American Journal of Biology and Natural Sciences
https://biojournals.us/index.php/AJBNS
ISSN: 2997-7185

# Smart Tillage\ A New Revolution in Agriculture to Improve Productivity and Protect the Environment: Review

**Hadeel Amer Jabbar, Alaa Salih Ati**
[1, 2] College of Agricultural Engineering Sciences, University of Baghdad, Iraq

**Received:** 2024, 15, May
**Accepted:** 2025, 21, Jun
**Published:** 2025, 29, Jul



**Annotation:** Smart tillage is an evolving type of cultivation that uses new technologies to prepare the soil to a tee for good crop production while conserving the health of the soil and promoting sustainable farming. The process is based on the combination of all such soil sensor-based real-time data collection, global positioning systems, auto machinery, and big data analytics that finally allows for minute-to-minute adjustments in how the soil is prepared in different spots in the field. This eliminates general and very intensive soil tillage that happens with most conventional systems and allows for customizing the intensity, depth, and timing of cultivation to the specific conditions of the soil, moisture, and the crop. Such precision goes a long way in reducing soil erosion, keeping organic matter in the soil, and enhancing the activity of beneficial microbes hence, either keeping or improving fertility. Expanding the described features, smart tillage practices would contribute to such important factors as infiltration and retention of water - both components of water use efficiency, and more so in regions that have restrictions on water availability. The use of autonomous vehicles and intelligent machinery will reduce labor and fuel consumption, hence reducing the cost of production and the carbon print in farming operations. Recent studies have shown that smart tillage can improve crop yields by 5–12% and reduce fuel consumption by up to 20%, while cutting soil $CO_2$ emissions by approximately 30% compared to conventional tillage methods. While the benefits are proven to be true, there are still barriers that will impede the extensive implementation of smart tillage, including the high initial investment, knowledge, and skill requirements, and compatibility with existing farm management applications.

**Keywords:** precision agriculture, Soil sensors, GPS technology, Automated machinery, Data analytics.

## Introduction

One smart tillage program combines traditional land preparation techniques with modern advanced technologies to improve field management and enhance crop productivity. These enable the uniform work of the soil to be tilled such that implements work the ground as efficiently as possible according to the variability reported. Technologies included in smart tillage are sensor and GPS technologies, automated machinery, and a comprehensive set of data analytics that ensure adequate monitoring and control support applied strictly in line with the reported conditions, leading to less soil cultivation wherever not needed, less fuel, and less labor consumed and improved soil health over time. Thus, the adoption of smart tillage is critical to the advancement of sustainable agriculture, notably soil erosion, water loss, and hunger production while keeping the environmental impact at its lowest (Alvarez & Steinbach, 2021; Ati et al., 2025b).

The major importance of the smart tillage is the conservation of the soil structure since it involves the targeting of areas that only require intervention. Over and indiscriminate tillage can cause soil erosion, loss of organic matter, and the disturbance of beneficial soil organisms, which in the end affects long-term soil fertility. In its practice, precision tillage reduces such negative effects therefore conserving the soil. Smart tillage also conserves water through the improvement of water infiltration and retention within the soil profile, making the efficiency quite high, especially in areas where there is drought or irregular rainfall, and the crop's resilience and yield can be greatly improved so long as moisture is made available optimally.

In addition, automated and intelligent machinery in smart tillage conserves a large amount of energy. Energy that would have been used for operations that tillage equipment adjusts itself can now conserve fuel by not being used for unnecessary operations. This does not only reduce production costs but also reduces associated greenhouse gas emissions of the agriculture machinery (Roy et al., 2024). This tillage further improves the crop productivity by providing an optimum rooting environment. Loose firmly compacted layers and keep soil aeration state where roots will uptake water and nutrients better targeted, which leads to high yield eventually (Lafta & Abdullah, 2024; Ati & Jabbar, 2025).

Different types of smart tillage systems have been developed for various agricultural needs. Variable depth tillage enables machinery to adjust penetration depths based on soil hardness, thus avoiding over-tillage in less compacted zones and preserving soil integrity. Zone tillage reflects the philosophy of only specific needy parts to be disturbed and leave the rest of the field undisturbed and keep the soil stable at that general level. Fully autonomous GPS-based self-propelled tillage machines would be able to perform tillage operations with no human presence, ensuring all passes are precise and operationally efficient. Such systems are often operated through data-driven tillage planning, remote sensing, soil mapping, and machine learning for site-specific variability within fields in optimal tillage scheduling (Vallejo-Gómez et al., 2023; Kumar et al., 2023; Ali et al., 2025).

