National Coal Ash Board
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Ministry of National Infrastructures
Ministry of Environment
Ministry of Interior
Israel Electric Company
National Coal Supply Corporation

Environmental conditions for coal ash utilization in agriculture

A discussion of the scientific-professional team attended by international experts
A workshop on the environmental aspects of coal ash utilization
Tel Aviv 16.12.09

Participants (quoted speakers) : Prof. Yona Chen (Chairperson), Dr. Pinchas Fine, Prof. Rami Keren, Dr. Jorge Tarchitzky, Dr. Ariel Metzger, Prof. Uri Mingelgrin, Dr. Yaacov Nathan, Dr. Asher Pardo, Dr. Hans. A. Van der Sloot

Background documents: Discussion platforms
Summaries of workshop's lectures
Presentations of workshop's lectures

Topics for Discussion:

Coal ash contains elements considered essential for plants but at the same time it contains trace elements, including their oxy-anions, which may, after being released from the ash, penetrate the groundwater. These elements, when found above certain concentrations in edible crops, are considered toxic to humans and animals.

An examination of the use of bottom ash mixed with compost as a growth medium for plants demonstrated no environmental hazards or health risks. Accordingly, the Ministry of Health approved this mixture for use as a growth medium for annual food crops, and the Ministry of Environmental Protection approved it for agriculture and gardening.

In recent years, coal fly ash was tested as a soil additive intended for improving the structural properties of agricultural soils; as a stabilizing material together with lime added to wastewater sludge to produce Class A Biosolids (FASB); and as an additive to the soil, being a source of organic matter and nutritional elements needed by plants.

The risk of having soil, agricultural crops or water sources contaminated by toxic elements originating from fly ash, imposes limitations on agricultural uses. These limitations were examined in depth in the deliberations of the National Coal Ash Board's workshop[1] held in December 2009, which focused on the following main topics:

A. Concentrations of trace elements in plants growing on soil amended with fly ash.

B. Leaching of trace elements from fly ash incorporated in various soils.

C. Concentrations of trace elements in plants growing on a bed of bottom ash coarsely sifted and combined with compost.

Summary of the main points raised in the discussion[1] :

Concentrations of trace elements in plants grown on soil amended with fly ash (as an independent additive and as a component of Class A Biosolids).

Dr. Pinchas Fine (Volcani Center for Agricultural Research)

Trace element content (mg/kg) of lettuce grown in pots on a sandy soil with different percentages of fly ash (5%-25%) and on bottom ash was measured and compared with that of lettuce grown on a sandy soil as a control. Measured elements included boron, chromium, vanadium, arsenic, molybdenum, and selenium. The concentrations of all those elements were higher in the presence of fly ash and increased as the percentage of fly ash in the mixture increased. Despite this, it can be stated that there is no significant effect of the ash, since the differences in the concentrations were hardly statistically significant except for boron, which showed a greater variation, and chromium, the concentration of which was weakly dependent on the ash content, yet relatively high. The elements (except for chromium) were found to be in the normal concentrations for the plants and all were below the phytotoxicity level. These concentrations do not arouse concern, even with a 25% fly ash load in the soil.

Field tests conducted in Kibbutz Revadim in 2007 showed a similar pattern. Adding fly ash improved the structure of the clayey soil. This improvement was expressed by less cracking, but in terms of environmental aspects, no contribution of the fly ash to the content of trace elements in the soil could be detected. That is, there were similar concentrations of metals in the soil under the various treatments (control without ash, loads of 200 tons and 800 tons of ash/hectare). In addition, there were also no differences in the concentrations of metals (including boron) in plants (corn, cotton and chickpeas) between the various treatments over three growing seasons, with the exception of chromium and molybdenum, the concentration of which increased with the fly ash content during the first growing season.

Metal uptake (mg/kg) was measured in the foliage of corn grown on different loads of FASB at percentages between 53 and 222 percent of the allowable application rate (according to nitrogen limitations), and raw sludge without fly ash as a control. The only difference found between the treatments were in the concentrations of copper, vanadium, and boron, although the difference was a small one, and these concentrations were lower than those that were measured in the foliage of adult corn in the control treatment in

[1] Minutes of discussion in Appendix 1. Originals in Hebrew and/or English. Transcript recorded &edited by Dan Shriki.

which only chemical fertilizers were applied, in field tests at Revadim in 2005. Another experiment tested the uptake of metals in wheat foliage and grains grown for fodder. No difference was found between the concentrations in the plants grown on FASB and those in the control treatment. Concentrations of cadmium were minimal and the concentrations of lead in the seeds grown on FASB (100 cubic meters per hectare) were even below the detection limit. No distinct contribution of the ash to metal concentrations in the crops was found in either of the above experiments.

