doi:10.2489/jswc.68.1.5A

IDEAS & INNOVATIONS

The global Land-Potential Knowledge System (LandPKS): Supporting evidence-based, site-specific land use and management through cloud computing, mobile applications, and crowdsourcing

Jeffrey E. Herrick , Kevin C. Urama, Jason W. Karl, John Boos, Mari-Vaughn V. Johnson, Keith D. Shepherd, Jon Hempel, Brandon T. Bestelmeyer, Jonathan Davies, Jorge Larson Guerra, Chris Kosnik, David W. Kimiti, Abraham Losinyen Ekai, Kit Muller, Lee Norfleet, Nicholas Ozor, Thomas Reinsch, José Sarukhan, and Larry T. West

Agricultural production must increase significantly to meet the needs of a growing global population with increasing per capita consumption of food, fiber, building materials, and fuel. Consumption already exceeds net primary production in many parts of the world (Imhoff et al. 2004).

In addition to reducing consumption, there are two options to meet these needs: production intensification and land conversion. Both strategies present unique opportunities, challenges, and risks. The largest gains achievable through agricultural intensification will likely occur on lands with the largest unrealized production potential, or yield gap. These lands have high potential production and low current production. Similarly, the highest returns on investments to be gained by land conversion should occur on lands with the highest potential production, assuming similar infrastructure, per acre conversion costs, and other market conditions.

The biggest long-term risk for both strategies is that application of nonsustainable land management practices will result in soil degradation that is often costly, if not impossible, to reverse. Exploiting these opportunities and minimizing risks depend on careful matching of production systems with the sustainable production potential of each type of land. Similar analyses can be applied to biodiversity conservation to prioritize land conservation and restoration efforts.

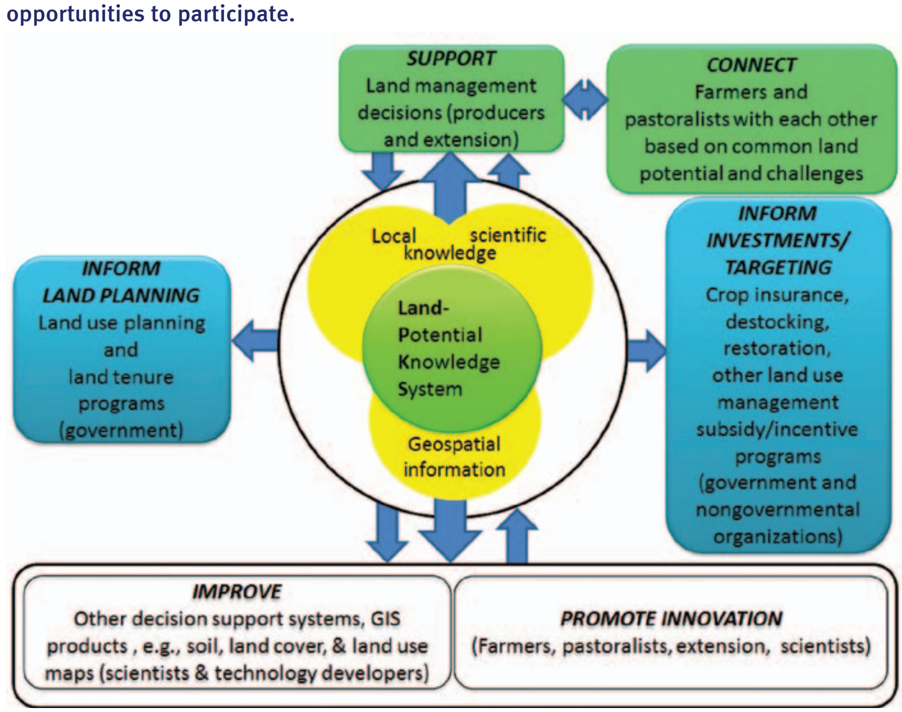
The ability to match land use with land potential is limited by four factors: (1) current land potential evaluation systems, while addressing potential productivity and degradation resistance, do not consider resilience, (2) it is virtually impossible to identify, access, and interpret all relevant scientific and local knowledge and information, (3) this information is often provided in the form of maps at a scale that is far too coarse for field-scale management, and (4) by the time land classification systems are established and maps developed, the information is often obsolete. Farmers and scientists are constantly innovating and adapting, effectively changing land potential to support different types of production.

This paper describes how a new cloud-based Land-Potential Knowledge System (LandPKS; www.landpotential.org; figure 1) will allow land potential to be defined explicitly and dynamically for unique and constantly changing soil and climate conditions and to be updated based on new evidence about the success or failure of new management systems on different soils. The knowledge engine (figure 2), together with simple applications for mobile phones, will also facilitate more rapid and complete integration and dissemination of local and scientific knowledge about sustainable land management.

