International Journal of Agricultural and Natural Sciences
E-ISSN: 2651-3617 15(1): 82-93, 2022
Research Article

EFFECT OF AEROBIC SLUDGE FROM THE OPAL'S SECONDARY WATER TREATMENT PLANT ON THE SOIL PROPERTIES

Ghulam Mustafa*, Karen Jones, Paul Chappell, Jacob Chretien

Opal Paper & Recycling Mill, Botany Road, Sydney, Australia

** Corresponding author:*
E-mail: ghulam.mustafa@opalanz.com

(Received 12th November 2021; accepted 13th March 2022)

ABSTRACT. A field study was carried out on a farmer's field to ascertain the physico-chemical properties of sandy clay loam and clay loam soils because of aerobic sludge application in tonnes/hectare (t/ha) at low, medium, and high rates from the Opal's Secondary Water Treatment Plant. Bulk density of topsoil significantly reduced (34%) when compared with the control. The reduction in soil bulk density was probably due to the increased soil aggregation. Other soil physical properties such as effective cation exchange capacity of topsoil increased at low, medium, and high aerobic sludge doses to 70, 60, and 46% respectively, compared to the control. Hydraulic Conductivity showed encouraging results at all the treatments in both depths. Overall, Ks increased from 60-98%. Soil aggregation and organic matter also showed a positive trend, after the application of Opal's aerobic sludge. Paddock with 52 t/ha showed a 74 and 61% increase in organic matter at upper as well as lower depths. Chemical properties such as pH moved towards neutrality whereas high Electrical Conductivity was observed at the lower depths, showing leaching with time. Total N increased 83% in topsoil at low aerobic sludge dose followed by 60 and 67% at medium and high doses, respectively. In the topsoil, total P increased 65% and 44% at the low and medium aerobic sludge application, respectively. Among the cations Ca and Mg concentrations were the highest on all the aerobic sludge treatment levels on both the soil depths except at the highest dose at the lower depth.

Keywords: *aerobic sludge, soil properties, organic matter, effective cation exchange capacity, aggregate stability*

INTRODUCTION

Sewage sludge can be used to enhance soil physico-chemical properties in the overall soil-plant-water biosphere. Sewage sludge also referred to as biosolids, is a by-product of sewage treatment processes. Land application of sewage sludge is one of the most important disposal alternatives [19]. Sewage sludge has potential fertilizer properties and can be used to enrich agricultural soils due to high nitrogen, phosphorus, and organic matter content [10]. Overall, the agricultural farmer community is keen to use nutrient and organic matter rich aerobic sludge [4]. Large quantities of aerobic sludge from the Secondary Water Treatment Plants are dumped into landfills, or these waste materials have traditionally been incinerated or dumped into oceans. With the recent interest in decreasing environmental pollution, agricultural scientists all over the world are advocating the utilization of these wastes on cropped land to minimise landfills. The composition of waste materials must be determined before land application to avoid potentially hazardous high levels of trace metals and toxic organic compounds. In general, for any organic waste such as aerobic sludge from the SWTP, soil and crop management practices will largely control the nature of the chemical and physical changes which occur.

Organic matter from the aerobic sludge improves the physical conditions of soils, as well as altering chemical and biological relationships, through the mechanisms by which it reacts have not been well documented. Likewise, the impact of aerobic sludge on desirable soil's physical, chemical, and biological properties is not well understood. This study would enhance the understanding of the way SWTP aerobic sludge contributes to OM and the soil's physical properties as a whole.

Sewage sludges of Calcutta, India, were characterised to assess their fertilization value. During the monsoon season, sewage sludge pH was found to be neutral to slightly alkaline and to have higher salt content in winter [8]. Finally, pH plays an important role to release macronutrients. Sewage sludge collected from Tamil Nadu, India contributed to improve cropland because this had nearly neutral pH, high organic matter, as well as N, P, and Ca contents [11]. First time aerobic sludge was used instead of sewage sludge to improve the nutritional content and soil properties of cropland in Australia.

Experiments on wastewater biodegradable waste solids were conducted for 16 years to assess the effects on soil's physico-chemical properties and found that the organic matter content of the soil increased significantly [13]. The results of the experiments on the effects of sewage sludge on the soil's physical properties found that the constituents of the organic matter act as a good conditioner of soil properties [6].

Land application of sewage sludge is becoming more popular due to the possibility of recycling valuable components, such as organic matter, N, P, and other plant nutrients. He used organic waste to see the effects on the soil's physical properties in the degraded semiarid ecosystem of Spain with a nitrogen content of 43.04% [9]. It was concluded that the biosolids from the wastewater treatment after 16 years of application increased the soil's nitrogen [13]. Whereas sewage sludge's application to soil enables the recycling of nutrients and may eliminate the need for commercial fertilizers in cropland [21].

