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Letters

Commentary

Aligning Land Use with Land Potential: The Role of Integrated Agriculture

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Core Ideas

- Agricultural lands have varying potential based on climate, topography, and soils.
- Aligning land use and potential improves sustainable delivery of ecosystem services.
- Integrated agricultural systems (IAS) are uniquely adapted to variable land types.
- Socioeconomic barriers to IAS implementation are significant.
- Considerable research and education is needed to facilitate IAS adoption.

Abstract: Contemporary agricultural land use is dominated by an emphasis on provisioning services by applying energy-intensive inputs through relatively uniform production systems across variable landscapes. This approach to agricultural land use is not sustainable. Achieving sustainable use of agricultural land should instead focus on the application of innovative management systems that provide multiple ecosystem services on lands with varying inherent qualities. Integrated agricultural systems (IAS) represent an alternative approach to prevailing land use, whereby site-adapted enterprises are implemented to enhance synergistic resource transfer among enterprises and sustainable delivery of ecosystem services. Sustainable deployment of IAS on agricultural land involves placing the "right enterprise" at the "right intensity" at the "right time" on the "right location," with the inherent attributes of location providing guidance for management decisions. There is an urgent need to design IAS that enhance delivery of ecosystem services while ensuring land potential thresholds are not exceeded.

Integrated agricultural systems (IAS) are increasingly recognized for their contributions to improve agricultural sustainability (Russelle et al., 2007; Lemaire et al., 2014; Ryschawy et al., 2014). As defined, IAS represent a form of agriculture whereby multiple agricultural enterprises interact in space and/or time, and the interactions result in synergistic resource transfer among enterprises (Hendrickson et al., 2008a). An emphasis on multiple enterprises makes IAS well suited for future growing conditions, as broadened production portfolios can serve to enhance adaptability to increasingly variable weather and market conditions (Hanson et al., 2007; Wilkins, 2008). Moreover, emergent conservation, climate-smart, and farming-for-services paradigms underscore the potential role of IAS to create more productive, resilient, and environmentally sound agroecosystems (Robertson et al., 2014; Steenwerth et al., 2014).

Despite their supposed benefits, adoption of IAS lags behind systems favoring high levels of production with low labor and management inputs (Hendrickson et al., 2008b). This is understandable, as agricultural industrialization has evolved to favor modes of production focused on specialization, simplification, and concentration (Kirschenmann, 2007). Additionally, management of IAS requires significant acumen (Park et al., 1997). In contrast to simpler agroecosystems, IAS have more "dials" in need of continuous adjustment to achieve objectives associated with multiple enterprises (Hanson et al., 2007; Hendrickson et al., 2008a). Management complexities associated with IAS can be further compounded by resource attributes inherent to working farms and ranches. As outlined by Hendrickson et al. (2008b), sustainable application of IAS requires harmonizing agricultural enterprises to environmental limitations and opportunities, as opposed to overcoming limitations with energy-intensive inputs. This, in turn, effectively requires completing a

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Abbreviations: IAS, integrated agricultural systems.

SWOT (strengths, weaknesses, opportunities and threats) analysis for each type of land within a production system (Newton and Newton, 2013).

Inherent attributes of agricultural land are inextricably linked to climate, topography, and soils (Herrick et al., 2013). How these attributes interact is expressed through land potential, which reflects the inherent long-term potential of land to sustainably generate ecosystem services (International Resource Panel, 2016). Matching land use with land potential should be a goal of land-use sustainability, and its realization could increase yields on underperforming land and limit degradation by allocating nonprovisioning land uses to fragile lands (Syswerda and Robertson, 2014).

Adoption of IAS could facilitate improved alignment of land use with land potential because of an expanded range of management options, allowing for greater flexibility in managing for the unique opportunities and degradation risks associated with each type of land. Such a development could result in a transition toward multifunctional agricultural landscapes, improved delivery of multiple ecosystem services, and ultimately, a more sustainable agriculture. Achieving greater IAS adoption, however, requires removing barriers, including making available the required information for their effective use. Accordingly, this commentary seeks to outline the role of IAS within the context of inherent land potential, with the intent of identifying knowledge and information gaps, and new technologies and systems for addressing purported gaps.

