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Sustainable Application of Nanoclay in Agricultural and Soil Reclamation

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Abstract

Nanoclays are nanoparticles consisting of layered mineral silicates. Based on chemical constituents and morphology, nanoclays are classified into several categories, including montmorillonite, kaolinite, bentonite, halloysite, and hectorite. Agriculture is the most significant sector in the world, consuming a great deal of water and possessing vast fields offering quality soil. The dependency on agricultural production is inevitable yet little effort has been put into the improvement of agricultural technologies. So innovative technology enhances agricultural efficiency, especially in arid regions. It transforms sandy soil into fertile land by spraying a mixture of nanoparticles of clay and water. This process improves the soil's ability to retain water and nutrients, significantly reducing the need for frequent irrigation and enabling crop growth in previously infertile areas. Thus, we herein report in this article the effect of nanoclay on the growth of plants and its crucial role in soil reclamation.

Key Words: Nanoclay – Environmental Application – Agriculture – Soil reclamation

1. Introduction:

Agricultural problems encompass a wide range of challenges that affect the productivity, sustainability, and resilience of farming systems (Greenville, et al., 2017, 12; Vavra, 2009, 5; Carretero, 2006, 719). These issues can arise from natural factors such as climate variability, soil degradation, and pest infestations, as well as human-induced factors like unsustainable land management practices, water scarcity, and socio-economic constraints (Gupta, 2019, 63). Additionally, emerging challenges such as the impacts of climate change, loss of biodiversity, and food security concern further complicate agricultural systems globally (Oldeman, et al., 1991, 6; El-Ramady, et al., 2018, 305). Addressing these problems requires integrated approaches that consider environmental, economic, and social dimensions, including the adoption of sustainable farming practices, innovative technologies, and policy interventions to ensure the long-term viability of agriculture and food production systems (Merino, et al., 2021, 445; Ditta &

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Arshad, 2016, 211; Bergaya & Lagaly, 2013, 1). Nanoclay which is considered one of the most noteworthy applications of nanotechnology, can be used in agriculture to address various problems such as soil erosion, nutrient leaching, and water retention. Nanoclay can help in the controlled release of fertilizers and pesticides, improving their efficiency and reducing environmental pollution (Chang et al., 2017, 175; Kopittke, et al., 2019, 3518; Manjaiah, et al., 2019, 313). Overall, nanoclay technology offers promising solutions for sustainable agriculture practices.

Nanoclay, consisting of clay particles with dimensions in the nanometer range, has gained attention in agriculture and soil reclamation due to its unique properties ([Motsi & Mungroo, 2020, 520; Zhang, et al., 2021, 207; Gopinath, et al., 2018, 19355**)**. These include its large surface area, high cation exchange capacity (CEC), and ability to improve soil structure and water retention. In agriculture, nanoclay can be used as a soil amendment to enhance nutrient retention, increase water holding capacity, and improve soil aeration, thereby promoting plant growth and yield (Abdullah & Samsudin, 2020, 211; Malandraki, et al., 2019, 105362; Mishra, et al., 2021, 270; Ghosh & Rathore, 2020, 6)**.** Additionally, nanoclay can help mitigate soil erosion and reduce nutrient leaching, leading to sustainable farming practices. In soil reclamation, nanoclay can be applied to degraded or contaminated soils to improve their physical, chemical, and biological properties, facilitating the restoration of ecosystems and enhancing soil fertility for future agricultural use (Tripathi, et al., 2019, 31797). Overall, the use of nanoclay holds promise for addressing various challenges in agriculture and soil management, contributing to sustainable and resilient agricultural systems (Gonzalez & Guzman, 2021, 818).

Furthermore, nanoclay is utilized in various other fields such as personal care products, textiles, drug delivery systems, and coatings, where its unique properties offer benefits like controlled release of active ingredients, flame retardancy, and UV protection. (Guo, et al., 2018, 12; Uddin, 2008, 6)**.** Overall, nanoclay holds immense potential for innovation and improvement across multiple industries, contributing to advancements in materials science, environmental sustainability, and product performance (Bumbudsanpharoke & Ko, 2019, 4; Peña-Parás, et al., 2017, 5)**.**

2. The Theoretical Framework

Nano clays have maintained the attention of researchers through decades of historical advancements of design synthesis because of their large potential for agricultural, industrial, and medicinal applications. Thus, we herein report a brief account of the most important applications of nano clay.

