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FEATURE

LandPKS Toolbox: Open-source mobile app tools for sustainable land management

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Land use planning and implementation of productive, sustainable land management practices requires careful matching of land use with its sustainable land potential at the field and even sub-field scale (FAO 2022). Sustainable land potential is defined as the potential of the land to generate ecosystem services for current and future generations (United Nations Environment Programme and International Resource Panel 2016). Appropriate matching of land use with land potential requires accurate, site-specific knowledge of land, including information on its long-term potential (based on inherent properties like texture, minerology, and slope), current condition (e.g., fertility, soil organic matter content, vegetation cover), and expected response to disturbances (e.g., management, climate). When land managers lack access to such information and knowledge, they are less likely to make informed management decisions that ensure long-term sustainability. To bridge this information gap, the Land Potential Knowledge System mobile application (LandPKS) was created with the goal of providing location-specific information on land potential that farmers and other land managers can use to make informed management decisions (Herrick et al. 2013, 2016). However, awareness of the availability of this free, open-source app with access to both US and global soil information remains low. The objective of this paper is to describe the app, with a focus on the recently released "Toolbox" feature.

LandPKS is a free, open-source smartphone app available for both iOS and Android mobile devices, and is downloadable from the Apple App Store and Google Play Store. LandPKS consists of a suite of modules that integrate user-collected soil and site data with cloud-based global databases and models to constrain the uncertainty of information needed to guide land management decisions at local scales. LandPKS is used across the globe to record and access location-specific information and currently has over 30,000 user-recorded "Sites" (i.e., a geolocated record in the app created and saved by users) (figure 1a). Historically, most LandPKS data collection tools and model outputs were only accessible by creating a LandPKS Site. While this system works well for cases where users want to record and save geolocated information, there are additional use cases where nongeolocated information is desired (e.g., teaching or collecting data outside of the LandPKS App), or where a user only seeks to temporarily view geolocated data. Since effective decision making requires access to the most relevant information about a management question or concern, recent efforts to support flexible management have focused on the development of virtual "Toolboxes" (i.e., collections of digital tools for data/information/knowledge generation/dissemination) that allow users to access the data and information most relevant to their objectives (Kachergis et al. 2022; Ziadat et al. 2021). In response to these user needs, LandPKS has added a virtual Toolbox, containing standalone tools that can be directly accessed and used without a Site record. This allows for users to skip the Site-creation process, which can be time consuming, when not necessary for their work. The LandPKS Toolbox consists of three main groups of tools that can be used for (1) measuring soil properties (Texture Guide, Soil Color), (2) accessing soil reference materials (Soil Health Methods, Soil Conservation Technologies [WOCAT]), and (3) generating/accessing site-specific modeled information (SoilID, Climate, Available Water-Holding Capacity [AWC] and Infiltration Calculation) (figure 1b).

All of the standalone app tools can be accessed on LandPKS's "Tools" screen (figure 1b), and several of the location-specific data tools (i.e., SoilID, Climate) are also accessible through an interactive map ("Map" screen) where users can manually scroll, zoom, and tap on locations to retrieve soil and climate data (figure 1c). In this paper, we provide an overview of the new tools and features available in the LandPKS virtual Toolbox and highlight some of its potential applications. The title of each section indicates whether the tool is only accessible though the Tools menu, or through both Tools and the Map view.

SOIL PROPERTY MEASUREMENT TOOLS

Texture (Tools). Soil texture is considered one of the most important properties influencing nearly all soil processes, including water holding capacity, aeration, drainage, and plant rooting depth (Salley et al. 2018). Soil texture classes are based on the relative proportion of sand-, silt-, and clay-sized particles, and are determined through established laboratory procedures (Gee et al. 1986; Zobeck 2004) or in the field where the sample's apparent "texture-by-feel" is estimated based on grittiness, cohesiveness, and stickiness (Rowell 2014; Thien 1979). Users who lack soil texture-by-feel experience often struggle with interpreting the soil texture triangle as well as mechanics of hand texturing (e.g., ribboning).