Jeffrey E. Herrick is Research Soil Scientist and **Brandon T. Bestelmeyer** and **Jason W. Karl** are Research Ecologists at the Jornada Experimental Range, USDA Agricultural Research Service, Las Cruces, New Mexico. **Kevin C. Urama** is Executive Director and **Nicholas Ozor** is Senior Research Officer at the African Technology Studies Network, Nairobi, Kenya. **John Boos** is Geospatial Advisor and **Chris Kosnik** is Team Leader at the US Agency for International Development, Washington, DC. **Mari-Vaughn V. Johnson** is Agronomist and **Lee Norfleet** is Modeling Team Leader/Soil Scientist at the USDA Natural Resource Conservation Service, Temple, Texas. **Keith D. Shepherd** is Principal Soil Scientist at the World Agroforestry Center (ICRAF), Nairobi, Kenya. **Jon Hempel** is Director, and **Larry T. West** is Soil Survey Research and Laboratory National Leader at the National Soil Survey Center, Lincoln, Nebraska. **Jonathan Davies** is Coordinator at the IUCN Global Drylands Initiative, Nairobi, Kenya. **Jorge Larson Guerra** is Use of Biodiversity Coordinator and **José Sarukhan** is National Coordinator at National Commission for Knowledge and Use of Biodiversity (CONABIO), Mexico City, Mexico. **David W. Kimiti** is Graduate Research Assistant at the New Mexico State University, Las Cruces, New Mexico. **Abraham Losinyen Ekai** is Ford Foundation Scholar at Duke University, Durham, North Carolina. **Kit Muller** is Strategic Planner at the US Department of the Interior Bureau of Land Management, Washington, DC. **Thomas Reinsch** is National Leader for World Soil Resources at the USDA Natural Resource Conservation Service, Beltsville, Maryland.

Figure 1

Land-Potential Knowledge System. See landpotential.org for more information and opportunities to participate.



This system expands the concept of an Ecological Knowledge System (Herrick and Sarukhan 2007) through the use of mobile technologies and cloud computing and making more extensive use of crowdsourcing both knowledge and information (Karl and Herrick forthcoming).

The system will include both simple, mobile phone interfaces and more sophisticated web tools that can be accessed via personal computers and linked with other decision tools. Individual producers will be able to use the system to answer questions about sustainable land management options at the field scale, while policymakers will be able to aggregate data across larger areas without losing key pieces of information, such as the presence of small, highly productive, biodiverse, or vulnerable sites within a region. It will also provide extension workers with the ability to instantaneously access the best available information and interpret it in the context of local socioeconomic conditions and local values, including crop preferences, while scientists will have access to a global georeferenced database for calibrating remote sensing imagery and testing hypotheses globally. Finally, as a social networking tool, it will allow individual producers to easily connect with others facing similar challenges on similar types of land.

LAND POTENTIAL

Overview. Land potential includes three elements: potential production of one or more ecosystem services, degradation resistance, and resilience, or the capacity to recover following degradation. While some definitions of resilience integrate both degradation resistance and capacity to recover, we distinguish them because different soil, vegetation, and landscape properties and processes affect resistance and resilience to different disturbance types in different ways (figure 3) (Seybold et al. 1999). For example, a flat, shallow, loamy soil may be relatively resistant but not resilient to water erosion. Conversely, the same soil may have low resistance to compaction, but recover relatively quickly and completely (high resilience). Similarly, sustainable cultivation of steep slopes tends to be limited by low soil erosion resistance, while recovery following soil erosion also

Figure 2

Knowledge engine for the Land-Potential Knowledge System.

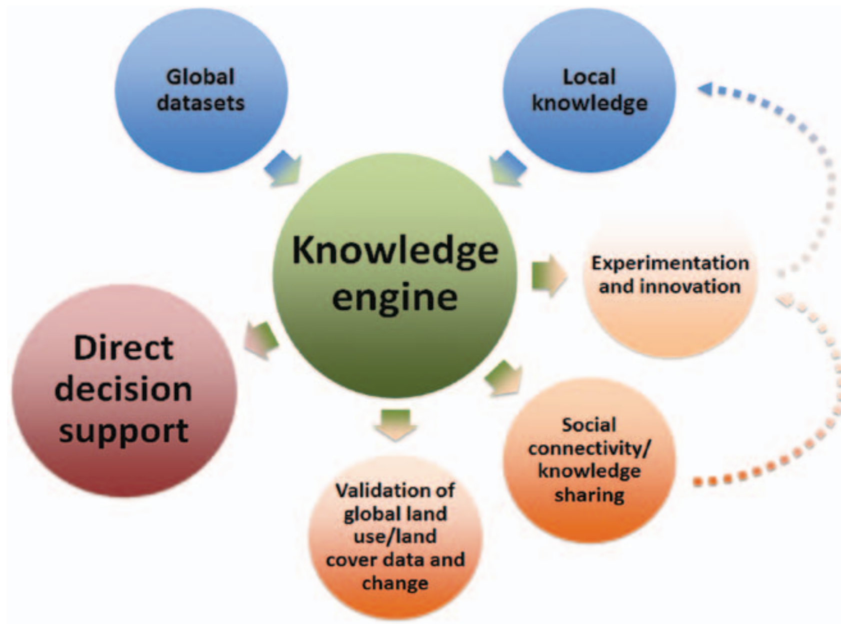
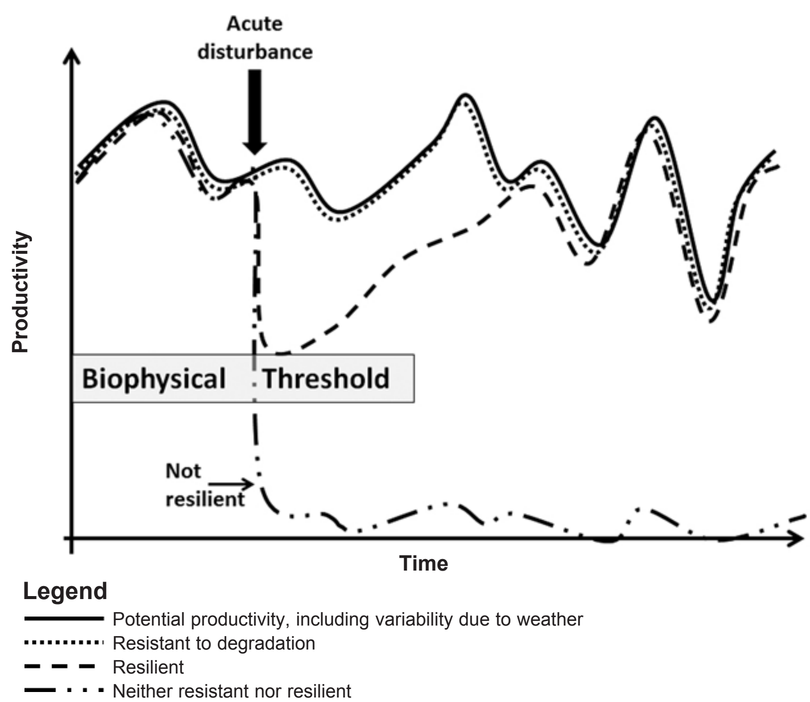


