## DEFINITIONS AND OBJECTIVES FOR SOIL QUALITY

Concerns about soil quality stem from three major issues in agriculture:

1) Are the land resources required for continued agricultural productivity being maintained?
2) Are agricultural lands harming the environment (water quality, air quality, biodiversity)?
3) Are agricultural products safe and nutritious?

Soil properties have a role in all of these goals (Table 1). For example, soil nutrient levels affect crop yield, nutrient leaching and crop composition. The multiple roles of soil have resulted in several broad definitions of soil quality. Acton and Gregorich (1995) defined soil quality as "the soil's fitness to support crop growth without resulting in soil degradation or otherwise harming the environment". Larson and Pierce (1994) stated that "soil quality describes how effectively soils: 1) accept, hold, and release nutrients and other chemical constituents; 2) accept, hold, and release water to plants, streams and groundwater; 3) promote and sustain root growth; 4) maintain suitable biotic habitat; and 5) respond to management and resist degradation". Karlen et al. (1997) defined soil quality as "the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation."

**Table 1.** Categorization of general goals for agroecosystems.

| **Goal type** | **General goal** | **Key controlling variables** |
|---|---|---|
| Economic viability | High productivity | Genetic potential, weather, soil, management, economics |
| | Low cost of production | Yield potential*, input requirements*, input costs |
| | Low production risk | Market variation, production variation* |
| Stewardship | Preservation of productive land | Soil, climate, management |
| | Healthy animals | Feed quantity and quality*, disease |
| | High quality food and fiber | Chemical or microbial contamination*, composition* |
| Social | Viable local communities | Population size, economic viability, economic diversification |
| | Viable industry, institutions, and infrastructure | Profitability, size and resilience of industry |
| Environment | Clean water | Climate, soil, management |
| | Clean air | Climate, soil, management |
| | Wildlife habitat | Climate, soil, management |

*Variables also influenced by soil properties.

More detail is required for the development of useful goals for soil quality. To be useful, goals must be clear and attainable.

A clear goal has measurable criteria that can be used to judge whether the goal has been achieved or not, whereas an unclear goal lacks measurable criteria. In most cases, clear goals also require explicit statements of conditions or constraints required for the achievement of the goal. For example, a goal related to the fitness of a soil to support crop growth needs to control for the effects of crop type, management practice and climate, and may be constrained by self-imposed or mandated limits to environmental impact. Finally, a clear goal does not contain conflicting criteria. Conflicting criteria are often formulated because more than one goal is important, but the variables controlling the achievement of multiple goals are negatively correlated (Dörner 1996). Labelling conflicting goals with a single conceptual label makes them easier to discuss, but does not resolve the conflict. Instead, options to resolve conflicting goals include compromising between goals, focusing on just one goal, or redesigning the system to eliminate the negative correlation.

Attainable goals do not mean easily achieved goals, but do imply the formulation of goals that are possible to attain. For example, a goal to increase soil water holding capacity within one year is not attainable for agricultural fields because soil properties can only be changed gradually over a period of many years. Many soil properties are not suitable as the subject of short-term goals; instead, they function as constraints or controlling variables.

For many practitioners using the soil quality concept, the goal for soil quality is simply to maintain or enhance it. Detailed goals with clear criteria and conditions are not formulated. One reason for this is that soil quality is not currently measurable, making it impossible to formulate a clear goal such as “soil quality in 2050 will be equal to or better than soil quality in 2000.”

By definition, soil quality can only be evaluated on assessing the outcomes of soil functions, i.e., by comparing ‘what the soil does’ to ‘what the soil is asked to do’ (Carter et al. 1997). Desired outcomes depend not only on inherent soil properties, but also on extrinsic factors such as landscape and climate (see below). Thus, land quality may be a better term than soil quality because it reflects the integration of soil, water, climate, landscape and vegetation attributes at scales important to agro-ecosystem goals (Carter et al. 1997). Soil quality might be considered one component of land quality, but soil quality cannot be defined or determined without accounting for land attributes.

The desired outcomes of soil/land functions include at least the following: crop production, clean water, clean air, low greenhouse gas emissions, safe and nutritious food, and preservation of wildlife habitat.

## Crop Productivity Goals

A useful framework for formulation of crop productivity goals is provided by Cook and Veseth (1991). They present "four A's" for wheat productivity that are applicable for all crops: absolute, attainable, affordable and actual yields (Figure 1). The *absolute yield* is the yield possible with no limiting factors except the genetic potential of the crop. This would be equivalent to at least the maximum yields ever recorded. The *attainable yield* is the highest yield possible in any given soil in any given year, i.e., yield is limited by factors that cannot be altered within the given year. These include factors such as water availability, growing-degree days, depth of topsoil, and total radiation. The *affordable yield* is limited by factors that cannot be ameliorated because management solutions are not affordable to the crop producer (value of potential yield gain is less than its cost) or to the larger society (ecological costs are too high). The *actual yield* is the yield harvested in any given field and is limited by factors that were not ameliorated because they were unforeseen or effective solutions were not known or not implemented.

