SCOPE OF NANOTECHNOLOGY IN AGRICULTURAL ENGINEERING

Abstract

The study of the effects of the introduction of new technologies, such as nanotechnology, into the agriculture sector, is of particular importance because this sector is one of the social and economic elements and indicators of sustainable development in any country. One of the main areas of agricultural engineering that deals with the mechanization of agricultural processes is farm machinery and power engineering. In recent years, agricultural engineering has used nanomaterials as an alternative solution to improve the performance of agricultural equipment, develop agricultural machinery, improve the performance of various prime movers by strengthening various components, enhancing wear and corrosion resistance, protecting agricultural equipment with nanocoatings, and enhancing the performance of machinery tires, lubricants, and coolants. This technology also helps to enhance the safety and comfort of agricultural workers. it also plays a significant role in the area of renewable energy. As a result, the systematic use of nanotechnology in agricultural engineering is demonstrated in this chapter.

Keywords: nanotechnology, farm power, machinery, renewable energy, ergonomics.

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I. INTRODUCTION

The recent nanotechnology revolution has had a significant impact on many different scientific domains (agriculture, chemistry, engineering, biology). More than 60% of the population depends on agriculture for their livelihood, making it one of the pillars of the national economy in emerging nations. The current era's sixth revolutionary technology is emerging as nanotechnology. There hasn't been much scientific research on its use in agriculture around the world up to this point, despite the fact that it is widely investigated in many scientific domains and is anticipated to play a significant role in agricultural and food science in the future. A nation's Gross Domestic Product grows significantly as a result of increasing food production rates (GDP). The agriculture industry is currently confronting a number of difficulties, including resource waste, excessive use of chemical fertilizers, and climate change. Since all of the equipment needed in daily life is being produced and manufactured, nanotechnology, as one of the new technologies, has become increasingly popular. Tractors and agricultural equipment are referred to as "mechanical equipment" in engineering. In order to achieve the same goals of improving performance and durability, nanotechnology has been applied to other types of mechanical equipment (earth moving equipment, road construction, cranes, lathes and cutting machines, drilling machines, concrete mixers, civilian and military vehicles, etc.). Nowadays, it is also evident that the majority of agricultural equipment of all kinds suffers from a number of problems. In order to address these problems, experts are developing nanotechnology-based solutions. Among the challenges that are becoming more prevalent are: Durability, dependability, low input efficiency, severe emissions, low human efficiency, worker safety in agriculture, and an increase in pest infestations are only a few factors. The intelligent characteristics of farm power inputs are enhanced by the employment of nanotechnology-based approaches. Contrarily, the use of nanosensors for pest and soil condition detection has enhanced traditional agricultural systems and transformed them into smart agricultural systems.

Both good and negative effects of nanotechnology use have been observed in agriculture, although further study is needed to determine the long-term effects. The use of many forms of nanomaterial in agriculture engineering is therefore summarized in the current chapter, with a focus on farm power sources, agricultural machinery, ergonomics, irrigation, and fertilizer applications.

II. NANOTECHNOLOGY

In order to explore the biological and material worlds at a nanometer-scale and use them in a variety of professions, from medicine to agriculture, nanotechnology is a new scientific approach that includes the use of materials and equipment capable of using a substance's physical and chemical properties at molecular levels [1]. Conceptually, nanotechnology is the ability to build new structures at the tiniest scales utilizing methods and instruments that enable the comprehension and control of matter at the nanoscale, which is typically between 0.1 and 100 nm. Chemical engineering, materials science, biochemistry, biophysics, solid state physics, and chemical engineering are all combined in nanotechnology. Nanotechnology is the study of small objects, such as materials with a size of less than 100 nm. 10^{-9} meters make up one nanometer. The size at which basic characteristics diverge from those of the comparable bulk material serves as the definition of the nanoparticle. Colloids, which have diameters between 1 nm and 1 mm, and nanoparticles have the same size range [2]. Nanomaterials have particular and distinctive chemical and optical characteristics in this size range. Additionally, nanoparticles' physical characteristics differ from those of the bulk substance [3]. Nanomaterials have higher surface-to-volume ratios and particular surface plasma resonance than bulk materials, which expands their potential for use in a variety of applications.

Nanotechnologies have a number of benefits because of the special functional characteristics of nanoparticles and materials, including:

1. The nanoparticles were stronger, more heat resistant, had a lower melting point and had different magnetic characteristics of Nano-clusters because of their high surface-to-volume ratio.
2. Due to their small size, nanoparticles have a higher charge density and greater reactivity [4].
3. Variations in the atomic distribution across various nanoparticles are caused by differences in the exposed surfaces of the nanoparticles, which in turn changes the kinetics of electron transfer between metal nanoparticles and the corresponding adsorbed species.
4. The activity of the atoms on the surface of the particles rises relative to the volume of the particles as the surface area increases.
5. Tetrahedral nanoparticles are more catalytically active than cubic and spherical nanoparticles, which are distinguished by improved chemical reactivity along the sharp edges and corners of the former [5].

Two fundamental techniques are used to prepare the nanomaterials. Top-down systems that rely on size reduction from bulk materials and bottom-up systems start with the atomic level to synthesis materials (according to the Royal Society and Royal Academy of Engineering).

Top-down system: This technique, which produces nanoparticles by using mechanical-physical techniques like grinding, milling, and crushing to create nanoparticles, is used to create nanocomposites and nano-grained bulk materials, such as metallic and ceramic nanomaterials, in a wide range of sizes (10–1000 nm), as shown in figure 1.

