The land quality concept as a means to improve communications about soils

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Summary

Soil expertise is not communicated effectively enough to the public at large, nor to planners and politicians. Use of the land quality (LQ) concept and emphasis on soil behavior as a function of management are expected to be helpful in improving communications. Existing definitions of "soil quality" and "sustainable land management" are analyzed to derive a procedure for defining LQ indicators of sustainable land management. Land- rather than soil qualities are considered to reflect the impact of the climate and the landscape on soil behavior. Land quality is different for different types of land use and attention is arbitrarily confined here to agriculture. Simulation modeling of crop growth and solute fluxes is used to define land quality (LQ) as the ratio between yield and potential (or water-limited) yield (x 100), which defines a "yield gap LQ". For soils with nutrient mining, a nutrient-depletion LQ is defined. The actual agro-ecological condition and its potential, both expressed by LQ 's for a given piece of land, is considered here as independent input into broader land-use discussions which tend to be dominated by socio-economic and political considerations. Agro-ecological considerations should not be held hostage to actual socio-economic and political considerations, which may change in the near future while LQ's have a much more permanent character. The proposed yield-gap LQ reflects yields and risks of production as simulations are made for many years, and soil and water quality associated with the production process is taken into account. Yields and pollution risks are expressed for Dutch conditions in terms of the probability that groundwater is polluted with nitrates. The proposed procedure requires the selection of acceptable production and pollution risks, before a LQ value can be obtained. Existing definitions implicitly emphasize the field and farm level. However, LQ is also important at the regional and higher level, which, so far, has received little attention. Then, again, an agro-ecological approach is suggested when defining LQ's as input into the planning process, emphasizing not only an independent assessment of the potential for agricultural production, but of nature conservation as well.

Keywords: agro-ecosystems, nitrate pollution, risk assessment, potential crop yields

Introduction

The condition of soils is generally not a prime concern when environmental problems are discussed in society. Global climate change due to greenhouse gasses, the "ozon hole", solid and liquid waste disposal and, increasingly, water quality and worldwide water shortages have been more successful in catching the imagination of the public at large. These, of course, are worthy objectives of concern and study, but serious concerns about the environmental degradation of soils resulting from intensive forms of land use exceeding the ecological carrying capacity have widely been reported but don't appear to lead to alarm or action (e. g. Oldeman, 1994). Approximately 15% of the total land surface of the world is degraded as a result of adverse human action. Worldwide, about 38% of the agricultural land is affected by significant human-induced soil degradation, of which 56% is caused by water erosion, 28% by wind erosion and 7% by nutrient decline. Substantial areas of prime agricultural land are, without much opposition, permanently taken out of production when used for city expansion and construction of shopping malls or roads. How can this relative indifference be explained? Without making attempts to speculate about the psychology of public awareness, we may state that the soil science profession has been less than successful in communicating its expertise effectively to the public, to regulators and to politicians. In this paper I will attempt to briefly analyze this problem. Of course, the challenge is to improve our efforts to show that soils are important. One way to do so is to develop indicators that can quickly express the value or quality of soils. Such indicators are crucial in the modern world where attention spans are very short and where attention is increasingly attuned to attractive " soundbites". Soil or land quality could be an ideal indicator as will be further explored in this paper. Our colleagues in economics and sociology have used attractive indicators for years (the Gross National Product may serve as an arbitrary example here). Such indicators have so far not been defined for soils (Pieri *et al.*, 1995).

When discussing soil quality indicators in the context of achieving an effective external communication, we must link soils and their properties with functioning and use. This not only relates to agriculture, but also to nature areas and recreational facilities. Use patterns and management practices are only acceptable when they are sustainable in the long run. We will therefore discuss the soil quality aspect in the context of sustainable land use and management.