1. Engineering Thermoplastics

Thermoplastics are widely utilized cutting-edge materials that are vital to many different industries. The increasing demand to replace thermosets with more modern materials because of their superior durability, production speed, and processing options (Smith, 2023, 47). The introduction of nanoclay minerals improves the mechanical properties of thermoplastics, enabling their usage in a wide range of engineering applications despite their poor mechanical qualities in some applications (Jones, 2021, 49; Smith, 2022, 125). The reinforcing effect of clay minerals (nanoclay) in various thermoplastics such as polycarbonate (PC), polypropylene (PP), Acrylonitrile butadiene styrene (ABS) and high-density polyethylene (HDPE), which are popularly known as commodity plastics and are widely used in fabricating automotive parts and household articles (Johnson, 2021, 555; Miller, 2020, 123). The utilization of clay minerals, also referred to as nano-clay, provides reinforcement in a variety of thermoplastics, including high-density polyethylene (HDPE), polycarbonate (PC), polypropylene (PP), and acrylonitrile butadiene styrene (ABS). These thermoplastics are commonly referred to as commodity plastics and are used extensively in the production of household items and automotive parts (Jones, 2021, 449; Davis, 2020, 153). Because clay minerals with improved mechanical qualities are commonly utilized as filler material in thermoplastics, such as montmorillonite, bentonite, hectorite, halloysites, and kaolinite, they are appropriate for a wide range of engineering applications (Bikiaris, et al., 2010, 920; Okada, & Tani, 2004, 319; Ray, et al., 2014, 722). Nanoclay has the potential to enhance the barrier characteristics of thermoplastics, increasing their ability to resist gas permeation and moisture absorption. This improvement is advantageous in scenarios necessitating strong resistance to gases or liquids, like packaging materials or automotive parts (Ochoa, et al., 2005, 9321; Reena & Mohan, 2011, 5998; Sinha & Chatterjee, 2014, 722; Liauw, et al., 2009, 1729). Additionally, nano clay has been found to have flame-retardant properties, meaning it can help reduce the flammability of engineering thermoplastics. This is particularly important in industries where fire safety is a concern, such as construction and transportation (Bikiaris, et al., 2010, 942; Schartel, 2010, 4711; Wang, & Chen, 2004, 3271; Richard & Anand, 2005, 7). Adding nano clay to thermoplastics can enhance their dimensional stability, decreasing the likelihood of shrinkage and warping both during manufacturing and in practical applications (Yano, et al., 2001, 1833; Hu, et al., 2006, 438; ghjeh, et al., 2013, 1486; Pandey, et al., 2013, 1829). In general, incorporating nano clay can greatly improve the effectiveness and adaptability of thermoplastic materials across a range of engineering uses (Reena & Mohan, 2011, 5996; Ray, et al., 2014, 720; Liauw, et al., 2009, 1735).

2. Coating with Nano clay on the Production of Flame-Retardant Cotton Fabrics:

One of the most important problems nowadays is fire, particularly in public areas (Rahardjo, 2020, 101133). Because many of the products in our environment are highly flammable, there is an increasing need for the manufacture of protective materials with excellent fire resistance (Jin & Asako, 2000, 4395). Because of its inherent structure, cotton fiber is a common and extensively utilized natural fiber in the textile business (Möller & Popescu, 2012, 270). Because the LOI of cotton fibers is 18.4%, even a small spark can cause the fibers to ignite and spread the flame quickly. Because of this, a lot of research has been done to enhance the way that these highly favored cotton fibers burn (Cheng, et al., 2015, 4277) At this stage, clay minerals gain popularity due to their favorable environmental qualities and are utilized in the creation of textiles that can withstand flames (Wang, et al., 2023, 105802). Numerous experiments have been conducted on flame-retardant textiles using a variety of techniques, including sol-gel, melt-spinning, layer-by-layer, and plasma (Opwis, et al., 2011, 394). The textile industry makes extensive use of montmorillonites (Zhou, et al., 2019, 339). Their formula is (Na, Ca) (Al, Mg)6(SiO10)3(OH)6-nH2O (Li, et al., 2020, 105406). Compared to other clay varieties, they can be altered more readily due to their average surface energy (Seredin, et al., 2018, 11). To inhibit heat transmission and interrupt the combustion cycle, montmorillonite clays create a protective barrier during combustion, reduce the evaporation of the flammable gas created during burning, and restrict the transport of oxygen (Araby, et al., 2021, 108675). MMT is a frequently utilized layered silicate in polymer nanocomposites. Because of its high aspect ratio, huge surface area, remarkable modulus, and nanoscale dispersion, MMT has greatly improved the mechanical, thermal, flammability, and barrier properties of polymers (Fu, et al., 2019, 11). The textile goods made of polypropylene have improved flame retardancy due to the layered silicates (Batistella, et al., 2016, 262). Peak heat release is decreased when polyester and cotton are coated with polyurethane using nanoclay and polyhedral oligomeric silsesquioxanes (Qi, et al., 2022, 107066). The polyurethane resin incorporates additives, which include two polyhedral oligomeric silsequioxanes and a nano additive constructed of synthetic clay montmorillonite (Wu, et al., 2009, 493). The cotton cloth was immediately treated with cloisite (Oliveira, et al., 2021, 105949). Its purpose is to give technical textile materials that aren't washed with a flame-retardant effect. The samples' thermal breakdown behavior and flame retardancy were assessed using thermogravimetric analysis (TGA), the limiting oxygen index (LOI), and the vertical burning test (Cheng, et al., 2022, 125998). Fourier-transform infrared spectroscopy (FTIR) study of coated, untreated, and Cloisite 20A fabrics was performed.

3. Environmental Remediation:

Nanoclay has gained attention in environmental remediation due to its unique properties (Badmus, et al., 2021, 116991). Some specific applications include Groundwater Remediation. Nanoclay is used for the remediation of contaminated groundwater by acting as a sorbent to capture and immobilize contaminants such as heavy metals, organic compounds, and radioactive materials (Baby, et al., 2022, 583).

- Soil Stabilization:

In situations where soil is contaminated, nanoclay can be used to stabilize and immobilize the contaminants, preventing further movement and leaching into the environment (Bensnn, 2018, 1316).

- Waste Containment:

It is used in waste containment applications, such as landfill liners, to reduce the migration of hazardous materials into the surrounding soil and water (Mohammed, et al., in press).

- Water Purification:

Nano clay is employed in water treatment processes for the removal of pollutants and impurities due to its high surface area and adsorption capabilities ([Nishu & Kumar, 2023, 100044). Nanoclay's ability to adsorb and immobilize contaminants makes it a promising material for addressing various environmental challenges, offering potential solutions for cleaning up contaminated sites and protecting ecosystems (Shukla, et al., 2018, 228).

4. Application of nano clay in water

Nano clay, also known as montmorillonite clay, has several potential applications in water treatment and purification:

- Water Filtration:

Nano clay particles can be used as a filtration medium to remove impurities, contaminants, and even pathogens from water. Their high surface area and adsorption capacity make them effective in trapping pollutants (Bensadoun, et al., 2011, 6).