The LandPKS Soil Texture Guide assists users in determining soil texture in the field using an interactive decision tree (figure 2a), where the user is asked a series of questions (e.g., Does the soil form a ball?) and with each answer is guided to the next

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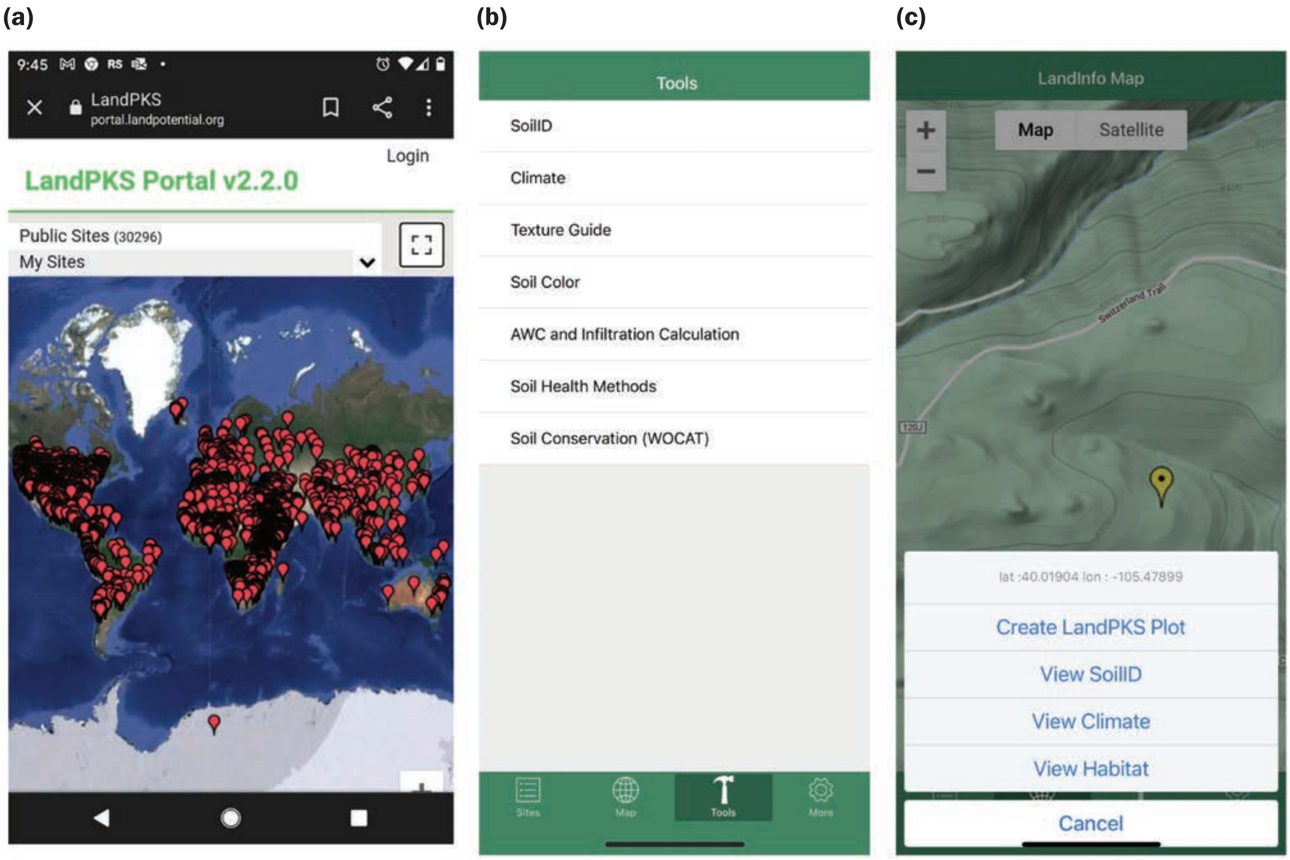
Figure 1
Panel figure showing (a) LandPKS data portal (accessed September 1, 2022) showing over 30,000 LandPKS Sites, (b) LandPKS Tools menu, and (c) LandPKS Map view with accessible geospatial tools.



appropriate decision point until arriving at a final textural class. Each decision node has a question mark symbol that users can tap on to see illustrations and simple animated videos (e.g., ribboning method) that guide users through the techniques used to answer each question in the decision tree. The interactive decision tree is based on the simple dichotomous key developed by Thien (1979). With proper training and calibration, this approach has been shown to produce relatively accurate soil texture estimates when compared to laboratory measurements (Salley et al. 2018; Vos et al. 2016).

