Impact of Tillage on Soil Sustainability

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***Abstract*- Soil sustainability plays a crucial role in ensuring food security and environmental stability. Agricultural activities, particularly those involving tillage practices that alter the physical properties of soil have significant impacts on soil quality. These practices are aimed at promoting crop establishment, controlling weeds, and managing nutrients, yet they often result in soil compaction, erosion, and organic matter decline. In recent years, there has been growing interest in reducing or eliminating tillage altogether, referred to as conservation tillage, including no-tillage and minimum tillage systems. While these practices have shown promising benefits in preserving soil structure, improving soil health, and preventing land degradation, questions remain regarding their overall long-term impact on soil sustainability. This study examines the impact of various tillage systems on soil quality parameters and evaluates the tradeoffs involved in implementing these practices.**

Keywords: **Soil sustainability, Soil quality, Soil health, Tillage.**

I.INTRODUCTION

Soil sustainability has become a critical concern as global population growth and climate change put increasing pressure on agricultural lands. One common method used by farmers to manage soil health is tillage, which involves manipulating the upper layers of soil using mechanical implements such as plows and disks. While tillage may have short-term benefits for crop productivity, there is growing evidence that certain types of tillage practices may have long-term negative effects on soil quality and are detrimental for soil health by decreasing aggregate stability, increasing susceptibility to compaction, reducing nutrient retention capacity, enhancing erodibility, and altering soil faunal populations. Therefore it is important that optimal tillage strategies take into account local environmental and agronomical situations so that it provides efficient conservation of natural resources, reduces input costs, increases efficiency, promotes beneficial flora and fauna, and lastly reduces offsite movement of sediment.

This study aims to provide an overview of current knowledge regarding how different tillage methods affect key indicators of soil sustainability. We examine how tillage impacts organic matter content, aggregation stability, erosion control, water retention capacity, nutrient availability, carbon sequestration potential, and microbial activity within the soil ecosystem.

II.BACKGROUND

The cultivation of crops requires proper soil preparation prior to planting to create suitable conditions for seed germination, root development, and water and nutrient uptake. Traditionally, farmers have relied upon mechanical tillage practices using plows, disks, and other implements to invert the soil profile, break down clods, destroy weeds, and incorporate amendments such as fertilizers and lime. These methods have had mixed results in achieving their intended goals. Primary tillage reduces soil bulk density and increases porosity, allowing water and air to penetrate deeper into the ground. It also exposes more surface area for better contact between roots and soil particles, facilitates seed placement, and speeds up decay of residue materials. But, frequent tillage can cause soil compaction, reduce soil aggregation, and accelerate soil erosion through wind and water. Additionally, excessive tillage can degrade soil structure, increase bulk density, and decrease macro-porosity, thereby limiting crop yields and water availability. To address these issues, alternative approaches known collectively as conservation tillage (CT), reduced-tillage (RT), or no-tillage (NT) systems have emerged, characterized by minimal soil disturbance or complete avoidance of tillage altogether. CT systems are designed to minimize the adverse impacts of conventional intensive tillage without sacrificing essential soil preparation functions. They enable growers to balance economic costs against ecological benefits without compromising crop yields or soil quality over time. Given the widespread concerns about soil sustainability and environmental quality associated with current farming practices, identifying effective alternatives remains an important goal of contemporary agriculture.

III.OBJECTIVES OF STUDY

1. Identify common tillage practices used in modern agriculture and understand how they affect soil physical properties.
2. Analyze the impact of tillage on key indicators of soil sustainability, including aggregate stability, organic carbon content, macro-pore formation, and microbial activity in the rhizosphere.
3. Evaluate the effectiveness of conservational tillage practices in mitigating negative effects of traditional tillage practices on soil sustainability.
4. Suggest areas needing further investigation.

IV.REVIEW OF LITERATURE

Tillage with moldboard plow increased soil infiltration capacity when compared to tine cultivator and no-tillage [1]. No tillage increases penetration resistance, bulk density and electrical conductivity when compared to conventional tillage. Also, no-tillage and minimum tillage do not improve soil quality vis-a-vis conventional tillage [2]. On comparing conventional tillage, reduced tillage and zero tillage, it was found that zero tillage had highest soil organic carbon (SOC) and carbon pool at soil depth of 0 to 10 cm. In addition, zero tillage had the lowest bulk density and soil penetration resistance at 0 to 10 cm depth [3]. A more adaptive and efficient intermediary tillage method suitable for farmers should be developed in order to practice sustainable agriculture [4].