Matching Land Potential with Agricultural Management

Developing sustainable management practices has challenged agriculturists for millennia (Montgomery, 2008). Pressures of increased agricultural production coupled with dynamic and often unpredictable growing conditions create a near-impossible context for successfully applying sustainable land management for extended periods of time. This challenge notwithstanding, efforts to effectively match agricultural management with land potential in a lasting, sustainable manner are more possible now than at any other time in human history (Foley et al., 2011). Multiple land evaluation systems, coupled with intimate knowledge of locally adapted agricultural practices, can serve to not only boost agricultural production but broaden the suite of ecosystem services offered by agricultural lands while providing economic stability for rural communities (International Resource Panel, 2016).

Sustainability of land (i.e., the capacity to generate ecosystem services over time) can be expressed through its *resistance* to degradation as well as its *resilience*, which refers to the capacity of land to recover from degradation (Seybold et al., 1999). Both resistance and resilience largely depend on intrinsic attributes associated with land that define levels of primary production, such as climate, topography, and inherent soil properties (e.g., texture, mineralogy, depth). Resistance and resilience, however, are also influenced by management, which serves to increase biomass production through alterations of easily manipulated system attributes, such as plant-available nutrients and soil structure. In this regard, management can increase land potential through the provision of inputs that limit plant growth. Doing so, however, can create outcomes whereby resistance and resilience decline as a result of management decisions that fail to consider inherent land potential. Because of this, it is critical to first define land potential for a particular piece of land and then identify multiple land uses that are deemed sustainable within its potential (International Resource Panel, 2016).

Numerous land evaluation approaches have been developed for categorizing land potential to guide management decisions and prevent degradation. Land capability classes (LCC) and agro-ecological zones (AEZ) represent two such approaches with worldwide adoption (Klingebiel and Montgomery, 1961; FAO, 1976). Both approaches focus on limitations to agronomic/productivity potential. Such focus explicitly prioritizes provisioning services over other ecosystem services derived from land, yet the approaches offer excellent foundations from which to develop a broader evaluation paradigm recognizing multifunctional aspects of agricultural land (Sanderson and Adler, 2008; International Resource Panel, 2016).

Linkages across land potential, land use, and ecosystem health are complex. Ecosystem services derived from agricultural land—although based on a foundation of inherent land potential—are very much the expression of land-use decisions derived from a labyrinth of interacting socioeconomic factors (Fig. 1). Regulations and incentives, consumer preferences, technology, land ownership/tenure, and producer goals all serve as “translation filters” between land potential and land use. Ecosystem service outcomes from land-use decisions can recalibrate the filters through feedbacks in a variety of ways (e.g., community health, economic vitality, landscape aesthetics, etc.), thereby providing a means for continual improvement of agricultural landscapes through market influences, public policy, and ultimately, producers’ decisions (Robertson et al., 2014).

Sustainable Land-Use Efficiency: Support for Integrated Agricultural Systems

Ensuring sustainable use of agricultural land requires development and application of innovative management systems that provide maximum benefit to multiple ecosystem services across variable landscapes. The concept of maximum sustainable benefit per unit area of land may be expressed through *sustainable land-use efficiency*, which has similar water and nutrient analogs common to agronomic assessments (Farahani et al., 1998; Cassman et al., 2002). The use of a land-efficiency metric underscores the value in identifying all possible production options that are sustainable within constraints of inherent land potential. Integrated agricultural systems, by virtue of their inclusion of multiple enterprises, broaden the portfolio of possible production options for a defined area of agricultural land, thereby increasing the potential for matching land use with land potential sustainably.

