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Research

Keywords: byproducts recycling, cost-benefit analysis, fly ash, stabilized sludge

Posted Date: July 20th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-42018/v1

Version of Record: A version of this preprint was published at International Journal of Coal Science & Technology on May 31st, 2021. See the published version at https://doi.org/10.1007/s40789-021-00439-z.

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Acknowledgements

This work was funded by the Israel National Coal Ash Board (INCAB) grant 39477#. The authors wish to express their deep gratitude to the late Mr. Omri Lulav, Head of the INCAB.

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Abstract A tool for calculating the economic and environmental impacts of the use of byproducts of industrial processes that can substitute for perishable resources is presented. This is exemplified by fly ash (the fine fraction of ash originating from coal burned to generate electricity and collected by filtering exhaust gases leaving the furnace), added to soil as a component of sewage sludge stabilized with fly ash and lime (NVS). Application to soil of NVS has potential agricultural and environmental advantages and disadvantages. The costs and benefits of such application were calculated using both a database and expert opinions. The calculations assumed a representative assemblage of soils and crops, with weights assigned to each crop type and soil characteristic. The annual weighted benefits (additional income for the farmer) and costs per hectare reached 324 $/He and 131 $/He respectively. Major potential benefits include: Chemical fertilizer replacement, 159 $/He; Improvement to the soil's physical properties, 75 $/He; Supply of vital trace elements, 33 $/He. Major potential costs are: Regulatory limitations on marketing of crops pending proof of absence of risk of heavy metals or radionuclides accumulation in these crops, (17 $/He and 36 $/He respectively); Application and incorporation cost, 50 $/He. The presented estimates of the costs and benefits refer to a hypothetical “representative soil” depicting a typical Israeli soil. It is possible to maximize potential benefits by applying fly ash only to the most suitable agricultural soils while improper use of fly ash will increase the costs incurred from its use.

Key words: byproducts recycling, cost-benefit analysis, fly ash, stabilized sludge

1. Introduction

Fly ash is a byproduct of burning coal to generate electricity and it is used primarily as a component in building and infrastructure materials but a relatively small quantity is used in agriculture. In the present study we shall calculate the costs and benefits of fly ash use in agriculture with the aim of demonstrating the considerable potential benefit of such use. Fly ash is primarily applied to soil admixed in sewage sludge pasteurized with lime and the ash. Upon the dissolution of the lime (about 10% of the sludge weight), the sludge heats up (>70° C), the pH rises (>12) and the fly ash (sludge to ash ratio of 1:1) fluidizes the sludge, enabling close contact between the sludge and the lime.

Application of sludge stabilized with lime and fly ash (N-Viro Soil©; NVS) to agricultural soils, substitutes for fertilizer inputs (Fine et al. 2014), improves the structure of problematic soils (Korcak 1995; Fine and Mingelgrin 2018) and reduces the infectiousness of plant pathogens in sandy soils (Gips 2008; Fine and Mingelgrin, 2018). Accordingly, Tsadilas and coworkers (2014; 2018), reported that application to an agricultural soil of a mixture of coal fly ash and municipal sewage sludge at appropriate rates increased substantially wheat grain and biomass yield and improved soil quality. Pasteurization of sewage sludge using lime and fly ash is a simple process, which is also applicable to sludge of primary sewage treatment (Logan and Burnham 1994). In contrast, composting requires the early, expensive anaerobic digestion aimed to reduce volatile components. In practice, the agricultural value of NVS increases as the level of preliminary treatment of the sludge is reduced (Fine 2015). The main disadvantages in using NVS as compared to other soil additives rich in organic matter, are the fact that the sludge component in the NVS comprises only 50% of the final product (up to 15% of the dry matter) and the fact that the final product's volume is greater than that of the raw sewage while its density drops considerably. However, one outstanding advantage of NVS for the farmer is that its cost is borne by the urban sector (which on its part, benefits from a relatively low cost of sludge removal), and currently, the direct cost to the farmer in Israel is mainly the cost of NVS incorporation into the soil.

