Economic land evaluation: why and how

by

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Abstract: Economic land evaluation is a method for predicting the micro-economic value of implementing a given land-use system on a given land area. This is a more useful prediction of land performance than a purely physical evaluation, since many land-use decisions are made on the basis of economic value. Measures of economic suitability include the gross margin, net present value, internal rate of return, benefit/cost ratio, and utility functions based on these. The economic value of the *in-situ* resource quality of a land area may be inferred directly from land characteristics or from Land Qualities which, when less than optimum, result in decreased yields or increased costs. The economic value of geographic land characteristics may be determined by spatial analysis. Single or multi-criteria economic optimisation and risk analysis can extend the economic land evaluation from a natural resource or management unit to a production or planning unit. Computerised tools may be used to assist in economic land evaluation.

INTRODUCTION

Land evaluation may be defined as "all methods to explain or predict the use potential of land" (van Diepen, Van Keulen *et al.*, 1991). In a land evaluation exercise, predictions are made about the expected performance of several different land uses on each land mapping unit in a project area. These predictions should be useful for rational land-use planning (FAO, 1993b) by individuals, collectives, or society.

How should land performance be measured, so as to provide predictions that are useful to decision makers? Early methods for land evaluation compare land in physical terms, by describing relatively permanent impediments to unrestricted land use. These physical land classifications usually have an implicit economic basis. For example, the USDA Land Capability Classification (Klingebiel & Montgomery, 1961) rates land from class 1 (best) to 8 (worst) according to the intensity of land use it can support and the degree of management that would be necessary to support that intensity. Implicit in this ranking is the supposition that a wider choice of land uses should allow the farmer more opportunities for income, and less stringent management requirements should result in lower costs of production. As another example, the Storie index (Storie, 1933) rates land on a scale of 0 to 100. It explicitly attempts to relate this rating both to the land's inherent productive capacity and to the difficulty of removing or working around physical limitations. Koreleski (1988), in his adaptation of the Storie index to Poland, explicitly tried to relate the index to land productivity. The USA Department of the Interior's Bureau of Reclamation's land evaluation for irrigation (1951) explicitly uses an economic measure, in this case the ability of a farm to pay for irrigation water, as its measure of land suitability.

One of the motives behind soil survey was the recognition that the productive capacity of the land, as measured by the crop yield that could be achieved on given land type, is an objective basis for valuing land areas (Simonson, 1938). It is a short step from crop yield assessment (Dumanski & Onofrei, 1989) to a simple economic land evaluation: yields are multiplied by prices, and costs of production are subtracted from this gross return, thereby calculating a predicted net return.

The modern era of land evaluation began with the publication of the FAO "Framework for Land Evaluation" (1976) and subsequent guidelines for land evaluation of general kinds of land use (FAO, 1983; 1984; 1985; 1991). The FAO recognised that a purely physical evaluation provides no objective method to compare different land uses, since the several physical constraints have no inherent common scale of measure. Also, physical land evaluation ranks land mapping units by the number and severity of physical constraints, but such an ordinal scale, using as it does arbitrary units of measure with no inherent origin, can not be used to determine relative value of land areas even with respect to a single land use. Most importantly, land users and project planners often make their decisions mostly by predicted economic value. For example, land evaluations that are used as the basis for equitable land taxes (Bird, 1974) obviously need to express their results in economic terms, such as the residual income to land (Clark, 1973) as an estimate of economic rent.

The concept of Land Utilisation Type (LUT) proposed by the FAO explicitly includes the social and economic context in which the land use system is to be applied. The reason for this broad definition of land use becomes clear when we consider the needs of economic land evaluation. Constraints on production factors such as labour and capital affect the feasibility of the LUT. Income expectations of the social groups engaging in a LUT are used to define overall suitability. Social preferences for type of occupation and consumption also help define the set of LUTs to be evaluated.

For these reasons, the FAO promoted the use of economic land evaluations, either subsequent to the physical evaluation (the ‘two phase’ approach) or in parallel with it. One of the earliest published applications of the FAO Framework (Young & Goldsmith, 1977) included an economic evaluation, and the textbook of Dent & Young (1981) includes a chapter on the economics of land evaluation. Unfortunately this did not become the rule. There are hardly any published economic land evaluations, and the recent trend seems to be for physical land evaluation only, even in FAO-sponsored projects (FAO, 1993a; Venema & Daink, 1992). A notable exception is from Australia (Johnson & Cramb, 1991; 1992b; 1994), which resulted from an interdisciplinary collaboration between an agronomist (Johnson) and social scientist (Cramb). Volume 2 of their study (Johnson & Cramb, 1992a) is a summary of economic theory applied to land evaluation.

