UNIVERSITI PUTRA MALAYSIA

ZINC-LAYERED HYDROXIDE WITH NITRATE AND PHOSPHATE AS COUNTER ANIONS AND ITS EFFECT ON GROWTH PERFORMANCE OF KELAMPAYAN SEEDLINGS [Neolamarckia cadamba (Roxb.) Bosser]

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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Chair : Prof. Mohd Zobir Hussein, PhD
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Currently, layered hydroxide is subjected to intense research as this type of 2-dimensional (2D) nanomaterial can be used in various aspects of agriculture, particularly as a slow-release matrix of nutrients for plant growth. In this work, zinc layered hydroxide was synthesized by co-precipitation and anion exchange method which produces zinc layered hydroxide nitrate (ZLHN) and zinc layered hydroxide phosphate (ZLHP) nanofertilizer, respectively to evaluate the effect of nitrate and phosphate sorption efficiency towards plant growth. ZLHN and ZLHP showed the formation of a new peak of the basal interlayer spacing of 9.57 Å and 6.78 Å in the powder X-ray diffraction (PXRD) pattern, respectively. The FTIR, thermal, elemental, surface area and morphology analysis supported the formation of ZLHN and ZLHP nanofertilizer. The synthesized ZLH fertilizer was also tested for release kinetic studies while the bioassay was performed on Kelampayan **(***Neolamarckia cadamba***)** seedlings. The controlled release studies of ZLHN and ZLHP were carried out in deionized water, 0.005M sodium carbonate and soil media solution at pH 6.5. The highest percentage release was recorded to be 63.87% of nitrate in 0.005M sodium carbonate solution and 6.4% of phosphate in deionized water while the lower percentage release was recorded at 29.61% of nitrate and 0.21% of phosphate in soil media solution at 96 hours, respectively. The release profile was best fitted to the pseudo-second-order model with R^2 values of 0.99 and 0.97 for ZLHN and ZLHP nanohybrid, respectively. The ZLH nanofertilizer were found to be non-toxic to plant, where all the green bean seeds were successfully germinated in the experiment. The percentage of seed germination can be arranged in order of ZLH nanofertilizer > commercial fertilizer > primary material treatment. Besides, after sixteen weeks of treatment of ZLH nanofertilizer toward the growth of kelampayan seedlings showed good performance and significant difference in diameter and height compared to other treatments. At the end of the study, the nutrient plant uptake was also determined and showed higher uptake in the leaves of Kelampayan treated with ZLH nanofertilizer and they are significantly higher compared to the other treatments. In conclusion, this study suggests that the development of ZLH nanofertilizer has the potential to be used as fertilizer nanodelivery systems.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

ZINK HIDROKSIDA BERLAPIS DENGAN NITRAT DAN FOSFAT SEBAGAI ANION PENGIMBANG DAN KESANNYA TERHADAP PRESTASI TUMBESARAN ANAK POKOK KELAMPAYAN [*Neolamarckia cadamba* (Roxb.) Bosser]

Oleh

NOR FARHANA BINTI KHADIRAN

Februari 2021

Pengerusi : Prof. Mohd Zobir Hussein, PhD
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Pada masa kini, hidroksida berlapis dikaji secara intensif kerana bahan nano daripada jenis 2-dimensi (2D) ini dapat digunakan dalam pelbagai aspek pertanian, terutamanya sebagai matrik pelepasan nutrisi perlahan untuk pertumbuhan tanaman. Dalam kajian ini, hidroksida berlapis zink telah disintesis dengan keadah pemendakan bersama dan pertukaran anion untuk menghasilkan baja nano zink berlapis hidroksida nitrat (ZLHN) dan zink berlapis hidroksida fosfat (ZLHP), masing-masing digunakan untuk menilai kesan kecekapan penyerapan nitrat dan fosfat terhadap pertumbuhan tanaman. ZLHN dan ZLHP menunjukkan pembentukan puncak baru dengan jarak antara lapisan masing-masing ialah 9.57 Å dan 6.78 Å dalam corak pembelauan sinar-X mereka. Analisis FTIR, terma, kandungan organik-tak organik, luas permukaan dan morfologi menyokong penghasilan baja nano ZLHN dan ZLHP. Baja ZLH yang disintesis juga telah diuji untuk mengkaji pelepasan kinetik nutrisi manakala biocerakinan dilakukan pada anak benih Kelampayan (*Neolamarckia cadamba*). Kajian pelepasan terkawal ZLHN dan ZLHP dilakukan dalam air deionisasi, larutan natrium karbonat 0.005 M dan larutan media tanah pada pH 6.5. Pelepasan peratusan tertinggi dicatatkan sebagai 63.87% nitrat dalam larutan natrium karbonat 0.005 M dan 6.4% fosfat dalam air deionisasi sementara pelepasan peratusan yang lebih rendah dicatat pada 29.61% nitrat dan 0.21% fosfat dalam larutan media tanah pada 96 jam. Profil pelepasan paling sesuai ditunjukkan pada model kinetik order pseudo-kedua dengan nilai R^2 0.99 dan 0.97 masing-masing untuk "nanohybrid" ZLHN dan ZLHP. Nano-baja ZLH didapati tidak beracun terhadap pokok, di mana semua biji kacang hijau berjaya bercambah dalam proses penyemaian. Peratusan percambahan biji boleh disusun mengikut urutan baja nano ZLH>baja komersial>bahan utama. Selain itu, setelah enam belas minggu rawatan baja nano ZLH terhadap pertumbuhan anak benih kelampayan, data menunjukkan prestasi yang baik dan perbezaan yang ketara dari segi ketinggian dan ukur lilit batang berbanding rawatan lain.

Pada akhir kajian, pengambilan nutrisi oleh anak benih juga telah di analisis dan menunjukkan pengambilan yang lebih tinggi pada daun kelampayan yang dirawat dengan baja nano ZLH dan jauh lebih tinggi dibandingkan dengan rawatan lain. Kesimpulannya, kajian ini menunjukkan bahawa penghasilan baja nano ZLH berpotensi untuk digunakan sebagai sistem penyampaian baja nano.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

LMH	Layered metal hydroxide
LDH	Layered double hydroxide
ZLH	Zinc layered hydroxide
ZLHN	Zinc layered hydroxide nitrate
ZLHP	Zinc layered hydroxide phosphate
ANOVA	Analysis of variance
2D	2 dimension
PXRD	Powder X-Ray diffraction
FTIR	Fourier transform infrared spectroscopy
TGA/DSC	Thermogravimetric and differential scanning calorimetry
FESEM	Field emission scanning electron microscope
CRBD	Complete randomized block design

CHAPTER 1

INTRODUCTION

1.1 Background of study

Lately, nanotechnology becomes one of the active fields of research (Moore, 2006; Sergeev, et al., 2008) due to its promising in opening a huge number of opportunity in many fields like medicine (Hesse, et al., 2012; Kura, et al., 2013), pharmaceuticals (Silva, et al., 2019), electronics (Chen, et al., 2013; Maduraiveeran, et al., 2017) and agriculture (Zulfiqar, et al., 2019; Raliya, et al., 2018). The term "Nanotechnology" has been defined by Norio Taniguchi from the Science University of Tokyo in 1974 (Qureshi, et al., 2018) which studied manipulating the atomic and molecular size. Nanotechnology involved the design, synthesis and properties determination and the application of structures, devices and systems that will be controlled by the size and shape at the nanometer scale (Madhuri, et al., 2012), where the size of nanoparticles is in the range between 1-100 nm (Thakkar, et al., 2010; Deepa, et al., 2016). It has a high surface area (Khan, et al., 2019) and unique properties in optical, physical and biological properties (Rawtani, et al., 2018; Zhang, et al., 2017) which promising significant contribution to agricultural problems such as controlled delivery of fertilizer (Ghormade, et al., 2011), etc.

Plants need enough water and nutrients to live, stand with their species and biodiversity (Songkhum, et al., 2018) also increase crop productivity (Wissuwa, 2003). Most of the plants faced with wide challenges such as water availability, multi-nutrient deficiency (Godfray, et al., 2010) and low nutrient use efficiency (NUE) (Marchiol, 2018) due to the properties of soil, leaching and characteristics of fertilizer (Baligar, et al., 2015). Based on the data compiled by the Food and Agriculture Organization of the United Nations (FAO), the reduction of water and nutrients uptake would affect the production of agricultural products to meet the needs of the world due to the increasing population (York, 2017).