The use of fly ash offers considerable environmental benefits. As a constituent of the NVS, the contributions of fly ash to the environment include: Reduction in the release of ammonia and other greenhouse gases which occurs during sludge composting or the manufacture of chemical fertilizers; Replacement of non-renewable resources (including fossil fuels used to manufacture commercial fertilizers or mined phosphorous-containing minerals). Finally, fly ash applied to soils can reduce the application of pest-controlling chemicals and its use conform to the recycling (or zero-waste) principle.

2. Methodology – the economic calculations

A number of investigations employed the LCA (life cycle analysis) methodology to reach a quantitative estimate of the effects of the use of fly ash (e.g., Epstein et al. 2011; Hong et al. 2013). These studies concentrated generally on the benefits accruing from that use rather than on an overall economic balance which encompasses both costs and benefits, including the value of environmental effects. Likewise, the IPCC (Intergovernmental Panel on Climate Change) reported an estimate on the damage due to greenhouse gasses for the years 2005-2006 (IPCC, 2006), with the environmental costs (rather than the cost/benefit balance) evaluated by an LCA-type methodology.

The methodology presented in this study for estimating the cost and benefit to farmers of the use of coal ash, is based on itemizing the benefits and costs and assigning a value to each item in nominal terms. Thus, it is possible to sum up the cost or the benefits and compare the total cost to the total benefit. This methodology is a tool for calculating the economic and environmental impacts of the use of a byproduct of any industrial process that can substitute for non-renewable resources.
The price of fly ash is based on its value to the specific consumer (e.g., industry, construction, road infrastructures or agriculture) and that includes expenses such as transportation and application costs as well as its scarcity (shadow) price. Presently, demand for fly ash in Israel exceeds its supply, which is expected to drop further due to the planned reduction in the future use of coal for electricity generation.
The possible environmental effects (benefits and damages) of using fly ash must also be given their appropriate weight in determining the true price of fly ash. Estimating the environmental costs and benefits is linked primarily to a market failure arising from the fact that environmental effects which are difficult to estimate, are not taken into account in determining the market price. Environmental costs and benefits when applying fly ash (as NVS) to agricultural fields are presented in this study in terms of quantified revenues and annual costs per hectare. It may be possible to improve the precision of the estimates by including additional advantages and disadvantages of NVS application (if such can be defined) and by refining the methodology needed to calculate the economic value of each.

The data used in the cost–benefit calculations of the, including the estimated effects of field application of fly ash embedded in NVS on the environment, was extracted from relevant research work performed in Israel (e.g., Fine 2018; Shargil et al. 2015; Teutsch 2018) and around the world (e.g., Logan and Burnham 1994; Korcak 1995; Veeresh et al. 2003; Manoharan et al. 2010) and from interviews with agronomists, both at the Israeli Ministry of Agriculture and in the private sector, whose assessments were translated into monetary terms. One primary, obvious benefit arising from the application of NVS is the increase in yield, but we have tried to break down and estimate the value of individual factors contributing to the higher yields (more efficient use of plant nutrients, improvement in soil structure, etc.) and therefore, the higher yield itself is not treated directly as a benefit.

In performing the calculations, the following assumptions were made:

1. Fly ash is applied at the standard NVS application rate adopted in Israel – 50 m^3 of NVS per hectare.
2. Application to any given area is limited to once every five years (even though it is permitted to apply NVS every year).
3. Revenues and costs are calculated per hectare per year. When they are spread over a number of years, they are calculated using standard accounting principles, spreading the cost over five years and using 7% capitalization interest (in economic terms, this type of payment spread is defined as PMT). The rate of interest for capitalization was set at 7% as this is the accepted practice for investments in agriculture in Israel.
4. Costs and revenues are converted into U.S. Dollar according to the average prices in 2019.
5. An exposure level was determined for every benefit, damage or risk, namely the fraction of the relevant entity (e.g., total cultivated area or total yield) which it is reasonable to assume will generate the benefit or will incur a given cost due to the application of the NVS. In the absence of any other information, it was assumed that the exposure level was equal to the ratio between the size of the area to which the benefit or the damage was applicable and the total area available for the application of NVS. When information enabling a more accurate estimate was available (e.g., from the aforementioned recommendations and estimates made by experts), the rate of exposure was determined accordingly.