This paper pleads the case of economic land evaluation to natural resource scientists, and suggests some techniques for carrying out such evaluations. The first key point is that the physical attributes of land, as quantified by the natural resource scientist, affect its economic value. The second key point is that these effects can be quantified in economic terms by the land evaluator. Although this quantification may be difficult, it is necessary for land evaluations that are useful to decision makers who base their decisions on economics. Land evaluators should not avoid this challenge.

A PROCEDURE FOR ECONOMIC LAND EVALUATION

The land use capacity (Barlowe, 1986), or in land evaluation terms, the economic suitability (FAO, 1976), of a land area for a land use, may be defined as the value of some economic measure, should the land area be dedicated to the use. This definition begs two others: the type of land area to be evaluated, and the economic measure to be used in the evaluation. It also leaves unspecified the key question: how should the physical land characteristics be costed? So, the land evaluation has five steps:

(1) Decide on the land units to be analysed;

(2) Decide on the appropriate economic measure;

(3) Decide what economic factors to include in the evaluation, and the type of price to use in the analysis;

(4) Specify how physical land characteristics affects economic values, perhaps using *in situ* and geographical Land Qualities;

(5) Compute the economic land suitability;

(6) Perform a sensitivity analysis to determine the effect of errors in physical factors and model assumptions on land suitability.

In practise, these steps may be iterated and revised. A particular advantage of economic land evaluation is shown by stage (6), by which an estimate of the uncertainty in the predicted economic value may be obtained.

Land evaluation for the purposes of land-use planning does not pretend to analyse the economics of land and production in complete detail. It is fundamentally a strategic, as opposed to a tactical, planning tool. Thus the economic analysis presented in this paper is not intended to substitute for micro-economic analysis of the most profitable combination of inputs or allocation of scarce resources in a tactical sense. However, for land allocation problems and strategic decisions at the production-unit level, the type of analysis presented here should provide a fairly objective and reproducible basis for deciding between land use options.

Economic land evaluation is not used to evaluate the effects of macro-economics policy on rural land use. Issues such as monetary and trade policy, price controls, and subsidies are important, and determine the context within which the micro-economic analysis of land evaluation takes place. The LUT must be placed in this context, and the agricultural economist should be able to provide information on prices and interest rates as affected by macro-economics policy. Sectorial economics is also outside of the field of economic land evaluation. However, the dynamics of the agricultural sector must be considered when defining the LUT. In particular, the sector is the unit of analysis for market constraints, price elasticity, and demand.

Economic land evaluation was tersely described by Dent & Young as follows:

> "The principle of economic land suitability evaluation is simple: cost the inputs, price the benefits, and calculate the net returns in money terms. … Decisions have to be made … about the manner of pricing, rates of discounting, costs and returns, external factors to be included, and which economic yardsticks to use for interpreting the results. These decisions call for careful judgement, since they have an equal or greater effect on the results than that of [i.e., the decisions concerning] qualities of the land". (Dent & Young, 1981, p. 187)

These decisions require the participation of an economist, along with a natural resource scientist and production agronomist, in the land evaluation team.

EVALUATION UNITS

Land evaluation attempts to determine the relative fitness of different land areas for different uses. This section presents the several kinds of 'areas' that may be evaluated.

1. Map units of natural resource inventories: When the evaluation starts with data from a natural resources data base (e.g. a soil survey or climate map), the map unit as shown on the resource map as a single legend class, or as derived from an intersection of several maps (e.g., soil type overlaid with climate type), may be considered sufficiently homogeneous with respect to the land characteristics implied by the legend, and forms the unit of analysis. This has been the usual approach for physical land evaluations based on soil survey interpretations or agro-ecological zones. All delineations of the map unit are considered to be the same, no matter where located, so that only the *in-situ* characteristics of the map unit, such as natural soil fertility, can be used to determine economic value. Economic results are normalised to a per-unit land area basis.

2. Map delineations of natural resource inventories: If economic suitability depends on geographical land characteristics, that is, characteristics that depend on the specific location on the earth's surface, the legend category of a natural resource inventory must be divided into its separate delineations for analysis. Map delineations are individual connected areas of the map unit, and are usually small and compact at the map's scale. The evaluation can consider the location of the delineation (either its centroid or nearest point) in relation to cultural features such as roads and markets; this is especially important for transport costs. The size and shape of the delineation, as well as topological relations such as adjacency and containment, can also be a land characteristic of economic importance. Economic results are usually normalised to a per unit land area basis.

