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LAND HEALTH AND ECOLOGICAL SITES: APPLICATION TO LAND USE PLANNING AND MANAGEMENT

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SUMMARY

Land health is a powerful tool for land use planning and management of croplands, forests, and rangelands. It is difficult, expensive and often impossible to assess and monitor the status of land relative to its potential to support each of these ecosystem services. However, there are three attributes of the land that reflect its capacity to support all of these services. These attributes include: Soil and Site Stability, Hydrologic Function, and Biotic Integrity. Applying the land health concept to land use planning begins with defining the land's potential using a land classification system (Step 1), assessing the land (Step 2), developing the plan (Step 3), developing early warning systems (Step 4), and adapting land use, often at different temporal scales (Step 5). Land use planning and management based on land health and ecological sites can improve the usefulness of land use planning. This approach requires farmers and technical specialists to work together to determine the land's potential and its current status relative to potential.

Key words: Monitoring, assessment, management, land use.

INTRODUCTION

The concepts of land health and protocols to support assessments can be powerful tools for land use planning and management of croplands, forests, and rangelands. In croplands, they are often associated with 'soil quality', while in forests, the term 'forest health' is commonly used. This paper focuses on 'rangeland health', including both pastures and rangelands, and how the concept can also be applied to croplands and, by extension, forests and agroforestry systems. Because many lands, especially in southern Mexico, are used at different times for pasture, crop production and forest, we have included references to all of them.

Rangelands include native pastures, grasslands, shrublands and savanna ecosystems. These ecosystems are managed to support a wide variety of objectives, including food and livestock production, watershed protection, wildlife habitat conservation, carbon sequestration and, increasingly, for ecotourism. Management objectives can change quickly, and many areas are now required to support multiple management objectives or ecosystem services. Managing for multiple ecosystem services can increase income for farmers and ranchers. For example, producers who sustainably manage their land for livestock production can potentially also receive payments for protecting the water supply of downstream municipalities, and for sequestering carbon in the soil. In some areas, UMAs (Unidades de Manejo para la Conservación de la Vida Silvestre) may be established to provide additional income from wildlife (Sisk et al., 2007)

It is difficult, expensive and often impossible to assess and monitor the status of land health relative to its potential to support each of these ecosystem services. However, there are three attributes of the land that reflect its capacity to support all of these services. These attributes are: Soil and Site Stability, Hydrologic Function, and Biotic Integrity (Figure 1). These three attributes can be thought of more simply as the three components necessary to support plant production: soil, water and a healthy plant community. Healthy lands conserve soil and water and support healthy, productive plant communities.