Soil disturbance by conventional tillage causes earth to act like a net producer of greenhouse gases instead of a natural sponge for them, making it unsustainable and harmful for nature. For soils with high clay content and slow water drainage, minimum tillage is recommended. On well-drained loamy soils with lower humus levels, no-tillage has been found to be suitable. Zero or minimum tillage is essential for maintaining good soil structure since continuous cultivation leads to soil degradation. Studies suggest that the application of conservation tillage techniques results in better soil chemistry than traditional tillage methods. Moreover, soil life activity and biological attributes improve significantly on lands utilizing conservation tillage practices when contrasted against conventionally tilled fields [5].

Study conducted by Feng, Q., et.al. found that Deep Tillage (DT) significantly enriches Soil Organic Carbon (SOC) by 7.79%. Moreover, subsoiling significantly enhanced SOC by 8.87%. For the whole soil profile, DT does not contribute significantly to SOC sequestration, but it significantly did increase SOC content in 20 to 50 cm depth. Soils in arid zones having high SOC and bulk density tend to benefit more by DT [6].

In contrast to the earlier aims and practices of meeting the required food production limits without due attention to environment, conservation tillage offers a new standard for agricultural research and development. Small farmers should adopt smaller tools for farming and pay due consideration to cover crop for protecting soil. Burning of crop residue should be discouraged and instead be incorporated into the soil [7].

In the coming years, agriculture must find ways to increase crop yields without expanding cultivation areas or causing harm to the environment. By adopting Conservation Agriculture management systems, we can achieve a sustained supply of food to match rising global demand [8].

V.DISCUSSION

Soil is the foundation of agriculture and maintaining its long-term health is critical to food security and the overall wellbeing of the planet. Soil tillage is used extensively in modern agriculture to prepare fields for planting, control weed growth and incorporate inputs such as fertilizer and manure. However, repetitive tillage can lead to soil degradation, reducing crop productivity and contributing to environmental problems such as soil erosion. Conversely, conservation tillage practices that minimize soil disturbance have been developed to mitigate these negative impacts while still ensuring adequate soil preparation for crop growth. The key components of our study are discussed below:

1) **Soil**

Soil is the thin layer of material covering the Earth's crust that allows plants to grow. It forms a vital interface between atmospheric gases, fresh water, rocks, and living organisms in terrestrial ecosystems, playing multiple roles crucial for our survival.

Soil acts like a sponge retaining rainfall, preventing water from running off, allowing air pockets for root aeration and storing essential minerals such as nitrogen, phosphorus, potassium, sulfur, calcium, magnesium, etc. It is home to myriad microorganisms which are responsible for soil formation processes and decomposition of organic matter, thus releasing these nutrients back to plants, supporting their growth, anchoring them against wind forces, removing carbon dioxide from atmosphere and locking up carbon. Hence without soil, life would not exist on earth.

While soil creation takes millions of years through geological weathering and rock transformation, human activities pose significant risks to soil degradation at alarmingly high rates owning to industrialization, urban sprawl, agricultural intensification causing deforestation, excessive irrigation, monoculture/cash crop cultivation and other unsustainable practices compromising inherent capacities of soil. This results in threatening food security, biodiversity loss, land desertification, and ultimately affecting climate change.

2) **Soil Quality**

Soil quality refers to the characteristics of soil that determine its ability to support plant growth and maintain environmental functions such as erosion control and water purification. Soil quality is essential for food production, climate regulation, water filtration, and other ecosystem services. Sustaining healthy soils requires careful management practices that ensure their long-term productivity without degrading environmental quality. Some key indicators of soil quality include:

- ***Structure** (e.g., aggregates stability):* Soil structure refers to the arrangement of primary particles such as clay, sand, and silt, along with organic matter, into larger aggregates called "peds." These aggregates form a stable porous framework that supports plant roots and enables movement of water and gases through the soil profile. Good soil structure typically exhibits properties such as crumbly texture, open pores, and moderate moisture retention capacity.
- ***Organic matter content:*** The organic content of soil is essential for maintaining its fertility, water holding capacity, and physical stability. Organic matter plays an important role in the formation of soil structure by binding together clay, silt, sand particles, and improving aeration and drainage. This allows for easier penetration of roots and promotes healthy microbial activity in the soil. In addition, organic matter provides essential nutrients required for plant growth such as carbon, nitrogen, phosphorous and calcium and serves as food for numerous microorganisms. An optimal level of organic matter for most agricultural soils ranges from 2% to 5%. Some soils naturally contain higher levels, while others require amendments through organic inputs such as compost or green manures to reach desired levels. Higher amounts than 5% may pose problems relating to soil nitrification and competition for micronutrients.