**Technologies Used in Smart Tillage**

The technological backbone of smart tillage includes real-time sensors for soil moisture, compactness and nutrient status, global positioning systems for machine guidance, autonomous vehicles for task execution, and advanced data analytics tools which incorporate machine learning algorithms. Jointly, these afford the decision-making capacity for farmers to till the land in an environmentally friendly and economically sustainable way. As agriculture comes under escalating pressure from climate change and resource scarcity in terms of demand for more productivity, smart tillage is the way forward for sustainable farming systems that deliver on both ecological preservation and food safety (Lal, 2019; Smith et al., 2020; Hamza et al., 2024).

Alreshidi (2019) has demonstrated the use of AI and IoT technologies to develop smart sustainable agriculture. He narrated a few teething challenges that come with the integration of these technologies in the operations of agriculture, such as issues related to data management and interoperability. He suggested a technical framework that would support the development of smart agriculture platforms that carry improved efficiency and sustainability for agricultural operations.

Al-Sammarraie & Albas (2024) to show in a recent study the contribution of automation technologies- AI, IoT, and machine learning, towards agricultural sustainability. In their study, these aspects were taken into the enhancement of tillage operations intelligently, all resulting in productivity, less resource consumption, and less waste. Their study revealed how the combination of all modern technologies can bring excellence in smart agriculture for the attainment of sustainable environmental and economic objectives.

The study found that there has been an improvement in the use of sensors and machine learning techniques to measure soil penetration resistance, which is a major input to the determination of the right depth for tillage. Good prediction of soil resistance would ensure that tillage operations are more efficient and less consuming in terms of energy, thus fostering productivity and environmental conservation.

**Benefits of Smart Tillage**

Intelligent-untilled systems curtail soil disruption, upholding its organic layout and boosting the activity of good microbes. This then raises the levels of organic materials and enhances the soil's ability to hold water, which in turn helps the plants grow well and with quality. For example, among them include vertical tillage and reduced tillage, which bring about a less loss of topsoil because of water and wind erosion; hence conserving soil fertility and allowing it to be washed away by watercourses less sediment (Jabbar et al., 2020b; Dawod & Jasim, 2023; Sumihiro, 2025).

Advanced systems, such as smart tillage, would enable the farmer to adjust the depth and speed of tillage to the type of soil and moisture content detected by sensors in use, therefore reducing fuel consumption and increasing equipment efficiency. In their study, Gisso et al. (2010) showed that the use of GPS guidance systems decreases the degree of superposition of passes, thus saving fuel by 15–20%. Excessive soil compaction may be reduced using smart tillage. Smart systems for instance will be able to precisely monitor the movement of agricultural machinery so that there is minimal reiteration of movement over the same place, therefore soil compaction- an agent of poor aeration and constraint to root growth is reduced. A study presented by Chamen et al. (2015) proves that in the surface layers, the bulk density of soil decreases by up to 20% with controlled traffic farming (CTF). Smart tillage improves agricultural productivity by facilitating an improved soil structure with better aeration and balanced moisture and nutrient content, thus promoting root growth and helping the plant to take up more nutrients. Some field studies have shown a yield increase of between 5% and 12% on lands where smart tillage was used as compared to traditional practices (Bongiovanni & Lowenberg-DeBoer, 2004). Smart tillage reduces carbon dioxide emissions since it conserves fuel and conserves unnecessary tillage. It also conserves erosion and loss of organic matter. Alvarez (2005) found a reduction of $CO_2$ emissions from the soil by up to 30% when using precision tillage compared to conventional tillage. This form of tillage helps the farmer have the right decisions at different times, areas, and ways of tillage.

**Field Applications**

In the study of Khalaf (2023) that was carried out to demonstrate the effect of the type of tillage system and tractor speed on the performance of a fertilized seeding device, it was found that Changing the tillage system and tractor speed did indeed significantly affect seed quality and fertilization efficiency. The study further detailed that settings in the choice should be done to the highest degree of accuracy to obtain the best results in tillage and seeding operations that would help improve crop productivity wasted on agricultural resources Ati et al. (2025a) carried out a study to evaluate the sustainability of water requirements for two okra cultivars under a minimum tillage system using cover crops discovered cover crops under minimum tillage thereby increasing soil moisture retention decreasing the necessity for irrigation-increasing water use efficiency in agriculture under such dry climatic conditions. Basso et al. (2025) utilized the system developed in 2013 that integrated moisture sensors with GPS guidance in a US agricultural area and retrofitted to it. It identified areas with moisture not optimal for tillage, saving 15% time and fuel, while friable soil condition led to more uniform crop emergence. A research team has developed a smart farm machine for plowing, fertilizing, and irrigating at the same time with a GPS and Arduino-based microcontroller. The field results for using this machine reduced the number of fields passes by 40% and fuel savings by over 15% compared with the traditional method. In a pilot study conducted by Karar et al., (2021), drones equipped with thermal cameras and LIDAR devices were used to analyze topographic and moisture distribution of the soil, so that plowing could be directed only to the degraded parts. It resulted in an experiment that plowed 23% less land area and led to better operational efficiency.