3. Management units: A management unit, sometimes called a 'decision area', is an area of land that the land manager intends to treat or allocate as a unit, and which can not realistically be subdivided, for example because of improvements such as drainage canals, or because a subdivided unit would be too small to manage. Since each management unit has a unique location, the analysis can include geographic considerations.

Management units based on the current land-use pattern, such as fields, are usually less homogeneous with respect to natural resources than map delineations of a natural resource inventory, because the boundaries of natural resources rarely correspond to the boundaries of management units. One way to deal with this heterogeneity within the evaluation unit is to ignore it, and simply use the dominant or most prevalent value of each land characteristic, with a loss of precision in the analysis. Another approach is to define the evaluation unit as a compound unit consisting of several homogeneous constituents in a defined proportion. Each constituent is evaluated separately, and these results are combined in weighted linear proportion to arrive at a result for the management unit as a whole.

4. Production units: Some economic decisions are taken on a whole-farm (or other production unit) basis. Production units have global objectives (for example, profit maximisation and risk minimisation) and constraints (for example, labour and capital supply) that apply to a production unit considered as a whole, not to the individual management units of which it is made up. In some land use systems, a production unit must contain a defined mixture of several land uses. The usual way to evaluate a production unit is to evaluate each of its management units separately, and then combine these into an aggregate farm plan, considering whole-farm objectives and constraints.

5. Planning units: In regional or catchment planning, decisions are taken on the whole area, subject to objectives and constraints that are expressed over the entire region. For example, there may be a limited amount of irrigation water available for an entire irrigation district, or a catchment plan may be required to include a set of land uses. Planning units are evaluated like production units.

MEASURES OF ECONOMIC SUITABILITY

There are various 'yardsticks' which may be used for economic land suitability evaluation. The chosen measure should correspond to the economic reality faced by decision makers, as well as their values and attitudes towards money and risk. Introductory texts in engineering economics (Newman, 1991) explain how to formulate and calculate these measures. Chapter 9 of the EUROCONSULT agricultural compendium (1989) also compares these measures.

1. Gross Margin**:** This is the cash flow in to the LUT, less the cash flow out of the LUT, on a per unit area (normalised) or aggregate (per-field or per-farm) basis, in one accounting period (usually a year). A different terminology is often used in North America. If the gross margin calculation includes the fixed costs of production, it is called the 'net return'; otherwise the 'gross return'. This measure does not take into account the time value of money. Capital costs can be ignored altogether by using rental prices. Thus, the gross margin is not sensitive to interest rates, and as such is a good first approximation of financial feasibility. It is an appropriate measure of economic suitability for annual or short-term rotational LUTs with few or no capital costs.

2. Capitalised value: This variant of the gross margin accounts for the time value of money. The annual return from a steady-state investment is a percentage of the total value of the investment determined by the interest rate. So, the total value can be calculated as: $EV = GM / IR$, where EV is the estate value, GM is the annual gross margin, and IR the interest rate in percent. It is an appropriate measure of economic suitability in the same situations as the gross margin. The capitalised value is an approximation to the portion of the land's value that can be attributed to its productive capacity.

3. Discounted Cash Flow Analysis: Money received in the future is less valuable than money in hand. To take into account this 'time value of money', amounts received or spent in the future are discounted to their present value according to the formula:

$$PV = FV \cdot \left[\frac{100}{100 + IR} \right]^{Y}$$

In this formula, *PV* is the present value, *FV* the future value, *IR* the interest rate in percent, and *Y* is the number of years from present, counting from zero. The present value of an annual cash flow becomes insignificant at some point in the future that depends on the interest rate. A typical use of discounted cash flow analysis is to evaluate the economic feasibility of agricultural projects such as land reclamation, where an initial investment is expected to yield benefits in the future.. There are three measures derived from the discounted cash flow with which to evaluated land suitability, as follows.

3.1. Net Present Value (NPV): This is the total value of the cash flows to be generated by the LUT, summed over its planning horizon, discounted to the present. The NPV may be normalized if investments are expressed on a per-unit area basis, otherwise it must be aggregated over the production unit. The NPV can not be annualised, since each year is discounted differently. It has the disadvantage that all land use options to be compared must have the same useful life or planning horizon, which is rarely the case in agricultural projects, although shorter planning horizons (e.g., rotations) can be lengthened to equal the longer planning horizons (e.g., plantation crops), by repeating the sequence of inputs and outputs of the shorter plans.