Dr. Yaacov Nathan (Geological Survey of Israel)

Application of sewage sludge adds a large amount of dissolved organic matter to the soil. As a result, the trace elements uptake by plants is reduced because the organic material and the plants "compete" for the trace elements in order to create a metallic complex between the non-metallic ions and the metallic ions (chelation).

Dr. H. A. van der Sloot (ECN, The Netherlands)

The presence of organic matter in the soil reduces the availability of metals and therefore decreases the metals uptake by the plants.

Trace elements leaching from fly ash incorporated in the soil (by itself and as an ingredient of FASB)

Prof. Rami Keren (Volcani Center for Agricultural Research)

Assessing the release of trace elements from coal fly ash into the soil may be accomplished with the aid of a formula proposed for calculating the amount of boron (as well as vanadium and selenium using other formulae). These elements can serve as a standard reference for all the elements, since their leachability is high as compared to other trace elements (above 10 percent of their content in the ash), when boron is the most leachable. The above assessment was accomplished by calculating the amount of boron in the fly ash that absorbed in the soil (on the clay surface), and from this calculating the amount of boron available in the soil solution that will reach the groundwater and be absorbed by the plants. In this way, it is possible to estimate the maximum amount of fly ash that can be added to the soil. This depends on the soil type, the mobility of boron, the system's pH, clay concentration and the content of water in the soil. A calculation done for fly ash applied at the rate of 780 tons/hectare of soil (a very high load), indicated that 32 percent of the boron leached from the ash was available to reach the soil solution.

Dr. Pinchas Fine (Volcani Center for Agricultural Research)

The content of trace elements was measured in the leachates (mg/l) of the growth medium of lettuce grown in pots on sandy soil with varying loads of fly ash (5%-25%), as well as on bottom ash; these were compared to sandy soil as the growth medium, which served as a control. If we take, for example, concentrations of chromium and boron (which are very soluble) in the leachate, we see that in pots containing the maximum (25%) fly ash, the concentrations of chromium and boron reach a maximal value of 10 mg/l and 20 mg/l, respectively. The boron concentration reached even a higher level, 30 mg/l, but at a lower load of fly ash (15%).

Concentrations of trace elements (μg/l) were measured in the drainage water of a mixture of sand and fly ash with the rates of fly ash ranging from between 8 to 15 percent. The drainage water was obtained after three rainstorms (in a laboratory rain simulator apparatus). Most trace elements met the drinking water standard, except for boron, nickel, lead, selenium and chromium. However, these concentrations were also close to the standard, except for chromium.

Concentrations of elements (mg/l) were also measured in the leachate of FASB with a S/L ratio of 1 to 10. The concentrations in all FASB treatments (as a component in a mixture with sand) and the control (raw sludge without ash) were similar and below the permissible threshold of wastewater used in irrigation. This held true for the elements: copper, boron, vanadium. The concentrations of the other elements were below the detection limit. The sludge has a diluting effect since it adds an organic matrix to the soil, which binds metals to it.

The loads used in these tests are well above those used in any agricultural application, and the risk to the environment or crops may be thus easily reduced. Furthermore, it should be remembered that the composition of the fly ash does not differ very much from that of the soil (clay), so by adding reasonable amounts of ash there should be no significant changes in the soil's quality.

Concentrations of trace elements in plants grown on a coarsely sifted bottom ash mixed with compost

Prof. Yona Chen (The Hebrew university, Faculty of Agriculture)

We have many metal concentration measurements made on leachates from bottom ash mixed with compost, and on plants that were grown on this growth medium, compared to leachates from tuff. The concentrations in the leachate (L/S ratio 5 to 1) meet drinking water standard, and the concentrations of radionuclides in the plants are within the allowable limit, so there is no cause for concern. This conclusion is reinforced by the approval given by the Israel Ministry of Health's Food Service for the use of this material as a growth medium for edible annual plants.

Recommendations, on the basis of which regulations can be formulated:

- Prof. R. Keren-

  Proposes to examine the possibility of setting a standard that will define the permissible amount of fly ash applied to soils, based on the sensitivity of the crop, the soil, and the groundwater.

- Prof. U. Mingelgrin-

  1. Recommends adopting Keren's formula for determining the permissible rate of adding fly ash to soil. Adding the determined quantities will present no risk of groundwater contamination by boron, but the sensitivity of plants to boron must be taken into consideration.
  2. In determining the maximum load of fly ash permissible, the ash's cumulative effect over time must be taken into consideration, and the recommendations should establish a total permitted load for 50 years of application.
  3. Recommends considering a long term observation in permanent plots to provide an indication of slow processes evolving over time that are not discernable at present.