In the past decades, chemical fertilizer containing multi-nutrients such as N, P, K which were needed by the plants were used, and played an important role in increasing crop yield and maintaining enough food supplies (Chaudhary, et al., 2017; Meena, et al., 2016). Unfortunately, it created a negative impact on agro-ecosystem (Ding, et al., 2017), due to the high nutrient release into the ground and topwater, which also causes the emission of gases into the atmosphere (Drechsel, et al., 2015). These phenomena would cause the appearance of many problems including atmospheric (Zahoor, et al., 2014) and groundwater pollution (Datta, et al., 1997), soil acidification, eutrophication and loss of biodiversity (Mahanty, et al., 2017). Therefore, to overcome these limiting factors, a new strategy of nanotechnology attracts more attention, creating new nano-fertilizer which were used to increase the efficiency of nutrients uptake by plants and decreasing the loss of nutrients to the environment. The nano-fertilizer also provide control and slow release of nutrient (Jyothi, et al., 2017) allowing lower used of dosage (Preetha, et al., 2017).

The combination of nanotechnology and fertilizer, the so-called nano-fertilizer has changed the world of fertilizer in agriculture practices by creating new opportunities for advancing the nutrient uptake of plants. Nano-fertilizers is a product made using nanoparticles to improve the efficiency of nutrient uptake. The nano-fertilizer can be classified into nanoscale fertilizer (nanoparticles containing nutrients), nanoscale additives (traditional fertilizer with nanoscale additives and nanoscale coating (traditional fertilizer coated with nanoparticles) (Mikkelsen, 2018). These nano-fertilizer creating more penetration capacity, high surface area and high efficiency and eco-friendly (Qureshi, et al., 2018).

Layered metal hydroxide is the latest and advanced way of creating a nanofertilizer that can slowly supply nutrients to crops. Layered metal hydroxide is classified into two; layered double hydroxide (LDH) (Halajnia, et al., 2013) and layered hydroxide salts (LHs). Nowadays, the layered double hydroxide in the world of fertilizer (nitrogen, phosphate and potassium) were exploited followed by slow and controlled release properties (Novillo, et al., 2014) as a nanolayered-hosts, but in this study, the layered hydroxide salt (zinc layered hydroxide) was used as a host, and also was introduced as one of the alternatives to solve the problems faced by the conventional fertilizer.

1.2 Problem statement

Fertilizer is a chemical compound that is applied and used to help improve the performance of plant and fruit growth. Fertilizer is usually applied either through the soil or by foliar feeding which will help the root and leaves nutrient uptake, respectively. Population growth in the coming years will give a direct impact on the world of agriculture. Agriculture is an important source of nutrients for humans, like plants. Fertilizers are formulated in appropriate concentrations and involving the combinations of three main nutrients which are nitrogen which promotes leaf growth and forms protein and chlorophyll, phosphorus which contributes to roots and fruit development and potassium contributes to stem and root growth and synthesis of protein for various crop and produce good growing conditions. (Corradini, et al., 2010). However, the fertilizer applied in the plant will lose about 40-70% nitrogen, 80-90% phosphorus and 50-7-% of potassium to the environment and cannot easily be absorbed by plants. This phenomenon will leave very serious environmental pollution problems (Corradini, et al., 2010). The growth of the plants and their quality usually depend on the fertilizer quality and amount of water used (Liu, et al., 2008). Based on that, various methods which are involving the latest technology with innovative techniques for increasing crop yield by using environmentally clean chemistry which is also known by several authors as "green chemistry" (Praveen, et al., 2012).

Nowadays, the highest attention from researchers has been paid to layered hydroxide salt (LHS) and some studies have been demonstrated the use of these nanomaterials as the host matrices for storage and slow release of biologically active products which are also known as a guest (Benicio, et al., 2015). This is because of the good properties of the LHS as the host, and it is biodegradable and easy to prepare (Mohsin, et al., 2013). In addition, the host is commonly used for control and slow-release study in many applications. The slow-release properties are important in maintaining nutrient

availability by releasing critical nutrients for effective plant growth gradually (Madzokere, et al., 2020). The main reason for the intercalation activity of the guest anions into the interlayer galleries of layered hydroxide is to minimize the exposure of the guest anions which act as nutrients into the soil media. Here the work is focused on a review of layered metal hydroxide (LMH) such as zinc layered hydroxide which is acts as nanomaterials with potential use for agriculture for plant nutrition. To date, there is no intercalation of nitrate and phosphate into zinc layered hydroxide has been reported. The slow-release study was done in order to understand the release behavior of nitrate and phosphate in different media. The slow release of nitrate and phosphate is hoped to be effective and environmentally friendly.

1.3 Significant of the study

This research is focused on the synthesis of zinc-layered hydroxide, where nitrate and phosphate are used as the counter anions using zinc nitrate hexahydrate, $Zn(NO_3)_2.6H_2O$ and potassium dihydrogen phosphate, KH_2PO_4 as the starting salts. The use of zinc-layered hydroxide as eco-friendly, low nutrients consumption, prolongs the release of the active agent at an appropriate rate and in the low-cost production process (Ahmed, et al., 2016). In planting application, the ZLH nanofertilizer has the potential for reducing the release amount of nutrients presented in nanofertilizer making the nanofertilizer more available to nanoscale kelampayan tree pores resulting in the high nutrient use efficiency (Dwevedi, et al., 2016).

1.4 Objectives

The objectives of this study are outlined as listed below:

1) To synthesis zinc layered hydroxide (ZLH) nanohybrid which is used as a host to containing two plant nutrients; nitrogen and phosphorous and deliver them for better plant uptake.

2) To characterize the physico-chemical properties of zinc layered hydroxide fertilizer nanohybrid and study the release behavior of the Nitrogen and Phosphorous from the synthesized nanohybrid.

3) To evaluate the suitability of this new fertilizer formulation toward plant growth and nutrient plant uptake.

1.5 Limitations

Although this research has reached its aims, there were some notable limitations:

1) The sample powder of ZLHN and ZLHP (ZLH nanofertilizer) were produced in small volume for each synthesis.

2) Each synthesized sample powder of ZLH nanofertilizer goes to XRD analysis for passing some criteria before applied to Kelampayan seedlings.

3 The Kelampayan seedlings growth study in a short duration due to the limited time to use the facilities of FRIM's nursery which followed the date of the project study.

REFERENCES

Abdelkader, A. E. (2019). Effect of different levels of farmyard manure, mineral fertilization and potassium humate on growth and productivity of garlic. *Middle East Journal of Applied Sciences., 9*(2), 287-296.

Abdou, A. S., Al-Darwish, F. H., Saleh, M. E., El-Tarabily, K. A., Azirun, M. S., & Rahman, M. M. (2011). Effect of elemental sulfur, phosphorus, micronutrients and Paracoccus versutus on nutrient availability of calcareous soils. *Australian Journal of Crop Science., 5*(5), 554-561.

Abed, N. N., Abudoleh, S. M., Alshawabkeh, I. D., Abed, A. N., Abuthawabeh, R. A., & Hussein-Al-Ali, S. H. (2017). Aspirin Drug Intercalated into Zinc-Layered Hydroxides as Nanolayers: Structure and In Vitro Release. *Nano Hybrids and Composites., 18*, 42-52.

Acharyya, S., Rathore, D. S., Kumar, H. S., & Panda, N. (2011). Screening of Anthocephalus cadamba (Roxb.) Miq. root for antimicrobial and anthelmintic activities. *International Journal Research Pharmaceut Biomed Sci., 2*(1), 297-300.

Ahmad, Z. Y., Hashim, M. N., & Sarifah, K. (2012). Study on the Domestication of Lesser Known Tropical Species Neolamarckia Cadamba Among the Small to Medium Scale Forest Owner in Malaysia. *Paper presented at 2012 IUFRO Small-Scale Forestry Conference: Science for Solutions, 24-27 September, Amherst, Massachusetts, USA.*

Akay, A. (2011). Effect of zinc fertilizer applications on yield and element contents of some registered chickpeas varieties. *African Journal of Biotechnology., 10*, 1309013096.

Al Ali, S. H., Al-Qubaisi, M., Hussein, M. Z., Zainal, Z., & Hakim, M. N. (2011). Preparation of hippurate-zinc layered hydroxide nanohybrid and its synergistic effect with tamoxifen on HepG2 cell lines. *International Journal of Nanomedicine., 6*, 3099-3111.