3.2. Internal Rate of Return (IRR)*:* This is the interest rate below which the 'project' (land use option) becomes financially attractive. At higher prevailing interest rates than the IRR, an investor would be better off investing the required capital at the offered rate rather than investing in the project. Mathematically, it is the discount rate below which the NPV becomes positive. The IRR is dimensionless, with no spatial or temporal component, and so can be used to compare land uses with different planning horizons. The IRR is a rough measure of the financial risk of a project that is due to rising interest rates, and is often used to compared investment options.

3.3. Benefit-to-Cost Ratio (BCR): This is the present value of the cash-in divided by the present value of the cash-out. Evidently, a project is feasible if and only if the BCR>1. The BCR is a measure of the return to investment; thus the BCR is an appropriate measure for the land user who wants to maximise the leverage of a limited investment.

4. Utility: The economic measures presented to this point are all expected values. Because of uncertainty in the production system, mainly due to uncertain weather and prices, the expected value will not be attained every year; rather, the time series of net returns will have some variance. If land users had unlimited reserves to get through low-income years, they would rationally choose the land use with the greatest expected value. In practice, they are willing to trade some total income over the long term for smoother and more certain incomes in the short and medium term. A measure of risk aversion is the degree to which land users are willing to forego overall benefit (high expected value) for more certainty (low variance). One kind of utility function (Hazell, 1986) combines the expected value $E[\mathbf{Y}]$ and variance $V[\mathbf{Y}]$ of a time-series $\mathbf{Y}$ of cash flows, for example the utility function $U(\mathbf{Y}) = E[\mathbf{Y}] - \frac{1}{2}\beta V[\mathbf{Y}]$, where β increases as the land user's risk aversion. Then one of the previously described economic metrics are used to compare LUTs on the basis of their utilities rather than their expected values.

Simpler risk-aversion functions can be used in place of utility, for example the absolute minimum, running multi-year averages, or the lowest quartile of the time-series of expected economic value.

5. Non-cash measures : Other measures of value than cash may be appropriate in certain socio-economic settings. Examples are calories or a nutritional index as 'income' to be maximised and amount of an input (e.g., labour) to be minimised. The net cash flow must still be favourable.

6. Economic suitability classes: Once each land use-land area combination has been assigned an economic value by the land evaluation, the question arises as to its 'suitability', that is, the degree to which it satisfies the land user. The land use must be financially feasible (for example, it must result in a positive gross margin), but beyond this minimum standard, the concept of 'suitability' depends on the financial expectations of the land users who will implement the LUT. The FAO framework defines two suitability orders: 'S' (suitable) and 'N' (not suitable), which are divided into five economic suitability classes: 'S1' (highly suitable), 'S2' (suitable), 'S3' (marginally suitable), 'N1' (not suitable for economic reasons but physically suitable), and 'N2' (not suitable for physical reasons). The subdivision of the ‘S’ order into three suborders is arbitrary, and can be expanded or contracted according to the precision of the evaluation.

The physical evaluation separates class ‘N2’ from the other classes; no economic evaluation should be carried out for physically unsuited land use-land area combinations. The evaluator assigns dividing points between the other classes, in the same units of measure as the economic analysis. The limit between ‘S3’ and ‘N1’ must be at least at the point of financial feasibility (i.e., gross margin, NPV, or IRR ≥ 0, BCR ≥ 1). The other limits depend on social factors such as farm size, family size, alternative employment or investment possibilities, and wealth expectations; these are specified in the LUT definition.

FACTORS TO INCLUDE IN THE CALCULATION OF ECONOMIC SUITABILITY

Since land is the entity being compared in land evaluation, no costs associated with acquisition or rental of the land should be included in any of the economic measures.

Economic suitability may be expressed in terms of the return to labour or the return to land. In the first case, the farmer’s family labour is not included as an expense, and the gross margin must be sufficient to allow the farm family an adequate income. In the second case, some of the family’s income has been accounted for, since their labour is included in the expenses, as if labour had been hired. If the land areas to analyse are map units or delineations of natural resource inventories or management units, labour is usually included as an expense; if the units of analysis are production units (e.g., farms), family labour is usually omitted, because the return to labour is not on the basis of one land area but on the basis of the whole farm. The net return to land is also called the ‘residual income to land’ (Clark, 1973). This is an estimate of economic rent in those economies where factors of production (other than land) can easily be exchanged, so that the average return to land (estimated by the land evaluation) equals the marginal return to land, which determines economic rent.