- Dr. P. Fine-

  1. We must relate to the mixture of fly ash in the soil and calculate the risk arising from the leachate accordingly, not the leachate of fly ash itself, which does not truthfully represent the soil's conditions.
  2. Mixing the ash with the soil raises the pH (of the leachate). The pH reverts back to its normal level within 30-60 days. This must be taken into consideration in determining the terms of a regulation.
  3. Coal fly ash adds significant amounts of trace elements to the soil. Nevertheless, it is possible to control and reduce the impact of the unwanted elements by:
     1. Taking into consideration the soil type; 2. Rate of application; 3. Fertilization regime; 4. pH levels retained in the soil.

- Dr. H. A. Van der Sloot-

1. We must consider not only boron but also all the relevant oxy-anions (molybdenum, selenium, antimony) that may be leached.
2. Predicting the future by using the appropriate prediction model can provide the regulator with sufficient security for using fly ash (and FASB) in long-term agricultural applications.
3. To assess the degree of risk from FASB, we must relate to the amount of organic material and its degree of mobility, since it reduces the availability of metals.

Summary – The findings support the following determinations:

1. There are no significant effects of fly ash application on the concentrations of metals in plants and soil:

A. The similar metal concentrations measured in plants grown on various loads of fly ash indicate no significant effects of the ash, except for boron, in which case the impact of the addition of ash is greater, and chromium, the concentration of which remained stable, but relatively high. Elements (except for chromium) are in normal concentrations in the plants and are below the phytotoxicity level in all treatments.

B. Similar results were obtained from pot and field tests. No contribution from fly ash to trace elements content in the soil was identified. No significant differences were found in the concentrations of metals (including boron) in plants (corn, cotton, and chickpeas) between treatments with different ash loads.

C. Similar concentrations of metals were found in plants grown on different loads of FASB and on control plants grown on sludge with no fly ash added. This holds true even for FASB containing a maximal load twice as great as that allowed for agricultural application, The content of some metals was even below the detection limit (e.g., lead).

2. There is no significant contribution of fly ash addition to the soil at the recommended rates on trace elements content in the leachate (i.e., no significant potential risk to groundwater):

A. Maximum concentrations of most trace elements in drainage water of mixtures of dune sand and fly ash at loads of 8 to 15 percent ash, satisfied the drinking water standard, except for boron, nickel, lead, selenium and chromium. The concentrations of these metals, except for chromium, were all rather close to the standard.

B. Concentration of the elements in leachates from FASB, were similar to those from the control, ash-free biosolids. These concentrations were all below the threshold concentrations allowed in wastewater used for irrigation. As a matter of fact only the concentrations of copper, boron, and vanadium were quantifiable. The concentrations of all other elements were below the detection limit.

3. There is no significant risk in using bottom ash as a growth medium for plants:

A. The concentrations of trace elements in the leachates of the tested media were below the drinking water standards.

B. Concentrations of trace elements (including radionuclides) were below the permissible level for foodstuff.

Conclusions

Although addition of coal ash may bring about an increase in the concentration of trace elements in the soil and drainage water, this increase does not pose either a risk of accumulation in plants grown on the ash-amended soil or a risk of groundwater contamination, certainly not when application rates are in the range reasonably expected in agricultural fields.

Appendix 1.

Excerpts from the Minutes of the session on Ash in Agriculture

* Text in brackets is for transcript clarification purposes.

Y. Chen (Chairperson): The discussion will address three components: fly ash, fly ash mixed with organic matter as a stabilizer, and bottom ash. Regarding soil contamination, heavy metals and radionuclides must be taken into consideration. As for water – refer to both water on the surface and groundwater.

R. Keren: There are two aspects to fly ash utilization in agriculture: the first is the pollution of groundwater and soil, the second is the indirect influence of fly ash on plants and the toxicity they carry with them, especially boron, one of the most important oxy-anions in the system. Unfortunately, many plants are sensitive to boron's concentrations in the soil solution; in some cases, it can cause a significant reduction in yield and even damage to the plant itself. The plants can be sorted according to their sensitivity to boron. Boron is also an essential element for the normal growth of plants. Its concentration in soil solution ranges from 0.1 ppm to 5-6 ppm, which is also the concentration of boron in seawater. The main species of boron in the solution are pH dependent. At a pH below 9.3 more than 50% of the element appear in the form of boric acid, at above pH 9.3 the main species is a borate ion with a dominant negative charge. Its chemical affinity is higher than boric acid since it is more difficult to disconnect the attached borate anions from the surfaces of clay particles. Knowing this mechanism makes it possible to create a formula that connects between these species and the pH in the solution, and the amount of boron absorbed onto the clay surface. Knowing the amount of boron in the soil makes it possible to calculate the boron species in the solution. The present case refers to calculating the amount of boron in the fly ash that gets adsorbed in the soil, and from this, it is possible to calculate the amount of boron available to the groundwater and for intake by the plants. The proposed method makes it possible to estimate the maximum quantity of fly ash that can be added to the soil, and this is dependent on the soil type, the availability of boron or the leaching thereof from the ash, the system's pH, clay concentration, and the amount of water in the soil.