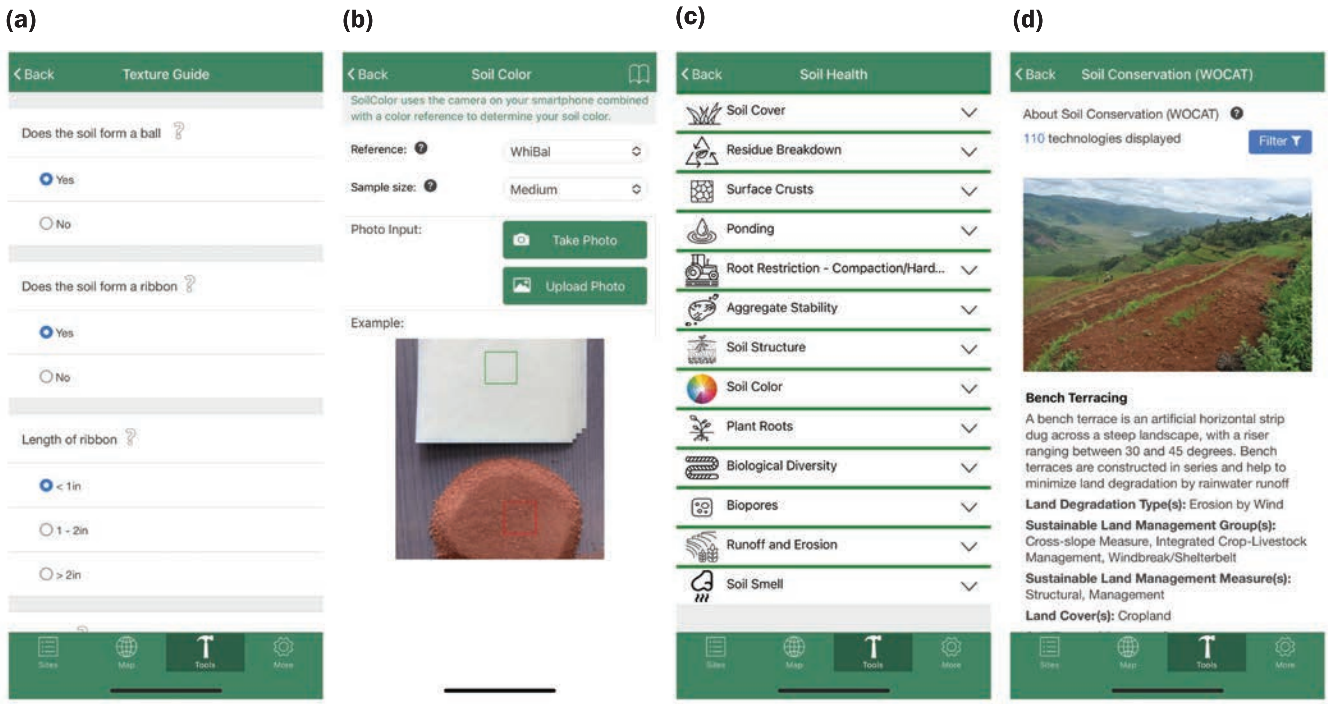
Soil Color (Tools). Color is one of the soil's most distinguishing characteristics and is used to classify, interpret, and differentiate soils due to the strong relationship between color and important soil properties. For example, soil color is an important indicator of many of the soil's chemical and physical characteristics, including mineral composition, soil moisture and drainage class, soil fertility and organic matter content, and soil classification (Baumann et al. 2016; Fan et al. 2017; Han et al. 2016). Standard estimation of soil color is accomplished by subjective perception between a soil sample and chips of standard colors, of which the Munsell Soil Color Chart and GLOBE Soil Color Book are the most common color references (Thompson et al. 2013).

