A success model and commercial supply of coal ash to Australian Agriculture

Jane T. Aiken[1,2, 3] and Melissa Cuturich[2,3]

[1] Environmental Studies Consulting (Soil Health Ecology) Coal Ash Utilisation, 2A Eskbank Street, Lithgow NSW 2790, Australia; [2] Classique Environment Solutions Pty Ltd, Level 40, 100 Miller Street, North Sydney. NSW 2060, Australia; [3] Ash Development Association of Australia, PO Box 1194, Wollongong, NSW, 2500, Australia.

KEYWORDS: systems, fly ash, agriculture, ash utilization;

ABSTRACT

Formerly the research with Australian fly ashes has been with run-of station raw feed products demonstrating mechanism and response in soils. These studies indicate the necessity to incorporate the fly ash into topsoil as the best methodology for Class F Australian fly ashes, which is a critical consideration given most fly ash particle size range is 2 μM to 200 μM. Putting these materials into situations where the appropriate soil delivery technologies are not developed is an operational risk to supplier or consumer and is commercially unviable.

This paper discusses a single solutions model to foster commercial opportunities for coal ash within a nationally based systems approach. Here we consider that solutions for the agricultural supply chain lie in tandem with a manufacturing and construction supply chain. A single solutions model offers to manufacturing and construction, civil land applications and agricultural industries an equitable opportunity for market development with production and materials handling of CCP based materials serviced through existing commodity supply chains. Similarly development is necessary to manage the consistency of the ash. To date there are no procedures in place to monitor the consistency in cementitious manufacturing or for agriculture, making it difficult to determine reactivity with any one application.

Submitted for consideration in the 2015 World of Coal Ash Conference, May 5-7, 2015.

INTRODUCTION

The Australian coal ash industry is in a unique market position [1-2]. It has relatively low rates of CCP benefication, which in turn represent a potential to establish new industries. With 42 % (5.4 Mt) production quotas of coal combustion products (CCPs) used annually [3] the remaining 58 % is stored, adding to a 400 Mt national stockpile [4]. Access to these resources presents an opportunity to develop cementitious and aggregate manufacturing and agricultural supply chains. With the target market into agriculture for Australian fly ash CCPs as a soil amendment well defined for the Australian fly ashes [5-8] the Ash Development Association of Australia (ADAA), through funding development projects [7, 9] identifies that opportunities in agriculture are those which solve soil problems to improve agricultural productive capacity. Soil acidity, soil sodicity, and salinity already cost to the agricultural industry profit of almost $3 billion annually [10] and together with nutrient supply and minimization of nutrient losses and amelioration of soil structural and hydrological properties, represent major constraints to plant growth and crop yield. Similarly, soils-based applications linked to enhancement, capture and protection of atmospheric carbon in soil due to fly ash addition [11-12] also provide additional benefits with alkaline and acidic fly ashes, minimising carbon footprints in coal-powered generation and agriculture [13].

Potential markets to the agriculture can be demonstrated through the likely scenario of lime to amend acidic soils [4-6, 8]. Australia's agricultural land has over 50 M ha [14] of acidic soil with only 1.7 M ha of agricultural land limed annually [15]. Australian CCPs are produced within six major coal basins supporting local power stations interspersed across the nation [1-2]. In 2012, ash production was approximately 12.8 Mt with 1.9 Mt used directly for cement manufacture being part of the 5.4 Mt used in some beneficial way [3], with approximately 9 Mt stored [16]. For a CCP suited to an acidic soil if applied by incorporation into topsoil at a nominated agronomic rate of 2.5 t/ha, the supply equivalent for 9 Mt of annual unused production would support a 22.5 M ha national market. At an equal cost of lime at $30.00 /t use of the 9 Mt would generate for the coal ash industry a $270 M value-add. In real terms, success in this hypothetical market relies on a nationally distributed product, with commercial aspects based on farmer acceptance, subject to favourable outcomes from field trials, as plant yields are matched to cost effectiveness. However, although mode and soil responses continue to be defined [8, 17-20], to date, Australian coal ash producers have no formalised field trials in place [21], or an established supply chain for the CCP as an agricultural resource [22-23] and neither a strategy to solve this situation.