Mixing of fly ash in soil at a rate of 20% on soil weight basis at an area of a quarter of an acre at 30 cm deep may contribute significantly to the boron (B) concentration in soil solution. This contribution can be evaluated using the the Keren's equations as follows:

The amount of fly ash in the soil of an area of one tenth of an hectare is:

$Q_{FA} = 0.3\ m \times 10^3\ m^3 \times 1.3\ ton\ m^{-3} \times 0.2 = 78\ ton$

The soil amount in this layer is:

M_S = 390 ton – 78 ton = 312 ton

The total amount of boron (QB) released from fly ash (FA) to solution in batch experiment

QB = 0.665 mg B / 3.5 g FA = 0.19 mg B/g FA

QB = 17×10^{-6} mol B/g FA

QB = 17×10^{-6} mol B/g FA × 78×10^{6} g FA = 1326 mol B

The total amount of boron released from fly ash in the soil layer:

Q_{BT} = 1326 mol B / 312×10^{6} g = 4.25×10^{-6} mol B/g soil

The adsorbed boron (Q_{AB}) by the soil can be calculated using Keren's equation (see appendix 2):

$$Q_{AB} = T\{1 + \frac{PR}{F(Q_T - Q_B)}[1 + K_{OH}(OH)]\}^{-1}$$

$$P = 1 + K_h \times 10^{14} \times (OH)$$

$$F = K_{HB} + K_B(P - 1)$$

where:

T = 6.8×10^{-6} mol/g soil

R = 0.48×10^{-3} L/g soil

Q_{AB} = 2.98×10^{-6} mol B/g soil = 3.22×10^{-5} g B/g soil

The total amount of adsorbed boron in the upper 30 cm layer (QBL) is:

QBL = 3.22×10^{-5} g B/g soil × 312×10^{6} g soil = 10.046×10^{3} g B

The total amount of leachable boron from fly ash in the added fly ash layer is:

78×10^{3} kg FA × 0.665 g B / 3.5 kg FA = 14.82×10^{3} g B

The fraction of the leachable boron from fly ash in soil solution (upper 30 cm layer) is:

(14.82×10^{3} g B – 10.046×10^{3} g B) / 14.82×10^{3} g B= 0.32

Thus, for this particular soil, 32% of the boron leached from the fly ash is available for uptake by plants.

By knowing the soil moisture it is possible to convert this value to a concentration and to compare it to the plant's tolerance value to boron. E.g., for citrus fruit that are very sensitive it is possible that the value will be too high; in such a case, a decision can be made to reduce the amount of fly ash added to the soil. This provides us with quite a good tool to evaluate or predict the toxicity level of boron in the soil due to the fly ash application. All of these calculations were made assuming that all the root system is in the 30 cm mix layer and it is entirely homogeneous, and so forth. If the ash is incorporated to a greater soil depth, then naturally the amount of boron leached from the ash and the amount that will be available to the plants will be different.

P. Fine: Presents the effect of alkaline fly ash and fly ash stabilized biosolids (FASB), on metals in soils and crops, and the environmental aspects of their application in the context of the leaching of macro- and microelements and heavy metals. Data was obtained from an experiment in which fly ash was added to potted plants and to field plots, and in which FASB were also added to potted plants and field plots. In the experiment with potted plants, lettuce was grown on a mixture of sand with fly ash whose part in the mixture was from 5 to 25% as fresh or stabilized ash, or (100%) bottom ash. We withdrew leachates on a weekly basis. The plants in the various treatments grew well and no differences were found between the treatments. The oxy-anions content in the lettuce leaves was measured. We found that the boron concentration increased with an increase in the amount of ash in the mixture. Chromium content was quite stable, and vanadium also remained fairly similar between treatments. Regarding arsenic and molybdenum, we found that the increase in concentration was affected (by an increase in the ash percentage). Selenium was not affected, but most of the metals were. Still, the concentrations were not that high, and even in a medium containing 25 percent ash the concentrations were not alarming. Most metals, at least boron, were leached out of the system.

I would like to relate to the pH in the leachates. The reduction to a normal value occurs within a short time (between 30-60 days). Keep this in mind when determining regulations.

The chromium concentrations in the leachates (μg/l) also showed that not everything went into the plants, and some or most of the heavy metals and trace elements were leached. Concentrations were higher in the leachates of the treatments in which plants were grown than those of the treatments lacking plants, because the amount of the leachate in the treatments with plants was smaller due to consumption by the plant.