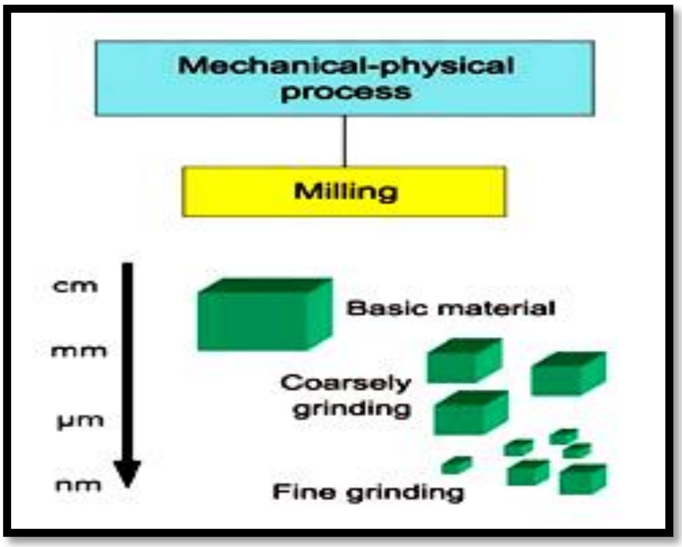

Figure 1: Schematic Diagram for Preparing Nanoparticles by Mechanical Process (Credit: Waleed Fouad Abobatta)

Bottom-up system: in ‘Bottom-up’ building up, numerous molecules self-assemble in parallel steps, as a function of their molecular recognition characters, this processing produces more complex structures from atoms or molecules, also, this method produces uniform controlling sizes, shapes, and sizes ranges of nanomaterials (Figure 2). Usually, this method is used for preparing most of the nano-scale materials (1 - 100 nm), it plays an essential role in the production of nanostructures and nanomaterials. Also, there are some other methods for producing Nanomaterials like attrition and pyrolysis, and the biological synthesis of nanoparticles [6].

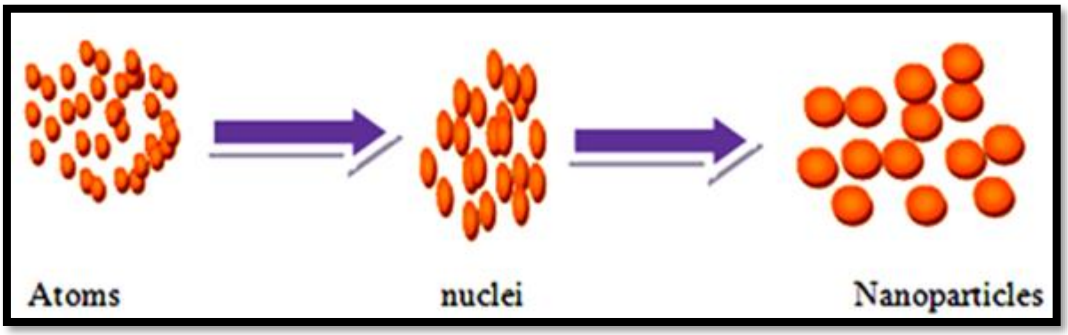

Figure 2: Structures of Nano Particles are Fabricated by Chemical Procedures (Credit: Waleed Fouad Abobatta)

III. NANOTECHNOLOGY IN AGRICULTURAL ENGINEERING

In the fields of medicine, electronics, electrical, solar, optical, and agriculture, nanotechnology is a developing technology. Nanotechnology has produced a variety of agricultural instruments in the form of nanopesticides, nanofertilizers, and nanosensors that have had a substantial impact on the practice of sustainable agriculture. Carbon nanotubes (CNT), inorganic non-metallic nanomaterials, metal alloys, nanoclays, nanopolymers, and nanocomposites are important members of this category. Improvements in mechanical characteristics (tensile strength, stiffness, toughness, friction coefficient), dimensional stability, thermal stability, thermal conductivity, and reinforcement are just a few of the enhanced qualities that can be used to good effect in the field of agricultural engineering. As a result, nanotechnology offers the manufacturing sector for agricultural machinery and equipment a new opportunity for growth. This chapter focuses on the possible applications of nanotechnology in several fields of agricultural engineering, particularly in the fields of farm machinery and power engineering (figure 3).

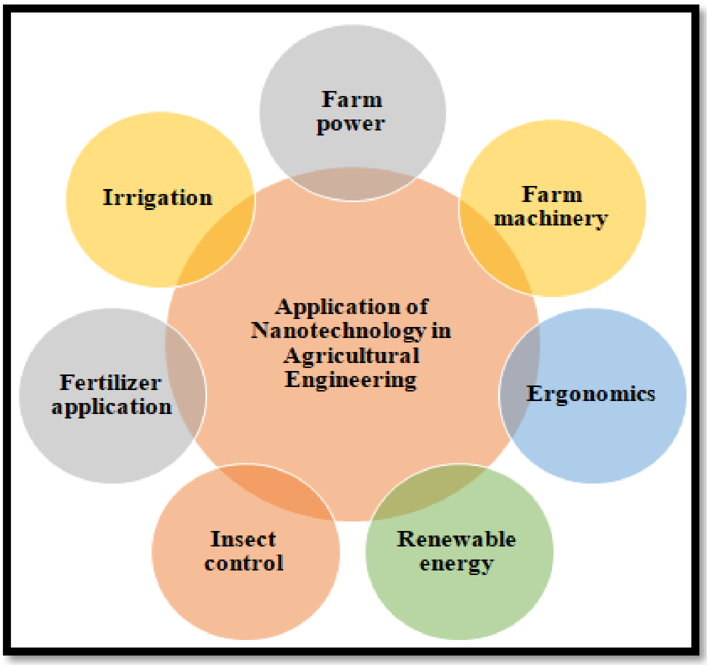

Figure 3: Application of Nanotechnology in Agricultural Engineering

1. **Nanotechnology in farm power:** Farm Power is a crucial component in agriculture for efficient field operations that boost the land's productivity and output. Farm power is utilized to run many stationary tasks such as running irrigation equipment, threshers, shellers, cleaners, graders, etc. as well as tillage, planting, plant protection, harvesting, and threshing machines.

   - **Engine construction:** Indian farms have access to a flexible form of power called engine power. Any advancement in engine functionality through nanotechnology will immediately increase the engine's effectiveness in terms of weight, price, and lifespan. Clay-reinforced nanocomposites are used for the first time in the manufacturing of timing chain coatings. These materials have great rigidity and excellent heat stability, and they can be used in the body of an automotive engine. Due to the lower content of organic fibers than nylon or propylene packed with glass fibers, the protective weight attained to cover the timing chain is 25% lighter [7].