Al-Jaberi, M., Naille, S., Dossot, M., & Ruby, C. (2015). Interlayer interaction in CaeFe layered double hydroxides intercalated with nitrate and chloride species. *Journal of Molecular Structure., 1102*, 253-260.

Al-Kaysi, R. O., Ghaddar, T. H., & Guirado, G. (2009). Fabrication of One-Dimensional Organic Nanostructures Using Anodic Aluminum Oxide Templates. *Journal of Nanomaterials.*, 1-14.

Antille, D. L., Hoekstra, N. J., & Lalor, S. J. (2015). Field-Scale Evaluation of Calcium Ammonium Nitrate, Urea, and Urea Treated with N-(N-Butyl) Thiophosphoric Triamide Applied to Grassland in Ireland. *Communications in Soil Science and Plant Analysis., 46*(11), 1345-1361.

Arizaga, G. C., Satyanarayana, K. G., & Wypych, F. (2007). "Layered hydroxide salts: synthesis, properties and potential applications". *Solid State Ionics, 178*(15-18), 1143-1162.

Bae, H., & Jung, H. (2012). Electron Beam Mediated Simple Synthetic Route to Preparing Layered Zinc Hydroxide. *Bulletin of the Korean Chemical Society., 33*(6), 19491954.

Bahadur, I., Maurya, B. R., Kumar, A., Meena, V. S., & Raghuwanshi, R. (2016). Towards the Soil Sustainability and Potassium-Solubilizing Microorganisms. In V. S.

Meena, B. R. Maurya, V. J. Prakash, & R. S. Meena, *Potassium Solubilizing Microorganisms for Sustainable Agriculture.* (pp. 255-266). Springer.

Baikousi, M., Stamatis, A., Louloudi, M., & Karakassides, M. A. (2013). Thiamine pyrophosphate intercalation in layered double hydroxides (LDHs): An active biohybrid catalyst for pyruvate decarboxylation. *Applied Clay Science., 75-76*, 126133.

Baligar, V. C., & Fageria, N. K. (2015). Nutrient use efficiency in plants: An overview. In A. Rakshit, H. B. Singh, & A. Sen, *Nutrient Use Efficiency: From Basics to Advances* (pp. 1-14). New Delhi: Springer.

Banerji, N., & Dutta, N. L. (1976). Structure of a New Saponin from Stem Bark of Anthocephalus cadamba Mig. *Indian Journals Chem. (Sec B).*, 614.

Barahuie, F., Hussein, M. Z., Abd Gani, S., Fakurazi, S., & Zainal, Z. (2014). Anticancer nanodelivery system with controlled release property based on protocatechuate– zinc layered hydroxide nanohybrid. *International Journal of Nanomedicine., 9*, 3137-3149.

Benicio, L. F., Constantino, V. L., Pinto, F. G., Vergiitz, L., Tronto, J., & da Costa, L. M. (2017). Layered Double Hydroxides: New Technology in Phosphate Fertilizers Based on Nanostructured Materials. *Sustainable Chemistry & Engineering., 5*, 399-409.

Benicio, L. P., Silva, R. A., Lopes, J. A., Aquino, L. A., Eulalio, D., Santos , R. M., Tronto, J. (2015). Layered double hydroxides: Nanomaterials for applications in agriculture. *R. Bras. Ci.Solo, 39*, 1-13.

Besford, R., & Maw, G. (1975). Effect of potassium nutrition on tomato plant growth and fruit development. *Plant and Soil., 42*(2), 395-412.

Bi, X., Zhang, H., & Dou, L. (2014). Layered double hydroxide-based nanocarriers for drug delivery. *Pharmaceutics., 6*(2), 298-332.

Biswick, T., Jones, W., Pacula, A., & Serwicka, E. (2006). Synthesis, characterisation and anion exchange properties of copper, magnesium, zinc and nickel hydroxy nitrates. *Journal of Solid State Chemistry., 179*(1), 49-55.

Biswick, T., Jones, W., Pacula, A., Serwicka, E., & Podobinski, J. (2007). The role of anhydrous zinc nitrate in the thermal decomposition of the zinc hydroxy nitrates Zn5(OH)8(NO3)2 2H2O and ZnOHNO3 H2O. *Journal of Solid State Chemistry., 180*(4), 1171-1179.

Biswick, T., Park, D.-H., & Choy, J.-H. (2012). Enhancing the UV A1 screening ability of caffeic acid by encapsulation in layered basic zinc hydroxide matrix. *Journal of Physics and Chemistry of Solids., 73*, 1510-1513.

Borges, R., Wypych, F., Petit, E., Forano, C., & Prevot, V. (2019). Potential Sustainable Slow-Release Fertilizers Obtained by Mechanochemical Activation of MgAl and MgFe Layered Double Hydroxides and K2HPO4. *Nanomaterials., 9*, 1-18.

Bown, H. E., Watt, M. S., Clinton, P. W., & Mason, E. G. (2010). Influence of ammonium and nitrate supply on growth, dry matter partitioning, N uptake and photosynthetic capacity of Pinusradiata seedlings. *Trees., 24*(6), 1097-1107.

Bukhtiyarova, M. V. (2019). A review on effect of synthesis conditions on the formation of layered double hydroxides. *Journal of Solid State Chemistry., 269*, 494-506.

Bullo, S., Mohd, Z. H., Samer, H. H., Palanisamy, A., & Sharida, F. (2013). Sustained release formulation of an anti-tuberculosis drug based on para-amino salicylic acid-zinc layered hydroxide nanocomposite. *Chemistry Central Journal*, 1-11.

Cataldo, S., Salice, P., Menna, E., & Pignataro, B. (2012). Carbon nanotubes and organic solar cells. *Energy & Environmental Science., 5*(3), 5919-5940.

Chakraborty, J., Roychowdhury, S., Sengupta, S., & Swapankumar, G. (2013). Mg–Al layered double hydroxide–methotrexate nanohybrid drug delivery system:Evaluation of efficacy. *Materials Science and Engineering C, 33*, 21682174.

Chaudhary, S., Dheri, G. S., & Brar, B. S. (2017). Long-term effects of NPK fertilizers and organic manures on carbon stabilization and management index under rice wheat cropping system. *Soil and Tillage Research., 166*, 59-66.

Chen , T., Luo, X., Zhu, H., Taylor, C. M., Ehrendorfer, F., Lantz, H., . . . Puff, C. (2011). Rubiaceae. *Flora of China., 19*, 57.

Chen, H., Hu, L., Chen, M., Yan, Y., & Wu, L. (2013). Nickel–Cobalt Layered Double Hydroxide Nanosheets for High-performance Supercapacitor Electrode Materials. *Advanced Functional Materials., 24*(7), 934-942.

Cheng, X., Huang, X., Wang, X., Zhao, B., Chen, A., & Sun, D. (2009). Phosphate adsorption from sewage sludge filtrate using zinc–aluminum layered double hydroxides. *Journal of Hazardous Materials., 169*, 958-964.

Corradini, E., Moura, M. d., & Mattoso, L. (2010). A preliminary study of the incorparation of NPK fertilizer into chitosan nanoparticles. *eXPRESS Polymer Letters, 4*(8), 509-515.

Costa, C., Dwyer, L. M., Zhou, X., Dutilleul, P., Hamel, C., Reid, L. M., & smith, D. L. (2002). Root Morphology of Contrasting Maize Genotypes. *Agronomy Journal., 94*(1), 96-101.

Costantino, U., Vivani, R., Bastianini, M., Costantino, F., & Nocchetti, M. (2014). Ion exchange and intercalation properties of layered double hydroxides towards halide anions. *Journal Transactions.*, 1-22.

Cursino, A. T., Gardolinski, J. d., & Wypych, F. (2010). Intercalation of anionic organic ultraviolet ray absorbers into layered zinc hydroxide nitrate. *Journal of Colloid and Interface Science., 347*, 49-55.

da Rocha, M. G., Nakagaki, S., Ucoski, G. M., Wypych, F., & Machado, G. S. (2019). Comparison between catalytic activities of two zinc layered hydroxide Salts in brilliant green organic dye bleaching. *Journal of Colloid and Interface Science., 541*, 425-433.

Dania , S. O., Akpansubi, P., & Eghagara, O. O. (2014). Comparative Effects of Different Fertilizer Sources on the Growth and Nutrient Content of Moringa . *Advances in Agriculture.*, 1-6.

