of sludge addition. The percentage of plant N derived from sludge (N difference method) varied between 1 and 54 % and increased with sludge rate.

The effect of irradiated and non-irradiated sludge (6-24 t/ha; 1 % N) on yield and N uptake of edible nightshade was also studied in a pot experiment with ¹⁵N-labelled ammonium sulphate applied at 20 kg N/ha in each treatment. The percentage of plant N derived from the labelled fertilizer varied from 14 to 28 % and was not markedly affected by the rate of sludge addition. The percentage of plant N derived from sludge (N difference method) was 13-55 %. Both yield and N uptake with 120 kg fertilizer-N/ha were higher than with the highest rate of sludge.

The effect of irradiated and non-irradiated sludge (120 to 480 kg sludge-P₂O₅ / ha) on yield and P uptake of edible nightshade was also studied in a pot experiment and compared with either no P or P applied as ³²P-labelled triple superphosphate (TSP) at 120 kg P₂O₅/ha. Estimates of plant P derived from sludge (P difference) varied from 30 to 62 %. P uptake in sludge-amended soil was greater than P uptake in TSP-fertilized soil, indicating that sludge is a good source of phosphorus.

Concentrations of micronutrients (Cu, Zn, Fe, Mn) in chilli and edible nightshade grown in sludge amended and control soils did not differ significantly. Similarly, there was no evidence that sludge application had a significant effect on total micronutrient or heavy metal concentrations in soil or on total coliform counts.

3.15 The use of irradiated wastewater sludge cake as a source of nitrogen for

maize.

J. Prasatsrisupab, C. Yathaputanon, V. Podisuk, S. Tammarate, M. Pumkiom and Chaiwanakupt

The second year field experiment was conducted on a reddish-brown lateritic soil at Praputtabart Crop Experiment Station, Saraburee province, to compare the effects of ammonium sulphate and irradiated wastewater sludge cake on growth, yields and uptake of N by two crops of maize (*Zea mays* L.). Heavy metal concentrations, total coliform counts and some soil properties were determined in soil after applying sludge cake and after the second crop.

Dry weight, plant height, ear height and N uptake in crop 1 were higher than those in crop 2. In crop 1, ammonium sulphate and the higher rate of sludge cake gave the same yield, but in crop 2 which was the residual study, sludge cake gave a higher yield than the residual fertilizer treatment. Irradiated sludge cake gave higher yields than non-irradiated sludge cake.

Total coliform counts in the soil after applying sludge cake and before the first crop were very variable and were present in soil without sludge. Total coliforms in non-irradiated sludge cake sub-plots were higher than in irradiated sludge cake sub-plots. After the second crop coliforms were not found in the soil, possibly due to the very dry and hot weather.

After applying wastewater sludge cake for two years, the clay loam texture of the soil did not change. Similarly, there were few significant or consistent effects of increasing rates of sludge application on soil pH, macro and micronutrient concentrations, cation exchange capacity, water holding capacity and organic C content.

4. Review of progress towards achieving project objectives

The project objectives as defined at the first RCM were:

- To quantify the availability of N and P from sewage sludge to crops, using ^{15}N and ^{32}P tracer techniques.
- To assess increases in crop yields as a result of application of sewage sludge.
- To assess improvements in soil properties, particularly increases in organic matter content and water holding capacity.
- To estimate the pathogenic organism content in non-irradiated and irradiated sewage sludge.
- To assess the extent of contamination of soil by heavy metals by the use of sewage sludge.
- To determine the beneficial effects of micronutrients in terms of increasing crop yields and soil fertility.

4.1 To quantify the availability of N and P from sewage sludge to crops, using ^{15}N and ^{32}P tracer techniques.

Only one Contract Holder has undertaken an experiment with ^{32}P -labelled fertilizer. The effect of sludge application on fertilizer-P uptake in a pot experiment was determined. The availability of sludge-P was determined by the difference in P uptake between treatments with and without sludge applied.