The results for boron were similar. Concentrations in the leachate from the mixture with lettuce plants containing 15-20 percent fly ash were between 30 and 15 mg/liter, respectively. Concentrations were lower without lettuce because there was more water. We received approximately the same concentrations with bottom ash (as in mixtures with plants containing 15 percent fly ash and 25 percent fly ash without plants) because bottom ash releases boron.

On a quantitative basis there is no difference in trace elements concentrations in the leachate between mixtures with plants and without plants; they both depend on the fly ash load in the sand.

Regarding concentrations of boron in the leachates (mg/l) as a function of the leachate's pH, when the pH is higher, less boron is leached. Plants may increase pH reduction and the leaching of boric acid out from the system, which means that plants affect the leaching by changing the matrix's pH.

Regarding field tests for soil improvement, we could not recognize the contribution of fly ash to the trace elements in the soil just by measuring them (mg/kg) in the soil, especially since some of the elements are soluble and undergo leaching, and other are in the same range of concentrations as in the soil itself. Except for chromium and molybdenum, other metals were not taken up in excess by the corn plants (cobs and canopy). No differences were found in the concentrations of elements in plants from the different treatments of the unamended control soil (without ash), with 200 and 800 tons of fly ash per hectare (1 hectare = 10 dunam, the local area measurement unit). We did not find any difference in the boron or other metals in corn, cotton, and chickpeas (among the different treatments spreading over three growing seasons), except for chromium and molybdenum in the first year, despite the fact that ash loads in the treatments were very excessive.

Concerning sludge experiments – we prepared mixtures of sand soil with lime-stabilized sludge, and lime with fly ash stabilized sludge (FASB) with different percentages. These were compared with unamended control sludge mixed with sand. FASB loads ranged from 53 percent to more than twice (222%) of the amount allowed by Israeli regulations. We tested the uptake of metals (mg/kg) in corn canopy grown on these mixtures (in various treatments). We only found small differences between treatments in copper, boron, and vanadium. Copper concentrations in all treatments were below the concentration levels measured in the Revadim field tests, boron was roughly the same, and vanadium was lower. We also performed extraction at a ratio of 1 to 10, and found no significant variation among the different treatments in copper, boron and vanadium concentrations. We are on the safe side.

In another field test, we tested wheat grown on various lime-stabilized sludge and FASB. Chromium concentrations (mg/kg) in the wheat seeds and canopy did not show variation among the various treatments. Cadmium concentrations in the seeds were minute, lead concentrations were below the detection limit and were the same for the canopy in all the treatments.

In another set of experiments we added Class B sewage sludge at different loads based on the nitrogen content allowed by the permissible limits set forth by regulations: 50 kg/hectare, 500 kg/hectare and 5000 kg/hectare, which is 10 times the maximum amount allowed for application. The sludges were mixed with three types of soils: sand, loess, and vertisol (clayey soil), and corn was grown on them. Regarding chromium, there was no difference in concentration between the different loads and the soil type had no influence. Molybdenum had a number of higher concentrations in the mixtures containing sand and in the load 10 times greater than permitted, but these concentrations are not alarming. For boron – the concentrations in the regular load of 500 kg sludge per hectare were similar to the values in the control treatment that contained no sludge. Effects were evident only with the load that was 10 times greater than permitted, and even so only for boron. This is the general picture, as opposed to Van der Sloot's position regarding the notion that adding sludge and fly ash may increase the concentrations of metals, possibly in leachates and possibly in uptake by plants. The tests were performed without leaching, so we are certain that the metals present were available, unless they were bound to solids. I.e., there is an attenuation effect of the sludge. Adding sludge adds a matrix that binds metals to it, not only contributes metals to the system. Similar behavior was evident in the mixture containing sand, loess, and vertisol, and this means that if there was a difference, it was caused by the sludge component.

To summarize, coal fly ash and fly ash added as stabilizer to solid (FASB) add significant amounts of oxy-anions, heavy metals, and dissolved salts. Nevertheless, one can control and attenuate the effect of the undesirable elements by: (1) Selecting the soil type, even though it has been shown that the soil types added showed no differences; (2) The rate of application - again, we did not see any difference between the application rate of 500 kg per hectare and application rates of up to 10 times higher than permitted, except in the case of boron; (3) A fertigation regime; (4) pH levels in the soil were maintained by the plants which served as a buffer for the system by respiration that caused carbonization of the excess hydroxide by reacting with the CO_2.

In summary, the permissible loads are not in agronomical rates. As I have shown, risks to the environment or the food chain caused by fly ash or FASB, may be easily attenuated. This, by way of "maturing" the ash and its interaction within the soil, and the benefits far outweigh the risks.