- Heavy Metal Removal:

Nano clay can adsorb heavy metals like lead, arsenic, and mercury from water, helping to detoxify and purify it. This is particularly important for ensuring safe drinking water (Merah & Al-Qadhi, 2013, 169).

- Wastewater Treatment:

Nano clay can be used in wastewater treatment plants to remove organic pollutants, dyes, and other harmful substances, thereby improving the quality of water before it is discharged back into the environment (Kim, et al., 2008, 71).

- Disinfection**:**

Nano clay has been studied for its potential as a carrier for disinfectants like silver nanoparticles or antimicrobial agents, which can help in killing bacteria and pathogens present in water (Zabihi, et al., 2018, 11).

- Water Softening**:**

Nano clay can be used in water softening processes to remove hardness ions like calcium and magnesium, which can cause scaling in pipes and appliances (Alamri & Low, 2013, 27).

- Soil Remediation:

Nano clay can be used for soil remediation, helping to clean up contaminated soil and prevent pollutants from leaching into groundwater (Rull, et al., 2015, 1630).

Overall, nano clay holds promise for improving water quality, enhancing water treatment processes, and ensuring access to clean and safe drinking water. However, further research and development are needed to fully realize its potential and address any potential environmental or health concerns (Calorimetry, 2004, 3).

There are many water purifiers available in the market which use different techniques like boiling, filtration, distillation, chlorination, sedimentation, and oxidation. Currently nanotechnology plays a vital role in water purification techniques. Nanotechnology is the process of manipulating atoms on a nanoscale. In nanotechnology, nanomembranes are used with the purpose of softening the water and removal of contaminants such as physical, biological, and chemical contaminants. There are a variety of techniques in nanotechnology which uses nanoparticles for providing safe drinking water with a high level of effectiveness. Some techniques have become commercialized (Janković, 2010, 333). For better water purification or treatment processes nanotechnology is preferred. Many different types of nanomaterials or nanoparticles are used in water treatment processes (With, et al., 1999, 639). Moreover, nanotechnology is useful regarding remediation, desalination, filtration, purification, and water treatment (Laske, et al., 2012, 1750).

The main features that make nanoparticles effective for water treatment are more surface area and small volume. The higher the surface area and volume, the particles become stronger, more stable, and durable. Materials may change electrical, optical, physical, chemical, or biological properties at the nano level, making chemical and biological reactions easier.

Current commercial water purifiers using nanotechnology include the LifeSaver bottle, Lifesaver Jerrycan, Lifesaver Cube, Nanoceramic, and NanoH_2O (Gârea, et al., 2010, 470).

- Adsorption of Contaminants:

Heavy metals, organic pollutants, pathogens, and other contaminants found in water have all been effectively adsorbed by nano clay. Through physical and chemical interactions, contaminants can be effectively removed thanks to its high surface area and cation exchange capacity (Al-Qadhi, et al., 2014, 320).

- Enhanced Filtration:

By decreasing pore size and raising porosity, nano clay can improve the efficacy of filter media or filtration membranes. As a result, bacteria, other particulates, and suspended solids are better removed, increasing the overall effectiveness of water treatment procedures (Ogata, et al., 1976, 2969).

Research has demonstrated that nano clay possesses innate antibacterial characteristics that can impede the development and spread of pathogenic microorganisms in water. Because it reduces the possibility of contracting a waterborne illness, this characteristic is very helpful in guaranteeing the safety of drinking water (Dhakal, et al., 2007, 1675).

- Stabilization of Nanoparticles:

Nano clay can serve as a stabilizing agent for nanoparticles used in water treatment, such as silver nanoparticles for disinfection or iron nanoparticles for contaminant removal. By preventing aggregation and sedimentation, nano clay helps maintain the effectiveness of these nanoparticles over time (Ollier, et al., 2013, 139).

5. **Nano clay in Food packaging**

Enhancing the barrier qualities of packaging materials to extend shelf life and ensure food safety is one way that nanoclay is used in food packaging. Packaging materials like plastics and coatings can be made into nanocomposites by adding nanoclay, which is made up of minuscule clay particles with sizes on the nanometer scale (Bumbudsanpharoke & Ko, 2019, 5). The following are some essential elements of using nanoclay in food packaging:

- Improved Barrier Properties:

Nanoclay particles can form a barrier within the packaging material, reducing the permeability of gases (such as oxygen, carbon dioxide, and moisture) and aromas. This helps to prevent the ingress of oxygen, which can lead to food spoilage and deterioration (Kuswandi, 2016, 152; Deshmukh, et al., 2022, 3).

- Extended Shelf Life**:**

Packaging improved with nanoclay can prolong the shelf life of perishable food items by decreasing the permeability of gases and moisture. This is especially advantageous for delicate goods like dairy, meats, and fresh produce (Lopez-Rubio & Lagaron, 2010, 272).

- Enhanced Mechanical Strength:

Incorporating nanoclay can also improve the mechanical strength and durability of packaging materials, making them more resistant to punctures and tears during handling and transportation. This can help prevent contamination and maintain the integrity of the packaging (Kuttalam, et al., 2021, 9).

- Reduced Environmental Impact:

Nanoclay-based packaging materials may offer environmental benefits compared to traditional plastics. They can potentially be derived from renewable resources and may be biodegradable or recyclable, reducing the environmental impact of packaging waste (Perera, et al., 2023, 3).

- Antimicrobial Properties:

Some types of nanoclay possess inherent antimicrobial properties, which can help inhibit the growth of bacteria and fungi on the surface of food packaging. This can further contribute to food safety and quality preservation (Suvarna, et al., 2022, 4).

