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Summary of the studies

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Lecturers (in order of lectures presentations): Dr. Ariel Metzger, Dr. Jane Aiken, Dr. Vimal Kumar (lecture present in absentia), Dr. Robert S. Reimers, Dr. Wayne F. Truter, Dr. Christos Tsadilas, Dr. Yona Chen, Dr. Eli Zaady, Dr. Pinchas Fine, Dr. Rami Keren, Gustavo Haquin.

Background material: Lecturers, Abstracts and presentations

Introduction

The main use of coal ash is in the construction industry (cement, concrete, building products). Compared to that, the volume of agricultural use is minor to negligible. Yet, countries put much effort and resources in developing and promoting that use (e.g. Australia). There are three main applications of coal ash in agriculture: fly ash directly applied to soil, fly ash used as a stabilizer component in municipal sewage sludge which is intended to be added to agricultural soil, and bottom ash mixed with compost to form a growing medium for plants in greenhouses. It can be shown that, as presented in the workshop, these uses of coal ash (as well as other uses) are justified on the basis of:

(1) Economic and agronomic considerations – coal ash as a replacement for fertilizers (source for micronutrients) and lime (in acidic soils), improving soil physico-chemical properties and altogether plant growth and crop yield;
(2) Environmental considerations - meeting standards for toxicity and radioactivity in plants, soil and groundwater exposed to the coal ash, as well as in the ash itself..

Economic and agricultural aspects

These aspects are often considered together. One of the reasons for preferring coal ash to other additives is cost saving. Based on the information presented in the workshop, it is apparent that:

- Fly ash as a source for micro (e.g. Zn, Mn, Cu)- and macro (e.g. N,P,K, Ca, Mg)-nutrients, can replace fertilizers. This was shown in the presentations of Kumar, Tsadilas and Fine , and holds true both when the ash is added to the soil directly or as a components of NVS (N-viro soil);
- Fly ash improves the soil's physico-chemical properties, such as raising the pH in acidic soils, and can replace the more expensive lime, limestone or gypsum (as shown in Truter's presentation). Fly ash can, improve soil structure (Fine, Zaady) and replace plant protection agents by ammonia gas produced during the temporary increase in pH following N-Viro application (Fine, Reimers) and finally reduce sludge treatment costs (Fine, Reimers). It is estimated by ADAA (Ash Development Association of Australia**)** (Aiken) that soil properties

which hinder plant growth and crop yield and which can be minimized by applying fly ash, cost the agricultural industry a profit of almost 3 billion $ each year;

The agronomic advantages of using fly ash as expressed in contribution to plant growth and increase in crop yield may be as high as 40%, as demonstrated by Aiken and Tsadilas, and in more detailed by Kumar for a variety of plant types. However, the optimal application rate of fly ash is specific for each soil and plant, and high rates can even cause adverse effects and a decrease in yield, as reported by Tsadilas.

Environmental and health aspects

Acceptance of the use of coal ash in agriculture depends also on the potential risk associated with that use. There is a lot of data regarding that risk, ranging from measurements of trace elements and radionuclides concentrations in the ash itself and in the N-Viro Soil, to measuring these pollutants in the agricultural product grown on land treated with the ash.

The risk from coal ash

Data gathered for the past 15 years, including routine analyses of trace elements in the fly ash leachate by the TCLP (leaching in acid) and the EN-12457/2 (leaching in demineralized water) procedures, and comparing the results to "useable ash" criteria, shows **no risk associated with fly ash in land application** (NCAB data). Also, the trace elements composition of fly ash is similar to that of soils and sewage sludges (Metzger). Regarding radionuclides, their concentrations in the fly ash are below the IAEA Exemption Level, which means it is exempted from regulatory control (NCAB data).

The risk from coal ash applications

The risk assessment of coal ash use in agriculture demonstrates, according to the studies presented in the workshop, that actually no risk exists, at **the range of acceptable application rates**. This holds true whether the risk to the soil, the plant or the environment (ground water), or the occupational exposure of workers to radiation is concerned, as will be detailed below.

