IJMRSETM

e-ISSN: 2395 - 7639

INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH

IN SCIENCE, ENGINEERING, TECHNOLOGY AND MANAGEMENT

Volume 9, Issue 11, November 2022

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

Impact Factor: 7.580

+91 99405 72462 +91 63819 07438 ijmrsetm@gmail.com www.ijmrsetm.com

International Journal of Multidisciplinary Research in Science, Engineering, Technology & Management (IJMRSETM)

| ISSN: 2395-7639| www.ijmrset.com| Impact Factor: 7.580 | A Monthly Double-Blind Peer Reviewed Journal |

|| Volume 9, Issue 11, November 2022 ||

|DOI:10.15680/IJMRSETM.2022.0811026|

A Review on Soil Health and Soil Quality Concept : An Issue of Concern for Sustainable Agriculture and Environmental Pollution

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ABSTRACT: Soil health is a state of a soil meeting its range of ecosystem functions as appropriate to its environment. In more colloquial terms, the health of soil arises from favorable interactions of all soil components (living and non-living) that belong together, as in microbiota, plants and animals. It is possible that a soil can be healthy in terms of eco-system functioning but not necessarily serve crop production or human nutrition directly, hence the scientific debate on terms and measurements.

Soil health testing is pursued as an assessment of this status[1] but tends to be confined largely to agronomic objectives, for obvious reasons. Soil health depends on soil biodiversity (with a robust soil biota), and it can be improved via soil management, especially by care to keep protective living covers on the soil and by natural (carbon-containing) soil amendments. Inorganic fertilizers do not necessarily damage soil health if 1) used at appropriate and not excessive rates and 2) if they bring about a general improvement of overall plant growth which contributes more carbon-containing residues to the soil.

KEYWORDS: soil health , quality, ecosystem, environmental pollution, sustainable agriculture

I.INTRODUCTION

Soil quality refers to the condition of soil based on its capacity to perform ecosystem services that meet the needs of human and non-human life.[1][2][3][4]

Soil quality reflects how well a soil performs the functions of maintaining biodiversity and productivity, partitioning water and solute flow, filtering and buffering, nutrient cycling, and providing support for plants and other structures. Soil management has a major impact on soil quality.

Soil quality relates to soil functions. Unlike water or air, for which established standards have been set, soil quality is difficult to define or quantify.

The term soil health is used to describe the state of a soil in:

- Sustaining plant and animal productivity (agronomic focus);
- Enhancing biodiversity (Soil biodiversity) (ecological focus);
- Maintaining or enhancing water and air quality (environmental/climate focus);
- Supporting human health and habitation.[2]
- sequestering carbon[3]

Soil Health has partly if not largely replaced the expression "Soil Quality" that was extant in the 1990s. The primary difference between the two expressions is that soil quality was focused on individual traits within a functional group, as in "quality of soil for maize production" or "quality of soil for roadbed preparation" and so on. The addition of the word "health" shifted the perception to be integrative, holistic and systematic. The two expressions still overlap considerably. Soil Health as an expression derives from organic or "biological farming" movements in Europe, however, well before soil quality was first applied as a discipline around 1990. In 1978, Swiss soil biologist Dr Otto Buess wrote an essay "The Health of Soil and Plants" which largely defines the field even today.

The underlying principle in the use of the term "soil health" is that soil is not just an inert, lifeless growing medium, which modern intensive farming tends to represent, rather it is a living, dynamic and ever-so-subtly changing whole environment. It turns out that soils highly fertile from the point of view of crop productivity are also lively from a

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biological point of view. It is now commonly recognized that soil microbial biomass is large: in temperate grassland soil the bacterial and fungal biomass have been documented to be 1–2 t (2.0 long tons; 2.2 short tons)/hectare and 2–5 t (4.9 long tons; 5.5 short tons)/ha, respectively. [4] Some microbiologists now believe that 80% of soil nutrient functions are essentially controlled by microbes.[5][6]

Using the human health analogy, a healthy soil can be categorized as one:

- In a state of composite well-being in terms of biological, chemical and physical properties;
- Not diseased or infirmed (i.e. not degraded, nor degrading), nor causing negative off-site impacts;
- With each of its qualities cooperatively functioning such that the soil reaches its full potential and resists degradation;
- Providing a full range of functions (especially nutrient, carbon and water cycling) and in such a way that it maintains this capacity into the future.