Application of IAS on land with varying potential represents an exercise in selecting the most appropriate agricultural enterprises in space and time. Similar to the 4R principles of nutrient stewardship (Thorup and Stewart, 1988), deploying IAS on agricultural land would involve placing the "right enterprise" at the "right intensity" at the "right time" on the "right location," with the inherent attributes of location informing management decisions associated with the other variables. Use of locally adapted frameworks for land evaluation could serve to help identify "best-suited" agricultural enterprises within land-type categories for facilitating producer innovation (Fig. 2). Doing so would not only enhance efficient use of land resources but likely expand the allocation of ecosystem services across variable land types through increased diversity of agricultural enterprises (Herrick et al., 2013).

Aligning the Arrows: Land Potential, Land Use, and Integrated Agricultural Systems

Contemporary challenges to align land potential with land use arise from unprecedented production intensification and growing recognition that declining ecosystem services affect water availability and quality, resilience to extreme events, and biodiversity protection (Robertson and Swinton, 2005; Power, 2010). Recent broadening of societal expectations from agricultural lands complements the potential role of IAS to increase the delivery of ecosystem services through multiple, site-adapted enterprises.

Evaluating the balance of ecosystem service outcomes from IAS is needed to determine the efficacy of enterprise × management scenarios to enhance agricultural sustainability, while ensuring thresholds to inherent land potential are not exceeded. This exercise would be rooted in assessment of biophysical factors common to the agronomic and environmental sciences, and inclusive of metrics encompassing agroecosystem resistance and resilience. Collectively,