The question now, is not whether reuse opportunities would include the agricultural sector, but how might the CCP materials be distributed to fulfil market potential, to achieve the commercial profits necessary to build CCP use for the Australian agricultural sector. In present situations site self-regulated targets, resource recovery legislation, waste management and disposal costs, environmental policies and best practice opportunities are unsuccessful modes for change that realize a commercial market return. Alternately a national strategy is needed in order to create a business case for product distribution. A concept for a national supply model, serviced through an existing commodity supply chain offers significant opportunity.

A national strategy is proposed because investors need market certainty and market certainty is essential to create the necessary commercial value to provide the push, to change, from a localised management world-view where containing CCPs in land fill or ash dams is a sustainable practice, to the worldview that use of CCPs is a strategic opportunity to invest in regions, jobs and industry. This paper discusses a single solutions model to foster commercial opportunities for the utilization of the CCP within a nationally based systems approach, brokered within the context of an agricultural market. This is a strategy attempting to coordinate the variable ash commodities and dispersed resources in tandem with manufacturing and construction supply chains, to service a billion dollar agricultural sector.

GAP ANALYSIS

Market assessment traditionally includes a gap analysis. Recent work undertaken to develop a marketing plan has identified gaps to progress market opportunity and commercialization [1, 22], and although material selection for land application is well defined on the basis of resource recovery legislation [2, 4, 24-25] this work highlights that a product assessment with material processing options still needs to be considered.

Formerly, research with Australian fly ashes has been with run-of-station raw feed product demonstrating purely the mechanism and responses in soils [1-2, 5-6]. These comparisons identify that incorporation into topsoil is the best methodology for Class F Australian fly ashes because it is size of the particles which confer benefits to sub-soils, with improvements in soil structure, hydrological properties, pH response and nutrient retention. However within agricultural practice, the fertilizer or gypsum and lime application (storage and soil incorporation) with conventional on-farm methods cannot be suited for placement of run-of-station raw feed fly ashes (Figure 1) [1]. Placement of these raw materials into situations where an appropriate soil delivery technology is not developed is, from a generator / supplier point of view, a significant commercial risk and may breach environmental regulation. Consequently, for in-field management of the CCP a sustainable methodology of product delivery is needed.

Figure 1, Conventional field techniques will not be appropriate for materials storage or achieving soil benefits, so materials processing is a marketing commercial necessity.

At current CCP annual production rates Australia has 7-9 Mt CCP resources available for use and about 400 Mt of stored CCP in ash dams and repositories nationally [4]. Offsetting storage costs with direct processing into aggregates is one pathway with potential management benefits, and offers outcomes to stabilize a raw product and allow for transport and distribution being essential for market development. Linking with other aggregation technologies also offers the cost benefit of servicing both sectors and therefore buffer financial investment with a high production process. Therefore coupling commercial development and strategic agricultural research within an industry's holistic model for a manufactured product, has synergy for commercial investors.

A NATIONAL MODEL TO SERVICE AUSTRALIAN AGRICULTURE

A nationally scaled supply chain to service the agricultural sector has the potential to transform raw ash into a manageable product for distribution to a farm gate customer (Figure 2). This is a strategy yet to be proven and relies on the cost benefit of commercial production. It is however, the first national concept for a CCP supply to the agricultural sector to utilise potential market opportunities that lie in management of extensive land areas with acidic and sodic soils, which rely on a commercial proposal to build and service this market distribution.

The premise in this proposal is the five attributes or problems already identified as limiting agricultural profits being 1) soil sodicity, 2) soil acidity, 3) nutrient loss, 4) soil structure and reduced hydraulic capacity, and 5) the ability to sequester and hold soil carbon, are matched to a coal fly ash product. A simplified solution is a national ash supply to agriculture through a commonly developed product within an achieved specification, such that a particular source CCP will address the market demand for a particular soil problem. Although some of the Australian CCPs are already suited for soil management [4-7] market developers would undertake product analyses to provide a classification of ashes into one of only five soil amendment types. This then becomes five coal ash products for the agricultural sector each named with a proprietary product as a national model that begins with a broad scale approach replicated for each power station across the nation [23]. For example, a new product range is proposed as

1. Fly Ash CCP Soil Amendment – Acidity Check™
2. Fly Ash CCP Soil Amendment – Sodicity Check™
3. Fly Ash CCP Soil Amendment – Sandy Soil Ameliorant™
4. Fly Ash CCP Soil Amendment – Carbon Plus™
5. Fly Ash CCP Soil Amendment – Nutrient Plus™

Ash supply is regional from power stations producing coal ash around Australia. Each station has their inevitable variation between coal burnt so that matching the ash to the target soil becomes complicated, and progress stalls within a myriad of regulatory and soil advice that is needed for the coal ash industry. Conversely, the details for soil management are highly out of scope in terms of the technical expertise or advocacy role undertaken and ash industry association like the Ash Development Association of Australia. Therefore the agricultural product supply-chain needs to be identified, the production specifications initiated and distribution networks need to become part of the market solution.