Sewage sludge contains soil nourishing macronutrients such as Ca, Mg, K, P and N. Experiments conducted to see the effect of sewage sludge on the soil's physical properties found that the sludge application produced several changes including increased concentrations of major cations such as Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} [24]. Furthermore, sludge was rich in organic carbon and available N. The addition of organic matter to the soil as sewage sludge compost, prepared using the municipal waste improved the soil properties, such as bulk density, porosity, and water holding capacity [18]. The sewage: sludge ratio plays a significant role in improving the soil's physical conditions [16]. The higher organic matter proportion in sludges decreased bulk density and increased the aggregate stability. Research work on the raw sludge and its role in aggregate stability showed that the raw sludge treatment had the highest percentage of stable aggregates during the first 118 days of the incubation, but after 175 days, the percentage of stable aggregates for the sludge treatments were the same, averaging 34% in comparison to untreated soil's 17%. Experiments were conducted a study the effect of 0.5% sewage sludge's application to soil on water retention, hydraulic conductivity, and aggregate stability, and found that the raw, as well as digested sludge, increased the total soil water retention capacity, with the greatest increase in the raw sludge amended soil. Furthermore, it was concluded that the sewage sludge addition in soil caused a significant increase in soil hydraulic conductivity after 27 days of incubation [3]. Relatively high rates of sludge application increased the cation exchange capacity, which helped to retain essential plant nutrients within the rooting zone due to additional cation binding sites [23].

All over the world emphasis was given to the use of sewage sludge to improve the soil's physical conditions. Less attention was given to the use of aerobic sludge from the SWTP to improve the soil's health. The use of SWTP aerobic sludge on agricultural lands is in the initial stage in Australia. Opal Paper & Recycling Mill, Australia took the initiative to use the aerobic sludge on the farming land to improve the soil characteristic. The use of SWTP aerobic sludge for the agricultural lands not only improves soil's physical and chemical properties but also would be useful to reduce the cost of aerobic sludge disposal to the landfills and to comply with the NSW Environment Protection Authority (EPA) regulations. It also improves the farmer's income and economic wellbeing. However, meagre research work on the use of aerobic sludge on agricultural lands is available in Australia. Therefore, in this study, we have attempted to see the contribution of aerobic sludge from Opal's SWTP towards the improvement of soil physical and chemical properties.

MATERIALS AND METHODS

This field study was conducted on clay loam and sandy loam soils. The paddocks where low and medium doses of aerobic sludge were applied had clay loam soil. However, a high dose of aerobic sludge was applied to the paddock which had sandy clay loam soil. Three aerobic sludge levels, low (52 t/ha) medium (105 t/ha), and high (158 t/ha) were applied on 7.1, 7.6, and 4.1 hectares of agricultural land, respectively. Opal's Paper & Recycling Mill produced water by using 100% recycled waste paper for paper production which was then fed to the microbes in the EGSB reactor. These microbes consumed pollutants which were undesirable for the environment and produced aerobic sludge as a by-product. Aerobic sludge from the Opal's SWTP was homogeneously applied and then pulverized in all the paddocks using a spreader. Ryegrass was grown to feed the animals per EPA requirements of 90 days hold period. Treatments of low and medium sludge applications were applied almost 18 months ago before the soil sampling. However, a high dose was applied just one and a half months before the soil sampling. Soil samples were taken from 0-15 cm and 15-30 cm depths from each of the aerobic sludge treatments as well as from control. All the samples were analysed for the physicochemical properties such as pH, EC, Ca, Mg, Na, K, N, P, bulk density, eCEC, OM, aggregate stability, and hydraulic conductivity to ascertain the change in the soil properties. Bulk density was determined by core method, cations were analysed using Atomic Absorption Spectrophotometer, and total nitrogen was determined by LECO, Dry Combustion method, total P [17], OM [25], aggregate stability [2] & hydraulic conductivity by 16 drops method. All the soil samples were analyzed by NATA accredited SESL, Australia.

RESULTS AND DISCUSSION

Bulk density

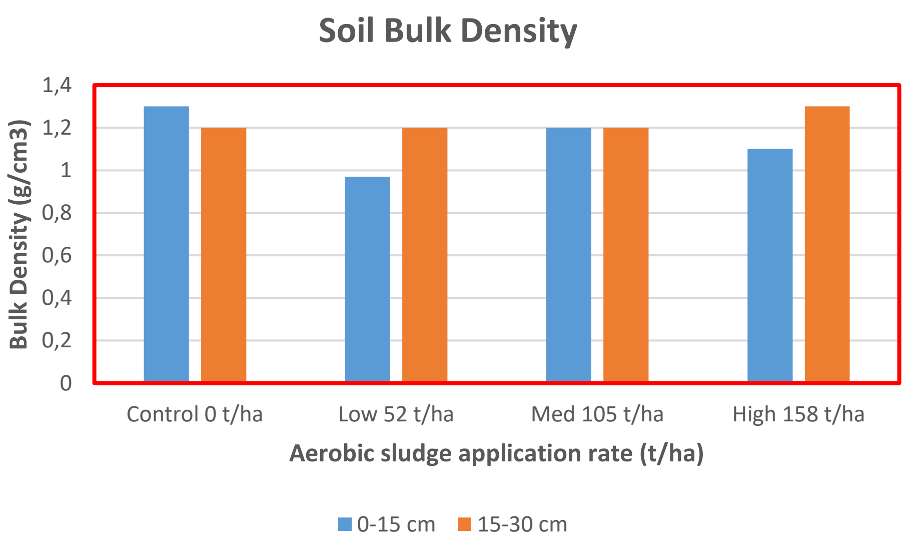

Fig. 1. *Changes in soil bulk density as a result of Opal's aerobic sludge application*