Externalities are off-farm effects, such as water pollution and sedimentation of reservoirs, that are not reflected in the production unit’s budget. In a financial analysis (from the point of view of the individual land user), externalities are ignored unless a monetary cost to the land user is imposed by society, for example, a tax on sediment discharge. In an economic analysis from the point of view of society, these must be included and assigned a (negative) economic value, using the techniques of resource economics (Carlson, Zilberman *et al.*, 1993).

If the economic evaluation is from the point of view of society, rather than individual land users, it may be necessary to use shadow, as opposed to market, prices for inputs and outputs. Shadow prices are set by the economist to reflect the opportunity cost to society, which may have been distorted by an imperfect market.

DETERMINING ECONOMIC VALUE FROM *IN SITU* LAND CHARACTERISTICS

As Dent & Young (1981, p. 187) say, "cost the inputs, price the benefits, and calculate the net returns in money terms". The problem is precisely in quantifying the inputs and benefits for a specific land area, because differences in land attributes affect both the benefits (yields) and input levels. In economic land evaluation, we attempt to quantify the effect of these differences in benefits and inputs, given the measured or estimated differences in land characteristics. This is the essential link between the physical facts and economic results that makes economic land evaluation useful. It is also the step where the land evaluator with a strong background in physical reality makes the biggest contribution to the economic land evaluation.

In this section I discuss how inputs and benefits are quantified in relation to *in situ* land characteristics, without (yet) taking into account the land unit's spatial position.

1. From Land Characteristics to economic value

Where data are sufficiently detailed and calibrated models have been developed, it is possible to estimate the effect of land characteristics on yields by statistical yield estimation (Simonson, 1938; De la Rosa, Cardona *et al.*, 1981; Olson & Olson, 1986) or dynamic simulation modelling (van Keulen & Wolf, 1986; de Wit & van Keulen, 1987; Jones & Kiniry, 1986; Wilkerson, Jones *et al.*, 1983). It is also possible to estimate the amount of inputs necessary to implement a LUT directly from land characteristics. An example is the irrigation water requirement for crops, based on soil texture, precipitation, and potential evapo-transpiration (Doorenbos & Kassam, 1986). The net return can then be calculated from a predicted yield and predicted input level. Interactions between land characteristics are explicit in the functional form of statistical relations, or implicit in the possibly non-linear behaviour of dynamic simulation models.

A major advantage of these techniques is that a time-series of predicted net returns can be obtained simply by repeating the calculation for a time-series of weather, either from historical records or simulated from a probability distribution. A problem with using dynamic simulation models of crop production (so-called 'systems simulation') for yield prediction is that these models are very complex, difficult to calibrate in new areas, and may be quite sensitive to input values or model parameters.

2. From Land Qualities to economic value

In FAO-style land evaluation, land suitability for a Land Utilisation Type (LUT) is usually disaggregated into a small set (up to 10 or so) of Land Qualities (LQ) which directly affect land suitability in a more-or-less independent manner, and which usually can not be directly or routinely measured. Land Qualities must be estimated or inferred from a set of diagnostic land characteristics (LC) which are the properties of land that are measured or estimated in routine survey. An advantage of the Land Quality approach in economic land evaluation is that LQs can be individually related to economic value, so that the analysis reveals which aspects of the LUT have the largest effect on economic land suitability.

Land Qualities can usually be thought of as limitations for the particular land use, with an optimum value which will give maximum yield or other benefit with minimum input, and with a series of values which are increasingly limiting. These 'severity levels' (gradations in the scale of goodness) can be linked directly to economic values. This link is the basis of the economic land evaluation. The evaluator must define the number of severity levels and their meanings. For example, a 'severe' moisture stress may be defined by the yield reduction or delay that it will cause, or by the amount of irrigation water that will be necessary to compensate for it.

This link can be made by specifying decreased yields, delayed yields, or increased costs of production.

2.1. Decreased yields: An increasing limitation can decrease yields of one or more products of the LUT. Typical examples are agronomic factors such as increasing moisture stress, decreased fertility, decreased aeration of the roots, and increasing limitations to root growth. These all limit crop yields to a fraction of what would be obtained in the absence of these limitations. Not all LQs limit yield: some only require more or different inputs or a change in management, or only affect physical suitability.

One way to express yield is as an optimum (within the context of the LUT and study area) and a set of reductions that can be represented as proportional yield factors, from 0 (no yield) to 1 (maximum yield). The maximum yield expected in the zone being evaluated, within the context of LUT, is sometimes called the 'S1 yield'.

The land evaluator must estimate the yield decrease; this is the most difficult step in economic land evaluation based on Land Qualities. The estimate can be made by experiment (isolating one or more Land Qualities that affect yield), statistical inference from survey data, dynamic simulation modelling, or expert judgement.

