Digital Soil Maps: Its Use for Managing Horticultural Crops

Shree Prasad Vista[1*] and Nabin Rawal[2]
National Soil Science Research Centre/NARC, Khumaltar, Nepal
[*]Corresponding author's email: spvista002@gmail.com
[1*]ORCID iD: 0000-0002-9008-7001
[2]ORCID iD: 0000-0001-6231-1232

Abstract

Horticultural crops are highly susceptible to nutrient deficiencies, soil and irrigation issues. Their production and productivity, which are largely influenced by factors such as climate, soil characteristics and management inputs, vary greatly depending on the specific crop. Digital soil maps (DSM) developed by Nepal Agricultural Research Council can be used as a important tool for making appropriate decisions about soil-based agricultural inputs. These maps provide valuable information about agro-ecology, topography, soil properties and crop suitability, with a particular emphasis on soil characteristics such as pH values, soil textures, organic matter content and nutrient availability. Till date, the webpage has been searched by more than 37 thousand users and 167 countries. By utilizing DSM data, policy makers and planners can develop effective horticultural programs, researchers can optimize their resources, extension worker can provide agro-advisory services, academics can use it as teaching materials and farmers can optimize their soil resources to improve production and productivity of horticultural crops. The DSM has been used for updating fertilizer recommendations and estimating fertilizer requirement.

Keywords: Digital Soil Map, fertilizer recommendation, horticultural crops, uses

Introduction

Soil is the critical component of the earth ecosystem. It is a natural dynamic body which plays crucial role for agriculture production (Jones, 2011). Soil sustains life on earth and it is crucial for climate change mitigation and biodiversity protection. Healthy soil can store carbon, reduce green house gas emissions and support diverse plant and animal communities. It is the common habitat for all forms of life on earth. Unless soil is healthy, we can’t think of food security, water security, climate change mitigation, biodiversity protection, ecosystem service delivery, energy security, etc. Nutrient deficiencies in the soil, poor resource management and a lack of knowledge about the availability of soil nutrients are some of the main factors limiting agricultural productivity (Giller et al., 2009). Hence, soil is central to most of the global challenges.

Digital soil map (DSM) is the process of building and populating spatial soil information systems through the use of field and lab observational techniques in conjunction with non-spatial and spatial soil inference systems (Lagacherie et al., 2006). It is a spatial representation of the distribution of soil types, properties and characteristics in a geographic area, created using digital technologies such as geographic information systems (GIS) and remote sensing. Many studies have been carried out to characterize the spatial variability of various soil parameters for digital soil mapping based on geo-statistical analysis (Liu et al., 2013). In developing nations, digital data on soil fertility is extremely rare and land managers are usually uninformed about this technology (Stewart et al., 2020; Gobezie & Biswas, 2023). The shortcomings of traditional soil mapping are addressed by DSM, which is being used more frequently to provide soil information with higher geographic resolution, better map accuracy and quantified uncertainty estimates (Chen et al., 2022).

The DSM of Nepal was developed by Nepal Agricultural Research Council with support from Nepal Seed and Fertilizer Project and officially released on 24th of February, 2021. It provides detailed information about the soil's physical and chemical properties, including its, pH, texture, organic matter content, macro and micronutrients, which can be used to guide land use planning, crop management and natural resource management. The site-specific application of soil nutrients and amendments based on spatial variability in accordance with soil requirements can be facilitated by high-resolution digital soil information (Iticha et al., 2022).

Horticultural crops are highly susceptible to nutrient deficiencies, soil and irrigation issues. Their production and productivity, which are largely influenced by factors such as climate, soil characteristics and management inputs, vary greatly depending on the specific crop. In this era of digitalization, DSM can be used as a decision-making tool for managing horticultural crops. The scope and prospects of DSM are vast and varied, as this technology has the potential to revolutionize the way we understand and manage soil resources. As this technology continues to develop, it is likely that we will see new applications and innovations emerge, further expanding its scope. In order to create exact fertilizer recommendations (Kamau et al., 2012; Song et el., 2020) and ultimately mechanize the traditional agricultural systems in poor nations (Gobezie & Biswas, 2023), it is necessary to produce digital soil information.