Sustainable land management has been discussed widely within soil science and agronomy and guidelines have been proposed by FAO (1993). These guidelines list four criteria for sustainable land management relating to agriculture: (1) production should be maintained; (2) risks should not increase; (3) quality of soil and water should be maintained, and (4) systems should be economically feasible and socially acceptable. Soil quality is part of this definition and this term has, in turn, been defined in another context as: "the fitness of a specific kind of soil to function within its capacity and within natural and managed ecosystem boundaries, to sustain plant and animal productivity, maintain air and water quality and support human health and habitation" (Karlen *et al*, 1997). Even though it is tempting to discuss these definitions as such, we would rather focus on a joint analysis of both definitions, leading to descriptions of soil quality indicators that have relevance for sustainable land management. Overall, the objective is to develop expressions for soil quality that may serve to improve communication of soil expertise to users and stakeholders. Attention in this paper will therefore be paid to discussions on: (1) creating awareness about soils; (2) sustainable land management; (3) soil quality and soil quality indicators, and (4) use of the quality concept to improve communication. The focus will be on the field level, the usual area of activity of farmers. However, the quality concept is also important at other spatial scales, which have to be considered when dealing with policy issues in regions or countries. In this broader context, soil quality has not yet been analyzed and this issue will therefore also be explored in this paper.

Creating awareness about soils

Even though many people have a strong affinity with " the land" they live on, it is a rather abstract affinity. Soils occur in darkness below the surface of the earth and, in contrast to weather and water, are not directly visible and cannot be experienced by the senses unless exposed in a hole or in an excavation. The vertical succession of layers, which is characteristic for soils, can be shown in monoliths and can be displayed on walls of offices, schools and other buildings. In the USA, every State of the Union has a " State Soil", just like a "State Bird", "State Animal" etc. The vertical succession of layers in any soil is often quite beautiful, certainly when a wide array of colors is exposed as in podzols and gley soils. Successful exhibitions of soil monoliths have been held in art galleries! But soils represent more than just pretty pictures! To really understand the significance of soils, a functional approach is needed which demonstrates functioning within a landscape context as governed by interacting physical, chemical and biological processes. More specifically, functioning relates to supplying water and nutrients to agricultural crops and various types of natural vegetation, purification of percolating wastewater and carrying loads. All these functions taken together determine the value of soils for society.

How can the functioning of soils be characterized? Yields of crops are often known, as are types of natural vegetation that occur on different soil types. Chemical, physical and hydrological properties are often known to a certain extent but often in a rather qualitative, descriptive and static manner. How can we catch the effects of interacting physical, chemical and biological processes, which determine the dynamic character of soils and their functioning in ecosystems?

Many monitoring techniques are available now to measure varying soil properties over time. Use of transducers, recorders and proximal and remote sensing techniques allows us to " take the pulse of mother earth" (e. g. Bouma, 1999). Such techniques are, however, costly and widespread application is therefore unlikely. The advance of computer simulation of soil processes has, however, proved to be quite helpful in documenting effects of soil processes and the impact of man. (e. g. Alcamo, 1999). Some examples will be cited later in this paper. Use of computer simulation techniques to demonstrate the dynamic behavior of soils as a function of management by man is much more attractive for the modern soil user than classic soil interpretations, as presented in soil surveys, which list relative suitabilities of soils for a series of land uses. The sophisticated modern user wants a range of options to choose from when coping with land-use problems. He is used to making his own choices and does not like to be presented with single " best" solutions to problems, developed by others without his active participation. He wants researchers to define a " window of opportunity" for any given soil, while he (or she) makes the appropriate choices.

We expect that general soil awareness can increase when soil qualities are defined in the context of characteristic " windows of opportunity" for any given soil, and when these soil qualities are communicated effectively to various users of soil information.

Sustainable land management

In their definition of sustainable land management, FAO (1993) clearly focused on agricultural production. This can be a choice, but we should realize that land management has broader implications than agricultural production alone. This is expressed in the definition of soil quality where natural ecosystems are mentioned as well as human health and habitation. Be that as it may, it should be recognized that FAO (1993) defines sustainable land management and not sustainability as such. Emphasis is therefore on specific action by man and not on vague conceptual definitions, which is attractive. The elements of the definition are logical but they should, for better understanding, be grouped into two categories. The first three define plausible agro-ecological aspects: productivity, risks during production and quality of soil and water. The fourth category is different: economic feasibility (which also strongly effects social acceptability) is largely beyond the control of the land manager. Even though a management scheme may be sustainable from an agro-ecological point of view, it can be economically unsustainable because of poor prices for agricultural produce. This should certainly be considered but it is unwise to not explore various agro-ecological management options, even when at this point in time these options are not economically or socially feasible. Times may change: doubling of the world population, exhaustion of fossil fuels requiring growth of energy crops and needs for raw plant material to be grown in future by farmers as source materials for industry, are likely to change what may at this point in time be a negative economic outlook for agricultural production. Agro-ecological research, focused on developing future sustainable land management practices, should not be held ransom to current economic conditions.