There are three ways to predict proportional yield for more than one LQ at a time:

(1) *Limiting yield factors*: This is the simplest approach, and corresponds to the 'law of the minimum', i.e., that the most limiting factor determines the yield, so that there are no interactions between factors. This is often a good first approximation to reality, and may be used if there is no specific information on interactions. The evaluator defines a predicted proportional yield (from 0 to 1) for each severity level of each Land Quality that affects yield.

(2) *Multiplicative yield factors*: This approach assumes that limitations have a synergistic, multiplicative, effect. The evaluator specifies yield factors exactly as in the limiting-yield-factor method, but if there is more than one limitation, these are multiplied to reach the final yield. This is similar to 'parametric' land evaluation by means of indices, for example the Storie index (Storie, 1933) and its derivatives (Riquier, 1974). This method usually over-estimates the synergistic effect of multiple limitations; this effect can be adjusted by using the geometric mean rather than the normalised product (Koreleski, 1988).

(3) *Proportional yield decision tree*: This is the most general method, and can explicitly represent known interactions between LQs. The evaluator starts with one LQ, usually the one with the most influence on yield. For each severity level, either a yield can be predicted without considering other LQs, in which case the evaluator specifies that yield, or other LQs must be considered. In this second case, the evaluator chooses another LQ that also affects yield, and now supposing that the first LQ is fixed at a particular severity level, tries to predict a yield based on both factors. The process continues recursively until all necessary factors have been taken into account. The disadvantage of this method is that if many factors are considered, the tree may become large and unwieldy. Also, specific information is required on a large number of interactions, implying that there are sufficient results from multi-factorial experiments.

2.2. Delayed yields: In some Land Utilisation Types, increasing limitations delay harvest rather than (or besides) lowering the yield of each harvest. A typical example is forestry: limitations due to unfavourable site characteristics (moisture, fertility, length of growing season) may not ultimately decrease yields, but may instead extend the amount of time until trees reach marketable size. In discounted cash flow analysis, the year when a harvest is realised can greatly affect the economic value of a LUT. The land evaluator can specify that yields be deferred, instead of, or in addition to, being lowered, due to increasing limitations. Harvest is delayed in inverse proportion to the proportional yield as previously defined.

The need to use delayed yields in the analysis may be avoided by annualising the yield, for example, by using mean annual growth increments in forestry, thereby avoiding the use of delayed yields, In this case, gross margin analysis can be applied instead of discounted cash flow analysis.

2.3. Increased costs to compensate: The land user is not powerless in the face of less-than-optimum land if limitations can be completely or partially overcome by a higher level of inputs. These can be major land improvements (e.g., drainage or irrigation projects), minor land improvements (e.g., deep tillage, incorporation of corrective doses of lime or phosphate, leaching of salts) or variable levels of annual inputs (e.g., fertiliser). The first two are capital costs, because the investment is expected to yield benefits in the medium to long term.

The specification of a Land Utilisation Type may include increased capital or ongoing costs for any or all severity levels of one or more LQ. In this case, the ‘severity level’ is really a management option within the same LUT, which will be applied by the land user on all lands with the same limitation. For example, increasing fertility limitation (decreasing natural fertility) can be overcome by increasing amounts of fertiliser (a non-capital cost). Increasing moisture limitation can be overcome by an irrigation system (a capital cost) and more frequent water applications for the drier lands (a non-capital cost). If, in addition, different soil types require different types of irrigation (e.g., furrow vs. drip) or variants (e.g. different furrow spacing), these differences can be related to another LQ, e.g. ‘suitability for furrow irrigation’. At a certain point, the inputs have changed qualitatively, and the evaluator should define a different LUT, which is compared to the other LUTs on all evaluation units.

The land user may have a choice between accepting a yield reduction (decreased income) and correcting the limitation (increased expenses), or a combination of these. Each combination is a separate LUT, because it represents a different management decision.

DETERMINING ECONOMIC VALUE FROM GEOGRAPHIC LAND CHARACTERISTICS

If the evaluation units are production units, management units or single delineations of natural resource units, they have a definite position and extent on the earth's surface. Therefore, the evaluation can include the economic effects of spatial land characteristics. Typically, the spatial analysis is performed with a geographic information system (GIS) (Burrough, 1986), and the *in situ* analysis is performed by map-unit based methods, with the following exchange of information:

(1) A base map is created in the GIS, showing the evaluation units, each with a unique identifier.

(2) The evaluation units from the GIS are defined as the evaluation units for the *in situ* analysis.