Y. Chen: a brief review of bottom ash, focusing on heavy metals and the radionuclides: In all cases (leachate metals concentrations in mg/l in various treatments, 1 to 5 leaching ratio of S/L) values lower than the drinking water standard were obtained, so there is no cause for concern. We also performed many tests with potted plant leachates, and even though the dissolved organic matter always moves within the system during the plant growth, the values for all the elements remain below the drinking water standard. We have a great deal of information on the concentrations of trace elements in fruits and vegetables, and in no case do they exceed the permitted concentration. So we feel very confident about this subject.

The following information relates to concentrations of elements (mg/l) in wine (in a vineyard growing on a bed of bottom ash), and boron was the only element with a slightly higher value. Boron is one of the elements with plant barrier, rather than human health. Whenever a plant dies before any damage is caused to a person, as farmers, we feel on the safe side. The plant will provide an indication of excessive boron. Humans are actually very tolerant to boron. So anybody drinking wine from such a source should have nothing to fear. We see no problems with the elements concentrations that were measured in the wine.

We conducted tests of radionuclides (Bq/kg) in fruits, vegetables, leaves, etc.; these were performed by the Soreq Nuclear Research Center. We did not find any problems and the levels that were measured did not raise any cause for concern. We feel quite confident.

Similar trace element levels were found in peppers grown on a bed of bottom ash and compost and a bed of tuff with compost. These materials are used throughout the world, and coal ash is no worse; in fact, it is sometimes even better. Trace elements were also examined in melons with two types of bedding and the same levels were found in both. The same is true for tomatoes we tested. All in all, they do meet the health standards. In fact, we have authorization from the Ministry of Health to use this material without any fear of health risks. Therefore, I see no reason for concern over health issues in using bottom ash for growing fruits and vegetables.

J. Tarchitzky: I am concerned about the differences between the findings of fly ash tested in infrastructure applications and those of agricultural applications. The same properties that are beneficial in the former prove to be detrimental in agricultural use. In some lectures, we heard that over time, this material becomes an impermeable layer, its hydraulic conductivity and water infiltration rate decrease, and the material eventually turns into stone and becomes a monolith. On the other hand, it was also stated that it is a good material for stabilizing the structure and reducing surface run-off. This gap must be clarified. In the proposal (for environmental conditions), there is a uniform limitation for applications, based on Rami Keren's calculations for boron. When moving from research to actual implementation we must understand that if the farmer thinks that the material is good, he will put it in the soil on a yearly basis. We must become well acquainted with the boundary line from coal ash behaving in infrastructure to its behaving like that but in agricultural plots, and understand the significance of the latter becoming impermeable. That is why I think we should include the parameter of frequency in the equation. Another thing, if we begin to use fly ash on a more massive basis, I think we should establish some kind of monitoring plan for specific sections, in order to detect any negative effects, before they occur.

P. Fine: We must be cautious in everything we do, especially when using fly ash, which as we have seen contains materials like boron, an element that not all plants like to have at high concentrations, as well as trace elements. However, we must apply what we have learned so far. One important finding is that on the site we have worked on (now in its the sixth year), after an application of 200 and 800 tons of fly ash per hectare, with the exclusion of the first year in which we saw a certain accumulation of chromium and molybdenum in the 800 ton application, we have not seen any of it. We must remember that only approximately 12 percent of the soils in Israel are above an active aquifer, so that the situation in Israel is very different from that in the Netherlands. Boron may pose a threat to certain plants, but if it undergoes leaching, there is no risk to human health. In conclusion, we have a long-term field experiment and we should continue with it. We applied huge amounts of fly ash in the field test; quantities no farmer would normally use. There is a large difference between infrastructures and agriculture, in the matter of application rate. If one cannot demonstrate that the material has a positive effect on the crop or soil, farmers will not pay money for it. So we are far from that point that farmers will use the material in their fields; surely not every year. Therefore, we are on the safe side concerning the use of fly ash in agriculture, and far from using it massively.

R. Keren: Using fly ash in agriculture is a completely different story from using it in infrastructures. It is not a question of rate of application; it is a question of form. Infrastructure means dealing with the bulk of fly ash that interacts with the soil on the surface only. Because of this fact, the interaction between ash particles in the bulk is completely different than the interaction between the ash and soil. If a large amount of fly ash is applied to a field, then the amount is to be considered, not the concentration, and vice versa. Therefore, the pair should go along together, and perhaps a standard should be established to determine how much ash may be applied, or a threshold criterion can be defined for allowable quantities, based on the sensitivity of the crop, or the soil, or the groundwater.