Goals for the soil function of crop productivity could be formulated at the level of attainable or affordable yields. For example, a possible goal might be as follows:

> "Maximum affordable crop yield, as estimated for all of Alberta using x model or statistical method, will be equal or greater in 2100 to that estimated for 2000, assuming crops, management and climate are unchanged."

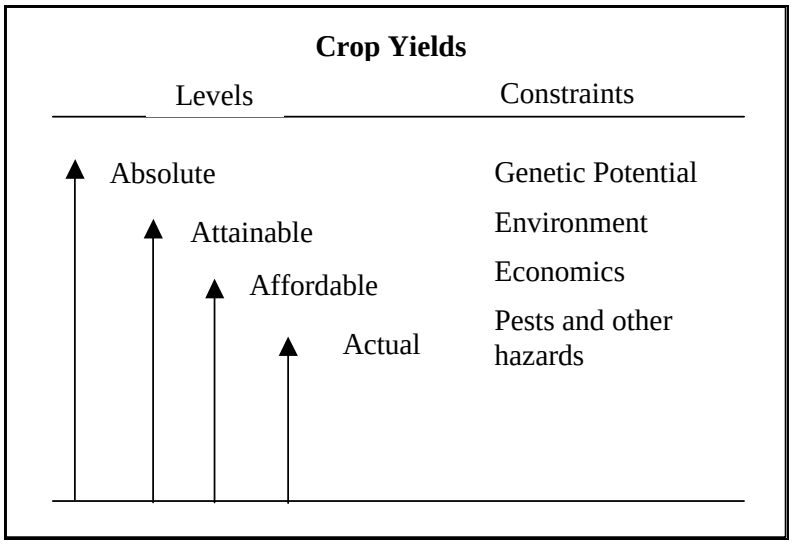


**Figure 1.** The four A's of crop productivity (modified from Cook and Veseth 1991)

This goal contains criteria and conditions that certainly can be debated and improved upon, in contrast to an unclear goal. Debate and improvement are the first steps in the formulation of useful goals.

## Water Quality Goals

Water quality is a measure of the fitness of water for desired uses, such as drinking water or the health of aquatic ecosystems. The main contaminants reducing water quality in runoff and drainage from agricultural lands are nutrients, suspended solids, fecal coliform bacteria, and pesticides. Contaminant levels in water leaving agricultural soils depend on the ability of the soil to modify water flow and to either retain contaminants or support their removal by the crop. These functions of soil depend on soil properties, soil position in the landscape, land management, weather, and interactions among these factors.

A goal for soil functions related to water quality might be formulated similarly to crop productivity:

> "Quality of water in runoff and drainage from Alberta's croplands will meet x water quality standard in 2050, based on y model or statistical method."

## Air Quality Goals

Air quality is primarily a measure of the purity of air. The main issues in air quality from agricultural lands are particulates and pesticides. Contaminant levels in air leaving agricultural soils depend on the ability of soil to retain soil particles and associated constituents. This function of soil depends on soil characteristics, soil position in the landscape, land management, weather, and interactions among these factors.

Air quality is not widely monitored, but wind erosion is a significant contributor to soil degradation in Alberta and elsewhere, and various models are available and have been tested in Alberta. A goal for soil functions related to air quality might be formulated as follows:

> "Wind erosion from Alberta's croplands will be equal or less in 2050 to that estimated for 2000, based on x model or statistical method."

## Greenhouse Gas Emission Goals

Canada's goal (Kyoto Protocol) is to reduce its average annual emissions of greenhouse gases (GHG) (nitrous oxide, methane and carbon dioxide) for the 2008-2012 period to a level 6% below its greenhouse gas emissions in 1990. Soil is a source and a sink of all of these gases. A goal for soil functions related to GHG emissions might be formulated as follows:

> "Net GHG emissions from Alberta's croplands in the 2008-2012 period will be 6% below that in 1990, based on the Intergovernmental Panel on Climate Change methodology."

## Natural Habitat/Biodiversity Goals

Loss of habitat is among the leading causes of decline in the number and diversity of natural organisms. In general, habitat quality is inversely related to the intensity of land management. For example, cropland generally provides better habitat than developed land, but poorer habitat than native pastures. A goal for soil functions related to habitat might be formulated as follows:

> "No net conversion of land under natural vegetation to more intense agricultural uses in x period in Alberta, based on y methodology."

## Food Quality Goals

There are two sides to food quality. One side is avoidance of harmful constituents in food, such as heavy metals or pathogenic microorganisms (Abrahams 2002). The other side is the achievement of constituents that promote human and animal health, such as desirable levels of micronutrients, protein and energy. Many factors affect food quality. Soil has an impact on food quality through its effects on the availability or mobility of undesirable constituents and through its effects on crop growth. A goal for soil functions related to food quality might be formulated as follows:

> "Composition of food grown on Alberta's agricultural land will meet x food standard, based on y monitoring methodology (e.g., sampling scheme of worst-case scenarios)."