In India The concentrations of trace elements (B, Mo, As, Se) and radionuclides (^{226}Ra, ^{40}K and ^{228}Ac) in soil loaded with fly ash (up to 650 ton ash/ha), the agricultural product (grain, straw, vegetables and oil seeds) and even in the fly ash itself, were well below the normal range of concentrations in soils, and it was concluded that the **plants grown on fly ash amended soils are safe for human and animal consumption** (Kumar).

In USA the **heavy metals concentrations (As, Cd, Cr, Cu, Hg, Mo, Ni, Pb, Se and Zn) in N-Viro Soils over the years (1990, 1994 and 2013) were found to be within the allowed range according to the criteria of different US agencies and in most cases met all standards**, including standards of the Association of American Plant Food Control Officials (APFCO), which deal with the laws and regulations related to fertilizers, including their effect on the environment (Reimers).

In Israel, trace elements (As, Cd, Pb) concentrations were measured in various crops grown on soils loaded with N-Viro (lettuce, potato, carrot), as well as in the leachate of the soils (in an experiments in

which lettuce was grown in lysimeters). The fact that the pollutants' concentrations in the crops and leachates were below the maximum allowed levels determined by the Ministry of Health, and were similar to the concentrations in the control plots, indicates that **application of N-Viro Soil is safe for both crops and the groundwater** (Fine).

Examination of the health aspects of the use of bottom ash, reveals that **concentrations of toxic elements and radionuclides in the tissue of plants (tomato, pepper, melon) grown on the ash** resembled those of plants grown on tuff, a widely used growing medium which is not subjected to health regulations. The same conclusions were drawn regarding the growing-medium's water leachate. In fact, the concentrations in the leachate even met the WHO standards for heavy metals in drinking water (Chen).

The above described assessment of risk associated with the use of coal ash was based on actual measurements. In order to evaluate the maximum potential risk to plants and drinking water (due to the pollutants reaching groundwater) emanating from toxic trace elements that originate from the fly ash-soil mixture, Keren has performed calculations based on stringent assumptions regarding the NVS application rate (20 ton/acre or 8 ton fly ash/acre), depth of incorporation it in the soil (top 20 cm), and the behavior of elements released from the ash (full extractability and free mobility in the soil solution). Based on these assumptions and on As, Cd, Pb and Hg concentrations in the ash, it is possible to spread fly ash in the soil every year for a period of 7 to 100 years, depending on the element, before reaching the elements' concentrations in the Israeli drinking water standard (DWS). **Under these conditions, there is no reason to suspect contamination of agricultural produce used for human consumption.**

The risk associated with internal exposure to radiation as a result of consuming agricultural products and water exposed to fly ash was assessed by Haquin who reported on radiation measurements in a variety of edible plants grown on bottom ash/compost growing medium and on plots amended with N-Viro Soil (wheat) and in milk produced from cows that were kept on bottom ash bedding. The measured radiation was compared to similar samples grown on a control (no ash) medium. The concentrations in all products were similar in the ash containing and in the control media, and were below detection and regulatory limits (10 Bq/kg) set by the Israel Ministry of Health. Similar results were obtained in tests of the fly ash leachate. Evaluating the risk associated with external exposure of workers to gamma radiation originating from bottom ash/compost growing medium (60:40) and from N-Viro soil (application rate - 20 ton fly ash/ha), showed an annual dose of 64 and 2.2 μSv, respectively, both values are under the limit of 1000 μSv (1 mSv), while 2.2 μSv is even considered a trivial dose by the International Committee of Radiological Protection. To conclude, **the use of coal ash in agriculture does not enhance the radiation exposure, and the annual doses to which the workers involved and the general public are exposed are considered negligible and far below the limits for external (1-20 mSv/year) and internal exposure (0.3 mSv/year), respectively.**

Future goals

Based on the information detailed above, the advantages of the agricultural use of coal ash are well known, and accordingly various countries are taking steps to promote and extend the use of fly ash in

agriculture. For example, steps that are taken by ADAA in Australia (Aiken) include the establishment of market confidence in coal ash by emphasizing the improved profitability resulting from using it and after giving it a legal approval. Time frame for market establishment will extend into the following decades and will depend on results from field experiments on the optimization of application regimes and establishment of the relationship between plant yields and related costs. Farmers' acceptance will follow these developments.