The following is a brief list of the benefits, the costs and examples of the equations used for their quantification. Also given are the references that served as sources for the quantitative information used in the calculations. These references can be accessed through the Israel National Coal Ash Administration's website at the address: http://www.coal-ash.co.il/tab_publish_plan.html.

3. Benefits from the application of fly ash as a constituent of NVS

3.1. Replacement of chemical fertilizers and soil fertility improvement

NVS contains a higher fraction of organic matter than most soils and its application increases organic matter content in the root zone, the magnitude of the increase being a function of the quantity applied per area and the amount of sludge in the additive. The application of 50 m^3 of NVS per hectare, releases 150 kg of nitrogen, 40 kg of phosphorus and 140 kg of potassium in the first year after application. In the second year after application of the NVS, nitrogen availability is 70 kg/He, phosphorus availability is 40 kg/He and potassium availability is 40 kg/He. Fertilizer prices (per kg of pure element, nominal price) are: Nitrogen 1.95 $/Kg; phosphorus 1.57 $/Kg; and potassium 0.88 $/Kg. Therefore, using a calculation based on the total value accumulated over five years (at 7% interest) and computing the average price per year, the annual savings in fertilizer application is 159 $/He. The exposure coefficient is 1, because the contribution applies to all the areas treated with NVS.

3.2. Higher soil water availability (WI)

The pozzolanic properties of fly ash and hence of NVS as well, may improve the soils' physicochemical properties. This is especially significant in sandy soils in which NVS addition improves the otherwise poor water holding capacity, thus generating higher water availability and soil stabilization against wind erosion. It is assumed that the increase in yield due to the improved water availability in the NVS-treated soil should be similar to the differences in yield between areas in which the rainfall differs in an amount that contributes to the soil's water content a quantity equivalent to the increase in water availability due to NVS application. The effect of NVS application to a sandy soil is to approximately double the water content at field capacity from about 2.5% to about 5% and hence an increase in available water content in the root zone contributed by 6mm rain (Bar-Tal 2008). The contribution made by rainfall to grain yields in areas above the drought line (200 mm/year) per hectare is 10 kg/mm under normal fertilizing conditions and therefore, the expected rise in grain yield will be 60 kg/He, which produces a 3% change in net income. This can be expressed as:

$$WI = YR \times RE \times (0.2) \qquad (1)$$

Where *YR* is the rate of change in yield, which is 3% of the average annual profit margin per hectare (*RE*). The annual profit margin was determined according to the standard profit margin on wheat at 489 $/ He; 3% of which i**s** 14 $/He. Given that sandy soils constitutes roughly 20% of the area available for application of NVS, the exposure coefficient was taken as 0.2 and the weighted benefit to the area was therefore 4 $/He.

3.3 Improvements to the soil's physical properties (TL)

As stated above, fly ash addition can improve marginal soils by raising water retention capacity in sandy soils; by stabilizing dune sands against wind erosion, for example by encouraging the formation of biological crusts; by reducing runoff from crust-forming soils such as loess; and by reducing plasticity and cracking in high-sodium, clayey soils.

The calculation of the associated benefits was performed on a potato crop. Potatoes are an important crop in the light soils in the northwest Negev region in Israel.
It was assumed that wind erosion occurs at a frequency of once every 15 years (F). The average net income (*RE*) is 1367 \$/He (Gal and Medlag 2012) and the interest rate used was again taken as 7%. The estimated benefit (*TL*) arising from soil improvements achieved by the application of fly ash or NVS is:

$$TL = \mathrm{PMT}(Rate,\ F, RE) = 150\ \$/\mathrm{He} \qquad (2)$$

Prevention of runoff and erosion (caused by either wind or water) is relevant to a wide range of soils, but given that most of the benefit can be expected to accrue in sandy and loessial soils, we shall only consider those soil types and hence the exposure coefficient was taken to be 0.5 and the weighted benefit in the area was estimated at 75 \$/He.