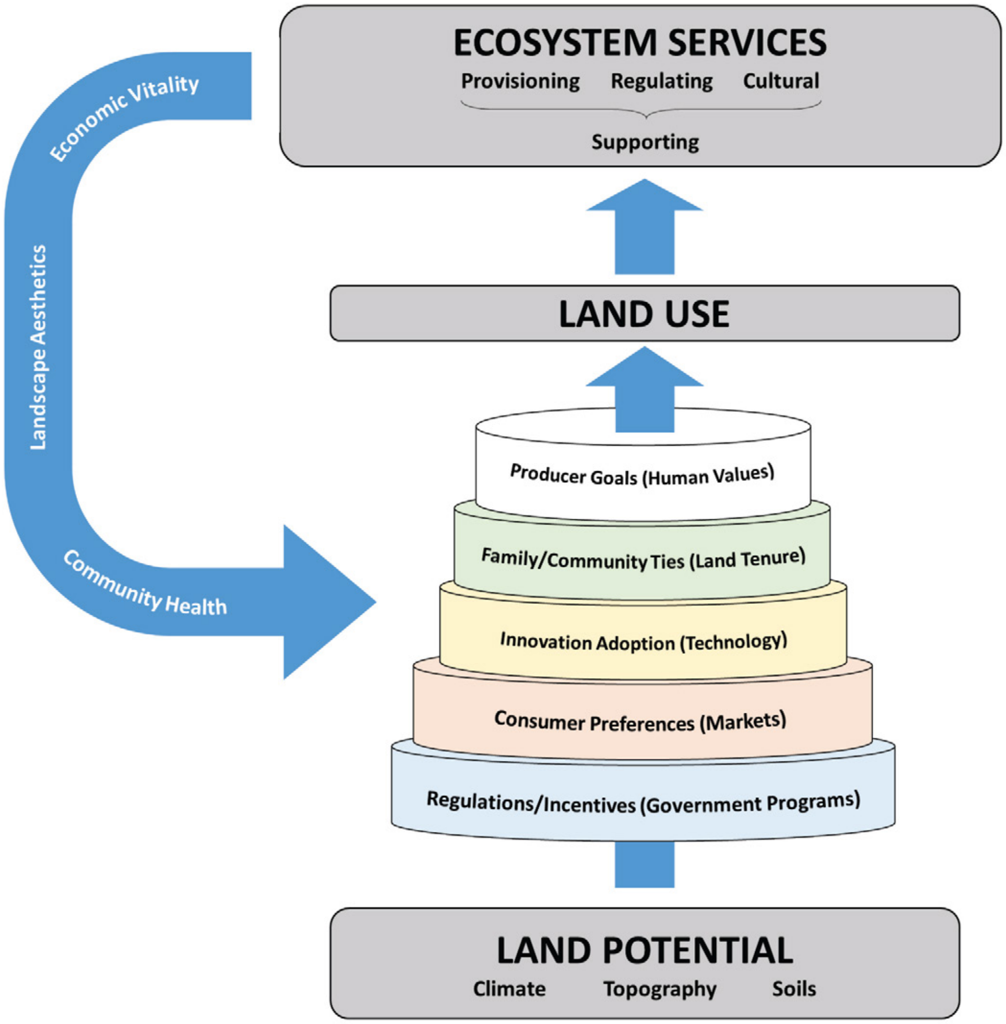

Fig. 1. Conceptual model reflecting 'translation filters' affecting the expression of land potential into land use, with concomitant ecosystem service outcomes and feedbacks.

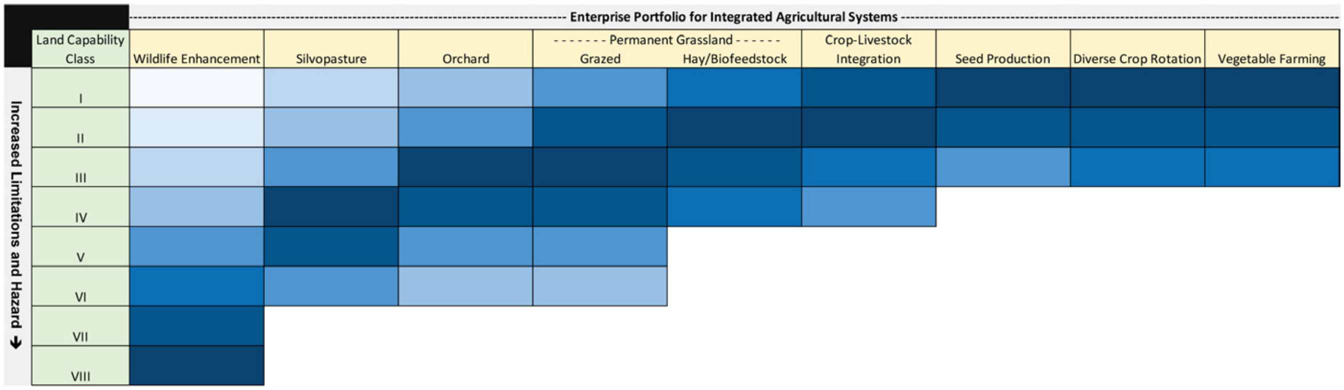

Fig. 2. USDA Land Capability Classification system matrix reflecting select enterprises within integrated agricultural systems for land with high (Class I) and low (Class VIII) potential (adapted from International Resource Panel, 2016). Shading reflects relative confidence in suitability of specific practices within a Land Capability Class (dark = high, light = low). Functionally, as Land Capability Class increases, the opportunities for sustainably deploying a complex IAS decline.

assessments would serve to identify tradeoffs and synergies among ecosystem services within and between agricultural enterprises. Identification of synergies would provide the basis for more immediate implementation, whereas tradeoffs would require further evaluation of enterprise × management scenarios until optimal outcomes are realized. By default, such research would need to be landscape scale, transdisciplinary, and long-term and (for greatest impact) include agricultural producers.