Bulk density is used to access the soil improvements due to the application of a given treatment. It can also be used as a Pedo Transfer Functions (PTF) which tells us soil transformations and improvements from low to high physicochemical properties. In our case, bulk density showed a 34% reduction due to the low aerobic sludge application of 52 tonnes/hectare (t/ha). However, high (158 t/ha) and medium (105 t/ha) treatments showed 15 and 8% reduction in bulk density in the topsoil compared to control (Fig. 1). No changes in bulk density were observed at the lower depth at all the aerobic sludge treatments. This no change in the bulk density, in particular at 158 t/ha, was because the Opal’s aerobic sludge was applied just 45 days before the soil sampling. Studies on the PTF using bulk density showed that bulk density reduces with the addition of OM in the soil [12].

Effective Cation Exchange Capacity

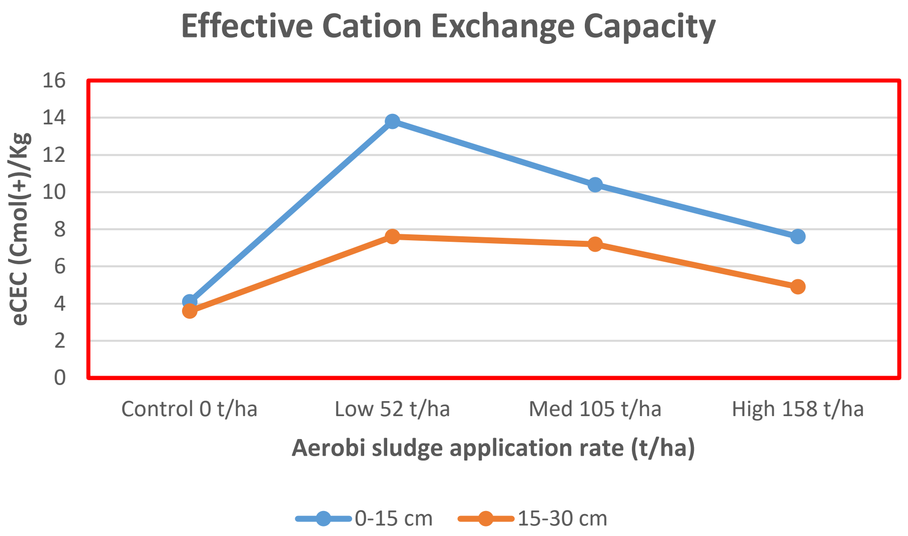

Fig. 2. *Improvements in eCEC as a result of Opal's aerobic sludge application in the farmer's field*

Effective Cation Exchange Capacity (eCEC) results at both depths showed encouraging soil improvements. Opal's aerobic sludge @ 52 t/ha at 0-15 cm depth showed 70% improvements in eCEC compared to control. However, improvements in eCEC were 60% and 46% where 105 and 158 t/ha doses, respectively were applied at the lower depth (Fig. 2). Similarly, consistent improvements in eCEC, but less than the upper depth, were observed at the lower depth. These improvements were 53, 50, and 27% where Opal's aerobic sludge treatments of 52, 105, and 158 t/ha, respectively were applied. Better results of eCEC may be due to the addition of organic matter (OM) in the soil which ultimately improved the soil structure [1].