3.4 Reduced demand for irrigation water (Q)

Higher water retention capacity in the soil achieved by the addition of fly ash enables saving of irrigation water. This refers mainly to pre-sowing irrigation, meant to ensure germination and crop establishment. It was assumed that the volume of pre-sowing supplementary irrigation is around 500 m^3/He and that in sandy soils it was possible to save 100 m^3/He (*S*) by adding fly ash or NVS. Given that the cost of irrigation water (*P*) is 0.41 \$ per m^3, the value of the reduction in irrigation water volume is:

$$Q = S \times P \qquad (3)$$

Or total savings of 41 \$/He. About one third of the total area available for the application of NVS is irrigated and therefore, the exposure coefficient is 0.3 and the weighted benefit for each representative area unit is 12 \$/He.

3.5 Reduction in loss of nutrients by leaching

It is assumed that most of the loss by leaching involves mineral nitrogen and that under Israeli conditions (semi-arid), the leaching of other nutrients is negligible. As compared with chemical fertilizers, the release of nitrogen from manure is relatively slow, slowing down its downward leaching. Nitrogen use efficiency under cereals is assumed to be~50% of fertilizer N applied (Raun and Johnson 1999), and it is reasonable to assume that only ca. 25% of the mineral nitrogen formed by mineralization of manure organic nitrogen will be leached due to its slow release character. This is about half the leaching rate of the mineral nitrogen applied as a commercial fertilizer which is exposed to leaching from the moment it is applied to the soil. Accordingly, measurements taken in a sandy, commercial field have shown that the efficiency of use of nitrogen applied as NVS was much higher than the efficiency of nitrogen added as a commercial fertilizer, much of which was leached away (Fine and Mingelgrin 2018). Based on the conservative assumptions detailed above, the loss of nitrogen by leaching in rain-fed fields was 50 kg/He, valued at 100 $/He. In irrigated areas, fertilization is better regulated (e.g., by fertigation) and the leaching potential is hence lower. Accordingly, the exposure coefficient was taken as 0.8 and when spread out over five years, the benefit from applying NVS was calculated to be 18 $/He. It should be noted that preventing nitrogen leaching has environmental benefits the value of which was not quantified.

3.6 Reducing of plant pathogens and weeds in soils

The biocidal effect of NVS results from the formation of gaseous ammonia. The high pH of NVS causes the production of ammonia gas in the soil (e.g., Gips 2008). This biocidal activity can be utilized to save some of the cost of soil disinfection often practiced for field crops. We assumed conservatively that the saving would be 136 $/He, effective only in the year of NVS application. When spread out over five years, the saving will be 33 $/He per year. Adopting an exposure coefficient is 0.3, (only irrigated areas), the weighted benefit is 10 $/He.

3.7 Contribution of essential micronutrients

Application of fly ash or NVS contributes vital trace elements as was demonstrated for a range of crops and soils (e.g., Ukwattage et al. 2013). Although the benefits accruing from the addition of trace elements is calculated in the present study on the basis of its value to the farmer, some elements such as selenium and molybdenum which originate in the fly ash are beneficial to human health and in the future it may be possible to charge the customer for their presence in the product. Thus, on packages of potato chips produced in Italy under the tradename Selenella appears the statement that it is rich in selenium as a sales promoting slogan. The cost of a single application of trace elements is estimated at 54 $/He and three applications are normal practice for vegetable crops per growing season. Addition of trace elements is not a standard practice for field crops, but higher micronutrients uptake and yield were observed (e.g., in forage legumes) even five years after NVS application. For the sake of conservative calculations it was assumed that the micronutrients will be available to vegetables only during the year of NVS application. Assuming a total value of 163 $/He for the vegetable crops, 38 $/He per year over five years was the value assigned to the added microutrients. For field crops, the total savings was estimated at 54 $/He during the first year and the availability goes down gradually over the next 4 years to yield an average of 30 $/He per year. Assuming that this applies to all the areas treated with NVS and that the area of intensive (e.g., vegetable) cropping is one quarter of the total cultivated area, the weighted advantage for the total area is 33 $/He (38x0.25 + 30x0.75).