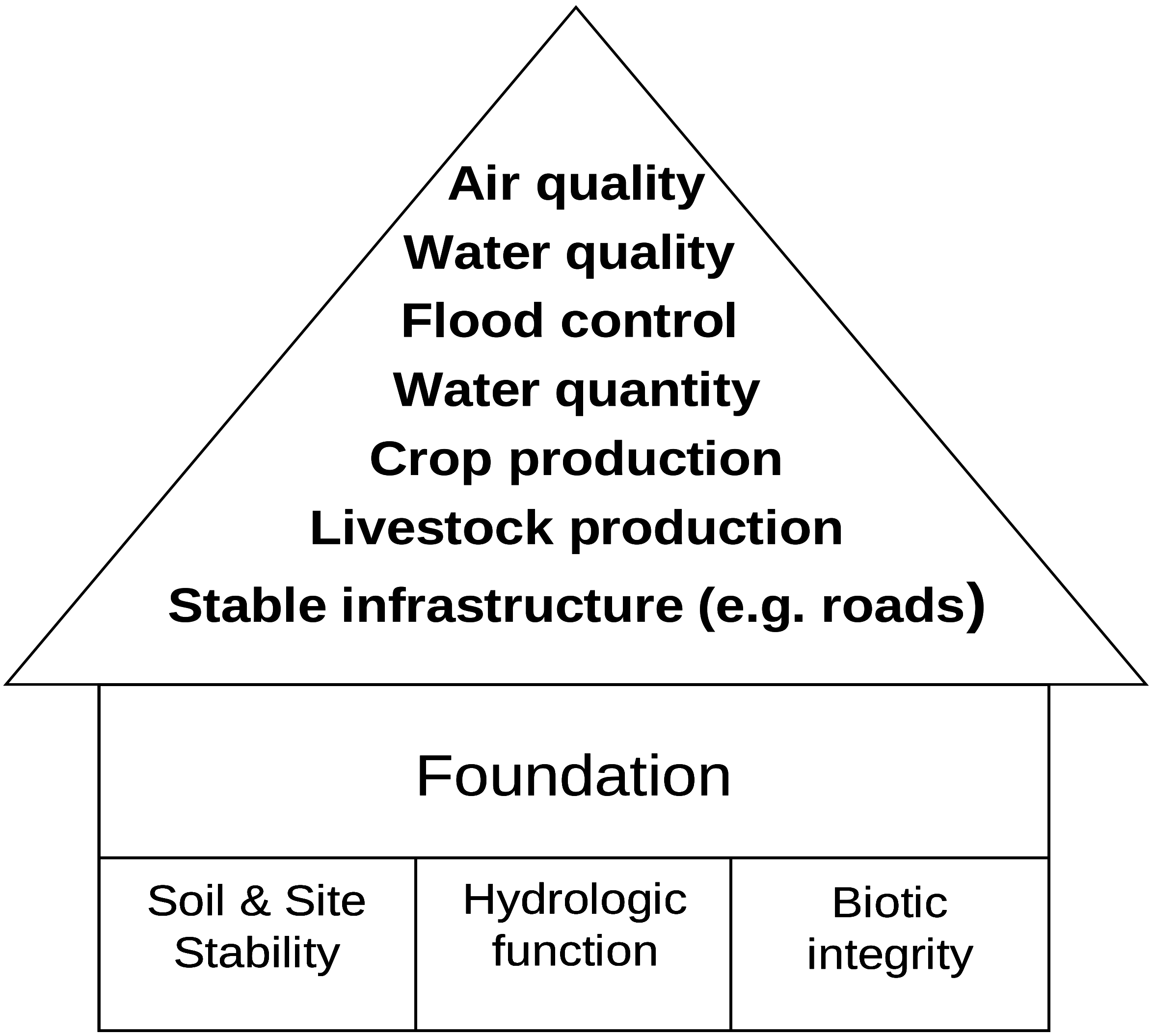


Figure 1. Three attributes of ecosystem health on which all ecosystem services depend (adapted from Herrick et al., 2006).

The Soil and Site Stability attribute reflects the extent to which soil is conserved. Since plants need soil to grow and hold water, this is the most basic of the three attributes. Without soil, there is no life (Hillel, 1991). In addition to soil conservation, the attribute is related to the condition of the soil: its structure and fertility.

The Hydrologic Function attribute can be best thought of as integrating all of the factors that make watersheds healthy. Healthy watersheds have high rates of infiltration and storage capacity, allowing them to support plant production during long droughts and to release water slowly through springs and seepage to maintain perennial stream flow.

The Biotic Integrity attribute reflects the health of the plant community. While the plant community health obviously depends on the first two attributes, healthy soil and abundant water alone are insufficient to guarantee Biotic Integrity. For this reason, Biotic Integrity is included as a separate attribute. In most ecosystems, healthy plant communities are more diverse and productive than unhealthy communities. These healthy plant communities support health soil biota, which rapidly decompose dead roots and plant litter, converting them back to nutrients the plants can use and creating the 'glue' that holds the soil together, keeping it from eroding and forming a crust that the water cannot penetrate.

The objectives of this manuscript are to (1) describe how the land health concept (and specifically rangeland health) can be used to develop and implement land use plans that can be adapted to support continuously changing priorities and (2) define how this approach can be used to adapt to rapid seasonal changes in drought and markets. This approach includes six steps. Each of these steps can be broken down into a large number of components or sub-steps. This paper simply provides an overview of the steps and how the land health concept is applied.