Soil health is the condition of the soil in a defined space and at a defined scale relative to a set of benchmarks that encompass healthy functioning. It would not be appropriate to refer to soil health for soil-roadbed preparation, as in the analogy of soil quality in a functional class. The definition of soil health may vary between users of the term as alternative users may place differing priorities upon the multiple functions of a soil. Therefore, the term soil health can only be understood within the context of the user of the term, and their aspirations of a soil, as well as by the boundary definition of the soil at issue. Finally, intrinsic to the discussion on soil health are many potentially conflicting interpretations, especially ecological landscape assessment vs agronomic objectives, each claiming to have soil health criteria.

Different soils will have different benchmarks of health depending on the "inherited" qualities, and on the geographic circumstance of the soil. The generic aspects defining a healthy soil can be considered as follows:

- "Productive" options are broad;
- Life diversity is broad;
- Absorbency, storing, recycling and processing is high in relation to limits set by climate;
- Water runoff quality is of high standard;
- Low entropy; and,
- No damage to, or loss of the fundamental components.

This translates to:

- A comprehensive cover of vegetation;
- Carbon levels relatively close to the limits set by soil type and climate;
- Little leakage of nutrients from the ecosystem;
- Biological and agricultural productivity relatively close to the limits set by the soil environment and climate;
- Only geological rates of erosion;
- No accumulation of contaminants

II.DISCUSSION

Soil quality can be evaluated using the Soil Management Assessment Framework.[5] Soil quality in agricultural terms is measured on a scale of soil value (Bodenwertzahl) in Germany.[6]

Soil quality is primarily measured by chemical, physical, and biological indicators because soil function cannot easily be measured directly.[7] Each of these categories comprises several indicators that provide insight into overall soil quality.

Physical

The physical category of soil quality indicators consists of tests that measure soil texture, bulk density, porosity, water content at saturation, aggregate stability, penetration resistance, and more. [8] These measures provide hydrological information, such the level of water infiltration and water availability to plants.

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Chemical

Chemical indicators include pH and nutrient levels. [9] A typical soil test only evaluates chemical soil properties.[7]

Biological

Biological measures include diversity of soil organisms and fungi.

The movement and biological functions of soil organisms (including earthworms, millipedes, centipedes, ants, and spiders) impact soil processes such as the regulation of soil structure, degradation of contaminants, and nutrient cycling. [10]

On the basis of the above, soil health will be measured in terms of individual ecosystem services provided relative to the benchmark. Specific benchmarks used to evaluate soil health include CO_2 release, humus levels, microbial activity, and available calcium.[7]

Soil health testing is spreading in the United States, Australia and South Africa.[8] Cornell University, a land-grant college in NY State, has had a Soil Health Test since 2006. Woods End Laboratories, a private soil lab founded in Maine in 1975, has offered a soil quality package since 1985. Bost these services combine test for physical (aggregate stability) chemical (mineral balance) and biology (CO_2 respiration) which today are considered hallmarks of soil health testing. The approach of other soil labs also entering the soil health field is to add into common chemical nutrient testing a biological set of factors not normally included in routine soil testing. The best example is adding biological soil respiration ("CO_2-Burst") as a test procedure; this has already been adapted to modern commercial labs in the period since 2006.