Saturated Hydraulic Conductivity

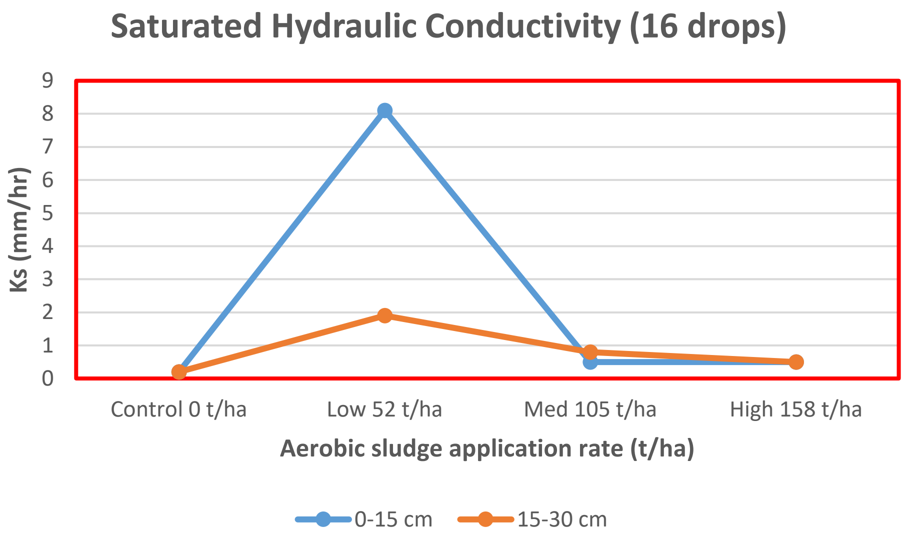

Fig.3. *Response of different treatments of aerobic sludge on Ks*

Saturated Hydraulic Conductivity (Ks) is one of the most important soil physical parameters which clearly tell us the soil response to the applied treatments. Opal's aerobic biomass treatments showed a positive response and a 98% increase in Ks compared to control was found at the upper depth where 52 t/ha aerobic sludge was applied. Almost 60% Ks improved where 105 and 158 t/ha of biomass were applied at the upper depth (Fig. 3). Our aerobic sludge treatments worked well not only at the upper depths as well as at the lower depth. At the lower depth Ks showed 89, 75, and 60% improvement at 52, 105, and 158 t/h, respectively. It was found that during the In-situ and laboratory investigations roots control the water uptake and improve the soil matrix and hydraulic conductivity [14].

Soil Aggregate Stability

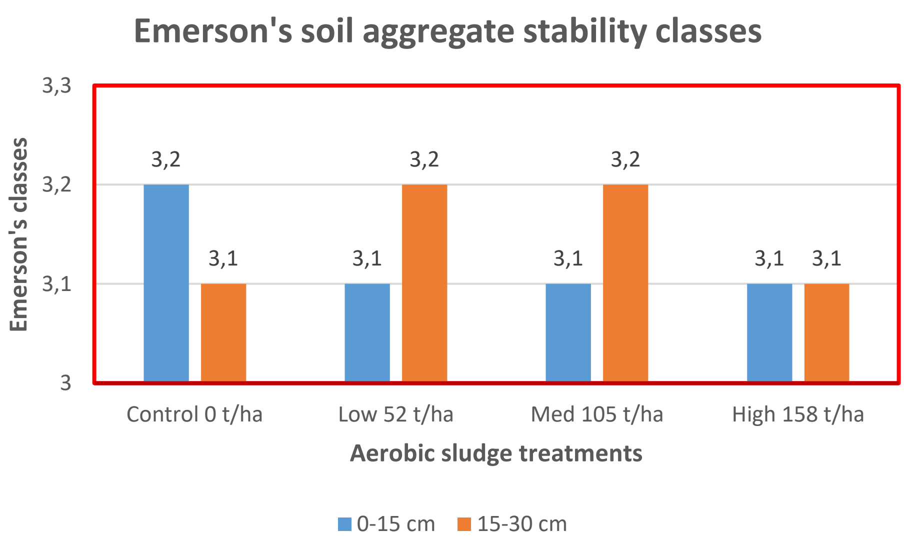

Fig. 4. *Aggregate stability classes of because of Opal's aerobic sludge applications*

As a result of Opal's aerobic sludge application, Emerson's aggregate stability class varied from 3.1 to 3.2, on the basis of the degree of dispersion (Fig. 4). Paddocks with low, medium, and heavy aerobic sludge treatments showed remoulding soil properties at water content equivalent to field capacity. Dispersion of soil was more evident with a slight milkiness. Furthermore, aggregate broke down but remained intact. Aggregate stability enhanced the nutrient holding capacity of the soil. Formation and stabilization of aggregates was found to be linked with the soil organic matter [21].

Soil Organic Matter

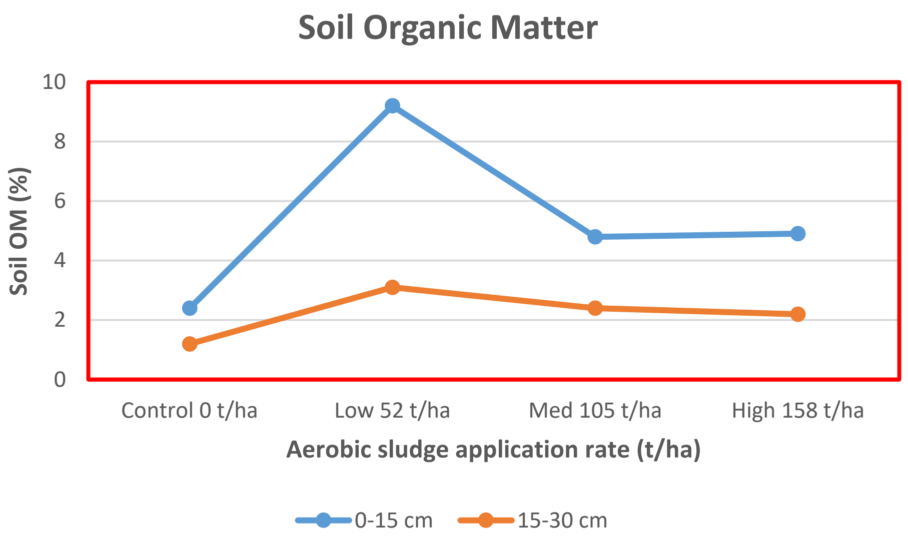

***Fig. 5.** Effect of different aerobic sludge treatments on the soil OM*

Soil organic matter plays a pivotal role to develop the soli matrix. It contains humus and is called the blood of soil. Organic matter (OM) not only improves soil physical parameters but also a rich source of nutrients supply as a fertilizer for the plants. Application of Opal's aerobic sludge to the agricultural land significantly contributed to improving the soil organic matter at both the depths and at all the aerobic sludge treatments. Paddock with low sludge treatments showed 74 and 61% OM increase at upper and lower depths, respectively as compare to control (Fig. 5). Soil OM improvements were also observed in the paddocks where medium and high sludge doses were applied. Soil OM improvements were 50% and 45% at 0-15 cm and 15-30 cm depths, respectively. Field experiments concluded that OM improves the soil properties [12]. Soils with OM in the ranges between 1.8 and 8.9% confirmed the importance and close relationships of OM with the abundance of the finer fractions (silt and clay) of the soil samples and moderate correlations with the plasticity index [7].