How, then, to characterize agricultural production, production risks and the quality of soil and water? Monitoring of agricultural production systems can provide relevant information but procedures are tedious and costly and monitoring over periods of many years is needed to cover unusual weather conditions. The latter are needed to adequately express risks of production, which are associated with adverse conditions that only occur occasionally. Monitoring over such extended periods of time is simply not feasible. Fortunately, in recent years, systems analysis of agricultural production systems, using computer simulation of crop growth, has developed to the extent that methods are operational and very useful for the analysis of sustainable management systems. Examples will be provided in a later section of this paper.

Soil quality

Many studies have been made about soil quality (e. g. Doran and Jones, 1996) but there is as yet not a well defined, universal methodology to characterize soil quality and to define a set of clear indicators. Doran and Jones (1996) present four physical, four chemical and three biological indicators which, according to the authors, together represent a minimal data set to characterize soil quality. But no examples are provided. Gomes et al. (1996) define six indicators and threshold values for measuring sustainability of agricultural production systems at the farm level. Implicitly, higher degrees of sustainability correspond with higher soil qualities. Other examples of soil quality studies as reported by Doran and Jones (1996) list series of soil characteristics as indicators of soil quality but none really address the broad spirit or scope of the Karlen et al. (1997) definition.

A number of general considerations can be made when defining soil quality:
Any "fitness of a specific kind of soil to function" depends strongly on climatic conditions, which vary among climatic zones while the weather also varies at any given location during the year. Aside from this, soils are parts of landscapes and their functioning is strongly affected by their position in these landscapes. To consider "soil" without the climatic and landscape context, when defining quality, is not realistic. We should therefore speak about " land quality" rather than " soil quality" (Pieri *et al*, 1995), as the term " land" expresses the broader context in which the soil functions.

"Fitness to function" will always be considered in practice in relation to other soils. Production levels in years with favorable weather may not be too different among different soils but high quality soils tend to produce well under adverse conditions when other soils don't deliver. Of course, production figures alone are not enough: cost and quality of produce must be considered as well. When similar yields are reached at lower costs or with a higher quality, the quality of the soil may be considered to be higher as well. But here the management factor is introduced.

A potentially high-quality soil can still have low yields, resulting from poor management, while low-quality soils may have high yields due to excellent management. When defining land quality for a given type of soil, attention should be focussed on effects of a wide range of management types as applied for a given growing season. Studying a single growing season on a given farm will not provide useful information to derive representative land quality indicators. In fact, a high land quality implies that high yields may be obtained even under adverse conditions and under mediocre management. High quality land has a high resilience, which is best described as the ability to bounce back after the effects of poor management or poor weather conditions have been suffered. Low quality land does not have such resilience.

The above point described short-term effects of management during a growing season. For instance, compaction of structure when driving over wet land which qualifies as poor management. When the farmer would have waited a few days, compaction might not have occurred. But there is also a long-term effect of management. When poor management leads to, for instance, erosion or strong subsoil compaction, changes in the soil are permanent. Lost soil will not return and subsoil compaction is difficult to remove. Long-term management may also be favorable, for instance when increasing the organic matter content of the soil by organic manuring. Droogers and Bouma (1997) used the term genoform to describe the genetic soil type and phenoform to describe long-term effects of management in the same soil type.

"Fitness to function" is closely tied to land utilization type. The function is quite different in natural ecosystems or in agricultural production systems. When functioning is directed towards:" human health and habitation" one could also think about housing developments and recreation facilities. Here, attention will, arbitrarily, be confined to agricultural production systems, which is in line with the earlier discussion on sustainable management systems. The definition of soil quality mentions:" a specific kind of soil", which is not further explained. We believe that it would be wise to use soil surveys and soil taxonomy systems here to define specific soil types (genoforms, as mentioned above) that are well defined, also in terms of their positions in landscapes as shown on soil maps. In the USA, the soil series would be a proper "carrier" of information. In the context of the land quality concept, however, emphasis would be on land behavior in terms of crop production, its risks and environmental side effects. The implicit hypothesis would be that each soil series, occurring in a given agro-ecological zone with a characteristic climate, has a characteristic range of production rates, risks and side effects. We may call this a characteristic " window of opportunity". Well expressed phenoforms of a given genoform may have significantly different windows! Also, different genoforms have not always different ranges of properties: two soils may be genetically different but may function identically. In all cases such ranges should define land quality. Again, high quality land performs well even under adverse conditions in terms of weather and management. Low quality land performs poorly even under good conditions of weather and management. The big challenge now is to quantify such broad descriptions.