There is however resistance among soil testing labs and university scientists to add new biological tests, primarily since interpretation of soil fertility is based on models from "crop response" studies which match yield to test levels of specific chemical nutrients, and no similar models for interpretation appear to exist for soil health tests. Critics of novel soil health tests argue that they may be insensitive to management changes.[9]

Soil test methods have evolved slowly over the past 40 years. However, in this same time USA soils have also lost up to 75% of their carbon (humus), causing biological fertility and ecosystem functioning to decline; how much is debatable. Many critics of the conventional system say the loss of soil quality is sufficient evidence that the old soil testing models have failed us, and need to be replaced with new approaches. These older models have stressed "maximum yield" and " yield calibration" to such an extent that related factors have been overlooked. Thus, surface and groundwater pollution with excess nutrients (nitrates and phosphates) has grown enormously, and early 2000s measures were reported (in the United States) to be the worst it has been since the 1970s, before the advent of environmental consciousness.[10][11][12]

Importance of soil for global food security, agro-ecosystem, environment, and human life has exponentially shifted the trends of research towards soil health. However, lack of a site/region specific benchmark has limited the research effort towards understanding the true effect of different agronomic managements on soil health. In 2020, Maharjan and his team, introduces a new term and concept "Soil Health Gap" and described how native land in particular region can help in establishing the benchmark to compare the efficacies of different management practices and at the same time it can be used in understanding quantitative difference in soil health status.[13]

III.RESULTS

Soil resilience should first be looked at in terms of soil formation and development (pedogenesis), a continuous process taking thousands of years – this puts into context the short time that humans have so extensively utilised, changed and depended directly on soil. Pedogenesis is the result of five factors: the first two are parent material and topography, which are passive and contribute to soil mass and position; the next two are climate and the biosphere, which are active and supply the energy in soil formation. Finally, there is time.[1]

It is the active factors in soil formation that vary so as to constitute an environmental change or shock. Over time, variations have been significant:

- Over millions of years the soil has endured varying atmospheric conditions including a complete absence of oxygen and associated behaviour of soil elements in a reducing environment, and the establishment of life – particularly of terrestrial vegetation 420 million years ago.

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- Over ten thousand years and following the last ice age, though average climate has remained relatively stable, the soil has faced periods of extended wet, dry and fire.

Soil conservation is the prevention of loss of the topmost layer of the soil from erosion or prevention of reduced fertility caused by over usage, acidification, salinization or other chemical soil contamination.

Slash-and-burn and other unsustainable methods of subsistence farming are practiced in some lesser developed areas. A consequence of deforestation is typically large-scale erosion, loss of soil nutrients and sometimes total desertification. Techniques for improved soil conservation include crop rotation, cover crops, conservation tillage and planted windbreaks, affect both erosion and fertility. When plants die, they decay and become part of the soil. Code 330 defines standard methods recommended by the U.S. Natural Resources Conservation Service. Farmers have practiced soil conservation for millennia. In Europe, policies such as the Common Agricultural Policy are targeting the application of best management practices such as reduced tillage, winter cover crops,[1] plant residues and grass margins in order to better address soil conservation. Political and economic action is further required to solve the erosion problem. A simple governance hurdle concerns how we value the land and this can be changed by cultural adaptation.[2] Soil carbon is a carbon sink, playing a role in climate change mitigation.[3]

Contour ploughing

Contour ploughing orients furrows following the contour lines of the farmed area. Furrows move left and right to maintain a constant altitude, which reduces runoff. Contour plowing was practiced by the ancient Phoenicians for slopes between two and ten percent.[4] Contour plowing can increase crop yields from 10 to 50 percent, partially as a result of greater soil retention.[5]

Terrace farming

Terracing is the practice of creating nearly level areas in a hillside area. The terraces form a series of steps each at a higher level than the previous. Terraces are protected from erosion by other soil barriers. Terraced farming is more common on small farms.

Keyline design

Keyline design is the enhancement of contour farming, where the total watershed properties are taken into account in forming the contour lines.