- ***pH level:*** The pH of the soil can significantly impact plant growth and health. In general, most plants prefer soils that are neutral to mildly alkaline (pH range of 6 to 7). However, there are exceptions to this rule and some plants require different pH levels to thrive. Plants grown in soils that fall outside their preferred pH range may struggle to obtain essential nutrients from the soil. For example, if the soil is too acidic, iron (Fe) and manganese (Mn) become soluble and leach out of the soil, resulting in deficiencies in the plant. Similarly, if the soil is too alkaline, nutrients such as phosphorus (P) may become unavailable for uptake by plant roots.
- ***Availability of nutrients:*** There are 17 essential plant nutrients found in soil: Carbon (C), Hydrogen (H), Oxygen (O), Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Sulfur (S), Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Molybdenum (Mo), Boron (B), Chloride (Cl), Nickel (Ni) and Silicon (Si). These elements play critical roles in supporting vigor, yield potential, and overall quality attributes for crops grown around the world. The availability and bioavailability of each element depends significantly upon soil properties (pH, EC, texture, etc.), management actions taken in the field (fertilizer applications, irrigation rate and timing, etc.) and interactions among competing species seeking to absorb them from the same volume of soil space.
- ***Water holding capacity:*** Water holding capacity refers to how much moisture a particular quantity of soil can hold at saturation before the surplus water drains away. It reflects the interaction of several soil features such as particle size distribution, organic matter and porous spaces between soil particles known as "porosity." Increasing the organic material percentage or altering textures via amendment additions can boost water holding capacity over time. Water holding capacity is important because it affects crop growth and development.
- ***Susceptibility to compaction or erosion:*** The property of soil known as "Susceptibility to Compaction or Erosion" refers to how easily the soil can become compacted or eroded under different environmental conditions. When a soil is highly susceptible to compaction, it means that the density of the soil increases when subjected to repeated traffic or heavy loads, leading to poor root growth and decreased crop yields. In contrast, a soil that is resistant to compaction allows for healthier plant development. On the other hand, a soil that is susceptible to erosion indicates that it is vulnerable to losing mass through natural processes such as wind or water movement, potentially causing damage to crops, infrastructure, and landscapes. By understanding the level of compaction and erosion susceptibility in soil, farmers, builders, engineers, and others can take appropriate measures to protect and manage these resources effectively.

A combination of physical, chemical, and biological factors determines soil quality, which varies depending on the specific location and land use history of the site. Maintaining good soil quality requires proper management practices such as crop rotation, conservation tillage, and application of appropriate amendments like organic fertilizers or lime. Monitoring changes in soil quality over time allows farmers and land managers to make informed decisions about how to protect this valuable resource for future generations.

3) **Tillage**

Tillage refers to the practice of disturbing the soil structure through mechanical means, usually by applying force with tools such as plows, discs, chisels, or harrows. The purpose of tillage is typically to prepare the soil for seeding or planting crops, control weeds, improve soil fertility, or modify soil physical properties such as texture and porosity. There are several types of tillage practices, including conventional (or intensive) tillage, reduced (or conservation) tillage, and no-tillage. Conventional tillage generally involves plowing deep into the soil to turn over large volumes of earth and destroy weed populations, while reduced tillage uses lighter equipment that disturbs only the surface layer of soil to minimize soil erosion and maintain crop residue cover on the soil surface. No-tillage practices involve direct drilling without any prior soil disturbance, preserving the undisturbed soil structure and maximizing crop residue coverage. Overall, appropriate tillage choice depends on local circumstances such as topography, soil type, moisture regimes, and desired crop yields while minimizing adverse environmental impacts.