(3) An *in situ* physical and economic land evaluation is calculated without reference to the location of the mapping unit.

(4) The results of the *in situ* analysis are used to reclassify the base map into a preliminary economic suitability map.

(5) Spatial analysis is performed in the GIS. For example, the GIS can be programmed to calculate the distance of each delineation to a market town and transform this to a transport cost. As another example, the GIS can be programmed to calculate the size of each management unit, and assign an increased cost to units that are too small for efficient mechanisation. This analysis results in one or more new cost maps.

(6) The results of the *in-situ* economic evaluation are overlaid with the results of the spatial analysis, according to the evaluation criteria, to produce a final suitability map. For example, transport costs can be subtracted from *in situ* estimates of profitability.

EVALUATING PLANNING UNITS: OPTIMISATION UNDER CONSTRAINTS

A planning unit, such as a farm or catchment, usually consists of several management units, so that the land user can mix land uses within the planning unit. This mix of activities is subject to constraints as has been generally recognised in the farm-planning and natural resource management literature (Hazell, 1986; Dykstra, 1984). Constraints are of five kinds:

(1) A minimum or maximum area must be dedicated to a specific land use. For example, government restrictions may dictate an upper limit on the area used for a certain crop.

(2) A minimum or maximum amount of a specific output must be produced. For example, a subsistence farmer will want to ensure enough food for the family before considering cash crops.

(3) There may be a maximum amount of an input (production factor) available, typically family labour, machinery, and suitable land. In an irrigation district, the total amount of water is usually limited, so that it is impossible to use the entire area for crops that need much water. The total amount of capital available for land improvements may be limited.

(4) The producer may desire a proportional relation between outputs, for example, if feed grain and hay must be produced in a definite proportion for balanced animal rations.

(5) Often a management unit may not be divided among land uses, but must be dedicated to a single use. This is usual in mechanised agriculture if field boundaries cannot easily be changed.

These constraints are normally expressed as a mathematical program (Hillier & Lieberman, 1986; Winston, 1991; Dykstra, 1984) and solved by computer. The technical coefficients (amount of input per unit land area) and components of the objective function, such as yields, are obtained from the economic land evaluation based on *in situ* or geographical land characteristics, without considering constraints or goals. The solution to a mathematical program is the optimal allocation of resources that maximises or minimises a single objective function, which is usually the total profit or utility for the farm. The first three types of constraints can be expressed in a linear program, whereas a proportional relation (constraint type 4) is non-linear. The fifth constraint type leads to an integer program, which is more difficult to solve mathematically, and which is more likely to have no feasible solution. The set of constraints may be inconsistent, so that no solution is possible; the evaluator then must relax some of the constraints, thereby modifying the definition of the Land Utilisation Type.

COMPUTER TOOLS FOR ECONOMIC LAND EVALUATION

Economic land evaluation requires numerous calculations, which may be automated for greater efficiency, easier scenario and sensitivity analysis, comparison of methods and more effective communication with clients. The following sorts of programs may be useful for economic land evaluation:

1. Standard office programs: These include spreadsheets, databases, document preparation, and graphics programs. In particular, the electronic spreadsheet is invaluable for routine calculations and farm budgets.

2. Statistics packages: These can be used to calibrate and validate prediction equations, usually multiple regressions, from a set of land characteristics to yields. Multivariate analysis of variance can be used to quantify interactions between Land Qualities.

3. Dynamic simulation models: These can be used to predict a time-series of yields from a time-series of climates. Examples include WOFOST (van Keulen & Wolf, 1986); CERES (Jones & Kiniry, 1986), SOYGRO (Wilkerson, Jones *et al.*, 1983), and GAPS (Riha, Rossiter *et al.*, 1994).

4. The Automated Land Evaluation System ALES: ALES (Rossiter & Van Wambeke, 1994; Rossiter, 1990) is a specialised program for physical and economic land evaluation based on *in situ* land characteristics, using Land Qualities. Land evaluators use the program as a framework within which they build their own expert systems for physical land evaluation and simple micro-economic models of land suitability. ALES is usually applied to map units of natural resource inventories or to management units. Economic results for each evaluation unit **-** LUT combination can include the gross margin, cash flow, NPV, Benefit/Cost ratio of the NPV, and Internal Rate of Return, as well as the amount of inputs necessary to implement the LUT on the evaluation unit, either in a specific year or integrated over the life of the LUT. The evaluator can define economic suitability classes based on these measures. ALES can create thematic maps of all results in the IDRISI GIS. It can also write the results to interchange files that can be read by spreadsheets, databases and other GIS's. Johnson & Cramb (1991; 1994) used ALES as part of their integrated economic land evaluation.