Described by Figure 2 the proposed supply chain includes product specification, with stages of processing, manufacturing and grading, distribution and freight to the destination farm customer. Developed as a systems diagram, this concept is tailored as a single solutions model. It comprises a proposed classification process for material selection to agriculture, similar to the needs for material selection in a cementitious manufacturing, in as much as this is a necessary step in a production system. Both situations have volume outputs with similar requirements for plant infrastructure investment; servicing opportunities for manufacturing within defined production specifications and therefore incorporating the value of manufacturing into the supply chain.

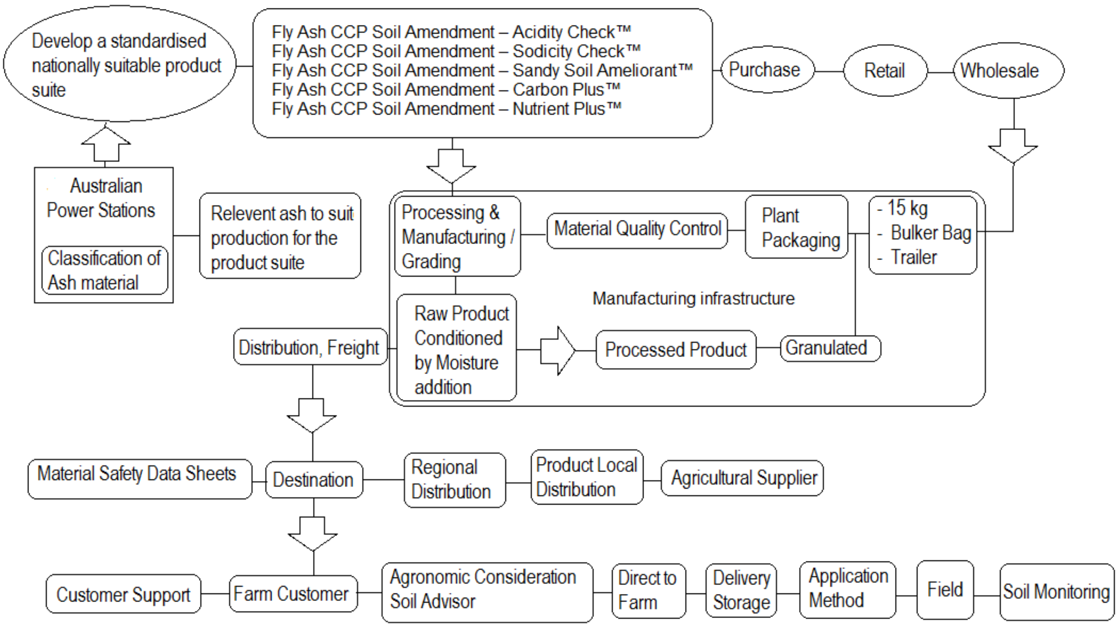

Figure 2, A national supply chain proposal for CCP and Australian agriculture

Several aspects for the general proposal noted by Figure 2 include:

1. Industry objectives, that on the premise of this proposal the supply chain for agriculture is based on the development of a standardized nationally represented product suite. Product options include various choices.
    a. A raw product - conditioned
    b. A processed product such as granulated.
    c. A product that has been developed within another by-product such as a compost or biosolid.
2. Processing of the ash is only on the basis of needing to alter the material densities from being a low density raw production dry fly ash sourced from a fabric filter or electro static precipitator (ESP) ash collection system. By changing the fly ash into a granulated material, the fly ash particle size would be increased and this would improve the properties of flowability with the aim of eliminating losses to dust.
3. Packaging is currently defined as three options. Logically for broad scale agriculture, these would be the predominant packaging types against proposed application rates. Packaging opportunities need to be built into the supply infrastructure at the power station.
    a. 15 kg bags
    b. Bulker bags
    c. Trailer

Therefore a power station from New South Wales and one from Western Australia may produce the same product called Fly Ash CCP Soil Amendment – Sodicity Check. The production supply chain then becomes a regional distribution network through which the fly ash CCP is made available to a farmer, anywhere in Australia. It is on this basis, working from the farm site and thinking back along a supply chain modelled as ‘plate to power station’ or ‘farm gate (field site) to power station gate’, that the needs of the customer and the supplier will be achieved by a model produced through 'harmonized material specifications', accounting for the inevitable range and variations in ash source, and the potential similarities and the differences of regional CCP production. Consequently, future CCP resource recovery is a competitively allocated national opportunity, expected to address in turn, the five aspects of soil management currently limiting agricultural yield and production profits.