LAND AND USE PLANNING: THE BASICS

Sustainable development is defined as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs."* (Brundtland and Khalid, 1987). Sustainable developed depends on land use planning to ensure that the land maintains its ability to support future generations with abundant food, clean water, energy, and raw materials for clothing, construction and other human needs. Land use planning begins with an understanding of how the land varies in its ability to support plant production and its resistance to degradation. This depends primarily on soils, topography and climate. In general, deep, highly fertile soils with abundant rainfall are less likely to degrade. If land is flat, it is more resistant to degradation from water erosion. If the soil is clay textured, it is also usually more resistant to wind erosion than silty or fine sandy soils.

One of the most widely applied systems for land use planning in non-urban areas is the "Land Capability Classification System" (Table 1; Klingebiel and Montgomery, 1961). It has been translated into many languages, including Spanish (Sarh, 1982) and applied throughout the world. A similar system was developed by the Food and Agriculture Organization (FAO, 1976). Both of these systems were developed with the assumption that the most important ecosystem service that land can provide is agricultural production. Today, we recognize the importance of managing land for many different ecosystem services (Millennium Ecosystem Assessment, 2005). However, because both systems are designed to help land use planners avoid land degradation, they are helpful in ensuring that the capacity of the land to support multiple ecosystem services will be sustained long into the future.

Table 1. Land capability classification system (Klingebiel and Montgomery, 1961; Sarh, 1982).

Classes and Subclasses	Definition
Class I	soils have slight limitations that restrict their use
Class II	soils have moderate limitations that reduce the choice of plants or require moderate conservation practices

Class III	soils have severe limitations that reduce the choice of plants or require special conservation practices, or both
Class IV	soils have very severe limitations that restrict the choice of plants or require very careful management, or both
Class V	soils have little or no hazard of erosion but have other limitations, impractical to remove, that limit their use mainly to pasture, range, forestland, or wildlife food and cover
Class VI	soils have severe limitations that make them generally unsuited to cultivation and that limit their use mainly to pasture, range, forestland, or wildlife food and cover
Class VII	soils have very severe limitations that make them unsuited to cultivation and that restrict their use mainly to grazing, forestland, or wildlife
Class VIII	soils and miscellaneous areas have limitations that preclude their use for commercial plant production and limit their use to recreation, wildlife, or water supply or for esthetic purposes
Subclass e	made up of soils for which the susceptibility to erosion is the dominant problem or hazard affecting their use. Erosion susceptibility and past erosion damage are the major soil factors that affect soils in this subclass
Subclass w	made up of soils for which excess water is the dominant hazard or limitation affecting their use. Poor soil drainage, wetness, a high water table, and overflow are the factors that affect soils in this subclass**.**
Subclass s	made up of soils that have soil limitations within the rooting zone, such as shallowness of the rooting zone, stones, low moisture-holding capacity, low fertility that is difficult to correct, and salinity or sodium content
Subclass c	made up of soils for which the climate (the temperature or lack of moisture) is the major hazard or limitation affecting their use

Two important limitations of both systems are that (a) they do not account for many sources of degradation, and (b) they do not account for local sources of variability that can have significant effects on resistance to degradation. Both systems focus primarily on soil erosion as a cause of degradation. While soil erosion is clearly one of the most important causes of degradation, there are others that can be locally important under certain conditions. For example, soil compaction, and especially subsoil compaction, can reduce productivity for long periods of time. Soil compaction is often encountered on Class I soils (Table 1) where risk of soil erosion is very low because they are flat (limiting water erosion) and fine-textured (clay, which limits wind erosion).

Local sources of soil variability are important for land management. On Class I flat land with fine-textured soils, there are often very small changes in topography. Water accumulates in the lower areas. Where drought limits production, these areas are often more productive and therefore may benefit from higher fertilizer inputs. Where there is too much water, soils in these areas can become anaerobic, limiting plant growth. Because they are wet longer, they are also more likely to become compacted. Soil compaction further reduces water infiltration rates, increasing the amount of time that these low areas remain inundated hence further reducing production.