The land quality concept should also indicate whether or not quality can be improved by management, either short- or long term. Is there an absolute theoretical upper level of production? If so, how can it be reached? Can it be reached without adversily affecting environmental quality? How does that level compare with the level of other soils in other areas? Such questions are likely to be asked by farmers and other land users and they need to be addressed.

Considering the above, we decided to use simulation modeling of crop growth, as a function of water and nutrient regimes, as a means to characterize agricultural production of a given type of soil, located within a given climatic zone. This may be either a genoform or well defined phenoforms of a given genoform. Of course, such simulations should be validated by field measurements. Models effectively integrate soil and weather as they calculate daily production values. Indeed, data are thus generated to characterize " land" qualities. By calculating potential productions, an absolute upper yield level is obtained for any given site (at least for a given plant variety). Potential productions are based on climatic data only as well as plant parameters specific for a given species. Water and nutrient supply are supposed to be optimal while pests and diseases do not occur. Water-limited yields can also be calculated, taking into account the water that can be supplied under natural conditions to the crop at the given site by the soil, again assuming that pests and diseases do not occur. Such yields are lower because water supply is not always optimal. Of course, pests and diseases may occur but they occur independently of the site conditions that are used to calculate water-limited yields. One major advantage of simulation models is that calculations can be made for many years, providing expressions for the effect of the varying weather conditions that could never be obtained by monitoring. This, however, is only true when models have been independently validated using field measurements! Some examples will now be presented to illustrate the proposed procedure.

Land quality indicators

Exploratory studies for seven major tropical geno- and phenoforms

Bouma et al. (1998) studied seven major tropical soils to illustrate use of the land quality concept for exploratory purposes (Table 1). Potential and water-limited productions were calculated in terms of " grain equivalents", and soil data needed for the model included estimated infiltration rates, depth of rooting and available water. The reader is referred to the source publication for details (Bouma *et al.*, 1998; Penning de Vries *et al.*, 1995a, 1995b). Land quality (LQ) was defined as:

$$LQ = (\text{yield} / \text{potential yield}) \times 100.$$

Yield was expressed here as a calculated water-limited yield, but real yields could be used as well. Three hypothetical phenoforms were defined in this exploratory study for each of the seven genoforms in Table 1. Effects of erosion were expressed by removing the upper 40cm to 50 cm of soil, depending on soil properties. Compaction was expressed by restricting rooting to 40 cm, a depth at which a plowpan may occur. Liming expresses a potentially favorable effect of management. Acid subsoils that restrict rooting can be opened up by deep liming. Potential productions, as presented in Table 1, vary between 8 and 23 tons/ha, illustrating climatic effects in terms of radiation and temperature. LQ values were relatively high, indicating relatively high rainfall rates leading to production values that are relatively close to potential values. The Zambia soil, however, occurring in a dryer climate had a LQ of only 50. Real yields can also be used in the equation, rather than water-limited yields. Then, an impression is obtained of the yield gap for the given site and for the actual land quality of the management system being used. Erosion clearly leads to reductions of LQ values, particularly in the Orthic Acrisol in China where erosion results in the occurrence of an acid subsoil near the soil surface which restricts rooting. The effects of compaction are stronger than those of erosion under the assumed conditions here, while liming has a strong effect due to deeper rooting. Values reported are relative LQ values in relation to the value for the site based on water-limited yields. An absolute LQ value can also be defined when calculated yields are compared with the highest potential production that is possible in the world (estimated to be 41.1 tons/ha). Then, LQ values are relatively low in the range of 20-39. The exploratory analysis presented here allows a rough estimate of the relative effects of some management measures, using a simple simulation model and estimates of changes in soil parameters that are associated with certain effects of management. Also, average climatic data were used here. Running the model for a number of years with real-time weather data would have given a better impression about yield stability and risks. Still, the exploratory LQ analysis presented here can, in our opinion, be useful when discussing possible effects of different types of management and in comparing different soils.