Figure 3

Changes in productivity in response to an acute disturbance, such as an extreme storm event on a freshly plowed field, demonstrate the difference in long-term productivity potentials for resilient and nonresilient land. Resistant land loses little soil in response to the disturbance. Potential productivity on land that is resilient but not resistant will be impacted by the disturbance, but will quickly recover and regain the previous potential productivity levels. Land that is resilient due to its recovery capacity may have relatively deep soils that change little with depth. Land that is nonresilient in response to extreme storm events following tillage often has shallow soils, or soils in which the lower horizons contain more clay than the surface, resulting in reduced infiltration (adapted from Seybold et al. 1999).



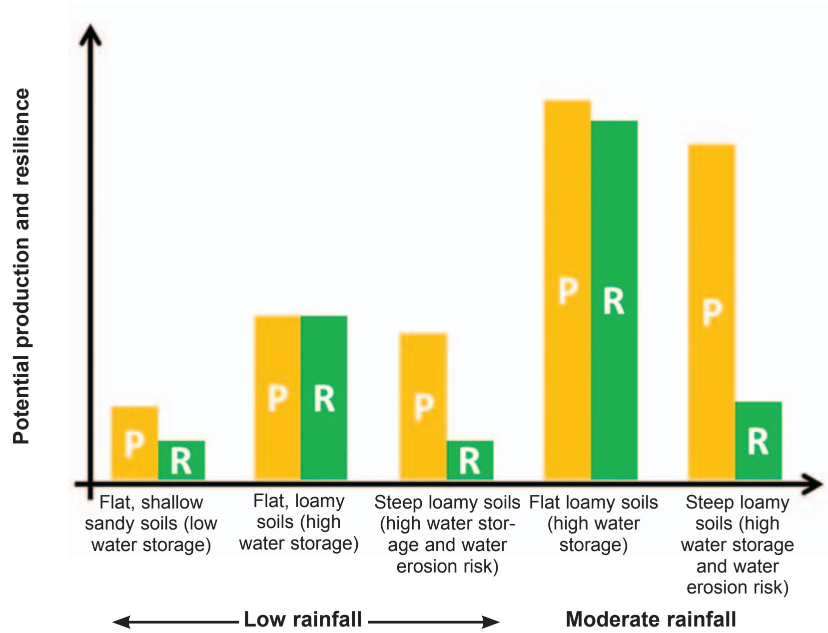
tends to be limited on otherwise productive shallow soils (figure 4).

A general definition of land potential that combines these three elements can be adapted from the definition of sustainability provided in the report "Our Common Future:" land potential is the capacity of land to support ecosystem services required to meet "the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland Commission 1987). Land potential can also be defined in terms of the capacity of land to support more specific land use objectives, including its potential to provide the resources necessary for one or more species to complete their life cycles and reproduce. The value of applying the land potential concept to biodiversity conservation is that it allows the potential future range of species to be predicted based on habitat requirements, rather than relying solely on historic or existing plant and animal community patterns. This is particularly important where climate change and invasive species modify the conditions necessary for species of interest to survive and reproduce. The fact that there are so many different land use objectives means that it can be difficult to generate land potential evaluations that address all needs (FAO 2007).

For most purposes, however, land potential can be evaluated based on knowledge of basic soil profile characteristics, topography, and climate. For example, a nonsaline, deep, well-drained, medium-textured soil with a slope of less than 2% in a 1,000 mm (39.4 in) summer-dominated precipitation zone clearly has greater potential to sustainably support a wide range of ecosystem services than a steep, shallow saline soil receiving 200 mm (7.9 in) of rain per year. Soil texture and depth largely determine soil water and nutrient supplying capacity. Erosion risk for bare soil can be predicted with the inclusion of topographic attributes easily derived from digital elevation models. Additional information may be required in regions where the soil parent material, age, or hydrology result in unique soil characteristics, including clay mineralogy, unusually high or low pH, and high salinity and sodicity. Feedbacks between vegetation, soil, and climate, including both hydrology and nutrient dynamics, are also important, particularly over longer time periods (Peters et al. 2004).

Figure 4

Simplified, generalized patterns of potential production (P) and resistance and resilience (R) based on climate, resistance to erosion, soil depth, soil texture, and potential for soil organic matter accumulation and soil structure development (under natural conditions for water-limited regions). The Land-Potential Knowledge System will improve and localize these predictions to individual fields.