Common tillage practices and their effects are as following:

i. ***Plowing:*** Mixes the upper soil layer deeply and thoroughly, breaking up compacted soil but also destroys soil structure and aggregates if done too often. It increases soil temperature fluctuations leading to accelerated erosion and reduces organic matter content in soil.

ii. ***Harrowing:*** Breaks up large lumps leaving behind crumbly soil particles. Shallower than plowing, it creates a fine-textured soil surface allowing better establishment of seeds, though its frequency leads to compaction problems.

iii. ***Disking:*** Creates good seed beds in well-structured soil for efficient cash crop planting or broadcast operations. As it operates at shallow depths there is less disruption of soil structure which in turn helps in reducing erodibility and maintaining macro-pore spaces. High-speed disking tends to produce less disturbance and more uniform mixing than conventional methods.

iv. ***Chiseling:*** Performed later in the year just before planting, this method targets compacted subsoils and helps improve penetration of plant roots. Chisel plow blades cut deep furrows while lifting only small portions of soil directly above the tines, limiting surface disturbance and avoiding throwing up lots of loose material. This lowers the risk of wind erosion and provides better moisture retention for root development. Improved air exchange and inorganic Nitrogen conversion increase overall soil health, supporting plant growth.

v. Ridge tillage: Ridge tillage is a form of reduced tillage performed in row crops and designed to increase efficiency of farming operations without sacrificing yields. The key difference from conventional methods is a focus on creating ridges running perpendicular to the direction of tillage and this done by an implement called Ridger. The raised profile formed by ridge building makes it easier to operate seed drills or apply herbicides mechanically. In snowy regions, ridged land also permits earlier plantings as snow melts faster, giving longer frost-free seasons for target crops such as potatoes and sugar beets. While these benefits seem appealing, there remain concerns about long-term soil degradation, reduced microbial diversity and functioning below the ridges.

vi. ***Bed forming:*** It is a type of tillage that involves leveling the soil surface to create flat areas for growing plants. The process may involve using implements like plows, cultivators, and harrows to smooth the surface of the ground and prepare it for planting. When properly executed, bed forming can have positive impacts on soil physical properties, including:

- *Better drainage:* By creating a flat surface, bed forming allows rainwater to easily move across the soil rather than standing on the soil's surface or accumulating in pockets. This can help prevent soil erosion and reduce instances of over-saturated soil conditions which can harm crop growth.
- *Improved aeration*: By smoothing the soil surface, bed forming enhances air circulation into the soil. Aerobic bacteria thrive in oxygen-rich environments, making them more effective at breaking down crop residues and releasing nutrients that are vital for plant growth.
- *Easier weeding:* With a flat surface, farmers find it simpler to use tools like hoes or cultivators to manually remove weeds, helping to keep fields free of unwanted plants and preserve soil nutrient balance. As most weed species prefer disturbed and unsmoothed soil surface; having such surface covered by mulches also make the weeding difficult to start or stop once established in an area.

vii. ***Strip tillage:*** It is also known as zone tillage or vertical tillage, is a method used in agriculture where only narrow strips of soil are disturbed, leaving untouched areas between each row of stubble or residue. It combines aspects of conventional tillage and no-till systems to balance cost savings, improved soil quality, and optimal crop establishment. Benefits include enhanced conservation of both soil moisture and nitrogen levels through more targeted usage of fertilizer and controlled release products. Moreover, this technique reduces trips over fields when compared with full cultivation prior to planting every season.

4) Effect of Tillage

i. On Soil Structure

Tillage is used to prepare seedbeds for cropping activities but it can either create better soil structure or destroy soil structure depending on the frequency and method of tillage being used. Prolonged or frequent tillage increases risks of adverse impacts on soil structure due to continuous mechanical breakdown of soil aggregates. Tilled ground then becomes compacted making plant establishment difficult and limiting root growth leading to yield reduction. Tillage disturbs microorganism populations further impeding soil structure development. However, in some cases, timely shallow tillage can increase soil aeration and reduce weed pressure thus improving soil productivity. It is best to minimize tillage practices whenever possible.

ii. On Soil pH

Soil pH can be temporarily influenced by tillage in various ways depending on tillage depth, intensity, frequency, weather patterns, previous soil management history, soil type, crop rotation, and presence of calcium carbonates. Generally, the effects are temporary and do not lead to lasting changes. Soil pH changes cannot solely be explained by tillage since other land uses contribute towards long-term trends. It is important to regularly test the soil pH level and adjust it accordingly through amendment application if necessary to ensure optimal plant growth and health.