Y. Chen: asks those present to address the following issues: boron leaching to the groundwater, soil pH, and dust created while applying fly ash to the field.

A. Metzger: Fly ash is not applied itself to the soil. It is mixed with an alkaline material- with lime, and with sewage sludge. Shafdan's commercial application is composed of this combination of stabilized sewage sludge with fly ash. I think it is still relatively moist. It may certainly create dust if it is too dry, but I believe it is a controlled process. We are not referring to uncontrolled applications.

P. Fine: As I have previously shown, the composition of fly ash does not differ very much from that of the soil itself, depending on the type of soil. Here, we are referring to clayey soil. Certain elements are found in excess quantities (in the ash), and others are at lower quantities than in the soil. So we will not change much by adding reasonable quantities of fly ash. Defining a "reasonable quantity" may be left for another discussion. However, changes in the composition in response to pH should be limited. If you mix 25 percent fly ash with pure sand, the pH will certainly increase significantly, and it will take much longer for it to decrease to normal. This is the situation we must address in the soil system or in the agricultural system, rather than the situation of fly ash leaching, since that does not represent what actually happens in the soil.

U. Mingelgrin: Regarding boron content in the groundwater, if we adopt Keren's formula as a recommendation for applying fly ash, which I think is a good idea, then, in my opinion, the bottleneck will be plants sensitivity. In other words, if we add these amounts, I do not think there is a risk of groundwater contamination from boron. Regarding dust, I agree that if the use of fly ash in agriculture becomes common, dust may be a problem. However, powdery materials are not uncommon. If fly ash is used routinely in agriculture, all the same precautions used with other powdery materials must be taken, from wetting the material and unloading it carefully, to possibly wearing masks while it is being spread. Regarding what Jorge Tarchitzky said about maximum loads over time - despite his being completely wrong in comparing pure fly ash used in road infrastructure to its mixing with agricultural soil, he is quite right that we must consider the maximum load of fly ash over time, and we should relate in our recommendations to an overall amount over 50 years.

Y. Nathan: In any case, when you add fly ash to soil, it must never be on the surface, but rather incorporate it inside and cover it with soil to prevent it from drying out and becoming a nuisance dust.

R. Keren: Leaving the ash on the surface will not accomplish the goal (for which the ash was added to the soil). It must be incorporated in the soil.

D. Weinberg: I think we are still very far from setting standards about what is permitted and what is not permitted. Most of the energy should be devoted to testing or assessing health risks and environmental effects of the proposed system. This should be the first step, before starting to determine how many tons (ash) per hectare may be added.

R. Keren: David, You would be right, if we were dealing with a new material about which we have no information, and if we did not have any background information about the elements available in fly ash. However, we are not at all at that stage. We have a great deal of information about how the various elements behave in the soil, and the function of pH. We also possess much information on the ash itself.

D. Weinberg: From what I have heard until now, I believe that it would be quite irresponsible to begin applying the ash without testing and acquiring further experience and an understanding of how this will affect the environment and health.

R. Keren: You are ignoring the fly ash and instead are focusing on the fact that we are adding boron, chromium III and chromium VI, and the other ash constituents to the system. You are ignoring the fact that all these elements are contained in the ash. We have all kinds of models, stochastic, deterministic, analytical, that explain all this. We have a great deal of information that allows us to predict the behavior of those elements and know the rate of their release from the ash.

H. A. Van der Sloot: Boron is not the only element to consider, but also all the relevant oxy-anions that can be leached. Molybdenum, selenium and antimony are elements that are of relevance. Regarding the comment on the organic matter, it must be understood that the form of its appearance (in the soil) affects the uptake of elements by the plants. The mobility of metals in ash (usually due to pH conditions) will be influenced by adding organic matter, but they will not be taken up by the plants because they are not available, although they can be leached and reach the groundwater. Therefore, in this context, we must find another way to assess what is happening. I think that it is the combination of the amount of organic matter and the degree of its mobility. It is probably not serious, but it is definitely something that must be taken into consideration. In the context of what was said about what happens if we add ash in agriculture year after year, I think this is a question to which we must devote research to find out how we can ultimately do more, also in order to convince the regulator that the proposed application is safe to use. However, there is no way to determine that it will be the same even in another hundred years, because we will not be here for another hundred years. We must build a system that will provide sufficient trust in projecting forward through modelling. I think this is a goal we must set for ourselves, to help us move forward, because such questions will continue to arise in the future.