MATERIAL ASSESSMENT

Technically there are no procedures in place to monitor the consistency for cementitious manufacturing (given the lack of products) and nor for agriculture (given the lack of field trials), making it difficult to determine reactivity with any one application. Thus work to achieve product classification across all alternate market sectors will be necessary, actioned through national and international collaborations with focus on commercial opportunity within the production supply chain. Similarly it was external interests in CCP use within the construction industry which has led to test regimes to identify the suitability of various CCPs as supplementary cementitious materials [26] and it is from this technical position that most CCP chemical assessment data has been derived [27] with industry development well established.

For agriculture and soils applications at the end of CCP agricultural supply chain is the need to find production benefit, manage the quality for environmental response and manage any aspects of production food quality [23]. A current example is a project initiated in Israel to define agricultural benefit of CCPs incorporated with municipal biosolids [28], as an alternative a pathway for CCP management and adjunct to use of CCPs for commercial construction. In this context the environmental assessment methodology chosen is the methodology recently published by the US EPA on their website called the Leaching Environmental Assessment Framework (LEAF) [29]. Traditional management of a risk to environmental quality is with leaching testing for material assessment with the Toxicity Characteristic Leaching procedure (TCLP), developed to simulate leaching through a landfill. The TCLP method determines a value based on a single point pH test which subjects the solid material being tested to a weak acid [30]. Alternatively, the LEAF protocol provides a pH dependent method of geochemical speciation modelling to assess phyto-availability through a nine-point pH range [30-31], with a better ability to inform environmental risks [32]. In this case applying the LEAF protocol is entirely consistent with the needs of working with a material labelled as waste and the perception of environmental risk associated with CCPs.

For agriculture soils, the methods of the LEAF protocol are still in the early stages of adoption for common uses such as leaching from native soils, clays silts and sands still to be developed and tested [30]. It is expected that the LEAF protocol will complement and support a broader scope across agronomic requirements providing the basis for a wide array of quality assurance programs to simplify the uncertainties for risk assessments generally, within a broader approach to testing for agronomic suites for plant and soils analysis.

Practitioners and industry partners also have an opportunity to quantify and predict the potential physical and chemical impacts of CCPs in the field. In order to characterize CCPs for agricultural applications in Australia, choice of testing includes chemical tests sourced from laboratories that would adopt the suite of soil chemical methods used by the soil science community such as those published by Australian soil scientists [33]. Relevant soil test methods include the extractable elements and iron exchange properties, soluble elements and pH, nutrients C, N, P, K, S, gypsum and lime and acidity as the essential knowledge base of a sustainable agricultural system. This will facilitate comparison of CCPs and their suitability for agricultural soil management and inform if individual CCPs can be applied to target specific soils. In this case, and given there is no standard methods for CCP analysis for soils, the key question for the Australian industry to answer is whether for Australia, soil chemical methods [33] methodology can be applied to ash analysis in developing standard methodologies for obtaining baseline data for CCPs, and whether these are methods would be consistent for international comparison.

Consequently, to further promote the use of these CCPs in soil either as substitutes or complements for commercial soil amendments, the consistency in all analytical procedures and interpretations of results needs consideration. With increased interest in the agricultural CCP supply, analytical suites are expected to diversify to testing of physical character, mineral composition and soluble element contents of the CCPs. Generally Australian studies for CCPs from an operations point of view were those identified by metal elements and chemical composition with LOI (loss on ignition) as an indicator of un-burnt coal, with a one off suite of site based analytical tests undertaken for ash assessment determining chemical and elemental composition. Now with identified market opportunities being promoted, a better understanding of the properties of the CCPs for agriculture is also expected.