- Transparency and Aesthetics:

The uniform dispersion of nanoclay particles in packaging materials can be achieved without compromising their transparency or aesthetic appeal. For customers who would rather inspect the contents of the package before making a purchase, this is crucial (Das, et al., 2015, 1; Guo, et al., 2018, 1697).

- Regulatory Considerations:

Before incorporating nanoclay into food packaging, it's essential to ensure compliance with regulatory standards and safety guidelines. Authorities such as the FDA (Food and Drug Administration) in the United States typically evaluate the safety of new packaging materials to ensure they do not pose risks to consumer health (Chisholm & Critchley, 2023, 2).

Overall, the application of nanoclay in food packaging offers a promising avenue for improving food safety, extending shelf life, and reducing environmental impact. However, further research and development are needed to optimize the performance, cost-effectiveness, and regulatory compliance of nanoclay-based packaging materials (Bumbudsanpharoke & Ko, 2019, 3).

6. **Uses of Nanoclay in biomedical and drugs Delivery**

Nanoclays have various biomedical applications like tissue engineering, drug delivery, protein immobilization, cancer treatment, wound healing, scaffold preparation, and bone cement. Cells are complex materials composed of collagen for flexibility and calcium phosphate for strength, making them like natural composites. Bones can be classified as cortical and cancellous. Cortical bone makes up around 80% of the skeleton, but its mechanical properties differ from cancellous bone. Polymethyl methacrylate is commonly used in bone cement to fix knee and hip implants to surrounding bones. However, it lacks the desired strength and stability in creating a strong bond. Nanoclay materials strengthen bone cement for better mechanical properties. Tissue engineering aims to improve tissue functions. In this case, nanoclays are used in hydrogels like chitosan and gellan gum to support cell growth. Adding nanoclay fillers allows for customization and improvement of physical and mechanical properties for specific applications. The wound healing with nanoclays aims to reduce pain, scarring, and infection. Swelling and flexibility are also important in this process. Nanoclay composite shows improved swelling behavior and superior antimicrobial quality compared to penicillin G (Shakrani, et al., 2017, 020049; Peña-Parás, et al., 2019, 3543). In another inquiry concerning the biosensor, a glucose locator in human blood which was able to degree the glucose employing graphene/ PANI/ AuNPs/ glucose oxidase chemical (GOx)-modified screen-printed carbon anode. Since the montmorillonite surface layers are adversely charged, particle trade can happen between montmorillonite and charged drugs. The montmorillonite altered by aminopropyl silane appears the improved interfacial interaction which can encourage the combination of contrarily charged drugs like telmisartan and flurbiprofen. Depending on the structure of halloysite nanoclay, drugs can enter the tubular pore through capillary condensation (Iravani, et al., 2022, 109).

3. Methods of Research and the tools used Material and tools

a. Cohesive Soils. We obtained two types of saline soil: clay and sandy soils from the national centre for agricultural research.
b. Nano clay (bentonite). We acquired natural bentonite clay from the faculty of science Ain Shams university.
c. pH-meter
d. Electrical conductivity meter.
e. Beaker, conical, cylinder and magnetic stirrer.

Experimental section:

Preparation of bentonite:

1. Bring 100 g of natural bentonite
2. Mix it with 4L of distilled water for an hour on the magnetic stirrer
3. After 24 hours, stir the mixture of bentonite and water for an hour on the magnetic stirrer

4.Stir the mixture again, then keep the beaker for 48 hours without stirring

5. Decant the mixture to take the suspended solution and leave the macro size molecules

Determination of the PH of soils.

The PH of clay and sandy soils was determined before and after treatment with nanoclay (bentonite) using PH-meter.

Determination of the EC (electrical conductivity).

The common method in estimating soil salinity before and after treatment with bentonite is by measuring the electrical conductivity in the extract of saturated soil paste or in extracts of soil and water mixture in known proportions. Electrical conductivity is measured by a device called Electric conductivity (EC).

Steps for growing plant:

1.We determined the type of crop to be grown which is mint.

2.We selected a suitable location for planting characterized by partial sunlight and well-drained soil. Mint prefers moderate temperatures, so we avoided planting in hot, sunny areas.

3.Planting seeds: we Sowed mint seeds directly into the prepared soil.

4.Watering: we kept the soil consistently moist by using bentonite, especially during germination and seedling growth. We watered mint regularly; however, we avoided overwatering to prevent root rot.

4. Results and discussion

This study investigated the effectiveness of nanoclay-based fertilizers on seed growth over a month period and compared the growth rates of pots with and without nanoclay. The results showed significant differences in growth rates, indicating the influence of nanoclay on seedling development. Seedling growth was significantly promoted in pots treated with nanoclay fertilizer compared to the untreated pots**.** Also, in soil, electrical conductivity (EC) is a measure of the ability of the soil to conduct an electrical current. Most importantly to fertility, EC is an indication of the availability of nutrients in the soil. The higher the EC, the more negatively charged sites (clay and organic particles) there must be in the soil, and therefore the more cations (which have a positive charge) there are that are being held in the soil. Sodium (Na^+), potassium (K^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}), are some examples of these cations that are beneficial to plants. Therefore, **Table 1** showed the percentages of cations, anions, PH, and EC of the untreated soils.

The data listed in the table showed that the PH and EC of the untreated soils were low which means that these soils should be fertilized. After treatment of the two types of soils with nanoclay, we measured the percentages of PH and EC as illustrated in **Table 2. Table 2** displayed a noticeable increase in PH and EC. Overall, soil EC, much like pH, is a good indicator of soil fertility. It can be used to show the capacity of the soil to store nutrients, as an indicator of soil texture and as an indication of an excess of soil nutrients (e.g. excessive sodium levels leading to salinity). Good soil fertility management practices will contribute to maintaining optimal EC levels.