The widespread availability of smartphones has motivated new research on the use of smartphone cameras and mobile-based apps for estimating soil color under controlled illumination conditions (Gómez-Robledo et al. 2013; Moonrungsee et al. 2015; Stiglitz et al. 2016). Several studies have reported variable accuracy of smartphone-based color estimation due to differences in smartphone cameras and the effects of variable lighting conditions (Han et al. 2016; Yang et al. 2021). The LandPKS Soil Color tool addresses these issues by calibrating directly to an in-frame color reference (Fan et al. 2017) (figure 2b). The Soil Color estimation tool allows users to select from four different color references: WhiBal, Camera Trax, 3M Yellow Post-it, and user input.

Research has shown that LandPKS Soil Color tool can reliably estimate soil color under natural, variable outdoor conditions, although testing has demonstrated that accuracy declines if the samples contain gravel, are not flattened (to minimize shadows), have uneven lighting, or are wet enough to glisten (Fan et al. 2017). This has led to the recommendation that photo-based soil color estimation be conducted with a flattened, sieved sample in the shade, which can also improve estimates using ocular comparisons with color chips.

Figure 2

Selection of tools from the Tools menu showing (a) soil texture guide, (b) soil color tool, (c) soil health methods, and (d) soil conservation technologies.



SOIL INFORMATIONAL REFERENCES

Soil Health Methods (Tools). Growing interest among farmers and other land managers in learning about the health of their land and how they can alter current management practices to sustain and/or improve it, has driven the development of simple field-based soil health methods. To be useful to farmers and other nonspecialists, these methods need to be inexpensive, easy to perform, and provide an accurate and interpretable result (Sarrantonio et al. 2015). The LandPKS Soil Health Methods tool provides a compilation of 13 qualitative soil health indicators that use simple sensory (i.e., sight, touch, smell) assessment methods (Karlen et al. 2021; Pellant et al. 2005; USDA NRCS 2021), including all of the USDA Natural Resources Conservation Service (NRCS) Cropland In-Field Soil Health Assessment protocols (USDA NRCS 2021). These indicators can be used independently or together as a diagnostic tool for assessing and monitoring soil health.

In assessing a field's soil health status, users may not need to evaluate all indicators but only those that address specific soil health resource concerns. Through evaluating specific subsets of indicators, users can objectively evaluate if a given resource concern is present (e.g., soil organic matter depletion; figure 2c) and, if so, begin to develop management alternatives. Local knowledge is important in determining which indicators are more representative of soil health for a given area based on variation in soil type, landscape position, climate, time of year, and production system. Additionally, some indicators require specific sampling times, such as after a rain or irrigation event (Ponding) or during the growing season (Surface Crusts, Root Restriction-Compaction, Plant Roots), while others require specific sampling conditions, such as adequate moisture (Root Restriction-Compaction, Biological Diversity) (USDA NRCS 2021). In using these indicators, land managers can quickly obtain a general sense of soil health and whether additional quantitative analyses are needed to inform management.

The Toolbox facilitates rapid access to the indicators and methods for individuals simply interested in learning how to independently evaluate soil health indicators. An additional benefit of the app, however, is that it allows users to simultaneously identify, using the SoilID tool described below, or at least characterize their soil using the soil texture and color tool described above. This allows soil-specific interpretations to be made. For example, a higher level of aggregate stability would be expected in a loamy soil in a humid climate than in a sandy soil in an arid climate.

Soil Conservation Technologies (WOCAT) (Tools). The LandPKS Soil Conservation tool provides information and data about various sustainable land management (SLM) technologies from the World Overview of Conservation Approaches and Technologies (WOCAT) catalogue (figure 2d). The Soil Conservation tool provides access to 110 SLM technologies, a subset of the WOCAT database selected to be globally representative across different land degradation types, annual rainfall, agro-climatic zones, landscape positions, altitudinal zones, soil textures and depth, market orientations, and spatial scale. The tool provides offline access to an image and brief description for each technology. For more in-depth information about a technology, a link is provided that directs users to the WOCAT SLM Database page for that technology (requires connectivity). Detailed information on the environmental and economic benefits of each technology is also provided.

The 110 SLM technologies are filterable by land degradation type(s), SLM Group, SLM Measure (e.g. agronomic, vegetative or structural), Land Cover type, Soil Texture, and/or Slope. If desired by the user, creating and saving a Site in the app can automatically filter the results according to the user's data. The WOCAT team is planning to update its database to increase the relevance of search results, while exploring opportunities to integrate additional technologies, such as USDA NRCS Conservation Practices, which are not currently organized in a searchable database (T. Lemann, personal communication).