Spatial Variability. Even across areas that share common rainfall and temperature patterns, production potentials may differ considerably, with some areas having shallow, highly eroded soils and other areas characterized by deep, relatively fertile soils that hold water long into droughts. Land degradation risk and recovery potential also vary widely: some soils recover quickly following tillage or overgrazing, while others may require centuries or millennia.

It is more widely recognized that land potential also varies at global and regional scales. In Antarctica, climate limits production to near zero and resilience is limited by both low resistance to soil erosion (Tejedo et al. 2009) and low recovery potential due to both climate and shallow soil depths. Conversely, all other continents have both regions of low land potential and limited resilience and regions with extremely high levels of productivity, degradation resistance, and resilience.

Change Over Time. Global circulation models predict that the currently observed spatial variability of land potential will be compounded by increased climate variability through the 21st century, creating even more heterogeneity.

CURRENT APPROACHES TO LAND POTENTIAL EVALUATION

A number of different evaluation systems have been developed and applied around the world in attempts to improve our understanding and management of land potential. An extensive review and analysis of these systems is forthcoming (United Nations Environment Programme International Resource Panel, http://www.unep.org/resourcepanel/). Two that have been widely applied globally are the USDA's Land Capability Classification (LCC) system (Klingebiel and Montgomery 1961) and the Food and Agriculture Organization's Agroecological Zoning (AEZ) system (FAO 2007). The Land Capability Classification was developed in the 1950s and focused on general biophysical limitations to sustainable crop production. The AEZ, developed within the Framework for Land Evaluation (FAO 1976), is a more holistic approach that addresses both the biophysical and socioeconomic factors that may affect production of a particular crop in a specific area. Both the LCC and AEZ effectively regard crop production as the highest and best use of land. They reflect differences in degradation resistance but not the capacity of the land to recover following degradation (resilience).

The Food and Agriculture Organization's Framework for Land Evaluation was recently updated in recognition of the need to address climate change, biodiversity, and desertification, incorporate new technologies for land evaluation, and address the benefits of participatory approaches (FAO 2007). This revision is based on a set of eight principles (FAO 2007):

1. Land suitability should be assessed and classified with respect to specified kinds of land use and services.
2. Land evaluation requires a comparison of benefits obtained and the inputs needed on different types of land to assess the productive potential, environmental services, and sustainable livelihood.
3. Land evaluation requires a multidisciplinary and cross-sectoral approach.
4. Land evaluation should take into account the biophysical, economic, social, and political contexts, as well as the environmental concerns.
5. Suitability refers to use of services on a sustained basis; sustainability should incorporate productivity, social equity, and environmental concerns.
6. Land evaluation involves a comparison of more than one kind of use of service.
7. Land evaluation needs to consider all stakeholders.
8. The scale and the level of decision making should be clearly defined prior to the land evaluation process.

The LandPKS will ultimately support the application of each of these principles for land evaluation at farm field to national scales. The LandPKS will facilitate the integration and application of local and scientific information and knowledge (Herrick et al. 2010), including existing land evaluation systems through the adoption of crowdsourcing, mobile phone, and innovative decision support system technologies (Karl and Herrick forthcoming).

Figure 5

Similar soil profiles occurring in areas with similar climate in the (a) southwest United States and (b) northwest Namibia. Both are shallow loamy sands on low gradients underlain by a partially rubblized petrocalcic horizon (inset).

(a) (b)

LAND-POTENTIAL KNOWLEDGE SYSTEM DEVELOPMENT AND APPLICATION

Overview. Development of the LandPKS takes advantage of recent advances in cloud computing, digital soil mapping, Global Positioning System–enabled camera phones, and mobile applications. These technologies allow knowledge and information about land potential to be gathered, integrated, and shared globally, while global databases and generic models make existing knowledge more accessible and allow similar sites to be more easily matched (figure 5) (Bestelmeyer et al. 2011; Herrick and Sarukhan 2007). Global Positioning System–enabled mobile phones can be used to capture and transmit geolocated photographs of soil, land use, and erosion features.

Applications can be used to record additional information about a site using drop-down menus, text-input, and picture matching. Slope and color can also be determined with many phones, and the USDA (Agricultural Research Service–Jornada and Natural Resources Conservation Service–Lincoln), in collaboration with World Agroforestry Centre (Shepherd and Walsh 2007), is currently developing an application that will increase the quality of color determinations using an integrated calibration system. Cloud computing allows completion of relatively sophisticated analyses requiring access to large databases, while innovative analysis approaches allow different types of data with currently unspecified error rates to be integrated (e.g., Hubbard 2010). These approaches facilitate integration of local knowledge with, for example, the increasing amounts of information being made available by the Global Soil Map consortium. This initiative was established in response to the rapidly increasing demand for soil information (Sanchez et al. 2009). The consortium includes leading global soil science institutions and is committed to producing digital soil maps that will predict important soil properties at a fine resolution using state-of-the-art and emerging technologies for soil mapping (figure 6).

These and other tools and technologies allow local knowledge to be crowdsourced and different sources of knowledge and information to be cross-referenced, enabling the LandPKS to generate site-specific interpretations about land potential which can be immediately shared with others, including farmers and scientists, who may have additional insights. The LandPKS extends earlier efforts to integrate local and scientific information (Barrios et al. 2006; Herrick et al. 2010) by allowing site-specific conclusions to be instantaneously updated based on input from other locations with similar soil and climate characteristics. As a result, the accuracy, precision, and relevance of the knowledge engine at the core of the LandPKS will increase with each use.