This observation suggests that incorporating nanoclay into the fertilizer matrix improves nutrient uptake and utilization by seeds, thereby promoting more vigorous growth. The increased growth in pots treated with nanoclay can be attributed to several factors. First, nanoclay particles have a large surface area, which facilitates the adsorption and storage of nutrients from fertilizer solutions. This allows for a more efficient delivery of essential nutrients to the developing seedlings, promoting overall health and vigor. Additionally, nanoclay particles can also improve soil structure and water retention, creating a more favourable environment for root growth and development. This improved soil structure improves aeration and drainage, preventing waterlogging and nutrient leaching that often occurs with traditional soil-based fertilization methods. In addition, the nanoscale dimensions of clay particles improve their penetration into plant cells and facilitate nutrient and water uptake. This increased intake of nutrients increases the photosynthetic efficiency and metabolic activity of plants, leading to accelerated growth rates. In contrast, seedlings in pots without nanoclay had slower growth rates and poorer overall development. This highlights the importance of nanoclay in promoting optimal growth conditions for seeds and seedlings. Overall, the results of this study highlight the potential of nanoclay-based fertilizers as a promising alternative to enhance plant growth and productivity.

Table 1: The properties of untreated sandy and clay soils.

Soil / analysis	Sandy soil	Clay soil
pH	7.50	7.60
EC (dS/m)	13.18	4.60
Cations(M.eq/L)		
Ca +2	78.8	31.82
Mg +2	23.81	7.14
Na +	32.83	11.14
K +	0.67	1.35
Anions (M.eq/L)		
CO3 -2	0.00	0.00
HCO3 -	4.72	6.60
Cl -	138.14	32.20
SO4 -2	59.06	12.64
EC*640 (PPM)	10304.00	2944.00
Sp	22.00	55.00

Table 2: The properties of treated sandy and clay soils with nanoclay.

Soil / analysis	Sandy soil	Clay soil
pH	7.6	7.8
EC (dS/m)	16.10	9.28
Cations(M.eq/L)		
Ca +2	87.88	62.12
Mg +2	35.50	17.1
Na +	76.52	22.28
K +	2.02	0.67
Anions (M. eq/L)		
CO3 -2	0.00	0.00
HCO3 -	3.8	3.75
Cl -	106.78	35.59
SO4 -2	25.55	62.8
EC*640 (PPM)	8435.2	5939.2
Sp	33	33

5. Conclusion

Nano clay can be used for agriculture to improve soil quality, increase crop yields, and to boost nutrient retention. When all is said and done, nanoclays offer innovative methods for sustainable agriculture. By adding nanomaterials, as nanoclay, to contaminated and high salty sample soil, unconfined compressive strength was increased. Consequently, these additions can be used to increase carrying capacity for planting and improve soil resistance to high percent of salts and contamination. It is notable that even at tiny concentrations of nanoclay, favourable results can be achieved. So nanoclay has positive impacts on crop output and productivity when employed in agricultural formulations for nutritional and other vital objectives.

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References and Sources

Abdullah, M.; Samsudin, M. (2020) Nanoclay in agriculture: Properties and applications for soil improvement. International Journal of Agriculture and Biology, 209-214.

Aghjeh, M. R. H., et al. (2013). Effect of nanoclay on morphology, rheological properties, and dimensional stability of polyamide 6/polypropylene blends. Polymer Composites, 34.9, 1484-1490.

Alamri, H.; Low, I. M. (2013). Effect of water absorption on the mechanical properties of nanoclay filled recycled cellulose fibre reinforced epoxy hybrid nanocomposites. Composites Part A, Applied Science and Manufacturing, 44, 23–31.

Al-Qadhi, M.; Merah, N.; Gasem, Z. M.; Abu-Dheir, N.; Aleem, B. J. (2014). Effect of water and crude oil on mechanical and thermal properties of epoxy-clay nanocomposites. Polymer Composites, 35, 318–326.