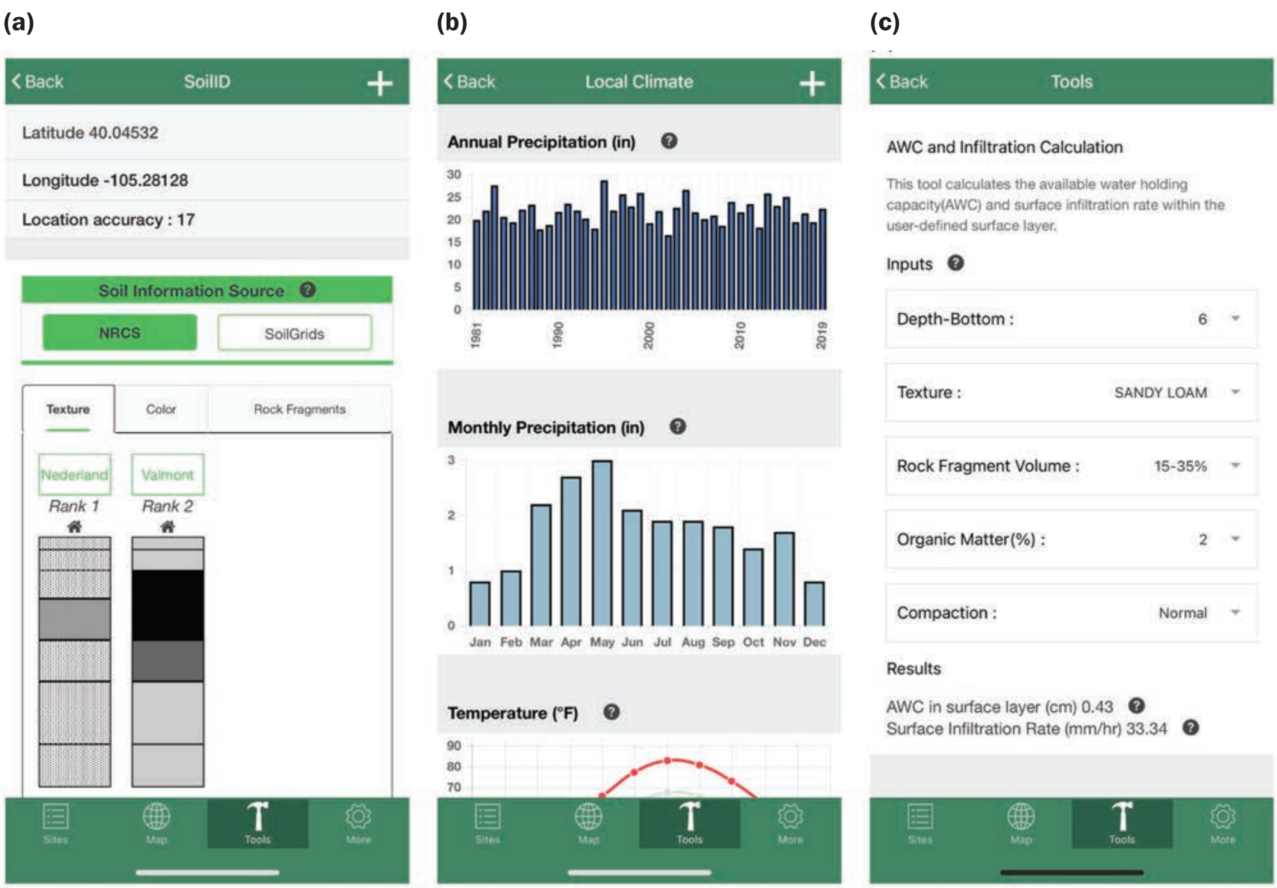
SITE-SPECIFIC MODELED INFORMATION

SoilID (Tools and Map). One of the greatest obstacles to matching land use with land potential is a lack of access to site-specific soil information. The LandPKS SoilID tool provides global access to site-specific soil information at either a user's current location using the phone's GPS receiver, by manually entering a set of coordinates (latitude, longitude in decimal degrees), or by selecting a location on a map.