All Contract Holders and one Agreement Holder have carried out experiments using ^{15}N -labelled fertilizer either in the glasshouse or the field. The objectives of these experiments varied according to the crop, namely

- to estimate legume N_2 fixation by isotope dilution.
- to estimate the effect of sludge addition on fertilizer-N uptake.
- to estimate N uptake from sludge using the indirect ^{15}N -dilution method.

Many contract holders have estimated N uptake from sludge by the difference in N uptake between treatments with and without sludge applied. In summary, a large number of experiments have been completed to quantify the availability of sludge N to crops, but this has been mainly achieved using the yield-dependent non-isotopic N difference method.

4.2 To assess increases in crop yields as a result of application of sewage sludge.

A large number of both pot and field experiments have been carried out by all Contract Holders to assess the affect of irradiated and non-irradiated sludge on crop yields. The redesigned treatments agreed at the second RCM were (i) a control (ii) N fertilizer at the locally-recommended rate (iii - vi) non-irradiated sludge at 100, 200, 300 and 400 % of the N fertilizer rate (vii - x) as for iii - vi but with irradiated sludge. Experiments have been conducted with annual additions to the same plots to assess cumulative effects or with an initial addition and subsequent crops to assess the residual value. Positive yield responses to incremental rates of sludge addition were obtained in a majority of experiments. The yield response

with irradiated compared with non-irradiated sludge was inconsistent, but there is evidence that N may be more available in irradiated sludge. The yield response with the highest rate of sludge was generally less than obtained with the recommended rate of fertilizer N.

4.3 To assess improvements in soil properties, particularly increases in organic matter content and water holding capacity.

In sandy infertile soils, repeated sludge application has resulted in an increase in the soil organic matter content and water holding capacity and a decrease in bulk density. Positive effects are unlikely to be demonstrated in finer-textured soils in the short term.

4.4 To estimate the pathogenic organism content in non-irradiated and irradiated sewage sludge.

Data on total coliform density in irradiated and non-irradiated sludge are available from a majority of Contract Holders. Data on total bacteria, fecal coliforms, Salmonella, parasitic ova (e.g. Ascaris) and viruses are incomplete. In some cases, acquisition of such data are beyond the financial/technical resources of the Contractor. Less data have been collected for sludge-amended and unamended soil than for sewage sludge. A gamma irradiation dose of 5 kGy for dried sludge was sufficient to eliminate pathogens and significantly reduce total bacteria, but the dose should be higher for wet sludge (> 35 % water).

At the second RCM in Cairo it was stated that a prime goal of the CRP was to prove that irradiated sewage sludge is safe, from a public health point of view, for use in crop production. While this has been done for pathogens, the estimation of hazardous organic compounds in irradiated sludge has not been carried out, and therefore no unequivocal statement about its safety can be made.

4.5 To assess the extent of contamination of soil by heavy metals by the use of sewage sludge.

All Contract and Research Agreement Holders have collected data on heavy metal concentrations in sludge, soil and plants. There is no difference between irradiated and non-irradiated sludge in heavy metal concentrations.

4.6 To determine the beneficial effects of micronutrients in terms of increasing crop yields and soil fertility.

Sludges, soils and plants have been analysed for micronutrient concentrations (principally Fe, Mn, Zn, Cu) by a majority of Contract Holders. Yield responses to sludge application have not been specifically attributed to amelioration of micronutrient deficiencies.