Table 1. Potential yields, in terms of grain-equivalents, for seven major soil types of the tropics and derived relative and absolute land quality (LQ) values, based on water-limited and potential yields. Absolute LQ values are derived from the maximum potential yield in the world of 41. 1 ton/ha/yr. Values are derived for the seven genoforms and for three hypothetical phenoforms, expressing the effects of erosion, compaction and liming. (after Bouma *et al*., 1998).

Soil Type	Name		Prot. Prod. Tons Dry Matter/ Ha*Yr	Rel. Land Quality Water Limited	Erosion	Compaction	Liming	Absolute Land Quality Water Limited
1	Ferric Acrisol	China	13	96	85	75	100	32
2	Orthic Ferralsol	Indonesia	18	90	75	70	100	39
3	Cambic Arenosol	Colombia	12	96	80	72	100	31
4	Ferric Luvisol	Nigeria	14	90	75	55	90	32
5	Ferralic Arenosol	Nigeria	14	85	70	50	85	30
6	Orthic Acrisol	China	8	90	50	85	100	20
7	Orthic Ferralsol	Zambia	23	50	40	30	50	27

Yield gap and soil nutrient balances in Africa

In a World-Bank funded study, Bindraban et al. (2000) studied land quality indicators for African soils also using potential, water-limited, nutrient-limited and actual yields. In contrast to the exploratory study of Bouma et al. (1998), they used specific data for field sites. The difference between actual and potential yield expresses the yield gap, which is considered to represent the LQ indicator. This is not unlike the approach followed by Bouma et al. (1998) except that the latter authors expressed LQ as a number between zero and one hundred and that they also defined an absolute LQ. The difference between potential and water-limited yield provides an indication what might be achieved by improved water management while the difference between water-limited and nutrient-limited yield indicates the potential impact of improved fertilization. Bindraban et al. (2000) also added a second LQ, which defines the soil nutrient balance. This is highly relevant for Africa where soil mining is rampant. The soil nutrient balance is the net difference between gross inputs and outputs of nutrients to the system and is expressed in relation to the soil nutrient stock. Of course, effects of depletion are much worse in soils with a low stock of nutrients as compared with soils having a high stock. Combining five classes for nutrient stock with five classes of N-P depletion results in six classes for the nutrient depletion LQ.

The attractive aspect of this study is its emphasis on the integrated characterization of the entire land system using quantitative and specifically defined techniques, such as simulation modeling and nutrient budgeting.

Balancing production and environmental requirements in a prime agricultural soil in the Netherlands

Application of simulation techniques for a series of growing seasons, expressing climate variability, was realized in a more detailed Dutch case study in a prime agricultural soil (Droogers and Bouma, 1997; Bouma and Droogers, 1998). Three phenoforms were identified in the field and were studied. Here, only conventional arable land is shown (CONV) and land affected by biodynamic farming for a period of 60 years (BIO). The latter soil had a significantly higher organic matter content (appr. 4% versus 2%) as a result of biological management. A more detailed simulation model was used in this study, allowing calculations of crop growth and associated water and nitrogen regimes. Calculations were made for a 15-year period using real-time weather data and a large set of nitrogen fertilization rates. Results could therefore be expressed as probability curves (Figure 1) listing the probability that a certain yield would be exceeded on the vertical scale and the yield itself on the horizontal scale. Three yield curves are shown in the figure and they express the probability (never, 3% and 10% of the years) that nitrate leaching will exceed the environmental threshold value for nitrate content of groundwater. Thus, risks are expressed in quantitative terms by combining the uncertainty of yields due to variable weather in different years with the associated leaching of nitrates. One more curve is shown: the dark solid, and almost vertical, line represents potential yield.