     Nanotechnology can increase an engine's moving parts' resistance to typical usage-related wear and tear. In the traditional method, the material is coated with another hard material to make it wear resistant, but this coating is readily delaminated and fractured. Aluminium oxide has showed promising results in reducing wear when metals are mixed with it in its nanopores. In terms of Brinell hardness number [8], aluminium reinforced nanocomposites are 63.7–81.1% stronger than base alloys, and they are 16% stronger in terms of tensile strength. Al_2O_3, SiO_2, and TiO_2 ceramic nanoparticles are suitable surface hardening materials to increase the scratch resistance of metals [9]. To boost the toughness of the metals, ceramic nanocomposite made of alumina and carbon nanotubes (CNT) is also utilized [10]. These materials can be used to lessen the wear on many engine parts, including the rocker arm assembly, crankshaft, camshaft, valves, piston, cylinder liner, and gears. Roughly 24-

28% of the fuel energy used in a conventional internal combustion engine (ICE) is lost as heat through the cooling system [11]. The fundamental goal of adiabatic engines, sometimes referred to as low heat rejection engines, is to maximize the efficiency of diesel engines by decreasing the flow of heat through the internal combustion engine walls. LHR engines are another name for the thermal barrier-coated engines [12]. The heat transfer through the cylinder walls to the cooling system is decreased as a result of the cylinder wall's insulation, which alters the diesel engine's combustion characteristics. Thermal barrier coatings regulate the heat rejection within the cylinder, guard against thermal deterioration of the metallic surfaces beneath, and also lessen CO, smoke, and HC emissions [13]. To improve the functional qualities of metal components, a variety of ceramic coatings can be used. For heat barrier coatings on engine parts, ceramic materials with high levels of hardness, thermal resistance, and melting temperatures are employed, such as zirconia and magnesium zirconated. To lessen the heat rejected from the aforementioned portion, the piston surface and valves of a single-cylinder diesel engine are covered with ZrO_2 ceramic coating material [14]. On occasion, copper and nickel nanocatalyst coatings are applied to the piston top to cut down on NOx, smoke, and hydrocarbon emissions. Copper nanocatalyst-coated pistons also enhance brake thermal efficiency and specific fuel consumption [15].

- **Transmission system:** The transmission system is crucial in keeping the power transfer from the engine to the tyres in agricultural machinery like tractors, power tillers, and combines. Clutch, brake, gearbox, differential, and tyres make up the transmission system. A brake slows down, stops, or controls the speed of an automotive system through the regulated release of energy, whereas a clutch makes a smooth, progressive connection of two coaxial shafts revolving at different speeds. Both have a functioning component that uses friction material. Nano-filled friction materials can be utilized in place of conventional styrene-butadiene rubber and nitrile-butadiene rubber, which are used to create clutch facings, disc brake pads, and brake linings. These friction materials feature an enhanced friction coefficient and a low wear rate [16]. Metal hybrid composites' frictional and wear resistance qualities are improved with the addition of silicon carbide (SiC), alumina, and silica [17]. By incorporating multi-walled carbon nanotubes and nano-clay, brake friction materials can perform better [18].

Due to a steadily growing need for higher productivity and lower costs, agriculture has gradually made the transition to faster operating speeds for all associated machines and a wider usage of transport-oriented farm tractors. For many agricultural vehicles' technical systems, this change presents a lot of questions. Due to its impact on operator comfort, agricultural machine adhesion, and soil compaction, the mechanical behavior of agricultural tyres is a topic of intense research [19]. To improve the physical qualities of the rubber, such as tear resistance, reduced rolling resistance, abrasion resistance, and grip, fillers including carbon black, calcium silicate, and silica are typically added [20]. The characteristics of tyres can be considerably enhanced by adding this substance at the nanometric scale. Rubber materials' strength and fatigue characteristics improve as a result of nanoparticle reinforcement [21]. To improve mechanical stiffness and tensile strength, carbon nanotubes (CNT) are dispersed in silica-filled natural rubber. The mechanical qualities of tyre rubber can be enhanced by adding various combinations of other nanofamily members such graphene, alumina, carbon nano-fibers, and reinforced polymer nanocomposites. For tractors and combines, all of these elements result in a high-quality product that can endure longer in a range of environments. Rubber composite's wear resistance is increased by up to 8 times with the addition of nano-Al_2O_3 [22]. The amount of rubber needed for the tyre can be decreased by adding these nanoparticles, which also makes the tyre lighter, more affordable, and able to keep its cool while being driven.

- **Cooling system:** Three crucial purposes are served by the cooling system. First, it removes extra heat from the engine; second, it keeps the engine operating at the temperature where it operates most effectively; and third, it swiftly raises the engine's operational temperature. Over the past few decades, extensive research has been done on nanocoolants. The rate of heat transmission in car radiators is increased by using coolants with nanoparticle dispersion. Because traditional fluids like water and ethylene glycol have low thermal conductivity, nanocoolant has emerged to address the need for greater heat transmission [23]. In compared to pure water, the addition of Al_2O_3 nanoparticles to the water can increase heat transfer efficiency by 40–45% [24]. Another type of nanofluid, CNT water, performs better at heat transmission than Al_2O_3 water [25]. For a better heat transfer rate, a water/propylene glycol-based TiO_2 nanofluid with pure water is employed when the operating temperature of the engine is high and a higher coolant flow is needed to dissipate the heat [26]. On the other hand, the use of copper nanofluids based on ethylene glycol improves the overall heat transfer coefficient and heat transfer rate in a vehicle cooling system. The production of oil-based nanofluids, which improve heat transfer characteristics more than water-based nanofluids, is the subject of a small but growing body of study.

  Additionally, a key factor in improved cooling system performance is radiator design. Aluminum-based multiwall carbon nanotube (Al-MWCNT) fins are now used in radiators instead of the radiator's traditional aluminium fins. Al-MWCNT permits a general reduction in the size of the radiators while improving the thermal performance of the radiator due to the strong thermal conductivity of MWCNT. And as compared to traditional fins, MWCNT nanofluid exhibits a greater decrease in working fluid temperature at an equivalent coolant flow rate [27]. To enhance performance in agricultural operations, tractor industries are implementing nanofluid mechanisms in engine radiators and cooling systems.

- **Fuel supply system:** Major limitations of conventional fuel injection techniques include poor atomization, incomplete combustion, carbon buildup, and environmentally hazardous exhaust emissions. Burning is most effective when fuel molecules are well dispersed and of uniform size and are well-mixed with air. Nanoparticle-impregnated molecules of gasoline or diesel can prevent the clumping of hydrocarbons, resulting in full burning. Numerous spherical nanoparticles present in nano-lubricants considerably enhance the lubricant's compressive capabilities while also reducing friction and wear. The benefits of using these materials can include improving speed and lowering energy requirements, extending the useful life of the materials, and minimizing environmental impact, depending on their purpose. Copper nanoparticles are added to engine oil to lessen engine erosion, and ferromagnetic nanoparticles are employed in both the structural lubricant and the leak-stopping structure. The main benefits of employing nanolubricants are decreased fuel consumption, increased engine life, and decreased engine service time.