Perimeter runoff control

Tree, shrubs and ground-cover are effective perimeter treatment for soil erosion prevention, by impeding surface flows. A special form of this perimeter or inter-row treatment is the use of a "grass way" that both channels and dissipates runoff through surface friction, impeding surface runoff and encouraging infiltration of the slowed surface water.[6]

Windbreaks

Windbreaks are sufficiently dense rows of trees at the windward exposure of an agricultural field subject to wind erosion.[7] Evergreen species provide year-round protection; however, as long as foliage is present in the seasons of bare soil surfaces, the effect of deciduous trees may be adequate.

Cover crops/crop rotation

Cover crops such as nitrogen-fixing legumes, white turnips, radishes and other species are rotated with cash crops to blanket the soil year-round and act as green manure that replenishes nitrogen and other critical nutrients. Cover crops also help suppress weeds.[8]

Soil-conservation farming involves no-till farming, "green manures" and other soil-enhancing practices which make it hard for the soils to be equalized. Such farming methods attempt to mimic the biology of barren lands. They can revive damaged soil, minimize erosion, encourage plant growth, eliminate the use of nitrogen fertilizer or fungicide, produce above-average yields and protect crops during droughts or flooding. The result is less labor and lower costs that increase

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farmers' profits. No-till farming and cover crops act as sinks for nitrogen and other nutrients. This increases the amount of soil organic matter.[8]

Repeated plowing/tilling degrades soil, killing its beneficial fungi and earthworms. Once damaged, soil may take multiple seasons to fully recover, even in optimal circumstances.[8]

Critics argue that no-till and related methods are impractical and too expensive for many growers, partly because it requires new equipment. They cite advantages for conventional tilling depending on the geography, crops and soil conditions. Some farmers have contended that no-till complicates pest control, delays planting and that post-harvest residues, especially for corn, are hard to manage.[8]

The use of pesticides can contaminate the soil, and nearby vegetation and water sources for a long time. They affect soil structure and (biotic and abiotic) composition.[9][10] Differentiated taxation schemes are among the options investigated in the academic literature to reducing their use.[11]

Alternatives to pesticides are available and include methods of cultivation, use of biological pest controls (such as pheromones and microbial pesticides), genetic engineering (mostly of crops), and methods of interfering with insect breeding.[12] Application of composted yard waste has also been used as a way of controlling pests.[13]

These methods are becoming increasingly popular and often are safer than traditional chemical pesticides. In addition, EPA is registering reduced-risk pesticides in increasing numbers.

Cultivation practices

Cultivation practices include polyculture (growing multiple types of plants), crop rotation, planting crops in areas where the pests that damage them do not live, timing planting according to when pests will be least problematic, and use of trap crops that attract pests away from the real crop.[14] Trap crops have successfully controlled pests in some commercial agricultural systems while reducing pesticide usage.[15] In other systems, trap crops can fail to reduce pest densities at a commercial scale, even when the trap crop works in controlled experiments.[16]

Use of other organisms

Release of other organisms that fight the pest is another example of an alternative to pesticide use. These organisms can include natural predators or parasites of the pests.[14] Biological pesticides based on entomopathogenic fungi, bacteria and viruses causing disease in the pest species can also be used.[14]

Biological control engineering

Interfering with insects' reproduction can be accomplished by sterilizing males of the target species and releasing them, so that they mate with females but do not produce offspring.[14] This technique was first used on the screwworm fly in 1958 and has since been used with the medfly, the tsetse fly,[17] and the gypsy moth.[18] This is a costly and slow approach that only works on some types of insects.[14]

Other alternatives include "laser weeding" – the use of novel agricultural robots for weed control using lasers.[19]

Salinity in soil is caused by irrigating with salty water. Water then evaporates from the soil leaving the salt behind. Salt breaks down the soil structure, causing infertility and reduced growth.

The ions responsible for salination are: sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}) and chlorine (Cl^-). Salinity is estimated to affect about one third of the earth's arable land.[20] Soil salinity adversely affects crop metabolism and erosion usually follows.