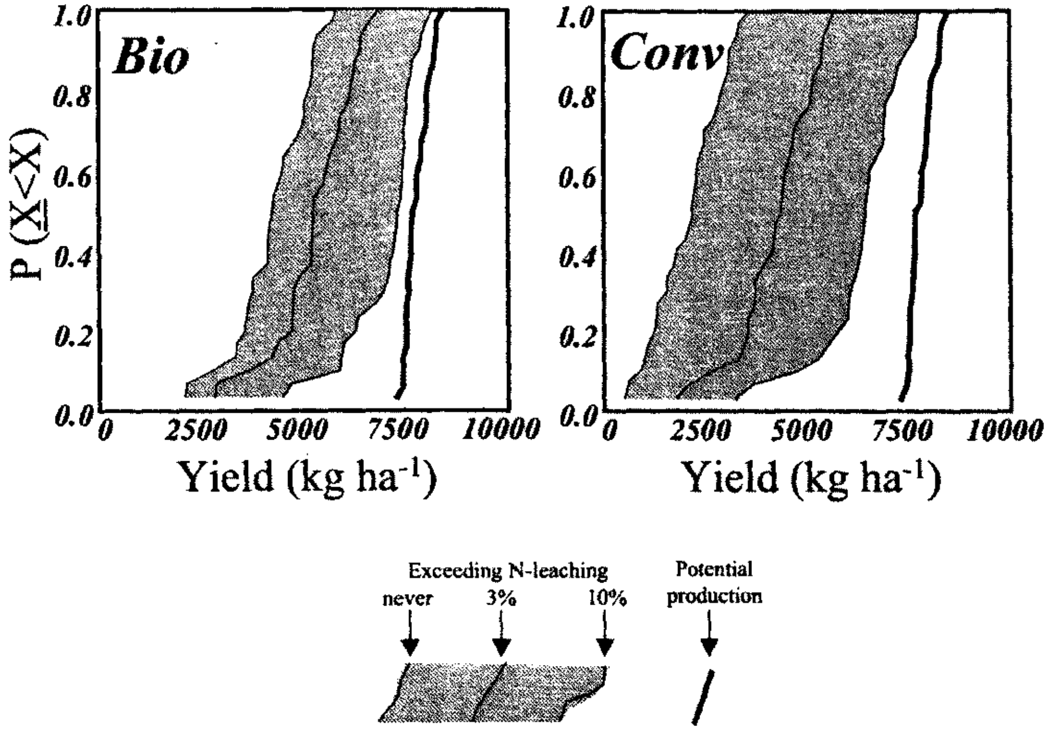

Figure 1. Probabilities that yields of wheat are exceeded as a function of three probabilities that the threshold value for nitrate leaching to the groundwater is exceeded as well. Data are based on simulations for a 30-year period for a prime agricultural soil in the Netherlands (after Droogers and Bouma, 1997).

The graphs in Figure 1 force the user to make choices about risks to take when balancing yield versus nitrate leaching. This is a relevant key problem in Dutch agriculture where production interests have to be balanced against environmental restraints. Again, land quality can be expressed by: (actual / potential yield) x 100.

Assuming, arbitrarily, a yield level that has a probability of 20% of being exceeded and a 10% probability that nitrate leaching will exceed the threshold, a LQ value of 89 is obtained for BIO and 84 for CONV. If however, the leaching probability is reduced to 3%, LQ values become 73 and 60. If leaching is never allowed, LQ values become 61 and 33, demonstrating the higher "quality" of the BIO soil. Different LQ values are obtained when different exceedance values for yield probability are used. They can all be derived from Figure 1 as needed. Figures such as Figure 1 are suitable to allow the user to make choices. To the dismay of some, they do not provide clear-cut answers and judgements. Science provides the tools to users to allow them to exercise their responsibility. Science does not take away their responsibility but allows users, be it farmers, planners or politicians, to make more rational choices.

Going back to the definition of soil quality, the procedure illustrated here to estimate LQ values, covers yields in different years, risks involved and environmental side effects in terms of nitrate pollution of groundwater, which is the most important problem in Dutch soils. Elsewhere other problems may figure. This comes close to what Karlen et al. (1997) must have had in mind. LQ's are also indicators for sustainable land management, as defined above. They define production levels over the years and risks involved as well as the quality of water. Management practices, defined in this context, relate only to nitrogen fertilization and management includes, of course, much more than that. Any LQ value indicates a yield gap, being the difference between observed yields and the potential one. A logical question is how to bridge the yield gap. To answer that question all factors, which affect real yields, have to be identified.