Friction causes wear and tear on engine parts, which occurs in any machinery with moving parts. Nano-lubricants made of Al_2O_3 and TiO_2 reduce friction by 35-51% and 51%, respectively, near the ends of the stroke [28]. The considerable decrease in friction coefficient may be attributable to nanoparticles' pivotal role in acting through many mechanisms, including film deposition and micro rolling bearing. To achieve homogeneous suspension, the nanoparticles like cerium oxide (CeO_2) and alumina (Al_2O_3) are used with the fuel mixtures. Because nanoparticles have a higher surface area to volume ratio, there was more mixing and chemical reactivity during combustion, which improved the diesel engine's performance, combustion, and emission characteristics. When compared to pure biodiesel, the engine's braking thermal efficiency for the nanoparticle fuels dramatically increased by 12%, while NO, carbon monoxide, hydrocarbon, and smoke emissions were all reduced by 30%, 60%, 44%, and 38%, respectively [29]. Cobalt oxide (Co_3O_4) and magnesium (Al-Mg) nanofuel additives are mixed throughout the Jatropha biodiesel. As an oxygen buffer, cobalt oxide enhances combustion and lowers emissions. Magnalium lowers the creation of pollutants by enhancing atomization by micro explosion events [30]. Diesel engine power and torque are increased, and brake-specific fuel consumption is decreased, when water and carbon quantum dot nanoparticles are added at optimal concentrations. This is because the fuel and air in the combustion chamber are mixed more effectively, and more oxygen is available for more efficient burning.

- **Ignition system:** We have entered a new era of more complicated, significant inventions as a result of the massive amount of technology breakthroughs in the last several decades. The need for batteries has increased as a result of the expanded role of electronics. But this need has brought up a lot of problems with the longevity of the present batteries. The active components in conventional lithium-ion technology include cobalt oxide and manganese oxide. The power that can be drawn from a battery and the time it takes to recharge must both be increased to meet the need for contemporary agricultural equipment. An electrode's surface can be coated with nanoparticles to accomplish this. This expands the electrode's surface area, allowing greater current to flow between the electrode and the battery's chemical constituents [31]. In lithium-ion batteries, graphene nanosheets are also utilized as anodes to store lithium. The improved reversible lithium storage capacity and strong cycle performance of graphene nanosheet anodes were demonstrated. Due to their aerogel structure, nano-crystalline materials can save much more energy than conventional removable plates in the new battery generation. Ni-MH batteries, which are composed of nano-crystalline nickel and metal hydrides, have a lower recharge requirement and a longer lifespan. The usual graphite electrodes in batteries are currently being replaced by carbon nanotubes (CNT). The extremely high surface area, excellent electrical conductivity, and linear shape of these nanomaterials make their surface areas highly accessible to battery electrolytes, increasing the generation of electricity. More power, smaller, and lighter batteries that can be used for a variety of purposes are produced by increasing output from a given quantity of material [32].

- **Emission control:** Limitations on the internal combustion engines exhaust emissions have gotten progressively stricter due to environmental safety concerns. Oxides of nitrogen, particulates, hydrocarbons, and carbon monoxide are the most significant pollutants produced by a diesel engine. These elements harm the environment and public health in a number of different ways. These toxins must be converted into harmless parts due to rising environmental concerns and governmental regulations. Traditionally, several catalysts have been used to accomplish this [33]. These catalysts have a short lifespan since the catalyst surface is so tiny. The active area of catalysts can be increased through the use of nanotechnology to react with contaminants. Diesel engines use a variety of in-cylinder combustion treatment techniques to reduce hydrocarbon, smoke particulate, and nitrous oxide emissions while improving brake thermal efficiency and specific fuel consumption. Examples of these techniques include ceramic coating on the piston, diamond-like carbon coating on the piston, copper and cadmium nano and zirconia coating on the piston, and various ceramic coatings on the cylinder head and liner. The emission of NOx, HC, and CO is significantly influenced by nanoparticle concentration together with engine speed and water volume fraction. The blend's optimal nanoparticle concentration results in a notable improvement in all engine performance metrics.

2. **Nanotechnology in farm machinery:** The agricultural machinery sector now has access to new possibilities thanks to nanotechnology. Nanotechnology can help with the design of agricultural machinery in a number of areas, including the primary skeleton, engine and transmission systems, paint and coatings, lubricants, and tyres. Blades for combine harvester machines, for example, benefit from increased wear resistance because to nanocoatings. The efficiency of agricultural machinery can be increased very effectively with the use of nanotechnology.

    - **Protection of machinery:** All of the equipment used in daily life is being produced and manufactured with a rising emphasis on nanotechnology. Additionally, the design, durability, and hardworking conditions of agricultural equipment are all special properties of nanotechnology. Tools and implements of the right kind and strength are required for every tillage operation. Because there are hard mineral particles in the soil, agricultural tools and implements have quite distinct working conditions and are subject to wear. For this, it is crucial that the apparatus is painted with sunlight- and wear-resistant paint. Understanding the corrosion behavior of materials at the microstructure level is essential for the use of nanotechnology in the field of corrosion protection. Due to their great strength and durability against environmental variables, nanometric coatings are utilized for a variety of reasons, including higher strength, improved bending and sheeting qualities, protective coatings resistant to corrosion, scratches, and wear, and nanocomposites.

      Numerous techniques can be used to apply nanocoating, including electrochemical deposition, physical vapour phase deposition, sol-gel processes, electro-spark deposition, and laser beam surface treatment. Nanoparticle-coated ceramic surfaces help engine parts resist erosion and maintain a constant temperature [34]. Siloxane encapsulated SiO2 nanoparticles can be employed to produce improved scratch and abrasion-resistant films [35]. The main factor limiting the lifespan and effectiveness of cutting tools and other tillage implements is wear. Compared to other agricultural instruments, cutting the soil and removing it from the ground in an intact manner causes the tillage blades to experience extreme wear. Numerous factors, including shape, strength, and surface characteristics, affect wear. In this context, moisture content may be a significant factor. The wear resistance of nanostructured materials can be impacted by changes in moisture in many ways [35]. Mechanical qualities like hardness and stiffness are greatly influenced by the size and form of the grains that make up a coating. Fine grain size materials (nickel nanostructured coatings) can increase stiffness without decreasing the material's flexibility. Less friction coefficient is produced by a coating with lower grain size. These coatings have a 40–50% lower coefficient of friction than traditional nickel coatings [36]. To reduce wear rate and surface roughness, a composite made of carbon nanotubes and hard chromium is utilized [37]. The following list includes some nanomaterials:

Table 1: Nanomaterials for Coating and their Function

Nanomaterials Electrical Conductivity	Functions
SiO_2, Al_2O_3, ZrO_2	Scratch resistance
Nanoclay	Corrosion and fire retardant
$BaSO_4$, TiO_2, ZnO, CeO_2, Graphene	Ultraviolet stability
Nanoclay, Graphene	Gas barrier
CuO, TiO_2, ZnO	Antimicrobial
$CaSiO_3$, SiO_2, CNTs, TiO_2	Impact resistance
ZrO_2, CNTs, Nanoclay	Heat resistance
CNTs, SiO_2, Graphene	Electrical conductivity

- **Construction of agricultural machinery:** The requirement for using more lasting parts is further specified by the demanding conditions for agricultural machinery and equipment, particularly tractors, combines, and other devices used in fields or gardens. Using carbon nanotubes and clay nanoparticles to create nanocomposites with better mechanical properties than traditional composites could be a novel way to replace or possibly completely replace metal parts in agricultural machines. Carbon nanotubes (CNT) are considerably lighter than steel and 150 times stronger. Therefore, it is crucial to incorporate nanocomposites in the design and building of agricultural machinery and equipment. CNTs are a viable alternative to steel in machinery because they increase strength and reduce weight [39]. Medium carbon steel with a little amount of silicon and manganese is typically used for soil engaging tools since alloy steel, which is very abrasive and corrosion resistant, is out of the price range of farmers [40]. The main drawback of using medium carbon steel is how little wear and abrasion resistance it has. Steel that is abrasion, mechanical load, and hydrogen penetration resistant is required to extend the lifespan of agricultural equipment. Heavy agricultural equipment compacts the soil and puts an excessive stress on the prime mover. We can improve fuel economy, lower CO_2 emissions, and lower production costs by making machinery lighter.

3. **Nanotechnology in ergonomics:** Design is a scientific branch where a specific product/facility/output is made using specific methods from predefined ideas, whereas ergonomics/human factor engineering (HFE) deals with designing equipment or devices and workplace that fit to the human body, its movements, and its cognitive abilities about

their work performance. The term "Nanoergonomics" refers to a study that combines ergonomics and nanotechnology [41]. While using nanomaterials to adapt human jobs, nanoergonomics does not imply adapting human jobs to nanoparticles. The following are examples of how ergonomics has applied nanomaterials:

- In the design field
- In occupational health and safety issues

- **Workplace design:** According to someone, if a design were a "lock," ergonomics would be the "key" to the lock. Construction, interior design, environment, management, and other factors all fall under the category of workplace design. For human performance, efficiency, and output, the ideal working environment must be created in the workplace. The following environmental elements should be taken into account at work: lighting (such as artificial or solar lighting), temperature, humidity, noise, and air quality [42]. Temperature, noise, air quality, sun radiation, and others have connections to certain properties of nanomaterials [43]. By using ergonomic design concepts, a more comfortable employment environment may be created thanks to nanotechnology.

  Intelligent glass can be made from the nanocrystalline materials created using the Aero-Gel technique. When exposed to strong sunshine, this glass turns black and opaque; conversely, when sunlight is there less, it becomes brighter. Because of this characteristic, the tractor driver's eyes are not bothered by sunshine. Additionally, this form of glass has its own self-cleaning qualities, which is a crucial quality of the glass used in the production of agricultural machinery and equipment because agricultural machinery is utilised in dust-free conditions. Another illustration is glass that can reflect infrared light from the sun and has a very thin layer of nanoparticles sandwiched between two layers of the material. This layer is in charge of diffusing infrared sunshine to keep the cabin from overheating [44].

  Nanomaterials can be utilised to control the temperature of workplaces since they offer unique thermal insulation and thermoregulation capabilities. Aerogel in the form of "nanogel" not only offers excellent thermal insulation but also works well to muffle sound in busy environments [45]. Aerogel's superior thermal insulation abilities are mostly dependent on the foam pore's nanoscale dimension. Air molecules trapped inside 20 nm-wide nanopores are immobile and thus suited for long-lasting thermal insulation.

  Maintenance of the workplace is a crucial component of workplace design. To maintain the surface clear, nanoscalar TiO_2 coatings with photocatalytic activity ([46]) are applied to car windshields, interior windows, doors, etc. [43] composed of glass or ceramic. For absorbing UV sunshine rays that damage the colour pigments and coatings of traditionally painted buildings or workplaces, nanomaterials' UV protection function is particularly helpful. Currently, colour coatings for UV protection use a novel method of UV protection using a single or combination of nanoscalar inorganic materials, such as titanium dioxide (absorbs UV-B rays), zinc oxide (absorbs both UV-A and UV-B rays), and ceroxide (absorbs not only UV rays but also a small amount of visible light) [47].

- **Health and safety of agricultural workers:** With the introduction of new technologies that could give materials unique functions and features, the textile industry is undergoing a revolution. fibres, flammability, resilience to UV rays, and numerous other qualities. The public has become increasingly concerned about those who are exposed to dangerous fungicides, herbicides, insecticides, pesticides, other chemicals, biological agents, and nerve gases, such as farmers, military personnel, agriculture and food science scientists, engineers, and workers. The likelihood of workers developing hyperthermia increases, especially during the hot farming seasons, because a significant amount of traditional protective clothing exhibits good barrier and protection capabilities but only moderate moisture and air permeability. As a result, it has compelled numerous public and private organisations to create new and effective protective clothing against those harmful compounds. An ideal substitute for the design of protective clothing for farm workers who are exposed to toxic chemical and biochemical agents such as pesticides, herbicides, or fungicides is the attachment of NPs in ultrathin fibres using electrospinning, a promising method to manufacture nanofibers (polypropylene) with control of their structure and properties. There are various commercially produced nano-silver clothing pieces, including pants, coats, and facemasks. Functional fill nanomaterials (aerosols) with a thickness of roughly 3 mm between glass panels make up the fire-resistant shield. It offers continuous flame exposure protection for more than 120 minutes at temperatures above 1000 C.