Salinity occurs on drylands from overirrigation and in areas with shallow saline water tables. Over-irrigation deposits salts in upper soil layers as a byproduct of soil infiltration; irrigation merely increases the rate of salt deposition. The best-known case of shallow saline water table capillary action occurred in Egypt after the 1970 construction of the Aswan Dam. The change in the groundwater level led to high salt concentrations in the water table. The continuous high level of the water table led to soil salination.

Use of humic acids may prevent excess salination, especially given excessive irrigation. Humic acids can fix both anions and cations and eliminate them from root zones.

Planting species that can tolerate saline conditions can be used to lower water tables and thus reduce the rate of capillary and evaporative enrichment of surface salts. Salt-tolerant plants include saltbush, a plant found in much of North America and in the Mediterranean regions of Europe.

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When worms excrete feces in the form of casts, a balanced selection of minerals and plant nutrients is made into a form accessible for root uptake. Earthworm casts are five times richer in available nitrogen, seven times richer in available phosphates and eleven times richer in available potash than the surrounding upper 150 millimetres (5.9 in) of soil. The weight of casts produced may be greater than 4.5 kg per worm per year. By burrowing, the earthworm improves soil porosity, creating channels that enhance the processes of aeration and drainage.[21]

Other important soil organisms include nematodes, mycorrhiza and bacteria. A quarter of all the animal species live underground. According to the 2020 Food and Agriculture Organization's report "State of knowledge of soil biodiversity – Status, challenges and potentialities", there are major gaps in knowledge about biodiversity in soils.[22][23]

Degraded soil requires synthetic fertilizer to produce high yields. Lacking structure increases erosion and carries nitrogen and other pollutants into rivers and streams.[8]

Each one percent increase in soil organic matter helps soil hold 20,000 gallons more water per acre.[8]

To allow plants full realization of their phytonutrient potential, active mineralization of the soil is sometimes undertaken. This can involve adding crushed rock or chemical soil supplements. In either case the purpose is to combat mineral depletion. A broad range of minerals can be used, including common substances such as phosphorus and more exotic substances such as zinc and selenium. Extensive research examines the phase transitions of minerals in soil with aqueous contact.[24]

Flooding can bring significant sediments to an alluvial plain. While this effect may not be desirable if floods endanger life or if the sediment originates from productive land, this process of addition to a floodplain is a natural process that can rejuvenate soil chemistry through mineralization.[20]

IV.CONCLUSIONS

Environmental soil science is the study of the interaction of humans with the pedosphere as well as critical aspects of the biosphere, the lithosphere, the hydrosphere, and the atmosphere. Environmental soil science addresses both the fundamental and applied aspects of the field including: buffers and surface water quality, vadose zone functions, septic drain field site assessment and function, land treatment of wastewater, stormwater, erosion control, soil contamination with metals and pesticides, remediation of contaminated soils, restoration of wetlands, soil degradation, nutrient management, movement of viruses and bacteria in soils and waters, bioremediation, application of molecular biology and genetic engineering to development of soil microbes that can degrade hazardous pollutants, land use, global warming, acid rain, and the study of anthropogenic soils, such as terra preta. Much of the research done in environmental soil science is produced through the use of models.[1][2]

Soil functions are general capabilities of soils that are important for various agricultural, environmental, nature protection, landscape architecture and urban applications. Soil can perform many functions and these include functions related to the natural ecosystems, agricultural productivity, environmental quality, source of raw material, and as base for buildings.[1] Six key soil functions are:[2][3][4][5][6]

1. Food and other biomass production
2. Environmental Interaction
3. Biological habitat and gene pool
4. Source of raw materials
5. Physical and cultural heritage
6. Platform for man-made structures

Food and other biomass production

Soil acts as an anchor for plant roots. It provides a hospitable place for a plant to live in while storing and supplying nutrients to plants. Soil also functions by maintaining the quantity and quality of air by allowing CO_2 to escape and fresh O_2 to enter the root zone.[7] Pore spaces within soil can also absorb water and hold it until plant roots need it. The soil also moderates temperature fluctuation, providing a suitable temperature for the roots to function normally. A fertile soil will also provide dissolved mineral nutrients for optimal plant growth. The combination of these activities supports plant growth for providing food and other biomass production.