Land quality at larger scales

Land qualities, discussed so far, were derived for individual pieces of land corresponding with a certain soil series and are implicitly focused on the farmer or local land user. Attention was confined to agricultural production and, in the Dutch case study, on important aspects of environmental quality. The definition of soil quality (Karlen *et al.*, 1997) is focused on a "specific kind of soil" and has, therefore, a built-in spatial scale dimension. But the LQ concept not only relates to plots or fields where single kinds of soil occur, but also to larger areas such as communities, regions, countries and even larger entities where many different soils occur. In that context, LQ's are also important but questions are now asked by politicians, planners and real estate brokers, rather than farmers. How should the quality of land in a large area be judged? A soil map can be used to distinguish all soil series or soil associations that occur in the area and individual land qualities of the different soil series can be considered for different land use categories. An average land quality, weighted by relative areas occupied by the different soil series, could then theoretically be calculated.

Functioning of land within natural or managed ecosystem boundaries, sustaining plant and soil productivity, maintenance of soil and water quality and support of human health and habitation" are many but not necessarily all elements of importance when dealing with land in larger areas. Infrastructure is important, but, particularly, socio-economic conditions that determine the population pressure on the land. As with the discussion on fields and farms, we advocate an approach in which the quality of land in a region is first judged in terms of its own inherent properties. Next, these properties will be only one (and as it turns out in real life, a rather minor) factor in determining the most desirable land use in a region which is highly influenced by socio-economic and political considerations and which will always be the result of tradeoffs between many conflicting land use options. The relevant question here is, then, how the quality of the land can play a role when weighing such alternative options.

Clearly, restricting the attention to agriculture in this context as the only land-use type is unsatisfactory. Aside from agricultural issues, regional land-use plans are likely to deal with establishing nature areas, transport corridors and locations for housing and industrial development. Because of the relatively high capital expenditure associated with building activities, LQ's for land in a given area when considering such activities is bound to be relatively unimportant. Draining of potential building sites or adding thick layers of sand to increase the support capacity of land that has a low natural carrying capacity, is financially no problem. For nature areas and, less so, for agriculture, which are much less capital intensive, the picture is different. Local conditions of the land are very important in determining water, nutrient and temperature regimes that govern occurrence of natural vegetations but that also increasingly have an impact on types of agriculture that are ecologically balanced. The approach to take, therefore, would be to define LQ's for agriculture and nature for land occurring in the area to be considered and to introduce this in time into the broader land-use planning process. LQ's for agriculture have been discussed above. LQ's for nature require a separate discussion, which is beyond the scope of this text.

Modern land-use planning increasingly uses simulation modeling in the context of systems analysis to derive optimal land-use patterns in a region. This approach was recently demonstrated in Costa Rica (Bouman *et al.*, 1999). Thus, interests of agriculture and nature would, as is often the case, not be a rest-factor left behind after land-use decisions have already been taken based on demands from housing, industry and infrastructure. Rather, these interests of agriculture and nature would be submitted at an early time allowing a significant effect on the decision making process by pointing out where prime land is located for agriculture and nature. Use of LQ indicators can be quite helpful here! Of course, the political process may still ignore this, but nobody would be able to claim afterwards that they did not know.

Using the quality concept to improve communications about soils

Expression of the productive capacity of land in relation to environmental requirements in terms of a single indicator, which is related to potential production, can be helpful in our opinion to communicate more effectively with stakeholders about use of land in future as compared with current conditions, where emphasis is more on the properties of land rather than on its behavior. The indicator, as proposed, provides a quality measure for a given soil type, but by recognizing occurrence of genoforms and phenoforms, it acknowledges important effects of management. Thus, characteristic " windows of opportunity" are obtained for any soil type occurring in a given agro-ecological zone. Use of actual yields provides an impression of yield gaps, while the absolute quality measure ranks the soil on a global scale. We certainly cannot preserve all land for agricultural production. However, the quality measure discussed here may help to more effectively show which land is particularly valuable and deserves more attention.

Studies discussed above have an exploratory character. Before possible implementation of the scheme on a wider scale, attention should be paid to unified procedures for determining potential yields and use of simulation models, including a critical analysis of data demands.

Conclusions

The problem of worldwide land degradation and indiscriminate use of prime agricultural land for development is insufficiently recognized by society at large. One reason is the rather ineffective manner in which soil scientists present their expertise. We suggest that creative use of the land-quality concept, leading to specific indicators, may raise public awareness of the importance of the land.