Darroudi , M., Ahmad, M. B., Abdullah, A. H., & Ibrahim, N. A. (2011). Green synthesis and characterization of gelatine-based and sugar reduced silver nanoparticles. *International Journal of Nanomedicine., 6*, 569-574.

Datta, P. S., Deb, D. L., & Tyagi, S. K. (1997). Assessment of groundwater contamination from fertilizers in the Delhi area based on 18O, NO3- and K+ composition. *Journal of Contaminant Hydrology., 27*(3-4), 249-262.

Deepa, M. K., Suryaprakash, T. N., & Kumar, P. (2016). Green synthesized silver nanoparticles. *Journal of Chemical and Pharmaceutical Research., 8*(1), 411-419.

Demel, J., Hynek, J., Kovar, P., Dai, Y., Taviot-Gueho, C., Demel, O., Lang, K. (2014).Insight into the Structure of Layered Zinc Hydroxide Salts Intercalated with Dodecyl Sulfate Anions. *The Journal of Physical Chemistry C., 118*(46), 2713127141.

DeRose, M. C., Monreal, C., Schnitzer, M., Walsh, R., & Sultan, Y. (2010). Nanotechnology in fertilizers. *Nature Nanotechnology., 5*(2), 91.

Ding, J., Jiang, X., Guan, D., Zhao, B., Ma, M., Zhou, B., . . . Li, J. (2017). Influence of inorganic fertilizer and organic manure application on fungal communities in longterm field experiment of Chinese Mollisols. *Applied Soil Ecology., 111*, 114-122.

Dong, L., Li, Y., Hou, W., & Liu, S. (2010). Synthesis and release behavior of composites of camptothecin and layered double hydroxide. *Journal of Solid Chemistry, 183*, 1811-1816.

Drechsel, P., Heffer, P., Magen, H., Mikkelsen, R., & Wichelns, D. (2015). *Managing Water and Fertilizer for Sustainable Agricultural Intensification.* First edition, Paris, France.

Du, Y., Rees, N., & O'Hare, D. (2009). A study of phosphate absorption by magnesium iron hydroxycarbonate. *Dalton Transactions.*, 8197-8202.

Dwivedi, S., Saquib, Q., Al-Khedhairy, A. A., & Musarrat, J. (2016). Understanding the Role od Nanomaterials in Agriculture. In S. D. Pratap, S. H. Bahadur, & P. Ratna, *Microbial Inoculants in Sustainable Agricultural Productivity.* (pp. 271-288).

Elkhattabi, E. H., Lakraimi, M., Badreddine, M., Legrouri, A., Cherkaoui, O., & Berraho, M. (2013). Removal of Remazol Blue 19 from wastewater by zinc–aluminium–chloride-layered double hydroxides. *Applied Water Science., 3*(2), 431-438.

Everaert, M., Slenders, K., Dox, K., Smolders, S., De Vos, D., & Smolders, E. (2018). The isotopic exchangebility of phosphate in Mg-Al layered double hydroxide. *Journal of Colloid and Interface Science, 520*, 25-32.

Garnica, M., Houdusse, F., Zamarreno, A., & Garcia-Mina, J. M. (2010). The signal effect of nitrate supply enhances active forms of cytokinins and indole acetic content and reduces abscisic acid in wheat plants grown with ammonium. *Journal of Plant Physiology., 167*(15), 1264-1272.

Ghormade, V., Deshpande, M. V., & Paknikar, K. M. (2011). Perspectives for nanobiotechnology enabled protection and nutrition of plants. *Biotechnology Advances, 29*(6), 792-803.

Giron, D., Frago, E., Glevarec, G., Pieterse, C. J., & Dicke, M. (2013). Cytokinins as key regulators in plant–microbe–insect interactions: connecting plant growth and defence. *Functional Ecology., 27*, 599-609.

Godfray, H. J., Beddington, J. R., Crute, I. R., Haddad, I., Lawrence, D., Muir, J. F., Toulmin, C. (2010). Food security: The challenge of feeding 9 billion people. *Science., 327*, 812-818.

Gogos , A., Knauer, K., & Bucheli, T. D. (2012). Nanomaterials in plant protection and fertilization: Current State, foreseen applications and research priorities. *Journal of Agricultural and Food Chemistry., 60*(39), 9781-9792.

Goh, K., Banas, A., Lim, T. T., & Dong, Z. (2010). Sorption characteristics and mechanisms of oxyanions and oxyhalides having different molecular properties on Mg/Al layered double hydroxide nanoparticles. *Journal of hazardous materials., 179*(1-3), 818-827.

Gopi, R., C. A. Jaleel, SairamR., G. M. A. Lakshmanan, M. Gomathinayagam, and R. Panneerselvam. "Differential effects of hexaconazole and paclobutrazol on biomass, electrolyte leakage, lipid peroxidation and antioxidant potential of Daucus carota L." *Colloids and Surfaces B: Biointerfaces.* 60 (2007): 180-186.

Grey, L. E., & Ragozzini, R. (1991). Formation and characterization of new magnesium aluminum hydroxycarbonates. *Journal of Solid State Chemistry., 94*(2), 244-253.

Halajnia, A., Oustan, S., NajafiN., Khataee, A. R., & Lakzian, A. (2013). Adsorptiondesorption characteristics of nitrate, phosphate and sulfate on Mg-Al layered double hydroxide. *Applied Clay Science., 80-81*, 305-312.

Hartung, J., Wagener, J., Ruser, R., & Piepho, H. (2019). Blocking and re-arrangement of pots in greenhouse experiments: which approach is more efective? *Plant Methods, 143*(15), 1-11.

Hasan, S., Al Ali, H., Al-Qubaisi, M., Hussein, M. Z., Ismail, M., Zainal, Z., & Hakim, M. N. (2012). Controlled-release formulation of antihistamine based on cetirizine zinc-layered hydroxide nanocomposites and its effect on histamine release from basophilic leukemia (RBL-2H3) cells. *International Journal Nanomedicine, 7*, 3351-3363.

Hashim , N., Muda, Z., Md Isa, I., Ali, N. M., Bakar, S. A., & Hussein, M. Z. (2018). The effect of ion exchange and co-precipitation methods on the intercalation of 3-(4methoxyphenyl)propionic acid into layered zinc hydroxide nitrate. *Journal of Porous Materials., 25*, 249-258.

Hashim, N., Sharif, S. M., Md Isa, I., Hamid, S. A., Hussein, M. Z., Bakar, S. A., & Mamat, M. (2017). Controlled release formulation of an anti-depression drug based on a L- phenylalanate-zinc layered hydroxide intercalation compound. *Journal of Physics and Chemistry of Solids., 105*, 35-44.

Hashim, N., Sharif, S. M., Muda, Z., Md Isa, I., Ali, N. M., Bakar, S. A., . . . Hussein, M. Z. (2018). Preparation of zinc layered hydroxide-ferulate and coated zinc layered hydroxide-ferulate nanocomposites for controlled release of ferulic acid. *Materials Research Innovations.*, 1-13.

He, H., Kang, H., Ma, S., Bai, Y., & Yang, X. (2010). High adsorption selectivity of ZnAl layered double hydroxides and the calcined materials toward phosphate. *Journal of Colloid and Interface Science., 343*, 225-231.

Heraldy, E., Suprihatin, R. W., & Pranoto. (2016). Intercalation of diclofenac in modified Zn/Al hydrotalcite-like preparation. *10th Joint Conference on Chemistry. 107*, p. 012026. IOP Conference Series: Materials and Engineering.

Hesse, D., Badar, M., Bleich, A., Smoczek, A., Glage, S., Kieke, M., . . . Prenzler, N. K. (2012). Layered double hydroxides as efficient drug delivery system of ciprofloxacin in the middle ear: an animal study in rabbits. *Journal of Materials Science: Materials in Medicine., 24*(1), 129-136.

Hewitt, C. A., Kaiser, A. B., Roth, S., Craps, M., Czerw, R., & Carroll, D. L. (2012). Multilayered Carbon Nanotube/Polymer Composite Based Thermoelectric Fabrics. *Nano Letters., 12*(3), 1307-1310.

Ho, W. S., Pang, S. L., & Abdullah, J. (2014). Identification and analysis of expressed sequence tags present in xylem tissues of kelampayan (Neolamarckia cadamba (Roxb.). *Physiology and Molecular Biology of Plants., 2*(3), 393-397.