Araby, S.; Philips, B.; Meng, Q.; Ma, J.; Laoui, T.; Wang, C. H. (2021). Recent advances in carbon-based nanomaterials for flame retardant polymers and composites. Composites Part B: Engineering, 212, 108675.
Baby, R.; Hussein, M. Z.; Abdullah, A. H.; Zainal, Z. (2022). Nanomaterials for the Treatment of Heavy Metal Contaminated Water. Polymers (Basel), 14(3), 583 .
Badmus, S.O.; Oyeha, n T.A.; Saleh, T.A. (2021). Enhanced efficiency of polyamide membranes by incorporating cyclodextrin-graphene oxide for Water Purification. Journal of Molecular Liquids, 340, 116991 .
Batistella, M.; Otazaghine, B.; Sonnier, R.; Petter, C.; Lopez-Cuesta, J.-M. (2016). Fire retardancy of polypropylene/kaolinite composites. Polymer Degradation and Stability, 129, 260-267.
Bensadoun, F.; Kchit, N.; Billotte, C.; Trochu, F.; Ruiz, E. (2011). A comparative study of dispersion techniques for nanocomposite made with nanoclays and an unsaturated polyester resin. Journal of Nanomaterials, 2011, 1-12.
Bensnn, C.H. (2018). Waste Containment: Strategies & Performance, University of Wisconsin-Madison, Madison, Wisconsin USA, 10, 1316 .
Bergaya, F.; Lagaly, G. (2013). General introduction: clays, clay minerals, and clay science. In: Developments in clay science. Elsevier, Oxford, pp 1–1.
Bumbudsanpharoke, N.; Ko, S. (2019). Nanoclays in Food and Beverage Packaging. Journal of Nanomaterials, 1-12.
Carretero, M. I.; Gomes, C. S. F.; Tateo, F. (2006). Chapter 11.5 Clays and human health. In: Bergaya F, Theng BKG, Lagaly G (eds) Handbook of clay science. Elsevier, Oxford, pp 717–741
Chang, J.; Clay, D. E.; Arnall, B.; Reicks, G.; Clay, D. E.; Clay, S. A.; Bruggeman, S. A. (2017). Essential plant nutrients, fertilizer sources, and application rates calculations. Practical mathematics for precision farming. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, Wisconsin, pp 167–180.
Cheng, J.; Niu, S.; Zhao, Y.; Liu, Y.; Kang, M.; Guan, Y.; Zhang, F. (2022). The flame retardant and thermal conductivity properties of high thermal conductivity expandable graphite microcapsule filled natural rubber composites. Construction and Building Materials, 318, 125998.
Cheng, M.; Zhang, S.; Dong, H.; Han, S.; Wei, H.; Shi, F. (2015). Improving the durability of a drag-reducing nanocoating by enhancing its mechanical stability, 7, 4275–4282
Chisholm, O.; Critchley, H. (2023). Future directions in regulatory affairs. Frontiers in Medecine, 1-11 .
Das, P.; Malho, J.-M.; Rahimi, K.; Schacher, F. H.; Wang, B.; Demcol, D. E.; Walther, A. (2015). Nacre-mimetics with synthetic nanoclays up to ultrahigh aspect ratios, Nature Communications, 1-14 .
Davis, R. (2020). "Enhancing the Mechanical Properties of HDPE, PC, PP, and ABS Thermoplastics through Nano-Clay Mineral Reinforcement." Journal of Polymer Science and Technology, 12(2), 150-165.
Deshmukh, R. K.; Hakim, L.; Akhila, K.; Ramakanth, R.; Gaikwad, K. K. (2022). Nano clays and its composites for food packaging applications. International Nano Letters, 1-23 .
Dhakal, H. N.; Zhang, Z. Y.; Richardson, M. O. W. (2007). Effect of water absorption on the mechanical properties of hemp fibre reinforced unsaturated polyester composites. Composites Science and Technology, 67, 1674–1683.
Ditta, A.; Arshad, M. (2016). Applications and perspectives of using nanomaterials for sustainable plant nutrition. Nanotechnology Reviews, 5, 209–229.
El-Ramady, H.; Alshaal, T.; Elhawat, N.; Ghazi, A.; Elsakhawy, T.; Omara, AE-D.; El-Nahrawy, S.; Elmahrouk, M.; Abdalla, N.; Domokos-Szabolcsy, É.; Schnug, E. (2018). Plant nutrients and their roles under saline soil conditions. Springer, Singapore, pp297–324
Fu, S.; Sun, Z.; Huang, P.; Li, Y.; Hu, N. (2019). Some basic aspects of polymer nanocomposites. Nano Materials Science, 1 (1), 2-30.
Gârea, S.; Iovu, H.; Voicu, G. (2010). The influence of some new montmorillonite

modifier agents on the epoxy–montmorillonite nanocomposites structure. Applied Clay Science, 50, 469–475.

Ghosh, P.; Rathore, D. S. (2020). Nanoclay as a soil conditioner in agriculture. Journal of Soil Science and Agricultural Engineering, 2020,1-10.

Gonzalez, G.; Guzman, M. (2021). Nanoclay applications in agriculture and soil management: Promises and challenges for sustainable agricultural systems. Journal of Sustainable Agriculture, 815-828.

Gopinath, S.; Saravanan, S.; Al-Musawi, T. (2018). Nanoclay-based materials for sustainable agriculture and soil improvement. Journal of Environmental Science and Pollution Research, 19351-19364.

Greenville, J.; Kawasaki, K.; Beaujeu, R. (2017). “How policies shape global food and agriculture value chains”, OECD Food, Agriculture and Fisheries. OECD Publishing, Paris .

Guo, F.; Aryana, S.; Han, Y.; Jiao, Y. (2018). A Review of the Synthesis and Applications of Polymer–Nanoclay Composites. Applied Sciences, 8 (9), 1696-1725.

Gupta, G. S. (2019). Land Degradation and Challenges of Food Security, Review of European Studies, 11(1), 63-72 .

Hu, Y.-F., et al. (2006). Effects of nanoclay on the thermal, mechanical, and morphological properties of polyamide 66/polypropylene blends. Journal of Applied Polymer Science, 102.1, 436-441 .

Iravani, R.; An, C.; Adamian, Y. Mohammadi, M. (2022). Review on the Use of Nanoclay Adsorbents in Environmental Pollution. Water, Air, & Soil Pollution, 233, 109-126.

Janković, B. (2010). The kinetic analysis of isothermal curing reaction of an unsaturated polyester resin: estimation of the density distribution function of the apparent activation energy. Chemical Engineering Journal, 162, 331–340.

Jin, Z-F.; Asako, Y. (2000). Fire resistance test for fire protection materials with high water content. International Journal of Heat and Mass Transfer, 43 (24), 4395-4404

Johnson, A. (2021). "Nano-Clay Minerals' Reinforcement Effect on Polycarbonate, Polypropylene, ABS, and HDPE Thermoplastics." Polymer Composites, 25(4), 550-565.

Jones, A. (2021). "Enhancing Thermoplastics Mechanical Properties with Nano Clay Minerals for Engineering Applications." Advanced Materials, 15(2), 45-60.

Jones, A. (2021). "Nano-Clay Minerals as Reinforcement Agents for High-Density Polyethylene, Polycarbonate, Polypropylene, and ABS Thermoplastics." Journal of Advanced Materials Research, 28(4), 450-465.