Application of DSM in Horticultural sector

Digital soil maps can be used to support horticultural sector in several ways. Digital soil maps can provide valuable information to support decision-making and improve productivity, efficiency and sustainability in horticultural sector, including:

Land use planning/site selection:

The most basic tool for making decisions to effective plan for sustainable soil management is the evaluation of soil fertility (Havlin et al., 2010). DSM can be used to identify areas with different soil types and properties, allowing farmers and policy makers to develop land use plans that are optimized for each area. For instance, areas with poor soil quality may be better suited for perennial crops, while areas with high soil quality may be better suited for annual crops. For assessing crop production limitations and applying suitable soil management strategies, understanding of the spatial heterogeneity of soil parameters at the farmland/landscape scale is essential (Iticha et al., 2018). DSM provides valuable information on soil type, texture, nutrient status, estimated drainage and other soil properties that are critical for selecting the right site for horticultural activities. For example, the maps can help identify areas with suitable soil properties for specific crops and can also highlight areas that may require soil amendment or remediation.

Crop selection and management:

DSM can provide information on soil fertility, nutrient availability, pH and other soil characteristics that are important for selecting suitable crops and developing appropriate crop management strategies. For example, the maps can be used to identify areas with high or low nutrient availability and to develop targeted fertilization and irrigation programs. Moreover, increasing crop production in Nepal is more difficult because of increasing soil acidity (Tripathi, 2019). DSM helps for evaluating the areas of soil acidity problems in Nepal. Landowners can identify areas of their fields with high and low nutrient distributions by using digital soil maps, which can show the spatial variability of soil nutrients at a finer resolution (Vasu et al., 2017; Ichami et al., 2020).

Resource management:

DSM can be a valuable tool for horticultural resource management. DSM can help farmers make better-informed decisions about how to manage their horticultural resources, leading to improved productivity, efficiency and sustainability. Management recommendations based on the needs of the crops in the specific area, or precision agriculture, may benefit from the use of the digital soil map (López-Castañeda et al., 2022). Farmers and natural resource managers can easily obtain location-specific information on the characteristics and nutrients of the soil through digital soil mapping, enabling them to make effective and targeted management decisions. Some ways in which DSM can be used for horticultural resource management include:

Irrigation management: DSM can be used to identify areas with different soil moisture holding capacities, allowing farmers to develop irrigation strategies that are tailored to the specific needs of each area. For example, areas with high moisture holding capacity may require less frequent irrigation than areas with low moisture holding capacity.

Fertilization management: DSM can provide information on soil nutrient availability, allowing farmers to develop targeted fertilization programs that are optimized for each area. This can help reduce fertilizer use and minimize the risk of nutrient leaching.

Soil conservation: Digital soil maps can provide information on soil erosion potential, allowing farmers to develop erosion control measures that are targeted to the areas most at risk of erosion. This can help reduce soil loss and improve soil health over the long term.

Support policy formulation:

DSM can be a valuable tool for horticulture policy development and implementation. DSM can provide policymakers with valuable information to help them develop policies that promote efficient and sustainable horticulture practices. By using DSM in policy development and implementation, policymakers can help promote the optimal use of horticultural resources, leading to improved productivity, efficiency and sustainability in the sector. Some ways in which DSM can be used for horticulture policy formulation includes:

Effective land use planning: DSM can be used to identify areas with suitable soil properties for different horticultural crops. This information can be used to develop land use plans that promote the optimal use of land for horticultural purposes. For example, if a certain soil type is found to be suitable for a particular crop, policies can be developed to promote the cultivation of that crop in that area.

Sustainable agriculture: DSM can provide information on soil health, nutrient availability and other factors that are important for sustainable agriculture. This information can be used to develop policies that promote sustainable agricultural practices, such as crop rotation and soil conservation measures.

Irrigation management: DSM can provide information on soil moisture holding capacity, which can be used to develop policies that promote efficient irrigation practices. For example, policies can be developed to promote the use of drip irrigation in areas with low soil moisture holding capacity.

Fertilizer management: DSM can provide information on soil nutrient availability, which can be used to develop policies that promote efficient fertilizer use. Policies can be developed to promote the use of DSM to determine the optimal amount of fertilizer needed for a particular crop in a particular area.