Hussein, M. Z., Al Ali, S. H., Zainal, Z., & Hakim, M. N. (2011). Development of antiproliferative nanohybrid compound with controlled release property using ellagic acid as the active agent. *International Journal of Nanomedicine., 6*, 13731383.

Hussein, M. Z., Ghotbi, M. Y., Yahaya, A., & Rahman, M. A. (2009). The effect of polymers onto the size of zinc layered hydroxide salt and its calcined product. *Solid State Sciences., 11*, 368-375.

Hussein, M. Z., Nazarudin, N. B., Sarijo, S. H., & Yarmo, M. A. (2012). Synthesis of a layered organic-inorganic nanohybrid of 4-chlorophenoxyacetate-zinc-layered hydroxide with sustained release properties. *Journal of Nanomaterials*, 9.

Hussein, M. Z., Rahman, N. A., Sarijo, S. H., & Zainal, Z. (2012). Herbicide-Intercalated Zinc Layered Hydroxide Nanohybrid for a Dual-Guest Controlled Release Formulation. *International Journal of Molecular Science., 13*, 7328-7342.

Inayat, A., Klumpp, M., & Schwieger, W. (2011). The urea method for the direct synthesis of ZnAl layered double hydroxides with nitrate as the interlayer anion. *Applied Clay Science., 51*(4), 452-459.

Jaafar, A. M., Anuar, A. N., Hashim, N., & Ayob, F. H. (2016). Intercalation study of Curcumin into Zinc Layered Hydroxide. *Malaysian journal of analytical sciences, 20*(6), 1359-1364.

Jaerger, S., Zimmermann, A., Zawadzki, S. F., Wypych, F., & Amico, S. C. (2014). Zinc Layered Hydroxide Salts: Intercalation and Incorporation into Low-Density Polyethylene. *Polimeros, 24*(6), 673-682.

Jamil, S., Khan, S. R., Alvi, A. R., Kausar, F., Ali, S., Khan, S. A., . . . Janjua, M. S. (2020). Morphologically controlled synthesis, characterization and application of zinc-aluminum layered double hydroxide nano needles. *Chemical Physics., 528*, 110530.

Jatav, J., Jatav, R., Bhardwaj, S. K., Sahu, P. K., & Kumar, K. (2016). Synthesis and characterization of hydrotalcites. *Journal of Chemical and Pharmaceutical Research, 8*(2), 678-696.

Jatav, K. S., Agarwal, R. M., Tomar, N. S., & Tyagi, S. R. (2014). Nitrogen metabolism, growth and yield responses of wheat (Triticum aestivum L.) to restricted water supply and varying potassium treatments. *Journal of Indian Botanical Society., 93*, 177-189.

Jyothi, T. V., & Hebsur, N. S. (2017). Effect of nanofertilizers on growth and yield of selected cereals- A review. *Agricultural Reviews., 38*(2), 112-120.

Kang, S. Z., Wu, T., Li, X., & Mu, J. (2010). A facile gelatin-assisted preparation and photocatalytic activity of zinc oxide nanosheets. *Colloids and Surfaces A., 369*, 268-271.

Keller, A. A., Wang, H., Zhou, D., Lenihan, H. S., Cherr, G., Cardinale, B. J., . . . Ji, Z. (2010). Stability and Aggregation of Metal Oxide Nanoparticles in Natural Aqueous Matrices. *Environmental Science & Technology., 44*, 1962-1967.

Khan, I., Saeed, K., & Khan, I. (2019). Nanoparticles: Properties, applications and toxicities. *Arabian Journal of Chemistry., 12*(7), 908-931.

Khodakovskaya, M., Dervishi, E., Mahmood, M., Xu, Y., Li, Z., Watanabe, F., & Biris, A. S. (2009). Carbon Nanotubes Are Able To Penetrate Plant Seed Coat and Dramatically Affect Seed Germination and Plant Growth. *ACS Nano, 3*(10), 32213227.

King, N., Seiler, J., Fox, T. R., & Johnsen, K. (2006). Johnsen K. The short-tem effects of fertilization on loblolly pine photosynthesis and biomass. In: Conner KF, editor. *Proceedings of the 13th Biennial Southern Silvicultural Research.* (pp. 113-116). Ashville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station.

Kratz, S., & Schnug, E. (2006). Rock phosphates and P fertilizers as sources of U contamination in agricultural soils. In B. J. Merkel, & A. Hasche-Berger, *Uranium in the Environment.* (pp. 57-67). Springer, Berlin, Heidelberg.

Krisnawati, H., Kallio, M., & Kanninen, M. (2011). Anthochepalus cadamba Miq. Ecology, silviculture and productivity. . *Indonesia: Center for International Forestry Research.*

Kumar, S., Nehra, M., Dilbaghi, N., Marrazza, G., Hassan, A. A., & Kim, K. (2019). Nano-based smart pesticide formulations: Emerging opportunities for agriculture. *Journal of Controlled Release., 294*, 131-153.

Kura, A. U., Al Ali, S. H., Hussein, M. Z., Fakurazi, S., & Arulselvan, P. (2013). Development of a controlled-release anti-parkinsonian nanodelivery system using levodopa as the active agent. *International Journal of Nanomedicine., 8*, 11031110.

Lal , R. (2008). Promise and limitations of soils to minimize climate change. *Journal of Soil and Water Conservation., 63*, 113A-118A.

Lal, M., Dutt, D., Tyagi, C. H., Upadhyay, J. S., & Upadhyay, S. (2010). Characterization of Anthocephalus cadamba and its delignification by kraft pulping by kraft pulping. *Tappi Journal., 9*(3), 30-37.

Lamprecht, H. (1989). Silviculture in the tropics; Tropical forest ecosystems and their tree species - Possibilities and methods for their long-term utilization. *Eschbor (DE): Deutsche Gesellschaft fur TechnischeZusammenarbeit (GTZ).*

Lee, K. X., Shameli, K., Miyake, M., Kuwano, N., Khairudin, N. A., Mohamad, S. E., & Yew, Y. P. (2016). Green Synthesis of Gold Nanoparticles Using Aqueous Extract of Garcinia Mangostana Fruit Peels. *Journal of Nanomaterials.*, 1-7.

Lei, X., Lu, W., Peng, Q., Li, H., Chen, T., Xu, S., & Zhang, F. (2011). Activated MgAllayered double hydroxide as solid base catalysts for the conversion of fatty acid methyl esters to monoethanolamides. *Applied Catalysis A: General., 399*(1-2), 8792.

Li, B., He, J., Evans, D. D., & Duan, X. (2004). Inorganic layered double hydroxides as a drug delivery system—intercalation and in vitro release of fenbufen. *Applied Clay Science., 27*(3-4), 199-207.

Li, C., Wang, G., Evans, D. G., & Duan, X. (2004). Incorporation of rare-earth ions in Mg–Al layered double hydroxides: intercalation with an [Eu(EDTA)]− chelate. *Journal of Solid State Chemistry., 177*(12), 4569-4575.

Liang, C., Tian, Z., Tsuruoka, T., Cai, W., & Koshizaki, N. (2011). Blue and green luminescence from layered zinc hydroxide/dodecyl sulfate hybrid nanosheets. *Journal of Photochemistry and Photobiology A: Chemistry., 224*(1), 110-115.

Lincoln, M. C., Will, R. E., Morris, L. A., Carter, E. A., Markewitz, D., Britt, J. R., Ford, V. (2007). Soil change and loblolly pine (Pinustaeda) seedling growth following site preparation tillage in the Upper Coastal Plain of the southeastern United States. *Forest Ecology and Management., 242*, 558-568.

Liu, H., Sun, X., Yin, C., & Hu, C. (2008). Removal of phosphate by mesoporous ZrO2. *Journal of Hazardous Materials., 151*(2-3), 616-622.

Liu, J., & Zhang, Y. (2016). Inorganic-organic nanohybrid materials of layered zinc hydroxide nitrate with intercalated salicylate: preparation, characterization and uvblocking properties. *International Journal of Nanoscience., 15*, 1-9.

Liu, M., & Wu, L. (2008). Preparation and properties of chitosan-coated NPK compound fertilizer with control-release and water-retention. *Carbohydrate Polymers, 72*, 249.

Liu, R., & Lal, R. (2015). Potentials of engineered nanoparticles as fertilizers for increasing agronomic productions. *Science of The Total Environment., 514*, 131139.