5. Recommendations

1. Research Contract Holders should provide the Scientific Secretary with details of work completed on ^{15}N , crop yields, pathogens and heavy metals according to the agreed data summary formats (Section 7 of this Report).
2. Experiments which are currently underway should be completed together with the associated analytical work. If necessary, ^{15}N -labelled plant samples can be analysed at Seibersdorf. Statistical analysis of all data should be completed.
3. Experimental work should be discontinued on soils/sites where crops have not responded to sludge application or where high spatial variability precludes significant differences.
4. The emphasis on future experimental work should be in relation to the value of sludge as a source of phosphorus. The use of ^{32}P in this regard is encouraged, either to investigate the effect of sludge on P fertilizer uptake or to use the indirect ^{32}P -dilution approach to estimate the proportion of plant P derived from sludge. Stored plant samples should be analysed for P content and the contribution of sludge to the P nutrition of the plant estimated by the difference in P uptake between sludge-treated and untreated (control) plots.
5. The data which have been collected from experiments using ^{15}N should be critically examined. In particular, comparisons between the N difference method and the ^{15}N -dilution method for estimating the proportion of plant N derived from sludge should be made. If negative estimates were obtained by ^{15}N -dilution, an attempt should be made to relate this to the experimental conditions or to sludge characteristics (e.g. C/N ratio).
6. Yield responses (or the lack of a response) and plant elemental composition should be critically examined to determine the soil/plant/environmental factors and sludge characteristics governing the response. The benefit of irradiated compared with non-irradiated sludge which was apparent in some experiments needs to be confirmed by statistical analysis of data. Observations on crops with respect to pests and disease may be helpful in interpreting the observed response to sludge addition.
7. Future efforts to collect data on pathogen kill in irradiated sludge and survival in soil should focus on fecal coliform and *Ascaris* ova. Some data already collected needs to be verified for accuracy.
8. Soil properties should be measured at the end of the experiments particularly for those with cumulative sludge addition. Sampling intensity needs to be addressed if the expected beneficial effects of sludge on soil properties are to be verified.
9. With respect to heavy metals the following are recommended:
 - Make sludge/soil metal balance (assumes metals are not leached)

- Use balance to check soil data veracity
- Check if soil data are consistent with crop data
- Missing data and statistical analysis to be completed
- Analysis of shoots/edible parts of crops
- Examine the value of soil extraction with ammonium nitrate to predict high metal concentrations in the plant.
- Check plant Cu, Zn and Mn against established threshold values.

10. Examine the feasibility for the Agency to award a Technical Contract to initiate work on toxic organic compounds in irradiated sewage sludge.

11. The fourth and final RCM of the CRP should be held in Vienna either during the last or penultimate week of September, 1999.

5 List of Participants

5.1 Research Contract Holders

Ms. Cecilia MAGNAVACCA (ARG-8475)
Comisión Nacional de Energía Atómica
Proyecto Irradiación de Barros (PIBA)
Tucuman 1728
1050 Buenos Aires
ARGENTINA
Fax: +541 3718423 (tel+fax) or +541 379 8322
Phone: +541 3798235
Email: cecimag@cnea.edu.ar

Ms. Sultana AHMED (BGD-8477)
Department of Soil Science
Bangladesh Institute of Nuclear Agriculture
P.O. Box 4
Mymensingh 2200
BANGLADESH
Fax: +88091-54091
Phone: +88091-54047, 54401 (home 55178)
Email: bina@bdmail.net

Ms. Rawia EL-MOTAIUM (EGY-8555)
Plant Research Department
P.O. Box 13759
Atomic Energy Authority
101, Kasr El Einy St
Cairo
EGYPT
Fax: +202 2740 238 +202 3902585 or ++**202 3540982**
Phone: +Work: 202 3558264; Home: 202 3822496 or 202 390 2585
Telex: 92790 EGTOM UN

Mailing Address:
3 Abu Zaid St. from Tarek Ibin
Ziad St.
Apt # 16 El-Taawen, El-Haram St.
Giza,
EGYPT

Mr. V.V. ATHALYE (IND-8480)
Head, Soil Science & Fertilizer Section
Nuclear Agriculture and Biotechnology Division
Bhabha Atomic Research Centre
Trombay, Bombay-400 085
INDIA
Fax: +9122 556 0750 or +9122 556 0534
Telex: 011 61017 or 011 61022 BARCIN
Phone: +9122 5563060 ext. 2697