The SoilID tool assists users in assessing potential soil limitations and management concerns through access to multiple sources of soil map information (i.e., conventional and digital soil map classes and properties). The SoilID tool retrieves conventional soil map information from NRCS Soil Survey data (SSURGO/STATSGO) in the United States, Food and Agriculture Organization (FAO) soil data (WISE30sec) outside the United States, and digital soil map information from SoilGrids250 v.2.0 globally (Poggio et al. 2021). The tool provides easy visualization of soil property differences through a graphical display of soil property depth profiles for soil texture, rock fragment volume, and soil color (United States only) at standard LandPKS depth intervals (i.e., 0 to 1, 1 to 10, 10 to 20, 20 to 50, 50 to 70, 70 to 100, 100 to 120 cm [0 to 0.4, 0.4 to 3.9, 3.9 to 7.9, 7.9 to 19.7, 19.7 to 27.6, 27.6 to 39.4, 39.4 to 47.2 in]) (figure 3a).

For conventional soil maps, the SoilID tool assists users in identifying the most likely soil class at their location. Since conventional soil maps characterize soil variability by grouping soils into management-relevant areas that often contain multiple soil classes, identifying the correct

Figure 3
Selection of tools from the Tools menu showing (a) SoilID, (b) local climate, and (c) the AWC and infiltration tool.



soil class at a location can be a challenging task. Rather than simply taking the dominant soil mapped in an area, the SoilID algorithm evaluates all soil classes mapped within a set distance from the user's location (United States: 1,000 m [3,281 ft] buffer; Global: 10,000 m [32,808 ft] buffer), and ranks them based on their percentage areal composition and the distance from the user's location to the closest mapped area (Fan et al. 2018).

For US locations, SoilID provides a direct link to SoilWeb's GMap web application (requires data connection). This generates an interactive SSURGO map at the user's location with linked soil property and management information for each mapped soil class (O'Geen et al. 2017).

Additional information and resources for assessing land potential can be accessed by tapping on each of the mapped soil classes. For international locations, this opens a new screen with a detailed soil description and management guidance for each FAO soil class, and a table of additional management relevant soil property values (e.g., pH, electrical conductivity [EC]) by depth. Tapping on an NRCS soil class brings up a screen with a detailed soil description, classifications for both Land Capability Classification (LCC) and the correlated Ecological Site Description (ESD), and a table of management relevant soil property values (e.g., pH, EC). Each NRCS soil description screen also provides direct links to SoilWeb's Soil Data Explorer for more detailed soil property information associated with each NRCS soil series class, and to the Ecosystem Dynamics Interpretive Tool (EDIT; https://edit.jornada.nmsu.edu/) for the full ESD (where available).

Local Climate (Tools and Map). The LandPKS Climate tool allows users to access modeled climate data at either their current location or by selecting a location on a map. The Climate tool returns long-term climate data aggregated as either long-term averages (monthly/annual climate normals) or as annual time-series. Climate variables include precipitation, temperature, Growing Period range, and the Aridity Index (figure 3b). For example, the tool returns an annual precipitation time-series (CHRIPS v2.0; 1981 to 2021, 0.05° resolution), which allows users to assess the long-term variability of annual precipitation and how recent (i.e., <5 years) annual rainfall patterns may influence current management strategies. Long-term average monthly and annual precipitation (CHPclim v1.0; 1981 to 2009, 0.05° resolution), and long-term monthly minimum, mean, and maximum temperature data (CRU-TS v4.05; 1971 to 2020, 0.5° resolution) are also provided. The Growing Period range (Data from FAO GAEZ v4, 1 km [0.6 mi] resolution. Available at https://gaez.fao.org/) provides a generalized range of days during the year when the temperature regime and moisture supply are conducive to crop growth and development, and Aridity Index (CGIAR's Global Aridity Index and Potential Evapotranspiration [ET0] Climate Database v2, 1 km resolution. Available at https://cgiarcsi.community/data/global-aridity-and-pet-database/) provides a general measure of water availability as a ratio of precipitation and potential evapotranspiration.