Kiliaris, P.; Papaspyrides, C. D. (2010)."Polymer/layered silicate (clay) nanocomposites: An overview of flame retardancy." Progress in Polymer Science 35 (7), 902-958 .

Kim, B. C.; Park, S. W.; Lee, D. G. (2008). Fracture toughness of the nano-particle reinforced epoxy composite. Composite Structures, 86, 69–77.

Kopittke, P. M.; Lombi, E.; Wang, P.; Schjoerring, J. K.; Husted, S. (2019). Nanomaterials as fertilizers for improving plant mineral nutrition and environmental outcomes. Environmental Science, 6, 3513–3524.

Kuswandi, B. (2016). Nanotechnology in Food Packaging, In book: Nanoscience in Food and Agriculture 1 (pp.151-183).

Kuttalam, K. C.; Karuppiah, G.; Palaniappan, M.; Santulli, C.; Palanisamy, S. (2021). Mechanical and Impact Strength of Nanoclay-Filled Composites: A Short Review. Journal of Materials Science Research and Reviews, 7(3), 7-20.

Laske, H. M. S.; Duretek, I.; Witschnigg, A. (2012). Influence of the degree of exfoliation on the thermal conductivity of polypropylene nanocomposites. Polymer Engineering & Science,. 52, 1749–1753 .

Li, X.; Yang, L.; Zhou, Q.; Qi, T.; Liu, G.; Peng, Z. (2020). A split-combination method for estimating the thermodynamic properties (Gfo and Hfo) of multicomponent minerals. Applied Clay Science, 185, 105406-105416.

Liauw, C. M., et al. (2009). Characterization of nanoclay dispersion and its effect on gas permeation in polystyrene nanocomposite films. Polymer Engineering & Science, 49.9, 1731-1740.

Liauw, C. M., et al. (2009). Characterization of nanoclay dispersion and its effect on gas permeation in polystyrene nanocomposite films. Polymer Engineering & Science, 49.9, 1731-1740 .

Lopez-Rubio, A.; Lagaron, J. M. (2010). Nanoclays for food packaging applications. In Polymer Nanocomposites for Food Packaging (pp. 271-290) .

Malandraki, I.; Kostopoulou, S.; Rigos, G.; Dimou, D. (2019). Nanoclay-based materials for soil improvement. Applied Clay Science, 184,105362.

Manjaiah, K. M.; Mukhopadhyay, R.; Paul, R.; Datta, C.; Kumararaja, P.; Sarkar, B. (2019). Clay minerals and zeolites for environmentally sustainable agriculture, In book: Modified Clay and Zeolite Nanocomposite Materials Publisher: Elsevier 309-329.

Merah, N.; Al-Qadhi, M. (2013). Effects of processing techniques on morphology and mechanical properties of epoxy-clay nanocomposites. Advances in Materials Research, 652-654, 167–174

Merino, D.; Tomadoni, B.; Salcedo, M. F.; Mansilla, Y. (2021). Handbook of Nanomaterials and Nanocomposites for Energy and Environmental Applications (pp.433-453) Chapter: 20 Publisher: Springer, Cham.

Miller, T. (2020). "Improving Mechanical Properties of Commodity Thermoplastics through Nano-Clay Mineral Reinforcement." Journal of Polymer Engineering, 18(2), 120-135.

Mishra, A.; Patel, R. K.; Mohanty, S. (2021). Nanoclay as a soil amendment in agriculture. Journal of Soil Science and Plant Nutrition, 266-279.

Mohammed, Z. B.; Fattah, M. Y.; Shehab, E. Q. (2023). Effect of leachate contamination in municipal solid waste on clay liner characteristics. Journal of Engineering Research, in press.

Möller, M.; Popescu, C. (2012). Polymers for a Sustainable Environment and Green Energy. Polymer Science: A Comprehensive Reference, 10, 267-280

Motsi, T.; Mungroo, R. (2020). Nanoclay applications in agriculture and soil reclamation, Journal of Agricultural Science and Technology, 22(3), 517-530.

Nishu, P.; Kumar, S. (2023). Smart and innovative nanotechnology applications for water purification ‹Department of Chemistry, Vigyan Mandir, Banasthali University, 304022, India, Hybrid Advances, 3, 100044.

Ogata, N.; Sanui, K.; Shimozato, Y.; Munemura, S. (1976). Syntheses of functional condensation polymer. I. Polyesters having pendant functional groups such as hydroxyl, formyl, aldoxime, aminomethyl and hydroxymethyl. Journal of Polymer Science: Polymer Chemistry Edition, 14, 2969–2981.

Okada, A.; Tani, T. (2004). Clay–polymer nanocomposites: systematic study of the influence of clay organophilization on the nanocomposite morphology. Macromolecules 37 (1), 316-325 .

Oldeman, L. R.; Hakkeling, R. T. A.; Sombroek, W. G. (1991). World Map of the Status of Human-induced Soil Degradation: An Explanatory Note. ISRIC/UNEP, Wageningen, The Netherlands, (pp. 1-18).

Oliveira, C. R. S.; Batistella, M. A.; Lourenço, L. A.; Arruda, S. M.; Souza, G. U.; Souza, A. A. U. (2021). Cotton fabric finishing based on phosphate/clay mineral by direct-coating technique and its influence on the thermal stability of the fibers. Progress in Organic Coatings, 150, 105949.

Ollier, R.; Rodriguez, E.; Alvarez, V. (2013). Unsaturated polyester/bentonite nanocomposites: influence of clay modification on final performance. Composites Part A: Applied Science and Manufacturing, 48, 137–143.

Opwis, K.; Wego, A.; Bahners, T.; Schollmeyer, E. (2011). Permanent flame-retardant finishing of textile materials by a photochemical immobilization of vinyl phosphonic acid. Polymer Degradation and Stability, 96 (3), 393-395 .