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Environmental interaction

Environmental interactions such as regulating water supplies, water loos, utilization, contamination, and purification are all affected by the soil. They can filter, buffer, and transform materials between the atmosphere, the plant cover, and the water table. Soil interacts with the environment to transform and decompose waste materials in to new materials. Through filtering, soil acts as a filter and captures contaminants through soil particles.[3] Contaminants are captured by the soil particles and water comes out cleaner in the aquifers and rivers. Lastly, it can accumulate large amounts of carbon as soil organic matter, thus reducing the total concentration of carbon dioxide that can mitigate global climate change.[7]

Biological habitat and gene pool

Soils also acts as a biological habitat and a gene reserve for a large variety of organisms.[6] Soils are the environment in which seeds grow, they provide heat, nutrients and water that are available to use to nurture plants and animals. The assistance of soil in the decomposition of dead plants, animals, and organism by transforming their remains into simpler mineral forms, can be utilized by other living things. 21

Source of raw materials

Soil provides raw materials for human use and impacts human health directly. The composition of human food reflects the nature of the soil in which it was grown. An example of soil as a source of raw material can be found in ancient ceramic production. The Maya ceramics showed traits inherited from soils and sediments used as raw material.[8] The understanding of soil formation process can help define certain type of soil and reflect the composition of soil minerals. However, the natural area of productive soils is limited and due to increasing pressure of cropping, forestry, and urbanization, extracting soil as a raw material needs to be controlled for.

Physical and cultural heritage

Soil also has more general culture functions as they act as a part of the cultural landscape of our minds as well as the physical world around us.[6] An attachment to home soils or a sense of place is a cultural attribute developed mores strongly in certain people. Soils has been around since the creation of earth, it can act as a factor in determining how humans have migrated in the past.[6] Soil also act as an earth cover that protects and preserve the physical artifacts of the past that can allow us to better understand cultural heritage. Moreover, soil has been an important indication to where people settle as they are an essential resource for human productivity.22

Platform for man-made structures

Soil can act as raw material deposits and is widely used in building materials. Approximately 50% of the people on the planet live in houses that are constructed from soil.[7] The conditions of the soil must be firm and solid to provide a good base for roads and highways to be built on. Additionally, since these structures rest on the soil, factors such as its bearing strength, compressibility, stability, and shear strength al need to be considered.[7] Testing the physical properties allow a better application to engineering uses of soil.

Mapping soil functions

Soil mapping is the identification, description, ad delineation on a map of different types of soil based on direct field observations or on indirect inferences from souch sources such as aerial photographs.[9] Soil maps can depict soil properties and functions in the context of specific soil functions such as agricultural food production, environmental protection, and civil engineering considerations. Maps can depict functional interpretations of specific properties such as critical nutrient levels, heavy-metal levels or can depict interpretation of multiple properties such as a map of erosion risk index.

Mapping of function specific soil properties is an extension of soil survey, using maps of soil components together with auxiliary information (including pedotransfer functions and soil inference models) to depict inferences about the specific performance of soil mapping units. Other functions of soil in ecosystems:

- source of building materials (clay, sand, rocks)
- carbon recycler

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|DOI:10.15680/IJMRSETM.2022.0811026|

- fiber production[23]