Extended summary of the lectures abstracts and presentations

Dr. Ariel Metzger, Israel Electric Company

Coal ash is produced at Israel's power stations (class F) from burning bituminous coal. It is subjected to environmental guidelines which dictate whether the ash is suitable for a given application or not. For that purpose Israel Electric Company (IEC) monitors the concentrations of sixteen trace elements and three radionuclides in representative samples of coal, fly ash and bottom ash collected every six months. Likewise, analysis of trace elements in a TCLP leachate is performed in order to evaluate the potential risk to the environment as a result of releasing these elements from the ash. The results obtained so far (since 1998), present no evidence of potential pollution, since the measured concentrations of the pollutants (with the exception of boron), were below the criteria defining the ash as "useable". More recently the low potential for water pollution of Israeli fly ash was confirmed using the EN-12457/2 leaching test, the test used in the European Union for characterizing the environmental risk of wastes.

With regard to major elements, fly ash contains mainly oxides of silicon, aluminium and iron, which together comprise more than 90% of the ash weight. The dominant minerals are in an amorphous alumino-silicate phase (glass) which is insoluble in water, and there are also lower amounts of crystalline phases (mullite and quartz). The water pollution potential depends mainly on the pH and the release of trace elements from the ash particles.

The radionuclides concentration in the coal ash is low and similar to that reported for coal ash produced in European countries. Studies conducted in Israel confirmed that under present conditions of use, there is no significant radiological risk from the utilization of coal ash in the building industry or in other applications such as agriculture.

Dr. Jane Aiken, Ash Development Association of Australia (ADAA), Australia

A key factor for coal ash utilization is the development of markets which beneficially use this material, knowing the advantages of this use. This holds true for the use of coal ash (mainly fly ash) in agriculture.

Market development in Australia is well advanced, including regulatory considerations, commercial implications, ash selections and application options for use of fly ash under Australian conditions. ADAA recognizes the potential for use of fly ash in agriculture which addresses a number of major soil problems and crop needs: soil acidity and sodicity, nutrient supply and minimization of nutrient

loss, and improving soil structural and hydrological properties. It is estimated that these barriers to plant growth and crop yield, cost the industry a loss in profit of almost 3 billion $ annually. Another application of fly ash is the capture of CO_2 that is produced in the soil due to microbial metabolism decomposition, through the carbonization of the ash.

The fly ash in Australia is classified as Class F, same as the coal ash produced in Israel. A major work was done by ADAA to identified significant contributions of the ash to the improvement of soil properties:

- Raising pH in acidic soils.
- Contribution to plant growth associated with nutrient supply and improving soil structure.
- Minimizing phytotoxicity by using the fly ash at agronomically sustainable rates as in the case of using gypsum or lime as soil amendments.
- Most of the benefits from using fly ash are obtained at application rates of no more than 10 ton/ha (1 ton/dunam), and for most purposed not more than 5 ton/ha.
- Fly ash meets regulatory standards.

Actions taken for extending the use of coal ash in agriculture include defining the market and its needs and facilitating identification of potential consumers and this is done not before giving this application a legal certainty which is the basis for coal ash use in civil and soil based industries.

The ADAA puts a lot of effort in promoting coal ash beneficial uses, for example by publishing technical literature and environmental monitoring reports, reference data sheets and research reports. Also, a CCP (coal combustion products) Handbook which was first published in 2007, will consolidate in its 2014 revised edition the major agronomic benefits of Australian fly ash as understood since 2007. At present, this application is negligible in Australia, and ADAA has no representative from the agricultural landholders group.