Available Water-Holding Capacity and Infiltration Calculation (Tools). The LandPKS AWC and Infiltration Calculation tool is used to calculate the AWC and surface infiltration rate within a user-defined surface layer. The tool calculates these properties by implementing the soil hydraulic pedotransfer functions (PTF) developed by Saxton and Rawls (2006), using a set of user-defined input parameters. Soil PTFs are statistical models that predict values of an unknown soil property (e.g., AWC) based on the measured values of other soil properties (e.g., texture, rock fragments, soil organic carbon [C] and bulk density) (Van Looy et al. 2017; Minasny et al. 1999). The tool requires users to select a bottom depth (assumes starting depth = 0 cm) in order define the surface layer depth, and the soil texture class and rock fragment volume class within this depth. Based on these three input parameters, the tool calculates the modeled AWC and surface infiltration rate (figure 3c). The tool has two optional parameters, organic matter and compaction, that can be adjusted from their default values (organic matter = 1%, compaction = normal) when a measured or estimated value is known. In general, higher organic matter increases AWC and infiltration rate due to its influence on aggregation and pore space distribution. Conversely, compaction results in a dense soil layer, often near the surface, which restricts plant root growth, lowers AWC, and limits water infiltration. Organic matter input levels can be adjusted between 0.1% and 8.0% and degree of compaction selected from the following classes: Loose, Normal, Slight, Moderate, and Severe. The actual amount of increase in AWC and infiltration associated with increases in soil organic matter also depend on changes in soil structure, which depend on management, biological activity, the form of soil organic matter inputs, and a number of other factors. Changes in the AWC of your own soil may be higher or lower than those predicted by the app.

APPLICATION OF THE LANDPKS TOOLBOX

The following section includes a subset of the potential uses of the LandPKS Toolbox. A growing community continues to identify new use cases as the app continues to grow and evolve.

Soil Science Education. Soil science has experienced a significant evolution over the past century, from once being regarded as a subdiscipline of agronomy, to its growing recognition as an important scientific discipline upon which many aspects of human and planetary health depend. As a result, soil education has evolved to address the needs of an increasing number of scientific disciplines, with soil courses becoming required curricula for many programs in the biological, ecological, and environmental sciences (Brevik et al. 2022). Foundational to any soil science curriculum is the development of a basic understanding of soil properties and processes, which often includes developing skills in soil characterization. The Soil Color and Texture Guide tools simplify the process of teaching students basic soil characterization, and the SoilID tool provides direct access to location specific soil map data that students and educators can use to interpret current land use and management. The LandPKS app has been used extensively for teaching soil science curricula at both the secondary and university level and, to an extent, for professional education of non-soil scientists. Educational resources for using the app can be found on the LandPKS website under the Knowledge Hub (https://landpotential.org/knowledge/).

Data Collection for Third Party Applications. There is a growing recognition that sustainable land management is dependent upon accurate information and knowledge about land potential. In recent years there has been a steady increase in the number of decision support tools (DST), often implemented on mobile devices, intended to address land management challenges at local scales (e.g., soil fertility management on smallholder farms). A major obstacle limiting the efficacy of many DSTs is a lack of accurate, site-specific soil data. The LandPKS Tools module provides users with access to both current soil map information and guided soil data collection tools, which can be used to assess and modify soil input data for more accurate DST results.

Land Use Management and Conservation Planning. While the number of mobile applications supporting land use management and conservation planning continues to increase, very few of these applications explicitly address the importance of soils for localizing recommendations. The LandPKS Tools module can assist land management and planning through (1) access to soil map information for assessing land potential, (2) guided soil data collection for assessing the accuracy of soil maps, and (3) access to SLM technologies that can be filtered by local conditions. Users that create Sites also have the ability to determine LCC (Quandt et al. 2020).

Home Gardening and Landscape and Septic System Design. All of the tools can be used by gardeners to learn more about their soil and to monitor changes in soil health. Additionally, the texture tool can be used for landscape and septic system design.

VIDEOS AND ADDITIONAL TRAINING RESOURCES

Training videos and additional training resources are available on the LandPotential.org website, which is maintained by the USDA Agricultural Research Service Rangeland Resource Unit at the Jornada. The training materials are organized in "learning collections" allowing users with different objectives to rapidly access the most relevant materials. For example, there is a set of training videos providing guidance on how to evaluate each of the soil heath indicators that can be used for instruction with or without the app.

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