Liu, X., Gu, X., Zhang, S., Jiang, Y., Sun, J., & Dong, M. (2013). Effect of dihydrogen phosphate intercalated layered double hydroxides on the crystal behaviours and flammability of polypropylene. *Journal of Applied Polymer Science., 130*(5), 3645-3651.

Loh, X. J., Lee, T. C., Dou, Q., & Deen, G. R. (2016). Utilising inorganic nanocarriers for gene delivery. *Biomaterials Science., 4*(1), 70-86.

Machado, G. S., Arizaga, G. C., Wypych, F., & Nakagaki, S. (2010). Immobilization of anionic metalloporphyrins on zinc hydroxide nitrate and study of an unusual catalytic activity. *Journal of Catalysis.*, *274*, 130-141.

Madhuri, S., Maheshwar, S., Sunil, P., & Oza, G. (2012). *Nanotechnology: concepts and applications.* CRC Press USA, 4.

Maduraiveeran, G., & Jin, W. (2017). Nanomaterials based electrochemical sensor and bio-sensor platforms for environmental applications. *Trends in Environmental Analytical Chemistry.*,*13*, 10-23.

Madzokere, T. C., Murombo, L. T., & Chirirriwa, H. (2020). Nano-based slow releasing fertilizers for enhanced agricultural productivity. *Materials Today: Proceedings.*

Mahanty, T., Bhattacharjee, S., Goswami, M., Bhattacharyya, P., Das, B., Ghosh, A., & Tribedi, P. (2017). Biofertilizer: a potential approach for sustainable agriculture development. *Environmental Science and Pollution Research International.*, *24*(4), 3315-3335.

Maheswari, M., Murthy, A. G., & Shanker, A. K. (2017). 12- Nitrogen Nutrition in Crops and Its Importance in Crop Quality. *The Indian Nitrogen Assessment.*, 175-186.

Malakouti, M. J. (2008). "The effect of micronutrients in ensuring efficient use of macronutrients," . *Turkish Journal of Agriculture and Forestry.*, *32*, 215-220.

Marchiol, L. (2018). *Nanotechnolog in Agriculture: New Opportunities and Perspectives.* Intechopen.

Marschner, H. (1995). *Mineral Nutrition of Higher Plant,.* Academic Press, Cambridge, MA, USA.

Marschner, H. (1995). *Mineral Nutrition of Higher Plants, 2nd edition.* . New York: Academic.

Mas-Balleste, R., Gomez-Navarro, C., Gomez-Herrore, J., & Zamaro, F. (2011). 2D materials: to graphene and beyond. *Nanoscale.*, *3*(1), 20-30.

Mastronardi, E., Tsae, P., Zhang, X., Monreal, C., & DeRosa, M. C. (2015). Strategic Role of Nanotechnology in Fertilizers: Potential and Limitations. *Nanotechnologies in Food and Agriculture.*, 25-67.

McCauley, A., Jones, C., & Jacobsen, J. (2011). *Plant Nutrient Functions and Deficiency and Toxicity Symptoms.*

Meena, M. D., Joshi, P. K., Jat, H. S., Chinchmalatpure, A. R., Narjary, B., Sheoran, P., & Sharma, D. K. (2016). Changes in biological and chemical properties of salina soil amended with municipal solid waste compost and chemical fertilizers in a mustard-pearl millet cropping system. *CATENA*, *140*, 1-8.

Meena, O. P., Maurya, B. R., & Meena , V. S. (2013).) Influence of Ksolubilizing bacteria on release of potassium from waste mica. *Agriculture for Sustainable Development., 1*(1), 53-56.

Meena, V. S., Maurya, B. R., Meena, S. K., Mishra, P. K., Bisht, J. K., & Pattanayak, A. (2018). Potassium solubilization: Strategies to mitigate potassium deficiency in agricultural soils. *Global Journal of Biology, Agriculture & Health Sciences., 7*(2), 1-3.

Micciche, C., Arrabito, G., Amato, F., Buscarino, G., Agnello, S., & Pignataro, B. (2018). Inkjet printing Ag nanoparticles for SERS hot spots. *Analytical Methods., 10*(26), 3215-3223.

Mikkelsen, R. (2018). Nanofertilizer and Nanotechnology: A quick look. *Better Crops with Plant Food, 102*(3), 18-19.

Mishra, G., Dash, B., & Pandey, S. (2018). Layered double hydroxide: A brief review from fundamentals to application as evolving biomaterials. *Applied Clay Science, 153*, 172-186.

Mishra, R. P., & Siddique, L. (2011). Antibacterial properties of Anthocephalus cadamba fruits. *Asian Journal of Plant Science and Research., 1*(2), 1-7.

Moezzi, A., Cortie, M., & McDonagh, A. M. (2013). Formation of Zinc Hydroxide Nitrate by H+-Catalyzed Dissolution-Precipitation. *European Journal of Inorganic Chemistry., 8*, 1326-1335.

Mohsin, S. M., Hussein , M. Z., Sarijo, S. H., Fakurazi, S., Arulselvan, P., & Hin, T. Y. (2013). Synthesis of (cinnamate-zinc layered hydroxide) intercalation compound for sunscreen application. *Chemistry Central Journal, 7*(26), 1-12.

Mohsin, S. N., Hussein, M. Z., Sarijo, S. H., Fakurazi, S., Arulselvan, P., & Taufiq-Yap, Y. H. (2014). Optimization of UV Absorptivity of Layered Double Hydroxide by Intercalating Organic UV-Absorbent Molecules. *Journal of Biomedical Nanotechnology., 10*, 1-11.

Mohsin, S. N., Hussein, M. Z., Sarijo, S. H., Fakurazi, S., Arulsevan, P., & Taufiq, Y. H. (2013). Synthesis of (cinnamate-zinc layered hydroxides) intercalation compound for suncreen application. *Chemistry Central Journal., 7*(26), 1-12.

Moore, M. N. (2006). Do nanoparticles present ecotoxicological risks for the health of the aquatic environment. *Envirnmental International., 32*, 967-976.

Mousavi, S. M., Hashemi, S. A., Salahi, S., Hosseini, M., Amani, A. M., & Babapoor, A. (2018). *Development of Clay Nanoparticles Toward Bio and Medical Applications.* Intechopen.

Mousavi, S. R. (2011). Zinc in crop production and interaction with phosphorus. *Australian Journal of Basic and Applied Science., 5*, 1503-1509.

Nabipour, H., & Sadr, M. H. (2015). Controlled release of Diclofenac, an antiinflammatory drug by nanocompositing with layered zinc hydroxide. *Journal of Porous Materials, 22*(2), 447-454.

Nabipour, H., & Sadr, M. H. (2015). Layered zinc hydroxide–ibuprofen nanohybrids: synthesis and characterization. *Bulletin of Materials Science., 38*(6), 1561-1567.

Nabipour, H., Sadr, M. H., & Soltani, B. (2016). Synthesis, identification and in vitro drug release of layered zinc hydroxide-gemifloxacin nanohybrids. *Journal of Inclusion Phenomena and Macrocyclic Chemistry*, 261-269.

Nasrollahzadeh, M., Issaabadi, Z., Sajjadi, M., Sajadi, S. M., & Atarod, M. (2019). Types of Nanostructures. *Interface Science and Technology., 28*, 29-80.

Naveena, E. B., & Prakash, S. (2013). Biological synthesis of gold nanoparticles using marine algae Gracilaria Corticata and its application as a potential antimicrobial and antioxidant agent. *Asian Journal of Pharmaceutical and Clinical Research., 6*(2), 179-182.

Newman, S. P., & Jones, W. (1999). Comparative Study of Some Layered Hydroxide Salts Containing Exchangeable Interlayer Anions. *Journal of Solid State Chemistry., 148*(1), 26-40.

Nguyen, T. X., Huang, L., Liu, L., Elamin Abdalla, A. M., Gauthier, M., & Yang, G. (2014). Chitosan-coated nano-liposomes for the oral delivery of berberine hydrochloride. *Journal Material Chemistry, 2*, 7149-7159.

Novillo, C., Guaya, D., Avendano, A. A., Armijos, C., Cortina, J. L., & Cota, I. (2014). Evaluation of phosphate removal capacity of Mg/Al layered double hydroxides from aqueous solutions. *Fuel, 138*, 72-79.

Ogawa, M., & Inomata, K. (2006). Preparation of Mg/Al Layered Double Hydroxide–Oleate Intercalation Compound by a Reconstruction Method under Hydrothermal Condition. *The Chemical Society of Japan., 79*(2), 336-342.