A. Pardo[2]: regarding what David Weinberg said, there are risk assessments for many things. We can conduct surveys on environmental effects of the ash as well as other types of studies. There is already much material on coal ash. We must review the current situation in Israel and see how it meshes with risk assessment. For example in agriculture – we see many cases where workers did not act in accordance with hygiene and safety measures. We actually know what can happen, but we have no quantitative estimates. For example what Yona Chen says, it may be that dust concentrations that farmers will be exposed to, will be much higher than any standard that will be determined. It will not matter if it is nuisance dust and then it will be at 10 mg/m^3 threshold limit, or if it is not nuisance dust and then will be at 4 or 6 mg/m^3 threshold limit. A treatment will be needed from the moment the concentrations will become much higher. The question is how will we be able to implement this type of treatment in agriculture, both on the level of engineering means and on the level of personal gear? because personal gear is limited. Personal gear provides a protection factor. If we give a farmer a one-time disposable facemask and the concentrations in the air are 50 mg/m^3, then the facemask will not suffice. I would like to see a farmer working with a blower mask or a hood blower and stating whether it is good or bad. Therefore something else needs to be done. We lack of quantitative assessments.

I agree that along with the applications of these things it is necessary to establish a set of measurements that will show: a) where we are standing; b) How does the situation compare with risk assessments of similar things throughout the world. People are doing these things in the world, they have done them before us and are still doing them now; and: c) where do we go from here? The same holds true for the environment.

If we want to do an environmental assessment, it is sufficient to recall the Almog Committee's recommendations regarding environmental standards; it is not likely that we will ever be able to meet them. If we want to decide that these are really the standards, then perhaps we should really decide not to start using coal ash due to its environmental impact. However, that is not precisely the thing to do, because it is simply not clear what the risk assessment is. Nor is the state of things in the field obvious and unambiguous.

Incidentally, when we do see clouds, it means that we can see the particles; when we see particles, it means that the particles are in a size too large to enter the respiratory system. We do not see the small ones that do enter and we do not know how many are there and how many are not there. It is not just a matter of respiration. It is also a matter of skin. It

[2] Editor's note: The speaker was not aware that fly ash is applied to agricultural fields only after conditioning (moistening).

may be that farmers will have to protect themselves head to toe with a space suit, in order to avoid having tons of dust on their skin and suffering from infections, in their respiratory system and in other places as well.

In my opinion we do not have sufficient quantitative data to evaluate the real problem we are facing in agricultural applications. We have more information of this kind on power stations and other applications. We are even lacking in data on greenhouse applications, and the more so on open field applications. I think that should be our next agenda, to collect quantitative data alongside the actual application.

U. Mingelgrin: There is no need to exaggerate. We should indeed take action to preclude any unreasonable risks. However, there is really no need to start talking about space suits and all that. I have yet to meet an Israeli farmer who does not shower every day when returning from work. Therefore, there is no need to exaggerate. A little coal ash on the skin for three hours will not kill anyone. It is not spread every day; it is spread in the fields, if at all, once every four years. I suggest we get back to reality.

A. Pardo: This is exactly the subject of risk assessment, which I say is lacking.

Y. Chen: I would like to comment on dissolved organic matter (DOM). Any model should consider it, even if its concentration is as low as 1 milligram per liter. It is always found in the soil, at tens of milligrams per liter. Any leaching experiments and models have to take DOM into consideration, because it is normally present, and the more so when the ash is mixed with sewage sludge. A second comment – it is well known that in applications containing great quantities of DOM or sewage sludge combined with coal ash, the uptake of elements by plants will be reduced, due to competition on chelation (creating chelate, which is a compound of metallic and non-metallic ions) between the organic matter, the metals and the plants.

R. Keren: To summarize the discussion, we first have to accumulate sufficient information on the material under discussion, and to then formulating standards and regulations based on that information. In time, more information will be obtained, and we will be able to make corrections accordingly.

Appendix 2. Keren's Formula

Knowing the soil adsorption coefficients for boron, which take into account all soil components, knowing the maximum amount of boron that may undergo aqueous leaching from coal ash mixed with a given layer of soil and soil's moisture content, we can estimate the amount of boron adsorbed in the soil layer mixed with coal ash using the following formula:

$$Q_B = T\{1 + \frac{PR}{F(Q_T - Q_B)}[1 + K_{OH}(OH)]\}^{-1}$$

Where:

$$P = 1 + K_h \times 10^{14} \times (OH)$$

Where K_h is the hydrolysis constant for the reaction

$$B(OH)_3 + 2H_20 \Leftrightarrow B(OH)_4^- + H_3O^+$$

$$F = K_{HB} + K_B(P - 1)$$

R is moisture content (L/g of soil),

T is the maximal amount of boron adsorbed per unit weight of adsorber (mol per gram soil),

K_B is the affinity constant of the adsorber to the boron species $B(OH)_4^-$,

K_{HB} is the affinity constant of the adsorber to the boron species $B(OH)_3$,

K_{OH} is the affinity constant of the adsorber to the species OH^-.