Efforts focused on assessing biophysical factors provide an important foundation for the expression of IAS through inherent land potential. Producer adoption of IAS, however, faces numerous barriers to implementation independent of land potential given their intrinsic management complexity and emphasis on delivering multiple ecosystem services. As outlined by Swinton et al. (2015), adoption of novel management practices providing ecosystem services relies on producer awareness, attitudes, available resources, and incentives. Forward-thinking investigations quantifying the value of ecosystem services from agricultural lands are central to providing adoption incentives (Robertson et al., 2014). Concurrent efforts focused on developing producer knowledge specific to IAS are also needed. Sustainable deployment of IAS depends on the producer's ability to successfully apply principles to locally specific situations (Morris and Winter, 1999). Accordingly, development of necessary management acumen may be facilitated through effective education and extension programs, coupled with decision aids, recognizing that useful guidance will accommodate the considerable fine tuning needed to make IAS sustainable on variable landscapes (Herrick et al., 2013). Finally, education efforts are needed to increase societal awareness of best use practices for lands of varying potential, as well as the role of IAS to create vibrant agricultural landscapes for the sustainable delivery of ecosystem services. Greater appreciation of agricultural landscapes, informed by a nuanced view of their inherent potential and multiple functions, can serve as a broader ideological shift that could translate to increased support for IAS.

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References

Cassman, K.G., A. Dobermann, and D.T. Walters. 2002. Agroecosystems, nitrogen-use efficiency, and nitrogen management. Ambio 31:132–140. doi:10.1579/0044-7447-31.2.132

Farahani, H.J., G.A. Peterson, and D.G. Westfall. 1998. Dryland cropping intensification: A fundamental solution to efficient use of precipitation. Adv. Agron. 64:197–223. doi:10.1016/S0065-2113(08)60505-2

Food and Agriculture Organization (FAO). 1976. A framework for land evaluation. FAO Soils Bull. 32. Food and Agriculture Organization of the United Nations, Rome.

Foley, J.A., N. Ramankutty, K.A. Brauman, E.S. Cassidy, J.S. Gerber, M. Johnston, et al. 2011. Solutions for a cultivated planet. Nature 478:337–342. doi:10.1038/nature10452

Hanson, J.D., M.A. Liebig, S.D. Merrill, D.L. Tanaka, J.M. Krupinsky, and D.E. Stott. 2007. Dynamic cropping systems: Increasing adaptability amid an uncertain future. Agron. J. 99:939–943.

Hendrickson, J.R., J.D. Hanson, D.L. Tanaka, and G. Sassenrath. 2008a. Principles of integrated agricultural systems: Introduction to processes and definition. Renew. Agric. Food Syst. 23:265–271. doi:10.1017/S1742170507001718

Hendrickson, J.R., M.A. Liebig, and G.F. Sassenrath. 2008b. Environment and integrated agricultural systems. Renew. Agric. Food Syst. 23:304–313. doi:10.1017/S1742170508002329

Herrick, J.E., K.C. Urama, J.W. Karl, J. Boos, M.V. Johnson, K.D. Shepherd, et al. 2013. The global Land-Potential Knowledge System (LandPKS): Supporting evidence-based, site-specific land use and management through cloud computing, mobile applications, and crowdsourcing. J. Soil Water Conserv. 68:5A–12A. doi:10.2489/jswc.68.1.5A

International Resource Panel, editor. 2016. Unlocking the sustainable potential of land resources: Evaluating systems, strategies and tools. A Report of the Working Group on Land and Soils of the International Resource Panel, UNEP. https://wedocs.unep.org/bitstream/handle/20.500.11822/7710/-Unlocking_the_sustainable_potential_of_land_resources_Evaluating_systems,_strategies_and_tools-2016Unlocking_Land_Resources_full_report.pdf.pdf?sequence=3&isAllowed=y (accessed 9 Mar. 2017).

Kirschenmann, F.L. 2007. Potential for a new generation of biodiversity in agroecosystems of the future. Agron. J. 99:373–376. doi:10.2134/agronj2006.0104

Klingebiel, A.A., and P.H. Montgomery. 1961. Land-capability classification. USDA Soil Conservation Service. Agric. Handb. 210. U.S. Government Print Office, Washington, DC.

Lemaire, G., A. Franzluebbers, P.C. de Faccio Carvalho, and B. Dedieu. 2014. Integrated crop-livestock systems: Strategies to achieve synergy between agricultural production and environmental quality. Agric. Ecosyst. Environ. 190:4–8. doi:10.1016/j.agee.2013.08.009

Montgomery, D.R. 2008. Dirt: The erosion of civilizations. Univ. of California Press. Berkeley.