Total Soil Nitrogen

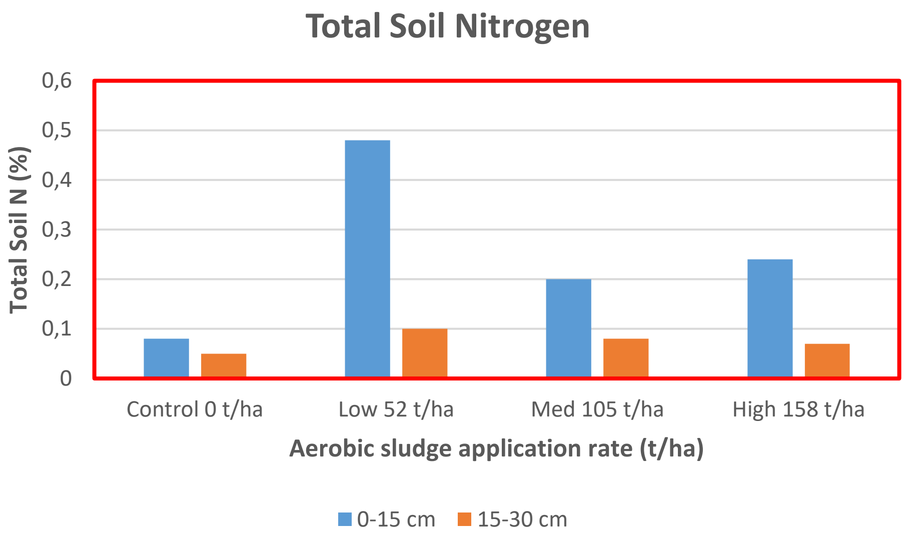

Fig. 6. *Status of total soil nitrogen in the three paddocks treated with aerobic sludge compared to control*

Interestingly, the status of total soil nitrogen improved as a result of our aerobic sludge treatments and act as a nitrogen fertilizer source. The maximum total soil nitrogen (83%) was measured as a result of aerobic sludge treatment of 52 t/ha at the topsoil compared to control (Fig. 6). Treatments such as 105 and 158 t/ha nurtured the soil well and in response, an increase in total soil nitrogen of 60 and 67%, respectively was measured at the upper depth. The data of total soil nitrogen at the lower depth also showed the contribution of Opal's aerobic sludge to enhance soil fertility. At the lower depth almost 50, 38 & 29% of total soil nitrogen increased as a result of aerobic sludge application @ 52, 105 & 158 t/ha, respectively. Sewage sludge addition to croplands of semi-arid regions helped to equilibrate soil humic balance, supplied nitrogen and phosphorus at lower costs, and most importantly, coped with farm manure shortages [19]. Currently, no cited reference of aerobic sludge application on the agricultural lands is available to improve the soil properties, particularly in Australia.

Soil Phosphorus

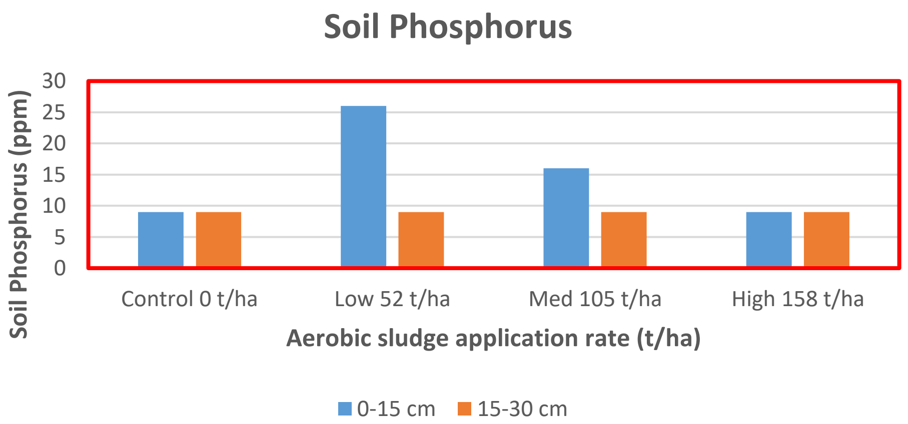

Fig. 7. *Soil Phosphorus status in the aerobic sludge treated soil compared to control.*

