SUNSHINE AGRICULTURE e-Newsletter

ISSN (E): 2583 – 0821

Sun. Agri.:e- Newsletter, (2025) 5(8), 28-31

Article ID: 420

Digital Soil Mapping and Precision Farming

Subedar Singh[1], Rajnish Kumar[2], Rita Fredericks[3], Manjul Jain[4]

[1]Assistant Professor, Faculty of Agriculture Motherhood University Roorkee Haridwar Uttrakhand, pin code- 247 661
[2]Assistant Professor, School of Agriculture, Eklavya University, Damoh (M.P.)-470661
[3]CEO, Precision Grow (A Unit of Tech Visit IT Pvt Ltd)
[4] Assistant Professor, School of Agriculture, Eklavya University, Damoh (M.P.)-470661

Open Access

*Corresponding Author
Subedar Singh*

Available online at
www.sunshineagriculture.vitalbiotech.org

Article History
Received: 9. 08.2025
Revised: 14. 08.2025
Accepted: 19. 08.2025

INTRODUCTION

Soil is literally the backbone of agricultural productivity because it directly determines crop growth, nutrient, water-holding capacity, and long-term sustainability of agricultural systems. As the world continues to face escalating global challenges like food security, depletion of resources, and climate change, there is a need for strong scientific innovations that can facilitate sustainable agricultural intensification. Precision agriculture, with emphasis on site-specific soil and crop management, is a promising solution. One of the enablers for this practice is Digital Soil Mapping (DSM), a new technique that combines soil science, geostatistics, remote sensing, and Geographic Information Systems (GIS) to create spatially explicit soil data. DSM delivers precise, high-resolution, and current soil information, enabling farmers and scientists to develop management options that best utilize inputs, reduce environmental effects, and increase crop yields.

Definition of Digital Soil Mapping

Digital Soil Mapping may be described as the computer-based process of generating soil maps through the combination of field observations of soils, laboratory examinations, environmental covariates, and sophisticated predictive models. In contrast to conventional soil surveys, which tend to be labor-intensive, time-consuming, and static in character, DSM utilizes extensive datasets alongside computational methodologies to provide dynamic and high-resolution soil property data. Through the applications of machine learning-based algorithms and geospatial analysis, DSM is capable of predicting soil attributes even in regions where direct sampling has been avoided.

The salient characteristics of Digital Soil Mapping can be detailed as follows:

High spatial resolution: DSM offers detailed soil data at various scales, from individual farm fields to regions, enabling farmers to make accurate decisions regarding fertilizer application, irrigation scheduling, and crop choice.

Dynamic updates: In contrast to traditional soil maps that become less accurate with time, DSM can be updated constantly using new data from ground sensors, drones, and satellite imagery, making real-time soil data available.

Multivariate data fusion: DSM integrates a variety of datasets, including soil samples, topography data, climatic variables, land-use data, and vegetation indices, to combine and interpret the knowledge in a comprehensive manner for soil variability over landscapes.

Predictive ability: Through the use of statistical and machine learning models, DSM is capable of predicting soil properties in unsampled areas with high accuracy, thereby augmenting the utility of sparse field measurements and laboratory analyses.

Essentially, Digital Soil Mapping converts traditional soil survey practice into a more sophisticated, data-oriented, and flexible system that has a pivotal role to play in facilitating precision farming techniques.

Methods and Tools in Digital Soil Mapping

Digital Soil Mapping (DSM) utilizes a broad variety of tools and techniques to model, analyze, and predict soil characteristics with great accuracy. Such methods combine conventional soil science with contemporary computational and geospatial technologies, which provide more accurate and accessible soil information. The key methods and tools utilized in DSM are:

Geostatistics: Methods like ordinary kriging, regression-kriging, and co-kriging are employed to estimate soil properties between sparse sample points. They depend upon spatial correlation among sampled values and enable prediction of soil variability at unsampled locations with measurable uncertainty.

Remote Sensing: Satellite and drone imagery offer rich datasets for DSM. Remote sensing, through the analysis of soil reflectance, vegetation indices, and moisture status, facilitates mapping soil properties over extensive areas on a rapid and cost-effective basis. Multispectral and hyperspectral imagery, for instance, is generally employed to estimate soil organic carbon, salinity, and texture.