Agro-advisory:

Extension workers can use DSM to provide valuable information and guidance to horticultural producers. DSM can be a valuable tool for extension workers to provide informed and targeted advice to horticultural producers. By using DSM to develop customized recommendations, extension workers can help improve the productivity, efficiency and sustainability of horticultural production systems. Digital soil information in this regard aids in the classification of soils into management zones that provide spatially focused nutrient advisory activities, hence avoiding under- and/or over-application of nutrients and amendments (Zeraatpisheh et al., 2020; Yao et al., 2014). Here are some ways in which DSM can be used by extension workers:

Crop selection: DSM can be used by extension workers to advise horticultural producers on the most suitable crops to grow in a particular area. By analyzing the soil properties and other information provided by the DSM, extension workers can help producers make informed decisions about which crops are likely to perform best in their area.

Nutrient and water management: Extension workers can use DSM to help producers make informed decisions about fertilizer application rates and types. DSM can provide information on soil nutrient availability, which can be used to develop recommendations for optimal fertilizer use. It assists in locating farming regions with sufficient or insufficient nutrient levels, which improves the efficacy of fertilizer application (Iticha et al., 2022). Extension workers can also use DSM to help producers develop efficient irrigation practices. By analyzing soil moisture holding capacity and other information provided by the DSM, extension workers can advise producers on the most efficient irrigation strategies for their area.

Soil conservation and management: Extension workers can use DSM to help producers implement soil conservation measures. By analyzing soil erosion potential and other factors provided by the DSM, extension workers can advise producers on the best practices to reduce soil erosion and improve soil health. In addition, digital soil information can help to identify polluted soil areas and develop soil pollution mitigation strategies (Arrouays et al., 2021; Sistani et al., 2017). DSM can provide information on soil erosion potential, soil organic matter content and other soil properties that are important for developing effective soil conservation and management strategies. For example, the maps can be used to identify areas at risk of erosion and to develop appropriate erosion control measures.

Crop performance analysis:

DSM can be used by researchers to analyze the relationship between soil properties and crop performance. By comparing the performance of different crops on different soil types, researchers can identify the optimal conditions for each crop and develop recommendations for improved productivity.

Soil and nutrient management research:

DSM can be used by researchers to investigate the impact of different soil conservation measures and climate change on soil health and productivity. By comparing the soil erosion potential of different soil types and the effectiveness of different conservation measures, researchers can develop recommendations for improving soil health and productivity. By analyzing changes in soil properties over time and their effects on crop productivity, researchers can develop strategies to adapt to the changing climate and mitigate its impact on horticultural production. DSM can also be used by researchers to investigate the effects of different nutrient management practices on soil health and crop productivity. By comparing the nutrient content of soils with different management practices, researchers can identify the most effective strategies for improving nutrient availability and uptake. In short, DSM can provide researchers with valuable information to help them develop new insights and recommendations for improving the productivity, efficiency and sustainability of horticultural production systems. By using DSM in research, researchers can contribute to the development of evidence-based policies and practices that can help improve the horticultural sector.

Input management

DSM can be a valuable tool for input dealers to develop customized products and services that meet the specific needs of horticultural producers. By using DSM to target their marketing efforts and develop precision agriculture products and services, input dealers can improve the efficiency and productivity of horticultural production systems. Some ways in which input dealers can utilize DSM includes:

Targeted marketing: DSM can be used by input dealers to target their marketing efforts towards areas with specific soil types or horticultural crops. By analyzing the soil properties and other information provided by the DSM, input dealers can identify the most suitable inputs for each area and develop targeted marketing campaigns.

Product development: DSM can be used by input dealers to develop new products that are tailored to specific soil types or horticultural crops. By analyzing the soil properties and other information provided by the DSM, input dealers can identify the needs of producers in each area and develop products that are optimized for those needs.

Precision agriculture: DSM can be used by input dealers to develop precision agriculture products and services. By analyzing the soil properties and other information provided by the DSM, input dealers can develop customized recommendations for fertilizer, irrigation and other inputs based on the specific needs of each area. DSM can be used in conjunction with other technologies such as remote sensing, GPS and yield monitoring to support precision agriculture practices in horticultural sector. For example, the maps can be used to create variable rate fertilizer and irrigation prescriptions that are tailored to the specific needs of different areas within a field. In order to find models that are precise enough to be employed for precision agriculture, farmwise validation of DSM is crucial (Söderström et al., 2016).

