TOOLS FOR IMPROVING LAND TENURE PROJECT OUTCOMES THROUGH MOBILE ACCESS TO LAND MANAGEMENT INFORMATION WITH THE GLOBAL LAND-POTENTIAL KNOWLEDGE SYSTEM (LANDPKS)

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Abstract

Securing land tenure is often a necessary but rarely sufficient requirement for long-term sustainability of agricultural production and rural communities. To maintain and increase its value, land must be managed within its sustainable potential. This paper reviews the challenges of determining the agricultural potential of specific land types (soil+topography+climate), and accessing relevant information and knowledge necessary for management. It describes the global Land-Potential Knowledge System (LandPKS), which is addressing these challenges described by using information on soil, topography, and climate to provide site-specific knowledge and information through mobile apps and cloud-computing. This system can also be used to more equitably allocate land based on its sustainable production potential. The free apps are currently being used to inventory and monitor the impacts of several rangeland restoration and management projects. By the end of 2017 they will provide users with relative potential production and soil erosion risk under several management scenarios, including annual cropping. The system is completely open, and all data are available on a data portal and through Application Programming Interfaces (API) thus allowing links to other mobile and web-based services. User inputs are used to increase the precision of soil identification and subsequent management relevant information using a simple icon-based interface supported by short embedded video clips. Future versions will provide soil-specific management information from new (including user-generated) and existing knowledge bases.

Key Words: cloud computing, mobile apps, open data, sustainable intensification, sustainable land management,

Introduction

Securing land tenure is often a necessary but rarely a sufficient requirement for long-term sustainability of agricultural production systems and rural communities (Place, 2009). In order to maintain or increase its value, land must be managed within its sustainable potential. Managing land beyond its sustainable potential can lead to degradation, which reduces the value of the land. Managing the land below its productive potential means that more land must be converted to agricultural production in order to produce the same amount of food and fiber.

Land potential is commonly defined in terms of potential productivity (e.g. FAO, 1996). The sustainable potential takes into account degradation resistance and resilience (International Resource Panel 2016). For example, a steep slope in an area with relatively high rainfall may have a high potential to produce annual crops, but a low sustainable potential due to the risk of soil loss through water erosion. Its sustainable potential for perennial crop or forage production is likely to be much higher.

Long-term sustainable potential depends on a combination of relatively static soil properties, topography and climate. Short-term potential depends on these attributes, as well as relatively dynamic soil properties, such as soil nutrient availability, structure, salinity, and pH.

Land degradation can result in a reduction in short-term land potential through nutrient loss and soil structure degradation, such as compaction. Relatively permanent, long-term reductions in land potential are often caused by soil erosion. Soil erosion impacts can be particularly severe where there is an increase the abundance of clay particles with increasing soil depth. Clay inhibits water flow into soils and so removal of the surface horizon through erosion results in reduced infiltration capacity and therefore increased runoff.

Land degradation can occur for a number of reasons, but can be reduced or prevented through improved knowledge and information thus leading to improve economic viability of agricultural production systems. Improved information can support better selection of crops for particular soils, improved planning for (and avoidance of) drought-related crop failure, and appropriate application of fertilizers that prevents the risk associated with under application (low crop growth) and over-application (water pollution, salinization, soil pH change).

Much of the knowledge and information necessary to optimize on-farm decision-making is available, but farmers' ability to access the information that is relevant to their particular soil, topography and climate is limited by two factors. The first (1) is that high resolution information on soils is rarely available and such information is critical for sustainable agriculture planning. Even the best soil maps are insufficiently precise to correctly identify soils at the field scale (1a), and few farmers or individuals implementing land tenure projects are able to identify which of several soils in a soil map unit is correct. Soil identification requires an understanding of the terms used by agronomists and soil conservationists, including percent sand, silt, and clay; mineralogy, slope, etc. (1b). The second (2) is that management recommendations are rarely systematically associated with the soil, topographic and climate conditions where they are relevant. This paper reviews and describes a system that is being developed to address these two limitations.

The Global Land-Potential Knowledge System (LandPKS)

Overview

The global Land-Potential Knowledge System (LandPKS) is being developed to address the challenges described above by providing soil-specific knowledge and information through mobile apps supported by cloud computing (landpotential.org; Herrick et al., 2013; Herrick and Beh, date?; Kimiti et al., 2016; Herrick et al., 2016). The mobile apps, which are available for free download for both iOS and Android, are currently being used to inventory and monitor the impacts of rangeland restoration and management projects. They are designed to be as simple to use as possible. Prioritizing the use of icons (Figure 1) and very short (a few seconds) embedded training video clips has limited the amount of text and drop-down menus. This allows training, where required, to be completed in the field with no classroom preparation (Figure 2).