SUMMARY RESEARCH DIRECTION

On the basis of the national model for commercial market supply [23] twelve general research and development questions are proposed to progress the opportunity for an Australian coal ash agricultural market supply chain. They are noted as:

1. *Testing and analytical standard methods for CCP analysis for soils* – developing an accepted suite to suite source and in-field materials.
2. *Material classification* - investigating the benefits or otherwise of a harmonized classification based on the farm site and the current Australian soil research recommendations. Goal: Setting a framework needed for testing and monitoring of product use in the environment, for health and the parameters for use an approval as a soil amendment.
3. *Material processing* - investigating the options for soil incorporation using existing or new farm equipment relative as i-v.
   i. the farm site.
   ii. the field site application process
   iii. the delivery and storage options
   iv. the ability to freight
   v. the options for packaging
4. *Product development* – to cover off the potential of the Australian coal ash industry and achieve the required product base, again a harmonized approach.
5. *Packaging* – the engineering aspects for individual processing specifications needed on farm.
6. *Product support* – the development of material safety data sheets, customer support information

7. *Customer support* - Soil advisory opportunities – checking that the needs of the farmer can be met
8. *Infrastructure* – assessment of site based supply chain freight or rail to ensure product transport is sustained and can be commercial.
9. *Regulation* – is an assessment framework for quality, environment and health. In this case the food production supply chain incorporates the supply chain from ‘gate to plate’.
10. *Site based production* – production support and integration into a production stream incorporating the use of other ash volumes for manufacture and processing.
11. *Site based supply* – demonstrating through cost benefit analysis that an integrated coal ash and agricultural sector is a sustainable option for both coal mining and agricultural production systems, including the aspect of quality improvements to food and fibre.
12. *Food production quality* – investigating through supply chain analysis a quality control process identifying the scope for Australian and International Standards.

CONCLUSION

Without exchange along a supply chain there is no commercialization or value expectation for changing to utilization of the CCP as an agricultural resource. To progress the use of the CCP into the Australian agricultural sector a strategic vision proposed includes, incorporating the practical aspects from broader fields of engineering, manufacturing and quality control as essential contributors in market development and the supply chain. Therefore the agricultural product supply-chain needs to be identified, the production specifications initiated and distribution networks need to become part of the market solution.

Australian coal resources lie in six major basins within the Australian continent, supporting coal-fired power stations intermittently located across the major agricultural regions. A national proposal is an undertaking offering significant opportunities to develop the various commercial sectors of soil management, to coordinate variable ash commodities and service a billion dollar agricultural sector. Yet to be proven, success relies on cost benefit of commercial production established within a harmonized system.

This proposal is a standardization of products into a target market to solve five existing soil constraints to agricultural production, distribution networks need to become part of the market solution. Similarly, harmonization for the ash industry as a prior commitment to agriculture provides an opportunity to investigate the scope and potential of a manufacturing and agricultural sector CCP supply. Production specifications when defined, will then recast the price point into a manufacturer-value based commercial supply chain, with further work into the detail of this part in the supply chain still needed.

Future project, grant and development proposals to support a commercialization model cover assessments in terms of standard methods for agronomic testing, the aspects of material processing, product development, packaging, product support, customer support, infrastructure, regulation, site based production, site based supply and food production quality assessment. Coupling manufacturing to infrastructure needs for the high volume markets that are available in construction and agriculture, is a proposal to sustain the resource recovery option of utilizing Australian CCPs for commercial outcomes and a strategy with which to realize the use of CCPs in the Australian agricultural sector.

REFERENCES

[1] Aiken JT, Heidrich C. Market opportunities for coal ash within Australian agriculture. In: Proceedings of the Soil Science Australia National Soil Science Conference: Securing Australia's soils - for profitable industries and healthy landscapes. Melbourne. Eds A Patti, C Tang and V Wong. Australian Society of Soil Science Inc. ISBN: 978-0-09586-595-2-9; 2014.

[2] Aiken JT, Heidrich C. Australian marketing perspective coal ash for agriculture. 2015 World Of Coal Ash (WOCA) Conference – May 5-7, 2015, Nashville, Tennessee http://www.flyash.info/: 2015.

[3] Heidrich CR, Ward C, Chalmers D, Heeley P, Ness J, Williams R. Production and Handling of Coal Combustion Products, Chapter 1. In, Coal Combustion Products Handbook: Second Edition, (Eds C Ward, CR Heidrich, O Yeatman). Ash Development Association of Australia, Wollongong, New South Wales: 2014, pp 1-34.