4. **Nanotechnology in renewable energy:** The development of renewable energy technology is one of the major technological challenges of the twenty-first century because of substantial issues with energy production and use. Nanotechnologies is a brand-new, very promising field of study that is expanding quickly and is now regarded as one of the best solutions to this issue. The scale and design of renewable energy devices used for energy conversion and storage, environmental monitoring, and green engineering of ecologically friendly materials have undergone a significant revolution thanks to nanotechnology. It has been demonstrated that nanoparticles have a substantial impact on human existence by supplying affordable, clean energy, which has grown into a global business. The role of nanotechnology in renewable energy is present in many different areas. Some of the examples below:

   - **Solar energy:** One of the best forms of renewable energy is solar energy. It is effective in a wide range of real-world uses, including solar power plants, solar cells, seawater desalination, solar collectors, etc. A huge electric infrastructure or fossil fuels have little chance of competing with current solar power technology. For large-scale energy generation, today's solar cells are simply not efficient enough and are therefore too expensive to manufacture. However, possible developments in nanotechnology may pave the way for the creation of solar cells that are less expensive and marginally more effective. Solar cell efficiency may be improved by nanotechnology, but the technology's potential for lowering manufacturing costs is much greater. TiO_2 nanoparticles are used to create a thin, flexible solar panel known as plastic. Solar panels made of plastic can be either opaque or semi-transparent. Installing, producing, using less material, moulding into curves, and contouring your designs are all simple. Nanowires are made of metal, exactly like conventional wires. Their sizes are the only meaningful conceptual distinction. They are not restricted in terms of length; they can be as lengthy as desired. Beyond what normal wire can do, they are capable of a great deal more. These brand-new plastic solar cells make use of a nano solar cell's small nanorods. For two key reasons, this sort of cell is less expensive to produce than conventional ones. First off, silicon is not a component of these nanotechnology solar cells. Second, no expensive machinery is needed to produce these cells. The nanorods in these solar cells may be tweaked to absorb light, which is another potential feature. Because more of the incident light could be used, this might greatly boost the solar cell's efficiency. The flat-plate solar collector can be improved by using a nanofluid in place of the working fluid. In order to create a nanofluid that increases the energy stored in a thermal storage system with a flat plate solar collector, zinc oxide nanoparticles are mixed with ordinary water. Another effective way to increase energy and exergy efficiency is to use MWCNT/water nanofluid in a thermosiphon flat-plate solar collector.

- **Hydrogen energy:** The current fuel shortage is one of the biggest issues. The majority of the energy utilised in cars and other internal combustion engines comes from fossil fuels. Since it comes from a non-renewable source, the fuel supply is progressively getting smaller every day. Therefore, it is the responsibility of an engineer to introduce a system that uses renewable or abundant energy sources. One of the solutions proposed by researchers is the use of hydrogen as a fuel in fuel cells. Hydrogen is merely an atomic energy transporter and not an energy source. One of the most beneficial answers to a variety of energy resources, energy sustainability, and the environment has arisen as hydrogen and fuel cell technology. Since the fuel cell converts hydrogen and oxygen into water while also providing energy and heat, it is typically thought of in terms of hydrogen. With no damaging carbon dioxide emissions, this happens in a sustainable manner. The fuel cell has many benefits, but it also has many disadvantages, including high cost, problems with durability, and operability. The fuel cells are criticised for their alleged indirect environmental pollution when producing hydrogen through the processes of steam reforming and electrolysis. The use of nanoparticles in the hydrogen manufacturing process solves this issue. Another issue is that there is no practical way to store hydrogen in the requisite basic quantity. Nanotechnology is used to address the issue in this instance as well. One way to produce hydrogen using nanotechnology is using photoelectrochemical means. The necessary amount of hydrogen is stored using carbon nanotubes. Similar to how a sponge absorbs water, these materials take in hydrogen and keep it (without leaking) until you need it. These carbon nanotubes have a hydrogen content of 8% by weight. Fuel cells offer a practical operational efficiency of 50–60% compared to IC engines' 20–30%.

- **Bioenergy:** All organic components derived from plants are collectively referred to as biomass (including algae, trees, and crops). All land- and water-based vegetation, as well as organic waste, are considered to be a part of biomass, which is created when green plants convert sunlight into plant material through photosynthesis. The biomass resource can be thought of as organic stuff that contains chemical bonds that store solar energy. By breaking the bonds between nearby carbon, hydrogen, and oxygen molecules during digestion or combustion, these chemicals release the chemical energy they have been holding in reserve. The output of unburned hydrocarbons and carbon monoxide is significantly reduced when biodiesel is used in conventional diesel engines (CO). The production of biodiesel is increased using KF/CaO nanocatalyst [49]. For the manufacture of biodiesel, a nanomagnetic solid base catalyst (KF/CaO-Fe_3O_4) is also employed [50].

5. **Nanotechnology in irrigation and fertilizer application:** Some plant diseases and insect pests have a significant impact on agricultural production and result in significant economic losses. Using precise and controlled releases of pesticides, insecticides, herbicides, and insect repellents, nanotechnology can be used in agriculture. Nanotechnology is also employed in irrigation to address a number of issues.

   - **Irrigation:** Irrigation is the process of applying water to crops and farms artificially in order to increase agricultural performance and output [52]. For increased output, continued soil productivity, and environmental protection, irrigation water quality is crucial. In less than 60 seconds of contact time, 99.9% of bacteria and viruses may be removed from water using nano-sized TiO_2 coated on silica beads and irradiated by UV light [53]. Groundwater salinity is a significant issue that can be resolved by nanotechnology employing CNTs. These technologies have demonstrated desalination efficiencies that are up to 1000 times greater than RO.

   - **Protection of crops and application of fertilizers:** Nanotechnology will revolutionise the agricultural and food industries with the creation of new tools for disease detection, disease diagnosis, boosting plant nutrient absorption capacity, etc. The agriculture sector will benefit from smart sensors and smart delivery systems to fight viruses and other crop pathogens. Future nanostructured catalysts will be able to boost the effectiveness of insecticides and herbicides, enabling the use of lower concentrations [51]. This technique for insect pest control uses pheromones to lure pests to traps, protecting plants and increasing crop yields. Electrospun nanofibers can successfully release the active components for the attraction of particular pests due to their high surface areas and flexibility.

     Recently, fertilising was investigated as a new use for electrospun nanofibers. To create nanofibers with the fertilisers, some of the fertilisers were dissolved in the proper solvents and added to the electrospinning solution. Compared to the loose tiny particles, the electrospun nanofiber network was more durable and less likely to be washed away. During farming seasons, an electrospinning process can help reduce the amount of fertiliser losses.