Phased Development. The LandPKS is being developed and implemented through a phased, modular approach (table 1) designed to complement, rather than replace, new and existing land evaluation, database development, and soil mapping

Figure 6

An example of a first generation digital soil map derived from existing soil map data (Soil Survey Geographic Database and US General Soil Map) using spatially map unit component weighted means calculation: soil organic carbon in the surface 5cm (Bliss et al. 2009). Red indicates low and blue indicates high soil organic carbon values.

Table 1

Phased approach to the development and implementation of the Land-Potential Knowledge System. This approach will continue to evolve based on input from a rapidly growing group of partners.

	Phase I (2012/13 to 2015)	Phase II (2014/15 to 2016)	Phase III (2015 to 2018)
Information sources	Existing online databases	Existing online databases + pilot user-contributed field observations	Existing online databases + user-contributed field observations
Knowledge sources	Published scientific sources	Phase I + pilot user-contributed local knowledge	Phase II full implementation and refinement
Knowledge system (mechanism)	Simple decision support based on basic user soil/site description and existing land evaluation systems	Phase I + pilot expert system iteratively integrating user responses to site-specific queries designed to increase accuracy and relevance of output	Phase II full implementation and refinement
Knowledge system (output)	Basic biophysical land potential for sustainable agricultural production (suitability for grazing, crop production, and identification of general types of SLM practices)*	Phase I + identification of specific SLM practices with emphasis on practices already in use locally	Phase II + identification of successful SLM options from other regions being applied on similar soils that are potentially relevant in local socioeconomic context
Connections with other mobile phone/ Web-based services†	Develop system so that it is open and has capacity to connect and identify potential connections.	Initiate connections and develop capability for other organizations to use LandPKS as a platform for their own products	Ensure that independent connection with LandPKS is supported
Implementation	Focused on USDA–US Agency for International Development pilot areas	Available for pilot application by other organizations	Full implementation

* These organizations will benefit from system's aggregation of knowledge and information potentially relevant to the specific site and soil description provided by the observer through the mobile application.
† For example, those providing more specific information (e.g., crop prices, input recommendations).
Note: SLM = sustainable land management.

initiatives, as well as government extension efforts and local and international development projects. Characteristics unique to LandPKS include the ability to provide site-specific information based on simple soil descriptions, to effectively integrate local and scientific knowledge through expert systems that assess multiple sources of qualitative and quantitative knowledge and information, and to provide an interactive self-learning platform that simultaneously collects and shares knowledge and information among a broad range of users.

Using a phased, modular approach will (a) allow stakeholders to apply early versions of the system to make basic determinations about land potential; (b) maximize opportunities for them to contribute knowledge and information to the system, including providing instant feedback on initial determinations; and (c) ensure that the system is sufficiently flexible and dynamic to take advantage of and contribute to future tools, technologies, and information and knowledge sources. In particular, we are encouraged by current progress and future plans of, among others, the Food and Agriculture Organization; Global Soil Map; African Soil Information System; European Environment Agency, including Eye on Earth; and several Consultative Group on International Agricultural Research centers; as well as a number of sustainable land management knowledge systems such as World Overview of Conservation Approaches and Technologies (WOCAT). Finally, we believe that the growth of the semantic web (Villa 2007) and new tools that essentially automate mobile application development will significantly increase the functionality of the system, while reducing maintenance costs.

Leadership and Participation. Development of the LandPKS is being led by the USDA together with a large and growing group of partners. Funding from the US Agency for International Development is supporting initial development and pilot implementation in Africa, and the Africa Technology Policy Studies Network is providing leadership and coordination throughout the continent. An open source, open participation format is being applied to both development and implementation. In order to facilitate broad participation, the amount of additional information provided by the user will be tiered based on user information needs, knowledge, input device (mobile phone vs. computer keyboard), time availability, and technical capacity (figure 7).

FUNCTIONS AND BENEFITS OF THE LAND-POTENTIAL KNOWLEDGE SYSTEM

Overview. The LandPKS is very much a means to multiple ends, rather than an end in itself. During an extended informal scoping process in 2012, we reviewed the project objectives and strategy with diverse stakeholders, including pastoralists and farmers in Turkana, Kenya (Losinyen 2012), and northern Namibia; leadership and technical staff of the USDA Natural Resources Conservation Service and US Department of the Interior Bureau of Land Management; global scientists; and participants in two African Technology Policy Studies Network meetings, including representatives of a broad range of government ministries and the African Union. Based on these conversations, we identified the following functions: connect producers with each other; directly support land management decisions by farmers, ranchers, and pastoralists, including through extension; inform land planning by governments and investments in land management by governments, nongovernmental, and overseas development assistant organizations; improve other decision support systems and geographic information system products; and promote innovation (figure 1).