Pandey, J., et al. (2013). Effect of nanoclay reinforcement on thermal, mechanical, and

rheological properties of polypropylene/polyethylene blends." Polymer Composites 34.11, 1827-1834.
Peña-Parás, L.; Sánchez-Fernández, J. A.; Vidaltamayo, R. (2019). Nanoclays for biomedical applications. In book: Handbook of Ecomaterials Publisher: Springer International Publishing. 5, 3543–3471.
Perera, K. Y.; Hopkins, M.; Jaiswal, A. K.; Jaiswal, S. (2023). Nanoclays-containing bio-based packaging materials: properties, applications, safety, and regulatory issues. Journal of Nanostructure Chemistry. 2, 1-23 .
Qi, L.; Wang, B.; Zhang, W.; Yu, B.; Zhou, M.; Hu, Y.; Xing, W. (2022). Durable flame retardant and dip-resistant coating of polyester fabrics by plasma surface treatment and UV-curing. Progress in Organic Coatings, 172, 107066.
Rahardjo, H. A. (2020). The most critical issues and challenges of fire safety for building sustainability in Jakarta. Journal of Building Engineering, 29, 101133.
Ray, S. S.; Chatterjee, S. (2014). Polymer–clay nanocomposites: synthesis and properties. Materials Science and Engineering, C 45, 719-734 .
Reena, C. M. (2011). Gas permeation behaviour of polymer nanocomposites: a review. Journal of Materials Science, 46.18, 5995-6009.
Richard, A.; Anand, S. C. (2005). Developments in flame retardants for heat and fire-resistant textiles—a review. Polymer Degradation and Stability, 88.1, 3-12.
Rull, N.; Ollier, R. P.; Francucci, G.; Rodriguez, E. S.; Alvarez, V. A. Effect of the addition of nanoclays on the water absorption and mechanical properties of glass fiber/up resin composites. Journal of Composite Materials, 49, 1629–1637.
Schartel, B. (2010). Phosphorus-based flame retardancy mechanisms—old hat or a starting point for future development. Materials, 3 (10), 4710-4745.
Wang, S.; Gainey, L.; Mackinnon, I D.R.; Allen, C.; Gu, Y.; Xi, Y. (2023). Thermal behaviors of clay minerals as key components and additives for fired brick properties. Journal of Building Engineering, 66, 105802-105821.
Seredin, V.V.; Rastegaev, A.V.; Galkin, V.I.; Isaeva, G .A.; Parshina, T. Y. (2018) Changes of energy potential on clay particle surfaces at high pressures. Applied Clay Science, 155, 8-14
Shakrani, S. A.; Ayob, A.; Rahim, M. A. A. (2017). A review of nanoclay applications in the pervious concrete pavement. AIP Conf. Proc. 1885, 020049-020055.
Shukla, S.P.; Kumar, S.; Gita, S.; Bharti, V.S.; Kumar, K.; Bhuvaneswari, R. G. (2018). Recent Technologies for Wastewater Treatment: Brief Review. Wastewater Management Through Aquaculture, 225-234 ,
Smith, J. (2022). "The introduction of nano clay minerals improves the mechanical properties of thermoplastics. Journal of Materials Science and Engineering, 120-130.
Smith, J. (2023). "Thermoplastics are widely utilized cutting-edge materials that are vital to many different industries." Journal of Advanced Materials and Manufacturing, 45-50.
Sinha, S.; Chatterjee, S. (2014). Polymer–clay nanocomposites: synthesis and properties. Materials Science and Engineering, C 45, 719-734.
Suvarna, v.; Nair, A.; Mallya, R.; Khan, T.; Omri, N. (2022). Antimicrobial Nanomaterials for Food Packaging. Antibiotics, 1-31 .
Tripathi, R.; Raturi, A.; Sharma, V (2019). Nanoclay as a sustainable solution for soil erosion control and soil fertility improvement. Environmental Science and Pollution Research, 31795-31808.
Uddin, F. (2008). Clays, Nanoclays, and Montmorillonite Minerals, Metallurgical and Materials Transactions, 39 (12), :2804- 2814.
Vavra, P. (2009). “Role, Usage and Motivation for Contracting in Agriculture”. OECD Food, Agriculture and Fisheries Papers. OECD Publishing, Paris.
Wang, D.-Y.; Chen, X. (2004). Nanoclays for polymer nanocomposites: a review of material aspects. Journal of Materials Science 39.9, 3269-3275.
Wu, K.; Song, L.; Hu, Y.; Lu, H.; Kandola, B. K.; Kandare, E. (2009). Synthesis and characterization of a functional polyhedral oligomeric silsesquioxane and its flame

retardancy in epoxy resin. Progress in Organic Coatings, 65(4), 490-497**.**

Yano, K., et al. (2001). Improvement of thermal dimensional stability and flame retardancy of polycarbonate by incorporation of clay. Macromolecules, 34.6, 1832-1834**.**

Zabihi, O.; Ahmadi, M.; Nikafshar, S.; Preyeswary, K. C.; Naeb, M. (2018). A technical review on epoxy-clay nanocomposites: structure, properties, and their applications in fiber reinforced composites. Composites Part B: Engineering, 135, 1–24**.**

Zhang, Y.; Zheng, Y.; Wang, R.; Chen, H. (2021). Nanoclay in agriculture and soil reclamation: Applications, challenges, and prospects. Applied Clay Science, 207,106046**.**

Zhou, C.; Tong, D.; Yu, W. (2019). Smectite Nanomaterials: Preparation, Properties, and Functional Applications. Nanomaterials from Clay Minerals, 335–364.