3.8 Higher soil temperatures

Application of fly ash or NVS darkens the surface of light colored soils (e.g., sand or loess), thus decreasing their albedo and causing their surface to heat up. That could be advantageous for winter vegetables such as potatoes (for which the profit margin is 1358 $/He). It was assumed that frost events occur at a frequency of once every five years. Given that the effects of NVS on soil temperature are not known, a minimum value was taken of a 10% reduction in loss of yield due to a frost event. This provides a benefit of 33 $/He per year. The exposure coefficient used was 0.4 (sand and loess areas) and the weighted benefit was estimated at 13 $ /He. In contrast, excessive heating of the soil in the summer will have a negative effect and if it becomes necessary to cool potatoes before harvesting in the summer, irrigation will be applied. Such an event will, of course, decrease the value of the elevation in soil temperature.

3.9 Summary of the benefits

The principal advantages arising from the application of NVS to agricultural soils are the addition of the major plant nutrients (nitrogen, phosphorus and potassium); Reduction in nitrogen loss (dry land cropping); Addition of essential trace elements; Rise in the organic matter content in the soil (resulting in better soil structure); Reduction in soil borne diseases; And better water retention.

4. The costs of agricultural application of fly ash or NVS

4.1 Higher soil salinity

Application of the recommended quantities of NVS using the appropriate application regime, should not increase salinity. Yet, the application of large quantities (such as those required at times to control soil borne diseases), might cause salinity damage, mostly due to addition of the soluble nitrate. The calculation of the cost of salinization damage was performed based on an estimate of the quantity of soluble salts added with the NVS (about 154 kg/He) and the cost of flushing out the salt (based on the cost of desalinating the volume of water required to leach out the salts). The calculated cost of the salt added to the soil once every five years is 52 $/He and in annual terms at market interest rates, that means 13 $/He per year. Assuming that the aforementioned cost refers only to dry land cropping, the exposure coefficient is 0.5 and the weighted annual cost is 6 $/Hectare. That is a stringent assessment because, as state above, under a proper application regime there will not be any salinization damage since most of the salinity is due to addition of nitrogen (an essential nutrient) as nitrate and during the years following application the nitrate will disappear by plant and microbial uptake, chemical transformations and leaching.

4.2 Contamination by heavy metals and other toxic elements

Field trials using fly ash and NVS demonstrated that the concentration of toxic elements (e.g., cadmium, lead and arsenic) in test plants grown in fields to which NVS or fly ash were applied, were usually very low and similar to the concentrations in the commercial control. Yet, regulatory agencies expressed fear that the application of fly ash to agricultural land will result in the accumulation of toxic metals in the environment and in the crops. Accordingly, the Israeli Ministry of Agriculture required that edible crops grown on a NVS-loaded soil must be monitored for a number of years before approval is granted for their marketing. Since such crops cannot be marketed during the monitoring period, the farmer incurs a significant loss caused by the reduced availability of cropping alternatives. A case in point is the prohibition of marketing leafy vegetables for 3 years which incurs a loss of income estimated at 543 $/He per year (Gal and Medlag 2012; The difference between the average value of leafy vegetables and root vegetables). With an exposure coefficient at 5% out of the entire area treated with NVS and spread over five years at 7% interest, the damage is estimated at 17 $/He per year.