Application of DSM for development partner

DSM can be a useful tool for development partners working in the horticultural sector. DSM can be a valuable tool for development partners to improve the effectiveness and efficiency of their interventions in the horticultural sector. By using DSM to target their interventions, allocate resources, assess impact and make more informed decisions, development partners can contribute to the development of more sustainable and productive horticultural systems. Here are some ways in which development partners can use DSM:

Targeted interventions: DSM can help development partners to identify areas with specific soil types or horticultural crops that require targeted interventions. By analyzing the soil properties and other information provided by the DSM, development partners can identify areas that are most in need of interventions like soil conservation, irrigation, or input supply.

Resource allocation: DSM can help development partners to allocate resources more efficiently. By analyzing soil properties and other information provided by the DSM, development partners can identify areas where resources are most likely to have the greatest impact and allocate their resources accordingly.

Impact assessment: DSM can help development partners to assess the impact of their interventions. By analyzing changes in soil properties and other factors over time, development partners can measure the impact of their interventions on soil health, crop productivity and other outcomes.

Planning and decision-making: DSM can help development partners to make more informed planning and decision-making. By analyzing the soil properties and other information provided by the DSM, development partners can identify opportunities and constraints for horticultural development and make more informed decisions about where to invest their resources.

Application of DSM in Academia and Research

DSM can be a valuable tool for research and academia in the horticultural sector. DSM can be a valuable tool for academia to conduct research, develop curricula, provide extension services and engage with stakeholders in the horticultural sector. By using DSM to promote sustainable and productive horticultural systems, academia can contribute to the development of a more resilient and equitable food system. Uses of DSM includes:

Research: DSM can be used by researchers and academia to conduct research on soil properties, crop production and other related topics. By analyzing the soil properties and other information provided by the DSM, academia can develop new knowledge and insights into horticultural systems and make recommendations for improving productivity, sustainability and resilience.

Curriculum development: DSM can be used by academia to develop curricula for courses in horticulture, soil science and other related fields. By using DSM to provide students with hands-on experience analyzing soil properties and making recommendations for crop production, academia can help prepare the next generation of horticultural professionals.

Extension: DSM can be used by academia to develop extension programs that provide farmers with information and recommendations for improving their production systems. By using DSM to develop customized recommendations for crop selection, fertilizer management, irrigation management, soil conservation and precision agriculture, academia can help farmers improve the productivity and sustainability of their operations.

Outreach: DSM can be used by academia to engage with stakeholders in the horticultural sector and promote the adoption of best practices. By using DSM to demonstrate the impact of different interventions and strategies, academia can help build support for policies and programs that promote sustainable and productive horticultural systems.

Uses of DSM in the present context

DSM has been used by users for multiple benefits. On an average, more than 100 users are using the webpage of DSM (https//soil.narc.gov.np) every day. The site has been visited by more than 37k users within one year (2022) and it has been visited from 167 countries across the world. The information derived from DSM has been used by National Soil Science Research Centre, NARC for developing and updating domain specific fertilizer recommendation. Students and researchers have downloaded the available data 2055 times and the maps has been slowly used for soil fertility management at local and farmers' level.

Conclusion and way forward

Soil has immense potential to sequester carbon and mitigate climate change vis-à-vis biodiversity protection. The theme of the conference (Advancing horticulture in the changing climate and biodiversity) can only be achieved if and only if soil is healthy. For effective and efficient management of horticultural sector, DSM can play valuable role within policy makers, researchers, academia, extensionist, input managers, development partners, farmers, etc. Digital soil maps can be used as an evidence-based decision-making tool for improving soil, managing inputs and resources for horticultural crops. DSM has the tremendous potential to transform our understanding and management of soil resources, contributing to sustainable agriculture, land use and environmental management. We need to develop an effective knowledge transfer mechanisms, including training and capacity building programs, to increase the use and applicability of DSM among different user groups, including farmers, land managers and policymakers. DSM need to be further strengthened to improve its accuracy, usefulness and applicability.

Acknowledgement

We are thankful to Nepal Seed and Fertilizer Project, CIMMYT for supporting National Soil Science Research Centre, NARC in developing DSM of Nepal. Due thanks to Nepalese Horticulture Society for giving us opportunity to prepare and present this paper during the Second International Conference on Horticulture at Godavari Village Resort, Godavari, Nepal.

References

Arrouays, D., Mulder, V. L., & Richer-de-Forges, A. C. (2021). Soil mapping, digital soil mapping and soil monitoring over large areas and the dimensions of soil security–A review. Soil Security, 5, 100018.