Morris, C., and M. Winter. 1999. Integrated farming systems: The third way for European agriculture? Land Use Policy 16:193–205. doi:10.1016/S0264-8377(99)00020-4

Newton, P., and H. Newton. 2013. SWOT analysis strategy skills. 1st ed. Free Management Ebooks, Warwickshire, UK. http://www.free-management-ebooks.com/dldebk-pdf/fme-swot-analysis.pdf (accessed 9 Mar. 2017).

Park, J., D.P. Farmer, A.P. Bailey, J.D.H. Keatinge, T. Rehman, and R.B. Tranter. 1997. Integrated arable farming systems and their potential uptake in the UK. J. Farm Manage. 9(10):483–494.

Power, A.G. 2010. Ecosystem services and agriculture: Tradeoffs and synergies. Philos. Trans. R. Soc. B 365:2959–2971. doi:10.1098/rstb.2010.0143

Robertson, G.P., K.L. Gross, S.K. Hamilton, D.A. Landis, T.M. Schmidt, S.S. Snapp, and S.M. Swinton. 2014. Farming for services: An ecological approach to production agriculture. Bioscience 64:404–415. doi:10.1093/biosci/biu037

Robertson, G.P., and S.M. Swinton. 2005. Reconciling agricultural productivity and environmental integrity: A grand challenge for agriculture. Front. Ecol. Environ 3:38–46. doi:10.1890/1540-9295(2005)003[0038:RAPAEI]2.0.CO;2

Russelle, M.P., M.H. Entz, and A.J. Franzluebbers. 2007. Reconsidering integrated crop-livestock systems in North America. Agron. J. 99:325–334. doi:10.2134/agronj2006.0139

Ryschawy, J., J.-P. Choisis, A. Joannon, A. Gibon, and P.-Y. Le Gal. 2014. Participative assessment of innovative technical scenarios for enhancing sustainability of French mixed crop-livestock farms. Agric. Syst. 129:1–8. doi:10.1016/j.agsy.2014.05.004

Sanderson, M.A., and P.R. Adler. 2008. Perennial forages as second generation bioenergy crops. Int. J. Mol. Sci. 9(5):768–788. doi:10.3390/ijms9050768

Seybold, C.A., J.E. Herrick, and J.J. Brejda. 1999. Soil resilience: A fundamental component of soil quality. Soil Sci. 164:224–234. doi:10.1097/00010694-199904000-00002

Steenwerth, K.L., A.K. Hodson, A.J. Bloom, M.R. Carter, A. Cattaneo, C.J. Chartres, et al. 2014. Climate-smart agriculture global research agenda: Scientific basis for action. Agric. Food Secur. 3(11):1–39.

Syswerda, S.P., and G.P. Robertson. 2014. Ecosystem services along a management intensity gradient in Michigan (USA) cropping systems. Agric. Ecosyst. Environ. 189:28–35. doi:10.1016/j.agee.2014.03.006

Swinton, S.M., N. Rector, G.P. Robertson, C.B. Jolejole-Foreman, and F. Lupi. 2015. Farmer decisions about adopting environmentally beneficial practices. In: S.K. Hamilton, J.E. Doll, and G.P. Robertson, editors, The ecology of agricultural ecosystems: Long-term research on the path to sustainability. Oxford Univ. Press, New York. p. 340–359.

Thorup, J.T., and J.W.B. Stewart. 1988. Optimum fertilizer use with differing management practices and changing government policies In: A.D. Halvorson and G.W. Randall, editors, Proceedings of the 25th Anniversary Symposium of Division S-8: Advances in Fertilizer Technology and Use, Anaheim, CA. 28 Nov. 1988. Published for SSSA by the Potash & Phosphate Institute, Atlanta, GA.

Wilkins, R.J. 2008. Eco-efficient approaches to land management: A case for increased integration of crop and animal production systems. Philos. Trans. R. Soc. B 363:517–525. doi:10.1098/rstb.2007.2167