4.3 Contamination by radionuclides

Although it is clear beyond any doubt that there is no danger of a buildup of radio-nuclides in the soil or in crops harvested from soils treated with fly ash or NVS (e.g., Koch 2002; Koch 2010; Chakin 2013; Katz and Shwartz 2013 and laboratory results from testing various crops), monitoring for the presence of radionuclides continues in crops for years while these crops are not authorized for marketing. Not growing a vegetable crop was estimated to result in a loss of earnings totaling 543 $/He per year. Assuming a 7year prohibition period and an exposure coefficient of 5% of the total area available to NVS application and after spreading the loss over 5 years at 7% interest rate, the cost is estimated to be 36 $/He annually.

4.4 Contamination by boron (B)

Boron concentrations in fly ash and in NVS are higher than in most sludges and manures and therefore, application of NVS could lead to boron toxicity in sensitive crops. Yet, even if boron surplus accumulates in the soil, it is likely to disappear after a short time because boron is leached away easily by rain or irrigation water. In Israel, no damage caused by the presence of boron was observed even after the application of exceptionally large quantities of NVS in any crop, (e.g., Fine and Mingelgrin 2018). Nevertheless, the potential risk to sensitive crops reduces the area and crops suitable for the application of NVS. It was estimated that the potential damage from excess boron would reach 543 $/He per year, but in view of boron's leachability, this damage would last for 2 years only. With a 5% level of exposure to particularly sensitive crops and at the aforementioned rate of interest for 5 years, the estimated cost would be 11 $/He per year.

$$B = \text{PMT}(7\%, 5 \text{ year}, \text{PV}(7\%, 2 \text{ year}, 543) \times 0.05) = 11 \text{ \$/He} \qquad (4)$$

Where PV is the present value.

4.5 Lower availability of phosphorus and trace elements native to the soil

Even though there is hardly any evidence of reduced availability of any essential elements due to NVS or fly ash application (including in four experiments involving ground nuts, which are especially sensitive to iron deficiency, Fine et al. 2014; Fine 2015). Nevertheless, it was decided to take this possibility into account because of the potential rise in pH and soluble calcium content in soils amended with NVS (but see section 4.6). Given that the content of trace elements in the soil rises following the application of NVS, it should suffice to add a chelate such as EDTA (10 mg/liter in 1500 m^3 of irrigation water) to ensure their availability. The quantity of EDTA required would be 15 kg per hectare per season at a cost of 122 $. Taking a conservative approach, the chances of any shortage of trace elements or P were assessed at 10% of the area grown to vegetables (exposure coefficient of 3%) for 5 years after application. Therefore, and the damage was estimated at 6 $/He per year.

4.6 Rise in pH and the concentration of carbonate and calcium in the soil

A rise in pH and calcium concentration can reduce phosphorus and trace element availability to the plant, primarily in soils of low calcium carbonate content. Yet, no such damage was observed upon NVS or fly ah addition. The rise in pH that accompanies NVS application lasts only for a few hours or, at most, a few days after application and it soon disappears due to carbonization of the surplus hydroxyls following wetting of the soil and breakdown of the added organic matter. Damage can however, be caused by a lasting rise in pH if the application regime and post application management are not suitable. A reasonable estimate is that this will occur on about

10% of the dryland farming area (i.e., exposure coefficient of 0.1) and that the damage will reach 20% of the potential standard profit margin. The standard profit margin for dryland forage crops is 1087 \$/He (Gal and Solomon 2014). The calculation for a five year period with the interest rate and other conditions as defined above, yields a cost of 5 \$/He per year. Although the main potential damage is a reduction in the availability of phosphorus and trace elements in the soil (section 4.5), in the interest of caution, we treated this phenomenon separately so as to cover other, unexpected potential forms of damage which may be caused by a rise in pH and carbonate content in the soil.