IV. CONCLUSION

The advancement of nanotechnology has opened up a fresh and fascinating frontier for numerous agricultural applications that have a significant bearing on human life. Numerous fields could benefit from nanotechnology. Nanotechnology is becoming more prevalent across all academic fields, including agriculture, and it is improving the performance and productivity of agricultural products. Future nanotechnology will incorporate all of the technologies of today and, rather than competing with them, will seize and consolidate their growth path. Nanotechnology has considerably demonstrated its applicability in agriculture as a nanopesticide, nanofertilizer, and nanosensor in plant development and crop production. Although it is slowly transitioning from theoretical knowledge to the application regime, nanotechnology's full promise in the agriculture and food industries has not yet been fully realised. . In general, abrasive wear, corrosion, fatigue wear, and cracks are the main reasons for equipment component failures. Nanoparticles refine the grains, preventing fissures, as a result of their addition. hence enhancing the thermal barrier, corrosion resistance, hardness, wear resistance, and strength. Nano lubricant additives and nano coolants have significant development potential due to their exceptional benefits for lubrication and cooling. Nanotechnology has the potential to drastically lower failure and damage rates for agricultural equipment. the use of nanotechnology in the creation of paints, coatings, metal nanocomposites, and nano-polymer composites for use in building materials and agricultural equipment. The renewable energy sector was impacted by nanotechnology as well. Although domestic users of agricultural machinery might not see the need for nanotechnology in machinery and equipment, manufacturing companies must be aware of the fact that using this technology will improve their products, satisfy customers, and ultimately have a significant impact on the sale of their goods. The introduction of nanotechnology into agriculture holds the promise of a vast and radical transformation that has the potential to change the world both economically and scientifically.

REFERENCES

[1] Fakruddin, M., Hossain, Z., & Afroz, H. (2012). Prospects and applications of nanobiotechnology: a medical perspective. *Journal of nanobiotechnology*, *10*(1), 1-8.
[2] Banfield, J. F., & Zhang, H. (2001). Nanoparticles in the environment. *Reviews in mineralogy and geochemistry*, *44*(1), 1-58.
[3] Buffle, J. (2006). The key role of environmental colloids/nanoparticles for the sustainability of life. *Environmental Chemistry*, *3*(3), 155-158.
[4] Yang, L., & Watts, D. J. (2005). Particle surface characteristics may play an important role in phytotoxicity of alumina nanoparticles. *Toxicology letters*, *158*(2), 122-132.
[5] Tapan, A., Biswas, A. K., & Kundu, S. (2010). Nano-fertiliser-a new dimension in agriculture. *Indian Journal of Fertilisers*, *6*(8), 22-24.
[6] Abobatta, W. F. (2018). Nanotechnology application in agriculture. *Acta Scientific Agriculture*, *2*(6).
[7] Dehkordi, Amin Lotfalian, Farideh Keivani. "Applications of Nanotechnology for Improving Production Methods and Performance of Agricultural Equipment." Vatan-Dolat-Xah, Ja'far. 2006. "Nanotechnology, Basic Science, and New Technology." 2017;9(2):102-6.
[8] Premnat A A; Varma L P; Ramakrishna S S P; Dheeraj P; Karthik N P. 2018. Mechanical properties of Al-SiC Nano Composites fabricated by Friction Stir Processing. IOP Conference Series: Materials Science and Engineering, 390(1).
[9] Bautista Y; Gonzalez J; Gilabert J; Ibañez M J; Sanz V. 2011.Correlation between the wear resistance, and the scratch resistance, for nanocomposite coatings. Progress in OrganicCoatings, 70(4): 178–185
[10] Ahmad, I., Kennedy, A., & Zhu, Y. Q. (2010). Wear resistant properties of multi-walled carbon nanotubes reinforced Al2O3 nanocomposites. *Wear*, *269*(1-2), 71-78.
[11] Liljedahl, J. B., Turnquist, P. K., Smith, D. W., & Hoki, M. (1979). *Tractors and their power units*. New York: Wiley.
[12] Murthy, P. V. K., Krishna, M. M., Raju, S. A., Prasad, V. C., & Srinivasulu, N. V. (2010). Performance evaluation of low heat rejection diesel engine with pure diesel. *International journal of applied engineering research*, *1*(3), 428.
[13] Yilmaz, I. T., & Gumus, M. (2017). Investigation of the effect of biogas on combustion and emissions of TBC diesel engine. *Fuel*, *188*, 69-78.
[14] Yilmaz, I. T., & Gumus, M. (2017). Investigation of the effect of biogas on combustion and emissions of TBC diesel engine. *Fuel*, *188*, 69-78.