Land use planning based on knowledge of this type of variability can be used to increase production and sustainability. In croplands, these areas might be planted with a different type of crop which is more tolerant of anaerobic soil conditions and flooding. The farmer might also make greater efforts to avoid tillage of these areas when wet. The same areas in pasture might be reserved as a forage bank for use during drought because they are likely to stay green and productive longer. In addition to ensuring that the livestock have a source of feed during drought, keeping them off the land during wet periods increases productivity. The knowledge may also be used to decide where to put pasture as opposed to cropped fields.

Applying the land health concept to land use planning begins with defining the land's potential using a land classification system (Step 1), assessing the land (Step 2), developing the plan (Step 3), developing early warning systems (Step 4), and adapting land use, often at different temporal scales (Step 5) (Figure 2).

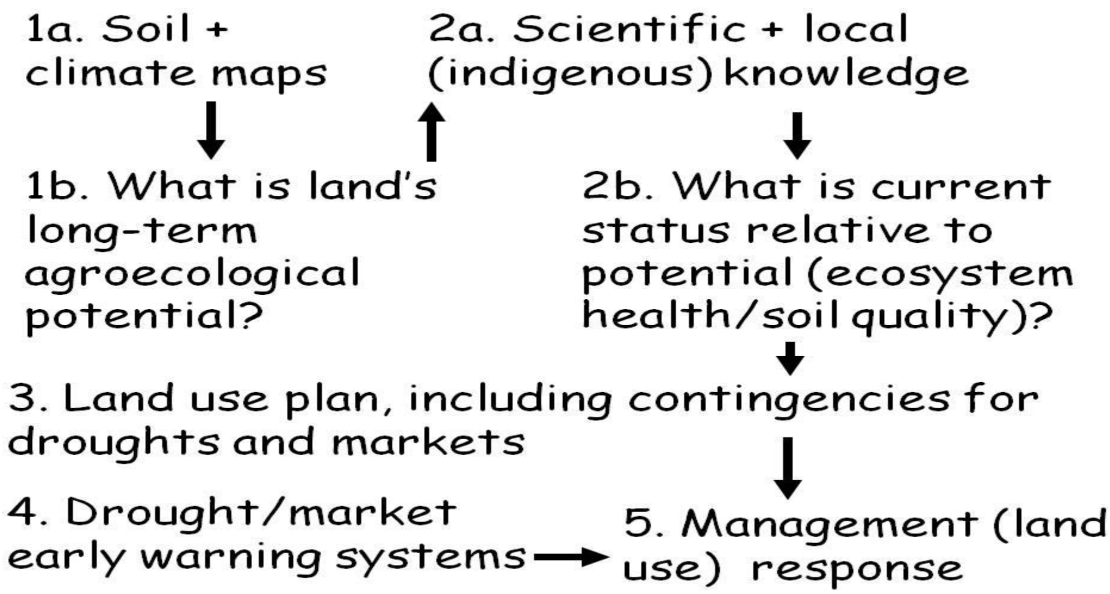


Figure 2. Application of land health to land use planning.