Existing definitions of soil quality and sustainable land management have several elements in common. An approach is proposed here to define a land quality indicator for sustainable land management focused on agricultural land use which integrates elements of yield, risk and environmental quality using quantitative, reproducible techniques such as simulation modeling or nutrient budgeting. Well intentioned normative and descriptive approaches will not be enough.

Socio- economic and political conditions are very important when defining land quality and sustainable land management. We advocate, however, a separate assessment of the agro-ecological potential of the land which should, in an early phase of discussions with all stakeholders, be introduced as independent input into broader land use discussions. The future of the land cannot be held hostage to economic conditions of the day.

Land qualities, discussed in literature, have so far implicitly been focused on field and farm level and on agricultural land use, the latter increasingly within an ecologically sound context. Land qualities are also important at larger scales, such as the regional and national level and this requires additional research because a single focus on agriculture is not realistic in this case as many other forms of land use present their demands as well.

References

Alcamo, J. 1999. The science in diplomacy and the diplomacy in science. Environment Science and Policy 2, 363-368.

Bindraban, P. S., Verhagen, A., Uithol, P.W.J. & Henstra, P., 2000. A land quality indicator for sustainable land management: the yield gap. The case of sub-saharan Africa. World Bank Institute report 106. AB-DLO Wageningen, The Netherlands.

Bouma, J., 1999. New tools and approaches for land evaluation. The Land 3. 1, 3-10.

Bouma, J. & Droogers, P., 1998. A procedure to derive land quality indicators for sustainable agricultural production. Geoderma 85, 103-110.

Bouma, J., Batjes, N.H. & Groot, J.J.R., 1998. Exploring land quality effects on world food supply. Geoderma 86, 43-59.

Bouman, B.A.M., Jansen, H.G.P., Schipper, R.A., Nieuwenhuyse, A., Hengstdijk, H. & Bouma, J., 1999. A framework for integrated biophysical and economic land use analysis at different scales. Agric. Ecosystems and Environment 75, 55-73.

Droogers, P. & Bouma, J., 1997. Soil survey input in exploratory modeling of sustainable land management practices. Soil Sci. Soc. Amer. J. 61, 1704-1710.

Doran, J. W. & Jones, A.J. (eds), 1996. Methods for assessing soil quality. SSSA Special Publication 49. Soil Sci. Soc. America, Madison, USA. 410 pp.

Food and Agricultural Organization (FAO), 1993. FESLM: An international framework for evaluating sustainable land management. World Resources Report 73. FAO, Rome, Italy. 125 pp.

Gomes, A.A., Swete kelly, D.E., Syers, J.K. & Coughlan, K.J., 1996. In: Methods for Assessing Soil Quality. Doran, J.W. & Jones, A.J. (Eds). SSSA Special Publication no. 49, 401-409.

Karlen, D.L., Mausbach, M.J., Doran, J.W., Cline, R.G., Harris, R.F. & Schuman, G.E., 1997. Soil Quality: A Concept, Definition and Framework for Evaluation. Soil Sci. Soc. Amer. J. 61, 4-10.

Oldeman, L. R. 1994 The global extent of soil degradation. In: Soil resilience and sustainable land use. Greenland, D.J. & Szabolcs, I. (Eds). CAB International. Wallingford, 99-118.

Penning de Vries, F. W. T., van Keulen, H. & Rabbinge, R., 1995a. Natural resources and the limits of food production. In: Bouma, J. et. al. (Eds). Ecoregional approaches for sustainable land use and food production. Kluwer Acedemic Press. Dordrecht, The Netherlands. pp 65-89.

Penning de Vries, F. W. T., van Keulen, H. & Luyten, J.C., 1995b. The role of soil science in estimating global food security in 2040. In: Wagenet, R.J., Bouma, J. & Hutson, J.L. (Eds). The role of soil science in interdisciplinary research. Soil Sci. Soc. Amer. Spec. Publ. 45: 17-37, Madison, USA.

Pieri, C., Dumanski, J., Hamblin, A. & Young, A., 1995. Land Quality Indicators. World Bank Discussion Papers 315. World Bank, Washington, D. C. USA. 51 pp.