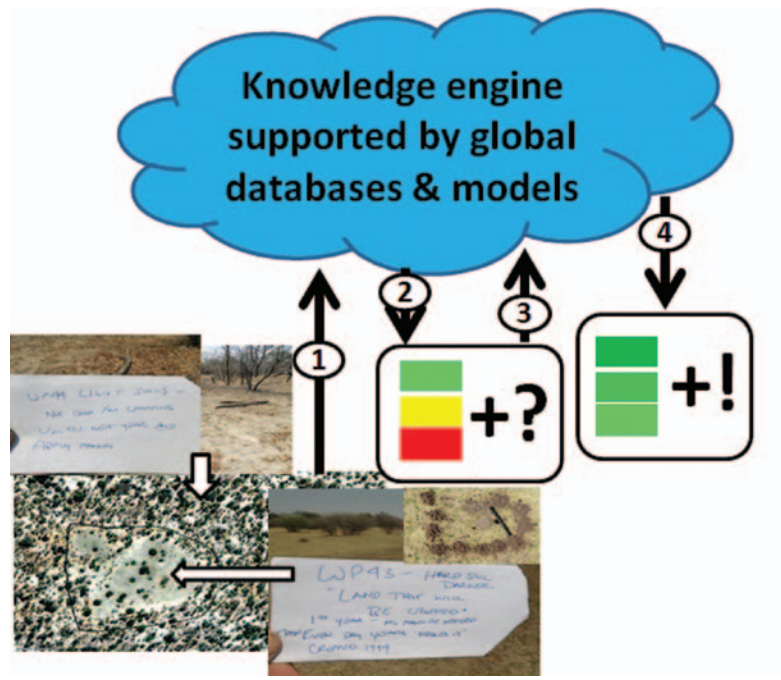
We recognize that it is impossible to optimize the LandPKS for all of these functions. We are committed to ensuring that other developers can easily connect with and leverage the LandPKS to create products that more effectively address one or more of these functions locally, nationally, or globally.

Connect Producers with Each Other. The local knowledge database developed as part of the LandPKS will include all of the elements necessary to support social networking. It will allow individual producers to easily connect with others facing similar challenges on similar types of land. This is particularly important in countries where extension services are limited. It can also be used to support extension activities by allowing facilitators working on farmer-to-farmer exchanges identify producers who are most likely to be able to benefit from each other.

Support Land Management Decisions. Integrating existing knowledge and information enables fine-scale interpretation of available knowledge and information at any location where a user provides descriptive soils information (figure 7). This is important because land potential often varies more at finer scales than it is possible to map. Accuracy of pixel-level predictions based on digital soil maps, such as those being developed by the Africa Soil Information System, will be further improved by user-provided photos, responses to simple questions about soil texture and depth, land use and cover, and new diagnostic soil color applications and protocols for mobile phones. We are working to leverage the extensive work that Africa Soil Information System has done to develop more sophisticated relationships based on near- and mid-infrared spectroscopy (Shepherd and Walsh 2007). Both Africa Soil Information System and USDA Natural Resources Conservation Service databases include visible bands that can be acquired using cameras included with many mobile devices.

Figure 7

Illustration of potential use of the LandPKS to guide land use management decisions in an area of northern Namibia where grasslands, savannas, and woodlands are being converted to annual crop production. User uploads geolocated soil photos and local knowledge (1); which is then integrated with global knowledge and information and sent back to the user as coded land management options, together with a request for additional information (2); which is again entered on the mobile phone (3); resulting in a refined suite of coded management options (4). The number of iterations and complexity of user input will be flexible, depending on user technical capacity and time availability.

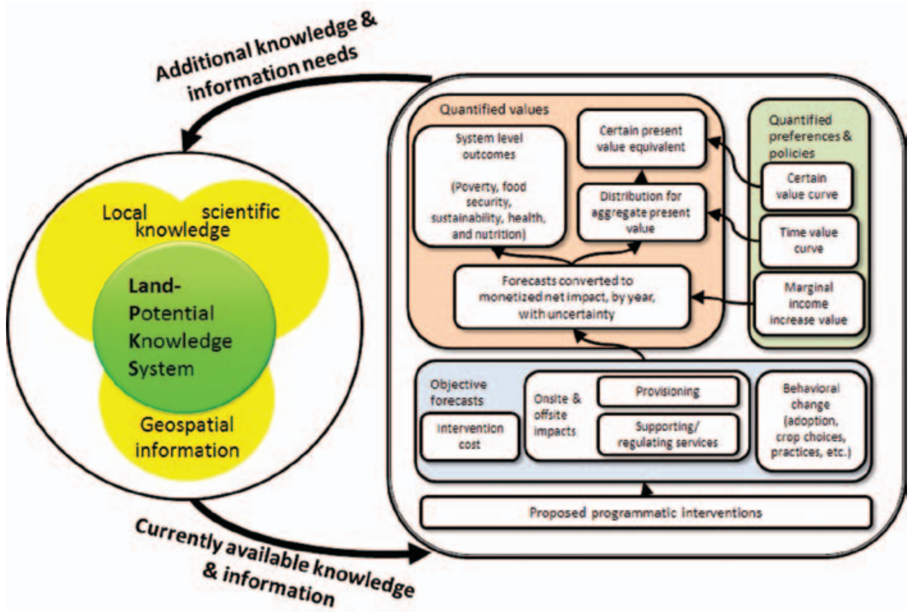


Inform Land Use Planning, Land Tenure, and Targeted Investments Designed to Sustainably Increase Production. In addition to the obvious benefits for land use planning, the LandPKS can, as desired by individual countries, be used to help ensure that land tenure reform programs result in an equitable distribution of land based on its potential, rather than simply distributing areas of equal size. LandPKS can also help governments, funders, and nongovernmental organizations identify specific locations within each region where investments in specific projects, such as technical support and drought assistance, are likely to have the greatest long-term impact and return on investment, while helping to select the interventions that are likely to have the greatest impact.