STEP 1: DEFINE LONG-TERM AGROECOLOGICAL POTENTIAL OF THE LAND

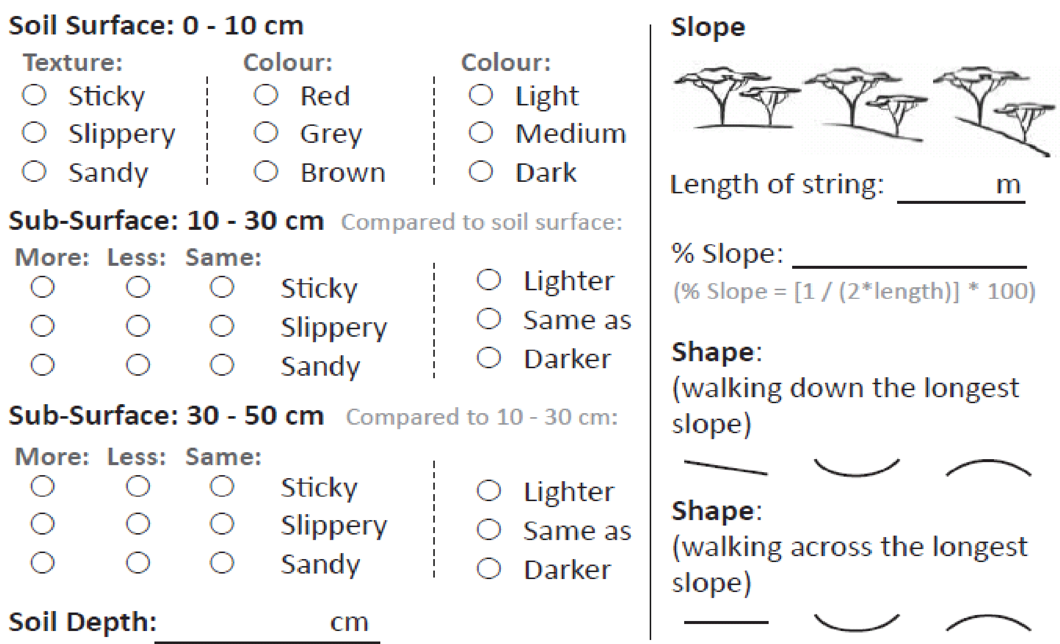
The 'Ecological Site' approach (Bestelmeyer et al., 2009) provides an opportunity to address the limitations of, and build on, existing land capability classification systems. It was originally developed for rangelands, but is now being extended to croplands in the United States. Its value for land use planning and management may be even greater for croplands than it is for rangelands, particularly for areas where there is a high risk of degradation. The ecological site system is also the basis for 'state and transition' models. These models are developed for each ecological site. They describe what happens to the land when it is managed in different ways. Other factors (e.g. extreme weather events and pest outbreaks) can also be included in the box-and-arrow diagrams to help communicate current understanding of how the land responds to management and other disturbances.

In areas where agriculture is the dominant land use, the concept may be more usefully communicated using the term 'agroecological sites'. This provides recognition of the importance of agricultural production, while continuing to emphasize the use-independent framework of the ecological site approach.

The most important requirement of this system is that land is classified by using relatively static properties of topography, soil and climate. Relatively static properties differ from dynamic properties in that dynamic properties change in response to management on a management time scale (years to decades). Static properties are the properties that ultimately limit plant production for non- irrigated systems. Some of these properties also limit the types and amounts of production that are possible with irrigation. In contrast, dynamic properties can generally be modified by management inputs. These include plant nutrient availability, soil organic matter and the rate that water infiltrates the soil. The range of variability of each of these properties is determined by the relatively static properties of the land, especially soil texture.

Two relatively static properties that are commonly used to characterize topography include slope and slope shape. Aspect and slope position are also very important in landscapes dominated by mountains and valleys. For soils, texture is key. Surface texture controls how quickly water can soak into the soil, with faster infiltration in sandy soils and slower infiltration in soils with more clay. The subsurface texture is also important because it controls how much water the soil can store in the plant rooting zone. In general, intermediate textures (loams) have the potential to store the most water. The dynamic properties, soil organic matter and soil structure, determine whether or not infiltration and water holding capacity are at potential.

When developing a land use plan, it is important to at least include basic information on soils and topography. While a soil map and complex soil information can be helpful, it is even more important for the farmer to recognize key soil properties and be able to map their distribution on their own farm. Figure 3 shows part of a form that was developed for grazing systems (Riginos and Herrick, 2010). It allows key topographic and soil properties to be recorded even by people who have no knowledge of soils. Figure 4 shows a simple example of how a photograph can be used to divide the land into areas of higher and lower potential.