GIS and Spatial Modeling: Geographic Information Systems (GIS) are an integral part of DSM by combining environmental covariates including slope, aspect, elevation, rainfall, and temperature. These spatial layers offer contextual data that affect soil variability and are applied in predictive soil models.

Machine Learning Algorithms: Sophisticated algorithms like Random Forest (RF), Support Vector Machines (SVM), Artificial Neural Networks (ANN), and Gradient Boosted Trees are utilized to fit intricate patterns between environmental covariates and soil properties. These algorithms enhance prediction precision and deal well with large, non-linear data.

Proximal Soil Sensors: Sensors placed on tractors or carried in the hand take measurements in real time of soil properties like pH, electrical conductivity (EC), and organic matter content. These sensors increase data acquisition speed and efficiency, eliminating the tedium of laboratory analyses.

All these equipment convert raw data into actionable soil information, enabling decision-making in today's modern agriculture.

Role of Digital Soil Mapping in Precision Farming

Precision farming relies on the concept of site-specific management where the appropriate input, in the correct place, at the correct time is being applied. Digital Soil Mapping provides a foundation for this by offering precise, spatially explicit information regarding the soils that allows farmers to optimize production practices. Its main contributions include:

Soil Fertility Mapping: DSM produces maps of nutrient distribution for nutrients like nitrogen (N), phosphorus (P), potassium (K), and soil organic matter. Farmers can use these maps to apply fertilizers more accurately, minimizing wastage, saving costs, and reducing environmental pollution.

Soil Moisture and Irrigation Management: Soil moisture maps at high resolution produced from DSM facilitate effective irrigation planning. Through the determination of water-deficit or water-excess zones, farmers are able to avoid over-irrigation, conserve groundwater, and avert plant stress through water limitation.

Soil Health Monitoring: DSM assists in the detection of degraded soil areas due to salinity, acidity, compaction, or erosion. Through these problem areas, it facilitates timely corrective measures like gypsum application, liming, or conservation tillage practices for the restoration of soil health.

Yield Forecasting and Crop Planning: By correlating soil characteristics with crop yield data, DSM helps in forecasting potential yield and choosing the most desirable crops for particular soils. This increases farm productivity and facilitates optimum land-use planning.

Climate-Smart Agriculture: DSM has a significant contribution towards climate resilience measures. It allows for the mapping of soil carbon stocks, facilitates practices that

ISSN (E): 2583 – 0821

sequester carbon, and assists in lowering greenhouse gas emissions via effective use of inputs. Hence, it directly contributes to sustainable and climate-smart farming.

Cost-Effective Utilization of Resources: DSM decreases frivolous usage of inputs like excessive fertilizer, pesticide, or water application, using correct soil data. This decreases the cost of production as well as ensures long-term environment sustainability.

Advantages of Digital Soil Mapping

Digital Soil Mapping (DSM) possesses various benefits that make it an unmissable piece of software for contemporary agriculture and precision agriculture. Among the most significant advantages are:

Offers data-based soil management: DSM converts conventional soil expertise to a digital, data-based system. Farmers, researchers, and policymakers gain access to precise and high-resolution soil data, facilitating more scientific and informed decision-making in agricultural schemes.

Improves precision input use effectiveness: Through the creation of elaborate maps of soil fertility, water, and other attributes, DSM ensures that fertilizers, irrigation water, and pesticides are sprayed only where and when they are required. Such precise application reduces wastage, maximizes utilization, and improves input-use efficiency.

Encourages sustainable agriculture: DSM minimizes the environmental impact of agriculture by reducing nutrient runoff, conserving groundwater, and avoiding soil degradation. This helps ensure long-term sustainability as well as conservation of natural ecosystems.

Enhances farm profitability: Reliable soil data helps farmers maximize crop production through greater yields, improved product quality, and lower cost of production. By reducing excessive input spending, DSM enhances overall profitability and economic resilience at the farm level.

Enables policy planning and land-use management: At a scale larger than individual farms, DSM is highly useful. Governments and institutions can utilize DSM outputs to plan land use, develop soil conservation measures, climate adaptation initiatives, and site-specific agricultural policy design.