Improve Other Decision Support Systems and Geographic Information System Products. One of the most frequently cited future benefit of the LandPKS by scientists is improving soil,

Figure 8

An example of how the LandPKS is being designed to both inform and be informed by other related decision support systems. In this illustration, probabilistic modelling is applied to the development and selection of land management interventions. The model will determine the uncertainty of onsite and offsite impacts of interventions, as well as behavioral factors like the adoption rate of a new practice or how incentives change behavior. Ultimately, the effects of an intervention and the quantified preferences are combined into a single monetized value so that interventions of different types and sizes can be compared (Shepherd and Hubbard 2012).



land use, and land cover maps by providing consistent data, including photographs, at potentially millions of points globally. User inputs including soil, vegetation, land use, and land use history information will be made available, subject to any country-specific limitations, in an online geo-database.

In addition to using the raw data provided by users, the LandPKS is being designed to allow other land management–related applications and other software to make more soil-specific recommendations about, for example, improved crop varieties, fertilizer forms and rates, and specific management interventions. The number of mobile applications supporting one or more aspects of land use management and conservation planning is increasing rapidly, but few explicitly address the critical importance of soils and, more generally, land potential, for localizing recommendations.

One particularly intriguing initiative that is already explicitly integrating soil information is the development of innovative models through the information systems and strategic research of the Consultative Group on International Agricultural Research Program on Water, Land and Ecosystems using Applied Information Economics (figure 8) (Hubbard 2010; Shepherd and Hubbard 2012). Land and water intervention decisions are being modelled in a way that captures the uncertainties in costs and impacts on agro-ecosystem productivity, environment and human well-being, and trade-off preferences of stakeholders. This probabilistic modelling approach identifies and quantifies the value of information and further research for improving intervention decisions and provides a holistic business case for intervention programs that includes environmental sustainability and equity concerns (Shepherd and Hubbard 2012).

Promote Innovation. Perhaps the most exciting function of the LandPKS is promoting innovation. Agriculture has continued to largely rely on the research-demonstration-extension model of innovation. The LandPKS can accelerate innovation in at least three ways. The first is by reducing the failure frequency in the implementation of new technologies by reducing the probability that the technologies will be applied on land that does not have the potential to respond. The second is by allowing for virtual instantaneous sharing of successes and failures to all producers with similar land potential. Scientists, too, can benefit by replacing preliminary trials with a global search of all producers who have already tried a similar approach on similar soils and can use the same process to validate conclusions across diverse soils. While there are clearly a number of risks associated with this crowdsourcing approach, we believe that they can be minimized by cross-referencing different types of knowledge and information, including producer observations, measurements, photographs, and physical models. This general approach to reducing the uncertainty of individual conclusions has been widely applied in the business sector (Hubbard 2010).

SOCIOECONOMIC FACTORS: A NOTE

We fully recognize that in many cases the ability to sustainably increase agricultural production and biodiversity conservation and to address other objectives is not limited by knowledge and information about biophysical land potential. Access to markets, prices for agricultural products and inputs, social and political instability, and local food preferences frequently constrain land use decisions. We acknowledge this to be true in many and perhaps most cases. However, we also believe that while not sufficient, an understanding of land potential is necessary to select the most sustainably productive land use or uses and management systems, and that this understanding can also be used to select from a range of options that is already limited by nonbiophysical factors. By starting with the biophysical potential of the land, we provide a foundation for integrating other factors, such as crop prices. Socioeconomic factors will be integrated as LandPKS evolves, either by linking to other programs, or as an integral part of the system itself.

Finally, by facilitating global connections, the LandPKS increases the probability that innovative solutions will be developed and communicated more rapidly and systematically. For example, an innovative approach to rehabilitating landscapes dissected by gullies developed in one country can be instantaneously shared with producers in other countries, who can then test it under local conditions.

SUMMARY AND CONCLUSIONS

The rapid expansion of internet accessibility through mobile phone networks together with simple mobile applications and expert knowledge systems provide new opportunities to connect farmers, extension and development workers, and policymakers with site-specific knowledge and information. The amount of electronically available knowledge and information about land potential, including resilience, is also rapidly increasing through the efforts of a number of organizations throughout the world. The proposed Land-Potential Knowledge System will leverage these emerging trends to connect land managers committed to sustainable land management with the most relevant and up-to-date knowledge and information available.

ACKNOWLEDGEMENTS

We thank all of the individuals who participated in the LandPKS scoping discussions during the past year. In addition to the coauthors listed here and a large body of literature (only a small portion of which is cited), a large number of individuals have also contributed to conversations that led to the development of the approach, including but by no means limited to Fee Busby (Professor, Utah State University, Logan, Utah), Joel Brown (Scientist, Natural Resource Conservation Service, Las Cruces, New Mexico), Ericha Courtright (Research Assistant, USDA-Agricultural Research Service, Las Cruces, New Mexico), Kris Havstad (Lead Scientist, USDA-Agricultural Research Service, Las Cruces, New Mexico), Elisabeth Huber-Sannwald (Professor, IPICyT, San Luis Potosi, Mexico), Mike Pellant (Great Basin Restoration Initiative Coordinator, Bureau of Land Management, Boise, Idaho), Debra Peters (Research Scientist, USDA-Agricultural Research Service, Las Cruces, New Mexico) , David Pyke (Research Ecologist, US Geological Survey, Corvallis, Oregon), James Reynolds (Professor, Duke University, Durham, North Carolina), Pat Shaver (Rangeland Management Specialist, Corvallis, Oregon), Chloe Stull-Lane (Program Quality Manager – African Drylands, Mercy Corps, Nairobi, Kenya), Dennis Thompson (National Rangeland and Pasture Lead, USDA Natural Resource Conservation Service, Washington, DC), Jason Taylor (Monitoring National Implementation Lead, Bureau of Land Management, Denver, Colorado), Gordon Toevs (National Monitoring Lead, Bureau of Land Management, Washington, DC), Justin van Zee (Research Assistant, USDA-Agricultural REsesearch Service, Las Cruces, New Mexico), Nick Webb (Post-doctoral Research Scientist, USDA Agricultural Research Service, Las Cruces, New Mexico) and Skye Wills (Soil Scientist, Natural Resource Service, Lincoln, Nebraska). Pat Shaver (Rangeland Management Specialist, USDA Natural Resources Conservation Service, Corvallis, Oregon), Corinna Riginos (Post-doctoral Research Associate, University of Wyoming, Laramie, Wyoming), and Carey Farley (Team Leader, CARE International funded by US Agency for International Development, Nairobi, Kenya) were instrumental in beta testing some of the rapid protocols that will be implemented as part of the approach, as were Uhangatenua Kapi, Colin Nott, Matthias Metz, Cornelis van der Waal, and the Agra field crew (all associated with and supported by the United States Millennium Challenge Corporation and the Namibia Millennium Challenge Account, Windhoek, Namibia).