The methods included in the first two modules (*LandInfo* and *LandCover*) are also compatible with those applied in association with MCC rangeland tenure and management projects in Mongolia and Namibia. By the end of 2017 they will provide users with relative potential production and soil erosion risk under several management scenarios, including annual cropping. The system is completely open, and all data are publicly available on a data portal through direct download and API's.

Detail: LandInfo

User inputs to *LandInfo* are used to increase the precision of soil identification (the first limitation) using a simple icon-based interface supported by short (5-15 second) embedded instructional video clips. Future versions will provide soil-specific management information from new (including user-generated) and existing knowledge-bases, which will address the second limitation.

The LandPKS *LandInfo* module allows the user to automatically generate location and slope information using the phone's internal sensors. Soil profile rock fragment content is described by selecting from among a set of diagrams, while texture is determined using a dichotomous key supported by training videos. This information is used to calculate plant-available water-holding capacity which, together with location-specific climate from global databases, is provided to the user as soon as cellular or wireless data access is available; a data connection is not required for data collection. Future versions (2017) will automatically select from among a global database of soil profiles which will be used to run soil-specific crop production and soil erosion models.

Detail: LandCover

The *LandCover* module is designed to facilitate rapid (20 minutes/plot) collection of vegetation and soil cover and structure information using a 1-meter stick with 5 marks (point intercept). This can be used to inventory and monitor both rangelands and croplands, and to provide the additional inputs required for various models, including carbon sequestration, and wind and water erosion. Indicators automatically calculated on the phone, and available through the portal following upload, include cover by vegetation type, average vegetation height, proportion of the soil surface in large (erosion-susceptible) gaps, and plant density.

Additional Apps

Additional apps currently under development include an app for inventory and monitoring of forage biomass, livestock (and possibly wildlife) body condition score, and an app specific to crop production. These will facilitate collection, storage and inter-comparison of crop inputs and yield data across land with similar production potential, eliminating one of the biggest limitations of current "yield gap" analyses at the local to regional level. We are also working on integration of a soil color app to provide additional soil specific fertility information.

LandPKS as a Platform

LandPKS is being developed as a platform for technology development. It is led by the Agricultural Research Service of the United States Department of Agriculture (USDA-ARS) in cooperation and with major support from USAID. Its development is further supported by a rapidly growing, relatively informal partnership of organizations committed to open-source technology development and open data, and which are interested in making their research and development products more widely available to land managers to land managers and policymakers. For example, RCMRD (Kenya) is contributing GIS layers and other regional data, IIASA and BOKU University (Austria) are involved in modelling, and

Texas A&M (US) is collaborating on integration with early warning systems. ISRIC (Netherlands) and NRCS (US) are contributing soils expertise and information, particularly as its relevance and utility increases within the United States. Finally, the USDA-ARS research unit @ the Jornada, New Mexico State University, and the Sustainability Innovation Lab @ the University of Colorado (SILC) are working together to provide the necessary technical and administrative support.

The platform is also being designed to allow other *public*- and *private-sector* organizations to use its APIs to independently develop apps and other tools that leverage the LandPKS apps, cloud computing and storage. The impact of many, if not most, technologies that are being developed to support increased productivity and sustainability can be increased through the simple integration of soil information. Most of these applications currently rely on soil maps, which are both imprecise and inaccurate. For example, drought risk varies with soil type because the amount of water the soil can hold varies ten-fold depending on the relative amounts of sand, silt, and clay, as well as organic matter content (which can be very roughly estimated with soil color). Drought risk also depends on the how much rainfall soaks into the soil, and the infiltration rate can vary by 100X or more depending on the same properties, and the structure of the soil. Design of drainage projects depends on the same variables.

Another example is fertilizer application, as fertilizer type and application timing and rate are all soil-dependent. Similarly, disease and pest pressure (particularly for root pathogens) very much depend on soil moisture status, which is a function of precipitation and soil physical properties.