Australian interest in the use of CCP's for soil amendment has been driven by: (a) recent research findings demonstrating the improved growth of crops, pasture, forests and turf following the addition of CCP's; and (b) **the need for the development of sustainable utilization options**.

As mentioned above, major problems in Australia are acid and sodic soils which are widespread there. Australian fly ashes can be used to treat acid soils. As for sodic soils, the ashes are low in SAR (sodium adsorption ratio), but there is a lack of field data regarding improving soil sodicity.

Since the use of coal ash in agriculture is negligible, there is no well-defined evaluation of commercial cost for ash utilized for that purpose compared with conventional soil additives (e.g., lime or gypsum). And at present, the goal is to promote coal ash as a product suited to improving profitability.

The optimal field management of CCP's used in agriculture is a technical aspect that is as yet not well defined. Time frame for market establishment will extend into following decades, as field experiments are expected to proceed for ten years or more. The rate of growth of farmers' acceptance will depend both on plant yields from these experiments and on the associated costs

To sum up, there is an understanding that coal ash can be beneficially incorporated in the soil because of its properties which make it suitable for soil and crop improvement. However, market opportunities for coal ash use in agriculture lie in the industry's ability to solve specific soil problems such as acidity or sodicity. Next step will be to establish market confidence in coal ash, with continuing advocacy of suitable policies and industry commitment over the next 5 to 10 years.

Dr. Vimal Kumar, Centre for Fly Ash Research and Management (C-FARM), New Delhi, India

Fly ash in India has been proven to be beneficial in agriculture applications: a good soil amendment, a source for micro- and macro-nutrients, promoting plant growth etc. From the environmental point of view, it is safe for use as far as both toxicity and radioactivity are concerned. As for 2013, 235 Mt of fly ash was generated in India and it is projected to exceed 325 Mt by 2017 and 1000 Mt by 2031-32. Prior to 1990, considerable effort was made to develop and commercialize technologies for use of fly ash. However, most of the work remained confined within the academy/research world. Less than 3 percent of the ash was being utilized and the rest was being stored in ash ponds through slurry discharge system.

A governmental program called Fly Ash Mission (FAM) was established in 1994 in order to find a solution for the non-utilized coal ash disposal. Over the last 20 years, through promoting coal ash utilization by technology development, infrastructure support and market development, and while **keeping a diversity of uses instead of a single utilization, including agricultural uses**, the image of fly ash has completely been changed from a "Polluting Waste" to "Resource Material", and the utilization has increased to about 130 Mt during 2013.

Laboratory and field research as well as large scale field demonstration projects have shown encouraging results in terms of 10 to 25% increased yield, improvement in water holding capacity, aeration, tillage, control of soil borne pests, crust formation, use efficiency of fertilizers, etc.

FAM included 16 R&D technology demonstration projects at 55 project sites in India during 1994-2004 and 10 field demonstration projects, on various soil types (Alluvial, Laterite and Black Soil) and plants, under fly ash doses of 0 (control) to 650 ton/ha.

Yield increase has been reported for all crops with application of fly ash. The crops include cereals, pulses, oil seeds, cotton, sugarcane, fodder crops, horticultural crops, ornamental and medicinal crops (rice, jute, potato, pea, berseem, arhar, soybean, paddy, wheat, maize, lentil, green gram, groundnut, sunflower, mustard, tomato, cabbage and lemon grass). The reported increase in yield of cereal crops has reached 10-15%, in case of pulses and oil seeds 20-25%, and in vegetables as well as in other crops up to 40%.

It was observed that the addition of fly ash to the soil results in a number of beneficial effects, including (i) improvement in the content of available N, available P_2O_5 and available K_2O, and in the availability of secondary nutrients such as Ca^{2+} and Mg^{2+} and of micronutrients such as Zn, Mn, Cu, and (ii) significant improvement in the physico-chemical properties of the soil (e.g., bulk density, water holding capacity, pH and electrical conductivity).