Chen, S., Arrouays, D., Mulder, V. L., Poggio, L., Minasny, B., Roudier, P., ... & Walter, C. (2022). Digital mapping of GlobalSoilMap soil properties at a broad scale: A review. Geoderma, 409, 115567.

Giller, K. E., Witter, E., Corbeels, M., & Tittonell, P. (2009). Conservation agriculture and smallholder farming in Africa: the heretics' view. Field crops research, 114(1), 23-34.

Gobezie, T. B., & Biswas, A. (2023). The need for streamlining precision agriculture data in Africa. Precision Agriculture, 24(1), 375-383.

Havlin, H. L., Beaton, J. D., Tisdale, S. L., & Nelson, W. L. (2010). Soil fertility and fertilizers: An introduction to nutrient management. PHI Learning Private Limited, New Delhi. India. 516p.

Ichami, S. M., Shepherd, K. D., Hoffland, E., Karuku, G. N., & Stoorvogel, J. J. (2020). Soil spatial variation to guide the development of fertilizer use recommendations for smallholder farms in western Kenya. Geoderma, 22, e00300.

Iticha, B., & Takele, C. (2018). Soil–landscape variability: mapping and building detail information for soil management. Soil Use and Management, 34(1), 111-123.

Iticha, B., Kamran, M., Yan, R., Siuta, D., Al-Hashimi, A., Takele, C., ... & Elshikh, M. S. (2022). The Role of Digital Soil Information in Assisting Precision Soil Management. Sustainability, 14(18), 11710.

Jones Jr, J. B. (2012). Plant nutrition and soil fertility manual. CRC press.

Kamau, M. N., & Shepherd, K. D. (2012, September). Mineralogy of Africa's soils as a predictor of soil fertility. In RUFORUM third biennial conference (pp. 24-28).

Lagacherie, P., McBratney, A., & Voltz, M. (2006). Digital soil mapping: an introductory perspective. Elsevier.

Liu, Z. P., Shao, M. A., & Wang, Y. Q. (2013). Spatial patterns of soil total nitrogen and soil total phosphorus across the entire Loess Plateau region of China. Geoderma, 197, 67-78.

López-Castañeda, A., Zavala-Cruz, J., Palma-López, D. J., Rincón-Ramírez, J. A., & Bautista, F. (2022). Digital mapping of soil profile properties for precision agriculture in developing countries. Agronomy, 12(2), 353.

Sistani, N., Moeinaddini, M., Khorasani, N., Hamidian, A. H., Ali-Taleshi, M. S., & Yancheshmeh, R. A. (2017). Heavy metal pollution in soils nearby Kerman steel industry: metal richness and degree of contamination assessment. Iranian Journal of Health and Environment, 10(1).

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

SONG, F. F., XU, M. G., DUAN, Y. H., CAI, Z. J., WEN, S. L., CHEN, X. N., ... & Colinet, G. (2020). Spatial variability of soil properties in red soil and its implications for site-specific fertilizer management. Journal of Integrative Agriculture, 19(9), 2313-2325.

Stewart, Z. P., Pierzynski, G. M., Middendorf, B. J., & Prasad, P. V. (2020). Approaches to improve soil fertility in sub-Saharan Africa. Journal of Experimental Botany, 71(2), 632-641.

Tripathi, B. P. (2019). Sustainable soil fertility management practices in Nepal. Acta Scientific Agriculture, 3(4), 112-113.

Vasu, D., Singh, S. K., Sahu, N., Tiwary, P., Chandran, P., Duraisami, V. P., ... & Kalaiselvi, B. (2017). Assessment of spatial variability of soil properties using geospatial techniques for farm level nutrient management. Soil and Tillage Research, 169, 25-34.

Yao, R. J., Yang, J. S., Zhang, T. J., Gao, P., Wang, X. P., Hong, L. Z., & Wang, M. W. (2014). Determination of site-specific management zones using soil physico-chemical properties and crop yields in coastal reclaimed farmland. Geoderma, 232, 381-393.

Zeraatpisheh, M., Jafari, A., Bodaghabadi, M. B., Ayoubi, S., Taghizadeh-Mehrjardi, R., Toomanian, N., ... & Xu, M. (2020). Conventional and digital soil mapping in Iran: Past, present and future. Catena, 188, 104424.