4.7 Application and incorporation

NVS application costs around 2 \$ per m^3 and incorporation cost is again 2 \$ per m^3. Thus, application of 50 m^3/He, assuming an exposure coefficient of 1 and that NVS is applied once every five years, will involve an annual cost of 50 \$/He.

$$PMT(0.07,5,200) \times 1 = 50 \text{ \$/He} \quad (5)$$

5. Summary and conclusions

Table 1 summarizes the results of the cost-benefit analysis of long term use of fly ash and NVS in agriculture in terms of the potential annual damage and benefit per hectare.

Benefit	\$/He	Costs	\$/ He
Replacement of Synthetic Fertilizers	159	Higher soil salinity	6
Higher Soil Water Availability	4	Introduction to the Soil of Heavy Metals and Other Toxic Elements	17
Improvements to the Soil's Physical Properties	75	Introduction to the Soil of Radionuclides	36
Savings in Irrigation Water	12	Addition of Boron to the Soil	11
Reduced Leaching of Nutrients	18	Decreasing Availability of Phosphorus and Essential Trace Elements in the Soil	6
Reduction of Plant Pathogens and Weeds in Soils	10	Elevation of pH and Concentration of Carbonates and Calcium in the Soil	5
Addition of essential nutrients	33	Application and Incorporation	50
Higher Soil Temperature	13		
Total weighted benefit	**324**	**Total weighted cost**	**131**

Table1. Weighted benefits and costs of the application of fly ash or NVS to agricultural soils (in \$ /He; 2019 prices and under the assumptions stipulated in the text)

Short and long term effects of the application of fly ash and NVS on crops, the soil and the environment determine the economic viability of the application for the farmer. NVS can replace chemical fertilizers while offering an added benefit of slow release, improves the soil's physical and chemical properties and helps control weeds and soil borne pathogens. Most of studies, both in Israel and around the world show that the proper application of fly ash as a component of NVS can improve the fertility of soils and that under all reasonable circumstances such applications do not adversely affect the quality of the soil as a substrate for growing plants. The agricultural use of NVS contributes not only to the profitability and the sustainability of the agricultural enterprise, but it also contributes to the quality of the rural and urban environments. The contribution to the environment is made, for example, by eliminating ammonia and greenhouse gases emission which occurs during sludge composting or the manufacture of chemical fertilizers. NVS amendment results in a reduction in the use of non-renewable resources (e.g., fossil fuel used for the manufacture of commercial fertilizers or minerals containing phosphorus, potassium or trace elements quarried for the production of such fertilizers.). Finally, NVS can be used as a partial substitute for pest-control chemical agents and, since it contains sludge and coal ash, its use conforms to the maximum-recycling principle. The redirection of NVS to agriculture after a very cost-efficient process of sludge-pasteurization, contributes to the urban sector by reducing the cost of both sludge treatment and removal.

The assessment of costs and benefits conducted in this study is based on conservative and stringent assumptions such as the inclusion of the costs of potential damages even if the likelihood of their occurrence is extremely low. Cost calculations took into account the concern for long term damage to the soil caused by unforeseen factors associated with the application of fly ash, notwithstanding the fact that the information and experience accumulated over the years on all matters pertaining to the application of NVS to agricultural soils indicate that the likelihood of such damage to occur is slight. Field trials conducted in Israel and elsewhere, as well as the many years in which NVS has been used in commercial fields, prove that the risk of long term damage due to its application to the soil is very low. Nevertheless, monitoring continues in those areas where NVS was applied in the manner in which any new additive is monitored, so as to remove all doubts about possible damage as unlikely as they may be.

Declarations

Availability of data and materials

All related data and materials are available upon request.

Competing interests

The authors declare that they have no conflict of interest.

Funding

This work was funded by the Israel National Coal Ash Board (INCAB) grant 39477#.

Authors' contributions

Efrat Hadas: Coceptualization, methodology, software, resources, writing-original draft.
Uri Mingelgrin: Methodology, writing-review&editing, visualization.
Pinchas Fine: Validation, formal analysis, investigation, writing-review, &editing, visualization, funding acquisition.

Acknowledgements

The authors wish to express their deep gratitude to the late Mr. Omri Lulav, Head of the INCAB.

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