Concentrations of radionuclides (^{226}Ra, ^{40}K and ^{228}Ac), heavy metals (B, Mo, As) and Se in Indian fly ash and fly ash-amended soils are below the normal range in soils, and the plants grown on fly ash-applied soils are safe for human and animal consumption.

Extensive studies conducted in India have demonstrated that the fly ash could serve as an efficient insecticide and an active carrier for chemical and herbal insecticides used against various kinds of pests infesting different crops including rice, vegetables, oil seeds, fruit plants and store grains. There is also a potential for application of the fly ash as a carrier for insecticides targetting household pests such as cockroaches.

Results of field demonstrations of fly ash application in forest plantations and other experimental settings indicate significant improvement in biometric parameters such as germination rate, height and girth of the tree, as well as a reduction in the mortality rate of the plants in the demonstration plots as compared to those grown on the control (no fly ash) plots, while no adverse effects were observed.

Fly ash has also been successfully used for reclamation of sodic soils, and it can replace gypsum at a much lower cost. It was shown that 1.5% (30 ton/ha) of pond ash can substitute 50% gypsum requirement and about 6% (120 ton/ha) pond ash can replace 100% gypsum requirement.

Robert S. Reimers, Tulane University, Louisiana, USA

The first alkaline treatment of municipal sludge was developed by N-Viro Corporation in the 1980s. According to this technology, fine alkaline materials (cement kiln dust, lime and/or fly ash) are uniformly mixed into a dewatered municipal sewage sludge to raise the pH to 12 for 72 hours and heat the mixture to 52°C for >12 hours as a result of the exothermic reaction between CaO and water which gives $Ca(OH)_2$ and releases heat. The combination of increased pH and temperature assists in pathogen disinfection, as does the formation under such conditions of ammonia which is an excellent biocide and is a product of the alkaline hydrolysis of the amines.

A comparison of heavy metals concentrations in N-Viro Soils to criteria of different US agencies shows that heavy metals concentrations in the N-Viro Soil are within the range of the different criteria and in most cases meet all standards.

Among the specific factors that need to be taken into consideration in assessing the N-Viro product are:

1. Optimizing the process of heat/chemical stabilization/disinfection for the specific sludge;
2. Developing a cost effective process to convert municipal wastes, manures and other waste materials to value-added products, such as landfill cover, soil amender, engineering soils, ornamental horticultural fertilizer, and turf grass;
3. Evaluating value-added products against comparable commercial products on an economic and risk assessment basis;
4. Developing engineering, economic, and outreach plans to promote the beneficial use products in the marketplace.

Yet, the influence on crop yields and quality and on nutrient value of the N-Viro product has not been fully assessed so far, and will be addressed in the near future.

Dr. Wayne F. Truter, University of Pretoria, South Africa

In South Africa, improper reclamation of surface coal mines and poor agricultural practices, such as unsustainable fertilization during re-vegetation, cause a loss in yield of croplands. Under these conditions of acidic and nutrient deficient soils, farming that produces only marginal yields is practiced in order to meet the demand for increased food production. Use of lime and limestone to raise the soil pH is usually effective, but it is not always economic and it has short lived effect and low efficiency. Also, these materials are non-renewable natural resources and hence their use should be reduced as much as possible.

This study consisted a field trial with soil amendments for the purpose of the reclamation of a cover soil after surface coal mining compare to untreated land. it was demonstrated that a significant increase in biomass production (plant growth) was evident where Class F fly ash had been applied as a soil amendment compared with dolomitic lime-treated soil, SMT – standard mine treatment (use of fertilizer and lime) and untreated control plots, when the fly ash application rate was 50 ton/ha (5 times the lime treatment application rate). The pH of the soil was the most affected parameter. Fly ash also improved the physical properties of the soil (bulk density, hydraulic conductivity, infiltration rate). These beneficial effects were still evident in the 6^{th} year after application.