The type of information generated by LandPKS is already being applied in increasingly sophisticated ways by large operations using “precision farming” systems provided by large agricultural input and machinery companies. These systems rely on a combination of existing geospatial data, remote sensing imagery and static and mobile (drone- and tractor-mounted) sensors to predict optimal germplasm (seeds), and input types, timing and rates. Developers of phone-based sensors designed to provide similar services to small farmers can easily leverage LandPKS technology simply by asking their users to complete a 1-time soil evaluation using LandInfo. The LandCover app can then be used to calibrate or validate remote sensing data in real time throughout the season, at no cost to the technology developer or vendor.

Application to Land Tenure Projects

Most projects that assign tenure to land currently in production, and particularly those that are associated with intensification of production include two implicit, and often explicit assumptions (among others): (1) that any redistribution of land is equitable, and (2) that the intended use of the land is sustainable.

The LandPKS simplifies the process of testing the first (equitability) assumption anywhere in the world by providing a simple tool to collect, archive and compare the basic soil and landscape properties that together determine its potential productivity and degradation risk under the intended or likely land use. Potential productivity is one of a number of factors, together with location and size, that determine land value. Future versions of LandPKS (beginning 2017 for selected countries) will make these comparisons even easier by providing estimates of relative potential productivity and erosion risk. These new features, together with additional tools, will also help address the second assumption (sustainability).

The importance of testing the assumptions of equitable redistribution and agricultural sustainability can be immense, as a failure to do so can lead to massive land degradation and social dislocation, as experienced by in the United States during the “Dust Bowl” of the 1930’s. This resulted in part from a government land redistribution program that promoted cultivation of marginal lands that could sustain annual crop production during years with average to above-average rainfall, but where repeated crop failures occurred during periods of extended drought. The disturbed soil in was then exposed to wind (as well as water) erosion, resulting in massive land degradation and the clouds of dust which travelled half-way across the continent to darken the skies of the Atlantic coast.

In addition to providing the ability to complete comparisons of land potential in the field, LandPKS can also be used to support large-scale land-use planning by applying it as a calibration and validation tool for soil maps and other geospatial layers. The strength of LandPKS its ability to provide much more precise estimates of land potential at the point, field or pasture scale than can be generated from remote sensing and other geospatial layers. In the future, land tenure registration systems could easily link to and reference rough estimates of land potential, which could then be refined following a field visit (or crowdsourced inputs) using LandPKS.

Summary and Conclusions

Improving land tenure project outcomes, and avoiding unintended and unanticipated outcomes, such as the United States Dust Bowl of the 1930’s, requires understanding the sustainable potential of the land *before* a change in land use occurs. GIS-based analyses can be used to predict how land potential might vary within a region, but the inaccuracy of soil maps means that it cannot be used to conclusively determine land potential for a particular parcel of land. The Land-Potential Knowledge System is increasingly providing tools that anyone can use to make more conclusive determinations with just a mobile phone and a shovel. A suite of mobile phone apps connected to Cloud-based global databases and models. In summary, LandPKS is a system for *collecting, storing*, *accessing and interpreting* soil and land cover data. It also allows users to share data and information. In the future it will allow them to also share their knowledge to others managing similar types of land, and to find, retrieve and interpret information and knowledge that is relevant to their specific type of land. More information is available at landpotential.org.

References

FAO. (1996). Agro-ecological zoning: guidelines. FAO Soils Bulletin 73. http://www.fao.org/soils-portal/resources/soils-bulletins/en/.

Herrick, J.E., K.C. Urama, J.W. Karl, J. Boos, M-V.V. Johnson, K.D. Shepherd, J. Hemple, B.T. Bestelmeyer, J. Davies, J.L. Guerra, C. Kosnik, D.W. Kimiti, A.L. Ekai, K. Muller, L. Norfleet, M. Ozor, T. Reinsch, J. Sarukhan, and L.T. West. 2013. The global Land-Potential Knowledge System (LandPKS): Supporting evidence-based, site-specific land use and management through cloud computing, mobile applications, and crowdsourcing. *Journal of Soil and Water Conservation* 68: 5A-12A.

Herrick, J.E., A. Beh, E. Barrios, I. Bouvier, M. Coetzee, D. Dent, E. Elias, T. Hengl, J.W. Karl, H. Liniger, J. Matuszak, J.C. Neff, L. Wangui Ndungu, M. Obersteiner, K.D. Shepherd, K.C. Urama, R. van den Bosch and N.P. Webb. 2016. The Land-Potential Knowledge System (LandPKS): mobile apps and collaboration for optimizing climate change investments. *Ecosystem Health and Sustainability.* 2(3):e01209. doi: 10.1002/ehs2.1209.