Mr. Mardjo MITROSUHARDJO (INS-8481)
Soil and Plant Nutrition Division
Centre for the Application of Isotopes and Radiation
Jl. Cinere Pasar Jumat
P.O. Box 7002 JKSKL
Jakarta 12070
INDONESIA
Fax: +6221 7691607
Telex: 47113 Cairca IA
Phone: +6221 7690709

Ms. Che Fauziah ISHAK (MAL-8483)
Department of Soil Science
Universiti Putra Malaysia
Faculty of Agriculture
43400 UPM, Serdang, Selangor
MALAYSIA
Fax: +60 3 9434419
Phone: +60 3 9486101 ext. 2689
e-mail: fauziah@agri.upm.edu.my

Mr. Farooqe AZAM (PAK-8484)
Soil Biology Division
Nuclear Institute for Agriculture and Biology
Jhang Road, P.O. Box 128
Faisalabad,
PAKISTAN
Fax: +92 41 654221
Telex: 43356 NIAB PW
Phone: +92 41 654221
e-mail: farooq@niab.fsb.erum.com.pk

Mr. Eugénio Mendez FERREIRA (POR-8486)
Departamento de Pedologia
Estação Agronómica Nacional
Quinta do Marquês
2780 Oeiras
PORTUGAL
Fax: +351 1 4416011 / 351 01 4416011
Phone: Work: +351 1 4416855 or 4416856; Home: 3511 466 1562
e-mail: ean@mail.telepac.pt

Mr. Mihail DUMITRU (ROM-8487)
Research Institute for Soil Science and Agrochemistry
Bd. Marasti No. 61
71331 Bucharest
ROMANIA
Fax: +40 1 2225979
Phone: +40-1-2229442
Telex: 11394 asas
e-mail: mdumitru@icpa.ro

Ms. Jariya PRASATSRISUPAP (THA-8488)
Nuclear Research in Agriculture Section
Division of Agricultural Chemistry
Department of Agriculture
Chatujak, Bangkok 10900
THAILAND
Fax: +662 5797158 or +662 579 034
Phone: +662 5797156, 662 5797158, 622 5794114
Email: amsat@mozart.inet.co.th

5.2 Research Agreement Holders

Mr. Martin H. GERZABEK (AUT-8476)
Head, Environmental Research
Austrian Research Centre Seibersdorf, Seibersdorf
AUSTRIA
Fax: +43 2254 780 3653
Phone: +43 2254 780-3521
Telex: 14353 fzs
e-mail: Martin.Gerzabek@arcs.ac.at

Mr. Hans HARMS (GFR-8479)
Institute of Plant Nutrition and Soil Science
Federal Agricultural Research Centre (FAL)
Braunschweig-Völkenrode
D-38116 Braunschweig
GERMANY
Fax: +49 531 596 377
Phone: +49 531 596 303/323
Email: harms@pb.fal.de

Mr. Mitsuo CHINO (JPN-8482)
Faculty of Agriculture
University of Tokyo
Bunkyo-Ku
Tokyo 113,
JAPAN
Fax: + 813 3234 4301 or 81 3 5689 7226 or
Phone: +81 4 7335 5537 (home) 81 3 3234 4301
E-mail: VZB03022@niftyserve.or.jp

Mr. Andrew C. CHANG (USA-8490)
Department of Environmental Sciences - 084
University of California, Riverside, 2208 Geology Building
Riverside, California 92521-0424
UNITED STATES OF AMERICA
Fax: +1909 7873993
Phone: +1909 7875325
e-mail: acchang@mail.ucr.edu

Mr. Steve McGRATH (UK-8489)
Integrated Approach to Crop Research, IACR - Rothamsted
Harpenden, Hertfordshire AL5 2JQ
UNITED KINGDOM
Fax: +44 1582 760 981 or 0044 582 461336
Phone: +44 1582 763 133
Email: steve.mcgrath@bbsrc.ac.uk