**Recommendations**

1. Enhance programs of government support on the use of smart agriculture technologies by way of providing financial support on the adoption of smart tillage equipment, especially in the areas of soil degradation or water scarcity.
2. Develop continuous education and certification programs for farmers and technicians for maximizing the benefits of the use of GPS systems, sensors, and data analysis in the technology.

3. Promote scientific research for the development of low-cost smart tillage systems based on local environment and small- and medium-scale farming.
4. Develop open digital agricultural databases for accurate information on soil, climate, and crops, etc., required for decision support systems
5. Encourage public-private-partnerships for designing customizable smart equipment for soil and crop type
6. Develop smart digital infrastructure at the rural periphery, comprising internet coverage and remote-control systems as an integral part and parcel of the smart agriculture approach.
7. Smart agriculture concepts should form part of the curricula and extension programs until the transfer of knowledge to the new generation has been achieved.
8. There should be an elicitation of participatory models to encourage collaborative practices for the use of smart tillage that would reduce cost and bring efficiency.
9. Create awareness for local smart farming software with simple interfaces that are easy for farmers to use.
10. Connecting smart plowing technologies to sustainable development goals by keeping an eye on environmental as well as economic indicators.

**Conclusion**

Smart tillage is not just about using agricultural machinery; it extends to integrating modern technologies to improve every aspect of the tillage process. This includes precise control using sensors and smart control systems to determine the optimal tillage depth and efficient resource allocation, as well as pre-analyzing soil and crops to determine the best plowing time and path, using drones and satellites to monitor field conditions and identify areas requiring plowing, as well as smart planning using algorithms to optimize plowing paths and avoid overlaps, and using robots and automated control systems to execute plowing operations accurately and efficiently. Recent studies and field applications have demonstrated clear environmental, economic, and agricultural benefits of smart agriculture, ranging from improved soil health and water use efficiency, to reduced fuel consumption and improved yield results.

In the future, the successful implementation of smart tillage will require concerted efforts across policy, research, education, and the private sector. Future research should focus on developing effective technologies that are easy to use and cost-effective. Smart tillage has the potential to become a cornerstone of sustainable agriculture and address global food security challenges by improving soil quality and aeration, maintaining soil fertility, and avoiding environmental degradation. This leads to increased crop yields, reduced water and fuel consumption, and lower labor and energy costs, thus achieving a balance between agricultural production and environmental protection, thus advancing sustainable agriculture.

**References**

1. **Ali, A., Hussain, T., & Zahid, A.** (2025). Smart irrigation technologies and prospects for enhancing water use efficiency for sustainable agriculture. *AgriEngineering*, *7*(4), 106. https://doi.org/10.3390/agriengineering7040106
2. **Alreshidi, E.** (2019). Smart Sustainable Agriculture (SSA) Solution Underpinned by Internet of Things (IoT) and Artificial Intelligence (AI). *arXiv preprint* arXiv:1906.03106. https://arxiv.org/abs/1906.03106
3. **Al-Sammarraie, M. A. J., & Ilbas, A. I.** (2024). Harnessing Automation Techniques for Supporting Sustainability in Agriculture. *Technology in Agronomy*, *4*, e029. https://doi.org/10.48130/tia-0024-0026