Dr. Christos Tsadilas, Hellenic Agricultural Organization, Greece

Among the **plants the yield of which increased due to fly ash application are**: alfalfa (*Medicago sativa*), barley (*Hordeum vulgare*), bermuda grass (*Cynodon dactylon*), white clover (*Trifolium repens*), sunflower (*Helianthus sp*.), groundnut (*Arachis hypogaea*), aromatic grasses, i.e. *Cymbopogon martini* and citronella (*Cymbopogon nardus*), *Sesbania cannabina*, *Cajanus cajan*, maize, eggplant, mung bean (*Vignaradiata L.*), ornamental plants and oil seed crops such as *Mentha piperita*. Application rates of fly ash with positive effect on crop yield were 90 ton/ha in soybean, 8% (w/w) to either calcareous or acidic soils in several agronomic crops, 2-4% (w/w) in rice and in Chinese cabbage, 5% in rye grass, and 5.5 to 11 ton/ha in wheat (*Triticum vulgare*). Application of fly ash in agronomic doses improves soil properties and fertility and enhances plant growth and crop yield. Yet, high doses can cause adverse effects and a decrease in yield, as it was reported for *B. vulgaris* at rates 20% (w/w). However, due to the high variability in the nature and composition of fly ash (pH, macro- and micro-nutrients content) and of the soil (pH, texture, fertility), a specific fly ash application rate cannot be universally recommended.

Prof. Yona Chen, Hebrew University of Jerusalem, Israel

Characterization of the physical and chemical properties of coarse-sieved bottom ash (2-8 mm) and their comparison to those of volcanic ash (tuff), which is widely used in many countries, shows that a mixture of this bottom ash and compost (produced from separated cattle manure) with a recommended level of 25 to 40% compost in the mixture, can replace tuff as a growing medium for plants and

vegetables. The reasons for that are the porous structure which improves the roots aeration and high water holding capacity, attributed to the compost, which also increases the P content in the medium solution. Yet, bottom ash is low in nutrients, so in order to achieve optimal plant growth an addition of fertilizer is needed. In experiments in which melon, pepper, cherry tomato, basil, cabbage, lettuce, carnation and croton plant were grown on the coal ash:compost medium, high yields, resembling those usually obtained in other growing media were achieved.

Concentrations of toxic trace elements in the plant tissue of tomatoes, peppers and melons were in the safe range and resembled those found in plants grown on tuff. Same results were obtained for the concentrations of radionuclides and of trace elements in the leachate of the growing medium. In fact, these concentrations even met the WHO standards for heavy metals in drinking water.

Also, mixtures of coal ash:compost were used to re-establish 10-15 old oak trees that needed to be transferred from one area to another due to road constructions. The experiment proved that that trees grown on that mixture re-established very successfully when transferred in about 0.5 m^3 of medium.

Dr. Eli Zaady, Gilat Research Center, Volcani Center, Israel

The conversion of sand dunes areas in southern Israel to farm land involves leveling the surface with heavy equipment, a practice that disturbs the natural stability of biogenic crusts that are created by cyanobacteria on the surface of dunes. As a result, the agricultural land becomes susceptible to wind erosion and sand migration from the nearby dunes to the cultivated land. The crops are thus covered with sand, causing agronomic and economic damage.

Laboratory experiments in which the use of fly ash, which is rich in fine particles, as an agent for the re-stabilization of the sandy surface by enhancing the redevelopment and stabilization of the biogenic crusts, was tested, have proven the feasibility of such a use of fly ash at an optimum application rate of 2%.

In a test in which trays of sand with cyanobacteria and/or fly ash (2%) and trays of unamended sand (control) were exposed to wind, an increase in growth of the biogenic crusts was demonstrated, which in turn contributed to the soil surface stability. Tests in which fly ash (2%) was added to experimental plots in a greenhouse and a sand dune area, were performed. The control treatment displayed lack of stability and a relatively high susceptibility to erosion.