International Resource Panel. 2016. Unlocking the Sustainable Potential of Land Resources: Evaluation Systems, Strategies and Tools. A Report of the Working Group on Land and Soils of the International Resource Panel. Herrick, J.E., O. Arnalds, B. Bestelmeyer, S. Bringezu, G. Han, M.V. Johnson, D. Kimiti, Yihe Lu, L. Montanarella, W. Pengue, G. Toth, J. Tukahirwa, M. Velayutham, L. Zhang. 89pp. http://unep.org/resourcepanel/KnowledgeResources/AssessmentAreasReports/LandSoils/tabid/133334/Default.aspx

Kimiti, D.W., A.C. Hodge, J.E. Herrick, A.W. Beh and L.E. Abbott. 2017. Rehabilitation of community owned, mixed use rangelands: Lessons from the Ewaso ecosystem in Kenya. *Plant Ecology* ##: ###-###. http://link.springer.com/article/10.1007/s11258-016-0691-9

Place, F. 2009. Land tenure and agricultural productivity in Africa: A comparative analysis of the economics literature and recent policy strategies and reforms. *World Development*, *37*(8), 1326-1336.

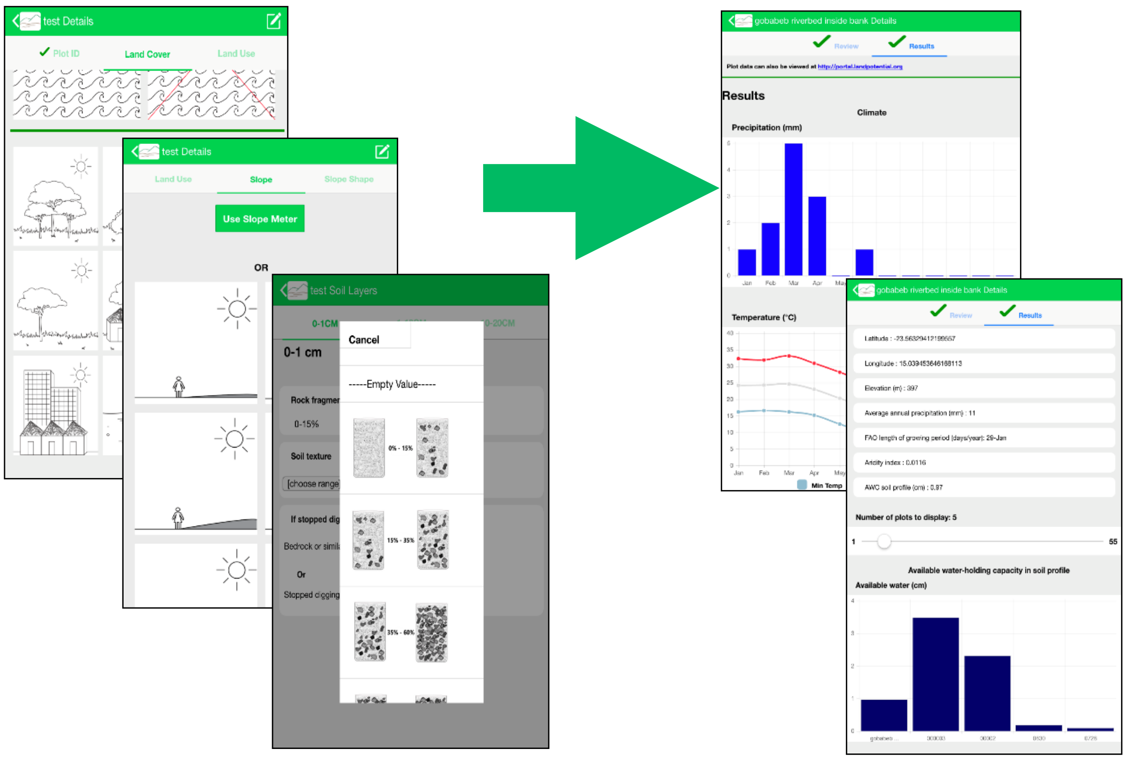

Figure 1. Sample LandInfo data input and output screens (as of February 2017).

Figure 2. Beta testing LandPKS apps with a potential user group.