Oh, J., Biswick, T. T., & Choy, J. (2009). Layered nanomaterials for green materials. *Journal of Materials Chemistry., 19*, 2553-2563.

Patel, D., & Kumar, V. (2008). Pharmacognostical studies of Neolamarckia cadamba (roxb.) Bosser leaf. *International Journal of Green Pharmacy.*, 26-27.

Perez-Ramirez, J., Abello, S., & van der Pers, N. M. (2007). Memory Effect of Activated Mg–Al Hydrotalcite: InSitu XRD Studies. *Chemistry-A European Journal., 13*(3), 870-878.

Praveen , G., Sreerekha, P. R., Menon, D., Nair, S. V., & Chennazhi, K. P. (2012). Fibrin nanoconstructs: a novel processing method and their use as controlled delivery agents. *Nanotechnology, 23*, 95-102.

Preetha, P. S., & Balakrishnan, N. (2017). A Review of Nano Fertilizers and Their Use and Functions in Soil. *International Journal of Current Microbiology and Applied Sciences.*, *6*(12), 3117-3133.

Pujos, A., & Morard, P. (1997). Effects of potassium deficiency on tomato growth and mineral nutrition at the early production stage. *Plant and Soil.*, *189*, 189-196.

Qin, L., Wang, W., You, S., & Dong, J. (2014). In vitro antioxidant activity and in vivo antifatigue effect of layered double hydroxide nanoparticles as delivery vehicles for folic acid. *International Journal of Nanomedicine.*, *9*, 5701-5710.

Qados Abdul, A. M.S. "Effect of salt stress on plant growth and metabolism of bean plant Vicia faba (L.)." *Journal of the Saudi Society of Agricultural Sciences.* 10 (2011): 7-15.

Qureshi, A., Singh, D. K., & Dwivedi, S. (2018). Nano-fertilizers: A Novel Way for Enhancing Nutrient Use Efficiency and Crop Productivity. *International Journal of Current Microbiology and Applied Sciences.*, *7*(2), 3325-3335.

Rahman, S. A., Muhammad, N., Hassan, N. H., Ismail, H., Abdullah, N., Yahya, M. F., Awan, M. A. (2015). DEVELOPMENT OF NEOLAMARCKIA CADAMBA (KELEMPAYAN) TISSUE CULTURE TECHNIQUES FOR SUSTAINABLE SUPPLY OF PLANTING MATERIALS FOR COMMERCIAL PLANTATION. *Jurnal Teknologi*, *77*(24), 159-163.

Raliya, R., Saharan, V., Dimkpa, C., & Biswas, P. (2018). Nanofertilizer for Precision and Sustainable Agriculture: Current State and Future Perspectives. *Journal of Agricultural and Food Chemistry.*, *66*, 6487-6503.

Ramimoghadam, D., Hussein, M. Z., & Taufiq-Yap, Y. H. (2012). The effect of sodium dodecyl sulfate (SDS) and cetyltrimethylammonium bromide (CTAB) on the properties of ZnO synthesized by hydrothermal method. *International Journal of Molecular Science.*, *13*, 13275-13293.

Ramli, M., Hussein, M. Z., & Yusoff, K. (2013). Preparation and characterization of an anti-inflammatory agent based on a zinc-layered hydroxidee-salicylate nanohybrid and its effect on viability of Vero-3 cells. *Internationa; Journal of Nanomedicine*, *3*(8), 297-306.

Ramteke, K. H., Dighe, P. A., Kharat, A. R., & Patil, S. V. (2014). Mathematical Models of Drug Dissolution: A Review . *Scholars Academic Journal of Pharmacy*, *3*, 388396.

Rawtani, D., Khatri, S., Tyagi, S., & Pandey, G. (2018). Nanotechnology-based recent approaches for sensing and remediation of pesticides. *Journal of Environmental Management.*, *206*, 749-762.

Razaq, M., Zhang, P., Shen, H., & Salahuddin. (2017). Influence of nitrogen and phosphorous on the growth and root morphology of Acer mono. *PLOS ONE.*, *12*(2), 1-13.

Richards, R. (2009). *Nanoscale materials in chemistry.2nd ed.*

Richardson-Chong, S. D., Patel, R., & Williams, G. R. (2012). Intercalation and contrilled release of bioactive ions using a hydroxyl double salts. *Ind Eng Chem Res., 51*, 2913-2921.

Rives , V., Arco, M. d., & Martin, C. (2014). Intercalation of drugs in layered double hydroxide and their controlled release: A review. *Applied Clay Science*, 239-269.

Roe, N. E., Stoffella, P. J., & Graetz, D. (1997). "Composts from various municipal solid waste feedstocks affect vegetable crops.II. Growth, yields and fruit quality". *Journal of the American Society for Horticultural Science., 122*(3), 433-437.

Rosenani, A. B., R. Rovica, P. M. Cheah, and C. T. Lim. "Growth Performance and Nutrient Uptake of Oil Palm Seedling in Prenursery Stage as Influenced by Oil Palm Waste Compost in Growing Media." *International Journal of Agronomy.*, 2016: 1-8.

Ruiz, C. V., Rodriguez-Castellon, E., & Giraldo, O. (2019). Hybrid materials based on a layered zinc hydroxide solid and gallic acid: Structural characterization and evaluation of the controlled release behaviour as a function of the gallic acid content. *Applied Clay Science., 181*, 1-10.

Saleh, T. A., & Gupta, V. K. (2016). Synthesis, Classification, and Properties of Nanomaterials. *Nanomaterials and Polymer Membranes.*, 83-133.

Salleh, N. M., Mohsin, S. N., Sarijo, S. H., & Ghazali, S. A. (2017). Synthesis and Physico-Chemical Properties of Zinc Layered Hydroxide-4-Chloro-2Methylphenoxy Acetic Acid (ZMCPA) Nanocomposite. *IOP Conference Series: Nanomaterials and Materials Engineering.*, 1-5.

Sarijo, S. H., Ghazali, S. M., Hussein, M. Z., & Sidek , N. J. (2012). Synthesis of nanocomposite 2-methyl-4-chlorophenoxyacetic acid with layered double hydroxide: physicochemical characterization and controlled release properties. *Journal of Nanoparticle Research., 15*(1), 1356-1359.

Scarpellini, D., Falconi, C., Gaudio, P., Mattoccia, A., Medaglia, P. G., Orsini, A., . Richetta, M. (2014). Morphology of Zn/Al layered double hydroxide nanosheets grown onto aluminum thin films. *Microelectronic Engineering, 126*, 129-133.

Schlitt, S., Greiner, A., & Wendorff, J. H. (2008). Cylindrical Polymer Nanostructures by Solution Template Wetting. *Macromolecules., 41*, 3228-3234.

Sciortino, A., Mauro, N., Buscarino, G., Sciortino, L., Popescu, R., Schneider, R.,Messina, F. (2018). β-C3N4 Nanocrystals: Carbon Dots with Extraordinary Morphological, Structural, and Optical Homogeneity. *Chemistry of Materials.*, *30*(5), 1695-1700.

Sekhon, B. (2014). Nanotechnology in agri-food production: an overview. *Nanotechnology, Science and Applications., 7*, 31-53.

Sekhon, B. S. (2014). Nanotechnology in agri-food production: an overview. *Nanotechnology Science and Applications., 7*, 31-53.

Sergeev, G., & Shabatina, T. I. (2008). Cryochemistry of nanometals.Colloids and Surface A: Physicochemical and Engineering Aspects. *Nanoscience and Nanotechnology.*, 18-22.

Shang, Y., Hasan, M. K., Ahammed, G. J., Li, M., YinH., & Zhou, J. (2019). Applications of Nanotechnology in Plant Growth and Crop Protection: A Review. *Molecules, 24*(14), 2414-2558.

Shen , J. P., Zhang, L. M., Guo, J. F., Ray, J. L., & He, J. Z. (2010). Impact of long-term fertilization practices on the abundance and composition of soil bacterial communities in Northeast China. *Applied Soil Ecology., 4*(1), 119-124.

Silva, L. B., Yun, A. K., Aguilera, C. B., Sousa, A. D., Melo, C. G., Timoteo, T. R., . . . Rolim-Neto, P. J. (2019). Influence of drying processes on Layered Double Hydroxides as pharmaceutical excipients. *Materials Letters, 255*, 1-4.