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| ISSN: 2395-7639| www.ijmrset.com| Impact Factor: 7.580 | A Monthly Double-Blind Peer Reviewed Journal |

|| Volume 9, Issue 11, November 2022 ||

|DOI:10.15680/IJMRSETM.2022.0811026|

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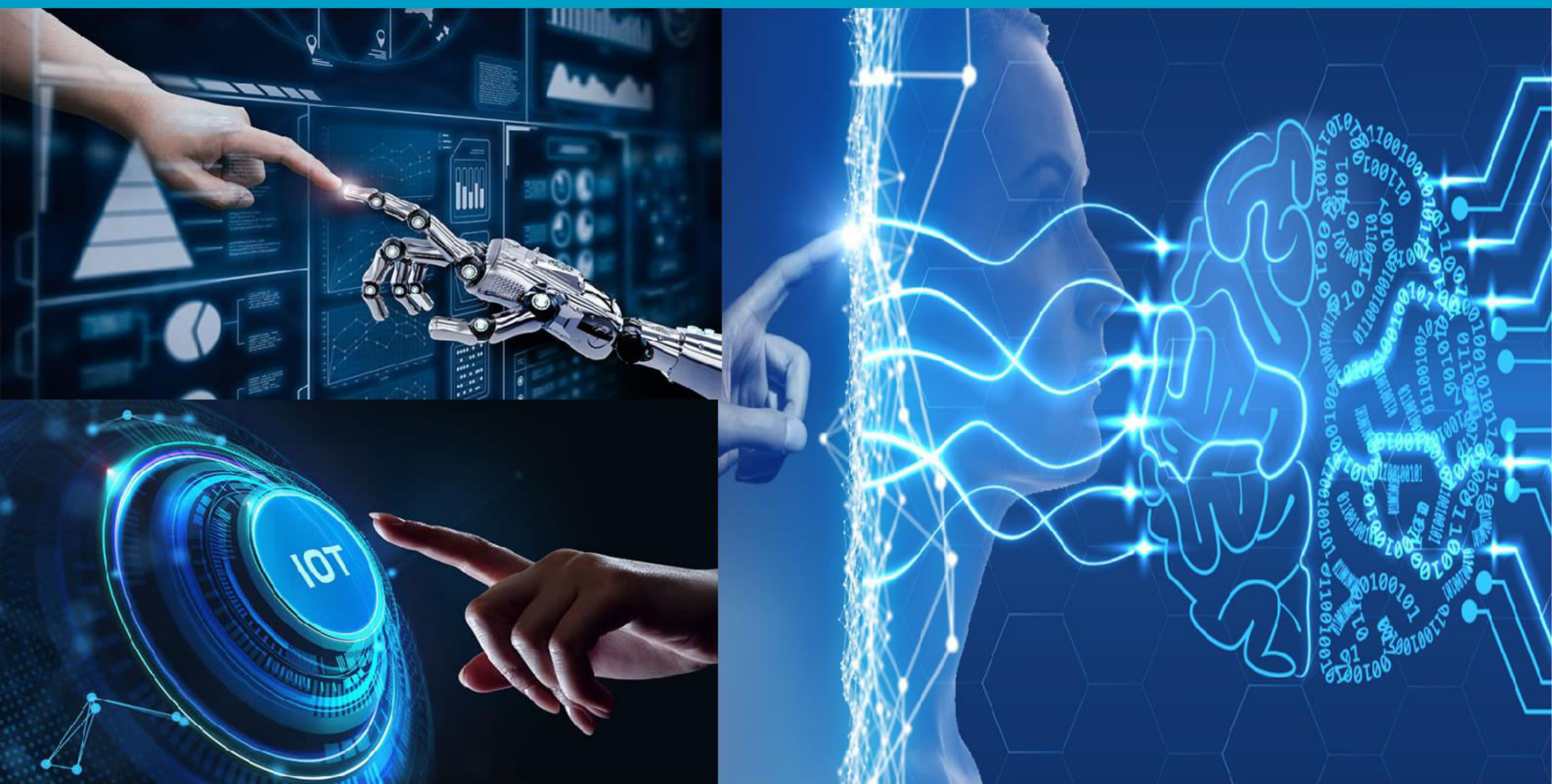
e-ISSN: 2395 - 7639



INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH

IN SCIENCE, ENGINEERING, TECHNOLOGY AND MANAGEMENT

Volume 9, Issue 11, November 2022

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

Impact Factor: 7.580