[4] Yunusa IAM, Eamus D, DeSilva DL, Murray BR, Burchett MD, Skilbeck GC, Heidrich C. Fly ash: An exploitable resource for management of Australian agricultural soils. Fuel 2006: 85, 2337-2344.

[5] Yunusa I, Manoharan V, Burchett, M, Eamus D, Skilbeck G. Utilisation of Coal Combustion Products in Agriculture, Chapter 12. In Coal Combustion Products Handbook: Second Edition, (Eds C Ward, CR Heidrich, O Yeatman). Ash Development Association of Australia, Wollongong, New South Wales: 2014, pp 365-408.

[6] Yunusa IAM , Loganathan P, Nissanka SP, Manoharan V, Burchett MD, Skilbeck, CG, Eamus D. Application of Coal Fly Ash in Agriculture: A Strategic Perspective. Critical Reviews in Environmental Science and Technology 2012: 42, 559–600.

[7] Yunusa I, Manoharan V, Burchett, M, Eamus D, Skilbeck G. Utilisation of Coal Combustion Products in Agriculture. In Coal Combustion Products Handbook, Chapter 12. (Eds L Gurba, C Heidrich, C Ward) pp 373- 414. Cooperative Research Centre for Coal in Sustainable Development. Australian Black Coal Utilisation Research Limited: Australia: 2007.

[8] Seshadri B, Bolan NS, Kunhikrishnan A. Effect of Clean Coal Combustion Products in Reducing Soluble Phosphorus in Soil I. Adsorption Study, Water Air Soil Pollution 2013: 224:1524, DOI 10.1007/s11270-013-1524-2.

[9] Pathan SM. Fly Ash Amendment of Sandy Soils To Improve Water and Nutrient Use in Turf Thesis. Agriculture and Plant Sciences, University of Western Australia: 2003.

[10] Hajkowicz S, Young M. Costing yield loss from acidity, sodicity and dryland salinity to Australian agriculture. Land Degradation and Development 2005: 16:417-433.

[11] Ukwattage NL, Ranjith PG, Bouzza M. The use of coal combustion fly ash as a soil amendment in agricultural lands (with comments on its potential to improve food security and sequester carbon). Fuel 2013:109, 400-408.

[12] Palumbo AV, McCarthy JF, Amonette JE, Fisher LS, Wullschleger SD, Lee Daniels W. Prospects for enhancing carbon sequestration and reclamation of degraded lands with fossil-fuel combustion by-products. Advances in Environmental Research 2004: 8, 425-438.

[13] Yunusa IAM, Blair G, Zerihun A, Yang S, Wilson SC, Young IM. Enhancing carbon sequestration in soil with coal combustion products: a technology for minimizing carbon footprints in coal-power generation and agriculture. Climatic Change 2015: in press.

[14] Dolling PJ, Moody P, Noble A, Helyar K, Hughes B, Reuter D, Sparrow L. Soil acidity and acidification, Final report to National Land and Water Resources Audit for Project 54C, available as zip file through Australian Natural Resources Atlas, <http://auditeagovau/anra/land/docs/soil_acid/soil_acidity_final_reportzip>: 2001.

[15] ABS, Australian Bureau of Statistics. 4627.0 - Land Management and Farming in Australia, 2012-13, Soil Management http://www.abs.gov.au/ausstats/abs@.nsf/Latestproducts/4627.0Main%20Features92012-13: Accessed: March 2015.

[16] HBM Group. Ash Development Association of Australia, Annual Membership Survey Results January – December 2012. ADAA National Office, Wollongong, Australia. http://www.adaa.asn.au/documents/ADAA_Mship_Report_2012.pdf: Accessed 7th December 2013; 2012.

[17] Pathan SM, Almore LAG, Colmer TD. Reduced leaching of nitrate, ammonium and phosphorus in a sandy soil by fly ash amendment. Australian Journal of Soil Research 2002: 40(7), 1201-1211.

[18] Muir MA, Yunusa IAM, Burchett MD, Lawrie R, Chan KY, Manoharan V. Short-term responses of two contrasting species of earthworms in an agricultural soil amended with coal fly ash. Soil Biology and Biochemistry 2007: 39, 987-992.