REFERENCES

Barrios, E., R.J. Delve, M. Bekunda, J. Mowo, J. Agunda, J. Ramisch, M.T. Trejo, and R.J. Thomas. 2006. Indicators of soil quality: A south–south development of a methodological guide for linking local and technical knowledge. Geoderma 135:248-259.

Bestelmeyer, B.T., H.R. Peinetti, J. Herrick, D. Steinaker, E. Adema, and K. Havstad. 2011. State-and-transition model archetypes: a global taxonomy of rangeland change. IX International, Rangeland Congress, Rosario, Argentina.

Bliss, N.B., S.W. Waltman, and L. West. 2009. Detailed Mapping of Soil Organic Carbon Stocks in the United States Using SSURGO. Abstract B51F-0367. American Geophysical Union Meeting, Fall 2009.

Brundtland Commission. 1987. Our Common Future. New York, NY: Oxford University Press.

FAO (Food and Agriculture Organization). 1976. A framework for Land Evaluation. FAO Soils Bulletin 52. Rome, Italy: Food and Agriculture Organization.

FAO. 2007. Land Evaluation: Towards a Revised Framework. Land and Water Discussion Paper 6. Rome, Italy: Food and Agriculture Organization.

Herrick, J.E., and J. Sarukhan. 2007. A strategy for ecology in an era of globalization. Frontiers in Ecology and the Environment 5:172-181.

Herrick, J.E., V.E. Lessard, K.E. Spaeth, P.L. Shaver, R.S. Dayton, D.A. Pyke, L. Jolley, and J.J. Goebel. 2010. National ecosystem assessments supported by local and scientific knowledge. Frontiers in Ecology and the Environment 8:403-408.

Hubbard, D.W. 2010. How to Measure Anything. Hoboken, NJ: John Wiley & Sons.

Imhoff, M.L., L. Bounoua, T. Ricketts, C. Loucks, R. Harriss, and W.T. Lawrence. 2004. Global patterns in consumption of net primary productivity. Nature 429:870-873.

Karl, J., and J.E. Herrick. Forthcoming. A rangeland Wikicology? Implementing collaborative Internet technologies for rangeland management. Rangelands.

Klingebiel, A.A., and P.H. Montgomery. 1961. Land Capability Classification. Agricultural Handbook No. 210. Washington, DC: USDA.

Losinyen, A. 2012. Land Potential Knowledge System Scoping Exercise Report. Unpublished report. Las Cruces, NM: USDA Agricultural Research Service Jornada Experimental Range.

Peters, D.P.C., R.A. Pielke, B.T. Bestelmeyer, C.D. Allen, S. Munson-McGee, and K.M. Havstad. 2004. Cross-scale interactions, nonlinearities, and forecasting catastrophic events. Proceedings of the National Academy of Sciences of the United States of America 101:15130–15135.

Sanchez, P.A., S. Ahamed, F. Carre, A.E. Hartemink, J. Hempel, J. Huising, P. Lagacherie, A.B. McBratney, N.J. McKenzie, M.L. de Mendonca-Santos, B. Minasny, L. Montanarella, P. Okoth, C.A. Palm, J.D. Sachs, K.D. Shepherd, T-G. Vågen, B. Vanlauwe, M.G. Walsh, L.A. Winowieck, and G-L. Zhang. 2009. Digital soil map of the world. Science 325(5941):680-681.

Seybold, C.A., J.E. Herrick, and J.J. Brejda. 1999. Soil resilience: A fundamental component of soil quality. Soil Science 164:224-234.

Shepherd, K.D., and D.W. Hubbard. 2012. The need for an intervention decision model. Concept Paper. World Agroforestry Centre (ICRAF) and Hubbard Decision Research, Nairobi/Chicago.

Shepherd, K.D., and M.G. Walsh. 2007. Infrared spectroscopy—enabling an evidence-based diagnostic surveillance approach to agricultural and environmental management in developing countries. Journal of Near Infrared Spectroscopy 15:1-19.

Tejedo, P., A. Justel, J. Benayas, E. Rico, P. Convey, and A. Quesada. 2009. Soil trampling in an Antarctic Specially Protected Area: Tools to assess levels of human impact. Antarctic Science 3:229-236.

Villa, F. 2007. A semantic framework and software design to enable the transparent integration, reorganization and discovery of natural systems knowledge. Journal of Intelligent Information Systems 29:79-96.