[15] Ramalingam, S., Rajendran, S., & Ganesan, P. (2016). Performance improvement and emission control in a direct injection diesel engine using nano catalyst coated pistons. *Biofuels*, *7*(5), 529-535.
[16] Du, J. H., Zang, Y., & Zhu, X. Y. (2011). Effect of Nano-AlN on the Friction Performance of Cu-Based Friction Material. In *Materials Science Forum* (Vol. 694, pp. 413-417). Trans Tech Publications Ltd.
[17] Navin, M. P., & Deivasigamani, R. (2015). Material characterization of aluminium hybrid composite for clutch plate. *Int J Eng Sci Res Technol*, *4*(1), 297-305.
[18] Singh, T., Patnaik, A., Gangil, B., & Chauhan, R. (2015). Optimization of tribo-performance of brake friction materials: effect of nano filler. *Wear*, *324*, 10-16.
[19] Anifantis, A. S., Cutini, M., & Bietresato, M. (2020). An Experimental–Numerical Approach for Modelling the Mechanical Behaviour of a Pneumatic Tyre for Agricultural Machines. *Applied Sciences*, *10*(10), 3481.
[20] Edwards, D. C. (1990). Polymer-filler interactions in rubber reinforcement. *Journal of Materials Science*, *25*(10), 4175-4185.
[21] Al-Wazir, A. H. (2018). Modifying of fatigue characterization for natural rubber materials by carbon Nano-particle tube (CNT) reinforcement. *International Journal of Energy and Environment*, *9*(3), 303-310.
[22] Alkhazraji, A. N. (2018). Enhancement of mechanical properties and handling characteristic of tire rubber using different percentage of nano aluminum oxide and carbon black. *SMR*, *20*, 100.
[23] Saxena, G., & Soni, P. (2018). Nano coolants for automotive applications: a review. *Nano Trends: A Journal od Nanotechnology and Its Applications*, *20*(1), 9-22.
[24] Chavan, D., & Pise, A. T. (2014). Performance investigation of an automotive car radiator operated with nanofluid as a coolant. *Journal of Thermal Science and Engineering Applications*, *6*(2).
[25] Chougule, S. S., & Sahu, S. K. (2014). Comparative study of cooling performance of automobile radiator using Al2O3-water and carbon nanotube-water nanofluid. *Journal of Nanotechnology in Engineering and Medicine*, *5*(1).
[26] Salamon, V. (2017). D. Senthil kumar, and S. Thirumalini,“. *Experimental investigation of heat transfer characteristics of automobile radiator using TiO*, *2*.
[27] Jadar, R., Shashishekar, K. S., & Manohara, S. R. (2019). Performance evaluation of Al-MWCNT based automobile radiator. *Materials Today: Proceedings*, *9*, 380-388.
[28] Ali, M. K. A., Xianjun, H., Elagouz, A., Essa, F. A., & Abdelkareem, M. A. (2016). Minimizing of the boundary friction coefficient in automotive engines using Al2O3 and TiO2 nanoparticles. *Journal of Nanoparticle Research*, *18*(12), 1-16.
[29] Prabu, R. D., Valanarasu, S., Geno, H. A., Christy, A. J., Jeyadheepan, K., & Kathalingam, A. (2018). Effect of Neodymium doping on the structural, morphological, optical and electrical properties of copper oxide thin films. *Journal of Materials Science: Materials in Electronics*, *29*(13), 10921-10932.
[30] Ganesh, D., & Gowrishankar, G. (2011, September). Effect of nano-fuel additive on emission reduction in a biodiesel fuelled CI engine. In *2011 International conference on electrical and control engineering* (pp. 3453-3459). IEEE.
[31] Bruce, P. G., Scrosati, B., & Tarascon, J. M. (2008). Nanomaterials for rechargeable lithium batteries. *Angewandte Chemie International Edition*, *47*(16), 2930-2946.
[32] Echiegu, E. A. (2016). Nanotechnology as a tool for enhanced renewable energy application in developing countries. *J Fundam Renew Energy Appl*, *6*(6), 01-09.
[33] Johnson, B. T. (2008). Diesel engine emissions and their control. *Platinum Metals Review*, *52*(1), 23-37.
[34] Salehi Vaziri, H., Asadi Fard, R., & Elm Khah, H. (2004). Recommendations for the Management of Development of Nanotechnology in Iran. *Tehran, Nanotechnology Committee of Amirkabir University*.
[35] Horst, C., & Misra, A. (1978). Tribology: a systems approach to the science and technology of friction, lubrication and wear (tribology series, 1).

[36] Ebrahimi, F., Bourne, G. R., Kelly, M. S., & Matthews, T. E. (1999). Mechanical properties of nanocrystalline nickel produced by electrodeposition. *Nanostructured materials*, *11*(3), 343-350.

[37] El-Din, A. Z., Ahmed, S. F., Khattab, M. A., & Hamied, R. A. (2019). Influence of surface hardening with carbon nanotubes-hard chrome composite on wear characteristics of a simple tillage tools. *AMA, Agricultural Mechanization in Asia, Africa and Latin America*, *50*(4), 32-37.

[38] Gläsel, H. J., Bauer, F., Ernst, H., Findeisen, M., Hartmann, E., Langguth, H., ... & Schubert, R. (2000). Preparation of scratch and abrasion resistant polymeric nanocomposites by monomer grafting onto nanoparticles, 2 characterization of radiation-cured polymeric nanocomposites. *Macromolecular Chemistry and Physics*, *201*(18), 2765-2770.

[39] Steevan, S. (2015). Applications of Nanotechnology in Automobile Industry. *Manipal Technologies Limited*, 1-3.

[40] Stabryła, J. (2007). Research on the degradation process of agricultural tools in soil. *Problemy Eksploatacji*, 223-232.

[41] Karwowski, W. (2005). Ergonomics and human factors: the paradigms for science, engineering, design, technology and management of human-compatible systems. *Ergonomics*, *48*(5), 436-463.

[42] Attwood, D. A., Deeb, J. M., & Danz-Reece, M. E. (2004). *Ergonomic solutions for the process industries*. Elsevier.

[43] Leydecker, S. (2008). Nano Materials. In *Nano Materials*. Birkhäuser.

[44] Dehkordi, Amin Lotfalian, Farideh Keivani. “Applications of Nanotechnology for Improving Production Methods and Performance of Agricultural Equipment.” Vatan-Dolat-Xah, Ja’far. 2006. “Nanotechnology, Basic Science, and New Technology.” 2017;9(2):102-6.

[45] Schmidt, M., & Schwertfeger, F. (1998). Applications for silica aerogel products. *Journal of non-crystalline solids*, *225*, 364-368.

[46] Hashimoto, K., Irie, H., & Fujishima, A. (2005). TiO2 photocatalysis: a historical overview and future prospects. *Japanese journal of applied physics*, *44*(12R), 8269.

[47] Fink, D., Rojas-Chapana, J., Petrov, A., Tributsch, H., Friedrich, D., Küppers, U., ... & Zrineh, A. (2006). The “artificial ostrich eggshell” project: Sterilizing polymer foils for food industry and medicine. *Solar energy materials and solar cells*, *90*(10), 1458-1470.

[48] Mohamed, M. M., Mahmoud, N. H., & Farahat, M. A. (2020). Energy storage system with flat plate solar collector and water-ZnO nanofluid. *Solar Energy*, *202*, 25-31.

[49] Wen, L., Wang, Y., Lu, D., Hu, S., & Han, H. (2010). Preparation of KF/CaO nanocatalyst and its application in biodiesel production from Chinese tallow seed oil. *Fuel*, *89*(9), 2267-2271.

[50] Hu, S., Guan, Y., Wang, Y., & Han, H. (2011). Nano-magnetic catalyst KF/CaO–Fe3O4 for biodiesel production. *Applied Energy*, *88*(8), 2685-2690.

[51] Shaimaa H A-E; Mostafa M A M. 2015. Applications of nanotechnology in agriculture: An Overview. Egypt. J. Soil Sci., 55(2): 1-18

[52] Michael A M. (Arayathinal M., and Ojha, T. P. (2018). Principles of Agricultural Engineering Vol.-1 (10th Ed.). Jain Brothers

[53] Brame, J., Fattori, V., Clarke, R., Mackeyev, Y., Wilson, L. J., Li, Q., & Alvarez, P. (2014). Water disinfection using nanotechnology for safer irrigation: a demonstration project in Swaziland. *Environmental Engineer and Scientist: Applied Research and Practice*, *50*(2), 40-46.