Dr. Pinchas Fine, Volcani Center, Israel

Fly ash (FA) was tested as a soil amendment, either directly or as a component in the N-Viro soil (NVS), a product of sewage sludge, fly ash and lime at an approximately 50:45:5 mixing ratio.

In order to examine the effect of **direct FA addition to the soil** on the soil's physical properties, especially on the swelling and dispersivity of sodic soils, FA (and NVS) was tested using a rain simulator, wind tunnel runs and field experiments. FA addition to the soil at up to 20% (w/w) increased water retention of sand by up to 8 fold, and increased 3 times the sand's resistance to wind

erosion. Also, it inhibited crust formation and improved water infiltration (by up to 2.5 fold) in loessial soil. This, however, increased the soil's susceptibility to wind erosion. A clayey sodic soil loaded in the field with 200 and 800 ton/ha FA showed reduced swelling to such an extent that the soil ceased to crack upon drying, and disking the moist soil formed considerably smaller clumps. While laboratory rain simulations revealed oxyanions leaching, field-grown crops displayed almost no increase of oxyanions uptake even at an application rate of 800 ton/ha FA.

The agronomic aspects of **NVS** application was tested in the laboratory, in greenhouse and in full scale field experiments, with a wide variety of crops including potato, carrot, lettuce, corn, wheat, chickpeas and fodder legumes. The findings revealed that: (i) NVS possesses a fertilizer value as a source for N, P and micro-nutrients that are essential to plant growth and human health; (ii) NVS can potentially reduce soil-borne pathogens in calcareous, light-texture soils through the activation of the toxic gaseous NH_3. So far, successful disinfection of fungi, bacteria and nematodes was demonstrated; (iii) NVS application at 50 Mg/ha (Mg/ha is equivalent to tons/ha), improved seed bed quality and cotton seed establishment, which significantly increased lint yield. In all those aspects the NVS soil was equal or superior to other sludge types, including Class B sludge and sludge compost.

An example for the agronomical value of NVS: in a field trial (Revadim) with 16 treatments in vertisol with corn for fodder, including 2 application rates of 4 manures (including NVS), with and without nitrogen application, the yield (~20 ton/ha) and crop composition (NPK intake as well as other macro- and micro-elements and heavy metals) were very similar in all treatments. However, the farmers' revenue from NVS application is substantially higher than that from the application of composts (either municipal solid waste or sludge), due to the significant difference between the cost of these additives. Another economic advantage of NVS is in reducing sludge treatment costs.

Regarding the environmental aspects of the use of NVS: Firstly, its application to soil is a form of recycling both FA and sewage sludge. Secondly, toxic metals concentrations were measured in various plants: (1) lettuce grown in lysimeters containing three soil types (sand, loam and clay), after 3 repeated applications of NVS during 3 consecutive years at cumulative rates equivalent to 200 and 600 dry tons/ha. The lysimeters leachates were tested as well; (2) Potato tubers on sandy soil amended with 43 ton NVS/ha; (3) Carrots on a sandy Hamra soil amended with 120 ton NVS/ha. No significant differences in uptake by the plants or in leaching of toxic metals was detected as compared with those measured in control treatments. Finally, the emissions to the environment of ammonia and GHGs (greenhouse gasses) resulting from NVS use and production are minute as compared with those resulting from biosolids composting.

To conclude, the use of NVS has a considerable potential since it encompasses within it several advantages to the environment and even more so to the agricultural sector by reducing the need for synthetic fertilizers, improving soil till and directly enhancing profitability, while this use, when performed properly, entails no hazard to the soil, plants or groundwater.