Singhvi, G., & Singh , M. (2011). Review: In-Vitro Drug Release Characterization Models. *International Journal of Pharmaceutical Studies and Research , 2*, 77-84.

Songkhum, P., Wuttikhun, T., Chanlek, N., Khemthong, P., & Laohhasurayotin, K. (2018). Controlled release studies of boron and zinc from layered double hydroxides as the micronutrient hosts for agricultural application. *Applied Clay Science., 152*, 311-322.

Stahlin, W., & Oswald, H. R. (1971). The infrared spectrum and thermal analysis of zinc hydroxide nitrate. *Journal of Solid State Chemistry., 3*(2), 252-255.

Stoffella, P. Y., Roe, M., Ozeres-Hampton, & Greatz, D. A. (1997). Utilization of Organic Waste Compost in Vegetable Production System in Asia. In R. A. Moris, *AsianVegetable Research and Development Centre, Shanhua, Taiwan.* Food and Fertilizer Technology Center, technical bulletins.

Sun, W., He, Q., & Luo, Y. (2007). Synthesis and properties of cinnamic acid series organic UV ray absorbents-interleaved layered double hydroxides. *Materials Letters., 61*(8-9), 1881-1884.

Suri, V. K., Choudhary, A. K., Chander, G., & Verma, T. S. (2011). "Influence of vesicular arbuscular mycorrhizal fungi and applied phosphorus on root colonization in wheat and plant nutrient dynamics in a phosphorus–deficient acid alfisol of Western Himalayas,". *Communications in Soil Science and Plant Analysis., 42*(10), 1077-1186.

Szczerba, M. W., Britto, D. T., & Kronzucker, H. J. (2009). K+ transport in plants: Physiology and molecular biology. *Journal of Plant Physiology., 166*(5), 447-466.

Tabbara, H. (2003). Phosphorus Loss to Runoff Water Twenty-Four Hours after Application of Liquid Swine Manure or Fertilizer. *Journal of Environmental Quality, 32*, 1044-1052.

Taiz, L., & Zeiger, E. (2002). *Plant Physiology. Third edition.* Sinauer Associates Inc. Publishers, Massachusetts.

Thakkar, M. N., Mhatre, S., & Parikh, R. Y. (2010). Biological synthesis of metallic nanoparticles. *Nanomedicine : nanotechnology, biology and medicine., 6*(2), 257262.

Tinus, R. W. (1978). Production of container-grown hardwoods. *Tree Planters Notes., 29*, 3-9.

Ullah, M. A., Anwar, M., & Rana, A. S. (2010). Effect of nitrogen fertilization and harvesting intervals on the yield and forage quality of elephant grass (Pennisetum purpureumL.) under mesic climate of Pothowar plateau. *Pakistan Journal of Agricultural Science., 47*, 231-234.

Verma, S. K., Das, A. K., Patel, M. K., Shah, A., Kumar, V., & Gantait, S. (2018). Engineered nanomaterials for plant growth and development: A perspective analysis. *Science of The Total Environment., 630*, 1413-1435.

Wan Abdul Rahman, W., Mohd Yunus, N., Kasim, J., & Mohamed Tamat, N. (2018). Effects of Tree Portion and Radial Position on Physical and Chemical Properties of Kelampayan (Neolamarckia cadamba) Wood. *BioResources., 13*(2), 4536-4549.

Wang, H. (2008). *Method for preparing bio-organic fertilizer by use of peat with high fertilizer efficiency.* CN 101255072.

Wang, Y., & Zhang, D. (2011). Synthesis, characterization, and controlled release anticorrosion behavior of benzoate intercalated Zn-Al layered double hydroxides. *Materials Research Bulletin., 46*(11), 1963-1968.

Wissuwa, M. (2003). How do plants achieve tolerance to phosphorus deficiency? Small causes with big effects. *Plant Physiology., 133*, 1947-1958.

Woo, M. A., Kim, T. W., Paek, M., Ha, H., Choy, J., & Hwan (Woo, et al., 2011)g, S. (2011). Phosphateintercalated Ca–Fe-layered double hydroxides: Crystal structure, bonding character, and release kinetics of phosphate. *Journal of State Chemistry., 184*, 171-176.

Wurster, D. E., Oh, E., & Wang, J. T. (1995). Determination of the Mechanism for the Decrease in Zinc Oxide Surface Area upon High-Temperature Drying. *Journal of Pharmaceutical Sciences., 84*(11), 1301-1307.

Xu, Z. P., & Lu, G. Q. (2005). Hydrothermal Synthesis of Layered Double Hydroxides (LDHs) from Mixed MgO and Al2O3: LDH Formation Mechanism. *Chemistry of Materials., 17*(5), 1055-1062.

Yagoub, S. O., Ahmed, W. A., & Mariod, A. A. (2012). Effect of Urea, NPK and Compost on Growth and Yield of Soybean (Glycine max L.), in Semi-Arid Region of Sudan. *International Scholarly Research Network Agronomy.*, 1-7.

Yang, J., Han, Y., Park, M., Park, T., Hwang, S., & Choy, J. (2007). New Inorganic-Based Drug Delivery System of Indole-3-Acetic Acid-Layered Metal Hydroxide Nanohybrids with Controlled Release Rate. *Chemistry of Materials., 19*(10), 26792685.

York, N. (2017). *World Population Projected to Reach 9.7 Billion by 2050.* United Nations.

Zahoor, W. A., Khanzada, H., Bashir, U., Aziz, K., Zahir, S., Faheem, A. K., & Naz, R. M. (2014). Role of Nitrogen Fertilizer in Crop Productivity and Environmental Pollution. *International Journal of Agriculture and Forestry., 4*(3), 201-206.

Zaytseva, O., & Neumann, G. (2016). Carbon nanomaterials: production, impact on plant development, agricultural and environmental applications. *Chemical and Biological Technologies in Agriculture., 3*(17), 1-26.

Zhang S, Yongxin, Y., Wang, W., Gu, X., Li, H., & Li, J. (2018). intercalation of phosphotungstic acid into layered double hydroxides by reconstruction method and its application in intumescent flame retardant poly(lactic acid) composites. *Polymer Degradation and Stability, 147*, 142-150.

Zhang, B. A., Pinsky, J. S., Ananta, J. S., Arulkumar, S. S., Wan, H., Sahoo, M. K., . . . Dai, H. (2017). Diagnosis of Zika virus infection on a nanotechnology platform. *Nature Medicine., 23*(5), 548-550.

Zhang, J., Li, Y., Zhou, J., Chen, D., & Qian, G. (2012). Chromium (VI) and zinc (II) waste water co-treatment by forming layered double hydroxides: Mechanism discussion via two different processes and application in real plating water. *Journal of Hazardous Materials., 205-206*, 111-117.

Zhang, T., Li, Q., Xiao, H., Lu, H., & Zhou, Y. (2012). Synthesis of Li-Al layered double hydroxides (LDHs) for efficient fluoride removal. *Industrial & Engineering Chemistry Research., 51*, 11490-11498.

Zhang, X., Davidson, E. A., Mauzerall, D. L., Timothy, D., Searchinger, Dumas, P., & Shen, Y. (2015). Managing nitrogen for sustainable development. *Nature., 528*, 51-59.

Zhang, X., Liu, Z., Shen, W., & Gurunathan, S. (2016). Silver Nanoparticles: Synthesis, Characterization, Properties, Applications, and Therapeutic Approaches. *International Journal of Molecular Sciences., 17*(9), 1534.

Zhang, X., Wu, H., Chen, L., Wang, N., Wei, C., & Wan, X. (2019). Mesophyll cells' ability to maintain potassium is correlated with drought tolerance in tea (Camellia sinensis). *Plant Physiology and biochemistry., 136*, 196-203.

Zhao, D., Kane, M., Borders, B., & Harrison, M. (2008). Pine growth response to different site- preparation methods with or without post-plant herbaceous weed control on North Florida's Lower Coastal Plain. *Forest Ecology and Management., 255*(7), 2512-2523.

Zhu, Y., Fan, X., Hou, X., Wu, J., & Wang, T. (2014). Effect of different levels of nitrogen deficiency on switchgrass seedling growth. *The Crop Journal, 2*(4), 223-234.

Zulfiqar, F., Navarro, M., Ashraf, M., Akram, N. A., & Munne-Bosch, S. (2019). Nanofertilizer use for sustainable agriculture: Advantages and limitations. *Plant Science., 289*, 1-1