Soil Surface: 0 - 10 cm

Texture: ○ Sticky ○ Slippery ○ Sandy
Colour: ○ Red ○ Grey ○ Brown
Colour: ○ Light ○ Medium ○ Dark

Sub-Surface: 10 - 30 cm Compared to soil surface:

More:	Less:	Same:		
○	○	○	Sticky	○ Lighter
○	○	○	Slippery	○ Same as
○	○	○	Sandy	○ Darker

Sub-Surface: 30 - 50 cm Compared to 10 - 30 cm:

More:	Less:	Same:		
○	○	○	Sticky	○ Lighter
○	○	○	Slippery	○ Same as
○	○	○	Sandy	○ Darker

Soil Depth: ________ cm

Slope

Length of string: ______ m

% Slope: ____________
(% Slope = [1 / (2*length)] * 100)

Shape:
(walking down the longest slope)

Shape:
(walking across the longest slope)

Figure 3. **Example of a simple way to record basic soil and topographic information. All of the properties except color are relatively static properties. Color depends on both relatively static properties (soil mineralogy) but the darkness is a good indicator of soil organic matter content, which is a dynamic property. (Extracted from the 'Basic Site Information' form – Riginos and Herrick (2010), page 53).**

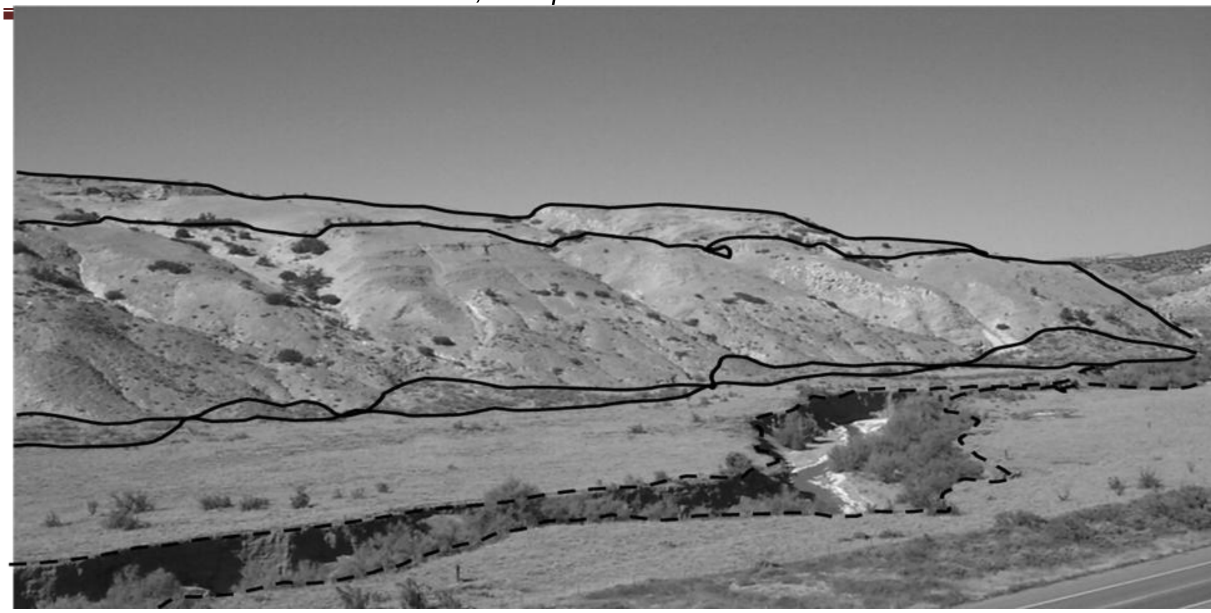


Figure 4. Stratification of the land into areas with higher and lower potential is the first step in land use planning based on land health and ecological sites.

Finally, climate is key. The total amount of rainfall is clearly important, but so is the distribution, especially timing, consistency, and intensity. As climate changes, all of these characteristics of climate may also change. However, it is important avoid blaming all droughts on climate change. Drought is a normal part of nearly all agroecosystems, and land use planning must take it into account, regardless of climate change.
After the land has been classified into types with similar potential, the potential needs to be defined for each type. The land health concept is helpful because it is independent of the particular current land use. Potential is described for each of the three attributes identified in the introduction: Soil and Site Stability, Hydrologic Function and Biotic Integrity. This can be facilitated through the development of 'reference sheets' that describe the potential for indicators of each attribute. This approach is used in the "Interpreting Indicators of Rangeland Health" assessment protocol that is used in the United States and other parts of the world, including parts of northern Mexico (Pellant et al., 2005).