Soil fertility not only depends on the addition and availability of nitrogen in the soil but also needs phosphorus. Our aerobic sludge contributed to improving the soil phosphorus. Treatment @ 52 t/ha enhanced 65% of phosphorus in the topsoil as compare to control (Fig. 7). The medium application rate of 105 t/ha also showed 44% enrichment of soil with the phosphorus at the upper depth. However, no treatment effect was observed at 158 t/ha of aerobic sludge applications at all. This could be because we applied this dose just 45 days before soil sampling and enough time was not given to release the nutrients from the aerobic sludge. The phosphorus leaching was not observed because the phosphorus concentration at the lower depth in all the treatments was found similar to control. Soil P improvement was observed as a result of sewage sludge application and found that sludge with high P concentration increased soil P concentration and can be considered as a slow-release fertilizer. It is important to note that no refereed reference is available to find the P release from the aerobic sludge and our research work is pioneer in the field of aerobic sludge application on the croplands in Australia [5].

Soil pH

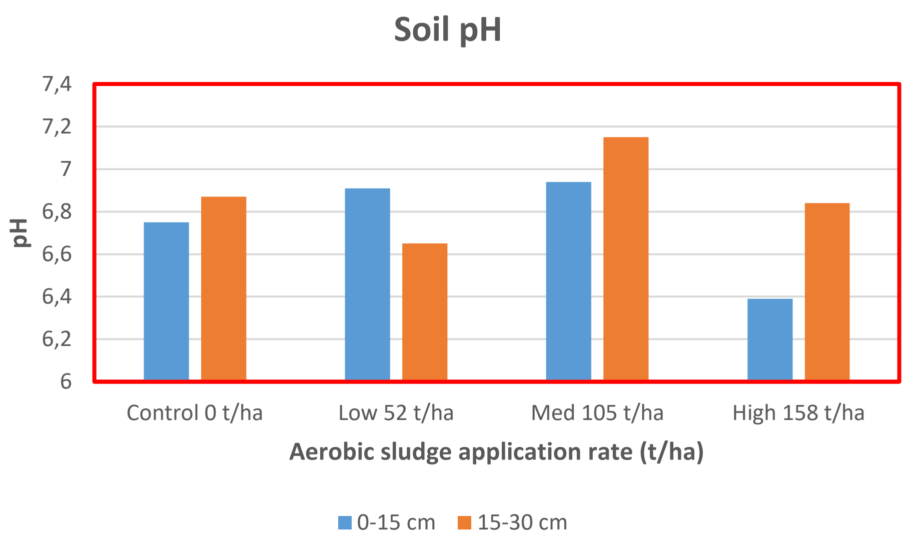

***Fig. 8.** Changes in soil pH of the three aerobic sludge treated paddocks.*

Soil pH plays an important role to release and make nutrients available for the crops. Opal's aerobic sludge application improved soil pH and brought it towards 7.0. Paddock, where 105 t/ha aerobic sludge was applied, showing a 15% increase in pH followed by 52 t/ha where pH increase was 2% at the upper depth (Fig. 8). However, at the lower depth, only 105 t/ha treatment showed a 4% increase in pH towards neutrality. Interestingly, pH became more acidic in the paddock where 158 t/ha was applied at the upper depth. It was because aerobic sludge did not decompose well after 45 days of its application. Our results showed an increase in pH as a result of aerobic sludge application on sandy loam soils. The increase or decrease in pH depends on the sludge application rates, but on Gypsiferous soils [15].