iii. On availability of nutrients in soil

Tillage has a moderate effect on the availability of nutrients in soil. Tilling breaks down soil aggregates and helps loosen compacted soil, improving root penetration and water movement. This enhances accessibility of nutrients held tightly onto soil particles. However, excessive tillage destroys beneficial fungi that help maintain soil structure, reducing the ability of soil particles to retain essential minerals like potassium and nitrate. Furthermore, repeated tillage results in subsoiling, introducing oxygen into lower levels of the soil profile and causing oxidization reactions that immobilize iron and sulfur complexes necessary for enzymatic functions crucial to overall plant performance. Therefore, appropriate tillage techniques must balance soil structural benefits against detrimental impacts on key biological components regulating nutrient availability in agriculture.

iv. On water holding capacity of soil

Sandy loam and clay soils hold water better than silt or fine sand soil types due to the presence of smaller pores and spaces between larger soil aggregates/particles, providing more room for water retention. However, the application of tillage can disrupt these soil textural components and alter the soil's ability to hold onto water. Tillage has both positive and negative effects on soil water holding capacity. For example, cultivation can destroy aggregates and reduce aggregate stability which decreases pore size, thus promoting rapid wetting and drying cycles; and increased crust formation; reducing surface percolation, thus slowing down rainfall entry and restricting air exchange. However, some forms of tillage, particularly conservation tillage systems like mulch tillage and no-till, can create favorable structural changes, improving soil stability, aggregate size, and macropore continuity without causing compaction or substantial reductions in surface roughness.

5) Measures to prevent deterioration of soil quality due to tillage

i. *Use of conservation tillage methods:* Conservation tillage involves reducing the amount of soil disturbance caused by primary tillage tools and eliminates secondary tillage completely. This approach reduces soil erosion, increases soil organic matter, and preserves soil structure. Common forms include minimum tillage, ridge tillage, and zero tillage.

ii. *Implementing crop rotation strategies:* Choosing crops that have differing root structures and physiologies helps vary soil disturbance patterns over time. This results in diverse root channel shapes and sizes that create better aeration, moisture storage, and increased nutrient availability. Additionally, breaking pest cycles contributes to lower pesticide use and encourages microbial communities necessary for stable soil aggregates.

iii. *Using cover crops:* Cover crops grow after harvest to protect bare soil, store carbon, attract pollinators, add fertility, suppress weed growth, and regulate temperatures. Some popular examples include field peas, winter rye, hairy vetch, clover, radishes, buckwheat, sudangrass and brassicas. Establishing appropriate termination times ensures the plants decompose naturally and leave the next growing season with more organic matter to work with.

iv. *Applying manure and slurry:* Adding organic wastes rich in nitrogen, phosphorus, and potassium serves as a natural form of fertility replacement for synthetic inputs, promoting higher yields at lower costs and environmental impact. However, proper application rates must occur according to crop requirements to avoid nitrate leaching or ammonia volatilization losses. Anaerobic digestion technologies further process waste products to recover liquid nutrients through concentrated slurries.

v. *Keeping livestock incorporated:* Integrating livestock with cropping systems can improve soil health by adding manure and urine as fertilizer inputs.

VI. CONCLUSION

The use of tillage has been a mainstay in agriculture since ancient times and is one of the most widely utilized farm practices throughout history. It serves multiple purposes such as destroying unwanted plants, aerating compacted soils, incorporating organic matter, redistributing nutrients, and controlling weed populations. Tillage also has significant implications for soil sustainability and environmental quality. The interaction between tillage intensity and soil productivity needs to be well understood. To achieve soil sustainability, an understanding of the tillage process and the factors influencing soil response must be considered. Ultimately, careful consideration of various tillage options is critical to maintaining soil integrity while meeting the demands placed on agricultural lands. By adopting appropriate practices tailored to specific situations, it may be feasible to balance both short-and long-term gains while minimizing negative consequences. And, a holistic approach that balances economics and environment through appropriate selection and refinement of agricultural practices tailored to each unique situation should be adopted by each farmer.

BIBLIOGRAPHY:

1. Amami, R., Ibrahimi, K., Sher, F., Milham, P., Ghazouani, H., Chehaibi, S., Zahra, H. & Iqbal, H. M. (2021). Impacts of different tillage practices on soil water infiltration for sustainable agriculture. *Sustainability*, *13*(6), 3155.
2. Amami, R., Ibrahimi, K., Sher, F., Milham, P. J., Khriji, D., Annabi, H. A., Khaoula, A. & Chehaibi, S. (2021). Effects of conservation and standard tillage on soil physico-chemical properties and overall quality in a semi-arid agrosystem. *Soil Research*, *60*(6), 485-496.
3. Babu, S., Singh, R., Avasthe, R., Kumar, S., Rathore, S. S., Singh, V. K., Ansari, M. A., Valente, D. & Petrosillo, I. (2023). Soil carbon dynamics under organic farming: impact of tillage and cropping diversity. *Ecological Indicators*, *147*, 109940.
4. Bhatt, R. & Arora, S. (2015). Impact of tillage on soil bio-chemical properties, water storage and environment. *Journal of Soil and Water Conservation*, *14*(3), 278-282.
5. Busari, M. A., Kukal, S. S., Kaur, A., Bhatt, R., & Dulazi, A. A. (2015). Conservation tillage impacts on soil, crop and the environment. *International soil and water conservation research*, *3*(2), 119-129.
6. Feng, Q., An, C., Chen, Z., & Wang, Z. (2020). Can deep tillage enhance carbon sequestration in soils? A meta-analysis towards GHG mitigation and sustainable agricultural management. *Renewable and Sustainable Energy Reviews*,*133*, 110293.
7. Gondal, A. H., Zafar, H., Yousaf, H., Farooq, Q., Imran, B., Ch, M. D. T., & Saleem, S. (2021). Impacts of tillage technologies on soil, plant, environment and its management: A short communication. *Indian Journal of Pure and Applied Biosciences*, *9*(3), 76-83.
8. Hobbs, P. R., Sayre, K. and Gupta R. (2008) The role of conservation agriculture in sustainable agriculture. *Phil. Trans. R. Soc.* B363543–555
9. Lal, R. (1993). Tillage effects on soil degradation, soil resilience, soil quality, and sustainability. *Soil and tillage Research*, *27*(1-4), 1-8.
10. Lal, R. (1991). Tillage and agricultural sustainability. *Soil and tillage research*, *20*(2-4), 133-146.
11. Larson, W. E., & Pierce, F. J. (1994). The dynamics of soil quality as a measure of sustainable management. *Defining soil quality for a sustainable environment*, *35*, 37-51.
12. M. Tahat, M., M. Alananbeh, K., A. Othman, Y., & I. Leskovar, D. (2020). Soil health and sustainable agriculture. *Sustainability*, *12*(12), 4859.
13. Ramzan, S., Pervez, A., Wani, M. A., Jeelani, J., Ashraf, I., Rasool, R., Bhat, M.A. & Maqbool, M. (2019). Soil health: Looking for the effect of tillage on soil physical health. *Int. J. Chem. Stud*, *7*, 1731-1736.
14. Reeves, D. W. (1997). The role of soil organic matter in maintaining soil quality in continuous cropping systems. *Soil and Tillage Research*, *43*(1-2), 131-167.
15. Reicosky, D. C., & Saxton, K. E. (2007). The benefits of no-tillage. *No-tillage seeding in conservation agriculture*, *2*, 11-20.
16. Roger-Estrade, J., Anger, C., Bertrand, M., & Richard, G. (2010). Tillage and soil ecology: partners for sustainable agriculture. *Soil and Tillage Research*, *111*(1), 33-40.
17. Sadiq, M., Li, G., Rahim, N., & Tahir, M. M. (2021). Sustainable conservation tillage technique for improving soil health by enhancing soil physicochemical quality indicators under wheat mono-cropping system conditions. *Sustainability*, *13*(15), 8177.
18. Šarauskis, E., Kriaučiūnienė, Z., Romaneckas, K., & Buragienė, S. (2018). Impact of tillage methods on environment, energy and economy. *Sustainable Agriculture Reviews 33: Climate Impact on Agriculture*, 53-97.
19. Šarauskis, E., Romaneckas, K., & Buragienė, S. (2009). Impact of conventional and sustainable soil tillage and sowing technologies on physical-mechanical soil properties. *Environmental Research, Engineering and Management*, *49*(3), 36-43.

20. Topa, D., Cara, I. G., & Jităreanu, G. (2021). Long term impact of different tillage systems on carbon pools and stocks, soil bulk density, aggregation and nutrients: A field meta-analysis. *Catena*, *199*, 105102.
21. Xiao-Bin, W., Dian-Xiong, C. A. I., Hoogmoed, W. B., Oenema, O., & Perdok, U. D. (2006). Potential effect of conservation tillage on sustainable land use: a review of global long-term studies. *Pedosphere*, *16*(5), 587-595.
22. Zhang, Z., & Peng, X. (2021). Bio-tillage: A new perspective for sustainable agriculture. *Soil and Tillage Research*, *206*, 104844.