STEP 2: DEFINE CURRENT STATUS RELATIVE TO POTENTIA

Completing an assessment of current status relative to potential is the next step in the process. The most common way to do this is using indicators. The indicators are evaluated relative to their value or status when the land is at potential. For example, an indicator of hydrologic function is water flow patterns. Water flow patterns should be minimal on an agroecological site in southern Mexico on coarse-textured (sandy) soils with a slope of less than 5%. If water flow patterns are observed, it is an indicator of excessive runoff and degraded hydrologic function. This is the approach used in Pellant et al. (2005).
Another approach that is even more useful in many cases is defining 'states' where the reference state is at potential, and land in the other states has crossed a degradation threshold (Bestelmeyer et al. 2009). Land with multiple potential states means that moving among states is not a simple management problem and will likely require substantial and committed effort. Thus, an index (how similar one state is to another expressed as a single number) can be misleading and is a poor tool for rating and communicating land health. One example of this is

an area where the soil surface horizon has become so degraded that there is very little soil structure and organic matter remaining, limiting both nutrient availability and water infiltration. The photograph in Figure 5 shows a pattern of more and less degraded states in a cultivated field in Oaxaca. If the field becomes too degraded, it may no longer support crop production.

Figure 5. **Patterns of soil degradation (dark and light areas in the center field), possibly reflecting different degradation states in Oaxaca, Mexico.**

STEP 3: DEVELOP LAND USE PLAN, INCLUDING CONTINGENCIES FOR MARKETS AND DROUGHTS

The third step is to develop the land use plan. Traditionally, agricultural land use plans have focused on maximizing sustained production in different parts of the landscape. The land health approach to land use planning is unique in three ways. First, is that it is based on an integrated analysis of both *current and potential* productivity of the land. The second is a strong emphasis on risk management and adaptive response by making the land use plan dynamic. This is particularly important in an era of climate change. Climate change effects are likely to be greater where the land is more degraded (e.g. more intensive flooding due to already increased runoff from degraded land or more extreme droughts due to loss of water holding capacity), and that land use plans must be adapted to account for land degradation that has already occurred: managing land as if it is still at potential is a recipe for disaster. The third is that because it emphasizes health, independent of use, it can be more flexibly applied as new production systems (e.g. for alternative crops and biofuels) are proposed.

The land use plan should include contingencies for droughts and changes in markets at two time scales. The first is inter-annual, or before planting. If early warnings of drought or market dynamics are anticipated, it is often possible to hedge risks through re-allocation of land. This is particularly important where there are areas of more marginal land on the farm that may produce during high rainfall years, but where a drought can lead to crop failure, increased soil erosion, and even lower yield in subsequent years due to soil degradation.

STEP 4: DEVELOP OR ACCESS MARKET AND DROUGHT EARLY WARNING SYSTEMS

Market and drought early warning systems are increasingly available via cell phones. A key element of successful land use planning is the need to access and include information on larger factors that occur offsite, but greatly affect local decisions (markets, policies, regional drought; see Brown and Havstad 2004). Market and drought early warning systems are increasingly available via cell phones and other mass communication outlets. While we acknowledge the importance of these factors in good decision making, it is beyond the scope of this paper to discuss them in detail.

STEP 5: ADAPT LAND USE

Adapting land use to address long-term land health objectives is the most challenging and important step. In some cases, local production systems may be determined to be no longer sustainable. Even systems that seemed to be sustainable in the past may no longer be able to stabilize the soil where significant degradation has occurred, or where storms have become more intense. In these cases, it may be necessary to search outside the region for solutions.

CONCLUSIONS

Land use planning and management based on land health and ecological sites can improve the usefulness of land use planning. This approach requires farmers and technical specialists to work together to determine the land's potential and its current status relative to potential.

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