Exchangeable Cations

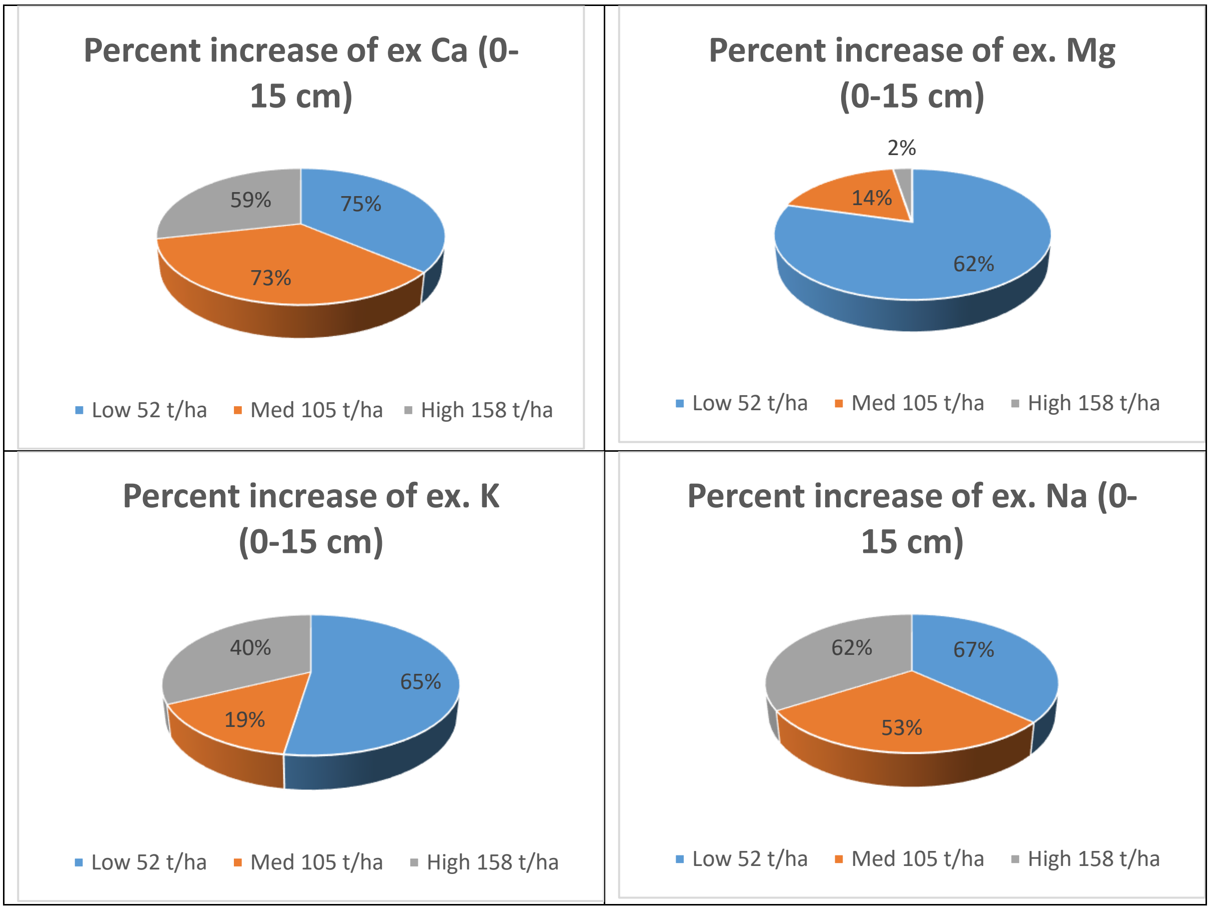

***Fig. 9.** Cation status in the soil as a result of Opal's aerobic sludge application.*

Exchangeable cations such as Ca, Mg, K concentration showed soil improvement as a result of aerobic sludge applications. Encouraging results were found due to Opal's aerobic sludge application at low medium and high doses in all the paddocks. These results were more promising at the upper depth in all the treatments (Fig. 9). Sodium concentration slightly increased at both depths but it did not have any saline trend. The addition of Ca, Mg, and K helped to improve physical properties such as bulk density, hydraulic conductivity, and aggregate stability. Sewage sludge application at 40, 80 and 180t/ha improved soil structural stability due to calcium addition as compared to control [26]. However, this research was on the application of sewage sludge. Little research is available in Australia and abroad on the use of aerobic sludge on agricultural lands which is produced by the SWTP.

RESULTS

The current field study investigated the quality of clay loam and sandy loam agricultural soils nurtured with the Opal's aerobic sludge at three levels. Our results showed that all the studied parameters were aerobic sludge dose-dependent. Overall, organic matter accumulation and its subsequent mineralization over the period of 18 months improved soil structural stability in proportion to sludge dose. Our treatments improved soil structure and fertility without causing physical degradation.

Results showed healthy Ryegrass crop in both the paddocks where low and medium doses were applied after 18 months. However, yet crop was not grown in the paddock where a high dose was applied 45 days before the sampling time (Figs 10-12). In this case, aerobic sludge was yet to be physically incorporated into the soil which had a significant effect on the soil properties.

Fig. 10. *Ryegrass in the LG9 paddock where 52 t/ha aerobic sludge was applied.*

Fig. 11. *Ryegrass in the LG8 paddock where 105 t/ha aerobic sludge was applied.*

Fig. 12. *Paddock where 158 t/ha aerobic sludge was applied.*

CONCLUSIONS

The use of Opal's SWTP aerobic sludge improved the soil physical properties. Opal's SWTP aerobic sludge application enhanced soil nutrients and organic matter at lower and medium aerobic sludge application rates. The use of aerobic sludge on agricultural land not only enhanced soil fertility but also helped to save cost and environmental pollution. The use of SWTP aerobic sludge leads to the decrease of the number of chemical fertilizers that should have been used to ensure the growth of plants and also helps to eliminate the problems created by the accumulation of increasing amounts of sludge.

Opal's aerobic sludge contains a significant amount of nutrients, which gives them organic fertilizer properties. The use of aerobic sludge from the SWTP improves the farmer's income and wellbeing. The use of aerobic sludge on agricultural land leads to lower production costs, as much lower amounts of synthetic fertilizers will be used or even in some cases can be completely replaced. The use of aerobic sludge on agricultural lands reduced environmental pollution. It is a cost-effective method of SWTP aerobic sludge disposal. This study will be continued in the future to evaluate the soil's physical and chemical properties.

Acknowledgements. This work is carried out at the farmer's field with the permission of Opal Paper and Recycling Mill, Sydney, Australia. The author is thank full to Opal Paper and Recycling Mill for the supply of the necessary resources and equipment required to conduct this research.

REFERENCES

[1] Beare M. H., Handrix P. F., Coleman D.C. (1994): Water- stable aggregates and organic matter fractions in conventional and no-tillage soils. Soil Sci. Soc Am. J. 58: 777-786.