4. **Al-Sammarraie, M. A. J., & Kırılmaz, H.** (2023). Technological advances in soil penetration resistance measurement and prediction algorithms. *Reviews in Agricultural Science, 11*, 93–105.
5. **Alvarez, R.** (2005). A review of nitrogen fertilizer and conservation tillage effects on soil organic carbon storage. *Soil Use and Management, 21*(1), 38–52.
6. **Alvarez, R., & Steinbach, H. S.** (2021). Precision tillage and its effects on soil properties and crop yields: A review. *Soil & Tillage Research, 210*, 104963. https://doi.org/10.1016/j.still.2020.104963
7. **Ati, A. S., & Jabbar, H. A.** (2025). Response of water requirement and lettuce yield to water stress and proline foliar under drip irrigation system. *International Journal of Environmental Sciences*, *11*(1s). https://doi.org/10.36103/ejmvxp19.
8. **Ati, A. S., Dawod, S. S., & Al-Halfi, K. M. M.** (2025a). Sustainability of the water requirement of two cultivars of okra under the use of cover crop and minimum tillage system. *Iraqi Journal of Agricultural Sciences, 56*(Special), 161–168. https://doi.org/10.36103/vdh0jv08.
9. **Ati, A.S., Wahaib, H.A., Saleh, H.S. & Majeed, S.S. (**2025b**)**. Sustainability of water productivity and quality of potato as affected by saline water irrigation and mineral fertilization under surface drip system. IOP Conference Series: Earth and Environmental Science, **1487**(1), p.012034. https://doi.org/10.1088/1755-1315/1487/1/012034.
10. **Bongiovanni, R., & Lowenberg-DeBoer, J.** (2022). Precision Agriculture and Sustainability. *Agricultural Systems, 198*, 103395. https://doi.org/10.1016/j.agsy.2021.103395
11. **Chamen, W. C. T., Moxey, A. P., Towers, W., Balana, B., & Hallett, P. D.** (2015). Mitigating arable soil compaction: A review and analysis of available cost and benefit data. *Soil & Tillage Research, 146*, 10–25.
12. **Dawod, S.S., Ati, A.S. & Abdu Jabbar, I.A. (2024)**. Management of using saline irrigation water and tillage systems on the soil mechanical and hydraulic properties. Iraqi Journal of Agricultural Sciences, **55**(6), pp.2050–2059. https://doi.org/10.36103/5b2srn23.
13. **Dawod, S. S., & Jasim A. A. (2023)**. Evaluation of the performance of locally developed combine equipment used for several agricultural operations at once. *Diyala Agricultural Sciences Journal*, *15*(1): 93-103. https://doi.org/10.52951/dasj.23150110
14. **Gebbers, R., & Adamchuk, V. I.** (2023). Precision agriculture and smart tillage: Integrating soil sensing technologies. *Computers and Electronics in Agriculture, 205*, 107509. https://doi.org/10.1016/j.compag.2023.107509
15. **Grisso, R. D., Perumpral, J. V., Vaughan, D. H., Roberson, G. T., & Pitman, R. M.** (2010). Fuel prediction for field operations. *Virginia Cooperative Extension, Publication* 442–073.
16. **Guo, Z., et al.** (2024). Research on the application of Internet of Things (IoT) for water and fertilizer integration and smart irrigation system in cotton production. *Applied Mathematics and Nonlinear Sciences, 9*(1), Article 2414. https://doi.org/10.2478/amns-2024-2414
17. **Hamza, M. J., Al-Janabi, A. M. S., & Khaleel, A. A.** (2024). Effect of tillage, crop rotation and residues on productivity of alfalfa, maize and mung bean. *Iraqi Journal of Agricultural Sciences*, 55(1), 131–141. https://doi.org/10.36103/ijas.v55i1.1906
18. **Hasan, M. M., Islam, M. U., & Sadeq, M. J.** (2022). Towards technological adaptation of advanced farming through AI, IoT, and Robotics: A Comprehensive overview. *arXiv preprint* arXiv:2202.10459.

19. **Jabbar, H.A., Ati, A.S., & Hassan, A.H.** (2020). Furrow irrigated raised bed (FIRB) technique for improving water productivity in Iraq. *Plant Archives*, *20*(2), 1017–1022.
20. **Karar, M. E., Alotaibi, F., AL Rasheed, A., & Reyad, O.** (2021). A Pilot Study of Smart Agricultural Irrigation using Unmanned Aerial Vehicles and IoT-Based Cloud System. *arXiv preprint* arXiv:2101.01851.
21. **Khalaf, F. S.** (2023). Evaluation of performance of fertilizer seeder under two different tillage systems and tractor speeds. *Iraqi Journal of Agricultural Sciences*, *54*(2), 123–132.
22. **Kumar, V., et al.** (2023). Autonomous tillage robots: A review of technology and applications. *Computers and Electronics in Agriculture*, *202*, 107453. https://doi.org/10.1016/j.compag.2023.107453
23. **Lafta, M. I., & Abdullah, W. D.** (2024). Revolutionizing agriculture: IoT empowered smart greenhouses for enhanced productivity. *Samarra Journal of Pure and Applied Science*, *6*(2), 232–241. https://doi.org/10.54153/sjpas.2024.v6i2.837
24. **Lal, R.** (2019). No-till farming for sustainable agriculture: A review. *Agronomy Journal*, *111*(2), 517–530. https://doi.org/10.2134/agronj2018.07.0502
25. **Roy, U. B., et al.** (2024). A smart irrigation system using the IoT and advanced machine learning model. *Journal of Smart Internet of Things*, *2024*(2), 13–25. https://doi.org/10.2478/jsiot-2024-0009
26. **Smith, P., et al.** (2020). Soil conservation through precision tillage. *Environmental Science & Policy*, *107*, 74–83. https://doi.org/10.1016/j.envsci.2020.03.006
27. **Sumihiro, G.** (2025). Precision agriculture is an investment in food security. *My Journal Courier*. Retrieved from https://www.myjournalcourier.com
28. **Vallejo-Gómez, D., Osorio, M., & Hincapié, C. A.** (2023). Smart irrigation systems in agriculture: A systematic review. *Agronomy*, *13*(2), 342. https://doi.org/10.3390/agronomy13020342