Prof. Rami Keren, Institute of Soil, Water and Environmental Sciences, Volcani Center, Israel

The European landfill directive (2003/33/EC) set criteria and leaching tests for different kinds of wastes, among them coal ash when it is disposed in a landfill. However, the risk to the environment

from that application is quite different from the risk associated with fly ash when it is applied to soil (e.g. as a direct amendment or as a stabilizer of sewage sludge used as an amendment for agricultural soils), because of the different behavior of the ash in any specific environment. The specific environment in which the ash is placed will affect the degree and dynamics of release of pollutants from the ash into the environment. For example, the directive assumes a permanent, direct leaching under fixed conditions which are more stringent than those actually existing in the field. The ash is exposed in the field to an aging process due to exposure to the atmospheric CO_2 which creates with time a water impermeable crust over the ash; the pH is maintained in the soil in the range of 7-8 due to buffering; elements released from the ash undergo adsorption and precipitation in the soil which inhibit the elements' movement to groundwater.

The health risk from using fly ash in agriculture is related to pollution of edible plant parts by toxic elements taken up from the fly ash-soil mixture solution, and to drinking water pollution after those elements reach the groundwater. The risk from eating the crops was assessed by calculating the maximum number of years of fly ash application at an annual rate of 8 tons/acre (equivalent to the actual agronomic rate of spreading), which is needed till the elements' concentrations released from the ash reach the maximum allowed level in drinking water (according to Drinking Water Standard), based on the following stringent assumptions: stabilized sewage sludge spread at a rate of 20 tons per acre (equivalent to 8 tons of coal ash per acre); incorporation depth of the sludge into the soil is 20 cm; the elements released from the ash are immediately and completely available (i.e., no adsorption, precipitation or leaching from the upper 20 cm soil layer); and soil water content is at field capacity. Based on these assumptions and calculation of As, Cd, Pb and Hg concentrations, it is possible to spread fly ash for 13, 18, 34 and 100 years in a clay soil and for 7, 10, 19 and 100 years in loess soil, respectively, before reaching the DWS concentrations. The above calculations demonstrate that there is no reason to suspect pollution of agricultural produce used for human consumption.

Gutavo Haquin, Soreq Nuclear Research Center (SNRC), Israel

The radiation exposure and environmental impact (in terms of radiation exposure) of agricultural use of coal ash has been assessed, relating to external and internal radiation.

The external exposure refers to occupational exposure of workers to gamma radiation from the growing medium which is composed of 60% bottom ash and 40% compost, or from N-Viro soil containing 40% (20 ton/ha) fly ash. Assessment of that exposure was based on the following assumptions: (1) an average activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in coal ash: 200, 250 and 450 Bq/kg, respectively, (2) a continuous exposure during 2000 hrs/y (conservative approach), (3) secular equilibrium of the ^{226}Ra and ^{232}Th decay chains, (4) The activity concentration of ^{222}Rn gas exhaled from the coal ash was assumed negligible because of a dilution in the open air to background ^{222}Rn level. An annual dose of 64 μSv was calculated upon exposure to the growing medium with bottom ash, which is under the limit of 1000 μSv (1 mSv), and 2.2 μSv in case of exposure to N-Viro soil, which is considered a trivial dose by the International Committee of Radiological Protection.

The internal exposure refers to the public exposure to alpha and beta radiation from radionuclides in the food basket containing crops grown on the bottom ash and compost medium (asphodel, pepper,

lettuce, cucumbers, strawberry, tomato, basil, milk) and N-Viro soil (wheat), with consumption of 1 kg/day. The activity concentrations of several crops were compared to that of crops grown on control (no ash). No additional activity concentration of radionuclides of natural origins was found in the crops and milk, and they were below detection limit and below regulatory limit (10 Bq/kg) of the Israel Ministry of Health.

The environmental effect of fly ash in N-Viro soil was evaluated by measuring the radionuclides concentrations in the fly ash leachate (leaching with demineralized water of Israeli fly ash has the highest ^{226}Ra concentration. and the highest uranium concentration). The measured levels for all the relevant radionuclides (^{226}Ra, ^{228}Ra, ^{224}Ra, ^{238}U, ^{232}Th) were lower than the limits of the Israel drinking water regulations.

It can be summarized that the use of coal ash in agriculture does not enhance the radiation exposure and the annual doses of the workers involved and of the general public, and that its contribution to radiation exposure and annual doses are considered negligible and far below the environmental levels.