[19] Manoharan V, Yunusa IAM, Loganathan P, Lawrie R, Murray BR, Skilbeck CG, Eamus D. Boron contents and solubility in Australian fly ashes and its uptake by canola (*Brassica napus L.*) from the ash amended soils. Australian Journal of Soil Research 2010: 48, 480-487.

[20] Seshadri B, Bolan NS, Naidu R, Brodie K. The role of coal combustion products in managing the bioavailability of nutrients and heavy metals in soils. Journal of Soil Science and Plant Nutrition 2010: 10, 378-398.

[21] Yunusa IAM, Manoharan V, Harris R, Lawrie R, Pal Y, Quiton JT, Bell R, Eamus D. Differential growth and yield by canola (*Brassica napus* L.) and wheat (*Triticum estivum* L.) arising from alterations in chemical properties of sandy soils due to additions of fly ash, Journal of the Science of Food and Agriculture 2013; 93: 995–1002.

[22] Aiken JT. Marketing Plan for Coal Ash within Australian Agriculture. Jane T. Aiken Consultancy, A formal submission to the Ash Development Association of Australia. Environmental Studies Consulting (Soil Health Ecology) Coal Ash Innovations, Lithgow NSW: 2014.

[23] Aiken JT. Investigation Into The Supply Chain Requirements For The Successful Use Of Coal Ash In Australian Agriculture – Part 1", a formal submission to the Ash Development Association of Australia. Prepared by Jane T Aiken Consultancy, *"Environmental Studies Consulting (Soil Health Ecology) Coal Ash Innovations".* Document Date June 20th, 2014: 2014.

[24] Heidrich C, Feuerborn HJ, Weir A. Coal Combustion Products: A Global Perspective. World of Coal Ash 2013. Lexington, Kentucky USA, CEAR & ACAA. Vol 1: pgs 17. http://www.flyash.info/; 2013.

[25] Heidrich CR, Heeley P. Review of Australian Market, Legislation and Regulations, Chapter 4, In Coal Combustion Products Handbook: Second Edition, (Eds C Ward, CR Heidrich, O Yeatman). Ash Development Association of Australia, Wollongong, New South Wales: 2014, pp 151-176.

[26] Standards Australia. Australian Standard AS3582.1-1998 Supplementary cementitious materials for use with Portland and blended cement Part 1: Fly ash. (Standards Association of Australia: Homebush, NSW): 1998.

[27] French D, Riley K, Ward C. Characterisation, Classification and Properties of Coal Combustion Products, Chapter 2. In, Coal Combustion Products Handbook: Second Edition, (Eds C Ward, CR Heidrich, O Yeatman). Ash Development Association of Australia, Wollongong, New South Wales: 2014, pp 35-100.

[28] Teutsch N, Fine P, Silber A, Kosson DS, Van der Sloot HA. Leaching and phytoavailability of trace elements in soils amended with coal-combustion fly ash and fly ash treated biosolids. National Coal Ash Board's WACAU – International Workshop on Agricultural Coal Ash Uses, Israel on 27th – 29th May 2014. http://www.coal-ash.co.il/wordpress/?page_id=1141: 2014.

[29] US EPA, United States Environmental Protection Agency. Test Methods for Evaluating Solid Waste, Physical/Chemical Methods (SW-846). In: Wastes | Hazardous Wastes | Test Methods | 1000 Series Methods 2013.

[30] Hattaway, J. Hardin, C.D. and Daniels, J.L. Recommended guidelines for the use and application of the leaching environmental assessment framework (LEAF) for coal combustion residuals. 2013 World of Coal Ash (WOCA) Conference – April 22-25 in Lexington, KY http://www.flyash.info/: 2013.

[31] Kossen D, van der Sloot H. Laboratory to Field Relationship and Recommendations for Leaching Assessment National Coal Ash Board's WACAU – International Workshop on Agricultural Coal Ash Uses, Israel on 27th – 29th May 2014. http://coal-ash.co.il/wordpress/?page_id=1141: 2014.

[32] Van der Sloot H, Kosson D. Use of Chemical Speciation and Mass Transport Models in Leaching Assessment of Coal Combustion Residues in Agricultural Applications. National Coal Ash Board's WACAU – International Workshop on Agricultural Coal Ash Uses, Israel on 27th – 29th May 2014. http://coal-ash.co.il/wordpress/?page_id=1141: 2014.

[33] Rayment GE, Lyons DJ. Soil Chemical Methods – Australasia, CSIRO Publishing: Collingwood, Victoria Australia: 2011.