Challenges in Adoption of DSM

Although Digital Soil Mapping (DSM) brings great advantages in precision farming and sustainable agriculture, its adoption is still hindered by a number of challenges. These constraints must be overcome to guarantee its proper implementation, especially in developing nations. The key challenges are:

High upfront cost of software, drones, and sensors: The hardware needed for DSM, including proximal soil sensors, drones, and sophisticated geospatial software, requires heavy investment. For small and marginal farmers, the costs are usually too high, restricting extensive adoption in the absence of external assistance or subsidies.

Technical skill demand for handling and analysis of data: DSM entails sophisticated tools like machine learning, remote sensing, and geostatistics. Farmers and extension agents lack the technical skills to capture, process, and analyze the sophisticated data, and hence there is a gap between technology development and on-field use.

Lack of data in certain areas because of poor soil sampling: A majority of regions, especially developing nations, have no adequate and current soil databases. Poor soil sampling limits the predictability of models such that it becomes hard to produce reliable maps for all areas.

Integration challenges with farmers' conventional practices: Most farmers use conventional farming practices and can be resistant to adopting DSM-based recommendations. The process entails behavioral transformation, awareness generation, and demonstration of visible benefits, which might be difficult to attain.

Need for standardization and validation of regional soil data: Soil data gathered from various platforms, sensors, or agencies can be inconsistent in terms of quality and methodology. In the absence of proper standardization and validation, there are inconsistencies that impact the reliability and comparability of DSM outputs among regions.

Future Prospects

Digital Soil Mapping (DSM) has a bright future, given that it is being combined more and more with advanced technologies like Artificial Intelligence (AI), the Internet of Things (IoT), cloud computing, and blockchain. The technologies will facilitate real-time acquisition, sharing, and analysis of soil data, hence enhancing the accuracy and timelessness of decision-making at the farm level. Low-cost on-the-go soil sensors, in conjunction with satellite and drone-based remote sensing, will make DSM increasingly available to farmers of all sizes. In addition, open-access databases on soils and collaborative platforms will improve data availability, reliability, and transparency by region.

No less significant will be government policies and institutional support, including financial subsidies, capacity development programs, and farmer training programs, that can reduce adoption hurdles. Public–private partnerships would also help create cost-effective DSM tools and facilitate their widespread use. With the growth of digital agriculture, DSM will increasingly be the core of sustainable land management, climate-smart agriculture, and food security planning.

CONCLUSION

Digital Soil Mapping is a paradigm change in soil science and precision agriculture. By transforming soil data into actionable knowledge, DSM enables farmers to better understand and control spatial variability in their fields. DSM allows for the optimal application of fertilizers, irrigation, and other inputs, resulting in increased yields, lower costs, and reduced environmental impacts.

Outside the farm level, DSM also contributes to regional and national planning by providing policymakers with information on soil health, land suitability, and resource management requirements. As agriculture is transformed in the digital age, DSM is poised to be a key bridge connecting sophisticated scientific understanding and pragmatic agricultural solutions. Eventually, mass use of DSM will not only ensure greater farm profitability but also agricultural sustainability and resilience to climate change over the long term.

REFERENCES

Dong, W., Wu, T., Sun, Y., & Luo, J. (2018, August). Digital mapping of soil available phosphorus supported by AI technology for precision agriculture. In *2018 7th International Conference on Agro-geoinformatics (Agro-geoinformatics)* (pp. 1-5). IEEE.

Iticha, B., & Takele, C. (2019). Digital soil mapping for site-specific management of soils. *Geoderma*, *351*, 85-91.

Ji, W., Adamchuk, V., Chen, S., Biswas, A., Leclerc, M., & Rossel, R. V. (2017, June). The use of proximal soil sensor data fusion and digital soil mapping for precision agriculture. In *Pedometrics 2017* (pp. 298-p).

Söderström, M., Sohlenius, G., Rodhe, L., & Piikki, K. (2016). Adaptation of regional digital soil mapping for precision agriculture. *Precision Agriculture*, *17*(5), 588-607.

Suleymanov, A., Abakumov, E., Suleymanov, R., Gabbasova, I., & Komissarov, M. (2021). The soil nutrient digital mapping for precision agriculture cases in the trans-ural steppe zone of Russia using topographic attributes. *ISPRS International Journal of Geo-Information*, *10*(4), 243.