5. Geographic information systems (GIS): GIS are used to display and manipulate spatially-referenced data. They are the only feasible way to calculate transport costs for an economic land evaluation. They can also calculate areas, which are used to determine non-normalized economic values. Two systems that have been widely applied to land evaluation are IDRISI (Eastman, 1992b; Eastman, 1992a) and ILWIS (Meijerink, Valenzuela *et al.*, 1988).

6. Optimisation under constraints: Well-established codes, such as LINDO and GINO (Schrage, 1991), are available for all classes of computers to solve constrained optimisation problems. Electronic spreadsheet computer programs such as Quattro Pro, Microsoft Excel, and Lotus 1-2-3 also include optimisation modules. These have the advantage that the model is displayed in a table rather than as a set of equations. The technical coefficients in a constrained optimisation model should be obtained from a land evaluation of each LUT for each evaluation unit, without considering constraints.

7. Risk and time-series analysis: A useful technique for risk analysis is Monte Carlo simulation (Morgan & Henrion, 1990) of an economic scenario. In this method, each uncertain variable is described by a probability distribution, the economic measure is calculated, and the results of the numerous simulations are expressed as frequency distributions of expected outcomes. The '@RISK' add-in module for the Lotus 1-2-3 and Microsoft Excel spreadsheets (Palisade Corporation, 1990) takes this approach. Johnson & Cramb (1991) used @RISK as part of their integrated economic land evaluation.. The appropriate probability distribution and parameters can be determined by a curve-fitting program such as BestFit (Palisade Corporation, 1993), using historical or survey data for each parameter.

The IDRISI GIS, V4.1 (Eastman, 1993), includes modules for decision making under uncertainty, including the use of fuzzy sets and Bayesian probabilities to represent and propagate uncertain facts and beliefs.

8. Multi-criteria optimisation: In many decision-making contexts, there are multiple goals to be (more or less) achieved; the techniques of multiple criteria analysis (Romero & Rehman, 1989; Janssen, 1992) provide a method for attempting to satisfy multiple goals. In a land-use planning context, the LUPIS program used in Australia (Ivie & Cocks, 1988; Cocks, Ivie *et al.*, 1983; Ivie & Cocks, 1983) allows multiple objectives by multiple decision makers to be incorporated into the decision matrix. DEFINITE (Janssen & van Herwijnen, 1992) is another program for multi-criteria optimisation. The IDRISI GIS, V4.1, (Eastman, 1993) includes modules for multi-criteria decision making, in which the costs and benefits of the goals may be expressed in economic terms.

CONCLUSION

Why is economic land evaluation the exception rather than the rule? Why is the land evaluation community not embracing economic land evaluation as a matter of course? I can identify three reasons: historical, institutional, and practical.

First, land evaluation evolved from earlier land capability classifications that were chiefly based on physical factors. Most land evaluations are still carried out by natural resource specialists with little or no economics training, such as soil scientists, agronomists, or agricultural meteorologists. Second, institutional barriers may also be significant: natural resource scientists and economist may be located in different organisations or in different sections of the same organisation, with little motivation or support for interdisciplinary projects. Each discipline often ignores or over-simplifies other discipline's techniques, rather than work in a multi-disciplinary team. Third, it is a regrettable fact that many land evaluations are only used to attract financial support for development projects, not to implement them. Therefore, the land evaluation is never used in the field, so that the land evaluator is not responsible for the consequences of the recommendations. That a recommended land use option may not be economically feasible is never exposed.

The chief obstacle to economic land evaluation is the difficulty of obtaining reliable data on the economics of production and how these are affected by Land Qualities. This difficulty can be handled in several ways. First, since land evaluation is a strategic rather than a tactical planning tool, its predictions do not need to be excessively precise. Second, sensitivity analysis can be used to see how wrong estimates of economic or land data must be before there is a change in predicted land allocation or economic suitability. Third, a variety of techniques can be used to estimate 'S1' yields and input levels and how these change with increasing limitation: rural surveys (Poate & Daplyn, 1993), expert judgement, statistical modelling, and simulation modelling. When several techniques give similar results, we can be confident that the economic predictions are close enough for land evaluation purposes.

Economic land evaluation is not excessively difficult. When due attention is paid to the details, it can provide a more useful prediction of land performance than a purely physical evaluation, because it can better reflect the decision-making criteria of land users. In this way, land evaluation can assume its proper role in support of rational land use planning.

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