[2] Emerson, W.W., Foster, R.C. Oades, J.M., (1986): Organo-mineral complexes in relation to soil aggregation and structure. In Interactions of soil minerals with natural organics and microbes. Soil Science Society of America. Madison WI.521-548.

[3] Epstein, E. (1975): Effect of sewage sludge on some soil physical properties. J. Environ. Qual. 4, 139–142.

[4] Giulio C., Enrico C., Tonia T., Debora F., Massimo P. (2020): Journal of Environmental Management. Vol. 269: 110767.

[5] Houben D., Michel E., Nobile C., Lambers H., Kandeler E., Faucon P. (2019): Response of phosphorus dynamics to sewage sludge application in an agroecosystem in northern Framnce. 137: 178-186.

[6] Logan T. J., Harrison B. J. (1995): Physical characteristics of alkaline stabilized sewage sludge (N-vitro soil) and their effects on soil properties. J. Environ. Qual. 24, 153–164.

[7] Masi E. B., Bicocchi G., Catani F. (2020): Soil organic matter relationships with the geotechnical-hydrological parameters, mineralogy, and vegetation cover of hillslope deposits in Tuscany (Italy). Bulletin of Engineering Geology and the Environment. 79: 4005-4020.

[8] Maiti P.S., Sah K. D., Gupta, S. K., Banerjee, S. K. (1992): Evaluation of sewage sludge as a source of irrigation and manure. J. Indian Soc. Soil Sci. 40, 168–172.

[9] Martinez F., Cuevas C., Walter T., Ingrid I. (2002): Urban organic wastes effects on soil chemical properties in degraded semiarid *R.P. Singh, M. Agrawal / Waste Management 28 (2008) 347–358* 357 ecosystems. In: Seventeenth WCSS, Symposium No. 20, Thailand. pp. 1–9.

[10] Metcalf E. (1991): Wastewater engineering treatment, disposal, and reuse, 3rd ed. New York, USA: McGraw Hill.

[11] Nandakumar K., Ramamurthy S., Rajarajan A., Savarimuthu, E. (1998): Suitability of Dindigul town's sewage sludge for field application: nutritional perspective. Pollut. Res. 17 (1), 61–63.

[12] Nemes A., Walter J. R., Yokov, A. P. (2005): Influence of organic matter on the estimation of saturated hydraulic conductivity. Soil Sci. Soc. Am. J. 69: 1330-1337.

[13] Neus R., Jordi S., Esther M., Marti N., Marta S., Jose L. D. (2012): Long-term amendment of Spanish soils with sewage sludge: Effects on soil functioning. Agriculture, Ecosystem & Environment. Vol. 158: 41-48.

[14] Ng C. W. W., Leung, A. K. (2012): In-situ and laboratory investigations of stress-dependent permeability function and SDSWCC from an unsaturated soil slope. Geotech Eng 43(1): 26–39.

[15] Nevas A., Bermudez F., Machin J. (1998): Influence of sludge application on physical and chemical properties of Gypsisols. 87 (1-2): 1233.135.

[16] Ojeda G., Alcaniz, J. M., Ortiz, O. (2003: Runoff and losses by erosion in soils amended with sewage sludge. Land Degrad. Dev. 14 (6), 563–573.

[17] Olsen S, Cole C, Watanabe F., Dean L. (1954): Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular Nr 939, US Gov. Print. Office, Washington, D.C.

[18] Ramulu U., Sree S. (2002): Reuse of municipal sewage and sludge in agriculture. Scientific Publishers, Jodhpur, India.

[19] Siebielec, G., Siebielec S., Lipski D. (2018: Long-term impact of sewage sludge, digestate and mineral fertilizers on plant yield and soil biological activity. Journal of Cleaner Production, 187, 372-379.

[20] Singh R. P., Agarwal, M. (2008): Potential benefits and risks of land application of sewage sludge. Waste Management 28:347-358.

[21] Six J., Bossuyt H., Degryze S., Denef, K. (2004): A history of research on the link between (micro) aggregates, soil biota, and soil organic matter dynamics. Soil & Tillage Research 79, 7-31.

[22] Sommers L.E. (1977): Chemical composition of sewage sludges and analysis of their potential use as fertilizers. J. Environ. Qual. 6, 225– 232.

[23] Soon Y.K. (1981): Solubility and sorption of cadmium in soils amended with sewage sludge. J. Soil Sci. 32, 85–95.

[24] Veeresh H., Tripathy S., Chaudhuri D., Ghosh B., Hart B., Powell M. (2003): Changes in physical and chemical properties of three soil types in India as a result of amendment with fly ash and sewage sludge. Environmental Geology. 43: 513-520.

[25] Walkley, A.J., Black, I.A. (1934): Estimation of soil organic carbon by the chromic acid titration method. Soil Sci. 37, 29.38.

[26] Zoghlami R. I., Hamdi H., Tlili S. M., Hechmi S., Khelil M. N., Aissa N. B., Moussa M., Bousnina H., Benzarti S., Jedidi N. (2020): Monitoring the variation of soil quality with sewage sludge application rates in absence of rhizosphere effect. Int. Soil & Water Conserv. Res. 8: 245-252.